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GEOLOGY

Evidence for the Mesozoic Endogenous Activity in the Northeastern Part of the Fennoscandian Shield

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Abstract—Paleomagnetic study of dykes and intrusions remanent in the central part of the Kola Peninsula has been carried out; the Devonian age of these objects has been confirmed by isotopic-geochronological studies. The component analysis of the magnetization vector in the samples has shown that there are two magnetization components in most samples. The paleomagnetic pole corresponding to the direction of a more stable component is located in the close vicinity of the Middle Devonian segment of the apparent polar wander path (APWP) for the East European Craton, so this enables us to estimate its age to be as old as the Devonian. The second magnetization component was found in Devonian dykes of both northern and southern parts of the Kola Peninsula; the paleomagnetic pole corresponding to this component is located close to the Mesozoic (Early Jurassic) part of the APWP for the East European Craton. It is suggested that the extensive remagnetization of Devonian intrusions in the Kola Peninsula was caused by the thermal effect of the Barents-Amerasian superplume and by the appearance of an extensive area with trap magmatism within the modern Arctic Basin region. Discovery of a significant thermal event that covered the Fennoscandian northeast allows us to explain the geochronological problem concerning the Mesozoic ages of particular singular zircon grains from Precambrian rocks of the shield derived via the SHRIMP method.

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There are several stages of endogenous activity identified in the geological evolution of the northeastern part of Fennoscandia; the longest of them finished 1.8 Ga and then this part of the craton stabilized and had a pattern with the structural features close to the modern ones. The following long amagmatic period of more than 1.3 Ga finished in the Paleozoic by plume-lithospheric processes that formed the Kola alkaline province (0.40–0.36 Ga) and completed the development of riftogenic structures of the southeast White Sea region [7]. Later geological evidence that could signify the manifestation of endogenic activity in the period from 350 Ma until the present has not been found within northeastern part of the shield.

Assessment of geodynamic environments existing at the Phanerozoic stage in the evolution of northeast Fennoscandia and reconstruction of motion trend for the Kola megablock in the Paleozoic are of great importance for determination of what the localization conditions of mantle melts produced the Kola alkaline province were. The paleomagnetic method can be involved in solution of this problem; however, the interval of 400–340 Ma BP is the most discussed in the Phanerozoic segment of the apparent polar wander path (APWP) for the East European Craton because of the nearly total absence of reliable paleomagnetic poles of the Devonian age.

In order to obtain new data corresponding the modern criteria of reliability, we carried out reconnaissance paleomagnetic studies of dolerite and alkaline lamprophyric dyke swarms, whose ages fall within the interval of 390–370 Ma according to the geochronological datings (Rb–Sr, Sm–Nd, $^{40}Ar/^{39}Ar$). During the field studies, we sampled nine dolerite dykes of the Barents Sea coast and the Pechenga area, 12 dykes composed of alkaline lamprophyres in Kandalaksha Bay (White Sea), and rocks from the Afrikanda and the Turii Mys intrusions (in the last case, a dyke complex was also sampled) (Fig. 1). The number of oriented samples ranged from 6 to 15 for every geological body; the samples were then treated via temperature magnetic cleaning with more than 12 steps with the top temperature being 630°C. In some cases, the contact zones and host rocks at the distance of 100 m from a dyke were also sampled in order to implement a baked contact test.

Analysis of the magnetic cleaning results has shown that most of the examined dykes and Paleozoic massifs carry a paleomagnetic record of an acceptable quality, and the samples of Archean rocks of the basement

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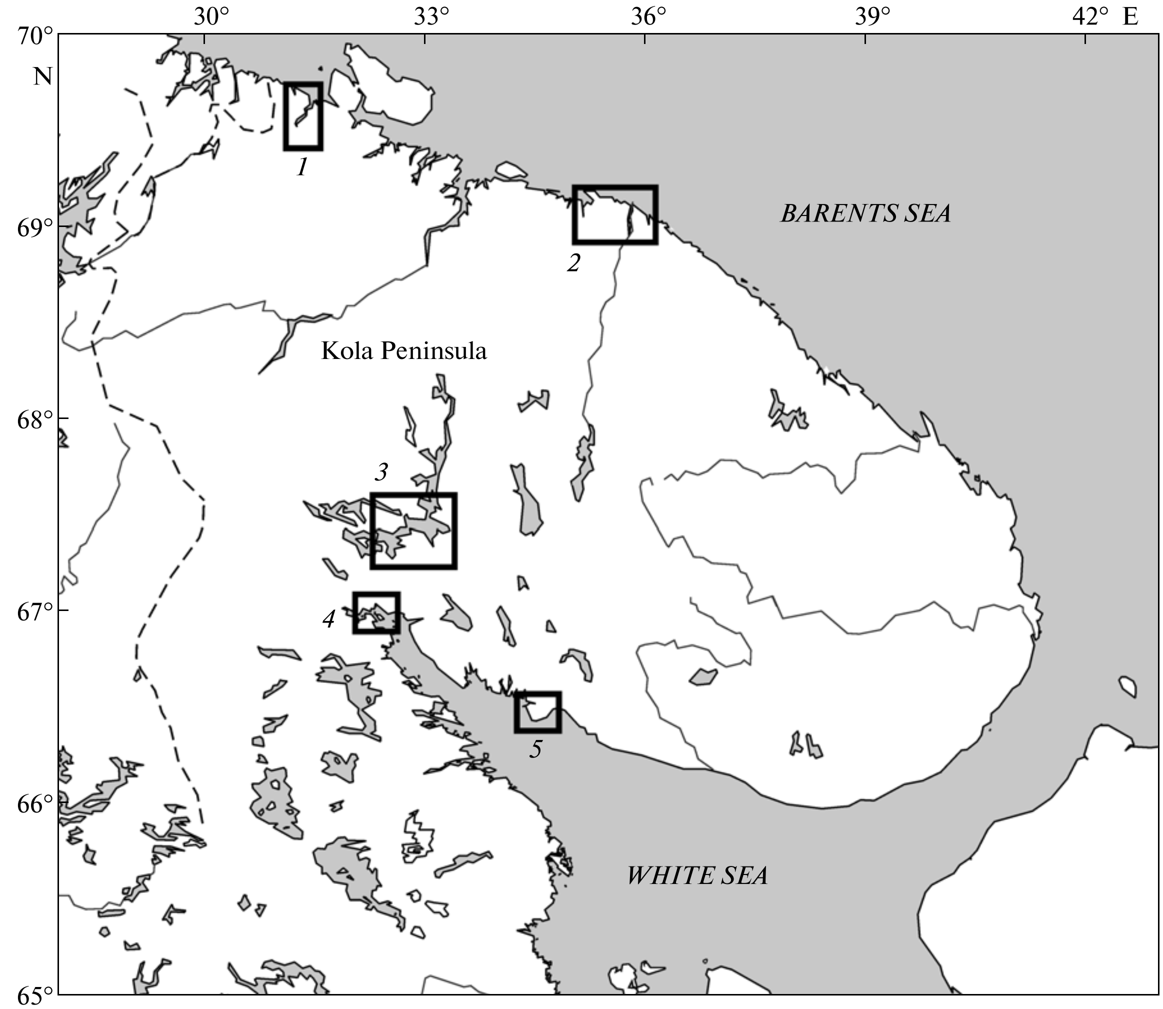

Fig. 1. Location of the studied dykes and intrusive complexes in the Kola Peninsula. (*1*) Pechenga area; (*2*) Dal'nie Zelentsy and Teriberka settlements; (*3*) Afrikanda intrusive massif; (*4*) Kandalaksha Bay; (*5*) Turii Mys intrusive complex.

have mostly a noisy paleomagnetic signal unacceptable for interpretation. In the samples of dykes, natural remanent magnetization (NRM) can be represented by one, two, or three components. The low-temperature component of magnetization is characterized by a direction close to that of the present magnetic field in this region and probably has a viscous nature. The directions of other magnetization components (middle and/or high-temperature) are localized in various domains of the stereogram and can be considered as parts of two groups of vectors.

The Pz group is represented by NRM components, whose directions are characterized by near-zero inclinations and northeast (6 dykes) and southwest (3 dykes) declinations (Figs. 2a, 2b, 2e). The oppositely directed component of magnetization does not pass the reversal test formally [12] at the level of samples ($\gamma/\gamma_{cr} = 12/11$), which can be explained by the low quality of the paleomagnetic signal and incomplete removal of more low-temperature magnetization components. Therefore, at this stage of studies, we assume that the oppositely directed magnetization components of the Pz group are antipodal. These components are identified based on remagnetization circles or as end-point components in several dykes of the Barents Sea shore, the southern shore of Kandalaksha Bay, and intrusive rocks of the Afrikanda massif, for which isotopic dates are referred to the Devonian [1]. The paleomagnetic pole, calculated at the site level for the mean direction of normal and reversed components of magnetization of the Pz group, is located in the immediate vicinity of the mid-Devonian part of the APWP for the East European Craton [15] (table, Fig. 3), which allows us to estimate the age of components of the Pz group as Devonian. The reasons for the primary character of magnetization components of the Pz group are their antipodality and difference of the calculated paleomagnetic pole from the earlier poles of the East European Craton. Implementation of the baked contact test for estima-

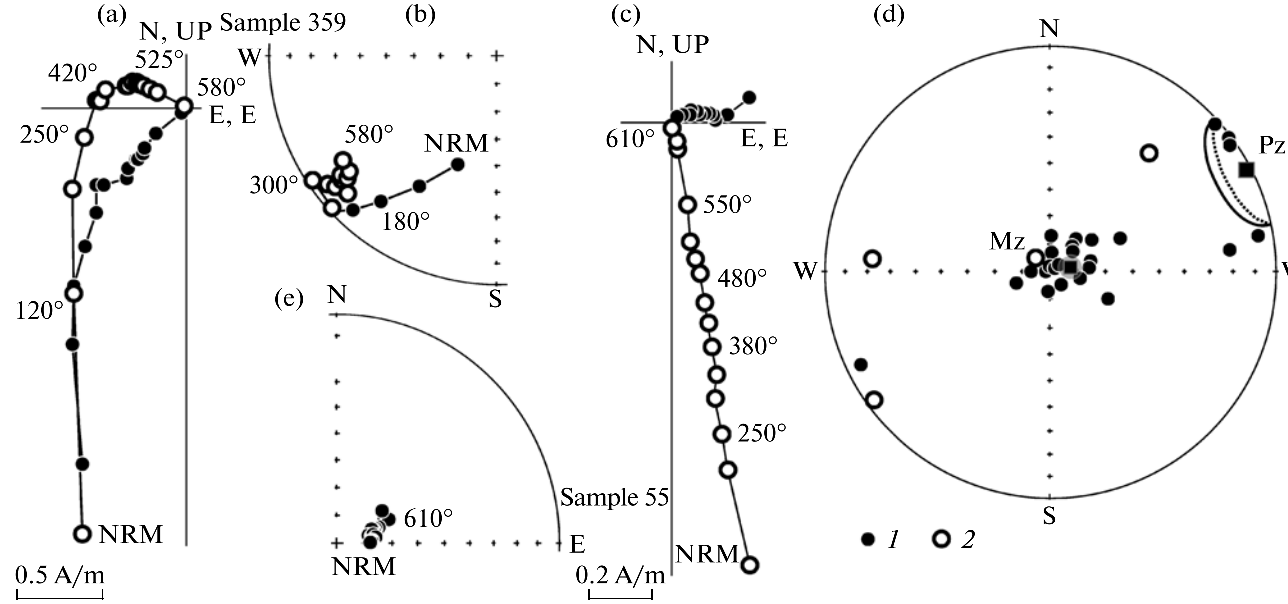

Fig. 2. Typical Zijderveld diagrams and stereoplots for the samples where the Pz (a, b) of the Mz (c, d) component is identified; (e) distribution of Pz and Mz magnetization components in the studied dykes and their mean directions (filled squares) with confidence circles (gray domains). (*1*) projections of vectors to the horizontal plane (lower semisphere); (*2*) projections of vectors to the vertical plane (upper semisphere).

tion of the Pz group magnetization components is impossible due to the highly noised paleomagnetic signal in the samples taken from host rocks of the basement.

The magnetization component, whose vectors compose the Mz group, was found in nearly all the studied dolerite dykes of the Barents Sea Coast, in the northern framing of the Pechenga structure and alkali lamprophyres of the southern part of the region; the geochronological age of all these objects was also estimated to be as old as the Devonian [1]. In a series of samples, this magnetization component is found jointly with the components of Devonian age (the Pz group), occupies the middle part of the spectrum of blocking temperatures, and has steep positive inclinations (table, Figs. 2c, 2d, 2e). The samples from Archean gneisses that host Devonian dykes, taken at distances up to several hundred meters from dykes to implement the baked contact test, usually carry only the Mz magnetization component. The paleomagnetic pole, calculated at the site level and corresponding to the average direction of the Mz component (Fig. 3), tends to the Mesozoic part of the APWP for the East European Craton that can be considered as a direct sign about the time of formation of this magnetization component.

The paleomagnetic pole derived for the average direction of the Pz component reflects the direction of the geomagnetic field in the period when the studied dyke swarms were formed in the Devonian, and can be used (with substantial restrictions) for elaboration of the APWP for the East European Craton and for paleotectonic reconstructions. To increase the reliability and quality of determination for the Devonian paleomagnetic pole based on the dykes of the Kola Peninsula, a significant increase in the number of studied objects is required.

Interpretation of the Mesozoic magnetization component (Mz) in Devonian dykes and intrusive massifs seems to be more difficult. The secondary

Paleomagnetic directions and paleomagnetic poles of identified magnetization components for dykes of the Kola Peninsula

Component	*N*/*S*	*D*	*I*	*K*	α_{95}	Φ	Λ	φ_m	d*p*/d*m*
Pz	76/9	63.3	2.5	12	15.7	10.9	147.6	1	8/16
Mz	219/21	62.5	83.3	53	4.4	70.4	70.3	77	9/9

Note: *N*/*S*, number of samples/sites; *D*, *I*, *K*, α_{95} are characteristics of the Fisher distribution: inclination, declination, concentration parameter, and radius of the 95% confidence interval, respectively; Φ, Λ, *dp*/*dm* are latitude, longitude, and lengths of semiaxes of the 95% confidence interval for the paleomagnetic pole; φ_m is the paleomagnetic latitude. Coordinates of paleomagnetic poles are given recalculated to the mean sampling point with coordinates latitude = 68 and longitude = 33.

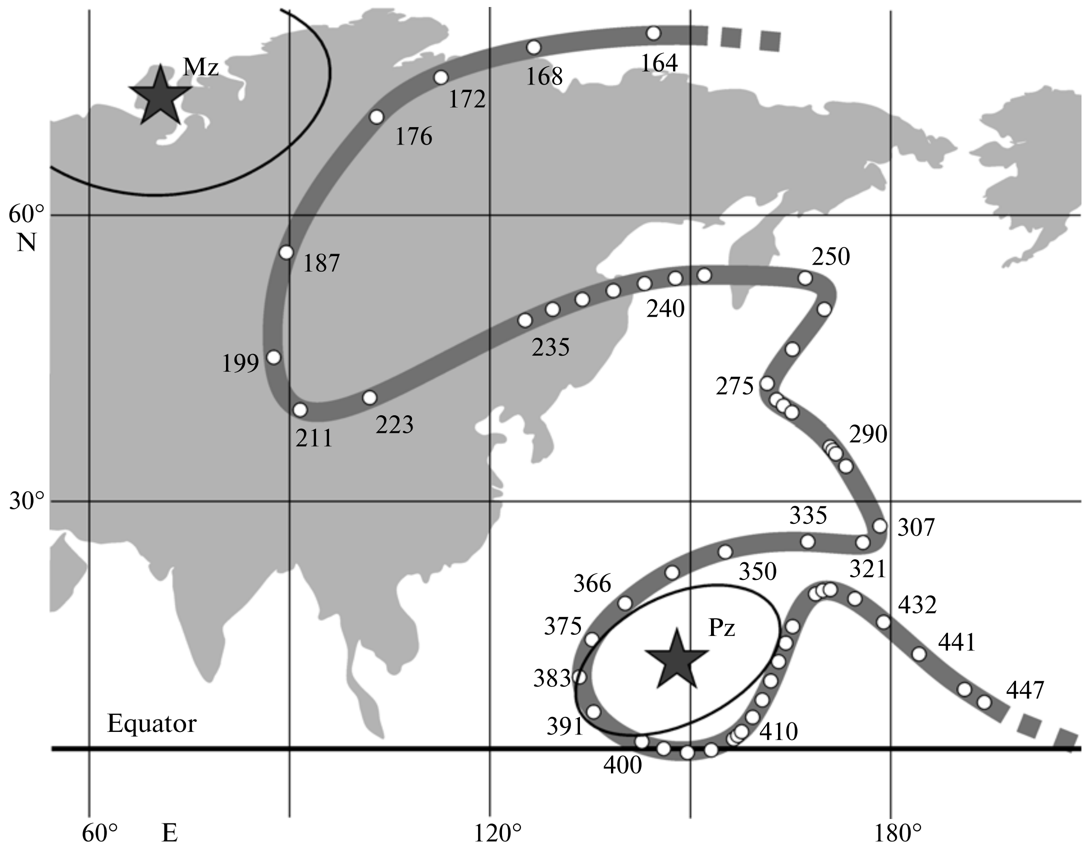

Fig. 3. Positions of the paleomagnetic poles for Pz and Mz components relative to the Phanerozoic part of the APWP for the East European Craton [15].

nature of this component is unlikely to be questionable, because it is found in a significant number of samples within the middle-temperature interval and partially overlaps the Devonian high-temperature component. Bipolarity of the Mz component (from 219 samples where it was identified, 22 samples from four dykes carry the magnetization component of the reversed polarity) can indirectly evidence the duration of a thermal remagnetizing event being sufficient for polarity change (inversion) of the geomagnetic field to occur. In terms of its direction, the Mz component is similar to the direction of the modern field in the study area; hence, there is a theoretical possibility to explain the appearance of stable modern magnetization during formation of new magnetic minerals in the zone of weathering as it was observed multiple times in paleomagnetic studies of sedimentary rocks (for instance, [3]). However, in a series of samples carrying the mid- or high-temperature Mz component, the low-temperature (<250°C) magnetization component is confidently identified and its directions are densely grouped around the direction of the present geomagnetic field. Moreover, the exemplified petrographic studies do not reveal any (even minimal) changes in the mineral composition of dykes; therefore, there is a minimal possibility for appearance of the modern chemical-related magnetization during formation of new magnetic minerals.

Paradoxically, analysis of the information shows an absence of any geological or geochronological evidence for Mesozoic thermal and/or other geological events that took place within the Kola Peninsula and the adjacent region of the Fennoscandian Shield that could be a reason for the appearance of magnetization related to the Mz component. Numerous isotopic datings of dykes and other objects from the Kola Peninsula made based on micas and amphiboles using the $^{40}Ar/^{39}Ar$ method, which is the most sensitive to thermal effects, have not revealed any signs of disturbance of this isotopic system by post-Paleozoic processes, whose temperature did not exceeded 300–350°C [9] with the temperatures of the K–Ar system closing taken into account. The data resulting from examination of single zircon grains from Precambrian rocks of the Fennoscandian Shield via the SHRIMP method [5] signifies the presence of processes that led to partial lead losses from particular zones of zircons and to the appearance of new generations of zircons throughout the Phanerozoic. However, the calculated lower discordia crossings that yield age estimates in the interval of 700–250 Ma [2, 4] apparently only show under the influence of the Devonian stage of magmatic activation [11]. The results of fission track dating [10] also add no certainty due to the uniqueness of available data for the studied territory; however, they do not exclude the presence of a certain overlain event of Mesozoic age.

Remagnetization throughout the Mesozoic—Paleozoic within the western part of the East European Craton was found in paleomagnetic studies of Ordovician and Devonian rocks in Leningrad region [14, etc.], of Proterozoic dykes in Karelia [6], and of Paleozoic sedimentary rocks in Estonia [13]. The most significant events that could cause such an extensive remagnetization are probably related to activation of the Barents-Amerasian superplume and to formation of an extensive break of Jurassic-Cretaceous trap magmatism ("large igneous province") within the modern Arctic basin [8]. The $^{40}Ar/^{39}Ar$ isotopic dates obtained in recent years for flood basalts in Franz Josef Land (189.1 ± 11.4 Ma on Hooker Island and 191 ± 3 Ma on Alexandra Land [4]) correspond to the initial phase of plume evolution manifested in breakup of the lithosphere and disintegration of the future Arctic Basin into block structures. The reconstructions [8] have shown that the center of magmatic activity covered Franz Josef Land and the Spitzbergen archipelagoes and, probably, the adjacent (in that time) northern part of the Fennoscandian Shield, while the fault zone related to the functioning apophyses of the plume were hampered by the paleomargin of the Barents Sea. The subsequent destruction and extension of the continental lithosphere in the Barents Sea region led to weakening of the thermal effect of the plume to the crystalline basement of the Arctic areas of Fennoscandia.

Thus, the results of paleomagnetic studies signify that, throughout the Phanerozoic, the eastern part of the Fennoscandian Shield both suffered the Devonian tectonic-magmatic activation and underwent the thermal effect of Mesozoic plume-lithospheric processes, which caused the appearance of marginal-continental polycyclic riftogenesis in the West Arctic.

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