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The New Permian–Triassic Paleomagnetic Pole for the East European Platform Corrected for Inclination Shallowing

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Abstract—The results of detailed paleomagnetic studies in seven Upper Permian and Lower Triassic reference sections of East Europe (Middle Volga and Orenburg region) and Central Germany are presented. For each section, the coefficient of inclination shallowing f (King, 1955) is estimated by the Elongation–Inclination (E–I) method (Tauxe and Kent, 2004) and is found to vary from 0.4 to 0.9. The paleomagnetic directions, corrected for the inclination shallowing, are used to calculate the new Late Permian–Early Triassic paleomagnetic pole for the East European Platform (N = 7, PLat = 52.1°, PLong = 155.8°, A95 = 6.6°). Based on this pole, the geocentric axial dipole hypothesis close to the Paleozoic/Mesozoic boundary is tested by the single plate method. The absence of the statistically significant distinction between the obtained pole and the average Permian–Triassic (P–Tr) paleomagnetic pole of the Siberian Platform and the coeval pole of the North American Platform corrected for the opening of the Atlantic (Shatsillo et al., 2006) is interpreted by us as evidence that ~250 Ma the configuration of the magnetic field of the Earth was predominantly dipolar; i.e., the contribution of nondipole components was at most 10% of the main magnetic field. In our opinion, the hypothesis of the nondipolity of the geomagnetic field at the P–Tr boundary, which has been repeatedly discussed in recent decades (Van der Voo and Torsvik, 2001; Bazhenov and Shatsillo, 2010; Veselovskiy and Pavlov, 2006), resulted from disregarding the effect of inclination shallowing in the paleomagnetic determinations from sedimentary rocks of "stable" Europe (the East European platform and West European plate).

Keywords: paleomagnetism, inclination shallowing, Permian, Triassic, Elongation–Inclination method, paleomagnetic pole, East European platform

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INTRODUCTION

Due to a number of properties, the Permian–Triassic (P–Tr) sedimentary sections of the Russian plate are unique, due to which they are used as stratotypes in the development of an international stratigraphic scale. However, the uniqueness of these sections for us primarily lies in the fact that in the 1950s, these sections were the first study object for the Russian paleomagnetologists leaded by Alexey N. Khramov and served as a basis for the first magnetic polarity scales. The data about the paleomagnetism of these deposits were presented in Khramov's book "Paleomagnetic Correlation of Sedimentary Strata" (Khramov, 1958); subsequently, the paleomagnetism and magnetostratigraphy of the P–Tr formations of the Russian plate were addressed in many papers and books, including those authored by the leading Russian and foreign paleomagnetologists. Today, 60 years after publishing the first paleomagnetic results for the Permian and Triassic of East Europe, we present the results of revisiting the paleomagnetology of several reference sections of these deposits; they are the first published results that have taken the effect of inclination shallowing into consideration. All the presented paleomagnetic determinations have been obtained in accordance with the modern standards regarding the quality of laboratory processing and representation of the data.

The statistically significant distinction of the average Late Permian–Early Triassic (P_3–Tr_1) paleomagnetic poles of the Siberian and East European platforms, which were parts of Laurussia in Late Paleozoic and were considered as a single lithospheric plate for that geological time, raised, inter alia, the question about the validity of the geocentric axial dipole hypothesis for the Paleozoic/Mesozoic boundary. This question has been actively debated in the paleomagnetic community for almost two decades. One of the arguments that led many authors (Van der Voo and Torsvik, 2001; Bazhenov and Shatsillo, 2010; Veselovskiy and Pavlov, 2006) to conclude about the probable significant (above 10% of the dipole field) contribution of the zonal nondipole components to the main magnetic field of that geological time was the systematic displacement of the individual paleomagnetic poles of the East European platform relative to the coeval Siberian poles along the paleomeridian, the so-called far-side effect. It is traditionally believed that this effect can be caused by the following factors: (a) a significant contribution of the nondipole (quadrupole and octupole) components to the magnetic field of the Earth at the Paleozoic/Mesozoic boundary and/or (b) disregard of the effect of inclination shallowing in the paleomagnetic data for the East European platform, most of which were obtained from sedimentary rocks. Indeed, even the assumption of a faint (~4%, $f = 0.9$) shallowing of the magnetic inclination in the P–Tr sediments of Europe makes the distinction between the average P–Tr paleomagnetic poles of Siberia and the East European platform statistically insignificant (Veselovskiy and Pavlov, 2006; Bazhenov and Shatsillo, 2010).

The question of the necessity to estimate and take into account the shallowing of the inclination for the paleomagnetic determinations, that are derived from sedimentary rocks and used for paleomagnetic reconstructions, has been raised in a number of the publications. For instance, recently it was shown that the correction of the existing paleomagnetic determination for inclination shallowing based on the known average values of the coefficient f for hematite- and magnetite-bearing sedimentary rocks (Kodama, 2012) has promoted the solution of the well-known problem of the reconstruction of the Pangaea supercontinent (Domeier et al., 2012). However, the shallowing of the inclination in the sediments depends on both their formation conditions and on their lithology. For example, the intensity of inclination shallowing depends on the grain shape and grain size of magnetic particles, as well as on the sedimentation setting and the rate of sediment deposition (Kodama, 2012). In Iosifidi et al. (2003), it is noted that the paleomagnetic information for sedimentary rocks containing magnetite and fine (pigment) hematite fairly reliably reflects the direction of the co-sedimentation magnetic field. However, the paleomagnetic directions determined from the rocks containing clastic hematite should be handled with caution since they are prone to the effect of inclination shallowing which may reach 10°–15°. This practically rules out the possibility of using unified values of the coefficient of inclination shallowing, even for rocks of the same lithological type and necessitates estimating of this coefficient directly for each particular section or even for particular segments of the section.

Until recently, the estimation procedure of the coefficient of inclination shallowing in sedimentary rocks required conducting lithological and rock magnetic studies with the use of specific laboratory instruments, including that for experiments on the redeposition of the previously disintegrated rocks. This strongly limited the possibilities of the average researcher to correct their paleomagnetic determinations for inclination shallowing. The development of the Elongation–Inclination (E–I) statistical method (Tauxe and Kent, 2004) made the calculations of the coefficient of shallowing f more readily available. However, practical application of the E–I method is constrained by the following limitations: (1) the sample of paleomagnetic directions for a particular section should include at least 100 vectors ($n \geq 100$); (2) each vector in the sample should express the record of secular variations rather than be the result of their averaging; and (3) the selected paleomagnetic samples should cover the interval of the section within which secular variations are averaged. The convergence of the results obtained by the statistical E–I method and laboratory approaches to estimating the coefficient of inclination flattening f is convincingly demonstrated in Bilardello et al. (2011) and Kodama (2012), which allows the E–I method to be used without the necessary additional verification of the obtained estimates.

The main purpose of our study was to obtain new paleomagnetic data from the reference sections of the P–Tr boundary deposits in the Russian plate and “stable” Europe, which are corrected for the inclination shallowing. In particular, in this work we have solved the important and difficult problem of obtaining new representative samples of paleomagnetic directions and, based on these determinations, estimating the coefficients of inclination shallowing f directly in each studied section.

STUDY OBJECTS

In the field works of 2013–2016, we have studied in detail four sections of the Upper Permian (P_3) and Lower Triassic (Tr_1) boundary in continental deposits in the central part of Russia—in the Middle Volga region (Puchezh, Zhukov ravine, Okskii S”ezd sections) and Orenburg region (Astrakhanovka section) (Fig. 1a). In this study we also considered the results of demagetization measurements on the samples from the composite Sukhona P–Tr section described in (Khramov et al., 2007). Besides, two outcrops of lacustrine and shallow marine deposits were studied in central Germany (Zechstein sedimentary basin, West European plate)—Caaschwitz and Nelben sections (Fig. 1a). All these sections are dominated by red clastic rocks and have a reliable correlation to the local stratigraphic scales (Fig. 1b). It should be noted that the problem of the correlation of regional P–Tr magnetostratigraphic scales to the corresponding interval of the global scale has not been completely solved. The correlation shown in Fig. 1b follows (Golubev et al.,

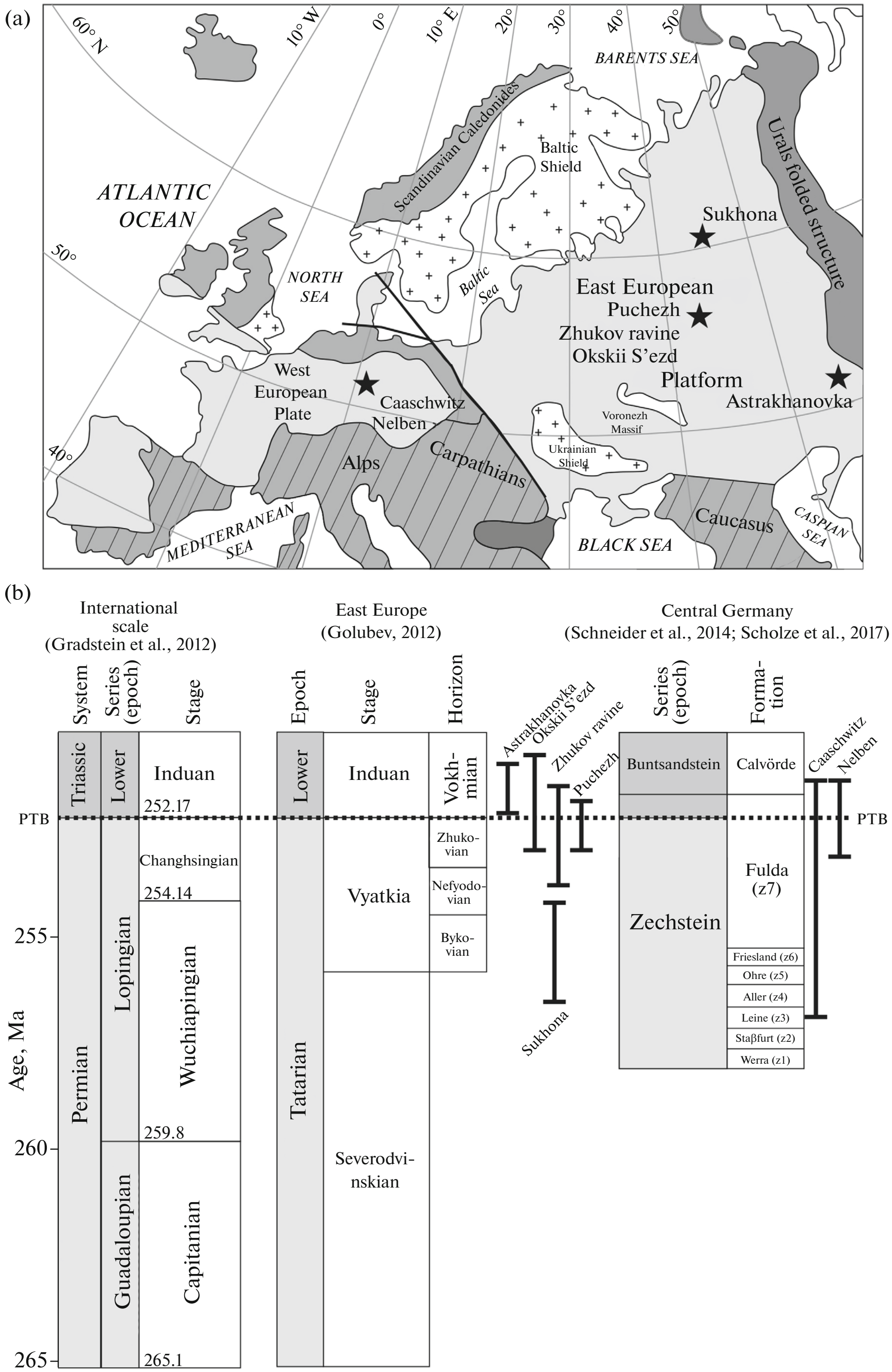

Fig. 1. (a) Position of studied sections on tectonic map of Europe; (b) correlation of magnetostratigraphic schemes of East Europe and Central Germany to the International magnetostratigraphic scale close to Permian–Triassic Boundary (PTB) and the stratigraphic ranges of the sampled intervals of the studied sections (thick lines).

2012) and is, to a certain extent, speculative. The studied sections are described below.

Russian Plate. The *Astrakhanovka* section (45 m thick) is composed of rocks of the Kopanskaya Formation, which are related to the bottom of the Vokhmian horizon of the Induan stage of the Lower Triassic series (Tverdokhlebov et al., 2002). Brown-red sandstones with a purplish hue alternate with tile red mudstones and fine gray-green sandstones.

The *Puchezh* section (20 m) at its base is composed of Vyatkian red-brown clays, silts, and sandstones alternating with light gray, pink, and red-brown marls of the Upper Permian. The upper portion of the section is composed of rocks of the Vokhmian horizon of the Lower Triassic represented by gray green sands (at the base) and a layered stratum of gray brown clays, silts, and sands with thin intercalations of pink brown marls. The ages of the rocks are cited according to (*Granitsa*..., 1998).

The *Zhukov ravine* section is composed of Vyatkian (P_3) clays, sands, silts, pink marls, and limestones with a total thickness of 40 m, which are overlain by similar rocks of the Vokhmian age (Tr_1) with a thickness of 15 m (Minikh et al., 2011).

The *Okskii S"ezd* section (45 m) in its basal parts is represented by a 11-m thick unit of alternating grayish brown clays and bluish gray sandstones (Vyatkian substage of the Upper Permian). At the higher levels, the section is represented by brown sandstones with interbeds of variegated clays of the Early Triassic Vokhmian formation. The cited age follows Golubev et al. (2016).

The composite *Sukhona* section (220 m) complied based on the results of studying a series of coastal outcrops in the Sukhona valley is composed of lacustrine alluvial variegated and alluvial red rocks of the Sukhona and Severodvinskaya Upper Permian formations (Khramov et al., 2007).

West European Plate. The *Caaschwitz* section was explored within the interval with a thickness of 33 m, which includes the P–Tr boundary. The sampled interval in its basal part is represented by claystones dated to the Upper Permian (Leine Fm.), which change higher on the sequence by a unit of alternating red brown mudstones and siltstones with marker horizons of coarse-to-fine-grain sandstones and thin interbeds of gray green clays (Fulda Fm.). The section is crowned by gray sandstones of the Lower Triassic (Calvorde Fm.) (Schneider et al., 2014).

The *Nelben* section (22 m) at its base is composed of red-brown fine sandstones of the upper part of Fulda Fm.; higher in the section, there are alternating fine gray green and brown Calvorde Fm. sandstones (Bachmann and Kozur, 2004).

We note that according to recent studies, the P–Tr boundary in the Zechstein sedimentary basin is located in the upper part of Fulda Fm. (Schneider et al., 2014) (Fig. 1b) and does not correspond to the boundary of the Zechstein (P_3) and Buntsandstein (Tr_1) groups, as it is assumed in a number of earlier works.

INSTRUMENTS AND METHODS

The field and laboratory studies and the processing and interpretation of the results followed the standard procedure (Khramov et al., 1982; Tauxe et al., 2016). Oriented samples were excavated by hand, with the help of a geological hammer and knife; sampling was as far as possible uniform across the entire studied interval of the stratigraphic sequence with the fixed vertical step varying from 2 to 50 cm, depending on the thickness of the section. The samples were oriented by a rock compass with allowance for local deviation according to the 12th generation IGRF model. The samples were sawn by a rock-cutting machine with a diamond cutting wheel into 2-cm cubes. The paleomagnetic collections were demagnetized on modern equipment in the laboratory of the main geomagnetic field and geomagnetism of the Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences on a SQUID magnetometer (2G Enterprises, United States) installed in a nonmagnetic room and in the rock magnetic laboratory at the Faculty of geology of the Moscow State University on a JR-6 spinning magnetometer (AGICO, Czech Republic). The samples were demagnetized in MMTD-80 (Magnetic Measurements, England) and TD48 (ASC Scientific, United States) thermal demagnetizers. Thermomagnetic studies were conducted with the use of KLY-4S and MFK1-FA (AGICO, Czech Republic) kappabridges with an attached CS3 and CS4 furnace for high-temperature measurements. The coefficient of inclination shallowing *f* was calculated by the E–I method with the use of the PmagPy v.3.2.1 program package (Tauxe et al., 2016).

RESULTS OF PALEOMAGNETIC AND ROCK MAGNETIC STUDIES

All the samples were subjected to detailed thermal cleaning up to complete demagnetization. The number of demagnetization steps ranged from 12 to 25. The results of the demagnetization were represented on the Zijderveld plots and stereograms. The components of the magnetization were calculated by the principal component analysis method (PCA) (Kirschvink, 1980).

The results of demagnetization of the most typical samples are presented in Fig. 2 for the Astrakhanovka, Okskii S"ezd, Caaschwitz, and Nelben sections. The results for the samples from the Puchezh and Zhukov ravine sections were published in our previous paper (Fetisova et al., 2017), and for the Sukhona section in Khramov et al. (2007).

The quality of the paleomagnetic record varies from section-to-section and within each particular

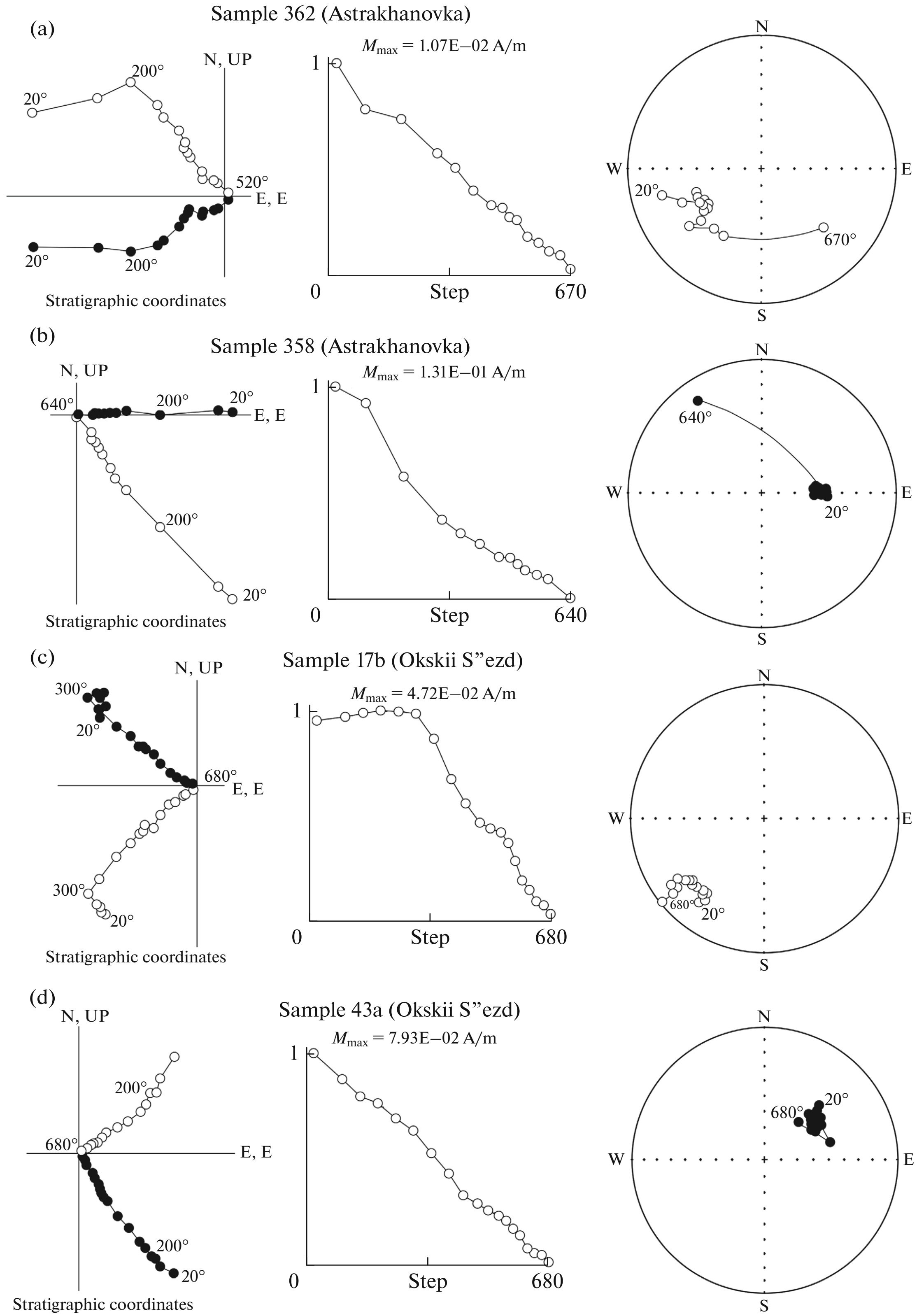

Fig. 2. Results of thermal demagnetization of typical samples from the studied sections: (a), (b), Astrakhanovka; (c), (d), Okskii S"ezd, (e), (f), Caaschwitz; (g), Nelben. Zijderveld plots, NRM demagnetization curves, stereograms. Filled (empty) circles in stereograms are vector projections on the lower (upper) hemisphere; filled (empty) circles in Zijderveld diagrams are vector projections on the horizontal (vertical) plane.

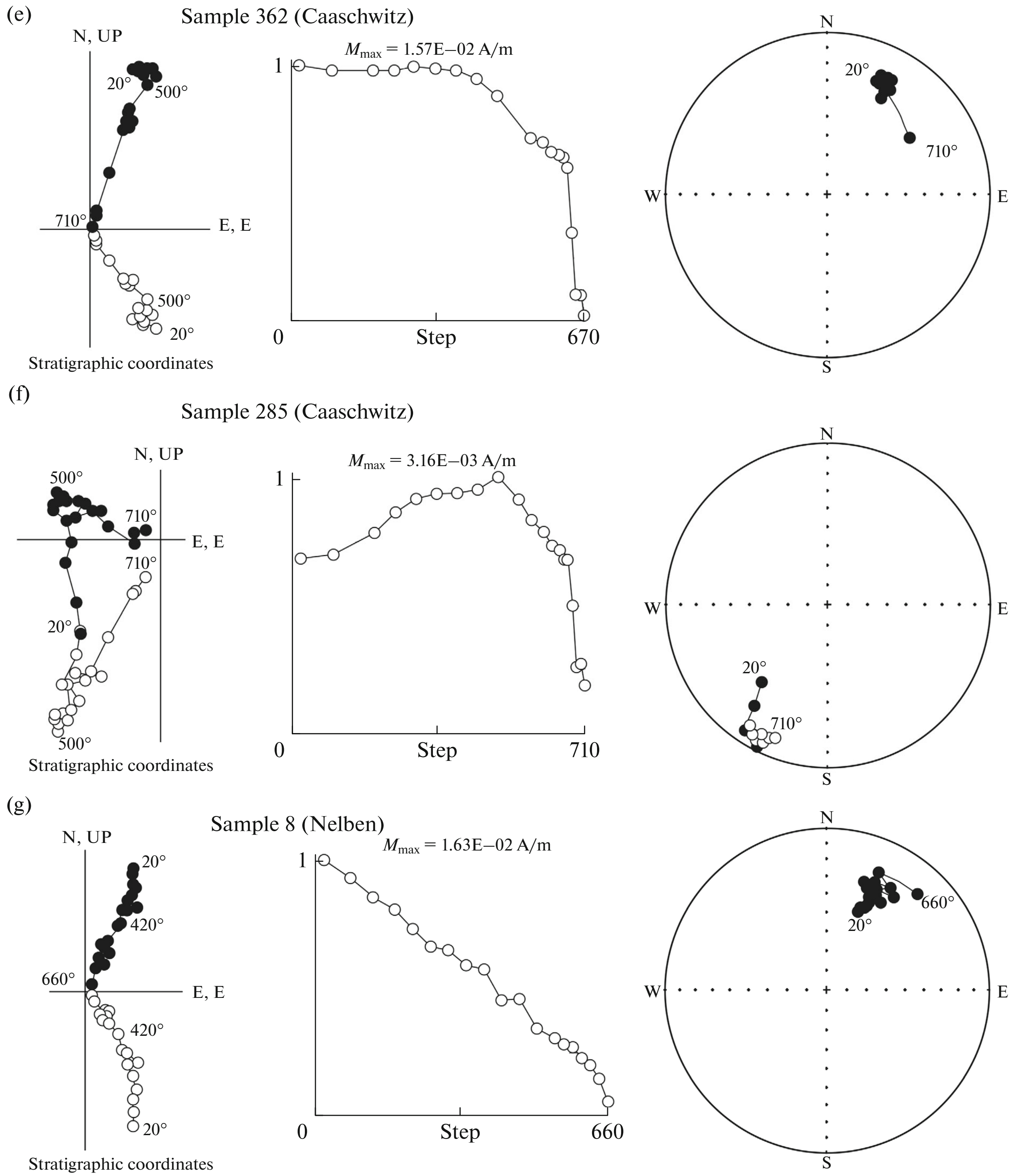

Fig. 2. (Contd.).

outcrop; however, the record overall can be characterized as reasonably good. The natural remanent magnetization (NRM) is represented by one or by a sum of two magnetization components. In several samples, the least stable NRM component is isolated in the interval 20–200°C. The orientation of this component in the geographic coordinates is close to the direction of the present field in the study region, which suggests its viscous origin.

The most stable NRM component in all the studied objects except for the Nelben section has the directions of normal (N) and reversed (R) polarity (Table 1), is isolated in the temperature interval 300–680°C, and is characteristic (ChRM). Although the geological situation prevents us from conducting field tests for estimating the age of the magnetization components, the primary nature of this component is suggested by the closeness of its mean direction to the expected direc-

Table 1. Paleomagnetic directions and coefficient of inclination shallowing *f*

No.	Section and age			Polarity	*n*/*N*	Geographic coordinates				Stratigraphic coordinates				$I_{f\text{-corr}}/f$, °
		slat, °N	slong, °E			D, °	I, °	K	α95, °	D, °	I, °	K	α95, °	
1	Astrakhanovka (Tr_1)	52.203983	55.715467	7 N 50 R	101/57	5.0	68.1	26.8	3.7	**48.8**	**46.7**	**26.8**	**3.7**	56.6/0.7
2	Puchezh (P_3–Tr_1)	56.99420	43.15810	148 N 9 R	269/157	36.7	43.8	19.7	2.6	**55.7**	**42.8**	**19.7**	**2.6**	45.8/0.9
3	Zhukov ravine (P_3–Tr_1)	56.188	42.649	54 N 49 R	147/103	**32.8**	**43.4**	**17.9**	**3.3**	–	–	–	–	46.4/0.9
4	Okskii S"ezd (P_3–Tr_1)	56.2	44.0	25 N 83 R	144/108	**42.9**	**36.4**	**15.2**	**3.6**	–	–	–	–	61.5/0.4
5	Caaschwitz (P_3)	50.953317	11.976383	26 N 11 R	85/37	25.4	30.7	11.7	7.2	**24.0**	**19.4**	**11.7**	**7.2**	26.7/0.7
6	Nelben (P_3)	51.671733	11.743383	82 N	119/82	50.2	59.1	29.2	3.0	**16.9**	**29.2**	**30.3**	**2.9**	38.6/0.7
7	Sukhona (P_3)	61.0	45.0	77 N 133 R	263/210	39.6	38.2	16.0	2.5	**40.3**	**38.9**	**16.8**	**2.4**	49.1/0.7

Slat, slong are sampling latitude and longitude; *n*/*N* is the total number of samples/number of samples involved in the calculation of mean direction; D, I, K, α95 are characteristics of Fisher's distribution: declination, inclination, precision parameter and radius of circle of 95%-confidence, respectively. *f* is the coefficient of inclination shallowing, $I_{f\text{-corr}}$ is the magnetic inclination corrected for the inclination shallowing using the coefficient *f*.

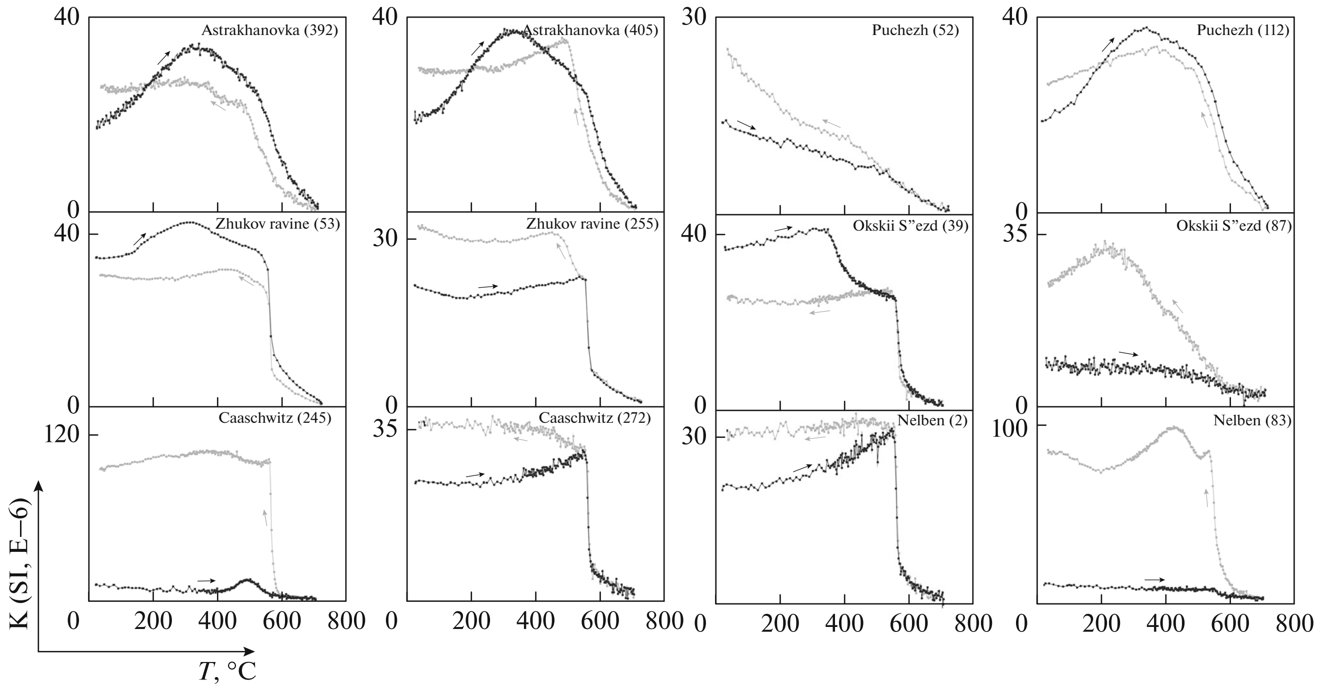

Fig. 3. Temperature dependence of the magnetic susceptibility in the samples of the studied sections. Curves of first heating and cooling are shown. The heating curve is black and the cooling curve is gray.

tion of the magnetic field in the Late Permian–Early Triassic (Bazhenov and Shatsillo, 2010) and by the ChRM bipolarity in six of the seven studied sections (Table 1). The reversal test (McFadden and McElhinny, 1990) performed for ChRM of normal and reversed polarity is only positive for the Puchezh and Zhukov ravine sections. The negative test for the other sections is, in our opinion, accounted for by the incomplete separation of the viscous and characteristic magnetization components due to the noisiness of the paleomagnetic record and partial (up to complete) overlapping of the spectra of their unblocking temperatures.

The magnetic minerals in the studied rocks were most frequently identified by the shape of the temperature dependences of the initial magnetic susceptibility at heating from room temperature to 700°C. Heatings were conducted in air at atmospheric pressure. The results are presented by the examples of the two most typical samples for each studied section (Fig. 3) except for the Sukhona section. It is established that the considered rocks contain magnetite, hematite and, in some cases, sulfides (Astrakhanovka, Puchezh, Okskii S"ezd). Since the spectrum of the unblocking temperatures of ChRM extends to the Curie temperature of hematite (~680°C, Fig. 2), it can be expected that the ChRM in the studied rocks is probably related to hematite. This hypothesis is supported by the experiments on demagnetization of the samples from the Puchezh and Zhukov ravine by the alternating magnetic field (Fetisova et al., 2017). In these experiments, the demagnetization in the interval of the amplitudes of the magnetic field from 0 to 40 mT only removed the recent (acquired in the present magnetic field) viscous magnetization component probably associated with magnetite. The further increase of the amplitude of the alternating magnetic field was inefficient.

The paleomagnetic poles corresponding to the mean ChRM directions in the considered sections (Fig. 4) and their average pole are presented in Table 2.

ESTIMATING THE INCLINATION SHALLOWING

The set of the single vectors corresponding to the characteristic magnetization direction on the sample level in four sections—Puchezh, Zhukov ravine, Okskii S"ezd, and Sukhona—meets the formal requirements of the E–I method (Li and Kodama, 2016) and can be used for estimating the coefficient of inclination flattening *f*. The sets of the directions of characteristic magnetization for the other three sections are less representative ($n < 100$); therefore, the estimates of coefficient *f* based on these sets can only be considered as tentative. However, in order to gain an idea of the reliability of these estimates, we tested the stability of the solution in the problem of estimating the coefficient *f* by the E–I method against the reduction of the set of the single paleomagnetic directions. This was done by the random elimination of the single paleomagnetic directions from the set with $n > 100$ to $n = 50$ elements. The results of this testing show that in 80% of the cases (16 trials) the values of coefficient *f* calculated in the

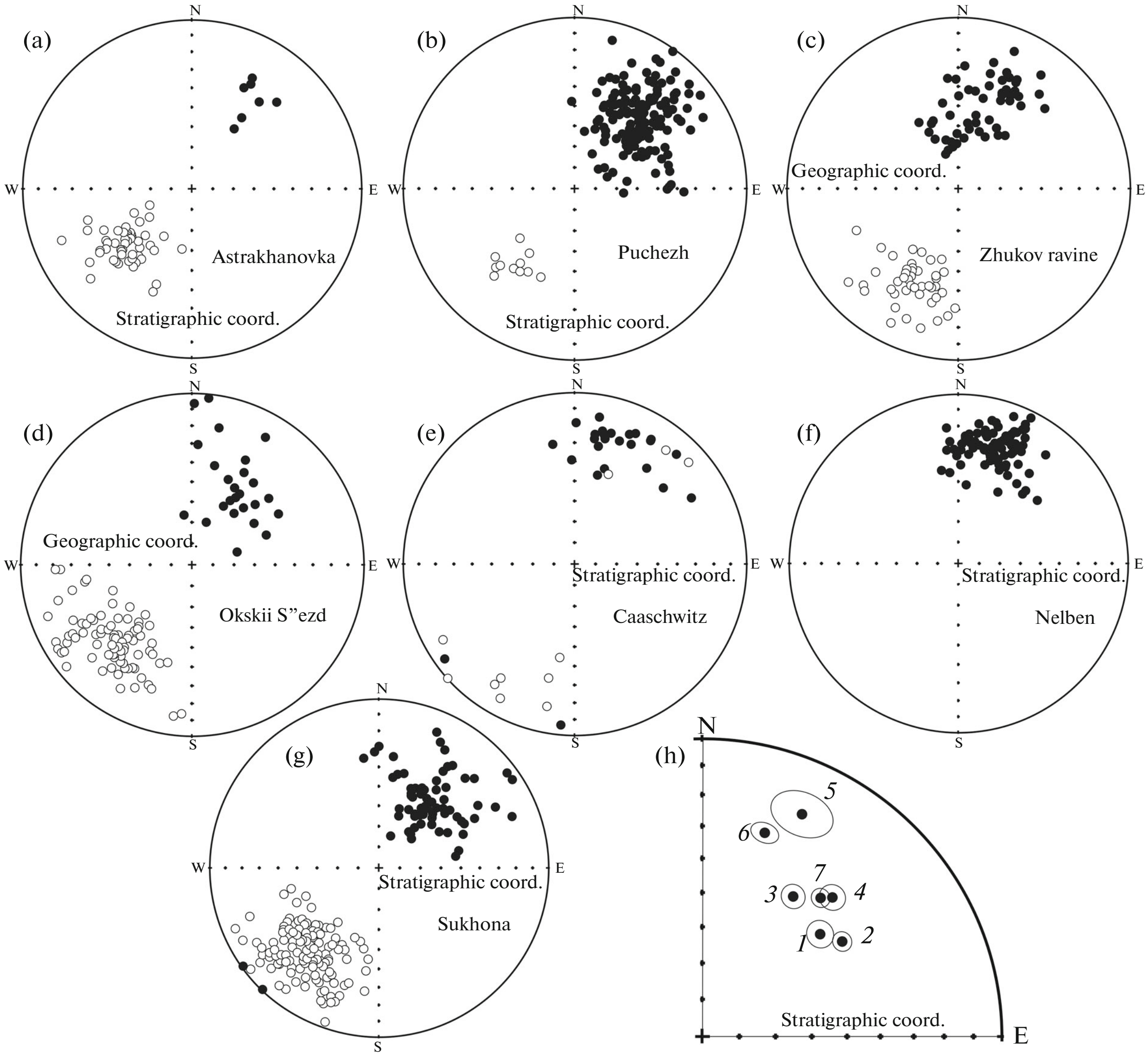

Fig. 4. Directions of characteristic magnetization component isolated in samples from the studied sections ((a), Astrakhanovka; (b), Puchezh; (c), Zhukov ravine; (d), Okskii S"ezd; (e), Caaschwitz; (f), Nelben; (g), Sukhona; and (h) their mean directions with circles of 95% confidence.

complete and truncated sets coincide and in the remaining 20% of cases (4 trials) they differ by 10% at most. This suggests that the estimates of the coefficient of inclination flattening for the Astrakhanovka and Nelben sections can be true, within the first approximation. However, the estimate of coefficient *f* for the Caaschwitz section cannot be, as of now, treated as reliable at all because there are very few single directions ($N = 37$).

The obtained estimates of coefficient *f* for most of the studied sections vary from 0.9 to 0.7 (Fig. 5, Table 1). Coefficient *f* for the Okskii S"ezd section, which is 0.4, testifies to a much more significant shallowing of the inclination in the rocks of this section. The cause of this phenomenon is unclear for us; perhaps it is associated with the lithological peculiarities of these rocks, and in order to elucidate these causes, we are conducting additional studies. The corrected inclinations of the mean paleomagnetic directions of the characteristic component for the discussed sections are presented in Table 1. Table 2 and Fig. 6b show the corresponding paleomagnetic poles corrected for the shallowing of the inclination, as well as the average pole (Table 1, pole EUR-F, no. 10).

DISCUSSION

Figure 6a shows the P–Tr paleomagnetic poles for the East European platform corrected for the inclination shallowing (Table 2). The comparison of the average P–Tr pole of the East European platform (no. 10, EUR-F) with the average P–Tr pole of the Siberian platform (NSP2, Table 2, (Pavlov et al., 2007)) shows that these poles do not statistically significantly differ from each other: $\gamma/\gamma_{cr} = 6.0°/7.7°$ (γ is the angular dis-

Table 2. Paleomagnetic poles

№	Section/Mean paleomagnetic pole	S (number)	Pole				Corrected using *f*			
			PLat, °	PLong, °	dp/dm (B95), °	Paleolat, °	PLat, °	PLong, °	dp/dm (B95), °	Paleolat, °
1	Astrakhanovka (Tr_1)	(57)	46.6	160.2	3.1/4.8 (3.9)	27.9	53.0	149.9	3.9/5.4 (4.6)	37.2
2	Puchezh (P_3–Tr_1)	(157)	39.1	148.1	2.0/3.2 (2.5)	24.8	41.0	146.3	2.1/3.3 (2.6)	27.2
3	Zhukov ravine (P_3–Tr_1)	(103)	51.1	171.4	2.6/4.1 (3.2)	25.3	53.2	169.5	2.7/4.2 (3.4)	27.7
4	Okskii S"ezd (P_3–Tr_1)	(108)	42.1	164.7	2.4/4.2 (3.2)	20.2	59.6	142.1	4.3/5.5 (4.9)	42.6
5	Caaschwitz (P_3)	(37)	44.5	157.8	3.9/7.5 (5.4)	10.0	48.4	155.4	4.2/7.8 (5.8)	14.1
6	Nelben (P_3)	(82)	51.5	165.0	1.8/3.2 (2.4)	15.6	57.3	161.7	2.0/3.4 (2.7)	21.8
7	Sukhona (P_3)	(210)	42.1	171.1	1.8/3.0 (2.3)	22.0	49.2	165.9	2.2/3.3 (2.7)	30.0
	SIBERIA:									
8	NSP2 (Pavlov et al., 2007)	8	55.1	147.0	5.0	K = 123	Rt+ (NSP2 *vs.* EUR-F) = 6.0°/7.7°			
	EUROPE:									
9	EUR (without correction for shallowing)	7	45.5	162.3	5.6	K = 117				
10	EUR-F (with correction for shallowing)	7	52.1	155.8	6.6	K = 85				
11	Early Triassic (Tr_1) (*Paleomagnitnye*..., 1986)	20	50.3	160.7	3.0	K = 109	Rt– = 5.2°/3.5°			
12	Late Permian (P_3) (*Paleomagnitnye*..., 1986)	52	46.2	165.4	1.8	K = 116				
	NORTH AMERICA:									
13	NA-curl (Shatsillo et al., 2006)	8	54.9	147.9	3.4	K = 296	Rt+ (NA-rot *vs.* EUR-F) = 5.5°/6.7°			

S (number) is number of single paleomagnetic poles (samples) from which the pole is calculated; PLat, PLong, Paleolat, dp/dm (B95) are latitude and longitude of paleomagnetic pole, paleolatitude of sampling site and semiaxes of oval (radius of circle) of 95% confidence, respectively. Rt is the reversal test (Rt+ positive, Rt– negative).

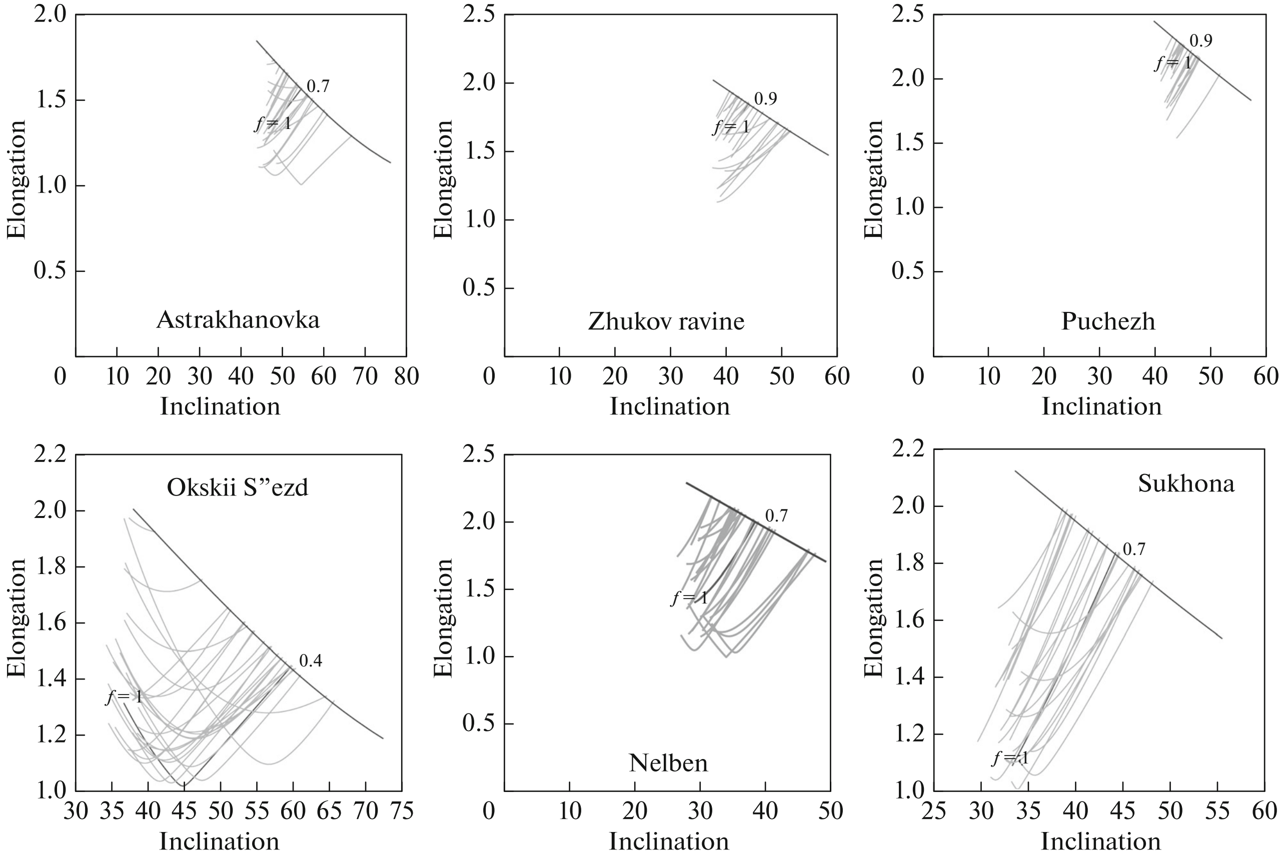

Fig. 5. E–I estimation of inclination shallowing coefficient *f* in the studied P–Tr sedimentary sections. Black segment of the curve shows E/I ratios predicted by the TK03.GAD model (Tauxe and Kent, 2004), gray segments show E/I ratios resulting from bootstrap modeling of the distribution of vectors with different values of inclination shallowing coefficient *f* (segments of curves corresponding to 20 bootstrap samples are shown).

tance between the vectors and γ_{cr} is the critical value of the angular distance) (McFadden and McElhinny, 1990). The same conclusion follows from a comparison of the EUR-F pole with the coeval pole of North America (no. 13, NA-rot, Shatsillo et al., 2006) corrected for the opening of the Atlantic: γ/γ_{cr} = 5.5°/6.7°. Hence, the dissimilarity of the P–Tr paleomagnetic poles of the Siberian and East European platforms, which was repeatedly noted in the previous works, can be interpreted as the result of the shallowing of the inclination in the sediments of the East European platform. Although this hypothesis has been suggested previously (Bazhenov and Shatsillo, 2010), the value of our study lies in estimating the values of parameter *f* for the studied sections.

Importantly, as was noted in several works (Shatsillo et al., 2006; Khramov et al., 2007), the example of the paleomagnetic studies of the P–Tr red rocks of the Russian Plate demonstrates the absence of a statistically significant distinction between the results that were obtained in the 1960s–1980s, which were frequently based on incomplete demagnetizations, and the results that were obtained with the use of an advanced procedure for determining the paleomagnetic directions. For instance, the average paleomagnetic pole of the East European platform that was calculated from seven poles obtained in the present work without correction for the inclination shallowing (EUR) is statistically indistinguishable (γ/γ_{cr} = 2.3°/5.3°) from the average pole that was obtained from 52 Late Permian determinations from the paleomagnetic database (*Paleomagnitnye*..., 1986) (Table 2, determination no. 12, Fig. 6a). They are also indistinguishable from the average pole obtained from 20 Early Triassic determinations (γ/γ_{cr} = 4.9°/6.1°, Table 2, determination no. 11, Fig. 6a).

However, we have to note that even the paleomagnetic poles of the East European platform corrected for inclination shallowing (Fig. 6b) demonstrate a so-called far-side effect relative to the P–Tr pole of the Siberian platform; i.e., they are shifted away from it along the paleomeridian. The pole for the Astrakhanovka section, which coincides with the Siberian pole, is an exception. We associate the probable cause of this effect with the somewhat different age of the average P_3–Tr_1 poles under comparison. Indeed, the sampled interval of the Astrakhanovka section exclusively corresponds to the Lower Triassic, whereas in the other sections, the sampling only captured the Upper Permian

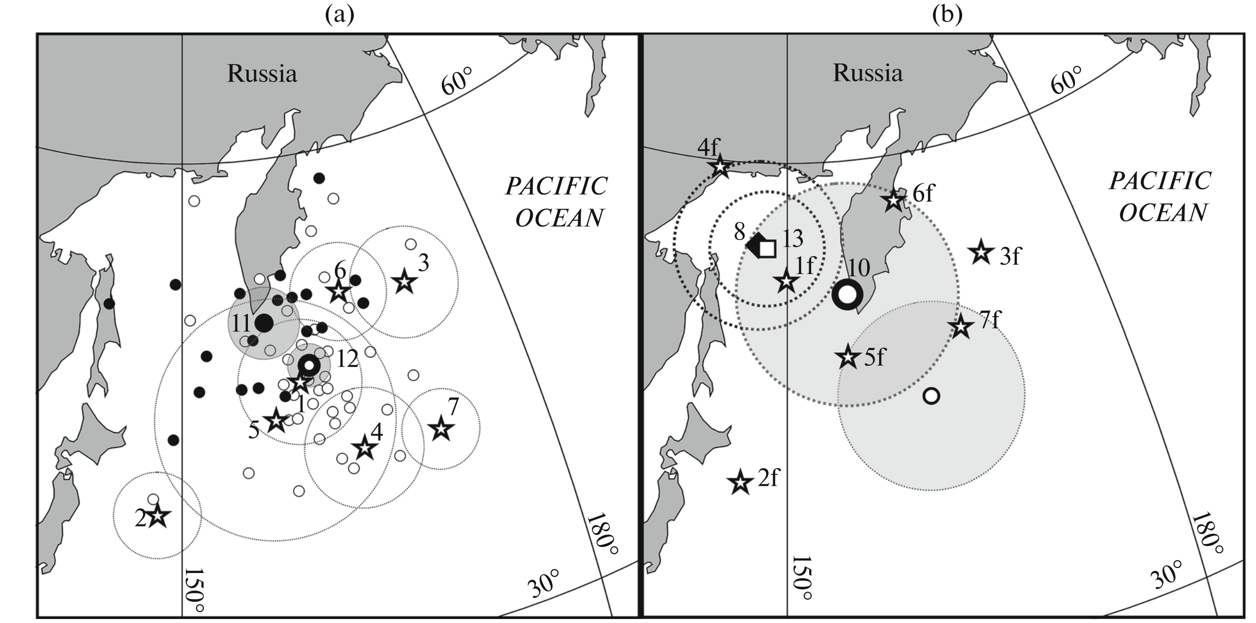

Fig. 6. (a) Comparison of P_3–Tr_1 paleomagnetic poles determined from the studied sections (asterisks numbers correspond to pole numbers in Table 2) with poles for Late Permian (white circles) and Early Triassic (black circles) from the catalog (*Paleomagnitnye*..., 1986): 1, Astrakhanovka; 2, Puchezh; 3, Zhukov ravine; 4, Okskii S"ezd; 5, Caaschwitz; 6, Nelben; 7, Sukhona; 11, average Early Triassic paleomagnetic pole according to data of *Paleomagnitnye*... (1986); 12, average Late Permian paleomagnetic pole according to data of *Paleomagnitnye*... (1986). Dashed lines show circles of 95% confidence; (b) comparison of P_3–Tr_1 poles corrected for inclination shallowing (1f, Astrakhanovka; 2f, Puchezh; 3f, Zhukov ravine; 4f, Okskii S"ezd; 5f, Caaschwitz; 6f, Nelben; 7f, Sukhona) and average P_3–Tr_1 paleomagnetic poles of the East European platform (9, pole does not corrected for inclination shallowing; 10, pole corrected for inclination shallowing) with P_3–Tr_1 poles of (8) Siberia and (13) North America.

interval or the P–Tr boundary interval with the predominant contribution of the Permian data (Fig. 1b). If we assume a significant hiatus in the sedimentation between the Permian and Triassic formations (Minikh et al., 2011), we should expect a shift of the paleomagnetic poles for the studied sections towards the more ancient part of the curve of the apparent polar wander path (APWP) of the pole for the East European platform, which is the case. This assumption places the primary importance on studying the Lower Triassic sections in the further research on the discussed problem.

SUMMARY AND CONCLUSIONS

Based on the rocks of four reference P_3–Tr_1 sections of the East European platform, reliable estimates are obtained for the shallowing of the magnetic inclination; similar results are also obtained for another three sections. With the use of the average paleomagnetic directions corrected for the effect of inclination shallowing, the new paleomagnetic pole of the East European platform is calculated for the P–Tr boundary interval. It is shown that the new paleomagnetic pole does not differ from the corresponding poles of Siberia and North America. We consider this supports the validity of the geocentric axial dipole hypothesis for the Paleozoic/Mesozoic boundary. The observed far-side effect of the particular paleomagnetic poles of the East European platform relative to the average poles of Siberia and North America could be the result of the more ancient (Late Permian) age of the European poles.

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