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Turkestan Ocean in the Middle Paleozoic: A Reconstruction Using Paleomagnetic Data for the Tien Shan

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Abstract—In the Early Paleozoic, the Turkestan oceanic basin separated the Tarim–Alay continent and a system of ensialic island arcs. In the Late Ordovician–Middle Paleozoic, the latter was transformed into the composite Kyrgyz (Kazakhstan–Kyrgyz) continental block. Sea-floor spreading in the Turkestan Ocean lasted from the beginning of the Paleozoic until the Middle Devonian. Calcalkaline volcanics appeared as a result of subduction of the oceanic crust at the Kyrgyz margin of the ocean in the Ordovician, Silurian, and Early–Middle Devonian. The spreading continued in the Givetian, whereas the subduction already ceased, and by the Late Devonian the oceanic basin apparently reached its maximum width. For 50 m.y.—from the Middle Devonian until the Visean—no subduction of the oceanic crust took place. It resumed at the Kyrgyz margin of the ocean in the Serpukhovian. As there was no sea-floor spreading, the subduction resulted in a relatively rapid (in 25 m.y.) shrinking and closure of the Turkestan Ocean. We studied paleomagnetism of the Givetian and Late Devonian rocks within the Kyrgyz and Tarim–Alay Middle Paleozoic continents. From the data obtained it was surmised that the long axis of the Kyrgyz continental block in the Late Devonian trended north-northeastward, and that of the Tarim–Alay continent had a N–S orientation (in the Devonian coordinates). The Chatkal region of the Kyrgyz block in the Late Devonian was located at a latitude of 23°, and the Baubashaty region of the Tarim–Alay continent—at a latitude of 8°.

The Turkestan Ocean [10] existed for about 300 m.y.—from the Vendian–Early Cambrian until the Middle Carboniferous [4, 5], the residual marine basins—sutures of the ocean—developing until the Early Permian. In the Early Paleozoic, the ocean separated the Tarim–Alay continent and a system of ensialic island arcs. As a result of a complex evolution, during the Late Ordovician–Middle Paleozoic the system was transformed into the composite Kyrgyz (Kazakhstan–Kyrgyz) continental block, which collided with the Tarim–Alay continent in the Bashkirian–Moscovian time. Evolutionary models for the Central Asia structure proposed by various workers [12, 14, 17, 19–21, 29] contain diverse interpretations of the size of the Turkestan Ocean and its role in the tectonic history.

Basaltic eruptions indicating sea-floor spreading occurred in the Turkestan Ocean from the beginning of the Paleozoic [4] until the Middle Devonian [18]. Calcalkaline volcanics appeared as a result of subduction of the oceanic crust at the Kyrgyz rim of the ocean in the Ordovician, Silurian, and Early–Middle Devonian. The spreading continued in the Givetian, whereas the subduction had already ceased, and by the Late Devonian the oceanic basin between the Kyrgyz and Tarim–Alay sialic blocks had apparently reached its maximum width. For 50 m.y.—from the Middle Devonian until the Visean—no subduction of the oceanic crust occurred. It was a critical period in the history of the Turkestan Ocean, when neither spreading nor subduction operated there. Subduction at the Kyrgyz margin resumed in the Serpukhovian, resulting in the closure of the oceanic basin in the Middle Carboniferous.

We have undertaken paleomagnetic studies in the Tien Shan in order to determine the paleolatitudes and orientation of the continental blocks during this critical epoch.

OBJECTIVES OF STUDIES

The studies were concerned with the Middle and Upper Devonian rocks found to the south and north of the Turkestan Ocean suture, i.e., within the Tarim–Alay and Kyrgyz Middle Paleozoic blocks of continental crust.

Tarim–Alay block. The Turkestan margin of this continent remained passive during most part or even the whole history of the Turkestan Ocean. During the Devonian, carbonates, epiclastics, and turbidites were accumulated here over the shelf, continental slope, and carbonate platforms. In northeastern Fergana in the Baubashaty Mountains, shelf limestones in places contain basalts, andesibasalts, their tuffs and tuffites, some of them alkaline, making up the Bossogotash Formation. At the periphery of the volcanic area, they compose sporadic interlayers among Givetian *Amphipora* limestones, and in the central part of the area they form a sequence 1.5–2 km thick. The bulk of these rocks belong to the Givetian Stage, their upper part being possibly Frasnian [7].

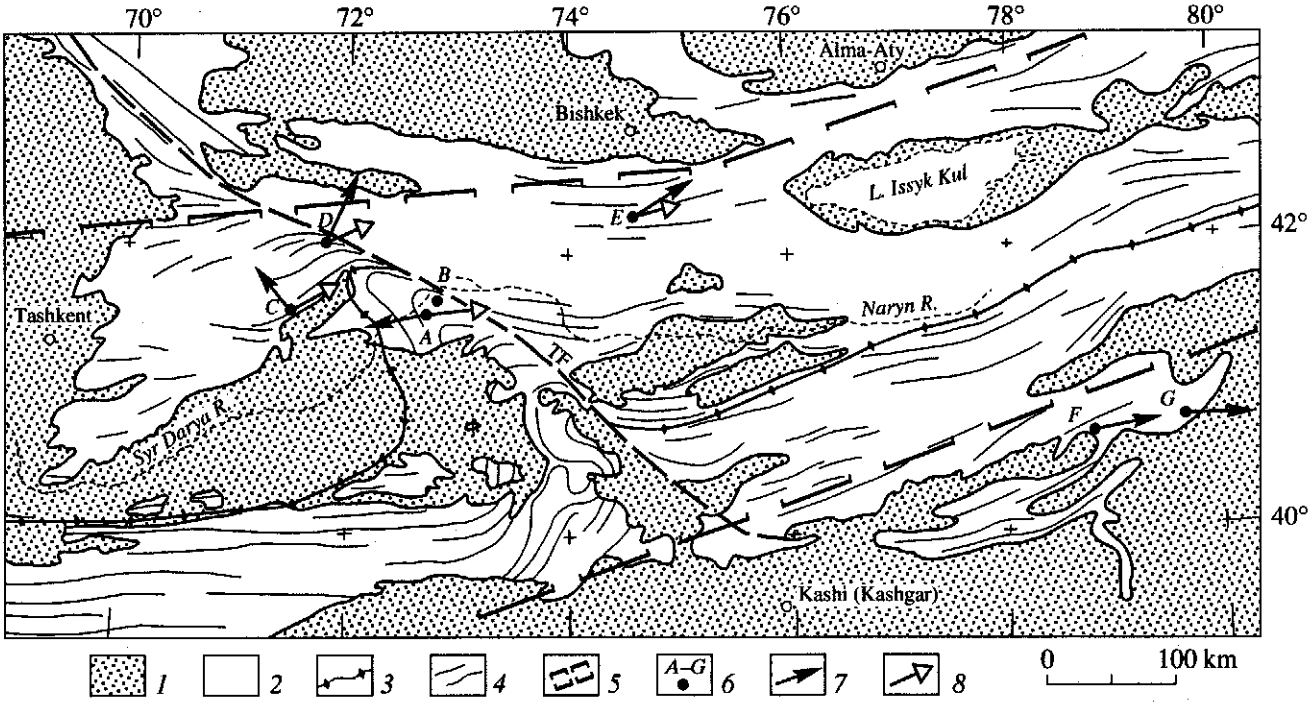

Fig. 1. Study sites (*1*) Cenozoic and Mesozoic; (*2*) Paleozoic and pre-Paleozoic; (*3*) suture of the Turkestan Ocean; (*4*) axes of vertical F_2 folds formed during deformation stage D_2; (*5*) zone of sinistral strike-slip stresses and deformations of stage D_3 after [1]; (*6*) sites of paleomagnetic studies; (*7, 8*) Late Devonian paleomagnetic inclinations: (*7*) measured, (*8*) reconstructed considering post-Devonian local rotations; (TF) Talas–Fergana strike-slip fault.

Basalts, tuffs, tuffaceous siltstones, and fine-grained tuffaceous sandstones of the Bossogotash Formation were studied in four outcrops in the valley of the Kaindy River (Fig. 1, *A*). The rocks lie at the gently sloping limb of a large synform overprinted by folds. The rocks of the Bossogotash Formation and underlying Givetian limestones were also studied within a monoclinal section in the valley of the Kaindy River (Fig. 1, *B*).

The **Kyrgyz block** was an active ensialic island arc since the Ordovician through Middle Devonian; then, the volcanic activity ceased and resumed only in the Serpukhovian. During the Givetian and Late Devonian, shallow marine carbonate–epiclastic deposits accumulated at the Turkestan margin in its outer zone, locally (in the Bozbutau Mountains in northern Fergana) being replaced by pure carbonates. A thick stratum of rhythmic detrital deposits was formed within the Kyrgyz block, unconformably overlying deposits of various ages. In the Chatkal–Naryn zone, this stratum forms the Tyul'kubashi Formation, and in the northern Tien Shan, the Tarsu Formation.

We have studied the carbonate–epiclastic deposits at two sites (Alabuka and Aksu) in the Chatkal region and detrital deposits at two sites (Besh-Alarcha and Suek) in the northern Tien Shan.

The *Alabuka site* (Fig. 1, *C*) is located on the southern slope of the Chatkal Range in the valley of the Alabuka River, near its middle reaches. The carbonate–epiclastic deposits contain Givetian and Frasnian brachiopods and are conformably overlain by Famennian limestones [9]. The deposits are about 750 m thick. The sequence contains mostly quartzy sandstones and siltstones alternating with limestones. Conglomerates and gritstones lie in the lower part of the sequence. The rocks are pink, red, lilac, and grey in color. Graded bedding, traces of erosion at the bottom of coarse-grained layers, ripple marks can be discerned in them. Siltstones and limestones at this site were studied in several sequences, both with normal and overturned bedding.

The *Aksu site* (Fig. 1, *D*) is located at the junction of the Chatkal and Talas ranges in the valley of the Aksu River, one of the tributaries of the Chatkal River. The studied sequence contains a stratum of quartz sandstones (over 500 m thick) overlying basal conglomerates and superposed by a member of alternating sandstones and sandy detrital limestones 100 m thick. An abundant fauna of Famennian brachiopods, including some forms typical of the Etroeungtian [9], was collected from the limestones (at the Kokuibel' Pass). Our paleomagnetic studies focused on the red fine-grained sandstones from this sequence found at the limbs of a compressed anticlinal fold.

The *Besh-Alarcha* and *Suek sites* (Fig. 1, *E*) are located 7 km apart in the lower reaches of the Besh-Alarcha and Suek rivers, respectively, in the basin of the Karakol-Zapadnaya River, the valley of which separates the Kyrgyz and Dzhumgal ranges of the northern

Tien Shan. Here, thick (over 2 km) red and variegated detrital deposits of the Tarsu Formation are found, containing Middle–Upper Devonian fish faunas and Upper Devonian floras [6, 8]. The deposits consist predominantly of arkose sandstones alternating with psephitic rocks and containing siltstone and mudstone interlayers. Graded bedding and the presence of cross-laminated members, traces of sediment rewashing, ripple marks, and desiccation fissures reliably indicate the top and bottom of the layers. Red siltstones and fine-grained sandstones were studied at these sites. The beds at both sites are arranged in monoclinal folds, the dip angle at the Besh-Alarcha site ranging from 45° to 80°.

PALEOMAGNETISM OF THE DEVONIAN DEPOSITS

Laboratory techniques. All the samples underwent stepwise thermal demagnetization up to temperatures of 570–670°C in heating units with a residual field of 10–20 nT. Magnetic measurements were carried out with a JR-4 rock generator; component analysis of the data from the stepwise demagnetization was accomplished by means of Zijderveld diagrams [24], using the programs developed by R. Enkin and obligingly put by the author at the disposal of the Paleomagnetic Laboratory of the Geological Institute, Russian Academy of Sciences. The study of the paleomagnetic directions obtained as a result of this analysis was carried out using various modifications of the fold test: adjustment, correlation test, and grouping test [3, 26, 27].

Almost all the studied Devonian volcaniclastics and epiclastics demonstrated a low degree of magnetization (from 0.5 to 6.5 mA/m). They are characterized by additional magnetization under laboratory conditions at heating temperatures over 580°C, the presence of which was verified by the results obtained on pairs of samples from each rock sample, differently oriented in the oven during the heating–cooling cycle. Volcanics (from the Kaindy sequence) are characterized by a high degree of magnetization (850 mA/m on the average).

The mean components for two specimens from each rock sample a given temperature interval were considered as conclusive analytical results. If the direction of the established components of the natural remanent magnetization for two specimens from each rock sample did not coincide, the data obtained were not used in further analysis.

The spectrum of blocking temperatures of the natural remanent magnetization was used, wherever possible, to make a tentative conclusion on the mineral carrying the established magnetization component.

Results of laboratory investigations. *Kaindy site.* The characteristic degree of magnetization in samples of various rocks (basalts, tuffs, tuffaceous siltstones and sandstones, and limestones) is positively determined within the temperature interval from 400–440 to 560°C (Fig. 2). Judging from the character of the thermal demagnetization curves (Fig. 3), it is most probably magnetite that is the carrier of the characteristic component. The distribution of projections of characteristic magnetization vectors over a sphere and their mean values are given in Fig. 4 and in Table 1.

The results of the grouping test, correlation test, and the ratio of concentration parameters (dip azimuth varies within the span 260°–330°, dip angle ranges from 5° to 40°) point to the prefolding age of the established magnetization component (Table 2). Maximum precision is reached at a 100% unfolding of the beds. The vectors of the established component of the natural remanent magnetization for basalts and epiclastics fully coincide. The vector obtained from overlapping demagnetization circles is also close to the vector determined by the component analysis.

The low-temperature components of the natural remanent magnetization in all cases are characterized by a wide spread of vectors, so they were not analyzed as a whole.

Alabuka site. Characteristic magnetization in the samples of siltstones and sandstones is established within the temperature interval 350–540°C (Fig. 2), its carrier being magnetite. All the results of the fold test suggest a prefolding age for this magnetization component; maximum precision is attained at a 100% unfolding of beds (Table 2). The sequence contains both normally and reversely magnetized rocks, the analysis of which produced matching results (Table 1).

Aksu site. Initial magnetization of the rocks averages 2 mA/m, rapidly dropping at the first stages of heating up to 200–300°C. For most samples, the high-temperature component is distinguished within the temperature interval of 350–570°C (Fig. 2), its carrier being magnetite or, possibly, oxidized magnetite. All the results of the fold test evidence the prefolding age of this magnetization component; maximum precision is achieved at a 100% unfolding of beds (Table 2). Median magnetization vectors determined by the component analysis and from demagnetization circles fully coincide.

Besh-Alarcha site. In most samples, characteristic magnetization is distinguished within the temperature interval 350–560° (Fig. 2), being associated mostly with magnetite. The results of the fold test and maximum precision at a 100% unfolding of beds (Table 2) allow us to speak with confidence of the prefolding age of the determined characteristic magnetization, the vector of the overlapping demagnetization circles fully coinciding with it.

Karasu and Suek sites. Initial and overprinted magnetization could not be distinguished in the rocks from the Karasu and Suek sites, so these data were not taken into account in the interpretation.

Discussion of the results obtained. The results of the accomplished investigation reveal the characteristics of the prefolding natural remanent magnetization of the Devonian rocks of the Tarim–Alay and Kyrgyz

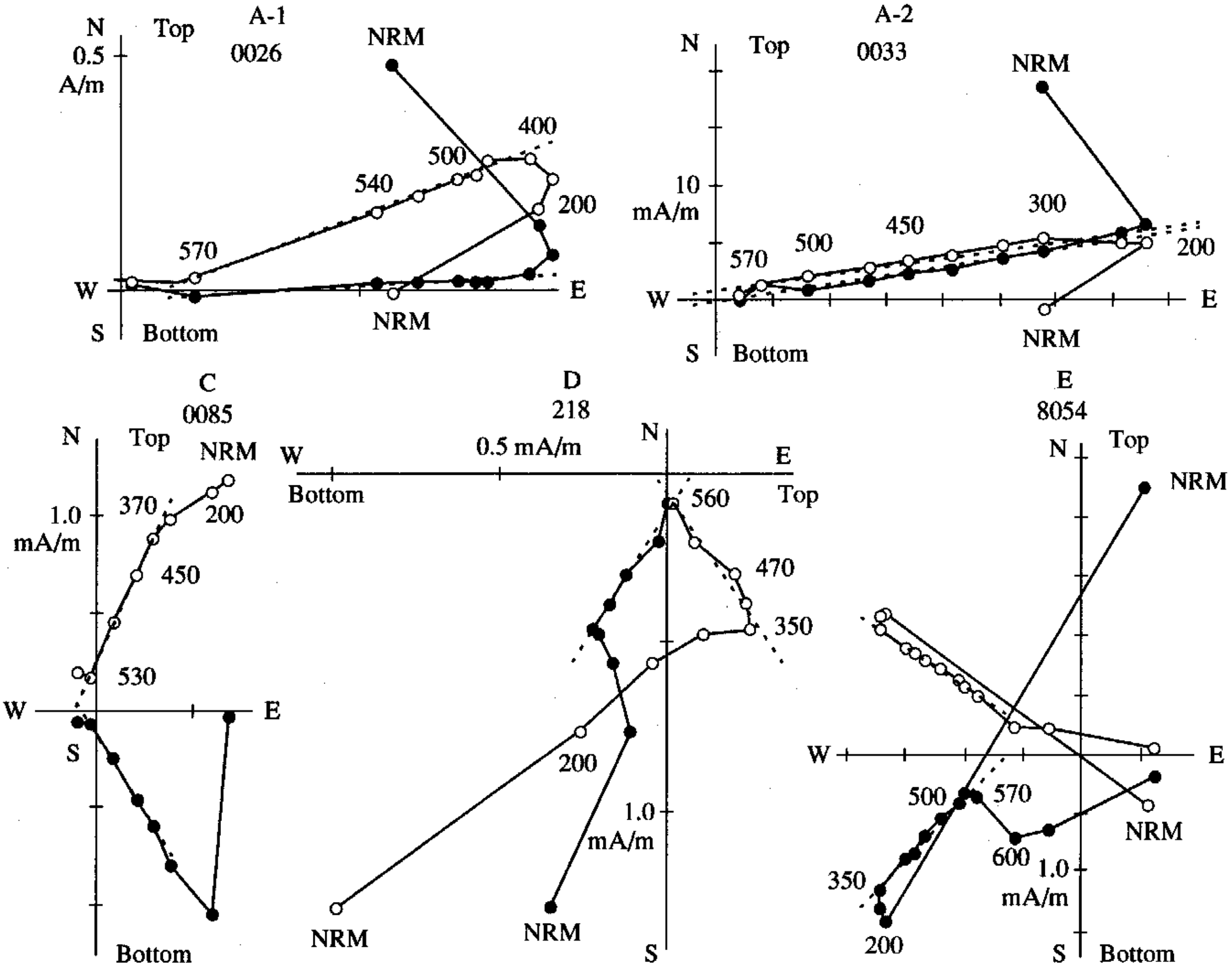

Fig. 2. Representative Zijderveld diagrams (geographic reference frame).
Solid circles show projections onto the horizontal plane, open circles, onto the vertical plane, and dashed line shows the interpreted component. (A-1) Basalts from Kaindy; (A-2) tuffites from Kaindy; (C) siltstones from Alabuka; (D) sandstones from Aksu; (E) siltstones from Besh-Alarcha.

blocks (Table 1), which were located in the Middle Paleozoic at the opposite sides of the Turkestan Ocean. Folding in the study area took place in the Late Carboniferous and Permian, its peak falling in the Late Carboniferous [10]. Consequently, the determined high-temperature component of magnetization predates the Late Carboniferous. Comparison of paleomagnetic data for the Permian [1] and Devonian (Table 1) rocks indicates that there was possibly no magnetic reversal in the Permian. The geomagnetic field inclination measured in the valley of the Kaindy River for the Lower Permian rocks equals –41°; for the Upper Permian rocks, –58°; in the Devonian rocks, –15°. In the studied areas of the Kyrgyz block, the mean Early Permian inclination is –48°; Late Permian, –57°; Devonian, –39°. No comparison of the data on the complete orientation of the Permian magnetic field is possible because of the rotation of separate parts of the study area at the later time.

The fit of the vectors for the determined magnetization components in different types of rocks (including both volcanics and epiclastics), as well as the concurrence of the direct and reverse paleomagnetic vectors at the *Alabuka site*, are the points in favor of the primary nature of the studied magnetization in the Middle and Late Devonian. The inclination determined for the Tarim–Alay block amounts to 15° ± 1.5° (Kaindy), and for the Kyrgyz block it averages 39° ± 1.5° (statistics for individual rock samples from [28]).

Data from publications. *Turkestan Ocean.* Studies of the Lower–Middle Devonian oceanic basalts from the ophiolitic suture of the Turkestan Ocean made it possible to single out the high-temperature prefolding magnetization component, possibly of Devonian age: $I = 37°$, $D = 317°$, $K = 126$, $\alpha_{95} = 5°$ [13]. The studies of the Lower Devonian oceanic basalts from other ophiolite outcrops reveal Early Devonian paleomagnetic

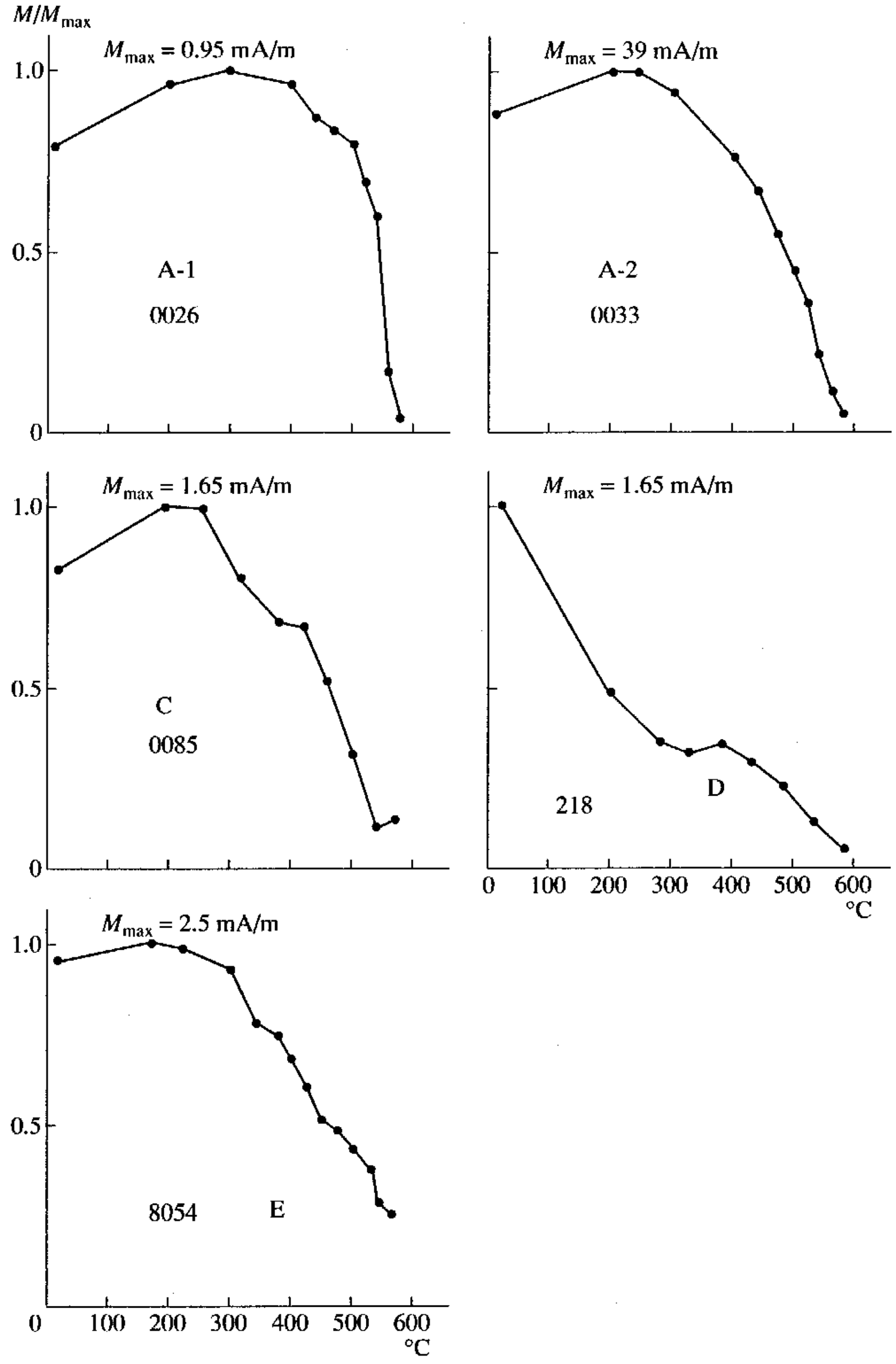

Fig. 3. Calibrated curves of thermal demagnetization.
For symbols, see Fig. 2.

vectors: I = 28°, D = 302°, K = 41, $\alpha_{95} = 10°$ and I = 21°, D = 318°, K = 18, $\alpha_{95} = 11°$ [17]. These data characterize the rocks formed at the ocean floor, which occupied an intermediate position in respect to the continental blocks we have studied. They conform to our determinations of paleomagnetic inclinations within the Devonian strata of these continental blocks.

Tarim–Alay block. The Devonian sandstones were studied at five sites of the Kelpin (Keping) dislocations at the northern periphery of the Tarim Massif [22, 23, 25].

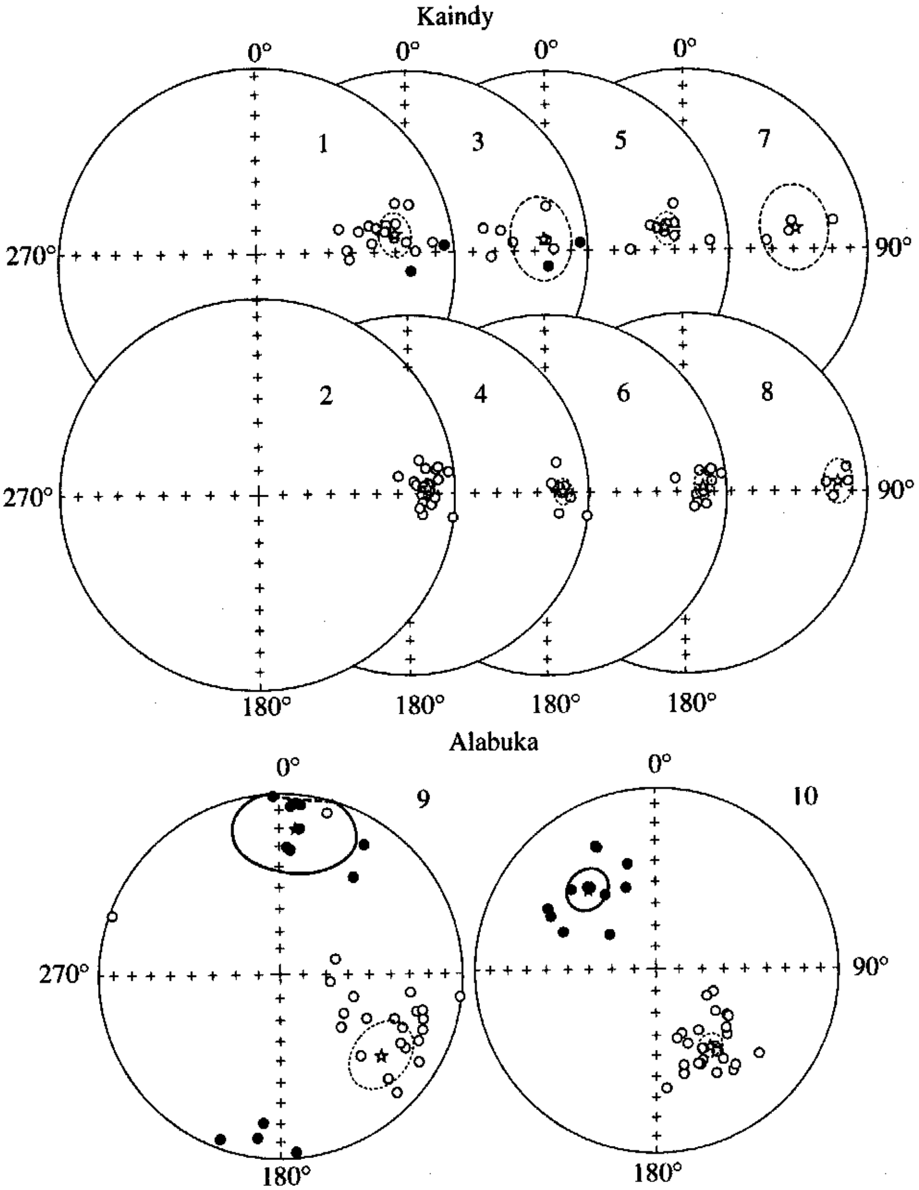

Fig. 4. Stereograms showing projections of vectors of the interpreted paleomagnetic components in the geographic (odd stereograms) and stratigraphic (even stereograms) reference frames.

Solid circles show projections onto the lower hemisphere, and open circles, onto the upper one. Mean values (☆) and their confidence ovals are shown on the stereograms.

The Devonian magnetization component was determined at two locations. At the Subaxi site (Fig. 1, *F*) the vector for the Middle–Upper Devonian rocks was: I = 25°, D = 79°, K = 18, α_{95} = 5° [25], and at the Dahuonggou site (Fig. 1, *G*) the vector in the Upper Devonian rocks was: I = 27°, D = 89°, K = 21, α_{95} = 8° [23]. With allowance made for the evaluation error, these results conform with our assessment of the paleomagnetic inclination for the Tarim–Alay block.

Paleomagnetism of the Lower–Middle Devonian rocks was studied at eleven locations in western Turkestan within the southern Tien Shan [17]. The obtained inclination values vary within a wide range, their averages differing by as much as 36°. Synchronous magnetization within this relatively small continental block could not show such a great scatter in inclination. The possibility of a synfolding age of the magnetization has not been considered. The scatter of the values in [17] could result from combination of various proportions of Devonian prefolding and Permian synfolding or postfolding magnetization components.

Kyrgyz block. Paleomagnetic studies were accomplished on small collections of rocks from the Tyul'kubashi Formation (Givetian–Frasnian) sampled

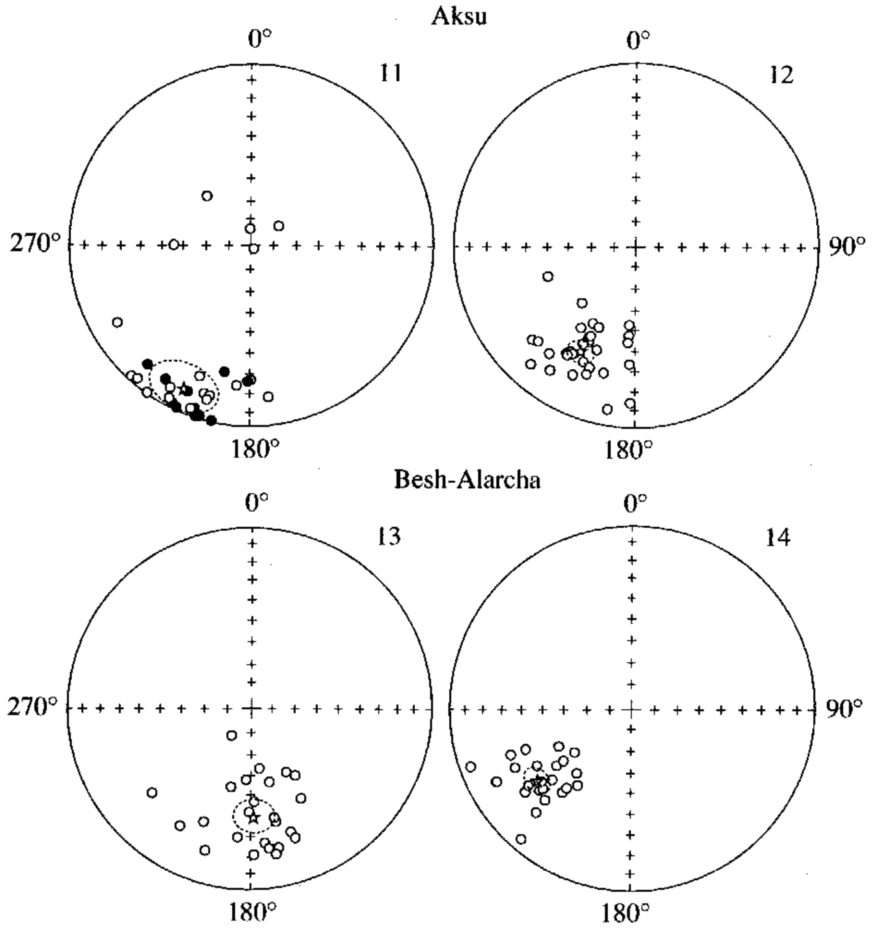

Fig. 4. (Contd.)

from monoclinal sections at two locations in the Chatkal region (the Sandalash and Chatkal ranges) [17]. With allowance made for the evaluation error, paleomagnetic inclination in the Chatkal Range (I = 43°, D = 310°, n = 13, K = 17, α_{95} = 9°) is close to our data. The data for the Sandalash Range show an abnormally shallow inclination (I = 28°, D = 300°, n = 8, K = 52, α_{95} = 7°).

Lower Devonian rocks were studied at eight locations in the northern Tien Shan and Chatkal region [17].

Table 1. Results of paleomagnetic studies of the Middle–Upper Devonian rocks

Sites	*N*/*n*	Geographic reference frame				Stratigraphic reference frame			
		D°	I°	K	$\alpha_{95°}$	D°	I°	K	$\alpha_{95°}$
	Tarim–Alay block								
Kaindy: basalts	12/10	85	–26	10.6	13.9	89	–16	102.2	4.4
Kaindy: tuffites, tuffs	13/11	80	–34	53.8	5.8	87	–15	88.2	4.5
Kaindy: general	25/21	82	–30	17.7	7.3	88	–15	97.0	3.1
	Kyrgyz block								
Alabuka: R	25	120	–37	4.4	13.4	145	–44	42.9	4.3
Alabuka: N	12	177	–19	4.7	21.6	316	+41	19.3	10.6
Alabuka: general	58/37	140	–37	3.2	86.3	14	–42	27.7	4.4
Aksu	48/31	202	–16	4.8	11.5	204	–37	17.6	6.0
Besh-Alarcha	29/22	183	–42	12.1	8.6	238	–36	21.0	6.5

Note: (*N*) number of the studied samples; (*n*) number of the samples, the data for which were used to attain the final result; (D, I) paleomagnetic declination and inclination of the direct (N) and reverse (R) polarity; (K) consistency; (α_{95}) radius of the confidence circle.

Table 2. Paleomagnetic tests

Site	n	Grouping test			Correlation test			Consistency ratio		*, %
		$F_{geogr.}$	$F_{strat.}$	$F_{critical}$	$R_{geogr.}$	$R_{strat.}$	$R_{critical}$	$K_{strat.}/K_{geogr.}$	critical	
Kaindy	21	22.75	0.29	2.38	0.980	0.451	0.594	5.48	1.69	100
Alabuka: R	25	4.89	1.87	2.58	0.770	0.439	0.539	9.67	1.62	100
Alabuka: N	12	12.79	0.15	3.49	0.932	0.593	0.761	4.08	2.05	100
Alabuka: general	37	9.96	1.29	2.50	0.761	0.291	0.453	8.75	1.48	100
Aksu	31	58.91	1.58	3.16	0.692	0.331	0.476	3.64	1.53	100
Besh-Alarcha	22	4.69	2.24	3.23	0.614	0.406	0.579	1.74	1.67	100

Note: (*) unfolding at K_{max}; (F) coefficient of correlation between the mean magnetization vector in a group of beds with close dip and strike and the average bed attitude in the group; (R) coefficient of correlation between the magnetization vector and bed attitude. For other symbols, see Table 1.

The average paleomagnetic vector we calculated from the data presented in [17] has the following direction: I = 36°, D = 143°, N = 8, K = 19, α_{95} = 13°. With allowance for the evaluation error, this result agrees with that we obtained for the Middle–Upper Devonian rocks (Table 1). This points to a low degree of mobility of the Kyrgyz block during the Middle Devonian.

PALEOTECTONIC RECONSTRUCTION

The Turkestan Ocean separated the Tarim–Alay continent and Kyrgyz block. The latter was an ensialic island arc, where volcanic activity ceased in the Middle Devonian. From the Middle Devonian until Serpukhovian, there was neither spreading nor subduction of oceanic crust in the Turkestan Ocean. The width of the oceanic basin during this period remained constant or changed only slightly. The results of paleomagnetic studies can be used to determine the spatial orientation of the Turkestan Ocean's coastlines—the margins of the Tarim–Alay and Kyrgyz continental blocks during the Late Devonian.

The spatial orientation is inferred from the tectonic interpretation of paleomagnetic inclinations. This is not an easy task for the Tien Shan in the Middle Paleozoic. As a result of the Late Paleozoic multistage deformations, paleomagnetic vectors rotated about vertical axes together with tectonic structures or relative to them [1]. The Devonian paleomagnetic inclinations presented in Table 1 do not coincide with the paleomagnetic orientation of the Tarim–Alay and Kyrgyz blocks. This orientation has to be reconstructed by introducing corrections for the subsequent rotations of the paleomagnetic vectors brought about by local causes.

Several stages can be distinguished in the Late Paleozoic evolution of deformations in the Tien Shan [10].

Stage D_1: Middle–Late Carboniferous. The stress field is produced by the head-on collision of the Tarim–Alay continent with the Kyrgyz ensialic island arc. At this stage, a system of overthrusts was formed. Study of the vergence of the folds appearing within the Tegermach thrust sheet in the Alay Range has revealed that this sheet was warped in plan while in motion [10]. Deformations of this kind should bring about distortions of the pattern of paleomagnetic inclinations. We managed to avoid these distortions by studying rocks in their autochthonous occurrence.

Stage D_2: Late Carboniferous–beginning of the Permian. The stress field remains the same, but the type of deformations changes. Due to the lateral compression of the region, a system of vertical F_2 folds is formed. We straightened out these folds while processing the paleomagnetic data, bringing their beds into horizontal attitude. In Table 1, in the column "Stratigraphic coordinate system," paleomagnetic vectors are given subsequently to the unfolding of the folds.

Stage D_3: Early–Late Permian. A sinistral system of stresses characterizes this stage of deformations. This stress field may have resulted from a lengthwise sinistral displacement of the Kara Kum and Tarim massifs in relation to the Tien Shan [1]. Two phases of deformation are distinguished during this stage, taking place in the same stress field.

The earlier phase (D_{3a}) was determined by structural-geology techniques [10] and confirmed by paleomagnetic studies of the Upper Carboniferous and Permian (Asselian) rocks [11, 15, 16]. It is worth noting that the results of these paleomagnetic studies are not very reliable, and they should be reproduced using modern techniques. Phase D_{3a} was the time when the sinistral horizontal flexure appeared in Fergana. It is outlined by the axial lines of F_2 folds bent into a double arc (Fig. 1). The time interval of the horizontal flexure spanned the Early Permian–beginning of the Artinskian [1]. The areas located on the central limb of the horizontal flexure rotated counterclockwise. In the Chatkal Range the rotation angle amounted to 30°–40°, and in northeastern Fergana (Baubashaty Mountains) it could exceed 90°.

Deformations of the later phase (D_{3b}) were discovered by paleomagnetic studies of the Permian rocks [1]. During this phase, most of the Tien Shan was occu-

Table 3. Reconstruction of the Late Devonian paleomagnetic inclinations

Sites	Dec (+)°	P_1		P_2		P_2–T		Σ°	Dec (D)°
		(±)	angle, deg.	(±)	angle, deg.	(±)	angle, deg.		
	Kyrgyz block								
(A) Kaindy	268	(+)	90–110	(+)	70–100		–	(+) 185	E
	Tarim–Alay block								
(C) Alabuka	324	(+)	30	(+)	60–80		–	(+) 100	ENE
(D) Aksu	24	(+)	30	(+)	30–60	(–)	30	(+) 45	ENE
(E) Besh-Alarcha	58	(+)	–	(+)	0–30		–	(+) 15	ENE

Note: Dec(+), measured paleomagnetic inclination in the Middle–Devonian rocks (negative paleomagnetic vectors are reversed); rotation of the Devonian paleomagnetic inclinations: (P_1) during the Asselian–Sakmarian (deformations of the phase D_{3a}), (P_2) during the Late Permian (deformations of the phase D_{3b}), (P_2–Tr?) during deformation stage D_4; direction of rotation: (+) counterclockwise, (–) clockwise; (±) overall average magnitude of rotation of the Devonian paleomagnetic vectors in the Late Paleozoic–Early Mesozoic; Dec(D) reconstructed vectors of the Late Devonian paleomagnetic inclination: (E) east, (ENE) east-northeast.

pied by a sinistral strike-slip zone (Fig. 1), within which paleomagnetic vectors dating from the Artinskian, Kungurian, and Late Permian rotated counterclockwise in relation to the coeval paleomagnetic directions determined within the Tarim Massif outside the strike-slip zone. This rotation is not reflected in the megastructure of the region. It is likely that a lengthwise tectonic flow occurred within the strike-slip zone, causing the paleomagnetic vectors to rotate relative to the tectonic megastructures and facies zones. In northern Fergana, where the Kaindy, Karasu, and Alabuka sites are located, the rotation angle amounted to 70°–100° [1].

Stage D_4: Late Permian–Early Mesozoic. Deformations took place under the influence of a lateral compression or transpression. Diagonal dextral folds were the main structures formed at this stage. Horizontal folds appeared near strike-slip faults, their limbs nearest to the faults rotating clockwise.

It should be added that the Permian paleomagnetic inclinations measured in the Tarim Massif and in the Tien Shan outside the strike-slip zone have in their turn rotated counterclockwise through 20° with respect to the orientation toward the Permian European pole [1]. The time and nature of this "background" post-Permian rotation are unknown. If the region rotated as a unit, its rotation is automatically considered in the reconstruction based on paleomagnetic data.

In the recent epoch, the western Tien Shan rotated through an angle of about 10° counterclockwise relative to the central Tien Shan [2]. This rotation is negligible in its influence on the Devonian paleoreconstruction.

In the light of the foregoing, let us consider the situation in the study areas.

Tarim–Alay block. The *Kaindy site* (Fig. 1, *A*) is located within the central limb of the Fergana horizontal flexure, near its northern bend. During the formation of the horizontal flexure, this area rotated counterclockwise through 90°–110° (stage D_{3a}). Counterclockwise rotation during phase D_{3b} added another 70°–100°. The overall correction approximates or exceeds 180°, the reconstructed orientation toward the Late Devonian pole (Table 3) turning out to be east-northeast or north–south (in the geographic reference frame). This corresponds to the paleomagnetic vector determined for the Middle–Late Devonian rocks at the northern periphery of the Tarim Massif (sites *F* and *G* in Fig. 1), where there was no stage D_3 deformation.

The long axis of the Tarim–Alay continent at present strikes roughly east–west. The angle between the strike of this axis and the paleomagnetic poleward orientation determines the orientation of the Tarim–Alay continent in relation to the Devonian meridian. The data we obtained at the Kaindy site and the data from the Tarim Massif [23, 25] suggest that the Tarim–Alay continent stretched roughly north–south (Fig. 5).

Kyrgyz block. The *Alabuka site* (Fig. 1, *C*) rotated during phase D_{3a} through an angle of about 30°, and during phase D_{3b} the paleomagnetic vectors rotated another 60°–80° counterclockwise (Table 3). The reconstructed orientation toward the Late Devonian pole after introducing these corrections turns out to be east-northeast (in the geographic reference frame).

The *Aksu site* (Fig. 1, *D*) is located on the horizontal flexure limb bordering on the strike-slip fault, near the flexure hinge line. During phase D_{3a}, this area rotated counterclockwise simultaneously with the formation of the Fergana horizontal flexure, and during stage D_4 it rotated clockwise concurrently with the formation of the horizontal fold near the strike-slip fault. These rotations cancelled out one other, and the strike of beds returned to the initial E–W orientation. Therefore, in this area it is necessary to consider only a correction for rotation of paleomagnetic inclinations during phase D_{3b}. The magnitude of the correction here has not been established, but it can be estimated on the following grounds. This site is located closer to the northern edge of the strike-slip zone, and thus the rotation angle here should be less than at the Alabuka and Kaindy sites. Introducing the correction, the orientation toward the

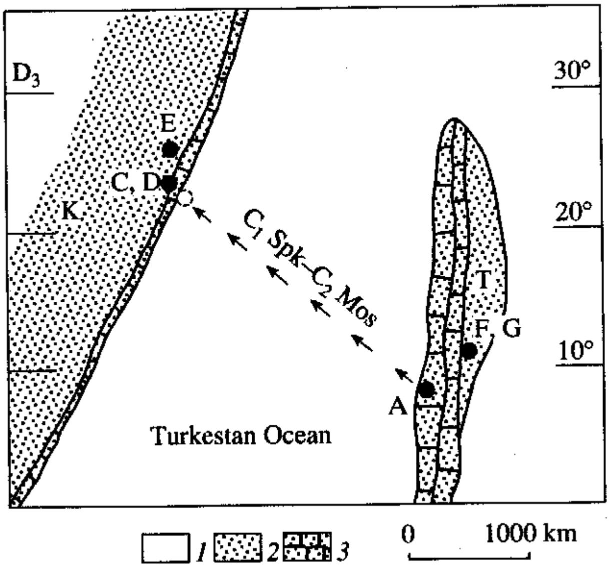

Fig. 5. Paleotectonic reconstruction for the Late Devonian. (*1*) Oceanic crust; (*2*) blocks of continental crust: (K) Kyrgyz, (T) Tarim–Alay; (*3*) shelf zones; (A–G) studied sites.

Late Devonian pole becomes east-northeast (in geographic reference frame).

The *Besh-Alarcha site* (Fig. 1, *E*) is located far away from the zone of sigmoid and horizontal folds. Only one correction has to be introduced into the data obtained for this site: the one for the counterclockwise rotation of paleomagnetic vectors during the deformation phase D_{3b}. For the region of the Sonkul Lake located further south, this correction lies in the range 25°–65° [1]. There is no appropriate data for this site. It is located at the northern periphery of the Permian strike-slip zone, where the rotation angle should be less.

On the whole, the reconstructed median orientation toward the Late Devonian pole for the Kyrgyz block turns out to be ENE–WSW (geographic reference frame). The trend of the Early–Middle Devonian island-arc facies within the Kyrgyz block is at present close to being N–S. Therefore, according to paleomagnetic data the Kyrgyz island arc in the Late Devonian coordinates stretched NNE–SSW (Fig. 5). According to these data, the edge of the Kyrgyz island arc stretched at an angle in respect to the margin of the Tarim–Alay continent, which could have influenced the character of deformations caused by the collision of these blocks. Indeed, the lateral shortening of the central and eastern Tien Shan due to the Late Paleozoic deformations is much greater than that of western Tien Shan.

In concluding this section, it is necessary to mention one point relevant for the proposed reconstruction (Fig. 5). The magnitude of the correction for rotation in the Permian and post-Permian periods depends on the accuracy in determining the Permian paleomagnetic pole for the Tien Shan. Such a determination contains a certain degree of uncertainty, as the estimated orientations toward the Tarim and European Permian paleomagnetic poles differ for Tien Shan by approximately 20°. Possible reasons for this are considered in [1]. Unfortunately, there is no decisive criterion. In this article, corrections determined in relation to the Tarim pole were used. In the other variant, Fig. 5 should be rotated through 20° counterclockwise without changing the relative position of the sialic blocks.

Paleolatitudes where the blocks under consideration were located are determined from the data on paleomagnetic inclinations. The situation here is simpler that the one considered above, as the paleomagnetic inclination is or is not affected only slightly as horizontal folds and flexures form. According to the paleomagnetic data available, the Chatkal region of the Kyrgyz block in the Late Devonian was located at the latitude 23° ± 1.4°, and the Baubashaty region of the Tarim–Alay continent, at the latitude 8° ± 0.8°. They were 15° apart along the Late Devonian meridian. This distance does not pinpoint the width of the ocean, as the blocks under consideration and facies zones in them trended roughly N–S in the Late Devonian (Fig. 5). The size of the ocean can be approximately estimated from the amount of the oceanic crust that could be consumed in the subduction zone during the ocean's closure.

The subduction of the Turkestan oceanic crust at the edge of the Kyrgyz block resumed in the Serpukhovian. This is evidenced by calcalkaline volcanism at its margin. As there was no sea-floor spreading, the subduction resulted in a relatively rapid (in 25 m.y.) shrinking and closure of the Turkestan Ocean. Most of it (with the exception of residual basins in eastern Fergana and Dzhaman–Davan) closed by the late Moscovian. Based on the average rate of subduction in the recent epoch (10 cm/year), the sheet of the oceanic crust consumed in the subduction zone during the closure of the Turkestan Ocean must have been about 2500 km wide.

The Devonian paleotectonic reconstructions given in [12, 19–21, 29] agree with the paleomagnetic data presented above, the reconstruction in [14] can be adjusted to them upon a slight updating, and the reconstruction in [17] disagrees with these data.

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