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The Uralian Paleoocean in the Devonian (As Inferred from Paleomagnetic Data)

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Abstract—The Early–Middle Paleozoic Uralian ocean separated the European (Baltic) continent from the Siberian continent and Kazakhstan sialic block. In the Early Devonian–Eifelian, the Uralian ocean hosted the Irendyk ensimatic volcanic arc. Paleomagnetic characteristics were obtained for the Lower–Middle Devonian rocks sampled from three areas of the Southern Urals corresponding to different geodynamic settings: the Sibai area (52°45′ N, 58°35′ E) in the Magnitogorsk tectonic zone represented by deep-sea deposits that had buried the subsided Irendyk volcanic arc, the Tobol area (52°22′ N, 61°40′ E) in the Transural Denisovka zone composed of rocks that had been emplaced in the margin of the Kazakhstan sialic block, and the Kaga area (53°35′ N, 57°40′ E), a former constituent of the European Paleozoic continent margin. According to our paleomagnetic data, the marginal zone of the Kazakhstan sialic block facing the Uralian ocean had an ESE strike in the Devonian, whereas the Irendyk ensimatic volcanic arc stretched in a SSE direction. The Tobol area of the Kazakhstan block margin had been located at 20.6° ± 3.8° N and the Sibai segment of the Irendyk arc, at –5.0° ± 3.4° S. The ocean had occupied an area between the Irendyk arc and the Kazakhstan block 25.6° ± 4.1° (2800 ± 450 km wide); the Irendyk volcanic arc had been located close to the European continent.

INTRODUCTION

The Early–Middle Paleozoic Uralian ocean is interpreted as a constituent of either the Paleo-Tethys [6], of a Paleoasian ocean [12], of a Khanty-Mansi back-arc oceanic basin [24, 27, 28], or as a continuation of the Turkestan ocean [2, 8]. In the Devonian, the Uralian ocean had separated the European (Baltic) continent from the Siberian continent and the Kazakhstan microcontinent. The latter can be viewed as an ensialic island arc [27, 28]. The oceanic area between the European and Kazakhstan major sialic blocks hosted volcanic arcs: the Early Devonian–Eifelian Irendyk and the Givetian–Late Devonian Magnitogorsk arc [7, 8, 15, 23].

We studied the paleomagnetic characteristics of the Lower–Middle Devonian rocks from three areas of the Southern Urals. The Sibai and Tobol areas are located in the eastern slope of the Urals and the Kaga area, in its western slope (Fig. 1). Our paleomagnetic studies covered different-age rocks formed in different settings: the upper Eifelian deep-sea rocks that buried the subsided Irendyk volcanic arc (Sibai area), Eifelian rocks from the edge of the Kazakhstan sialic block (Tobol area), and Emsian rocks from the marginal zone of the European Paleozoic continent (Kaga area).

DESCRIPTION OF STUDY AREAS

Tobol. This area is located in the Transural Denisovka tectonic zone (Fig. 1). After the closing of the Early Paleozoic Denisovka oceanic basin in the Silurian, the Transural zone became a marginal zone of the Kazakhstan sialic block. In the Devonian, this zone accumulated volcanogenic–terrigenous sediments. Nowadays, they are exposed near the Grishanka Settlement in the Tobol River valley (52°22′ N, 61°40′ E) composing a block that is bordered, with tectonic contacts, by Ordovician ophiolites [16]. Faults bordering the 700-m-wide block and its constituting beds of Devonian rocks show a roughly N–S strike. The block is composed of green and lilac tuff conglomerate, gravelstone, sandstone, siltstone, and argillite. Preponderant are coarse-clastic rocks. The argillite includes crinoid fragments, and the breccia hosts brachiopods. In 1935, A.A. Zotov found in these rocks *Spirifer elegans* Rein., a widespread species in the Emsian–Eifelian rocks. An abundant brachiopod, trilobite, coral, and bryozoan assemblage was collected in the 1950s by V.P. Gorskii and P.A. Litvin from similar rocks formerly exposed downstream of the river and now inundated by a water storage basin. This faunal assemblage indicates the Eifelian age of the host rocks.

The examined rocks are characterized by a monoclinal attitude varying from steep normal to overturned. The gradational bedding and pockets in the bottoms of the conglomerate and gravelstone beds clearly define the base of each bed. In total, 103 grab samples were collected from sandstone and siltstone beds totaling 500 m in thickness; the samples were united into 18 sampling sites.

Sibai. This area is located in the Magnitogorsk tectonic zone (Fig. 1, C1, C2). Two localities were studied in the area. Samples for paleomagnetic measurements were collected from the rocks composing the limbs of the Karamalytash anticlinal, or antiform, fold (52°45′ N,

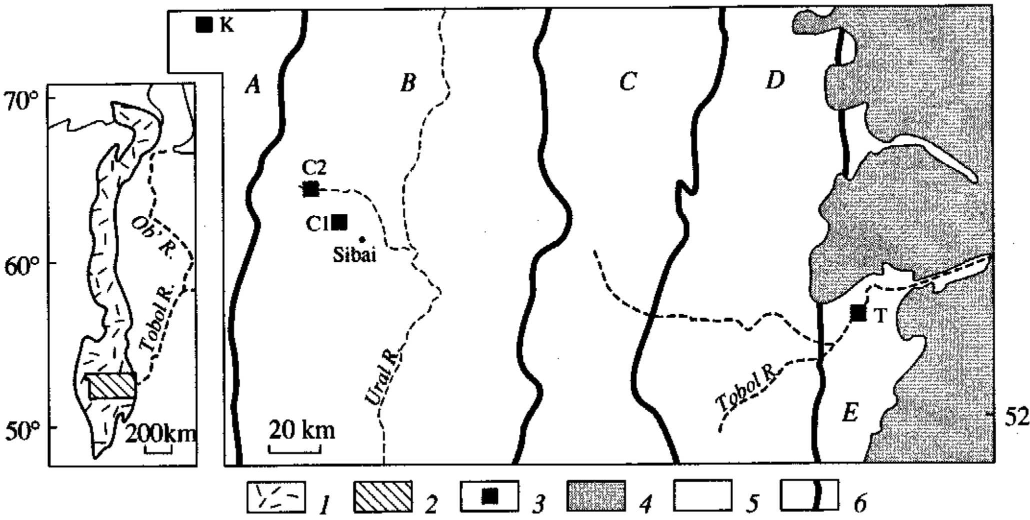

Fig. 1. The study region and location of the Sibai and Tobol areas. (*1*) Urals folded region; (2) study area; (*3*) areas of paleomagnetic investigations: (K) Kaga, (S1, S2) Sibai, (T) Tobol; (*4*) Cenozoic; (*5*) Paleozoic and Precambrian; (*6*) boundaries of tectonic zones after [18]. (*A–D*) tectonic zones: (*A*) West Urals, (*B*) Magnitogorsk, (*C*) East Urals, (*D, E*) Transural (*E*—Denisovka).

58°35′ E). The latter has a roughly N–S strike, with limbs dipping at an angle of 40–60°. The fold core is composed of amygdaloidal basalts with pillow jointing. They are overlaid by agglomerate lavas with thin tuffstone interbeds. The Karamalytash basalts have a tholeiitic composition similar to that of island-arc tholeiites. They are interpreted as a base of the Early–Middle Devonian Irendyk ensimatic island arc [8]. Up the section, these rocks are replaced by quartz porphyries (rhyolite, rhyodacite) with lentils of red flint. The latter encloses conodonts of the Upper Eifelian Substage of the European scale [10]. The boundary between the basic and acid lavas is sharp and gentle; the contact is unexposed. It may be stratigraphic or tectonic (corresponding to a thrust plane).

The volcanics are overlaid by a silicilite sequence (Bugulygyr Horizon) exposed at the limbs of the Karamalytash fold (Fig. 1, C1). The silicilites have an aleuritic and pelitic texture and a regular, partly gradational bedding. The beds have a red, green, or gray color. The horizon thickness is about 50 m. In this locality, it contains abundant Late Eifelian conodonts [10, 11]. In total, 56 grab samples united into 9 sites were collected from the red silicilites exposed at the western and eastern limbs of the Karamalytash fold. The Bugulygyr silicilites are overlaid by tuff conglomerates with preponderant pebbles of acid volcanics and single pebbles of underlying siliceous rocks. The conglomerates alternate with tuffstone, siltstone, and argillite beds. This sequence (Ulutau Formation) has a great thickness and encloses conodonts and brachiopods corresponding to the upper Eifelian and Givetian in the European scale [10]. Samples for paleomagnetic studies were collected from a green siliceous–tuffaceous siltstone near the base of the sequence (10 grab samples united into 2 sites).

Another locality was examined in the eastern limb of the Irendyk Range anticline in the Yakshidavlet River valley 18 km northwest of the previous locality (Fig. 1, C2). Here, similar samples of red-colored upper Eifelian silicilites were collected from the Bugulygyr Horizon (62 grab samples, 8 sites).

Kaga. Within this area, paleomagnetic measurements were first performed using rocks deposited in the Southern Ural margin of the European paleocontinent. Grab samples were collected at nine sites from the quartz sandstone of the Vanyashkino Formation (80 samples) exposed near the Kaga Settlement (53°35′ N, 57°40′ E) in the Belaya River valley; this formation corresponds to the Emsian of the European scale [17].

RESULTS OF PALEOMAGNETIC STUDIES

The samples collected for paleomagnetic studies were cut into cubes with an edge of 2.0 cm. One cube from every sample was subjected to complete thermal demagnetization in a furnace protected by a two-layer screen made of μ-metal. The remanent field in the furnace was less than 20 nT. All samples were subjected to stepwise thermal cleaning at a temperature of 530–700°C. To determine the additional laboratory magnetization, sample positions were randomly changed during every heating step. The latter varied from 50–100°C under the low-temperature regime to 10–20°C (Sibai area) and approximately 2–3°C (Tobol area) when approaching the Curie point for magnetite and hematite. To provide a 2–3°C step, 3–5 successive measurements were performed within the 10°C interval while slightly changing the temperature. Natural remanent magnetization (NRM) was measured using a magnetometer JR-4 placed in the Helmholtz coils; the samples were transferred from the furnace to the measuring

Table 1. Paleomagnetic results

Area	n	Modern coordinate system				Ancient coordinate system			
		D°	I°	k	α_{95}	D°	I°	k	α_{95}
Tobol N = 103(18)		**High-temperature prefolding component**							
Samples	**31**	**226**	**2**	**12.7**	**7.1**	**202**	**–37**	**27.9**	**4.8**
Sites	**(7)**	**225**	**0**	**12.5**	**16.2**	**201**	**–37**	**46.3**	**8.4**
		High-temperature postfolding component							
Samples	26	237	–48	46.3	4.0	181	–42	14.8	7.1
		Medium-temperature component							
Samples	24	243	–45	13.6	8.3	156	–44	5.7	13.7
Sibai N = 128(19)		**High-temperature prefolding component**							
Samples	**43**	**255**	**–15**	**6.5**	**8.4**	**253**	**10**	**10.2**	**6.7**
Sites	**(8)**	**256**	**–12**	**9.5**	**16.2**	**254**	**12**	**22.5**	**10.5**
		High-temperature postfolding component							
Samples	51	238	–51	35.6	3.3	252	–13	14.9	5.1
Kaga N = 80(9)		**High-temperature prefolding component**							
Samples	**47**	**228**	**–5**	**5.4**	**9.9**	**227**	**15**	**10.2**	**6.9**
Sites	**(9)**	**226**	**–8**	**6.9**	**21.0**	**226**	**15**	**41.7**	**8.1**

Note: (N) number of examined samples (sites); (n) number of samples (sites) used in calculations; (D, I) paleomagnetic declination and inclination; (α_{95}) radius of the confidence circle (in degrees); (k) precision parameter defined according to Fisher statistics.

Table 2. Results of the paleomagnetic test

Area	Test								Bedding correction with k max in %
	Leveling		Grouping			Correlation			
	S	S cr	F m	F cr	F a	F m	F cr	F a	
Tobol									
Samples*	**2.21**	1.53	16.42	2.27	**2.22**	0.717	0.476	**0.468**	90
Sites*	**3.70**	2.98	8.54	4.46	**1.68**	0.829	1.000	0.943	90
Samples**	0.32					0.496	0.527	0.931	20
Sibai									
Samples*	**1.56**	1.43	8.63	2.48	**1.50**	0.658	0.433	**0.319**	110
Sites*	**2.38**	2.49	4.08	3.89	**0.60**	0.756	0.922	0.595	110
Samples**	**0.42**					0.323	0.418	0.898	10
Kaga									
Samples*	**1.87**	1.41	45.93	3.10	**2.41**	0.736	0.424	**0.358**	100
Sites*	**5.99**	2.33	42.82	3.74	**2.80**	0.883	0.866	**0.783**	100

Note: S = km/ka, where k is precision parameter; F and R are selected statistical values: (a) in the ancient coordinate system, (m) in the modern coordinate system, (cr) critical value; grouping and correlation tests are positive (magnetization occurred prior to folding) with R_a and F_a values below critical ones; the leveling test is positive for S > S cr; boldface designates positive test results.

* High-temperature prefolding magnetization; ** high-temperature postfolding magnetization.

device in containers made of μ-metal. The NRM components were determined by analyzing the thermal demagnetization data using special programs kindly donated by R. Enkin. McElhinny's [25], grouping [24, 26], and correlation [24] fold tests were applied.

The data obtained, the distribution of vectors on the sphere, and the test results are presented in Figures 2 and 3 and in Tables 1 and 2.

Tobol. Based on their NRM values, the rocks from the Tobol area were subdivided into low (0.1–3.8 mA/m),

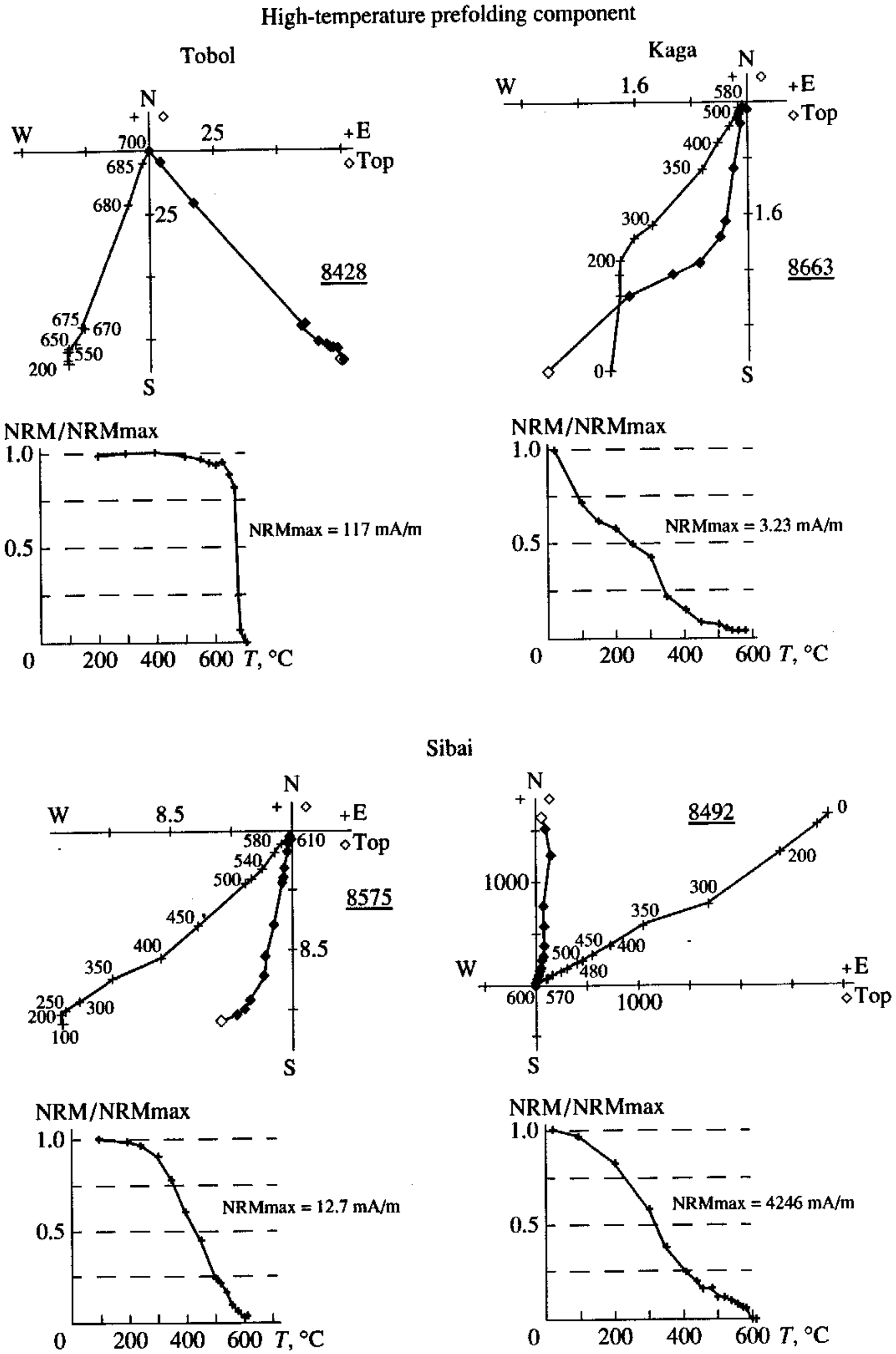

Fig. 2. Zijderveld temperature diagrams and thermal cleaning curves. Magnetization intensity in mA/m.

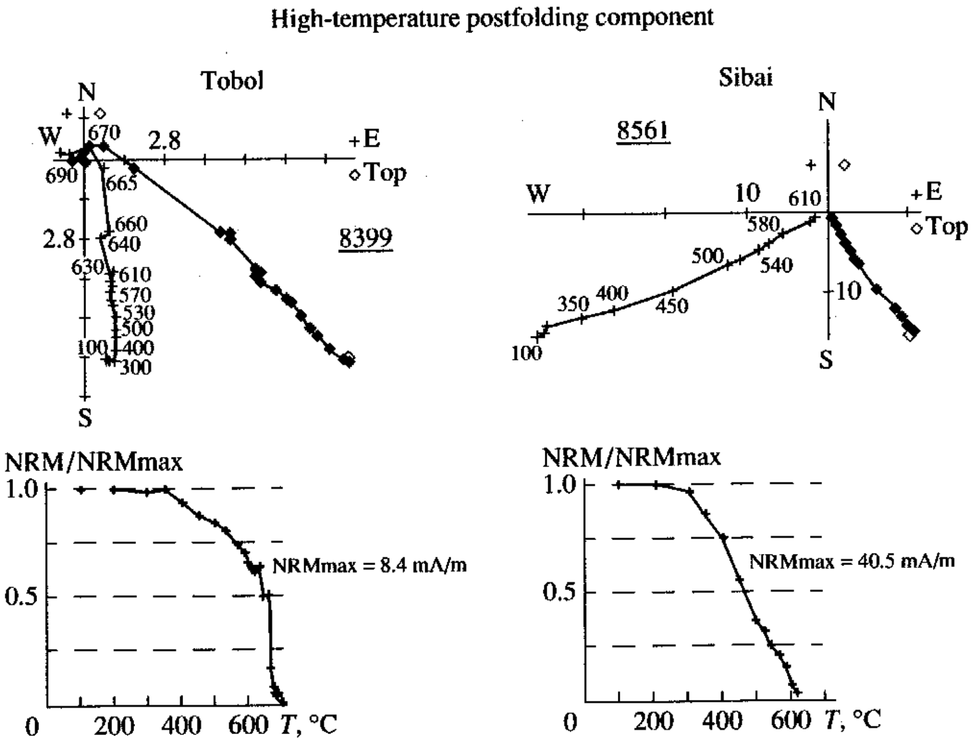

Fig. 2. (Contd.)

moderate (6–52 mA/m), and highly (60–380 mA/m) magnetic varieties. The moderately magnetized samples appeared to be most useful for the analysis. Judging from the value of the blocking temperature, magnetization is mostly due to hematite (Fig. 2). The examined samples were classified into three groups: (1) 24 samples with low-temperature (T = 100–300°C) and medium-temperature (T = 300–600°C) components; (2) 31 samples with low-temperature and high-temperature (T = 610–690°C) components; and (3) 26 samples with low-, medium-, and high-temperature components.

The low-temperature component was oriented closely to the medium one. The directions of the medium-temperature component coincided with that of the Late Paleozoic remagnetization. Based an all fold test modifications, this component was found to be of postfolding origin (Figs. 2 and 3; Tables 1 and 2). When the medium- and high-temperature components were close in direction (Fig. 2, Sample 8399), both of them were interpreted as postfolding, with the lowest concentration parameter (k) value related to the high-temperature magnetization. This component precisely was analyzed.

When a single high-temperature component supplemented the low-temperature one (Fig. 2, Sample 8428), the fold test indicated it to be prefolding. The high-temperature component had a reversed polarity. The demagnetization curve of these samples was almost rectangular, the pattern characteristic of uniform hematite grains with a very narrow interval of main blocking temperatures. Sometimes, the demagnetization curve pattern implied that hematite was accompanied by an insignificant amount of magnetite.

The maximal concentration parameter value of the prefolding component corresponded to 90% of the bedding correction. The uncertain result of the correlation test for different sites was caused by their small number and insignificant differences between average rock attitudes.

We also examined 35 pebbles from the tuff conglomerates. Only three of them yielded demagnetization curves similar to those characteristic of the samples with a prefolding component. Although the directions of the high-temperature component in these pebbles were different, the data were insufficient for using statistical tests.

Sibai. The NRM values of samples from this area varied significantly: there were samples with low- (0.2 to 0.4 mA/m), medium- (2 to 40 mA/m), and high-magnetization (200 to 13000 mA/m) components, the medium group being most abundant. The main blocking temperatures of 500–600°C (Fig. 2) indicated that the NRM was due to magnetite (probably oxidized). The 94 samples examined in this area revealed two components: the high-temperature (from 200 to 610°C) and the low-temperature (100–350°C). In its direction, the low-temperature component was found to be close to the modern one. The projections of the high-temperature component on a sphere in geographic coordinates produced two clusters. The average direction of one cluster (51 samples) coincided with that of the Late

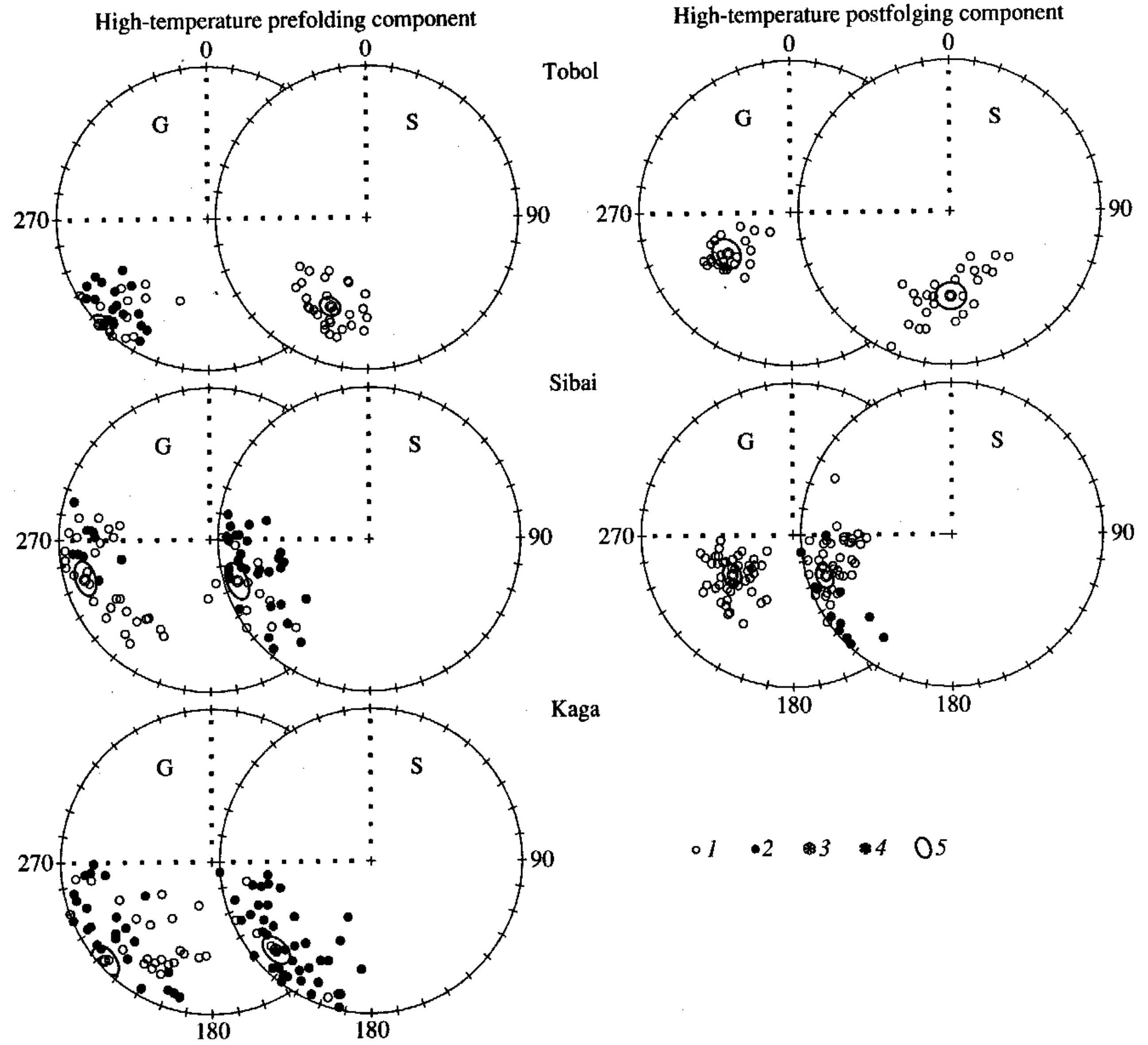

Fig. 3. Projections of paleomagnetic vector directions on stereograms. (*1*, *2*) vector projections on the upper (*1*) and lower (*2*) hemispheres; (*3*, *4*) average directions toward the upper and lower hemispheres; (*5*) confidence circle of average directions. Coordinate systems: (G) geographic, (S) stratigraphic.

Paleozoic remagnetization, which according to our fold test results was a postfolding event. These directions were obtained for the samples from the Karamalytash structure. The fold test revealed that the other cluster (43 samples) had prefolding NRM directions. The maximal k value was obtained using a 110% bedding correction. The defined component showed predominantly a reversed polarity, except for 15% of the samples which were found to be normally magnetized. The reversal test [26] was positive: F = 1.05 for $F_{critical} = 3.15$.

Kaga. The examined sandstones were found to be poorly magnetized (0.3 to 20 mA/m). Magnetization components were determined in 66 samples; the ultimate results were based on data for 47 samples (Fig. 3, Table 1). The main interpretable NRM component was found from its blocking temperature values to be magnetite (200 to 600°C) (Fig. 2). Magnetization showed normal and reversed polarities and, according to our fold test results, was a prefolding event (Table 2). The reversal test [26] was positive: F = 2.10 for $F_{critical} = 3.09$. The minimal k value was attained for a 100% bedding correction.

Thus, the samples from all areas show the direction of a prefolding NRM component suitable for calculating paleolatitudes (Table 3). Samples were collected from stratigraphic sections, and their discrimination into sites was conditional. Therefore, the established

Table 3. Calculated paleolatitudes

Area	I°	α_{95°	φ°	δφ°	Δφ°	δΔφ°
Tobol, samples	37	4.8	20.6	±3.8		
Tobol, sites	37	8.4	20.6	±5.8		
Sibai, samples	−10	6.7	−5.0	±3.4	25.6*	±4.1
Sibai, sites	−12	10.5	−6.1	±5.0	26.7*	±6.1
Kaga, samples	−15.1	6.9	−7.7	±3.7	28.3**	±4.2
Kaga, sites	−14.5	8.1	−7.4	±4.4	28.0**	±5.8

Note: (I) inclination of the average NRM vector in the ancient coordinate system (normal polarity); (α_{95°) radius of confidence circle; (φ) and (δφ) paleolatitude and its determination accuracy; (Δφ°) paleolatitude difference between Tobol and Sibai (*) and between Tobol and Kaga (**). (δΔφ°) its determination accuracy.

error based on the samples seems to be statistically substantiated.

In as much as fold test modifications vary in sensitivity to secondary magnetization (in our case, postfolding Late Paleozoic magnetization) as a function of the bed geometry and established NRM directions [22], we analyzed the reliability of our test results and estimated the specified directions of the prefolding components. For this purpose, prefolding magnetization with available parameters (magnetization and concentration parameter), which had been gradually overprinted by the postfolding magnetization, was calculated for every structure, taking into consideration the bed dip. It was found that, under the existing scatter in bed attitude elements and in the directions of the pre- and postfolding magnetization components obtained during the paleomagnetic analysis, the results of the correlation fold test were poorly affected by the relative share of postfolding magnetization: 0.4 for the rocks from the Tobol and Kaga areas and 0.6 for the rocks from the Sibai area. The probable systematic angle errors in the established directions of the interpreted components were less than 10°. Taking into consideration these error values, the calculated paleolatitudes would change by only ~3°, this correction being within the accuracy limit of paleolatitude determination and, thus, could be ignored in further interpretations.

In all the areas of study, we dealt with the magnetization that had originated prior to folding that occurred in the Late Carboniferous–Permian after the closure of the Uralian paleoocean. Comparison with the reference Late Carboniferous–Early Permian directions available for the East European platform (Table 4) implied that the prefolding magnetization of the examined rocks could not have been formed at that time. The rocks from the Sibai and Kaga areas, dominated by reversed magnetization, included some samples with normal polarity. This normal magnetization might have been induced in the Devonian–Early Carboniferous or Late Permian, or even later. Inasmuch as the Permian or a younger age of magnetization contradicts the results of our study, we conclude that the high-temperature prefolding magnetization component was introduced during the Devonian–Early Carboniferous. This magnetization might have been primary.

REVIEW OF PUBLISHED DATA

During the Late Paleozoic, the Kazakhstan (Kazakhstan–Kyrgyz) Middle Paleozoic sialic block experienced a complicated tectonic deformation, including displacements of tectonic blocks along strike-slip faults and their rotation [1, 8, 20, 29]. Reliable paleomagnetic measurements available for this region are too scarce to interpret the kinematics of its inner deformation. We used them to compare the paleomagnetic inclinations indicating the paleolatitude position of this block in the Devonian time.

Prefolding and, most likely, primary paleomagnetic components were measured in different areas of the Kazakhstan–Kyrgyz block including Central Kazakhstan and the Northern and Central Tien Shan. The Early Devonian rocks examined at eight sites of the Northern and Central Tien Shan [9] yielded an average paleomagnetic inclination value of 36° ± 13°. The Early–Middle Devonian volcanic rocks from the Spassk zone of Central Kazakhstan gave a paleomagnetic inclination value of 40° ± 10° [5]. A paleomagnetic inclination of 38° ± 5° was established for the Middle Devonian and Frasnian volcaniclastic–rocks of the Ermentau–Chin-

Table 4. Magnetization directions calculated for the Tobol and Sibai areas using relative paleomagnetic poles of the East European platform after [14] and compared with our data

Age, Ma	Tobol		Sibai	
	D°	I°	D°	I°
280	232.6	−35.5	230.6	−33.6
300	237.9	−35.8	235.9	−33.7
320	247.5	−33.3	245.4	−30.9
340	262.0	−24.5	259.7	−21.3
This study	202.0	−37.0	253.0	+10.0

Note: (D°, I°) declination and inclination.

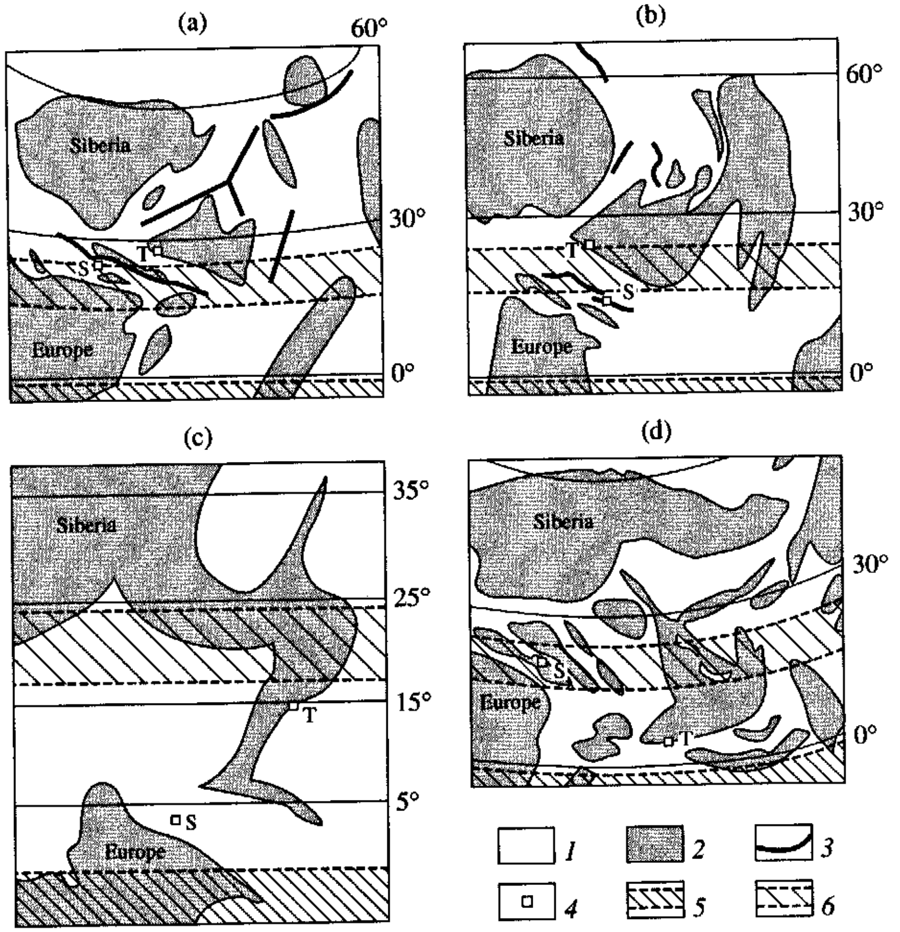

Fig. 4. Position of the paleomagnetically examined structures in Devonian palinspastic reconstructions: (a) Late Devonian [8]; (b) Early–Middle Devonian [12]; (c) Late Devonian [23, 26]; (d) Middle Devonian [13]. (*1*) oceanic crust; (*2*) continental crust; (*3*) ensimatic volcanic arc; (*4*) paleomagnetically studied areas: (S) Sibai, (T) Tobol; (*5*, *6*) calculated paleolatitudes for Sibai (*5*) and Tobol (*6*). The legend is unified.

giz–Tarbagatai zone of Central Kazakhstan [3]. The Middle–Upper Devonian clastic and carbonate–clastic rocks of the Northern and Central Tien Shan showed a paleomagnetic inclination of 39° ± 2.8° [4]. All of these results are consistent with our paleomagnetic inclination values determined for the Middle Devonian rocks of the Tobol area.

No paleomagnetic data of the modern level of quality have been reported for the Devonian rocks from the Magnitogorsk zone of the Urals.

CONCLUSION

Our paleomagnetic study of the Middle Devonian sedimentary and volcanogenic rocks from the Transural Denisovka and Magnitogorsk zones of the Urals was sufficient to determine the parameters of the prefolding magnetization (Table 1), which might have been primary in origin. The new data are consistent with the paleomagnetic results reported in the literature for the Devonian rocks from other areas of the region concerned. This proves that our paleomagnetic data are suitable for paleotectonic reconstructions.

As a result of our paleomagnetic analysis, we determined the positions that the structures under consideration had occupied during the Devonian time. Using paleomagnetic inclination values, we calculated the paleolatitudes (Table 3), and, using declination values, we determined the probable Devonian strikes of the structural–facies zones surveyed, which now strike N–S, parallel to the Urals. Our reconstructions can be summarized as follows:

(1) the marginal zone of the Kazakhstan sialic block adjacent to the Uralian ocean stretched in an ESE direction;

(2) the Tobol area of this zone was located at latitude 20.6° ± 8°;

(3) the Irendyk ensimatic volcanic arc whose facies zone is now meridional had a NNW strike;

(4) the Sibai area of this arc was located at –5.0° ± 3.4°;

(5) the width of the ocean between the Irendyk arc and the Kazakhstan block was not less than 25.6° ± 4.1°, that is 2800 ± 450 km along a paleomeridian.

To determine the complete width of the Uralian ocean, it was necessary to find a distance between the Irendyk volcanic arc and European continent in the Devonian time. The Devonian paleomagnetic poles were calculated by averaging data of varying quality obtained for different areas of the East European platform. Because the results of such averaging depend on the choice of source data, the positions of Devonian paleomagnetic poles obtained by different researchers differ from one another [14, 19, 29, 30].

The Kaga area is located at the margin of the European continent closest to the Sibai area. The position of the Kaga area in the Devonian calculated relative to the European paleomagnetic pole [14] for 380 Ma corresponds to a paleolatitude of +4.0° ± 3° and for 400 Ma, to a paleolatitude of –7.9° ± 4°. The paleolatitudes of this area calculated relative to the paleopoles in [19] only slightly differ from our results. Our data on the Lower Devonian rocks from the Kaga area are consistent wits these values and also indicate the position of the nearest margin of the European continent near the equator at that time—at latitude of –7.7° ± 3.7°. The paleomagnetic declination determined for the Kaga area implies its substantial rotation in the post-Devonian time.

The fact that the Devonian paleolatitudes of the Irendyk arc (5.0° ± 3.4° S) and of the nearest margin of the European platform (7.7° ± 3.7° S) are almost similar suggests that the arc was probably located close to the European continent. Consequently, the distance that we determined to have existed between the Tobol and Sibai areas (2800 ± 450 km along the paleomeridian) approximates the entire width of the Uralian ocean in the Middle Devonian time.

The paleomagnetic data on the postfolding magnetization (Table 1) examined in the rocks from the Sibai and Tobol areas imply that the distance between these areas during its formation was close to the modern one. Comparison with the reference paleomagnetic poles gave an Early Permian age (260–275 Ma) for the postfolding paleomagnetic components. This inference agrees with the geological data on the closing of the Uralian paleoocean in the Carboniferous and with modern views on the age of the Late Paleozoic remagnetization in the Urals region.

In the 1990s, several groups of researchers reported their Devonian paleotectonic reconstructions for the Urals and Central Asia. Let us compare our results with theirs. The reconstruction offered in [8] is consistent with our models (*1*) and (*3*) in Fig. 4a. The geodynamic reconstruction from [12] conforms with (1) and (2) (Fig. 4b), and that from [6], with our models (2) and (3). The paleotectonic reconstruction from [21, 28] is compatible only with our model (3) (Fig. 4c) and that from [27], with the assumptions (2) and (3). The paleogeographic map in the atlas [13] agrees with our model (3) (Fig. 4d). All of the above-mentioned reconstructions need to be corrected to fit the paleomagnetic data.

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