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GEOLOGY

New Data on the Age of Rocks in the Mirnyi Station Area, East Antarctica

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The Russian polar station "Mirnyi" located on the Davis Sea coast in the central sector of East Antarctica (Pravda Coast, 66°33′ S, 93°01′ E, Fig. 1) was the first national Antarctic observatory. Since 1956, it has been serving as a base for different scientific studies. During this time, about twenty rocky islands and nunataks were revealed in the vicinity of the station, which are composed of metamorphic rocks and charnockites, the total area of bedrock exposures making up 10 km^2 [3]. It is the only area on the Antarctic coast that is bare of ice, for about 800 km from the Vestfold Oasis to the Denman Glacier. L.V. Klimov and P.S. Voronov, pioneers of Soviet Antarctic geology, carried out geological observations in the Mirnyi Station area in 1956–1957. Later, the studied bedrock exposures in the station vicinity were covered with snow, and further study of them was impossible (except for magmatic charnockites making up islands near the coast). However, information about the age and geological nature of rocks that developed in the region is extremely necessary for interregional correlations and especially urgent in the context of ideas about the Gondwana supercontinent assembly due to collision of several continents in the late Neoproterozoic–Cambrian [4]. Presented in this work are results of isotopic studies of geological collections mainly acquired in the 1950s.

Four structural–lithological complexes make up the region (Fig. 2) [3]: (1) crystalline schists and plagiogneisses metamorphosed in granulite facies and migmatized and granitized with different intensity; (2) gabbroids (mainly dike-shaped bodies up to tens of meters thick) intruded after regional metamorphism and ultrametamorphism of the enclosing schists and substantially metamorphosed during recurring ultrametamorphism; (3) injection leucodiorites and plagiogranites forming a veined material of agmatized areas of metamorphic rocks; (4) rheomorphic charnockites (eulitie granitoids, essentially gneissic in places) formed during recurring ultrametamorphism, after intrusion of gabbroids.

The sequence of metamorphic rocks of the granulite facies (Complex 1) is mainly composed of hypersthene plagiogneiss containing intermittent (boudinated) interlayers and lenses 1–2 m thick, made of melanocratic pyroxene–plagioclase schists or, more rarely, garnet–hypersthene gneiss [3]. Plagiogneisses comprise plagioclase (60–70%), quartz (15–20%), and hypersthene (15–20%). Schists mainly consist of plagioclase, hypersthene, amphibole, and biotite, the content of which varies within a wide range; some samples comprise garnet and spinel. The rocks are intensely migmatized with the development of thin conformable plagiogranite veins (layered migmatites), the majority of which represents local melting, and only in places is of the injection nature. The second generation of injected felsic veins (hypersthene leucogranite and plagiogranite) exhibits an agmatite habit with clear intersecting contacts of veins and the enclosing metamorphic sequence. However, some part of the vein material of the second generation was melted and crystallized in situ, not exhibiting substantial transference. Vein rocks of the second generation are not gneissic and bear no traces of synmetamorphic deformations. Recurring migmatization also affected dike-shaped bodies of metamorphosed gabbroids (gabbro–dolerite, gabbro–norite) or gabbroids transformed into charnockites (monzonite–dioite developed on the eastern flank of the region in the immediate vicinity of charnockites) maintaining their own shape and relict magmatic structures.

Based on the K–Ar method of age determination for rocks from this and other regions of East Antarctica, metamorphic rocks from the basement of the Antarctic platform in this region were arbitrarily attributed to the "pre-Riphean interval" (with an inference about their even older age), and later rocks (gabbroids, ultrameta-

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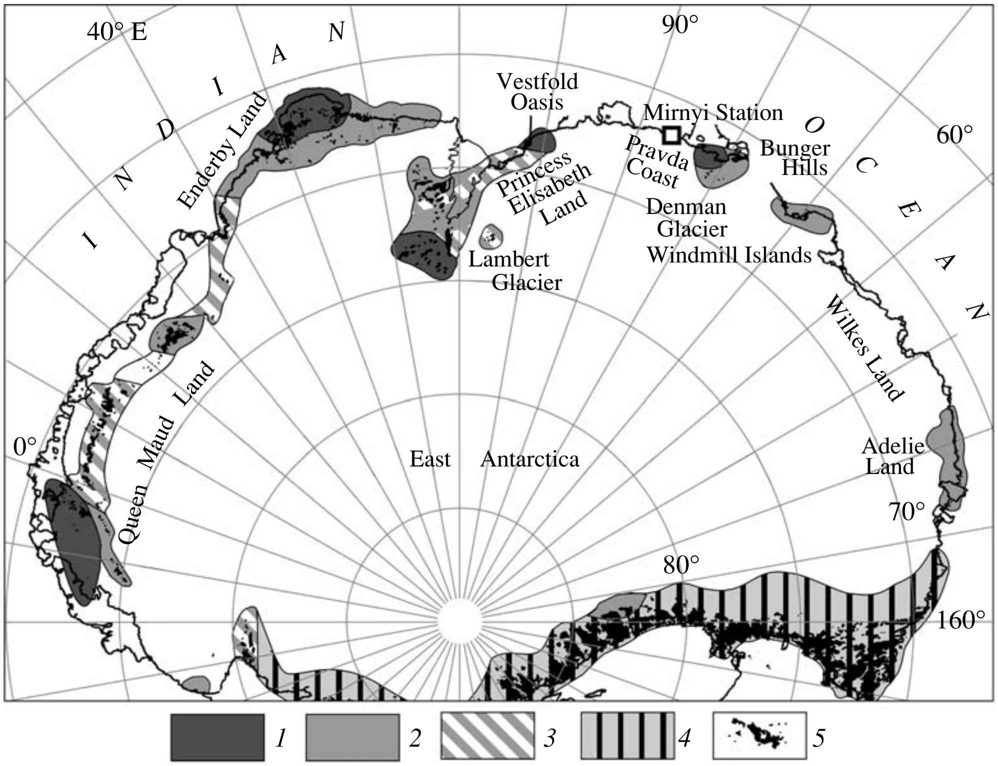

Fig. 1. A general chart of Antarctica and the studied area. (*1*) Archean cratons; (*2*) Proterozoic mobile belt; (*3*) areas of intense Cambrian tectonothermal activation; (*4*) Neoproterozoic–early Paleozoic Ross fold system; (*5*) rock exposures.

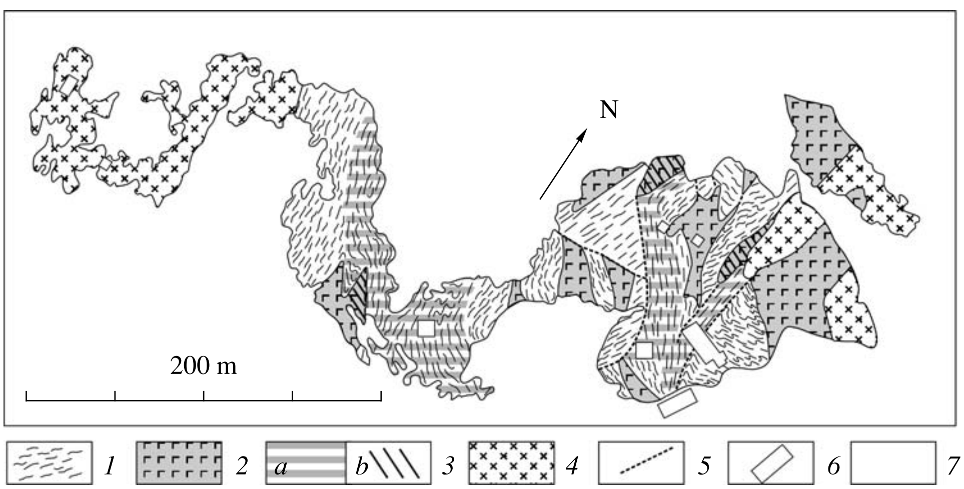

Fig. 2. Structural–lithological scheme of the Mirnyi Station area (modified after [3]). (*1*) Migmatized plagiogneisses and pyroxene–plagioclase schists (Complex 1); (*2*) gabbroids transformed into charnockites (Complex 2); (*3*) zone of vein complex related to recurring migmatization: (*a*) on gneisses and schists, (*b*) on metagabbroids; (*4*) charnockites (Complex 4); (*5*) boundary of structural domains (dislocation?); (*6*) Mirnyi Station buildings; (*7*) ice and snow.

morphic vein complex, and charnockites), to the Older Caledonian phase [3].

To establish the timing of the main geological processes, three rock specimens were studied with the SHRIMP-II ion–ion microprobe at the Center of Isotopic Studies of VSEGEI: mafic pyroxene-bearing granulite (Complex 1, Sp. 11309), felsic vein material of agmatites (Complex 3, Sp. 1127b), and charnockite (Complex 4, Sp. 45101-1).

Mafic granulite comprises zircon grains of different shapes: barrel-shaped, short- or long-prismatic, but in cases the grains are rounded and only rarely demonstrate the retained crystallographic habit. The grains are of a homogeneous internal structure, with no luminescence in the cathodoluminescent rays. The grains vary in size from 50 to 200 μm. Twelve analyses were obtained for twelve zircon grains. All the analyzed zircons exhibited high concentrations of uranium (1300–6200 ppm) and thorium (90–850 ppm), and mostly a low Th/U ratio (below 0.10). Three grains have higher Th/U ratios in the range of 0.34–0.69. All the analyses are close to concordia, but do not form a single cluster (Fig. 3a). Zircon grains with a higher Th/U ratio have relatively high $^{206}Pb/^{238}U$ ages (927 ± 6, 922 ± 7 Ma). The regression line drawn on the basis of twelve analyses has an upper intersection with concordia that corresponds to 981 ± 34 Ma and a lower intersection corresponding to 461 ± 110 Ma (MSWD = 1.14). The upper intersection may correspond to magmatic crystallization of zircon (which is indicated by a high Th/U ratio and the habit of some crystals) about 980 Ma ago. The lower intersection agrees with zircon recrystallization during metamorphism 500 Ma ago (in general, low Th/U ratios and a rounded shape of most grains, as well as concordance of one of the analyses).

The vein material of agmatites comprises large (100–500 μm), short-prismatic or angular-shaped zircon crystals with well-developed and practically unrounded faces; some grains exhibit clear zoning (Fig. 3b). Eight analyses were obtained for eight zircon grains. All the grains are characterized by high Th concentrations (180–975 ppm) and low U concentrations (300–1100 ppm), which is expressed in high Th/U ratios in the range of 1.1–2.0. The analyses are discordant to a certain extent, and the $^{206}Pb/^{238}U$ age of all zircon grains makes up 478–518 Ma. The regression line for eight analyses has an upper intersection with concordia corresponding to 504 ± 3 Ma and the lower intersection corresponding to 367 ± 3 Ma (MSWD = 0.20). Four analyses, the closest to concordia, exhibit the average weighted age value 504 ± 3 Ma (MSWD = 0.64), which indicates crystallization of the agmatite vein material at that time.

Charnockite comprises large (200–400 μm), extended–prismatic, well-bounded zircon grains exhibiting distinct zoning. Many grains have a thin external high-uranium rim expressed well in cathodoluminescent rays. In most grains, the rim represents a conformable overgrowing of oscillatory zoning. Six analyses were obtained for five zircon grains (five analyses for the inner zone and one analysis for the overgrowing rim). The inner zones of the zircon grains exhibit low concentrations of uranium (85–620 ppm) at the Th content varying within 80–450 ppm, which that is expressed in high Th/U ratios (0.8–1.5). The analysis of the rim of the overgrowing yielded a high uranium concentration (1091 ppm; Th/U = 0.33). All the analyses are concordant or slightly inversely discordant within the $^{206}Pb/^{238}U$ age from 448 to 508 Ma (Fig. 3c). The regression line drawn for six analyses has a lower intersection with concordia, which corresponds to 461 ± 16 Ma,

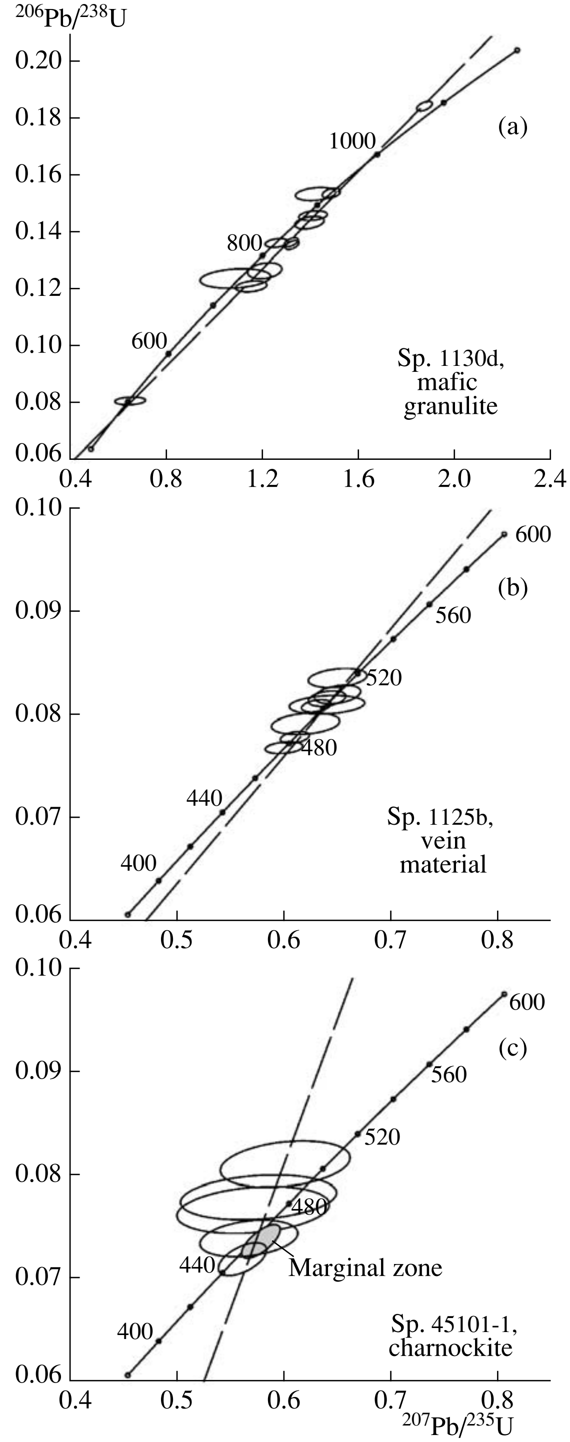

Fig. 3. Diagram with concordia for zircon from rocks of the Mirnyi Station area.

but has no upper intersection due to inverse discordance of some analyses. This seems to be associated with the excess of common lead (0.1–0.6% at a content of radiogenic lead from 6 to 70 ppm); therefore, it is admissible to take the $^{206}Pb/^{238}U$ date 503 ± 7 Ma, the maximal among all six analyses, as the time of zircon magmatic crystallization. The date is the maximal age estimate, and the weighted average value 480 ± 7 Ma for four analyses is the minimal age estimate. The isotopic composition of the marginal area (460 Ma) does not differ from the composition of the inner zones; thus, it may be inferred that the area reflects not a new growth of zircon but only the process of recrystallization due to fluid–metasomatic exchange at the final stage of magmatism during formation of the charnockite pluton.

The data obtained indicate that the geological history of this region involves, at the very least, two tectonomagmatic events, each finding confirmation in the history of adjacent regions of East Antarctica. The first event falls into the Rayner phase (1000–900 Ma ago, after [5, 7]) when presumably a magmatic mafic–salic complex was formed. Mafic rocks of this sequence are of slightly fractionated composition (MgO 7%, *mg* = 44–53), which indicates the juvenile nature of the complex especially as salic rocks are devoid of common potash feldspar and comprise abundant dark-colored minerals; these conditions indicate the magmatic nature of the protolith and its mantle origin in convergent geodynamic conditions. Magmatic complexes of the Mesoproterozoic origin (1300–1100 Ma) were revealed in the region of the Lambert Glacier–Amery Ice Shelf (Fig. 1) where volcanogenic sequences and different plutonic associations metamorphosed under conditions from epidote–amphibolite to granulite facies are exposed [6], older rocks being located in the northwestern part of the region. Geological structures as well as linear magnetic anomalies are, in general, of the east–northeast strike, and the Mirnyi Station is located on their strike. Hence, it may be inferred that progressive accretion of juvenile complexes took place from the east or southeast on a vast territory from the Lambert Glacier to the Pravda Coast in the late Mesoproterozoic–early Neoproterozoic. Further east of Mirnyi Station, geological complexes of an earlier Mesoproterozoic origin (1700–1150 Ma) are exposed, which probably were developed separately from regions located to the west and were isolated from them by the closed "Rayner" oceanic basin.

It should be noted that rocks of a later complex of metamorphosed gabbroids exhibits a more fractionated composition (*mg* = 39–43) with high concentrations of TiO_2 (3.3–4.3%) and P_2O_5 (1.4–1.9%). This suggests that the rocks were derived from mantle melts of intraplate origin and may reflect the Neoproterozoic magmatic activity probably related to the plume action or rifting. Hypabyssal intrusives within the Neoproterozoic sedimentary sequence in the upper reaches of the Lambert Glacier exhibit the identical (in the main components) composition [1]. This indicates the areal nature of plume magmatism; it is likely that Neoproterozoic tectonic processes played a more essential role in the formation of the Antarctica structure than has been assumed and predetermined the nature of further early Paleozoic processes.

Our data confirm the inferences of earlier investigations that recurring ultrametamorphism and charnockite intrusion proceeded at the same time—about 500 Ma ago. Agmatites were formed under conditions of granulite facies characteristic of the tectonothermal endogenous regime of that time on the vast coastal territory of East Antarctica from Queen Maud Land to Princess Elisabeth Land (except for some regions). Hence, the Pravda Coast represents the easterly region of an intense manifestation of this event. Further eastward (Banger Oasis, Windmill Islands), geological processes of that time represent a rebalance of isotopic systems during the thermal effect, but no traces of metamorphism or especially anatexis have been revealed. However, no deformations except brittle–plastic ones within narrow zones [3] are related to this stage on the Pravda Coast, whereas in the region of the Princess Elisabeth Land and the Queen Maud Land, related to the Cambrian are reiterated powerful plastic deformations and folding accompanied by metamorphism and partial melting. Isotopic dates for these processes mainly fall within the interval of 530–510 Ma [1], which indicates the synchronous nature of early Paleozoic tectonothermal activity. Charnockite intrusion at the terminal phase of this stage is a typical phenomenon as well [2]. The lack of new mantle formations and deformations of that time interval on the Pravda Coast, like the revealed synchronism of Cambrian tectonic activity in different regions of Antarctica casts some doubt on the collision nature of geological events at that time. Conversely, the similarity of the Meso–Neoproterozoic history of different regions suggests that East Antarctica formed mainly during the Rayner stage.

The data obtained allow the following conclusions: (1) in the Mirnyi Station area, an early Proterozoic (980 Ma) magmatic complex is developed, which is presumably of juvenile origin, and represents the youngest "addition" to the structure of the Proterozoic mobile belt; (2) the territory was stabilized prior to the early Paleozoic time, Cambrian events were not accompanied by plastic deformations; (3) the Pravda Coast represents the eastern flank of the early Caledonian orogen where tectonomagmatic activity of the static thermal nature died out; granulite facies metamorphism and charnockite intrusion proceeded about 500 Ma ago and were not separated by a considerable time interval.

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