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GEOCHEMISTRY

Magmatism of the Karoo–Maud Superplume in the Schirmacher Oasis, East Antarctica

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The origination of large plateau basalt provinces in the Earth's geological history has traditionally been referred to the deep thermal convection caused by plume geodynamics [1]. The emplacement of a large plume into the lithosphere of central Gondwana in the Early–Middle Jurassic (180–173 Ma ago) resulted in the formation of a vast igneous province 2000 km across [2, 3] and probably predetermined the subsequent breakup of the supercontinent and opening of the Southern Ocean (Fig. 1). This province encompasses Southeast Africa (Karoo Complex) and the western Dronning Maud Land in East Antarctica [2, 3] along with its continental margin, where thick volcanic piles (Explora Complex) have been detected by seismic survey beneath the Upper Mesozoic sedimentary cover [4].

In the western Dronning Maud Land, the Jurassic basic igneous complexes related to the emplacement of the plume (called the Karoo–Maud plume, or province, hereafter) consist of basaltic lava and dolerite dikes dated at 173–180 Ma [5]. It has been suggested that the Jurassic basalts and dolerites of the Ferrar Complex that occur along the extended (>1000 km long) Transantarctic Mountains also are related to the Karoo–Maud plume. The melts penetrated into the impaired crustal zone of this lineament as an offset of the main mantle anomaly beneath central Gondwana (Fig. 1) [3]. The eastern boundary of the Karoo–Maud plume has been delineated only from seismic data, according to which the Explora volcanic complex is traced to the continental margin of the central Dronning Maud Land (Fig. 1) [6].

In the western Dronning Maud Land, igneous complexes have been revealed in the Vestfjella, Heimefrontfjella, and Kirwanveggen Mountains (mainly basalts and minor gabbrodolerite intrusions) and on the Ahlmannryggen Plateau (dolerite dikes, see Fig. 1) [7]. The basaltic lavas from the Vestfjella and Kirwanveggen Mountains were dated at 180 and 183 ± 1 Ma (K–Ar age of plagioclase) [7]. As follows from the study of the dike complex, the igneous activity on the Ahlmannryggen Plateau was rather prolonged, lasting for 10–15 Ma [8] with a peak of intensity at ~178 Ma ago.

In this communication, we present the results of a new investigation of basic rocks in the Schirmacher Oasis (~35 km^2) on the coast of the Riiser–Larsen Sea in the central Dronning Maud Land near the Novolazarevskaya Station at 11° E, at the inferred eastern boundary of the Karoo–Maud plume (Fig. 1). The Proterozoic high-grade gneisses cut by dikes and veins varying from calc-alkaline lamprophyres and basic rocks to pegmatites and aplites crop out in this territory [9]. The olivine dolerite and gabbrodolerite dikes are the youngest. They are porphyritic rocks with fine-grained microdoleritic, microgabbroic, or vitrophyric texture. The chilled margins are observable in the thickest dikes. Olivine and clinopyroxene phenocrysts occupy 10–25% of the rock volume. In terms of chemical composition, basalts and dolerites of the Schirmacher Oasis fit the low-alkali picrobasalt (0.6–1.6 wt % K_2O, 0.7–2.0 wt % TiO_2, and 10–17 wt % MgO). As a rule, the NW- and NE-trending dikes are <1.5 m thick, occasionally reaching 8 m in thickness.

The dikes from the western Dronning Maud Land [10] and the Schirmacher Oasis are identical in composition (Fig. 2). The dikes from both localities are also close to each other in petrography. The apparent order of crystallization—olivine–plagioclase–clinopyroxene—is confirmed by the compositions of minerals: olivine is

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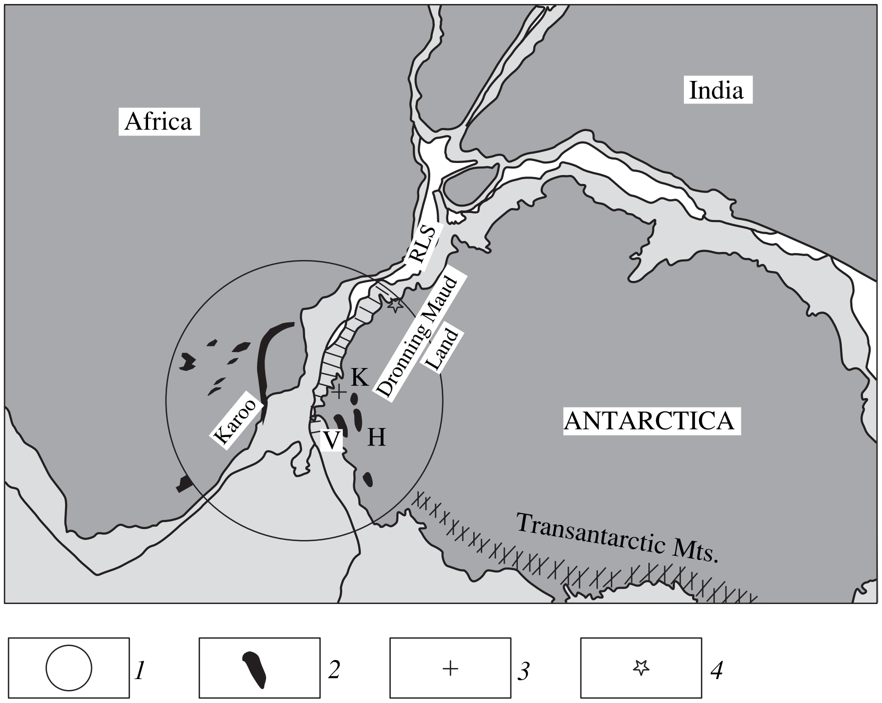

Fig. 1. Reconstruction of Gondwana for the period of 180–170 Ma ago. (*1*) Jurassic Karoo–Maud superplume in the Earth's crust of central Gondwana [3]; (*2*) Mesozoic igneous complexes of the Karoo Province, South Africa and the western Dronning Maud Land: (V) Vestfjella, (H) Heimefrontfjella, (K) Kirwanveggen; (*3*) dike complex of the Ahlmannryggen Plateau; (*4*) Schirmacher Oasis. The hatched area is the Explora Complex. Oblique crosses designate the Ferrar Complex. (RLS) Riiser–Larsen Sea.

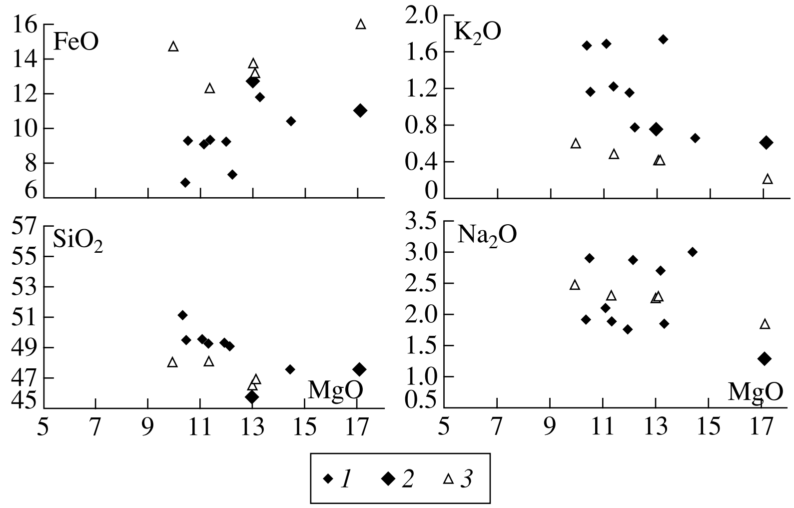

Fig. 2. Petrochemical characteristics of dikes from the Schirmacher Oasis. (*1, 2*) Jurassic dikes from the Schirmacher Oasis; (*3*) dikes from the western Dronning Maud Land.

more magnesian than clinopyroxene. The composition of olivine varied from $Fo_{91.5}$ to Fo_{55} in the course of magma crystallization (~400 grains have been measured). The most abundant compositions ($Fo_{88–89}$) are close to the highest-Mg olivine from the least fractionated Jurassic lavas in the western Dronning Maud Land [11]. The occurrence of high-Mg olivine ($Fo_{90–91}$) in dolerites probably indicates the fast ascent of the melt from its source.

Most of the studied olivine grains contain spinel inclusions. Their compositions are typical of mantle-derived igneous rocks. The standard deviation of $\log(f_{O_2})$ from QFM buffer is close to 1.0–1.2 log units. The Mg number of clinopyroxene ranges from 0.65 to 0.85. The composition of clinopyroxene is also characterized by low Cr/Al and Na/Al ratios (0.01–0.14 and 0.10–0.15, respectively). In terms of all geochemical

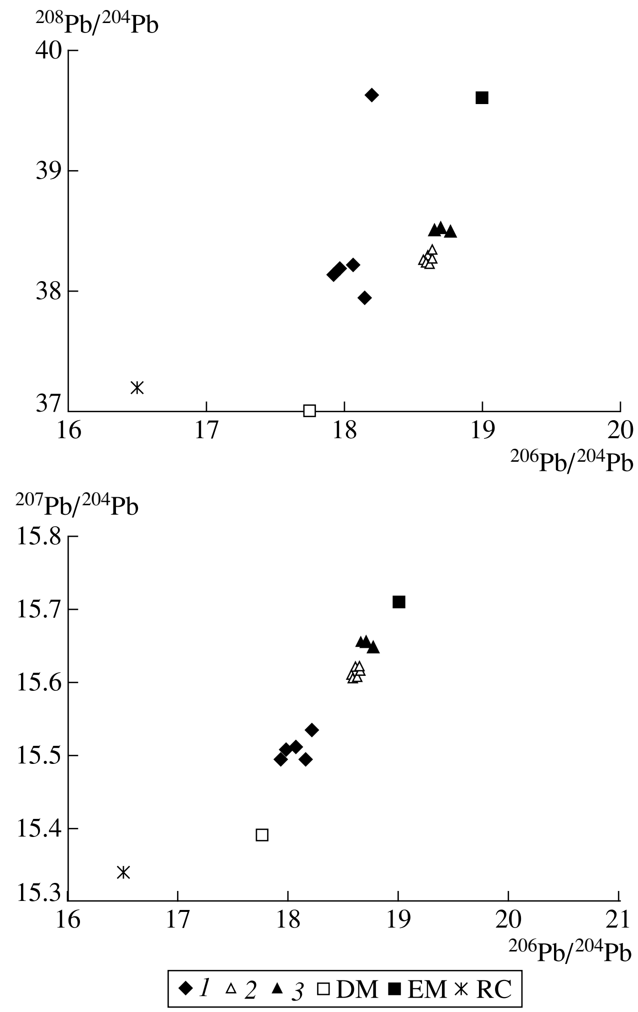

Fig. 3. Pb isotopic compositions in basalts and dolerites of the Karoo–Maud plume association of East Antarctica. (*1*) Jurassic dikes of the Schirmacher Oasis; (*2*) basalts of the Ferrar Province, Transantarctic Mountains; (*3*) basalts of the western Dronning Maud Land; (DM) depleted mantle source; (EM1, EM2) enriched mantle sources; (RC) recycled component [13].

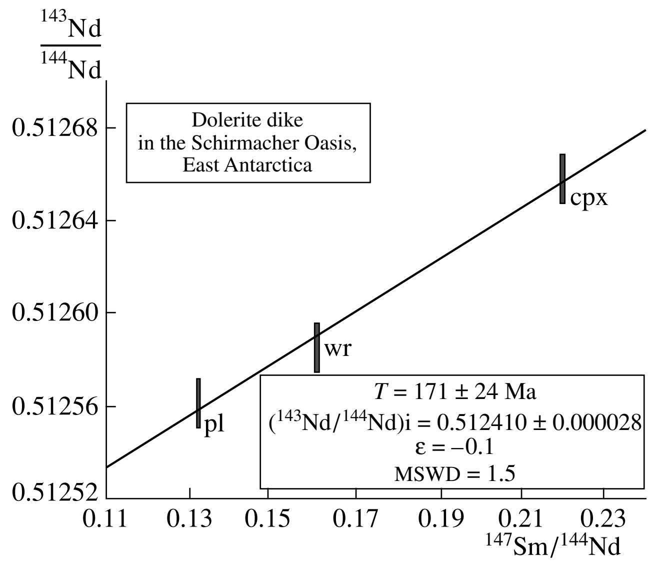

Fig. 4. Sm–Nd isochron for dolerite of the Schirmacher Oasis. (wr) Whole-rock sample, (pl) monomineral plagioclase fraction (99.5%), (cpx) monomineral clinopyroxene fraction (>90%). Analytical uncertainty (2σ) along coordinate axes corresponds to the measured values and is no less than 0.2% for the *x* axis and 0.002% for the *y* axis. The isochron was calculated and plotted with the Isoplot/Ex 3.11 program. Errors are given at a level of 2σ.

parameters, including contents of lithophile elements, this mineral is close to clinopyroxenes from basalts occurring in the western Dronning Maud Land [11]. Thus, both of the compared rocks belong to the Karoo–Maud igneous province.

The variation of Pb isotope ratios in basalts of the Transantarctic Mountains, the western Dronning Maud Land, and the Schirmacher Oasis indicates that their enriched sources were similar in contents of lithophile elements. At the same time, the sources somewhat differed in isotopic parameters, demonstrating an obvious trend (Fig. 3). In the $^{208}Pb/^{204}Pb$–$^{206}Pb/^{204}Pb$ and $^{207}Pb/^{204}Pb$–$^{206}Pb/^{204}Pb$ plots, dolerites from the Schirmacher Oasis are the most depleted end members, whereas basalts from the western Dronning Maud Land [12] and the Transantarctic Mountains markedly contaminated by the crustal material [6] correspond to the enriched component. The single grains of older zircons (500–850 Ma) found in dolerites serve as direct evidence for the contamination of the Jurassic high-temperature magmas with material of the ancient country gneisses.

The Sm–Nd isochron age of dikes from the Schirmacher Oasis determined in plagioclase and clinopyroxene fractions and whole-rock sample of olivine dolerite yielded 171 ± 24 Ma (Fig. 4). This date corresponds to the age of igneous complexes in the Karoo–Maud Province within uncertainty limits. The initial Nd isotopic composition of dolerite dikes from the Schirmacher Oasis (ε_{Nd} = –0.1) is typical of hot spots [13], although it cannot be ruled out that this value is a result of the mixing of the depleted upper mantle and enriched crustal materials.

The dike complex of the Schirmacher Oasis is localized at the inner boundary of the pericontinental rift system of the Riiser–Larsen Sea, which appeared as a result of the extension of the East Antarctica crust before the Gondwana breakup (separation of Africa and Antarctica and seafloor spreading) about 160 Ma ago [14] (Fig. 1). Therefore, the igneous activity dated at 171 Ma could have been stimulated by continental rifting. However, the melts most likely had the plume origin.

Thus, the new data show that the Karoo–Maud superplume, which was active in South Africa and Antarctica 180–173 Ma ago, could have reached 11° E in Antarctica over the course of a few million years. The deep mantle convection beneath central Gondwana probably spread east and west after 40–50 Ma, creating the younger (130–120 Ma) igneous provinces of the Kerguelen Plateau (the southern Indian Ocean) and Etendeca–Parana (Southwest Africa and South America).

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