

Paleostrength of the Geomagnetic Field in the Early Permian

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Rocks of the Lower Permian section in the neighborhood of the Teberda River (Northern Caucasus) were investigated by the Telye method. Paleostrength was determined in 260 samples from 23 "points" (calcined contacts and covering porphyrites). The paleostrength was 0.46 of the modern level with a standard deviation $S = 0.09$. A study was also made of a section in Central Asia (Chatkal Range, Uzbekistan), related to the bottom of the Lower Permian. A paleostrength equal to 0.82 of the modern level was obtained for 8 "points" (108 samples). The standard deviation is $S = 0.06$.

A very small number of studies have been devoted to research on paleostrength of the geomagnetic field in the Late Paleozoic and especially in the Permian. In order to estimate paleostrength during the Permian, Krs [1] and Schwarz and Symons [2] used the Telye successive heatings method; in [1] for cassiterites, and in [2] for basalts. In [3], Khramov determined paleostrength in the Late Paleozoic by the reprecipitation method, using the magnetization of sedimentary rocks. The Telye method and the reprecipitation method gave consistent results for the Permian, which enabled Bolshakov and Solodovnikov [4] to conclude that in the Permian, paleostrength was close to the modern level.

Among the later investigations, mention should be made of a study by Senanayake and McElhinny [5], who for estimating paleostrength applied the Shaw method for strongly oxidized Permian igneous rocks. Paleostrength was determined from the magnetizations associated, in the opinion of the authors, with different ferromagnetics: magnetite and hematite. In this case, identical H_{anc} values were obtained, which made it possible to conclude that oxidation proceeded to the thermomagnetization of the rocks. Different results were obtained in two collections of Permian rocks of different age: in one collection, H_{anc} was 0.87 of the modern geomagnetic field, and in the other, 0.45. The study by Senanayake and McElhinny evidently gave the most convincing data on the paleostrength of the geomagnetic field in the Permian. These results indicate that in the Late Paleozoic the geomagnetic field was different from that in the Mesozoic.

SECTION IN NORTHERN CAUCASUS

An effusive-sedimentary rock complex ($\varphi=43^\circ$ N, $\lambda = 42^\circ$ E), belonging to the upper stratum of the Lower Permian [6], is exposed between Verkhnyaya Teberda and Nizhnyaya Teberda villages on the left bank of the Teberda River [6]. Paleomagnetic

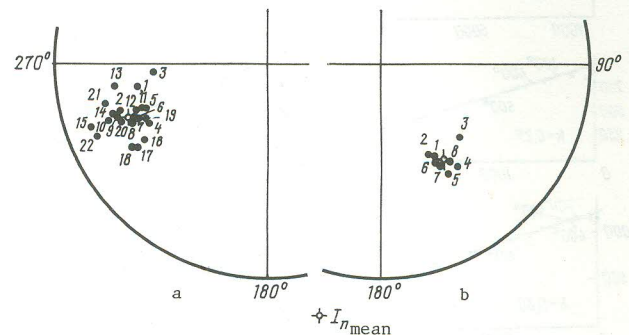


Fig. 1. Stereograms of I_n directions:

a) Northern Caucasus section; b) Uzbekistan section.

research was carried out earlier in this region [7, 8]. The results confirm the Early Permian age of the rocks.

The studied section, whose thickness is roughly 350 m, consists of flows of porphyrites, and between them, there are sometimes small interlayers of tuffogenic-sedimentary rocks. More than 20 calcined contacts were found in which, because of the small thickness of the covering porphyrites, the calcined zones usually make up only a few tens of centimeters below the contact line. The calcined rocks are represented primarily by tuffogenic-sedimentary material (tuff clays, tuffs) and calcined porphyrites of the underlying flows. At a number of contacts (5, 13, 16, and others), it was possible to sample lithologically different calcined rocks. In all cases, in addition to the basic sampling in the calcined zones, oriented samples of calcining porphyrites were also taken. More than 750 oriented specimens were taken from 23 points (contacts) in the section. They are numbered from the recent to the more ancient rocks.

Laboratory measurements indicated that most

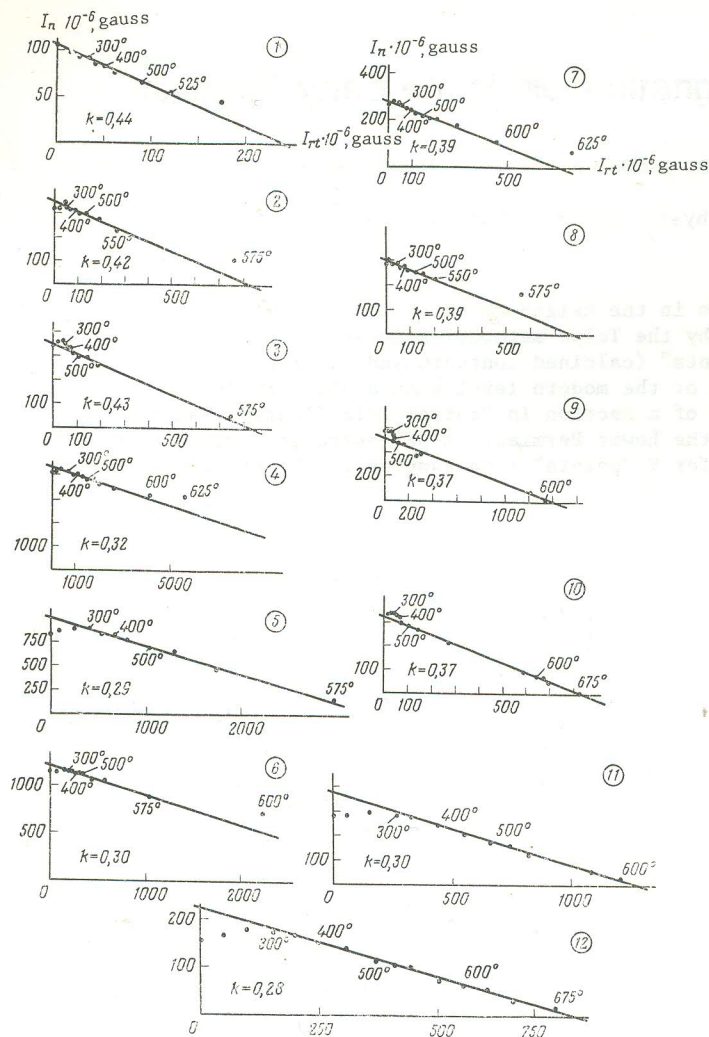


Fig. 2. Arai-Nagata dependencies of samples from Northern Caucasus section for calcined: tuff clays (Nos. 1, 11, 12), porphyrites (Nos. 2-4, 8-10), tuffs (No. 5), tuff sandstones (No. 6), and for covering porphyrites (No. 7).

of the samples have reverse magnetization. Only some of the covering porphyrites have magnetization of direct polarity, but laboratory thermal cleaning indicated that this magnetization is unstable and apparently was acquired later. The stereogram (Fig. 1a) shows the mean directions for the entire section. The mean position of the paleopole for the entire section ($\Phi=25^\circ$, $\Lambda=132^\circ$) agrees well with similar data obtained in [7].

Temperature research indicated that some of the section samples are characterized by the presence of maghemite. However, in the calcined rocks, in comparison with the covering porphyrites, the contribution of the maghemite to the total magnetization is considerably less, and in the high-temperature intervals (beginning with 350°), its influence can evidently be neglected.

DETERMINATION OF PALEOSTRENGTH AND RELIABILITY OF RESULTS

After laboratory heatings of the entire col-

lection by the Wilson-Burakov method [9], some of the samples, not having a similarity to the $I_n(T)$ and $I_{rt}(T)$ curves, were rejected (for the most part, these were samples of covering porphyrites), but the more than 300 remaining samples were subjected to heating by the Telye method. Most of them were suitable for determining paleostrength: insignificant changes in α and stability of the direction I_n in the course of heating, and also checking by repeated 300° degree heatings, together made it possible to use them for computing the similarity coefficient K . The principal temperature intervals for determining K were from $300-400^\circ$ to $600-625^\circ\text{C}$. However, for some of the samples, it was also possible to compute K in the low-temperature region. In this case, the K coefficient values virtually did not differ from one another. Figure 2 shows Arai-Nagata dependencies for a number of section samples. For example, on graphs 1-3 (Fig. 2), for three samples from the very same contact, the temperature intervals for determining paleostrength were different.

Table 1
Paleomagnetic Directions, Poles and Paleostrength of Lower Permian Section of Northern Caucasus

Number of contact (points)	Rock	No. of samples	D_n°	j_n°	α_{95}°	Φ	λ	θ_1	θ_2	n_2	K	$H_{anc, oe}$	M_{anc}/M_0
1	Porphyrite	2	260	-34	-	20	125	-	-	2	0.32±0.01	0.16±0.01	0.44±0.03
2	Calcedined porphyrites	7	252	-24	5	22	132	5	3	5	0.31±0.01	0.16±0.01	0.47±0.06
3	Same	8	266	-41	6	19	117	7	4	7	0.36±0.02	0.18±0.01	0.46±0.05
4	Same	8	266	-41	6	19	117	7	4	9	0.34±0.01	0.17±0.01	0.47±0.06
5	Calcedined tuff clays	6	243	-33	8	32	124	9	5	6	0.34±0.01	0.17±0.01	0.47±0.06
	Mean for 4th point	8	252	-32	5	25	132	6	3	5	0.34±0.01	0.17±0.01	0.58±0.05
	Covering porphyrites	8	252	-32	5	25	132	6	3	5	0.41±0.01	0.21±0.01	0.58±0.05
	Calcedined tuff clays	7	245	-38	6	32	127	7	4	11	0.39±0.01	0.20±0.01	0.56±0.05
	Calcedined porphyrites	8	245	-38	6	32	127	7	4	11	0.37±0.01	0.19±0.01	0.50±0.05
	Mean for 5th point	23	250	-34	5	27	130	6	3	27	0.39±0.01	0.20±0.01	0.55±0.05
6	Covering porphyrites	23	250	-34	5	27	130	6	3	27	0.39±0.01	0.20±0.01	0.55±0.05
	Calcedined porphyrites	16	248	-29	4	27	132	4	2	12	0.41±0.01	0.21±0.01	0.60±0.03
7	Mean for 6th point	16	248	-29	4	27	132	4	2	17	0.41±0.01	0.21±0.01	0.60±0.03
	Covering porphyrites	4	248	-29	4	27	132	4	2	4	0.41±0.01	0.21±0.01	0.60±0.03
	Calcedined porphyrites	10	247	-30	5	28	132	6	3	7	0.38±0.01	0.19±0.01	0.56±0.05
8	Mean for 7th point	10	247	-30	5	28	132	6	3	11	0.39±0.01	0.20±0.01	0.56±0.05
	Covering porphyrite	4	247	-30	5	28	132	6	3	4	0.39±0.01	0.20±0.01	0.56±0.05
	Calcedined porphyrite	11	246	-27	7	27	125	8	4	15	0.40±0.01	0.21±0.01	0.60±0.05
9	Mean for 8th point	11	246	-27	7	27	125	8	4	15	0.40±0.01	0.21±0.01	0.60±0.05
	Calcedined porphyrite	12	250	-23	5	23	129	5	3	11	0.43±0.01	0.22±0.01	0.65±0.05
10	Covering porphyrites	12	250	-23	5	23	129	5	3	11	0.43±0.01	0.22±0.01	0.65±0.05
	Calcedined tuff clays	5	250	-23	5	23	129	5	3	5	0.33±0.01	0.17±0.01	0.65±0.05
	Mean for 10th point	7	250	-18	6	21	125	6	3	10	0.38±0.03	0.19±0.02	0.54±0.03
	Covering porphyrites	12	252	-35	5	26	129	6	3	15	0.36±0.02	0.18±0.01	0.43±0.03
11	Mean for 10th point	12	252	-35	5	26	129	6	3	15	0.36±0.02	0.18±0.01	0.43±0.03
	Calcedined porphyrites	11	246	-30	4	28	126	6	3	4	0.32±0.01	0.16±0.01	0.42±0.04
	Calcedined porphyrites	13	247	-35	4	30	132	5	3	14	0.28±0.01	0.15±0.01	0.42±0.04
	Calcedined tuff clays	36	250	-33	3	27	132	3	2	30	0.29±0.01	0.15±0.01	0.41±0.04
12	Mean for 11th point	36	250	-33	3	27	132	3	2	42	0.29±0.01	0.15±0.01	0.41±0.04
	Covering porphyrites	11	252	-33	5	25	128	6	3	10	0.40±0.01	0.21±0.01	0.58±0.05
	Calcedined tuff clays	13	248	-29	4	27	132	4	2	12	0.43±0.01	0.22±0.01	0.62±0.05
13	Mean for 12th point	13	248	-29	4	27	132	4	2	22	0.43±0.01	0.22±0.01	0.62±0.05
	Covering porphyrites	24	250	-31	3	26	132	3	2	22	0.42±0.01	0.22±0.01	0.62±0.04
	Calcedined tuff clays	4	250	-31	3	26	132	3	2	4	0.28±0.01	0.14±0.01	0.42±0.04
	Mean for 12th points	4	250	-31	3	26	132	3	2	4	0.28±0.01	0.14±0.01	0.42±0.04
	Covering porphyrites	5	252	-32	4	27	132	4	3	5	0.28±0.01	0.14±0.01	0.42±0.04
	Calcedined tuff clay	12	262	-24	7	14	127	7	4	13	0.27±0.01	0.14±0.01	0.41±0.04
14	Mean for 13th point	12	262	-24	7	14	127	7	4	13	0.27±0.01	0.14±0.01	0.41±0.04
	Covering porphyrites	5	262	-24	7	14	127	7	4	5	0.26±0.01	0.13±0.01	0.41±0.04
	Calcedined porphyrites	8	262	-24	7	14	127	7	4	8	0.26±0.01	0.13±0.01	0.41±0.04
	Calcedined tuff sandstone	7	251	-21	7	21	126	7	4	13	0.26±0.01	0.13±0.01	0.41±0.04
	Mean for 14th point	7	251	-21	7	21	126	7	4	13	0.26±0.01	0.13±0.01	0.41±0.04

Table 1 (continued)

Number of contact (points)	Rock	No. n ₁ of samples	D _n ^o	j _n ^o	α ₉₀ ^o	Φ	Λ	θ ₁	θ ₂	n ₂	K	H _{anc,oe}	M _{anc} /M _o
15	Calciné porphyrite	6	250	-40	8	48	122	8	4	7	0.26±0.02	0.43±0.01	0.40±0.04
16	Same									4	0.28±0.01	0.14±0.01	
	Calciné tuff sandstone									3	0.27±0.02	0.14±0.01	
	Calciné tuff									5	0.27±0.01	0.14±0.01	
17	Mean for 16th point	11	238	-28	6	33	100	7	4	12	0.27±0.01	0.43±0.01	0.40±0.04
18	Calciné tuff sandstone	6	237	-24	6	33	99	6	3	7	0.26±0.01	0.43±0.01	0.39±0.04
19	Calciné porphyrites	2	238	-22	7	31	98	-	3	2	0.25±0.01	0.43±0.01	0.38
	Covering porphyrites	6	245	-36	7	32	132	8	5	2	0.27±0.01	0.14±0.01	0.38±0.05
	Calciné porphyrites	7	245	-32	5	30	130	6	3	6	0.28±0.02	0.14±0.01	0.39±0.04
20	Mean for 19th point	13	245	-33	5	31	132	6	3	8	0.28±0.02	0.14±0.01	0.39±0.04
	Covering porphyrites									3	0.23±0.01	0.12±0.01	
	Calciné tuff sandstone	10	248	-23	8	24	125	8	4	6	0.25±0.01	0.13±0.01	0.35±0.04
21	Mean for 20th point	3	256	-19	9	17	131	9	5	9	0.24±0.01	0.12±0.01	0.39±0.05
22	Calciné porphyrites	4	247	-11	7	20	119	7	4	3	0.25±0.02	0.13±0.01	0.40±0.04
23	Same									3	0.25±0.03	0.13±0.01	0.39±0.04
	Porphyrites	22	249	-26	4	25	132	4	2	23	0.32±0.01	0.16±0.01	0.46±0.04
	Mean for section	(236)								(260)	S=0.07		S=0.09

Table 2

Paleomagnetic Directions, Poles and Paleostrength of Lower Permian Section of Uzbekistan

Number of contact (points)	Rock	Number of samples	D _n ^o	j _n ^o	α ₉₀ ^o	Φ	Λ	θ ₁	θ ₂	n ₂	K	H _{anc,oe}	M _{anc} /M _o
1	Calciné tuff	18	450	-44	5	61	318	6	4	11	0.69±0.02	0.35±0.01	0.82±0.07
2	Igimbrite	14	452	-46	4	63	317	5	3	13	0.69±0.02	0.35±0.01	0.80±0.06
3	"	18	434	-44	5	49	331	6	4	20	0.66±0.03	0.34±0.02	0.79±0.08
4	Lilac tufts	11	144	-35	6	52	314	7	4	13	0.73±0.02	0.37±0.01	0.94±0.07
5	Calciné tuff	13	148	-35	4	55	311	5	3	12	0.65±0.01	0.35±0.01	0.84±0.05
6	"	14	450	-43	4	60	315	5	3	14	0.69±0.01	0.35±0.01	0.82±0.06
7	Calciné tuff lava	12	450	-40	5	59	314	6	4	12	0.66±0.01	0.34±0.01	0.82±0.06
8	Calciné tuff	14	445	-38	5	55	319	6	4	13	0.56±0.01	0.29±0.01	0.72±0.06
	Mean for section	8(114)	447	-41	2	57	317	2	1	8(108)	S=0.05	0.34±0.01	S=0.06

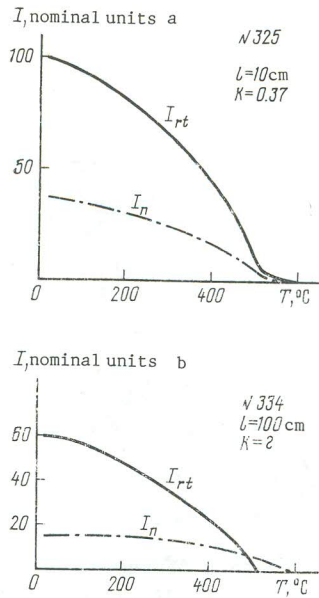


Fig. 3. $I_n(T)$ and $I_{rt}(T)$ curves: a) sample from calcined zone; b) sample from uncalcined rock ($l = 100$ cm).

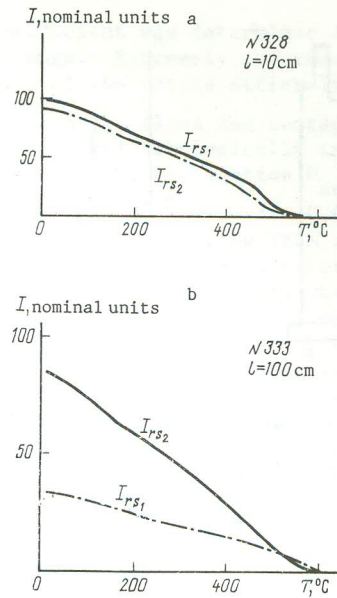


Fig. 4. $I_{rs}(T)$ curves: a) sample from calcined zone; b) sample from uncalcined zone.

calcined tuff clays, this was $0-525^{\circ}$, for calcined porphyrite $300-550^{\circ}$, and for covering porphyrite $450-575^{\circ}$. However, the K coefficient in these cases is the same within the limits of accuracy.

The final results of determination of the paleostrength value for both each point (contact) and for the entire section are given on the right-hand side of Table 1. The investigated section must be deemed rather homogeneous in paleostrength: at all points (contacts), there are considerably reduced M_{anc} values in comparison with M_0 . However, it can be noted that in the upper part of the section (points 1-12), the H_{anc} values are greater than the corresponding values for the bottom of the show. For example, for points 1-12, $K_{mean} = 0.37 + 0.01$, but for points 13-23, $K_{mean} = 0.26 + 0.01$. According to 260 determinations from 23 points, $M_{anc}/M_0 = 0.46 + 0.04$ with a standard deviation $S = 0.09$. This value is very close to the corresponding value M_{anc}/M_0 , determined earlier for Jurassic rocks [10]. We feel that the reliability of the results is confirmed by the following.

1. In comparison with samples from the uncalcined tuffogenic-sedimentary parts of the section, rocks from the calcined zones have a greater stability during the course of laboratory heatings, but the I_n and I_{rt} thermal curves are similar in the temperature intervals for determining H_{anc} .

Figure 3 shows two graphs: $I_n(T)$ and $I_{rt}(T)$.

For a sample from the calcined zone of point 12, there is a similarity of the $I_n(T)$ and $I_{rt}(T)$ curves in virtually the entire temperature interval. The $I_n(T)$ and $I_{rt}(T)$ thermal curves of a sample of uncalcined rock ($l = 100$ cm) are characterized by an absence of similarity and a change in T_c after heating. A similar picture can also be seen for the $I_{rs}(T)$ curves (Fig. 4) of samples from this same contact. In the calcined zone, there is an $I_{rs}(T)$ and $I_{rs}(T)$ similarity and insignificant changes in I_{rs} after the first heating. In the sample from the uncalcined zone, after the first heating, there is a considerable increase in the I_{rs} value, and there is no similarity of the thermal curves for the first and second heatings.

2. In many contacts of the Teberda section, the H_{anc} value was computed for lithologically different rocks calcined by the very same flow. However, the determined H_{anc} values differed insignificantly from one another. The graphs 4-6 in Fig. 2 show the Arai-Nagata dependencies for calcined porphyrite, tuff, and tuff sandstone for contact 16. Within the limits of accuracy, determinations of the K coefficient for these three samples can be considered identical.

3. In this section, in contrast, for example, to the Lower Jurassic shows, it was possible, when determining H_{anc} , also to make use of samples taken

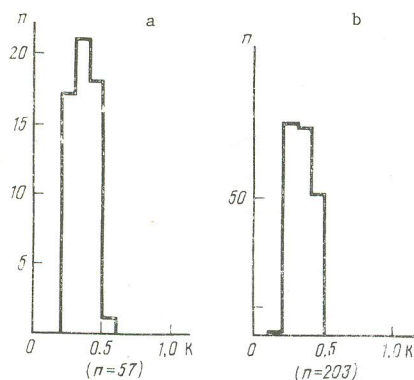


Fig. 5. Histograms of K coefficient values obtained using samples of porphyrites (a) and calcined rocks (b) of Northern Caucasus section.

from calcining porphyrites. In this case (see Table 1), there is a good agreement between the K coefficients computed separately for samples of porphyrites and calcined rocks. The graphs 7 and 8 in Fig. 2 (point 6) show one such example. Figure 5 shows histograms of the K coefficient values computed for samples from the covering porphyrites and calcined rocks. It can be seen that the K distributions have the same single-mode form and in general differ insignificantly from one another.

4. In most section samples, the ferromagnetic minerals have Curie points close to T_c of magnetite. However, for some contacts, there are samples whose T_c differ considerably from one another. For example, on graphs 9 and 10 in Fig. 2, two samples of calcined porphyrites (contact 3) have different T_c . In calcined tuff clay from contact 11 (graphs 11 and 12 in Fig. 2), the very same picture is observed. In both cases, the K coefficients are virtually identical.

On the basis of the material presented above, taking into account the great number of H_{anc} determinations and the good convergence of the data registered at each point (contact) and in the entire section, one can conclude that the results cited in Table 1 are to a high degree reliable.

SECTION IN UZBEKISTAN

A series of effusive rocks belonging to the Shurabsay suite of the Early Permian [11] is exposed in the southwestern spurs of the Chatkal Range (Tashkent Oblast, Uzbek SSR, $\varphi=41^\circ N$, $\lambda=70^\circ E$) in the neighborhood of the Shavzsay River. Absolute age determinations gave a value 280 ± 5 million years [12]. The section, whose thickness is 250-300 m, for the most part consists of acidic effusive flows of liparitic composition, alternating with strata of tuffs and ignimbrites. Many

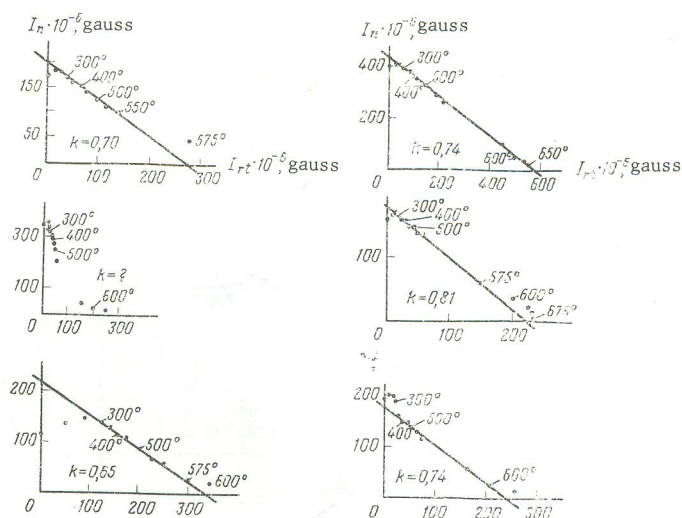


Fig. 6. Arai-Nagata dependencies for samples from Uzbekistan section: a) calcined tuff ($l = 10$ cm); b) tuff ($l = 70$ cm); c) calcined tuff lava; d) lilac tuff; e) ignimbrite; f) calcined tuff.

calcined contacts were detected in the show. Unfortunately, the main mass of both the effusives and the contact zones has extremely low magnetization (on the order of 10^{-6} cgs units). For this reason, the Telye method cannot be used for determining paleostrength. More magnetic rocks are found only amidst the flows of tuffs and ignimbrites. A total of more than 150 oriented specimens from 8 points in the section were sampled, including 5 calcined contacts.

The mean directions of the natural remanent magnetization of the flows and contacts after temperature cleaning, as well as the positions of the virtual poles, are represented in the left part of Table 2. All this is shown graphically in the stereogram in Fig. 1b. Mean I_n for the section as a whole: $D = 147^\circ$, $j = -41^\circ$. This is in very good agreement with the data in [13, 14], obtained earlier. After discarding the heatings by the Wilson-Burakov method, we heated the remaining samples by the Telye method; 108 of them were suitable for determining H_{anc} . The results for both the points and for the section as a whole are indicated in the right-hand side of Table 2.

Figure 6 shows the Arai-Nagata dependencies for a number of samples from different points in the section. The graphs 1 and 2 in Fig. 6, for example, represent tuff samples for point 1 from the calcined zones 70 cm below the contact line. In the first case, there is a similarity of $I_n(T)$ and $I_{rt}(T)$ in a great temperature interval (100-550°). In the second graph, such a similarity is

absent; that is, at a distance of 70 cm from the contact line, there probably was no longer high-temperature tuff calcining.

In contrast to the Lower Permian Teberda rocks, the temperature intervals for determining H_{anc} of this section are more representative, and are limited to 100–300° from below and 550–575° in the high-temperature range. In the main mass of the samples, the ferromagnetic mineral is evidently magnetite (for example, on graph 3 in Fig. 6). Only in individual cases is it possible to compute H_{anc} in samples containing hematite. For example, on graph 4 in Fig. 6 H_{anc} was determined in the temperature range to 650°C.

A whole series of samples evidently contains hematite (its contribution to total magnetization I_n is usually insignificant), and its thermoremanent origin I_n must be questioned. The similarity of $I_n(T)$ and $I_{rt}(T)$ at temperatures 575–675° is impaired, and stability of D and j in this heating interval is absent. There are few such samples in the general mass, and they scarcely exert a substantial effect on the final results of the determined H_{anc} values. An example of such a sample containing hematite is the ignimbrite from point 3. The Arai-Nagata dependence for it is shown on graph 5 in Fig. 6.

We note that in the Lower Permian section of Central Asia, samples that contain maghemite are rarely encountered. The contribution of maghemite to total I_n is considerably less than in the Lower Permian Teberda rocks. For example, from 11 samples at point 1, maghemite was discovered only in one. The Arai-Nagata dependence for it is shown on graph 6 in Fig. 6.

The Lower Permian section of Uzbekistan is naturally less representative than the corresponding section for the Northern Caucasus. However, five calcined contacts were investigated there,

and the K coefficient was determined in a broad temperature range. Extremely important, the mean M_{anc}/M_0 values of the points differ little from one another, although the flows and contacts entering into the section are lithologically inhomogeneous.

As an average for the section $M_{anc}/M_0 = 0.82 + 0.02$ with a standard deviation $S = 0.06$.

Strength values, differing from one another by a factor of almost 2, were therefore obtained for two widely separated sections, the formation of which is assigned to different times in the Permian (Uzbek section, to the onset of the Early Permian, but for the Northern Caucasus section, to its end). The determined H_{anc} values, almost perfectly coinciding with values determined in the study by Senanayake and McElhinny, indicate that the change in paleostrength in the Late Paleozoic had a complex character and differed considerably from its behavior in the Mesozoic. The small value of the standard deviation, which indicates that in the Late Paleozoic as well as in the Mesozoic, the secular paleostrength variations were less by a factor of 5–8 than in the Cenozoic, merits attention.

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