

Paleostrength of Geomagnetic Field in Middle-Late Carboniferous

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A determination of the paleostrength of the geomagnetic field was made from samples of three sections and sintered exocontacts of dikes of the Middle and Late Carboniferous (Uzbekistan), for the most part by the Tellier method and in part by the Wilson-Burakov method. A ratio of the ancient geomagnetic moment (M_{anc}) to the modern geomagnetic moment (M_0), equal to 1.10 ± 0.04 with a standard deviation $S = 0.09$, was obtained from 732 samples from 77 points (contacts).

There are very few data available on the paleostrength of the geomagnetic field (H_{anc}) in the Carboniferous. Individual determinations made by the reprecipitation method [1, 2] do not make it possible to draw conclusions about the nature of the field at that time, and the few H_{anc} determinations made by other methods are inadequately reliable. Accordingly, we sampled Carboniferous rocks from representative volcanogenic sections and made an attempt to determine H_{anc} on the basis of extensive statistical material.

Oriented samples were collected in the territory of Tashkent Oblast in the Uzbek SSR. The mean coordinates of the sampling sites were $\varphi = 41^\circ N$, $\lambda = 70^\circ E$. With respect to age, two sections belong to C_2-C_3 [3-5]. One section was located in the southeastern spurs of the Chatkal Range (the section was named Dukent), and the second, more ancient, in the western spurs of the Kuramin Range (Nishbash). A third section of Late Carboniferous age [6] was located in the southeastern part of the Karzhantau Range. (Karzhantau).

The sections were separated from one another by a distance of 15-25 km. The thickness of each is 300-500 m. The rocks are represented by flows of andesites, andesitic basalts, tuff lavas, and tuffs. The oriented pieces were sampled both from zones of sintered contacts and from slagging zones, local zones of reddening.

In the same regions, in addition to the mentioned sections, samples also were taken from the near-contact regions of three dikes. The age of two of them was C_3 , whereas that of the third was C_2-C_3 . In addition, samples of reddish ignimbrites were taken from a so-called extrusive dome of the age C_2-C_3 .

Thus, a total of more than 1500 oriented pieces were selected, some of which after laboratory analysis proved to be unsuitable for determining H_{anc} as a result of partial or complete

magnetic reversal of primary I_n of reversed polarity. For the most part, these were samples of sintering effusives.

In the course of laboratory heatings by the Tellier method, there was a change in the direction of I_n , but for a large part of the samples in which the H_{anc} values were determined, this process was completed at $300^\circ C$.

Because the amount of material is great, the initial paleomagnetic data for all the points (contacts) of the sections cannot be cited here. The results for all points of the Karzhantau section are given only as an example (Table 1). The principal paleomagnetic data for the sections are given in Table 2.

The mean position of the paleopole (it was determined with mean data for each point, not the mean values for the sections) $\Phi = 21^\circ$, $\Lambda = 325^\circ$ differs rather greatly from the coordinates of the paleopole ($\Phi = 52^\circ$, $\Lambda = 318^\circ$), obtained earlier from rocks of this region of a close age [5].

In earlier studies, for the most part we used the Tellier method for determining H_{anc} in younger rocks. In the selected collection of Carboniferous samples, some of them were unsuitable for determining H_{anc} by this method. In all probability, as a result of the prolonged heatings in the Tellier method, especially in the region of quite high temperatures, there are mineralogical changes in the samples that preclude their further use in determining H_{anc} . This is indicated, in particular, by the substantial change in χ the course of heatings, sometimes attaining 30-40% of the initial value.

However, in the same samples, heated by the Wilson-Burakov method [7], it is possible in many cases to make H_{anc} determinations: There is a similarity of the I_n and I_{rt} temperature curves. The Curie points do not change in the course of heatings, but the value of the repeated I_{rt} either differs insignificantly from the initial I_{rt} (in

Paleomagnetic Directions, Poles, and Paleostrength for Rocks of Karzhantau Section
of Late Carboniferous

Number of point (contact)	Rock	n_1	D°	I°	K_1	α_{95}	Φ	Λ	A	Wilson-Burakov method		Tellier method		H_{anc} , oe	M_{anc}/M_0
										n_2	K_2	n_3	K_3		
1.	Red andesites	9	87	-45	85	6	15	318	6	6	0,91±0,02	12	0,90±0,01	0,46±0,01	1,05±0,07
2.	Red tuff	9	90	-56	71	7	23	311	8	1	1,0	10	0,91±0,01	0,47±0,01	0,94±0,09
3.	Ignimbrite	13	74	-56	55	6	13	302	7	-	-	9	0,92±0,01	0,47±0,01	0,94±0,08
4.	Sintering porphyrite	9	105	-57	59	7	34	312	8	-	-	7	0,94±0,01	0,48±0,01	0,95±0,08
5.	Sintered tuff	11	98	-57	82	5	29	314	6	12	0,90±0,02	19	0,94±0,01	0,48±0,01	0,95±0,08
6.	Tuff lava	9	104	-40	64	6	25	331	5	8	0,95±0,02	8	0,93±0,01	0,48±0,01	1,15±0,09
7.	Tuff lava	7	119	-46	43	9	39	338	9	-	-	8	0,92±0,01	0,47±0,01	1,06±0,12
8.	Red ignimbrite	10	90	-48	109	3	19	318	3	6	0,90±0,05	10	0,94±0,01	0,48±0,01	1,06±0,06
9.	Same	11	77	-46	61	6	9	311	6	11	0,91±0,02	12	0,96±0,01	0,49±0,01	1,10±0,08
10.	Same	12	77	-39	56	6	5	315	5	11	0,87±0,02	13	0,97±0,01	0,50±0,01	1,20±0,09
11.	Same	5	99	-57	48	11	30	315	14	9	0,98±0,04	5	0,90±0,03	0,46±0,03	0,91±0,12
12.	Trachytic red andesite	9	95	-55	53	8	26	314	9	-	-	8	0,90±0,01	0,46±0,01	0,96±0,11
13.	Same	4	76	-52	24	9	12	307	10	-	-	4	0,94±0,02	0,48±0,02	1,01±0,12
14.	Same	9	98	-52	36	9	32	312	10	-	-	4	0,89±0,02	0,46±0,02	0,97±0,13
15.	Same	7	86	-55	28	11	20	310	13	-	-	7	0,86±0,01	0,44±0,01	0,89±0,14
16.	Sintering red andesite	9	96	-50	29	8	24	319	9	-	-	9	0,87±0,02	0,45±0,02	0,97±0,10
17.	Sintered tuff	8	99	-56	36	7	29	315	8	-	-	10	0,90±0,02	0,46±0,02	0,92±0,09
18.	Andesite	6	87	-40	48	9	13	321	9	-	-	5	0,89±0,03	0,46±0,03	1,10±0,15
19.	Andesite	10	87	-53	92	5	19	312	6	2	0,94±0,02	10	0,89±0,01	0,46±0,01	0,96±0,07
20.	Red andesite	10	93	-56	93	5	25	312	6	11	1,06±0,02	13	0,97±0,01	0,50±0,01	1,00±0,08
21.	Sintering red andesite	14	72	-57	163	3	12	301	3	12	1,09±0,03	13	0,98±0,01	0,50±0,01	0,99±0,04
22.	Sintered porphyrite	12	79	-56	170	3	16	305	3	12	1,10±0,02	12	0,96±0,01	0,49±0,01	0,98±0,05
23.	Sintered andesite	10	111	-53	54	7	36	310	9	-	-	10	0,90±0,02	0,46±0,02	0,96±0,12
24a.	Sintered andesite	7	115	-38	74	3	32	335	3	-	-	7	0,93±0,01	0,48±0,01	1,17±0,04
24b.	Sintered tuff	10	108	-42	109	5	29	333	5	5	0,88±0,02	9	0,92±0,01	0,47±0,01	1,10±0,06
24c.	Sintered tuff sandstone	15	105	-43	167	3	27	329	3	-	-	16	0,92±0,01	0,47±0,01	1,09±0,04
24d.	Sintered rocks together	32	108	-41	110	3	28	331	3	5	0,88±0,02	32	0,92±0,01	0,47±0,01	1,11±0,04
25.	Trachytic reddish andesite	9	103	-56	25	10	32	317	12	3	0,88±0,03	10	0,92±0,01	0,47±0,01	0,94±0,12
26.	Same	8	93	-57	52	8	26	311	10	2	0,92±0,03	10	0,93±0,01	0,48±0,01	0,95±0,11
27.	Mean for section	26	93	-52	68	3	23	316	3	15	0,95±0,02	26	0,92±0,01	0,47±0,01	0,99±0,04
		(262) samples									(111) samples	(270) samples		$S = 0,05$	

Note: The numbering of the points (contacts) runs from young to more ancient rocks; n_1, n_2, n_3 - number of determinations at point (contact); K_1 - clustering of I_n vectors; K_2, K_3 - proportionality factors equal to I_n/I_{rt} ratios; all the paleomagnetic directions were computed in a modern coordinate system.

the range $\pm 10\%$) or is virtually the same.

The explanation for the different behavior of the samples with heatings by the two methods is evidently that in contrast to the Tellier method, heatings by the Wilson-Burakov method were brief, and mineralogical changes could not occur.

In some cases, however, heatings by the Tellier method make it possible to compute the H_{anc} values, whereas these same samples undergoing thermal processing by the Wilson-Burakov method, are unsuitable for this purpose. Usually such a situation is observed when the mineralogical changes (regardless of the times of laboratory heatings) occur in the range of temperatures close to the Curie points of the ferromagnetic components and when the Wilson-Burakov method, naturally, "does not work"; but with the Tellier method, by virtue of the stepped character of the heatings, it is possible to use the temperature intervals up to the onset of mineralogical changes. For example, Table 1 shows the number of cases when it is impossible to use the Wilson-Burakov method.

Naturally, the reliability and informativeness of the results of the Wilson-Burakov method are

considerably poorer than the similar results with heatings by the Tellier method. However, in the prevailing situation, adhering to the tests for rejection of samples indicated above, one can evidently use the Wilson-Burakov method in combination with the Tellier method.

Only in the Dukent section were about half the H_{anc} determinations made by the Wilson-Burakov method, but less than 20% of the samples in the Nishbash section were processed by this method, whereas in the most representative Karzhantau section, all the determinations included in the statistics were made by the Tellier method (although for increasing the number of investigated samples, it also would be possible to include some determinations by the Wilson-Burakov method when computing H_{anc}).

A confirmation of the reliability of the results obtained by the Wilson-Burakov method is probably the very good convergence of data determined by both methods and cited together as an example in Table 1. We also point out that for the Dukent section, the mean K (a proportionality factor

Table 2

Composite Paleomagnetic Data Obtained in C_3 and C_2-C_3 Rocks in Uzbekistan

Sections, contacts	n_1	D°	j°	K_1	α_{95}°	Φ	Λ	A	n_2	K_2	H_{anc}, oe	M_{anc}/M_0
Karzhantau section (C_3)	26 (262)	93	-52	68	3	23	316	3	26 (270)	0,92±0,01	0,47±0,01	0,99±0,04
Contact with dike C_3	1 (11)	96	-34	22	5	17	330	5	1 (9)	0,90±0,01	0,46±0,02	1,16±0,10
Same	1 (10)	118	-34	11	12	33	336	12	1 (4)	0,90±0,02	0,46±0,02	1,16±0,16
Dukent section (C_2-C_3)	13 (103)	120	-32	42	6	34	336	6	14 (172)	0,93±0,01	0,48±0,01	1,23±0,10
Nishbash section (C_2-C_3)	34 (256)	90	-37	35	4	13	324	4	32 (245)	0,93±0,01	0,48±0,01	1,18±0,07
Contact with dike (C_2-C_3)	2 (7)	131	-33	17	15	43	327	15	2 (7)	0,83±0,03	0,43±0,03	1,09±0,15
Extrusive dome (C_2-C_3)	1 (17)	140	-47	58	5	55	331	5	1 (25)	0,91±0,02	0,47±0,02	1,04±0,10
Sum of all studied points of sections	78 (666)	98	-42	22	3	21	325	3	77 (732)	0,92±0,01	0,47±0,01 $S=0,09$	1,10±0,04

Note: n_1, n_2 , number of points (contacts) (the number of samples is given in parentheses); K_1 is the clustering of I_n vectors, K_2 is a proportionality factor, main ratio I_n/I_{rt} ; all the paleomagnetic directions were computed in a modern coordinate system.

equal to the ratios of I_n to I_{rt} values, determined by the Wilson-Burakov and Tellier methods, are equal to 0.93 and 0.92, respectively, but for the Nishbash section, they are equal to 0.94 and 0.91.

One of the principal problems in determining the paleostrength of the geomagnetic field is the reliability of the results (that is, whether the final data to one degree or another reflect the values of the earth's really existing ancient magnetic moment). A good many factors confirm the reliability of our determinations of the M_{anc}

values in the C_2-C_3 range:

1. The K coefficients, computed for samples from sintered zones and their sintering effusives, differ little from one another. As an example, it is possible to cite the pairs of points of the Karzhantau section 4 and 5, 16 and 17, 21 and 22, and 23 and 24 (Table 1). The figure, a and b, shows Arai-Nagata dependencies for sintering porphyrites and sintered tuff of points 4 and 5 of the Karzhantau section.

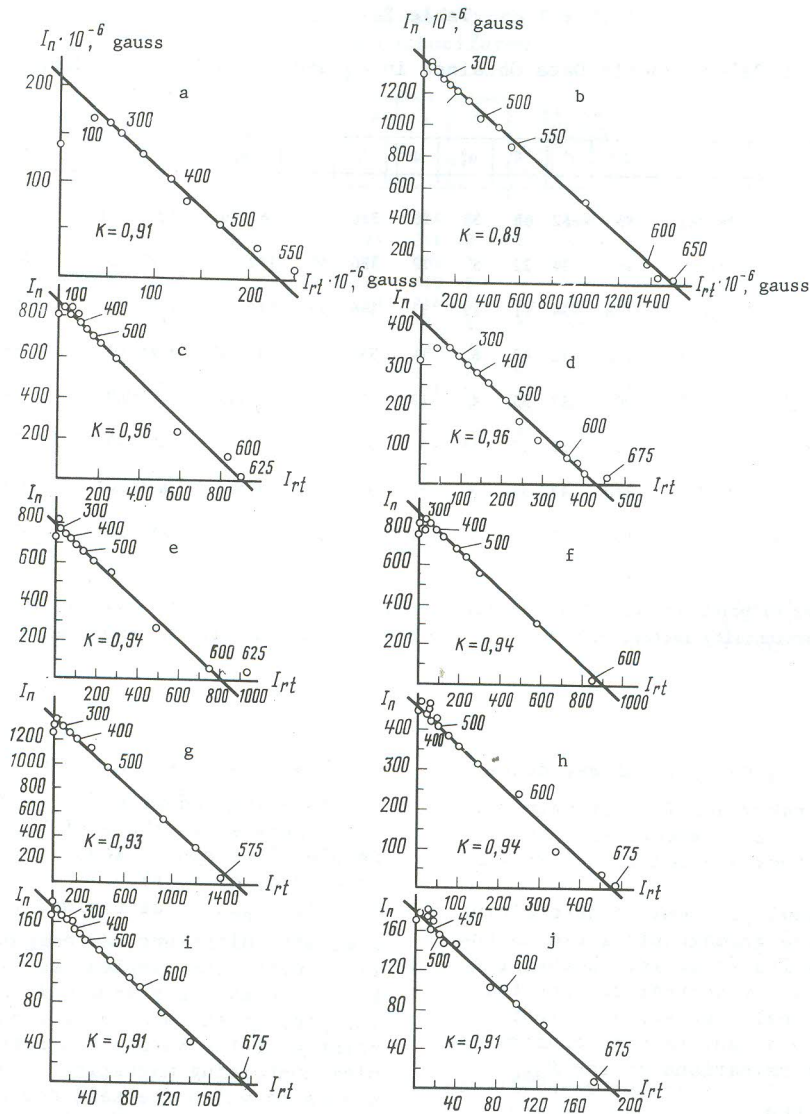
2. M_{anc} determinations were made in lithologically different rocks: effusives, tuffs, ignimbrites, and tuff sandstones (for example, see Table 1). In this case, there are no regularities in change in the K values.

3. The very same flow sometimes sinters different rocks, and the H_{anc} values determined for them are identical. An excellent example of such a case are points 24a, 24b, and 24c of the Karzhantau section (Table 1). The K coefficients, determined for sintered samples of andesite, tuff, and tuff sandstone are virtually identical.

In this case, the H_{anc} value, obtained for samples of sintering andesite (point 23), also is the same. The figure shows the Arai-Nagata dependencies for samples from sinter zones and covering porphyrites (graphs c, d, e, f).

4. H_{anc} is determined in many cases in samples with different ferromagnetic components. Frequently such samples, as is very important, belong to the very same point (contact). For example, in the sintering flow of porphyrites of point 4 of the Karzhantau section, there are samples containing magnetite (graph g, figure) and pieces in which the main component is hematite (graph h, figure). The K coefficients determined for such samples are identical.

5. For a whole series of samples, the main temperature interval in which the H_{anc} values were determined was 300-550°, because in the initial part of the heatings, temperature cleaning occurred, whereas laboratory mineralogical changes began to appear in the high-temperature part. However, there are many samples, and in general, points (contacts) at which the temperature limits of K determination were considerably expanded. For example, at point 22 of the Karzhantau section, K was determined from 100°C to the Curie points. Thus, the "shortened" temperature region of K determination evidently exerts an insignificant influence on the accuracy in computing H_{anc} . The graph and figure give the Arai-Nagata dependence for a sample from point 1 of the Karzhantau section; K was computed in the range 100-675°C. On the graph j, K was determined for a sample from this same point in the range 450-675°C. In both cases, the K coefficients are the same.



Characteristic Arai-Nagata dependencies for some samples of Karzhantau section: a) sintering porphyrite from point 4; b) sintered tuff from point 5; c) sintering andesite from point 23; d) sintered andesite from point 24a; e) sintered tuff from point 24b; f) sintered tuff sandstone from point 24c; g) sample containing magnetite from point 4; h) sample containing hematite from point 4; i, j) two samples from point 1.

6. A principal factor exerting an influence on the reliability of the results is the number of investigated points (contacts) and samples taken there (to be sure, in this case there must be adherence to other, earlier mentioned reliability elements). Naturally, an increase in the number of studied objects, despite all their diversity, also considerably increases the reliability of the overall results.

In this respect, we feel that this study is extremely reliable. Thus, on the basis of much statistical material, paleostrengths of the geomagnetic field (Table 2) which were close in value were obtained for 77 points (contacts), which included 732 individual H_{anc} determinations. The mean ratio of M_{anc} to M_0 is 1.10 ± 0.04 . As in our earlier studies, the standard deviation S is small and equal to 0.09.

Thus, in a quite prolonged geological time interval C_2-C_3 and C_3 (the duration of this interval is indicated, if by nothing else, by the considerable thicknesses of the studied sections, not duplicating one another), there was a terrestrial

magnetic field which in its strength was not only close to its modern strength but even somewhat exceeded it.

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