TECTONICS AND PALEOMAGNETISM OF STRUCTURAL ARCS OF THE PAMIR-PUNJAB SYNTAXIS

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(Accepted May 23, 1986)

ABSTRACT

Bazhenov, M. L. and Burtman, V. S., 1986. Tectonics and paleomagnetism of structural arcs of the Pamir-Punjab syntaxis. *Journal of Geodynamics*, 5: 383–396.

The Pamir-Punjab syntaxis consists of two structural arcs with the crests facing northward—the Pamir and Hindu-Kush-Karakorum arcs. These arcs are mutually disharmonious, and the exterior (Pamir) arc is more tight, as compared to the inner one. Paleomagnetic study of the Pamir arc has shown that the structures of the future Pamirs had a northeastern strike in the Paleogene and Cretaceous, and they occurred on the eastern limb of the Darvaz-Kopetdag structural arc, whose crest faces south. The Pamir arc originated after the Paleogene during the process of the formation of the Pamir-Punjab syntaxis. Knowledge of the kinematics of the Pamir arc, combined with data on the geometry of the syntaxis and the character of its boundaries, enable us to choose a model of the development of the syntaxis. The process of "plastic flow" of crustal masses around the underthrusting segment of the Indian plate was likely of paramount importance.

INTRODUCTION

The Alpine folded systems of Middle Asia are of arcuate form. The Pamir-Punjab syntaxis is formed by structural arcs with their convex parts facing north. West and east of the syntaxis, there are vast arcuate folded systems with convex parts facing south: the Darvaz-Kopetdag and Beludzhistan arcs in the west, the Kuenlun and Himalayan arcs in the east. Many researchers have discussed the conditions of formation of the structural arcs of Middle Asia, and have suggested various models of the development of the Pamir-Punjab syntaxis. Data on the geometry of the syntaxis and the results of studying the kinematics of structural arcs in a region using the paleomagnetic method are of the greatest importance for the evaluation of these hypotheses.

0264-3707/86/$3.00

JOG 5/3-4-9

GEOMETRY OF THE SYNTAXIS

The Pamir-Punjab syntaxis is made up of rocks that constituted the crust of three oceanic structures and their continental margins. The paleo-Tethys suture (I in Fig. 1), initiated in the Carboniferous, passes through the North Pamirs and West and Central Kuenlun. Its western continuation can be traced into North Afghanistan and South Turkmenia (Bazhenov, Burtman, 1982). The suture of the meso-Tethys Ocean (II in Fig. 1), which was closed at the end of the Early Cretaceous, passes along the boundary between the Central and Southern Pamirs (Pashkov and Shvolman, 1979). The western continuation of this suture, displaced along strike-slip faults, lies in the Farahrud zone, in Afghanistan. Its eastern continuation, also displaced along a strike-slip fault, is probably located in Central Tibet (Jang-Tang), where ophiolites in associaton with Early Mesozoic folded deposits occur. The suture of the main branch of the Tethys (IV in Fig. 1) passes from the Indus zone to the Quetta zone. This suture was initiated in the Paleogene as a result of the convergence of the Indian plate and an island arc at the margin of the Eurasian plate. Still another suture (III in Fig. 1) marks a collision of the island arc with the Eurasian continent.

The northern boundary of the syntaxis is represented by thė Vakhsh thrust (7 in Fig. 1) which has a gentle-dipping thrust-plane and an amplitude of overlap of not less than 50 km, and likely more than 100 km. In the northwest, the boundary of the syntaxis is the South Hissar right strike-slip fault (6 in Fig. 1). The Tadzhik Depression, composed of Mesozoic and Cenozoic rocks, is between the Hissar Ridge and the Pamirs. These rocks are deformed into folds which testify to the NW movement of the Pamirs. The transverse contraction of the Tadzhik Depression, due to folding and thrusting, reaches 100 km.

At the boundary of the Pamir-Punjab syntaxis with the Tarim block in the piedmonts of Western Kuenlun, overthrusts are seen in satellite images. These can have resulted from the NE overthrusting of the Pamirs over the western part of the Tarim block.

In this case, an interesting situation can be observed, if the Pamirs prove to have been overthrust in three directions: to the north, west and east.

The boundary of the syntaxis with the South Afghan block is the Makuro-Chaman left-lateral strike-slip fault (1 in Fig. 1). Its southern boundary is the main boundary thrust of the Himalayas.

The folded structures developed within the syntaxis outline two arcuate systems—Hindu-Kush-Karakorum and the Pamir, which are mutually disharmonious. The radius of the curvature of the Hindu-Kush-Karakorum arc is 200 km.

The Pamir arc is outlined by structures of the Pamirs, Kuenlun and

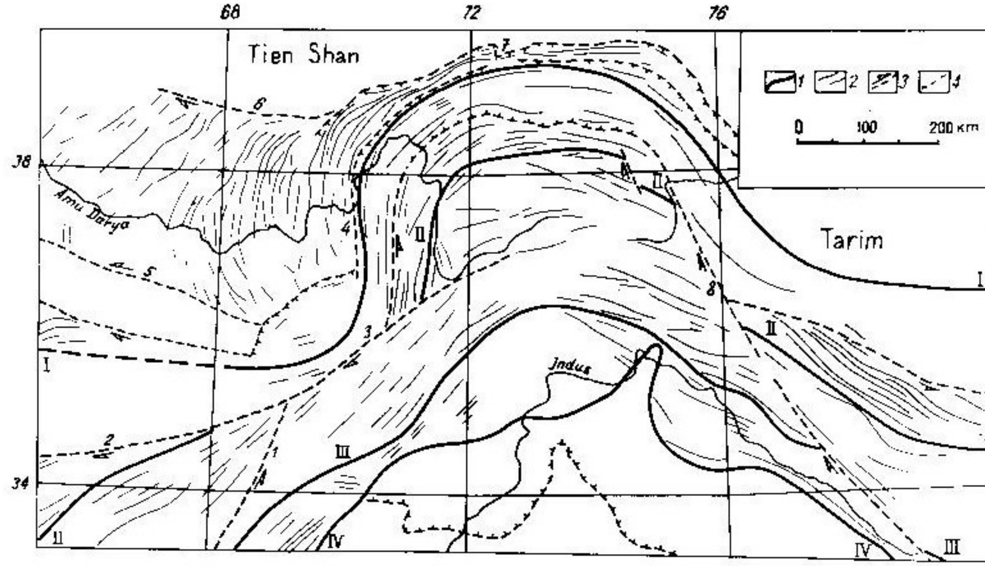

Fig. 1. Structural map of the Pamir-Punjab syntaxis (Burtman, 1982). 1) oceanic sutures, 2) axes of Alpine folds, 3) strike-slip faults, 4) overthrusts.

Badakhshan. Its western limb is complicated by the Darvaz and other left-lateral strike-slip faults (4 in Fig. 1). Available data on the structure of this region suggest that strike-slip faults have not disturbed the overall pattern of plastic deformation. Displacement along them evidently was relatively small, and insufficient to break up the tectonic zones.

The eastern limb of the Pamir arc is broken by the Pamir-Karakorum right-lateral strike-slip fault (Peive *et al.*, 1964). It trends northwest (8 in Fig. 1), close to the direction of the relative movement of the Indian and Eurasian plates. Displacement decreases in the same direction, being compensated for by the Pamir system of over- and underthrusts. The scantiness of information from Kuenlun precludes determination of the locality where the fault dies out. It is probable that the paleo-Tethys suture extends to western Kuenlun without any displacement. The western Kuenlun structures extend along the strike-slip fault and over to the east in Central Kuenlun. On the whole, the North Pamir and the western and eastern Kuenlun structures outline a dextral horizontal flexure associated with the Pamir-Karakorum strike-slip fault.

The radii of curvature of various parts of the Pamir arc are different. The crest of the arc—a segment outside the flanking flexures and strike-slip faults—has a radius of curvature of over 250 km in the North Pamirs. In other words, this part of the Pamir arc is not as sharply curved as the

Hindu-Kush-Karakorum arc. On the whole, however, the Pamir arc is more compressed than the Hindu-Kush-Karakorum. A pronounced disharmony between the arcs originated in the western limb of the syntaxis as a result of displacement along the Zebak-Mun'ya right-lateral strike-slip fault (3 in Fig. 1). This fault is described by Desio (1976) as a continuation of the Hindu-Kush-Harirud fault (2 in Fig. 1). The following features of geometry of the Pamir-Punjab syntaxis are genetically the most important.

1. The exterior and interior arcs are mutually disharmonious, the exterior arcuate system being more compressed. In addition, the exterior (Pamir) arcuate system is asymmetrical: its western limb is considerably steeper than the eastern limb.

2. Strike-slip faults with displacements increasing southward are developed in the flanks of the syntaxis. Such a change in displacement has been observed for the Pamir-Karakorum strike-slip fault (Peive *et al.*, 1964). The same is true for the Darvaz-Badakhshan strike-slip fault, as compared with that on the Makuro-Chaman fault.

3. The structure of the syntaxis is characterized by a high degree of tectonic stacking, and the crust within it is significantly thicker than the normal continental crust.

An important aspect of the problem concerned is the relationship between the Pamir-Punjab syntaxis and strike-slip faults of Central Asia. Analysis of movements on strike-slip faults shows that the following displacements accompanied the development of the syntaxis: a) westward displacement of the Tadzhik block along the South Hissar right-lateral faults (6 in Fig. 1), that bound the block on the north, and the left-lateral Alburz-Mormul fault (5 in Fig. 1) at the south edge of the block; b) westward displacement of the South Afghan block along the right-lateral Hindu-Kush-Gerirud fault (2 in Fig. 1); and c) eastward displacement of the Tibetan block along the left-lateral Altyntag fault. The young folding on the northern margin of the Tarim block, in conjunction with data on earthquake focal mechanisms, indicate a northward movement of the block.

PALEOMAGNETISM AND TECTONICS

In order to determine the position and configuration of the tectonic zones of the syntaxis prior the Alpine deformations, we carried out paleomagnetic studies of Paleogene and Cretaceous rocks in the Darvaz-Kopetdag and Pamir structural arcs. Sedimentary rocks have been analyzed: sandstones, siltstones and clays. The sampling was done following the "one layer – one sample" scheme, the distances between samples being from one to some tens of meters, with allowance for thickness of the deposits. The thickness of a section analyzed was so chosen that the number of samples and the stratigraphic interval were sufficient for reliable averaging of all kinds of occasional noises, secular variations included. All samples underwent thermocleaning up to 400°; some specimens were heated to 550°. To prove the paleomagnetic reliability of the results, field tests were used, mainly the reversal test and the fold test. The latter was always carried out by means of comparisons of mean directions of magnetization rather than the concentration-parameter test. It has been proven that stable magnetization in the rocks studied is of prefolding and, most probably primary, origin.

A more detailed description of the methods is given in other papers (Bazhenov and Burtman, 1982; Bazhenov, in press). These same papers analyzed the results of the paleomagnetic investigation in localities 1–11 (see Table 1, Fig. 2, 3). This paper deals with new data obtained at localities 12–15 (see Table 1, Fig. 3) as a result of additional investigations.

Darvaz-Kopetdag arc. This structural ars is composed of the folded systems of Badakhshan, North Afghanistan, North Khorasan and South Turkmenia. Paleomagnetic studies were carried out on the western limb in the Kopetdag Ridge, and on the eastern limb in the Darvaz Ridge. In the Kopetdag Ridge, about 200 samples from 12 sections of Lower- and Middle Cretaceous rocks were studied (locality 11 in Fig. 2, and in Table 1). The declination of pre-folded magnetization in these rocks is parallel to the direction of the Cretaceous paleomeridian of Eurasia. This shows that the Kopetdag probably did not undergo any rotations relative to Eurasia in the Cretaceous and Cenozoic. Such a conclusion agrees with geological data showing that the Kopetdag region is a part of the Eurasian plate, beginning from the Late Paleozoic.

The Darvaz-Kopetdag and Pamir structural arcs are conjugate, and the eastern limb of the Darvaz-Kopetdag arc is the western limb of the Pamir arc.

Pamir arc. The northern part of the Pamir-Punjab syntaxis is composed of the Alpine folds of the outer zone of the North Pamirs. This zone is composed of Mesozoic and Cenozoic rocks which make up the mountain ridges: Transalai, Peter the First and Darvaz. The Alpine folds trend along the tectonic zone, and form an arc convex to the north. In various parts of this zone, 400 samples of Lower Cretaceous rocks were analyzed at 7 localities, and over 200 samples from Paleogene (Eocene-Oligocene) rocks at 5 localities. The results of the study of these samples are presented in Table I. Supplementary studies of Lower Cretaceous rocks were carried out in the eastern part of the Pamir arc at localities 12 and 13 (Fig. 3).

At locality 12, the Lower Cretaceous layers dip to S-180° with an angle of 80°. The stratigraphic sequence (300 m) consists of two members. Its lower part is composed of red, coarse-grained sandstones. In these sandstones, the

TABLE I

Paleomagnetic data (localities 1–10 – from Bazhenov, Burtman, 1981; locality 11 – from Bazhenov, in press; localities 12–15 – new data)

Regions	Locality on Fig. 2, 3	N a	N b	D°	I°	K	α_{95}
				Lower Cretaceous			
	12	30	8	72	63	36	8.3
	13*)	25	18	–	–	–	–
	3	114	72	92	54	10	5.4
Pamirs	5	32	30	40	30	–	12.0**)
	6	44	43	5	52	22	4.7
	7	57	50	7	44	45	3.0
	10	45	36	316	42	20	5.3
	14a	7	6	12	47	29	10.7
	14b	22	17	8	52	30	6.2
Tien-Shan	15a	6	0	–	–	–	–
	15b	22	19	14	45	25	6.5
	4***)	15	11	355	55	26	8.3
				Lower-Middle Cretaceous			
Kopetdag	11	(12)	(11)	20	56	153	3.7
				Paleogene			
	1	31	27	35	37	14	7.6
	2	34	28	43	41	11	8.3
Pamirs	8	39	31	329	40	12	7.3
	9	53	32	352	30	12	7.2
	10	54	39	305	29	11	6.9

*) due to streaked distribution of sample-means the locality-mean direction and statistics have not been calculated here.

**) approximation.

***) slightly changed in comparison to earlier article ( ) after additional demagnetization.

N – number of samples (or sites – in blackets): a – taken, b – used; D, I – section-mean-declination and inclination; K – precision parameter; α_{95} – radius of confidence circle. Statistics giving unit weight to samples (for locality 11 to sites).

within-sample scatter of paleomagnetic vectors is very large, and they are not suitable for study. The upper part of the sequence is composed of sandstones with different-sized grains. In these rocks, the within = sample scatter of paleomagnetic vectors is not great, and the sample-means form a compact group (Fig. 4). As a considerable number of the samples was rejected, the results of paleomagnetic studies in locality 12 are suitable for qualitative interpretation only.

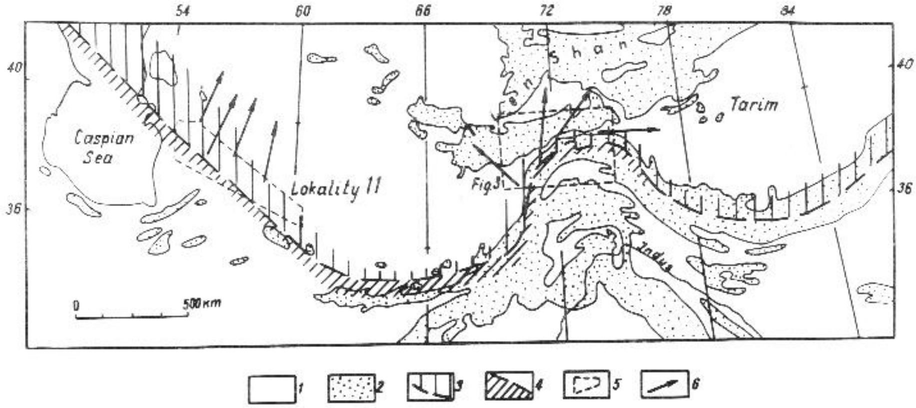

Fig. 2. Structural arcs of Middle Asia: DK – Darvas-Kopetdag, K – Kuenlun, P – Pamir. 1) Cenozoic and Mesozoic; 2) Paleozoic and Precambrian; 3–4) Paleotethys (3 – zone of the oceanic crust, 4 – zone of active margin); 5) region of paleomagnetic studies; 6) paleomagnetic vectors for Lower and Lower-Middle Cretaceous.

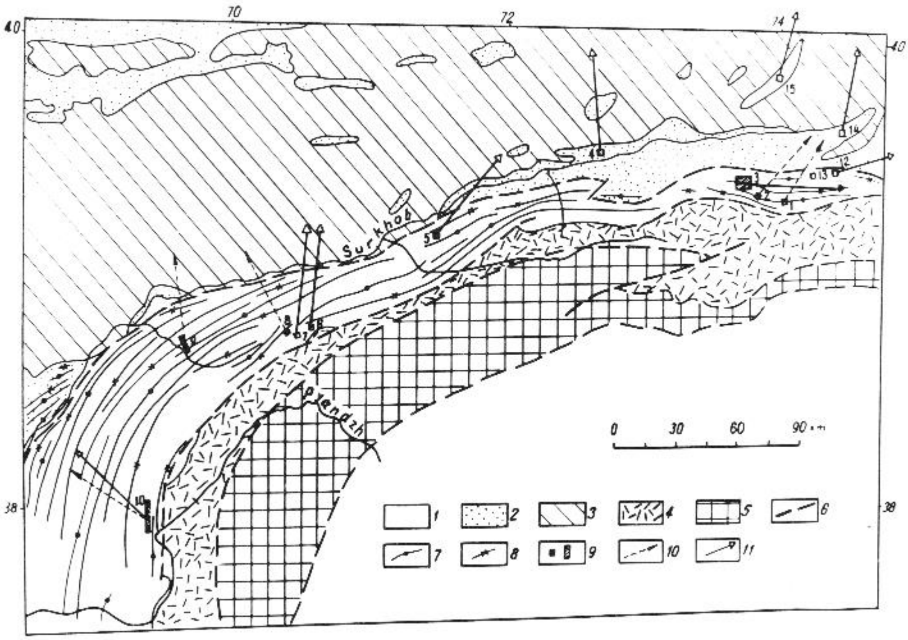

Fig. 3. Structural map of the North Pamirs and results of paleomagnetic investigations. 1–2) Cenozoic and Mesozoic (1 – on the Pamir base, 2 – on the Tien-Shan base); 3) Tien Shan Variscides; 4–5) Paleotethys Variscides (zone of the oceanic crust, 5 – zone of active margin); 6) tectonic boundaries; 7–8) axes of folds in the outer zone of the North Pamirs (7 – anticlines, 8 – synclines); 9) areas of paleomagnetic studies; 10–11) paleomagnetic declinations in rocks (10 – Paleogene, 11 – Lower Cretaceous).

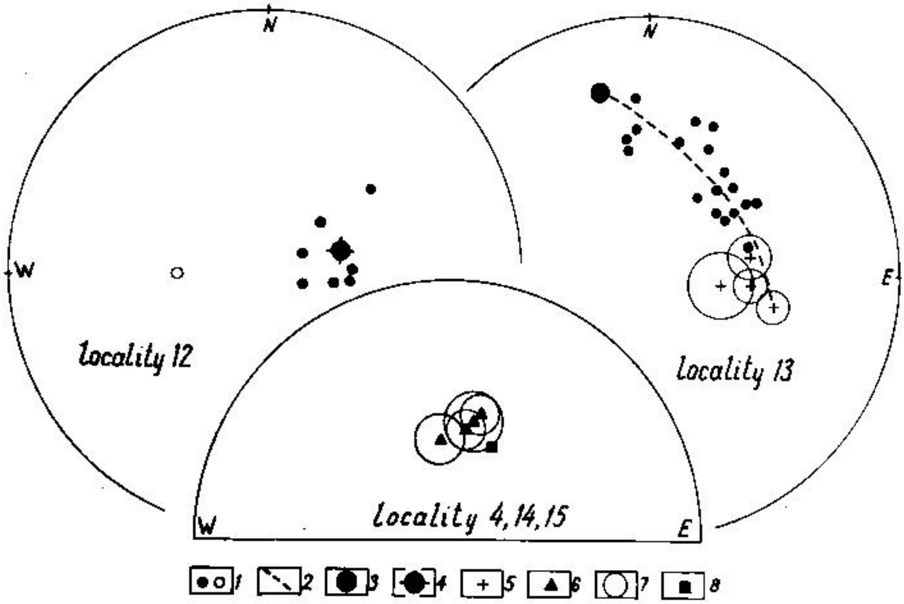

Fig. 4. Equal-area stereograms with projections of the tilt-corrected paleomagnetic directions after thermocleaning. 1) sample-means (solid symbols denote the downward-pointing directions); 2) the best-fitting plane; 3) direction of remagnetization (tilt-corrected direction of modern dipole field); 4) mean direction for locality 12; 5) section-means for locality 3 (after Bazhenov, Burtman, 1981); 6) section-means for the South Tien Shan; 7) circles of confidence; 8) direction recalculated from the mean Early Cretaceous pole of Eurasia.

A sequence of Lower Cretaceous red sandstones, 120 m thick, was studied at locality 13. The beds dip to NW-325 at an angle of 40°. In these rocks the sample-means have a streaked distribution (Fig. 4), though separate vectors were almost unaltered with heating up to 560°. The best-fitting plane of this elongated distribution passes very close to the tilt-corrected direction of a modern field, and close to the position of the section-means of locality 3. We believe that the streaking of the distribution at locality 13 is caused by post-fold remagnetization by a modern field; and the vector of the ancient magnetization here is close to the mean direction obtained at locality 3 (Bazhenov and Burtman, 1981). On the whole, the results of the studies carried out at localities 12 and 13 support the data from locality 3, which are the most reliable for the eastern part of the Pamir arc.

Both in the Kopetdag and in the Pamirs, abnormally shallow paleomagnetic inclinations were measured in some sections. An additional study (Bazhenov, 1983) showed that these data have nothing in common with the tectonics of the region. They are a result of the inclination error due to diagenetic compaction of sediments.

The distribution of the paleomagnetic declinations in Lower Cretaceous rocks in the outer zone of the Pamir (localities 3,5–10, 12 and 13 in Fig. 3, and in Table I) suggest a conclusion that the Pamir arc did not exist as such in the Early Cretaceous. When judged by these data, the North Pamir zone stretched northeastwards in the Early Cretaceous, and had the form of a gentle arc convex southeastward. Paleomagnetic declinations on Eocene-Oligocene rocks (localities 1, 2, 8–10 in Fig. 3 and in Table I) show that by the end of Paleogene the configuration of the zone concerned became similar to rectilinear. Consequently, the Pamir arc was initiated in the Neogene-Quaternary.

Tien-Shan. Worth comparing are paleomagnetic data obtained from Lower Cretaceous rocks on the northern part of the Pamir arc and from Tien-Shan. At the southern margin of Tien-Shan near the boundary with the Pamirs, red sandstones and siltstones of Lower Cretaceous age were investigated at locality 4 (Bazhenov and Burtman, 1981) and at localities 14 and 15 (see Table I and Fig. 3).

Two stratigraphic sequences were studied at locality 14 (150 and 250 m), in which the beds dip to NW-300 at an angle of 85°, and to SE-135 at an angle of 50°. Two sequences (40 and 270 m) were studied at locality 15, where beds dip to SE-145 at an angle of 35°, and to NW-335 at an angle of 70°. In these rocks, an insignificant viscous component of magnetization was destroyed in heating up to 200–250°, and in subsequent heating the magnetization was vectorially stable. Close grouping of sections-means after tilt correction testify to the pre-folding age of magnetization. An exception is section 15a, where magnetization is almost entirely post-folding. This result is excluded from the subsequent analysis.

The mean paleomagnetic vectors on Tien Shan rocks (Fig. 4) are close to the direction recalculated from the mean Cretaceous pole of Eurasia, and differ sharply from the vectors from coeval rocks in the Pamir arc. The conclusion can be drawn that the South Tien Shan was not affected by movements resulting in the curvature of the Pamir zone.

Paleomagnetic vectors in Lower Cretaceous rocks of South Tien Shan do not depend upon the strike of the Cenozoic folds. The structural pattern here was initiated in the Hercynian orogenesis, and, judged by paleomagnetic data, did not change in the newest deformations which resulted in folding of Mesozoic-Cenozoic rocks.

KINEMATICS OF THE PAMIR ARC

A zone of development of Early Carboniferous ophiolites stretches from the North Caucasus via the Caspian Sea, and further through the Kopetdag into Hindu-Kush. The ophiolites mark a suture of the paleo-Tethys Ocean that was closed in the Middle Carboniferous. Directly to the south, there is a zone of development of andesites and dacites of the same age. These zones have been traced by outcrops, boreholes and magnetic anomalies, from the Caspian Sea cia Kopetdag and Hindu-Kush to the North Pamirs (Bazhenov and Burtman, 1982). Further eastwards, their continuation is fixed in Kuenlun (Fig. 2). These Paleozoic zones reliably connect the Kopetdag and the North Pamirs, where Cretaceous and Paleogene magnetizations have been studied. Therefore, in reconstructing the movements of the North Pamirs in Alpine time, it is necessary to take into account its continuous connection with the Kopetdag. In this case, the Kopetdag plays the role of a point fixed to the Eurasian plate, and the North Pamir the role of a pendulum which swung towards Eurasia. Fig. 5 shows two reconstructions: the extreme southern and a more northern one.

These reconstructions show that after the lower Cretaceous, the tectonic zones of the North Pamirs underwent displacement towards Eurasia over a distance of not less than 300 km, and in the southern reconstruction of 600–700 km. Thus, the greater part of the displacement, and the major deformation that resulted in initiation of the Pamir arc, took place after the Paleogene.

The results of paleomagnetic studies show that the tectonic history of the Pamir arc differs from that of the Darvaz-Kopetdag arc. The Paleozoic and Early Mesozoic tectonic zones of the North Pamirs, North Afghanistan, North Horasan and Kopetdag already had the configuration of an arc whose crest faced south in the Early Cretaceous. The limbs of this arc were mutually oriented at an angle 90°. No convex-north Pamir arc existed in the Early Cretaceous and Paleogene, and the territory of the North Pamirs formed part of the eastern limb of the Darvaz-Kopetdag arc. The Pamir arc

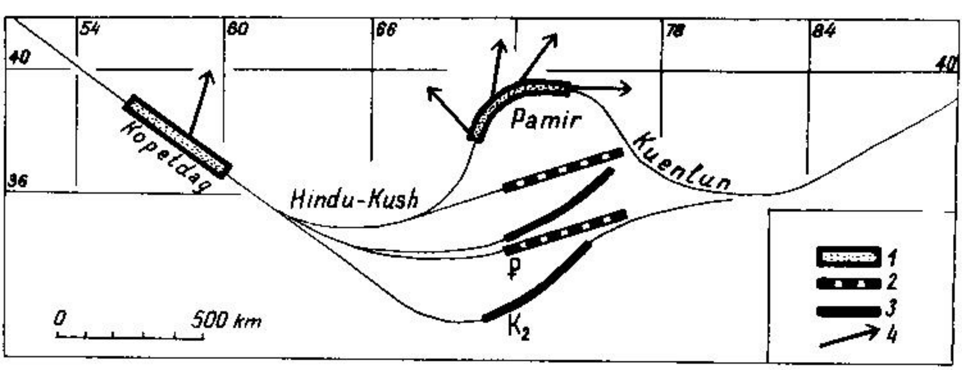

Fig. 5. Scheme of formation of the Pamir structural arc. 1–3) position of the North Pamirs zone (1 – present, 2 – in Late Paleogene, 3 – in Early Cretaceous); 4 – paleomagnetic directions for the Late Cretaceous.

was initiated after the Paleogene as a result of deformation of the eastern limb of the Darvaz-Kopetdag arc. These deformations took place during formation of the Pamir-Punjab syntaxis.

At present, the pole of rotation of the Indian plate relative to the Eurasian plate is located in the Red Sea area. The Pamir block is now moving together with the Indian plate, with the pole of rotation relative to Eurasia probably close to the pole of rotation of the Indian plate. If so, the vector of movement of the Pamirs relative to Eurasia has a northwest trend (about 340°). This is consistent with the direction of horizontal displacement of the North Pamirs, as determined geodetically (Pevnev *et al.*, 1978). Repeated geodetic measurements showed that the Peter the First (North Pamirs) and Hissar (South Tien Shan) ranges are approaching each other at a rate of 1.5–2.0 cm/year. The horizontal projection of the displacement vector trends north-northwest. Repeated triangulations have yielded a longitudinal extension of the exterior zone of the North Pamirs, indicative of a continued development (bending) of the Pamir arc.

ORIGIN OF THE SYNTAXIS

Concepts of the factors and mechanism of development of the Pamir-Punjab syntaxis can be grouped around the following premises: a) crustal deformation brought about by penetration of a rigid Punjab wedge into rigid-plastic Eurasia; b) crustal deformation in the coming together of the Tarim and Tadzhik-Karakum rigid massifs; c) crustal deformation as a response to an upper mantle current; d) flow of crustal material from the underthrusting segment of the Indian plate; and e) flow of crustal material from the Himalayan-Tibetan zone of convergence of lithospheric plates. Hypotheses for further consideration can be selected on the basis of the data cited.

a) According to many investigators, the Punjab segment of the Indian plate plays the role of a rigid wedge whose penetration into rigidly-plastic Eurasia promoted initiation of the Pamir-Punjab heaping and its arcuate form. Some authors believe that interaction of the Indian and Eurasian plates affected the development of the newest structure over a considerable part of Eurasia (Molnar and Tapponnier, 1975; and others). Consistent with this view, a region of intense structural reworking, extending as far as Tarim and Tien Shan, can be identified, as well as a region of dispersed deformations extending as far as Baikal.

Emplacement of a rigid wedge produces a system of folds around the wedge. The degree of compression in the arcs decreases with distance from the wedge (Fig. 6). Data on the geometry of the Pamir-Punjab syntaxis contradict this deformation mechanism, because the Pamir arc is more com-

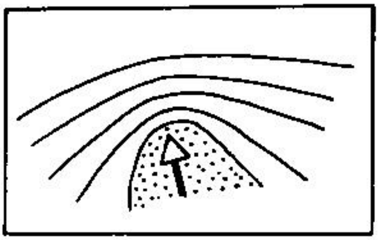

Fig. 6. Scheme of formation of arcs under the effect of rigid stamp.

pressed than the Hindu-Kush-Karakorum arc. To justify this hypothesis, it is necessary to bring in additional forces affecting the stronger compression of the Pamir arc.

b) A drawing together of the Tarim and Tadzhik-Karakum blocks (Desio, 1976; Sarwar and De Jong, 1979) might bring about a stronger compression of the Pamir arc in the context of the preceding hypothesis and might even explain the arcuate form of the entire syntaxis. In case of such a drawing together, left-lateral displacements should take place at the boundary between the Tadzhik-Karakum block and Tien Shan. This boundary has been well investigated and shows only right-lateral displacements, which is inconsistent with this hypothesis. In addition, data on the direction of displacement on strike-slip faults in the limbs of the Pamir arc likewise contradict the hypothesis. If this arc had developed as a result of flank compression, plastic deformation should have been accompanied by right-lateral displacements in the west limb, and by left-lateral in the east limb of the arc (Fig. 7b). The structural situation is the reverse (Fig. 7a): right-lateral

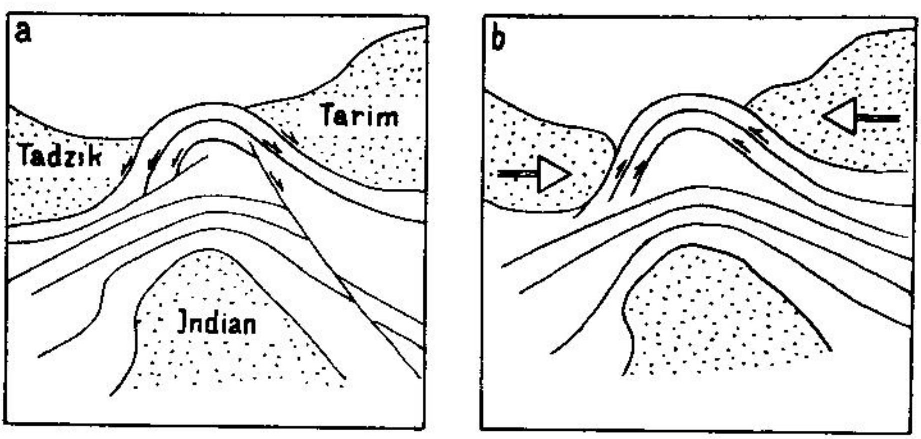

Fig. 7. Scheme of displacement on limbs of the Pamir arc (a). In Fig. b the direction of displacements is shown which should have taken place as a result of drawing together of the Tarim and Tadzhik-Karakorum massifs.

strike-slip faults are present in the Kuenlin limb of the arc, and left-lateral in the Badakhshan limb.

c) In looking for factors responsible for the syntaxis, some investigators turned to subcrustal currents. Ritsema (1966) speculated on the existence of an upper-mantle current producing compressive stresses in the crust and displacements of faults. In support of this view, Desio (1976) adduced the analogy with an ice floe carried by currents into a bay. The ice floe is represented by the continental crust carried by a subcrustal current into the gap between the Tarim and Tadzhik-Karakum massifs.

This hypothesis cannot be geologically substantiated. It is based on analysis of seismic data obtained from deep-focus earthquakes in the Hindu-Kush (Ritsema, 1966). Subsequently, these data have been reinterpreted (Lukk and Vinnik, 1975; Billington *et al.*, 1977).

d) According to another view, the Indian continent was underthrust a considerable distance under the Eurasian continental crust, so that the Hindustan crust underlies all High Asia including the Karakorum and Pamirs (Argand, 1924; and others). In a geodynamic model illustrating this concept (Powel and Conaghan, 1973), the Tethys oceanic crust was absorbed in the Indus subduction zone which died away in the collision of the Indian and Eurasian plates. Subsequently, the Indian plate was thrusted under the peeling-off Asian crust, while the upper mantle of the Eurasian plate sank and was absorbed.

The northward underthrust of the Punjab segment might have produced a flow of crustal masses from it. According to this hypothesis, the Punjab segment of the Indian plate played a dual role. On the level of the lower part of the crust, it acts as a wedge pushing rigid massifs apart. A plastic flow of crustal material from the underthrusting segment led to the stacking of tectonic zones to produce a syntaxis. The available field data are not inconsistent with this mechanism. This hypothesis satisfactorily explains the character of the boundaries and the geometry of the syntaxis, and is consistent with the overall picture of movement on the faults of Central Asia. Data on centres of earthquakes (Shirokova, 1974; and others) do not contradict this hypothesis either.

e) In addition to these hypotheses, there is a view that development of the Pamir-Punjab syntaxis was accompanied by plastic flow along the fold belt, as a result of squeezing of the crust out of the Himalayan-Tibetan zone of convergence of lithospheric plates (Burtman, 1982). This view is based on the kinematics of lithospheric plates. Following the collision with Eurasia, the Indian plate rotated counterclockwise, with the direction of its relative movement veering from northeast to north and north--northwest. As a consequence of such a path for the Indian plate, stresses within the Himalayan-Tibetan convergence zone increased south-eastward along this zone. This stress gradient, maintained for millions of years, could have produced plastic flow of crustal masses along the fold belt, in the direction of the Pamir-Punjab syntaxis. The hypothesis does not pretend to offer a better explanation for the entire syntaxis, than the preceding hypothesis, but its implications are not inconsistent with the facts. An inflow of crustal material from the southeast might have had an effect on the development of the interior structure of the syntaxis. It explains the asymmetry of the structure.

REFERENCES

Argand, E., 1924. La tectonique de l'Asie. 13th Intern. Geol. Congr. Comptes rendus, pp. 169–371.

Bazhenov, M. L., 1983. Investigation of the correlations between the paleomagnetic directions and the lithology of the Cretaceous and Paleogene deposits in West Kopetdagh. Izv. AN SSSR, Ser. Fisika zemli, No. 8, pp. 67–75.

Bazhenov, M. L., in press. Paleomagnetic studies of the Cretaceous and Paleogene rocks in Kopetdagh.

Bazhenov, M. L. and Burtman, V. S., 1981. Formation of the Pamirs-Punjab syntaxis: implications from paleomagnetic investigations of Lower Cretaceous and Paleogene rocks of the Pamirs. In "Contemporary geoscience research in Himalaya." Vol. 1, Dehra Dun, India, pp. 71–82.

Bazhenov, M. L. and Burtman, V. S., 1982. The kinematics of the Pamir arc. Geotectonics (American edition), Vol. 16, No. 4, pp. 288–301.

Billington, S., Isacks, B. G. and Barazangi, M., 1977. Spatial distribution and focal mechanisms of mantle earthquakes in the Hindukush-Pamir region: a contorted Benioff zone. Geology, Vol. 5, No. 11, pp. 699–704.

Burtman, V. S. Development of the Pamir-Punjab syntaxis. Geotectonics (American edition), Vol. 16, No. 5, pp. 382–388.

Desio, A., 1976. Some geotectonic problems of the Kashmir-Karakorum-Hindukush and Pamir area. In "Geotectonica della zone orogeniche del Kashmir Himalaya-Karakorum-Hindukush-Pamir." Atti convegni Lincei, Vol. 21, Roma, pp. 115–129.

Lukk, A. A. and Vinnik, L. P., 1975. Tectonic interpretation of the deep structure of the Pamirs. Geotectonica, No. 5, pp. 73–80.

Molnar, P. and Tapponnier, P., 1975. Cenozoic tectonics of Asia: effects of a continental collision. Science, Vol. 189, pp. 419–426.

Pashkov, B. R. and Shvolman, V. A., 1979. Rift margins of the Tethys in the Pamirs. Geotectonics (American edition), Vol. 13, No. 6, pp. 447–456.

Peive, A. V., Burtman, V. S., Ruzhentsev, S. V. and Suvorov, A. I., 1964. Tectonics of the Pamir-Himalayan sector of Asia. In: "Himalayan and Alpine orogeny." 22nd Intern. Geol. Congr. Report, part 11, New Delhi, pp. 441–464.

Pevnev, A. K., Guseva, T. V., Odinov, N. N. and Saprykin, G. V., 1978. Pattern of crustal deformations in the junction zone of the Pamirs and Tien Shen. In: Sovremennye dvizhenya zemnoy kory (Present-dey movements of the Earth crust), Nauka, Novosibirsk, pp. 86–92.

Powell, O. and Conaghan, P. J., 1973. Plate Tectonics and the Himalayas. Earth Planet. Sci. Lett., Vol. 20, No. 1, pp. 1–12.

Ritsema, A. R., 1966. The fault-plane solutions of earthquakes of the Hindukush centre. Tectonophysics, Vol. 3, No. 2, pp. 147–163.

Sarwar, G. and De Jong, K. A., 1979. Arcs, oroclines, syntaxes: the curvatures of mountain belts in Pakistan. In "Geodynamics of Pakistan," Quetta, Pakistan, pp. 341–350.

Shirokova, E. I., 1974. Detailed study of stresses and faults in earthquake centres of Central Asia. Izv. AN SSSR, Ser. Fisika Zemli, No. 11, pp. 22–36.