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GEOLOGY

New Paleomagnetic and Isotopic Data on the Mesoproterozoic Igneous Complex on the Northern Slope of the Anabar Uplift

R. V. Veselovskiy[a], P. Yu. Petrov[b], S. F. Karpenko[c], Yu. A. Kostitsyn[c], and V. E. Pavlov[a]

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The existence of the Paleoproterozoic (2.1–1.5 Ga ago) supercontinent Columbia is one of the most debatable geological problems in the Late Precambrian geology. The subsequent evolution of the Siberian Craton and other ancient blocks within the supercontinent remains unclear as well. According to [7], the breakup of Columbia produced two supercratons. Arctica included Laurentia, Siberia, Baltica, North Australia, and North China. Atlantica was composed of Amazonia, Congo, West Africa, North Africa, and Rio de la Plata. The supercratons were subsequently integrated into the Neoproterozoic supercontinent Rodinia.

The model proposed by Condie differs from breakup scenarios of the Earth's other well-known supercontinents, which were disintegrated into a substantially greater number of cratonic blocks. The confirmation of this model can significantly refine the present-day views on the origination and breakup of supercontinents.

Paleomagnetic data on ancient cratonic blocks, which were presumably constituents of the hypothetical supercontinent Columbia and its daughter cratons Arctica and Atlantica, can confirm or refute their existence and substantially constrain their configuration.

In this connection, it is of interest to compare respective Paleo- and Mesoproterozoic paleomagnetic poles for Siberia and Laurentia. Recent studies provided a number of reliable paleomagnetic measurements within the indicated age interval for some Laurentian objects. For Siberia, such data are extremely scarce [3, 8]. Therefore, identification of new reference paleomagnetic poles for the Siberian Craton with reliable age and paleomagnetic constraints is an important task. Its solution can contribute much to development of the Meso- and Paleoproterozoic segments of the apparent polar wander path (APWP) and allow us to compare corresponding APWP segments of Siberia and Laurentia.

Therefore, we performed in 2004–2005 paleomagnetic and isotopic–geochronological investigations of Mesoproterozoic igneous bodies of the northern Anabar Uplift. This paper reports the results of these studies.

MATERIALS

In the summer of 2004, we carried out fieldwork and paleomagnetic sampling of intrusive bodies at the northern margin of the Siberian Craton. These bodies are exposed over more than 150 km in the Fomich River valley, a left tributary of the Popigai River (Fig. 1). In total, 16 basic dikes and sills were sampled.

Based on petrochemical and isotopic–geochronological data on sills and dikes of the Anabar Uplift and taking into consideration their strike and geographic position, Okrugin et al. [11] suggested that most of these igneous bodies intruded during the Proterozoic and they can be divided into at least ten generations ranging in age from 1800 to 900 Ma.

The intrusive bodies examined in the study area belong to an igneous complex confined to the Riphean sequence, including its uppermost part (apparent roof of the Yusmastakh Formation). The igneous complex is absent in the unconformably overlying Vendian–Cambrian section (Staraya Rechka and overlying formations). Hence, the upper age limit of these intrusive bodies is constrained by a hiatus at the base of the Staraya Rechka Formation. According to recent Rb–Sr data, the age of the Yusmastakh Formation and its

[a] *Institute of Physics of the Earth, Russian Academy of Sciences, ul. Bol'shaya Gruzinskaya 10, Moscow, 123995 Russia; e-mail:veselovskiy@ifz.ru*
[b] *Geological Institute, Russian Academy of Sciences, Pyzhevskii per. 7, Moscow, 119017 Russia*
[c] *Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, ul. Kosygina 19, Moscow, 119991 Russia*

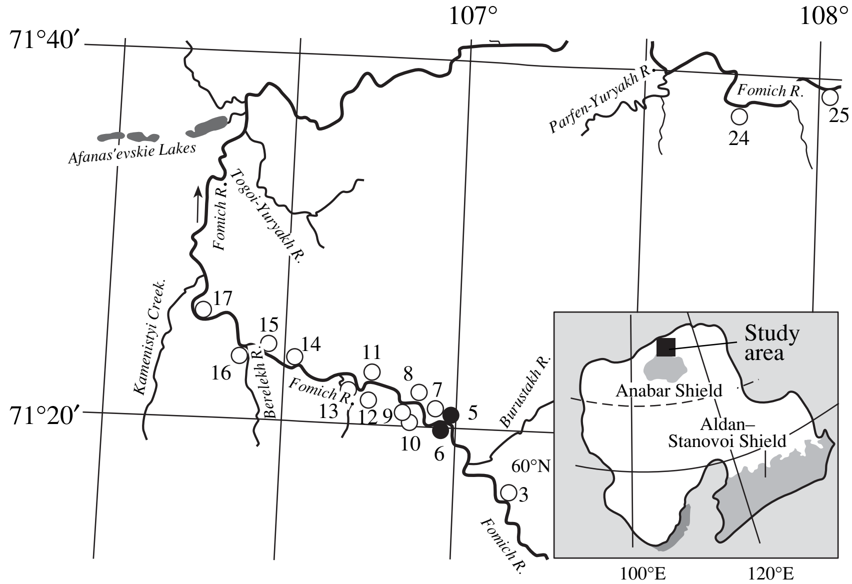

Fig. 1. Location of the study area in the Siberian Craton and sampling points for paleomagnetic (open circles) and geochemical (solid circles) studies of intrusive bodies in the Fomich River valley.

diagenetic subsidence is estimated at 1280–1270 Ma [2] and the K–Ar age of the Staraya Rechka Formation is estimated at 673–624 Ma [4].

The Ka–Ar dates obtained by Kuteinikov et al. [4] for four subvolcanic bodies in the Fomich River basin are 912 (for two bodies), 1100, and 1540 Ma.

Thus, the majority of available data indicate that the examined subvolcanic bodies formed 1500 to 600 Ma ago.

Results of Isotopic Studies

Samples taken from a sill outcropping in the Fomich River valley approximately 10 km downstream from the Burustakh Creek mouth (Fig. 1, points 5 and 6) were used to determine the isotopic composition. The bulk rock and plagioclase, apatite, and two pyroxenes separated from the initial sample using magnetic separation and heavy liquid techniques were analyzed. The pyroxene-1 sample was pure hypersthene, while the pyroxene-2 sample represented fine-grained orthopyroxene disseminated in magnetite. The Nd and Sm isotopic compositions were determined with a Triton TI 10-channel mass-spectrometer at the Institute of Geochemistry and Analytical Chemistry with an accuracy of at least 0.005 and 0.1% for the ^{143}Nd/^{144}Nd and ^{147}Sm/^{144}Nd values, respectively. The results obtained were used to compile the isochron diagram, according to which the age of examined dolerites determined with a sufficient confidence level is 1513 ± 51 Ma (2σ).

Results of Paleomagnetic Studies

Except for one sill (Fig. 1, point 13), all the examined bodies provide information on the direction of the ancient geomagnetic field. The natural remanent magnetization (NRM) in most of the examined samples contains usually two (low-temperature recent and high-temperature ancient) components, which are readily deciphered during the analysis of results of thermal demagnetization (Fig. 2a). However, some samples show a specific behavior of the NRM vector during thermal cleaning. By analogy with the phenomenon previously recorded for Permian–Triassic traps in the Stolbovaya River valley [1], the NRM behavior can suggest a partial magnetization self-reversal (Fig. 2a, sample 193).

Vectors of the high-temperature component demonstrate the bipolar distribution (Fig. 2b). The reversal test [9] performed for defined directions at the sample level provides, however, negative result with a 95% confidence level (γ/γ_c = 15.5/14.0), which is probably explained by the incomplete removal of the present-day component during thermal cleaning.

Nevertheless, the practice and simple model experiments show that directions calculated by averaging such bipolar distributions are slightly (frequently in the confidence oval limit) displaced relative to the true direction and can be considered as good approximations. The paleomagnetic pole corresponding to the obtained mean direction is presented in Table 1.

The primary character of magnetization in the igneous bodies examined is confirmed by the following facts: (1) the obtained paleomagnetic pole differs from younger poles recorded for the Siberian Craton; (2) the new pole position is located near the previously obtained pole estimated at 1503 ± 5 Ma [8]; (3) partial self-reversal of the magnetization vector is observed in some samples; and (4) the paleomagnetic data array includes two opposite magnetization components.

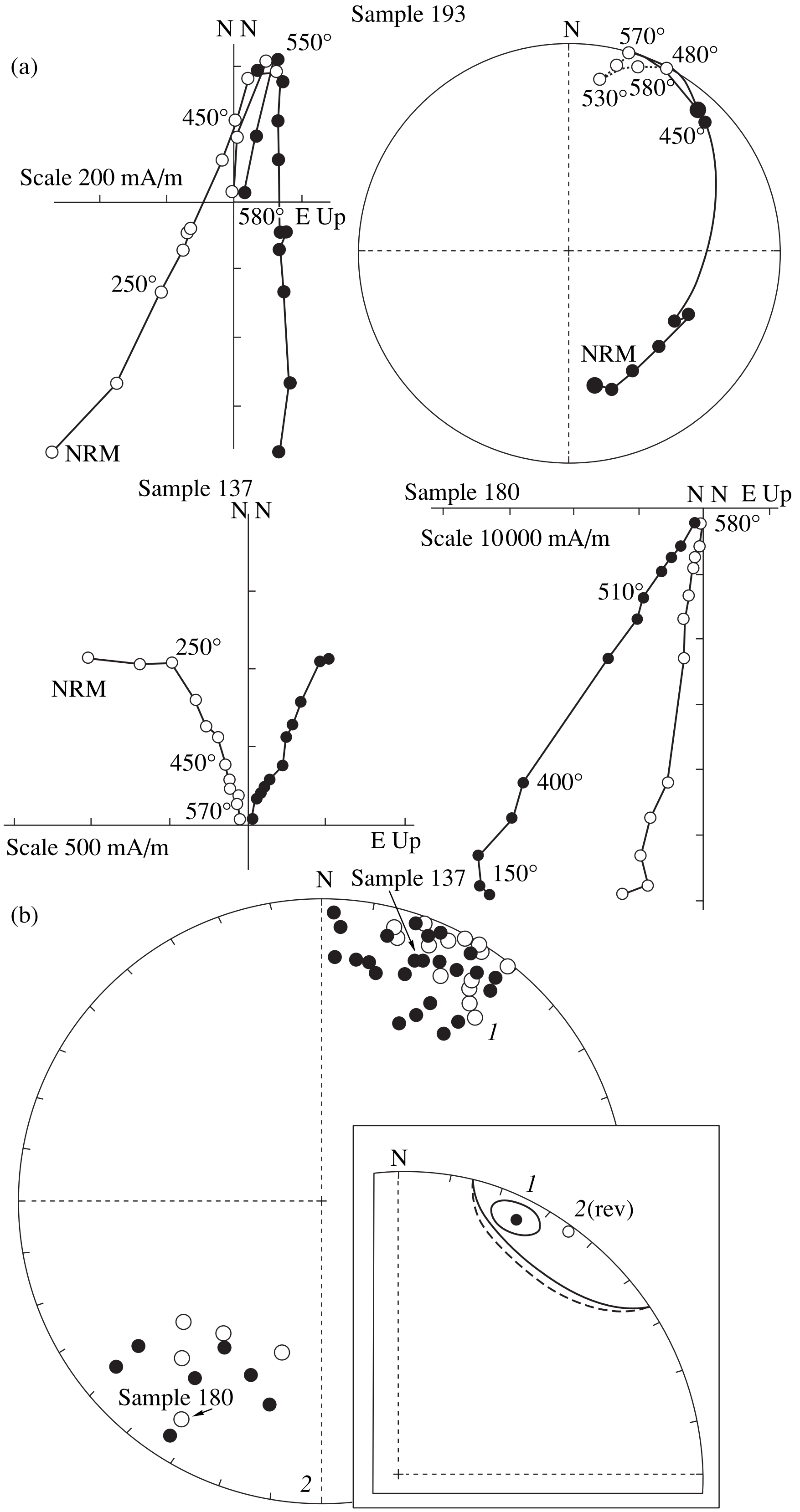

Fig. 2. (a) Probable partial magnetization self-reversal (sample 193) and examples of typical Zijderveld diagrams (samples 137 and 180); (b) bipolar distribution of magnetization components and their mean directions (mean direction for cluster *2* is reversed). Solid circles in the Zijderveld diagrams (stereograms) designate projections of vectors onto the horizontal surface (lower hemisphere). Open circles correspond to projections of vectors onto the vertical surface (upper hemisphere).

Table 1. Paleomagnetic directions and mean paleomagnetic pole of plutons in the Fomich River valley

Parameter	*N*	*D*	*I*	*K*	α_{95}
Reverse polarity	40	24.6	7.8	19.5	5.4
Normal polarity	12	216.0	2.8	5.9	19.5
Total mean	52/15	27	5.6	12.3	5.9
λ = 106.5°	Paleomagnetic pole				
φ = 71.5°	Φ = –19.2°, Λ =77.8°, *dp*/*dm* = 3.0°/5.9°				

Note: (φ, λ) mean latitude and longitude of sampling sites; (*N*) number of samples/sites; (*D*, *I*, *K*, α_{95}) characteristics of Fisher's distribution: declination, inclination, precision parameter, and confidence oval radius, respectively; (Φ, Λ, *dp*/*dm*) latitude, longitude, and half-axis of the confidence oval of the paleomagnetic pole, respectively.

The data presented above suggest the following conclusions. The calculated pole is 1513 ± 51 Ma old. Among the recorded Laurentian paleomagnetic poles that meet modern reliability requirements [13], the closest value is 1476 ± 16 Ma obtained recently for acid igneous rocks from southeastern Missouri [10]. The values obtained for the Anabar and Missouri poles differ insignificantly. However, their true age difference can be as large as 40 Ma or more because of the relatively large confidence intervals. Therefore, direct comparison of these two poles and reconstruction of the mutual positions of Siberia and Laurentia based on these poles appear to be insufficiently correct. At the present stage of investigations, we would prefer to compare general trends in the motion of these two cratons in the period of 1500–1000 Ma that are based on our data and the paleomagnetic poles reported in [5, 14].

It should be remembered that possibilities for such comparison were substantially limited until recently because of the uncertainty with the choice of polarity for Siberian Precambrian paleomagnetic directions [5]. The data obtained recently by A.V. Shatsillo et al. (private communication) probably reduce this uncertainty to a great extent and confirm the necessity for revision of traditional views on the position of northern Meso- and Neoproterozoic paleomagnetic poles in the Siberian Craton.

When considering some paleomagnetic poles of the Siberian Craton, one should keep in mind the presumable opening of the Vilyui rift system in the Middle Paleozoic. According to [6], this event was responsible for counterclockwise rotation of the Angara–Anabar block relative to the Aldan block by 20°–25° around the pole located in the area with the present-day coordinates 117° E and 62° N. New paleomagnetic measurements and data based on the analysis of the basement geometry of the Vilyui Syneclise (V.E. Pavlov and V.O. Mikhailov, private communication) confirm this assumption. Coordinates of the Anabar pole corrected for the opening of the Vilyui rift system are presented in Table 2.

Figure 3, which is based on data presented in Table 2, shows the position of the Siberian Craton at different moments within the period of 1513 ± 51 to 960–1000 Ma ago. The position of Laurentia at that time is also shown for comparison.

The figure shows that Siberia was located 1.5 Ga ago virtually at the equator with its present-day southwestern margin oriented northward. By the period of 1100 Ma ago, the Siberian Craton moved to tropical and, partly, subtropical latitudes of the Northern Hemi-

Table 2. Paleomagnetic poles of Siberia and Laurentia

Ord. no.*	Age, Ma	Paleomagnetic pole**				Source
		Φ, deg	Λ, deg	*N*	A_{95}	
			Siberia***			
1	1513 ± 51	–12.1	58.4	15	5.9	Laurentia****
2	1045 ± 20	22.5	50.4	4	2.5	[5]
3	1000–1030	13.3	23.2	8	10.7	[5]
4	950–1000	3.1	356.7	3	4.3	[5]
			Laurentia			
1	1476 ± 16	–13.2	219.0	18	6.8	[10]
2	1100–1110	44.8	192.2	3	27.3	[14]
3	1050–1075	24.3	176.8	4	12.0	[14]
4	1000–1020	9.2	164.6	6	16.1	[14]
5	960–990	–23.1	147.8	3	26.8	[14]

Note: (*) Ordinal numbers of poles for corresponding cratons used for paleoreconstructions (Fig. 2); (* Φ, Λ*) latitude and longitude, respectively, of the mean paleomagnetic pole (in degrees); (A_{95}) confidence oval radius of the mean paleomagnetic pole (in degrees); (*N*) number of poles used in averaging; (***) paleomagnetic poles of Siberia with consideration of changes in the polarity option of Siberian paleomagnetic vectors; (****) pole position corrected for the closure of the Vilyui rift system (see discussion).

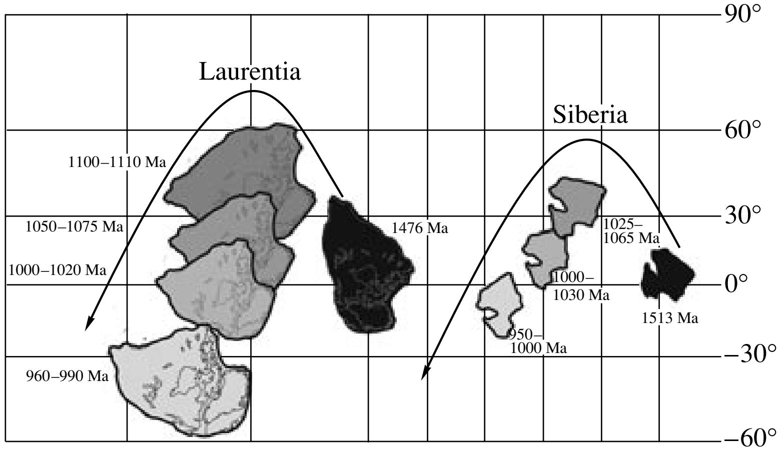

Fig. 3. Reconstruction of the mutual position of Siberia and Laurentia for the period of 1500–1000 Ma ago.

sphere and rotated simultaneously by approximately 30° counterclockwise relative to the meridian. Later on, the Siberian Craton moved again toward equator. By 960–1000 Ma ago, the major part of this craton crossed the equator and continued the counterclockwise rotation.

The paleomagnetic data [14] indicate that Laurentia underwent similar dislocation experienced during the period under consideration; i.e., there is coordination between general motion of the Laurentian and Siberian cratons. This inference is consistent with the hypothesis implying the existence of the single Arctica supercraton during the entire Mesoproterozoic that was later integrated into the Neoproterozoic supercontinent Rodinia. Our data and materials published in [5] indicate the following scenario: Siberia was located in the supercraton in such a way that the present-day south-southeastern side of the Siberian Craton was oriented toward modern northern areas of Laurentia. Such a mutual position of Siberia and Laurentia accords with reconstruction of the hypothetical supercontinent Columbia based on the analysis of geological data [7].

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