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Paleomagnetically Derived Reconstruction of the Relative Positions of Siberia and Laurentia in the Terminal Mesoproterozoic

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Abstract—The paper discusses the results of paleomagnetic studies of rocks from the Malga Formation of the Uchur–Maya region (southeastern Siberian craton) that were formed in the terminal Middle Riphean (Late Mesoproterozoic). The obtained data are completely consistent with the criteria of paleomagnetic data reliability [58] and, being compared with paleomagnetic determinations for approximately coeval rocks from Laurentia, support an assumption that Siberia and Laurentia represent fragments of a single continent. The inferred connection between Siberia and Laurentia requires, however, a revision of the polarity of the Late Proterozoic paleomagnetic directions in Laurentia and Gondwana, which complies with the latest data obtained [21, 42, 48]. Paleomagnetic data, which we obtained for the Malga Formation, confirm an assumption that the Siberian craton could be located near the modern northern and northeastern Laurentian boundaries [23, 29, 43]. However, in contrast to the reconstructions suggested by these authors, our data indicate that Siberia was turned toward the northern and northeastern margins of Laurentia by its south-southeastern side. This is in excellent agreement with the recent reconstruction [46] based on new isotopic data on the Upper Riphean rocks of the Uchur–Maya region.

INTRODUCTION

An avalanche or, according to Dalziel [26], an "explosion" of new geological data (for a review see [25, 47]) and the global correlation of the Mesoproterozoic Grenville orogeny and Neoproterozoic rift systems had a consequence that several researchers almost simultaneously inferred the existence of a Mesoproterozoic–Neoproterozoic supercontinent Rodinia [24, 29, 38]. The central part of this supercontinent was presumably formed by Laurentia, which was bounded by Siberia and East Gondwana (the Indian, Australian, and East Antarctic cratons) on the east and north and by the Baltic, South American, and African cratonic blocks on the south and west.

During the last 3–4 years, the hypothesis of Rodinia attracted more adherents. It has presently turned into a historical–geological and tectonic (sub)paradigm, which explains the most important events of the Late Proterozoic and Early Paleozoic history: formation of Gondwanaland [30–57] and the Pacific Ocean [24], major Precambrian glaciations [54], low frequency of magnetic reversals [55], Early Vendian evolutionary spurt [25], "explosion of life" at the Proterozoic–Paleozoic boundary [39], and others.

The methodical and analytical revolution in paleomagnetic studies that occurred in the 1980s resulted in an appearance of new high-quality paleomagnetic determinations. Analyzing paleomagnetic data available for Laurentia and East Gondwana by that time, Powell *et al.* [45] showed that they agree with the proposed reconstruction of supercontinent position for the time interval of 1050–720 Ma.

Despite the attractiveness of this hypothesis, one cannot but infer that its substantiation is not sufficiently reliable. This is particularly well-exemplified by Siberia, where proposed geological reconstructions contradict each other [23, 43], whereas paleomagnetic determinations satisfying modern requirements are extremely rare. A well-substantiated confirmation or refutation of the fact that Siberia is a fragment of Rodinia would be an important argument in the dispute regarding the existence of the latter.

The essence of the problem is whether or not Siberia and Laurentia were the constituents of a single continent in the Proterozoic and, if so, what were their relative positions? Sears and Price [51] were probably the first to consider this problem in detail. Based on some features in common between Laurentia and the Siberian craton, these authors proposed that the latter was rifted away from the western margin of Laurentia in the Late Proterozoic. The same mutual arrangement of Siberia and Laurentia was suggested by Piper [44] in his reconstruction of the Late Proterozoic supercontinent that was mainly based on paleomagnetic data available by that time.

Based upon paleoclimatic and paleomagnetic data, Scotese and McKerrow [50] also believe that Siberia and Laurentia were constituents of a single continent in the Late Precambrian, although they place Siberia east of Greenland in their reconstruction.

Based on a correlation between ancient fold belts and magmatic zones of the North American and Siberian cratons, Hoffman [29], Condie and Rosen [23] infer that Siberia was attached to the northern part of Laurentia. However, Hoffman shows that Siberia turned toward Laurentia, whereas the latter authors argue that Siberia was rotated approximately through 60° counterclockwise relative to its position in the Hoffman's reconstruction.

In 1996, Pelechaty [43] cited the results of stratigraphic studies of the Vendian–Cambrian rocks in North Siberia, which confirm, in his opinion, the Hoffman's reconstruction and indicate the Early Cambrian time for the separation of the Siberian and North American cratons.

The recent isotopic data on the Late Proterozoic sills and zircons from the upper Ui Group in the Uchur–Maya region [46] place certain constrains on the possible reconstructions of the relative positions of Laurentia and Siberia. Authors of this work emphasize that their new original data would comply with the previously available data only if the Siberian craton was turned toward the northern margin of Laurentia by its southern part.

Thus, several alternative and differently substantiated reconstructions of the relative positions of Siberia and Laurentia in the Late Proterozoic have been proposed to date. The direct and natural way to test them is to compare paleomagnetic data on the coeval Late Proterozoic structures on the North American and Siberian cratons. Objects to be examined should fulfill the following requirements: firstly, their age should be determined with the highest possible accuracy for this time interval and, secondly, the data on these objects should satisfy the criteria of paleomagnetic data reliability [58]. It should be noted that there are several dozens of magnetic pole determinations for the Late Proterozoic on the North American craton, and the data meeting the above-mentioned requirements can be easily obtained by strict selection, whereas the relevant data on the Siberian craton, necessary for correlation, are extremely scarce.

Probably, the best object in Siberia for the solution of the considered problem is the Malga Formation of the Uchur–Maya region. The Malga Formation is among the first Precambrian complexes that were studied by the paleomagnetic method in the former USSR [18]. The subsequent studies showed that even those data could be used to estimate the approximate position of the Siberian craton at the end of the Middle Riphean.

Later, a more detailed investigation was carried out [5, 9], during which the method of step-by-step demagnetization of samples from the pilot collection was used with the subsequent cleaning of the entire collection under a selected optimal regime. In the course of these studies, the Middle and Upper Riphean rocks of the Totta, Tsipanda, Neryuen, Ignikan, Kandyk, and Ust'-Kirba formations were studied in addition to the Malga Formation. However, only final results of these studies were published without any details, which could allow their reliability to be estimated. According to reasoning from modern requirements on the accuracy and reliability of the recognition of paleomagnetic components, the data cited in works [5, 9] need to be refined because only some of the samples were subjected to detailed magnetic cleaning, and the method of main components [31] was not used when calculating the directions of magnetic components.

The paper presents the results of recent studies of rocks from the Malga Formation that were carried out using modern methods and sophisticated paleomagnetic equipment.

GEOLOGY AND AGE

The Riphean section of the Uchur–Maya region is complete, well studied, fossiliferous, weakly altered, and well exposed. In these and other characteristics, it is the best Riphean section in the world. The Lower, Middle, and Upper Riphean rocks, separated from underlying Archean and Early Proterozoic and overlying Vendian–Cambrian formations by major regional unconformities, are exposed over an area of several hundred thousands of square kilometers [17].

In terms of structure, the Uchur–Maya region comprises two large areas separated by the regional Nel'kan–Kyllakh thrust: the Uchur–Maya platform of the Siberian craton and the Yudoma–Maya fold–block zone, which is a part of the Verkhoyansk–Kolyma fold system. The Riphean of the Uchur–Maya region includes five sedimentary rock groups: the Lower Riphean Uchur, Middle Riphean Aimchan and Kerpyl', and the Upper Riphean Lakhanda and Ui groups [15]. The Kerpyl' Group is most widespread in the study area and includes (upward) the siliciclastic Totta and the mainly carbonate Malga and Tsipanda formations.

The work presents the results of the paleomagnetic studies of rocks from the Malga Formation exposed within the Uchur–Maya platform in the Maya (Khaakhar, Emeleken, and Seliya exposures) and Ingili (Ingili exposure) river valleys. The examined exposures are located 30 to 80 km apart (Fig. 1).

The rocks of the Malga Formation studied in the Ingili River valley compose, among others, a steep (dip angles of 60°–90°) western limb of the Ingili structure that was formed 640–680 My ago [15] as a result of the emplacement of a large alkaline ultramafic massif. In the Khaakhar, Emeleken, and Seliya exposures, the rocks show almost horizontal bedding.

In the studied exposures, the Malga Formation is composed of variegated (red, green, greenish gray, pale yellow) flaggy clayey limestones, sometimes grading into bituminous limestones and dolomites in the upper part of the section. The lower part of the formation encloses lenses and discontinuous beds of endoclastic

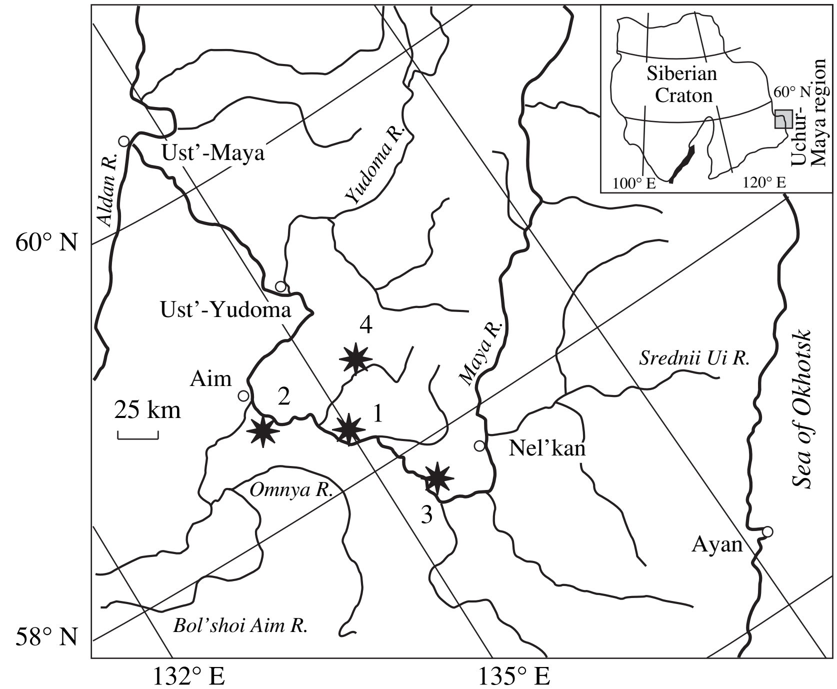

Fig. 1. Location of the studied sections. Studied exposures are marked by asterisk: (1) Emeleken, (2) Seliya, (3) Khaakhar, (4) Ingili. The inset map shows the geographic position of the study area.

flat-pebbled conglobreccia. The thickness of the formation in studied sections varies from 40 to 110 m.

Oriented samples for paleomagnetic studies were collected at fairly regular intervals along the formation section with a step of 1–2.5 m. In this paper, the results of the study of about 120 oriented samples are presented.

As is evident from the analysis of paleontologic, lithostratigraphic, and isotopic–geochronological data [1–4, 6–8, 11, 12, 15–17, 20, 32–34, 40, 52), the Kerpyl' rocks were formed during the period of 1200–1000 Ma. The age of the Malga Formation is constrained from below by two Pb–Pb isochron datings. One of them (980 Ma), obtained for the Tsipanda Formation, was published in 1976 [2]. Another dating (1035 ± 60 Ma) was obtained recently for the Sukhaya Tunguska Formation, the equivalent of the Tsipanda Formation from the Turukhansk section [40].

For the Totta Formation underlying the Malga Formation, more than ten K–Ar datings on glauconite are available; in general, they form a regular succession of values increasing downward from 970 to 1170 Ma. It should be noted that these glauconite datings were obtained more than a quarter of a century ago using the methods that do not meet modern requirements to such investigations and, therefore, should be considered as approximate. Nonetheless, the available data suggest that the accumulation time of the Malga Formation can be limited to 1100–1000 Ma.

PALEOMAGNETIC ANALYSIS

The laboratory-based paleomagnetic studies and primary data processing were performed in the paleomagnetic laboratories of the Institute of General and Applied Physics (Munich) and the Institute of Earth Physics (Paris) according to the standard procedure [19, 22, 27, 31, 36].

The comparison of results of alternating magnetic field and thermal magnetic cleaning that was performed on the pilot collection showed a much higher efficiency of the latter for defining the natural remanent magnetization (NRM) component. Therefore, all samples were subjected to detailed thermal cleaning, which was performed in most cases at 685–690°C. The samples were usually heated at least 15 times, sometimes even more. Special nonmagnetic TSD-2 furnaces of the Shonstedt Company were used for sample demagnetization. Normal remanent magnetization (NRM) was measured using cryogenic 2G Enterprises and CTF magnetometers. All of the laboratory procedures were performed in a room screened from the external magnetic field. The NRM values of studied rocks vary from 3×10^{-3}–20×10^{-3} A/m; red-colored rock varieties are generally characterized by higher magnetization values. The magnetic susceptibility is usually $(20–150) \times 10^{-6}$ SI.

Magnetic cleaning. In most of the samples studied, NRM includes two components: a less stable one, which is destroyed at temperatures below 300–350°C, and a characteristic (ChRM) one, with much higher

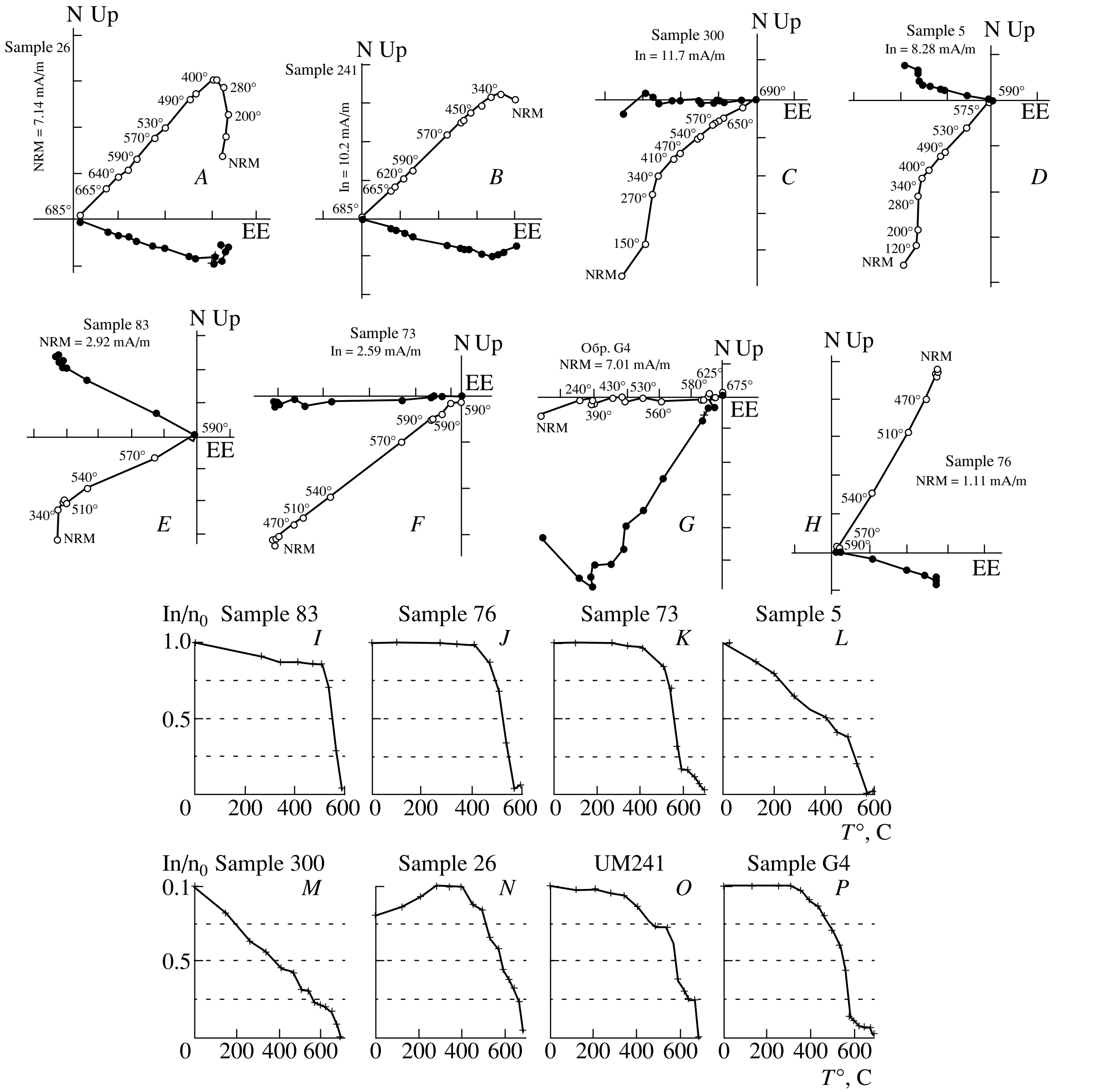

Fig. 2. Zijderveld diagrams of typical samples (*A–H*) and changes in the NRM values (*I–P*) during their temperature demagnetization. Solid circles designate projections of vectors on the horizontal plane, open circles denote projections of vectors on the vertical plane. Diagrams are given in the stratigraphic system of coordinates.

unblocking temperatures (Figs. 2*A*, 2*B*–2*D*). The direction of the less stable component is close to the direction of the modern geomagnetic field in the study area. The characteristic component shows either an easterly declination and a moderate negative inclination or a westerly declination and a moderate positive inclination. NRM behavior in the course of thermal cleaning indicates that magnetization is carried largely by two magnetic phases. The maximum unblocking temperature of one of them is close to the Curie point of magnetite and the other, the Curie point of hematite (Figs. 2*K*, 2*O*, 2*P*). The earlier detailed magnetic–mineralogical studies of the Malga Formation [13] also indicated that the main magnetic minerals in these rocks were magnetite and authigenic hematite. There are also samples amid the studied ones, in which only one of the abovementioned minerals is responsible for magnetization (Figs. 2*I*, 2*J*, 2*L*, 2*N*). It is important that, as is seen in Figs. 2*B* and 2*F*, the directions of the "magnetite" and "hematite" constituents of the characteristic component are virtually indiscernible. The statistical analysis confirms this conclusion.

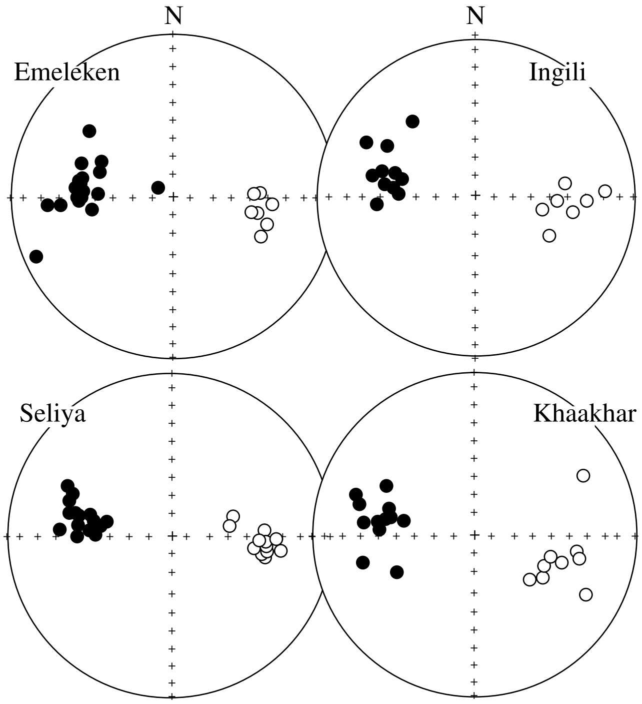

Fig. 3. Distribution of characteristic component in the Emeleken, Seliya, Khaakhar, and Ingili sections. Solid circles designate projections of vectors on the horizontal plane, open circles denote projections of vectors on the vertical plane. Stereograms are given in the stratigraphic system of coordinates.

Analysis of vector distribution. The distribution of the vectors of the characteristic magnetization component is shown in Fig. 3. Each of the studied exposures shows vector groups with normal and reversed polarities, whose mean directions differ by an angle statistically close to 180° (Table 1).

Despite the fact that the bedding of rocks in the Ingili exposure substantially differs from that in the other examined exposures, the mean directions of the characteristic components in all sections are virtually the same in the ancient coordinate system and evidently different in the modern system (Figs. 4*A*, 4*B*). It means that the detected component successfully withstands the fold test at a regional scale.

Twenty-seven pebbles sampled from conglobreccias in the lower part of the Seliya exposure were used for the pebble test. In the course of thermal cleaning, NRM behavior in these pebbles was virtually the same as that observed during the demagnetization of the other samples from the Malga Formation with the only exception that the "magnetite" constituent of the ChRM noticeably prevailed (Fig. 2*G*). However, such a behavior is usual for the samples collected from the lower part of the Seliya exposure. Only some pebble samples show a slightly more complicated NRM behavior within the temperature interval of 580–680°C, probably due to a certain delay in the formation of the "hematite" ChRM constituent. The vectors of the high-temperature component are distinctly present in 25 pebbles. They are chaotically distributed (Fig. 4*C*) and show a normalized value of the resultant vector (0.190). This value is considerably below the critical value of 0.321 [22], the surpassing of which indicates the probable presence of a systematic component in the studied vector group. Despite the fact that studied pebbles are composed of rocks from the lower part of the Malga Formation, the obtained positive result can be extended onto the rocks overlying rocks of this formation because, firstly, they contain a similar (in terms of direction) characteristic component and, secondly, they are similar to the lower part of the formation in terms of lithology and magnetic–mineralogical properties.

Thus, the positive results of the pebble, fold, and rotation tests, as well as the similar ChRM directions in distant exposures and coincidence in the directions of "magnetite" and "hematite" magnetization constituents, indicate that the determined characteristic magnetization component was formed during or immediately after the deposition of the Malga Formation.

INTERPRETATION AND DISCUSSION OF RESULTS

The paleomagnetic pole of the Malga time that was calculated proceeding from the obtained direction of characteristic magnetization is located in the southeastern segment of the Pacific at a point with coordinates of 25° S and 230° E. It means that in the Malga time, the region under consideration was located approximately at 25° S and was rotated through approximately 100° counterclockwise relative to the meridional net.

The assessment of data reliability. There are several schemes that allow the reliability of paleomagnetic data to be estimated more or less formally [14, 35, 58, and others]. All these schemes are proposed by well-known researchers and based on approximately similar criteria. Each of them has its advantages and disadvantages, therefore, we selected Van der Voo's scheme [58], which is the most popular one, to test the data presented in this work. According to this scheme, the tested paleomagnetic data receive an estimate Qv on a 7-point scale depending on compliance with each criterion in succession. The higher the estimate, the higher the reliability of paleomagnetic data. Let us try to estimate the reliability of our data on Van der Voo's scale.

1. The age of studied rocks is well constrained.

The point is the accuracy of age determination of the Malga Formation and the meaning of "an accurate dating" for the Middle Riphean. The dating accuracy of 20 My cannot be considered as a boundary value for the dating of Precambrian rocks, as it is used by Pecherskii and Didenko [14] for younger rocks. Spot isotopic datings of Precambrian rocks with an accuracy of several millions of years are known from the world practice (although it is not always clear what the cited values

Table 1. Paleomagnetic directions and paleomagnetic poles

Exposure	N	Geographic system of coordinates				Stratigraphic system of coordinates				Rotation test		Paleomagnetic pole coordinates		
		D	I	K	α_{95}	D	I	K	α_{95}	γ	γ_c	Φ	Λ	dp/dm
Emeleken $\varphi = 58.3°$ $\lambda = 135.0°$														
Normal polarity	7	99.3	–44.3	92.8	6.3	99.3	–44.3	92.8	6.3					
Reversed polarity	16	275.5	42.3	66.7	4.5	275.5	42.3	66.7	4.5	3.4	7.8	–24.5	233.3	2.7/4.3
Total	23	96.6	–42.9	73.9	3.5	96.6	–42.9	73.9	3.5					
Khaakhar $\varphi = 57.6°$ $\lambda = 135.4°$														
Normal polarity	9	104.2	–42.0	17.1	12.8	105.0	–41.8	17.8	12.6					
Reversed polarity	12	278.7	39.4	30.7	8.0	278.8	39.4	30.4	8.0	4.9	13.7	–25.4	229.0	4.9/8.1
Total	21	101.0	–40.5	23.7	6.7	101.4	–40.5	24.0	6.6					
Seliya $\varphi = 58.7°$ $\lambda = 134.1°$														
Normal polarity	12	93.4	–44.8	44.3	6.6	93.4	–44.8	44.3	6.6					
Reversed polarity	15	282.1	42.6	62.1	4.9	282.1	42.6	62.1	4.9	6.7	7.8	–25.9	231.3	3.1/5.0
Total	27	98.3	–43.7	50.2	4.0	98.3	–43.7	50.2	4.0					
Ingili $\varphi = 58.5°$ $\lambda = 135.5°$														
Normal polarity	7	191.6	–61.1	39.9	9.7	94.6	–40.2	31.1	11.0					
Reversed polarity	11	8.5	52.1	33.5	8.0	287.0	40.8	34.4	7.9	9.4	12.6	–26.0	228.1	4.6/7.6
Total	18	9.5	55.6	33.9	6.0	102.2	–40.7	31.5	6.3					
Mean for the exposures	4	113.1	–51.2	33.6	8.5	99.8	–41.9	1139.3	2.7			–25.5	230.4	$A_{95} = 2.5$

Notes to Tables 1 and 2: φ, λ—latitude and longitude of sampling sites; N—number of samples; D, I, K, α_{95}—characteristics of the Fisher distribution: declination and inclination, compactness ratio and confidence circle radius, respectively; γ—angular distance between the mean vectors of normal and reversed polarity; γ_c—critical angular distance; Φ, Λ, A_{95}—latitude, longitude, and confidence circle radius of paleomagnetic pole; dp/dm—values of semiaxis of the confidence circle.

reflect, either the true dating accuracy or an instrumental error). However, it is virtually impossible to estimate the duration of time intervals in the Precambrian with the accuracy less than several dozens of million years. The Malga Formation is among those of the Precambrian sections of Siberia that are best tied to the time scale.

It is probably impossible to give an unprejudiced answer to the question of whether or not the obtained data meet the requirements of the first Van der Voo's criterion; the mark −1 or 0 strongly depends, in this case, on the personal opinion of the researcher.

2. The data is based on more than 25 samples, the compactness ratio exceeding 10, and the confidence angle less than 16°; the obtained result completely complies with this criterion (Table 1).

3. Samples were subjected to detailed laboratory studies including thorough magnetic cleaning and component analysis; the data obtained completely meet the requirements of this criterion.

4. The reliability of paleomagnetic data is supported by the positive results of field tests; the paleomagnetic data cited in the paper are substantiated by positive fold and pebble test results.

5, a. The examined geological objects are located in areas with an established structural setting (belonging to a certain craton, tectonic block, etc.).

The studied sections of the Malga Formation are located on the eastern slope of the Aldan shield within the Uchur–Maya platform, which is a constituent of the Aldan geoblock of the Siberian craton. Some researchers [19, 60] assumed that the Siberian craton as a single rigid block was formed as a result of amalgamation of the Aldan, Anabar–Olenek, and other geoblocks in the latest Precambrian to earliest Cambrian. However, the close spacing of coeval Middle Riphean paleomagnetic poles determined for the rocks from the southeastern, northwestern, and southwestern parts of the Siberian craton [10], the absence of reliable evidence for a Vendian–Cambrian collision event within the craton, and apparently the similar geological structure and evolution histories of the Riphean sections located in different parts of the Siberian craton support an alternative viewpoint. According to the latter, the Siberian craton (probably shaped differently than at present) had

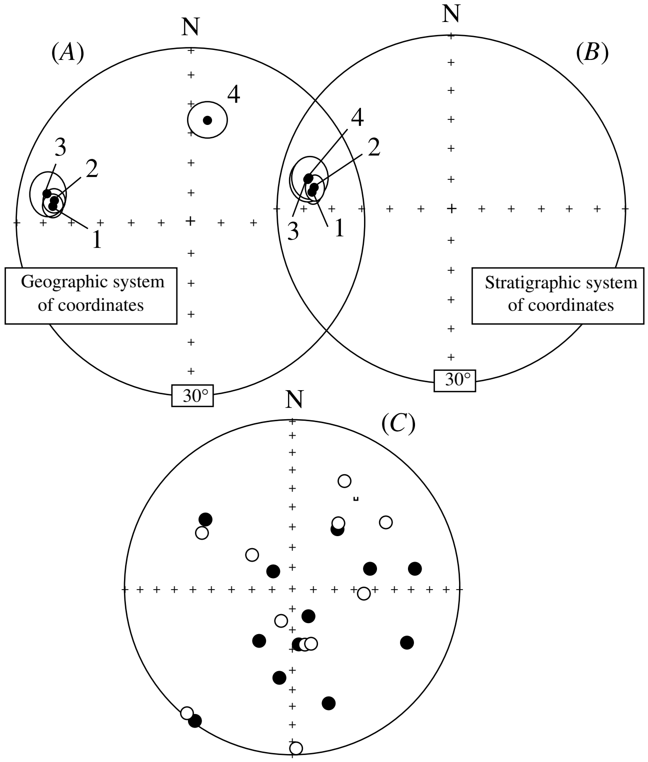

Fig. 4. Distribution of magnetization vectors: (*A*, *B*) mean directions of characteristic magnetization of the Malga Formation rocks from the (*1*) Emeleken, (*2*) Seliya, (*3*) Khaakhar, and (*4*) Ingili exposures and their confidence circles in geographic (*A*) and stratigraphic (*B*) coordinates; (*C*) distribution of characteristic magnetization vectors in pebbles from conglobreccia of the lower part of the Seliya section.

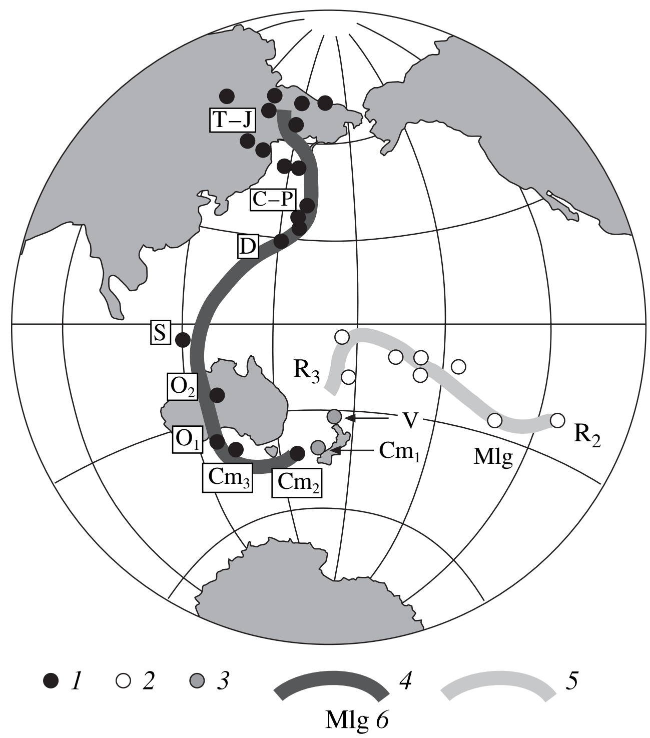

Fig. 5. Comparison between the Phanerozoic apparent polar wander path for Siberia and the Riphean apparent polar wander path of the Uchur–Maya region. (*1*, *2*) Apparent polar wander paths: (*1*) Middle–Late Riphean of the Uchur–Maya region, (*2*) Phanerozoic of Siberia; (*3*–*6*) paleomagnetic poles: (*3*) Phanerozoic of Siberia, (*4*) Middle–Late Riphean of the Uchur–Maya region [10], (*5*) Vendian and Early Cambrian of Siberia [53], (*6*) Malga Formation

consolidated by the Riphean. This gives grounds to extend the paleomagnetic data for the Malga Formation to the entire Siberian craton. A great distance between studied sections prevents errors related to possible influence of local tectonics.

5, b. A good structural control.

In this context, the availability of reliable field data is needed for the reconstruction of the initial (predeformation) position of the studied geological objects. The Malga Formation is distinctly stratified. This enables the strike and dip measurements for each sampled bed in order to determine the direction of the detected magnetic component in the ancient (pre-deformation) system of coordinates. As noted above, the bedding of rocks in three studied sections (Khaakhar, Seliya, and Emekelen) is virtually undisturbed. As regarding the Ingili section, the rock dislocation model (rotation of beds around the horizontal axis), which is usual for paleomagnetic studies, is obviously applicable due to the absence of any geological evidence for more complex deformations, and on the other hand, it is due to the similarity between the mean paleomagnetic directions obtained for the Ingili and other studied sections.

6. The occurrence of normal and reversed polarity vectors in the studied objects, which differ (statistically) by an angle of 180°; the obtained data completely satisfy this requirement.

7. The absence of similarity between the positions of the obtained paleomagnetic pole and younger poles; the Malga paleomagnetic pole is located at a considerable distance from all the younger poles determined for the Siberian craton, the Upper Riphean formations of the Uchur–Maya region in particular [9].

Thus, according to the Van der Voo's scheme, the Malga paleomagnetic pole shows the highest reliability corresponding to Qv equal to 6 or 7.

Selection of polarity. A general approach to the selection of paleomagnetic direction polarity for ancient rocks is based on the minimal displacement principle. The latter implies that of the two possible north pole positions one should choose the position, which is the closest to the reliably determined paleomagnetic north pole with the closest age. A comparison between the succession of the Phanerozoic north paleomagnetic poles of Siberia with the Riphean paleomagnetic poles of the Uchur–Maya region (Fig. 5) suggests that the poles located in the central and western Pacific should be considered as the north poles. Smethurst *et al.* [53], who recently performed a thorough analysis of Siberian paleomagnetic data and proposed Late Proterozoic and Paleozoic apparent polar wander paths for the Siberian craton, arrived at the same conclusion. We selected the polarity of the obtained paleomagnetic directions according to this path.

Despite the limited number of reliable paleomagnetic pole determinations, which served as a basis for the curve constructed by Smethurst *et al.* (especially considering the duration of the studied time interval), the proposed apparent polar wander path is well substantiated and, presently most adequately reflects the available paleomagnetic data on the horizontal movements of the Siberian craton in the Late Precambrian and Paleozoic. The selected polarity suggests that the vectors of the easterly declination and negative inclination correspond to the normal polarity of the geomagnetic field, whereas the vectors of the westerly declination and positive inclination correspond to its reversed polarity. With allowances made for obtained results, it means that the Siberian craton was located at subtropical and middle latitudes of southern hemisphere in the Malga time and was oriented northward by its modern eastern side. It should be noted, however, that the available paleomagnetic pole succession shows significant gaps (of which the longest Late Riphean–Early Vendian gap lasted at least 100–120 My). Therefore, the selected polarity should not be considered as unambiguous and ultimate.

Selection of the paleomagnetic poles for Laurentia. As of now, about three dozens of paleomagnetic pole determinations for the period of 1100–1000 Ma are available for Laurentia. These determinations were subjected to a strict test [45, 59] in order to select those that most completely satisfy the requirements of modern reliability criteria. Grouping these data in time intervals, we obtain the mean paleomagnetic poles shown in Table 2.

Despite a fairly large number of reliable paleomagnetic data available for North America, the Late Precambrian apparent polar wander path for Laurentia cannot be considered as finally established so far. This is mainly explained by the uneven distribution of the obtained paleomagnetic poles through time intervals. Moreover, new data obtained for Vendian rocks [37, 41, 42] indicate that Laurentia experienced a fast movement from the equator realm to the south pole at the end of the Late Precambrian and then returned again to low latitudes by the end of the Cambrian. Based on these data, Park [42] proposed a new Late Precambrian apparent polar wander path for Laurentia. According to the latter, the paleomagnetic poles, which were previously considered as the south poles, are actually north poles and vice versa. Such interpretation, however, results in important consequences. In particular, as is noted in the works [37, 45], it requires either a complete revision of the classic configuration of Rodinia or the necessity to change the polarity of Gondwanan pre-Devonian paleomagnetic directions. If both cases prove to be unacceptable, the paleomagnetic evidence for the existence of Rodinia [45] vanishes completely and, therefore, the hypothesis of a Late Proterozoic supercontinent is questioned.

Table 2. Paleomagnetic poles of Laurentia

Age, Ma	Paleomagnetic pole			Source
	Φ	Λ	A_{95}	
1090–1100	–37.5°	7.9°	14.5°	[59]
1050–1075	–24.3°	356.8°	12.0°	[59]
1020–1050	–5.8°	358.0°	–	[28, 45]

Note: See note to Table 1.

The possibility of an alternative interpretation of Gondwanan pre-Devonian paleomagnetic polarity was mentioned by Schmidt and Morris more than 20 years ago [49]. New highly reliable data obtained recently for the Middle Paleozoic rocks of northeastern Australia [21] support this hypothesis. However, as noted by Schmidt [48], the change in Gondwana pre-Devonian paleomagnetic polarity would inevitably (if Rodinia did exist) call for a change in Laurentian Late Precambrian paleomagnetic polarity, which perfectly conforms with Park's proposition [42]. Thus, the available data strongly suggest that the poles shown in Table 2 are the north poles. This means that, in the time period of 1100–1000 Ma, Laurentia was located in the southern hemisphere moving from midlatitudes toward the equator (Fig. 6*A*).

Relative positions of Siberia and Laurentia. The reconstruction of the relative positions of Siberia and Laurentia in the latest Mesoproterozoic greatly depends on the selected paleomagnetic polarity. Based on our data, we may state that if the current viewpoint [45, 56] were true, then Siberia and Laurentia could never be amalgamated in a single continent, whatever configurations they might have and whichever possible paleomagnetic pole of Laurentia we select. In this case, the distance between the nearest points of these cratons would be at least 500 km at best (Fig. 6*B*).

To the contrary, if we accept the paleomagnetic polarity following from the apparent polar wander path proposed by Park [42], then the paleolatitudes of Siberia and Laurentia appear to be mutually consistent (Fig. 6*A*). In this case, the obtained data confirm the possible location of the Siberian craton near the modern northern and northeastern boundaries of Laurentia as assumed in the works [23, 29, 43]. However, in contrast to the reconstruction proposed by these authors, our data suggest that Siberia was oriented toward the northern and northeastern areas of Laurentia by its southern-southeastern side. This result perfectly conforms with the recent reconstruction by Reinbird with colleagues [46], who proceeded from new isotopic data obtained during the study of Upper Riphean rocks of the Uchur–Maya region.

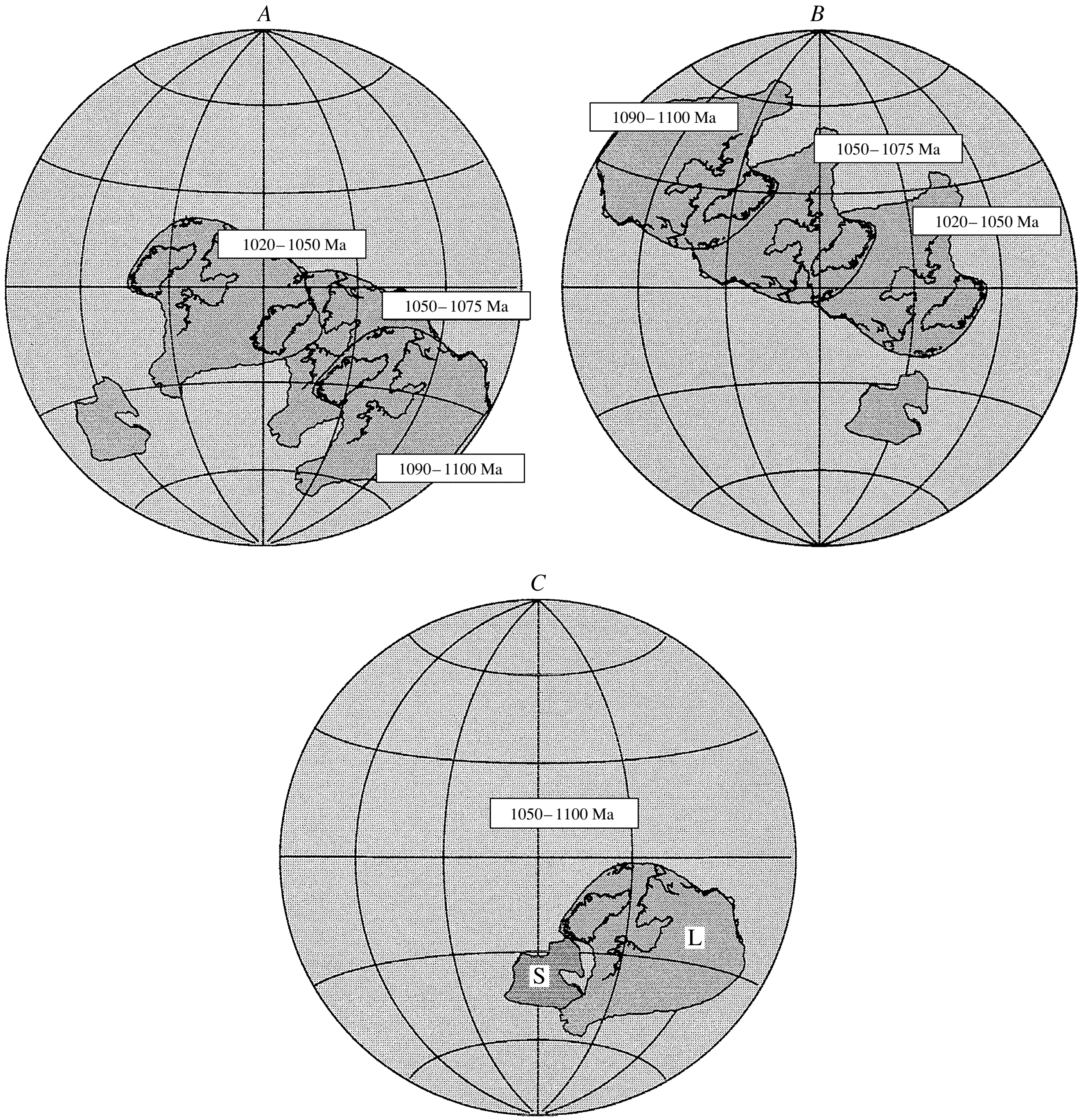

Fig. 6. Paleolatitudes of Siberia and Laurentia 1000–1100 Ma. (*A*) According to polarity of Late Proterozoic direction of Laurentia after [42]; (*B*) according to traditional selection of polarity; (*C*) reconstruction of the relative positions of Siberia and Laurentia in the Malga time. Letters S and L designate Siberia and Laurentia, respectively.

The reconstruction of the relative positions of Siberia and Laurentia in the latest Mesoproterozoic proposed in the present paper (Fig. 6*C*) allows our paleomagnetic data to be harmonically united with those cited in previous publications [21, 42, 46, 48, 49, 53, 59]. In conclusion, it should be emphasized that additional reliable paleomagnetic data on the Vendian and Lower Cambrian rock of Siberia are needed to test the proposed reconstruction. These data could allow the problem of polarity of Riphean paleomagnetic directions to be eventually solved for Siberia.

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