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Cenozoic crustal shortening between the Pamir and Tien Shan and a reconstruction of the Pamir–Tien Shan transition zone for the Cretaceous and Palaeogene

V.S. Burtman *

Geological Institute, Russian Academy of Sciences, 109017 Moscow, Russia

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Abstract

The magnitude of the Late Cenozoic crustal shortening during convergence of the Pamir and Tien Shan was determined using a contemporary pattern consisting of facies zones, palaeomagnetic data (regarding the rotation of tectonic units) and data on the structure of the Tadjik Depression. By Late Cenozoic, Cretaceous and Palaeogene facies zones were cut by the Vakhsh–Trans-Alay overthrust and Darvaz strike–slip faults and a significant part of the Cretaceous–Palaeogene Tadjik Basin was overthrust by the Pamir massif. The sediments of easternmost part of the basin are preserved in the Tarim Depression. The facies zones of the southern slope of the Afghan–Tadjik Basin were deformed and moved northward. A pattern of facies zones indicates a convergence between the Pamir and Tien Shan over a distance of 300–400 km.

A number of cross-sections through the Tadjik Depression were used to establish the structure before folding. A rotation of tectonic units, indicated by structural data, conforms to the angles of rotation as determined in palaeomagnetic studies. The data suggest 300 km of convergence between the Pamir and Tien Shan.

Stratigraphic, lithological, structural and palaeomagnetic data formed the basis for the construction of the palinspastically-restored palaeogeographic and sedimentologic environments for the Tadjik shallow sea basin which was situated between the Pamir and Tien Shan before their convergence in the Late Cenozoic. The maps were constructed for the eight stratigraphic levels of the Cretaceous and Palaeogene.

The Tadjik Sea was a bay in the enormous Turan Sea. In the Early Aptian this bay was located in what is now the Afghan–Tadjik Basin. In Late Cretaceous, the eastern shore of the bay lay 600–700 km further eastward and in the Eocene, marine environments extended even further eastward but after the Rupelian continental environments occupied all of this region.

Keywords: Cenozoic; Cretaceous; crustal shortening; palaeogeography; Pamir; Tien Shan

1. Introduction

The part of the Alpide folded belt to the north of India and between Tibet and the Tarim in the east and Afghanistan in the west is known as the Pamir–Pundjab suntaxis. This area was strongly affected by the India–Eurasia collision in the Cenozoic (Molnar and Tapponnier, 1975). Crustal shortening between the Pamir and Tien Shan is an important consequence of this India–Eurasia convergence.

The problem of Cenozoic interaction between the Pamir and Tien Shan goes back a long time;

* Tel.: +7-095-251-8276. fax: 7-095-251-8276.
E-mail address: burtman@ginran.msk.su (V.S. Burtman)

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after the pioneering article of Mushketov (1919) and the well known work of Argand (1924) many geologists became involved in the debate. A general conclusions about convergence between the Pamir and Tien Shan being the result of collision between India and Eurasia and about the overthrusting of the Pamir onto the Tien Shan received strong support but opinions on the magnitude of crustal shortening differed. Estimations of the magnitude of overthrusting ranged 10 and 700 km (Gubin, 1960; Peive et al., 1964; Zaharov, 1964; Suvorov, 1968; Bazhenov and Burtman, 1986; Hamburger et al., 1992; Burtman and Molnar, 1993; Thomas et al., 1996; Bourgeois et al., 1997) and conclusions were made using structural, palaeomagnetic and lithological data analysed separately rather than as a whole.

The magnitude of Cenozoic crustal shortening between the Pamir and Tien Shan is determined in this study by analysing as a whole the contemporary pattern of the facies zones, the results of palaeomagnetic studies and data on structure of the Tadjik Depression. Stratigraphic, lithological, structural and palaeomagnetic data allow the reconstruction of palaeogeographical outlines of the Pamir–Tien Shan transition zone for several stages of the Cretaceous and Palaeogene.

2. Cretaceous and Palaeogene facies zones

The territory between the Pamir and Tien Shan (Fig. 1) was an area of marine and continental sedimentation in the Cretaceous and Palaeogene. The Earth's crust of this area was shortened during convergence between the Pamir and Tien Shan in the Late Cenozoic, when the original pattern of facies was disrupted (Suvorov, 1968; Burtman and Molnar, 1993).

The facies of Cretaceous and Palaeogene deposits of the northern part of the Tadjik Depression and the Pamir-Alay area were used by Gubin (1960) and Suvorov (1968) for determination of the magnitude of the overthrusting of the Pamir arc onto the Tien Shan. Gubin (1960) and Suvorov (1968) concluded that the magnitude of the overthrusting was 10–15 and 100 km, respectively. Burtman and Molnar (1993) extended the area of analysis to the southern part of the Tadjik Depression and concluded that the facies zone patterns shows that the magnitude of overthrusting was much larger.

The Afghan–Tadjik Basin, the Pamir-Alay area, the western part of the Tarim Basin, the Pamir and the Hissar, Zeravshan, Turkestan and Alay Ranges of the Tien Shan (Fig. 1) are used in the analysis detailed in this article. For much of the Cretaceous and Palaeogene, this territory was an area of marine sedimentation in the Tadjik Sea, which was the eastern bay of the Turan Sea (Akramhodjaev et al., 1971). Cretaceous and Palaeogene continental deposits and sediments of the Tadjik Sea are distributed in the Afghan–Tadjik Basin and its mountainous surroundings. North of the Amu-Darya River this basin is known as the Tadjik Depression.

East of the Vakhsh overthrust fault part of the Tadjik Depression belongs to the External Belt of the Pamir (Fig. 2).

Most deposits of the eastern part of the Tadjik Sea were buckled up and the territory was overthrust by the Pamir during its convergence with the Tien Shan in the Late Cenozoic. The easternmost marine sediments from the Tadjik Sea are preserved in the western part of the Tarim Basin.

The territory discussed is in Tadjikistan, Uzbekistan, Kyrghyzstan, Turkmenistan, Afghanistan and China. Data for the territory of Tadjikistan, Uzbekistan and Kyrghyzstan are numerous and of much better quality then the data for Afghanistan and China. Detailed stratigraphic sections for the Cretaceous and Palaeogene have been correlated across the study area. The sources of data are explained in Figs. 3–10. It should be noted, however, that geologists from different countries have used different local stratigraphic subdivisions. Rich fauna in neritic marine sediments and presence of freshwater fossils in non-marine deposits provide the basis for the correlation of regional and local stratigraphic subdivisions on the European scale (Tables 1 and 2).

2.1. Early Cretaceous

The map of the Early Cretaceous facies zones in Fig. 3 is based on stratigraphic sections which

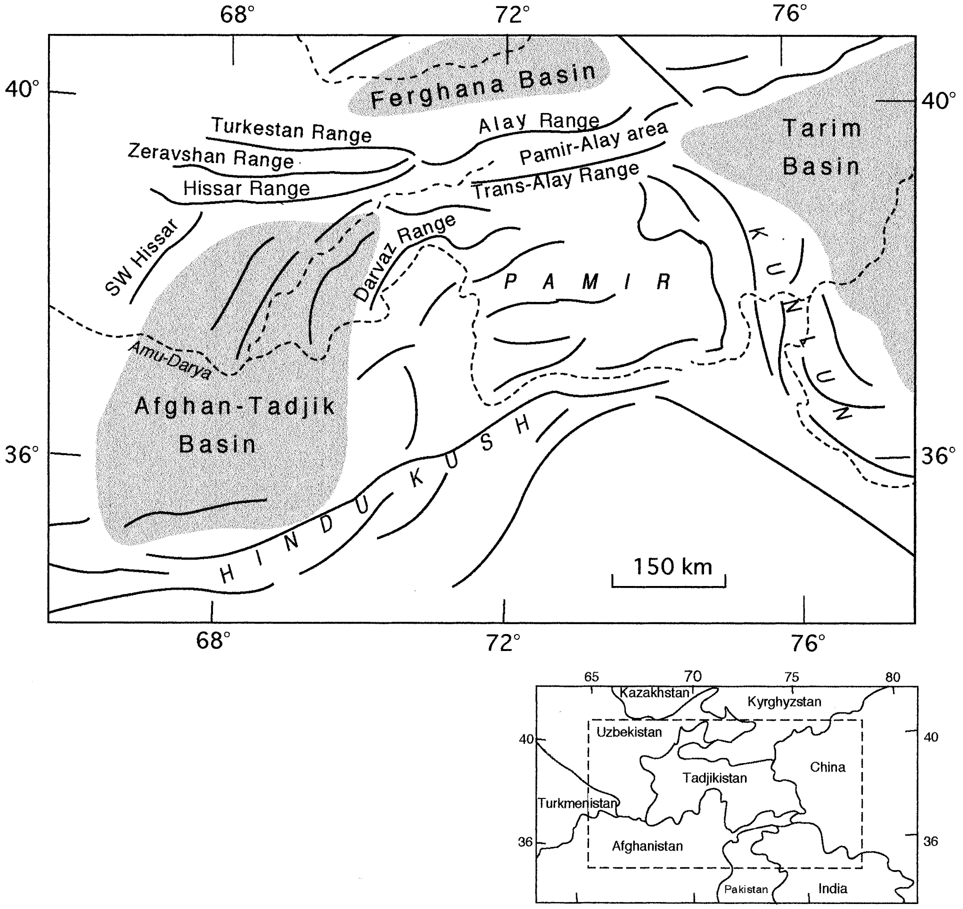

Fig. 1. Outline of discussed region. Afghan–Tadjik, Tarim and Ferghana Basins are shaded in grey. The bold lines mark the ranges and the dashed lines mark the rivers.

are indicated on the map and some of which are further presented in Fig. 4.

2.1.1. Zone A

The main part of zone A was a denudation area in the Early Cretaceous. Non-marine sedimentation occurred in some places. The strata lies unconformably on rocks of different age. Freshwater fauna is known at a few points (7 in Figs. 3 and 4; 21 in Figs. 5 and 6).

2.1.2. Zone B

Thin Lower Cretaceous deposits lie disconformably on Jurassic sediments and unconformably on Palaeozoic rocks. The lower part of the Cretaceous section is composed of red-coloured clastic fluviatile sedimary rocks, which may be Aptian in age. They are covered by strata with Early and Late Albian marine fossils. Marine and non-marine deposits alternate in the Albian section.

2.1.3. Zone C

Non-marine sedimentation took place here from the Berriasian to Early Barremian. Lacustrine clays with freshwater fauna are found in Lower Barremian deposits. Neritic and non-marine sedimentary rocks alternate in the Upper Barremian–Albian section.

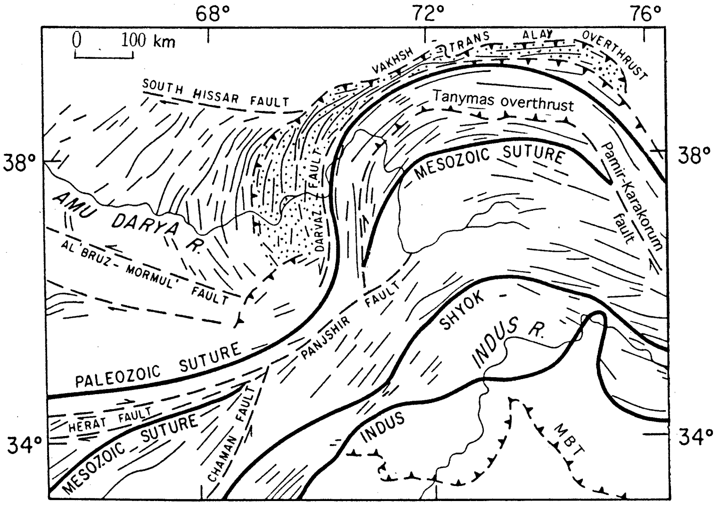

Fig. 2. Structural map of the Pamir and Afghan–Tadjik Basin [after Burtman and Molnar (1993) with some changes]. Sutures are shown by bold lines. Axes of Cenozoic folds are shown by finer lines. Strike–slip faults are indicated by dashed lines. Thrust faults are indicated by lines with teeth pointing down-dip. The shaded area is the External Belt of the Pamir. MBT, Main Boundary Thrust of the Himalayas.

2.1.4. Zone D

This zone occupies the central part of the Early Cretaceous Tadjik sedimentary basin. The non-marine sedimentary rocks are Berriasian and Valanginian. This zone was an area of neritic sedimentation in the Hauterrivian, Late Barremian, Aptian and Albian. Lacustrine sediments with freshwater fossils were deposited in Early Barremian.

2.1.5. Zone E

Stratigraphic section of this zone comprises non-marine deposits except for uppermost Albian marine sediment.

2.1.6. Zones F and G

Zone F is similar to the zone B. Non-marine sedimentation began in the Barremian or Aptian times and marine sediment was deposited in the Albian. Zone G is probably similar to zone A, but Early Cretaceous sediments are not found in zone G.

2.2. Late Cretaceous

The maps of Late Cretaceous facies zones (Figs. 5 and 7) are based on stratigraphic sections as indicated on the maps. Some of the stratigraphic sections used for this analysis are presented in Figs. 6 and 8.

2.2.1. Zone A

Freshwater lacustrine sediments were accumulated in Early Cenomanian times and neritic sedimentation took place from the Late Cenomanian to the Maastrichtian in the eastern part of the Alay Range (21 in Figs. 5 and 6). The western part of the zone remained in continental environments until the Late Senonian when it was covered by the sea.

2.2.2. Zones B and C

The Late Cretaceous interval was characterized by marine environments but a break in sedimentation took place in part of the zone during the Campanian. Coarse-grained Cenomanian sedimentary rocks lie disconformably on Jurassic beds and cover Palaeozoic rocks unconformably in some locations in zone B. The thickness of the Upper Cretaceous section is <600 m in zone B and ranges from 600 to 900 m in zone C.

2.2.3. Zone D

Zone D is an axial zone of the Late Cretaceous basin, where marine sedimentation was continuous

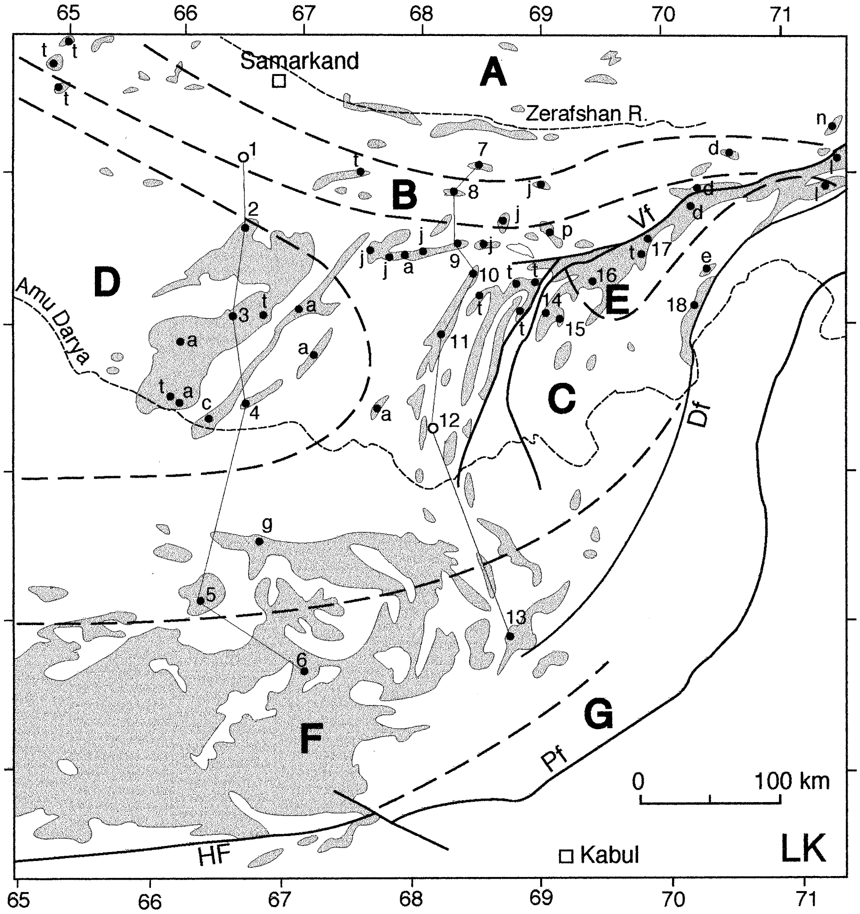

Fig. 3. Lower Cretaceous facies zones (A–G) of the Afghan–Tadjik Basin and mountain frame. Distribution of Cretaceous deposits is shown by grey shading. Undivided Upper Cretaceous–Palaeocene deposits are included in areas south of the Amu-Darya river. The bold lines mark main faults and heavy dashed lines show boundaries of facies zones. The solid circles mark stratigraphic sections observed in outcrops and the open circles mark the bore holes. Main faults: Df, Darvaz; Hf, Herat; Pf, Panjhir; Vf, Vakhsh. 1–18, stratigraphic sections in Fig. 4. The bibliographical sources are denoted in Figs. 3, 7 and 9 by: a, Akramhodjaev et al. (1971); b, Andreev et al. (1972); c, Bratash et al. (1970); d, Burmakin and Starshinin (1967); e, Vlasov et al. (1964); f, Vjalov et al. (1966); g, Dronov (1980); h, Davidzon et al. (1982); i, Djalilov (1963, 1971), Djalilov et al. (1971); l, Kafarsky and Pyjanov (1970); n, Marushkin and Lyashkevich (1969); q, Nadyrshin (1978); r, Pojarkova (1959, 1969); s, Ryskina (1981); t, Simakov (1952a,b, 1959); v, Solun and Chapov (1964); z, Urtaev and Kamalov (1972).

and the thickness of the section exceeds 900 m. In some places the thickness is >1300 m.

2.2.5. Zone E

Zone E is a small area near the Vakhsh overthrust fault. Its stratigraphic section is much like that of zone D. Zones F and G are identical to zones B and A, respectively.

2.3. Palaeogene

Maps of the Palaeogene facies zones (Figs. 9 and 11) are based on the stratigraphic sections as indicated in the maps. Some of the sections are presented in Figs. 6 and 10. Facies zones differ in the thickness of the marine deposits and the completeness of the stratigraphic columns. The upper

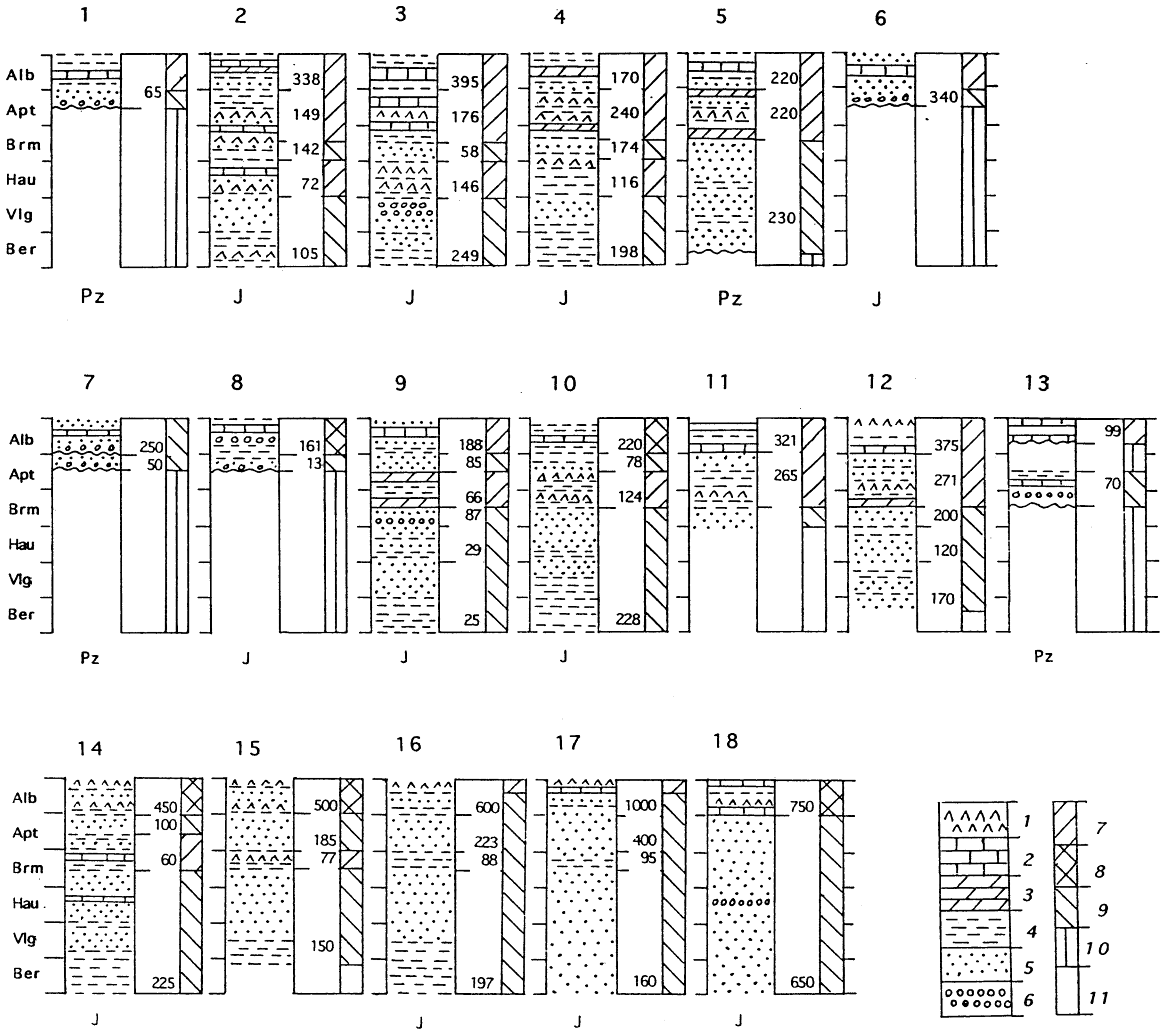

Fig. 4. Stratigraphic columns of Lower Cretaceous deposits of the Afghan–Tadjik Basin along lines 1–6, 7–13 and 14–18 in Fig. 3. Locality 7 is in zone A, localities 1 and 8 are in zone B, localities 5, 9–12, 14 and 15 are in zone C, localities 2–4 are in zone D, localities 16 and 17 are in zone E and localities 6 and 13 are in zone F. Lithology: 1, gypsum; 2, shallow-water carbonate; 3, marl; 4, clay; 5, sandstone, siltstone; 6, conglomerate. Thicknesses are in metres. The indexes (Pz, Palaeozoic; J, Jurassic) show the age of the rock which underlines the Cretaceous sediment. General palaeoenvironments: 7, marine neritic; 8, alternating marine and continental; 9, continental sedimentation; 10, erosion source area; 11, no information. Bibliographical sources: 1, 2, Ryskina (1981); 3, 11, Akramhodjaev et al. (1971); 4, 10, 16, Simakov (1952a,b); 5, 6, Bratash et al. (1970); 7–9, Djalilov et al. (1971); 12, Andreev et al. (1972); 13, Dronov (1980); 14, 15, Filonov and Koroly (1966); 17, Muftiev and Shachnev (1967); 18, Vlasov et al. (1964).

stratigraphic boundary of the Palaeogene is situated among non-fossiliferous continental deposits of the Late Oligocene–Early Miocene age and its position cannot exactly be determined.

The thickness of marine deposits is 350 m. in zone A. A stratigraphic hiatus covers the Priabonian in full or for most of it. An Early Oligocene marine transgression partly extended to zone A.

The thickness of the marine deposits varies from

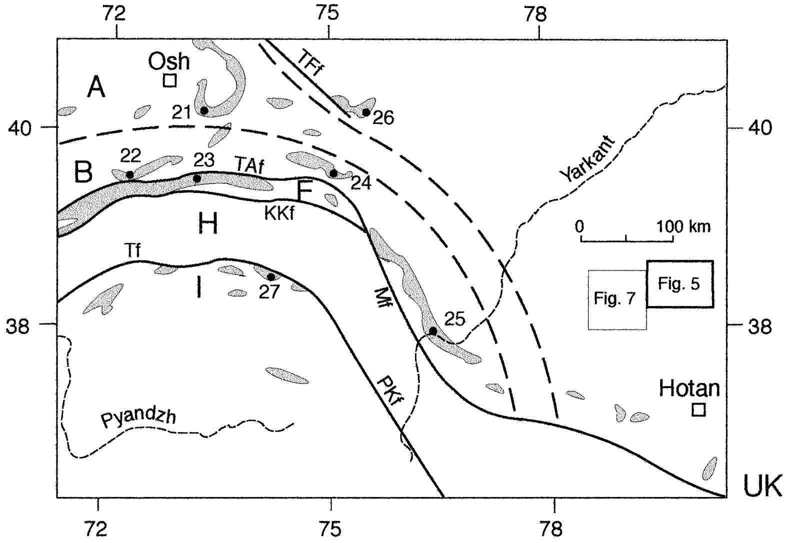

Fig. 5. Upper Cretaceous facies zones (A–I) of the Pamir–Alay area and the Western Tarim. Distribution of Cretaceous deposits is shown by grey shading. The stratigraphic sections (21–25) are shown in Fig. 6. Main faults: KKf, Karakul; Mf, Momuk; PKf, Pamir–Karakorum; Tf, Tanymas; TAf, Trans-Alay; TFf, Talas–Ferghana. Other notation used is explained in Fig. 3.

350 to 500 m in zone B and from 500 to 1100 m in zone C. The priabonian hiatus here is shorter than in zone A.

Zones D and E are similar to zones B and A. There are no good sections in zone D, but its intermediate position is suggested by the sections in the neighbouring zones C and E.

2.4. Application of facies data to the determination of the magnitude of Cenozoic crustal shortening between the Pamir and Tien Shan

All facies zones are cut by the Vakhsh–Trans-Alay overthrust and the Darvaz strike–slip Late Cenozoic faults (Figs. 2, 3, 7 and 9). A significant part of the Cretaceous–Palaeogene Tadjik Basin was covered by the Pamir in the Late Cenozoic. The sedimentary rocks of the easternmost part of the basin are preserved in the western part of the Tarim Depression (Figs. 5 and 11). The facies zones of the southern slope of the Afghan–Tadjik Basin were deformed and moved far northward. They constitute the External Belt of the Pamir. Most spectacular is the pattern of the Palaeogene facies zones (Figs. 9 and 11). A pattern of facies zones and the deflection of their borders near the Pamir indicates that southern facies zones of the Afghan–Tadjik Basin might be displaced northwards over 300–400 km.

3. Palaeomagnetic data

Sound palaeomagnetic data were obtained from Cretaceous and Palaeocene rocks of the northern part of the Afghan–Tadjik Basin, the Southern Tien Shan, the Pamir–Alay area and the Western Tarim (Fig. 12, Tables 3 and 4). They show the counterclockwise rotations of some tectonic units of the Tadjik Depression (Table 4) through considerable angles with respect to the surrounding mountains of the depression (Table 3). Comparison of Cretaceous, Palaeogene and Miocene palaeomagnetic data indicate that the rotation took place after the Late Miocene.

Seven main tectonic units (Bekker, 1996) were recognized in the Tadjik Depression (I–VII in Fig. 12). The general structure of the depression is convergent. Units I–III were thrust to the south-east and units V–VII were thrust to the north-west

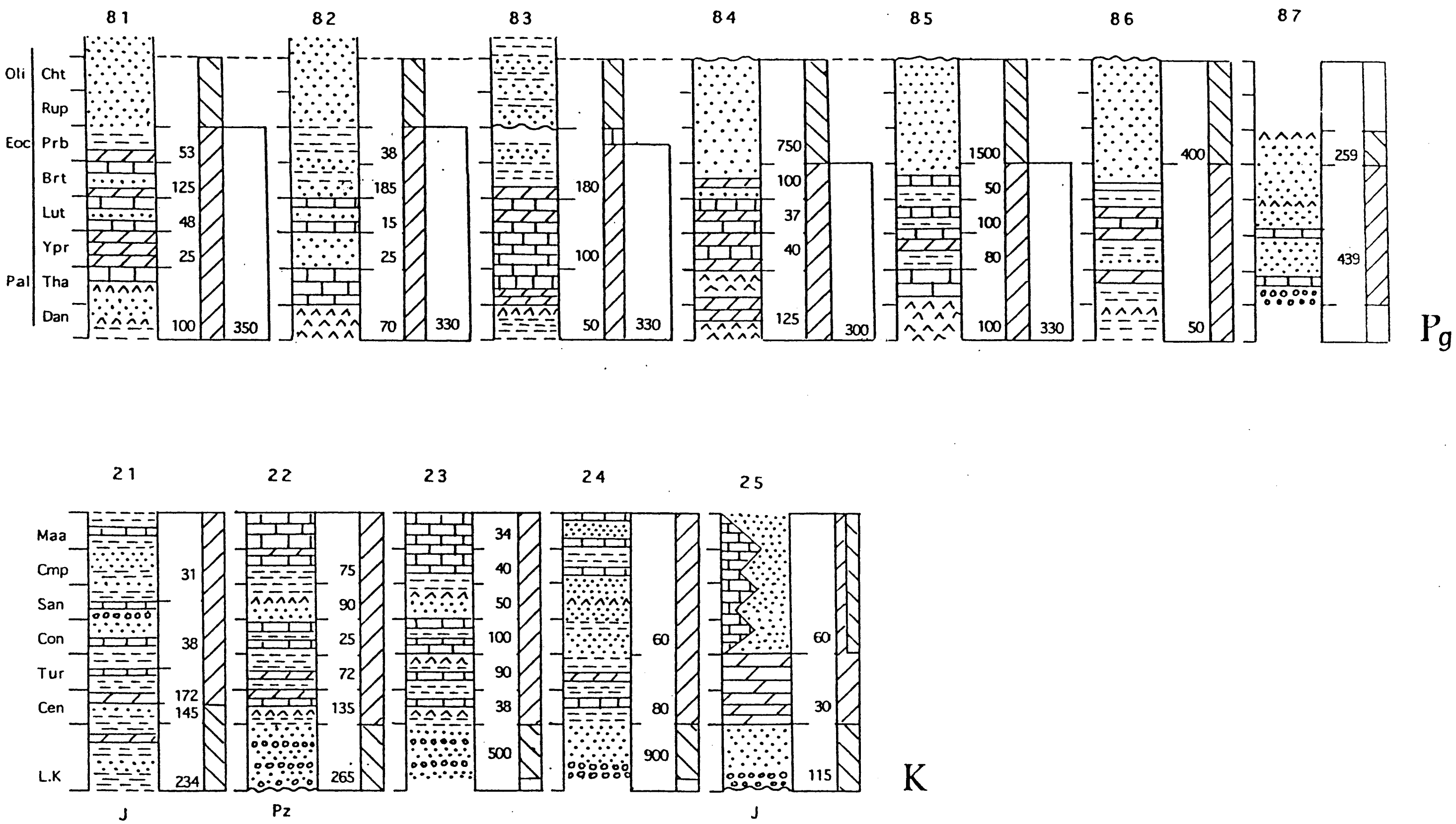

Fig. 6. Stratigraphic columns of Cretaceous (K) and Palaeogene (Pg) deposits of the Pamir–Alay area and Western Tarim along lines 21–25 in Fig. 5 and 81–87 in Fig. 11. Legend as in Fig. 4. Sources of data: 21, Sochava (1965); 22, 23, Pojarkova (1969); 24, 26, 83–86, Sinitsyn (1957); 25, Kazmin and Faradjev (1961); 81, 82, Kozlov and Artemov (1966); 87, Yin and Nie (1996).

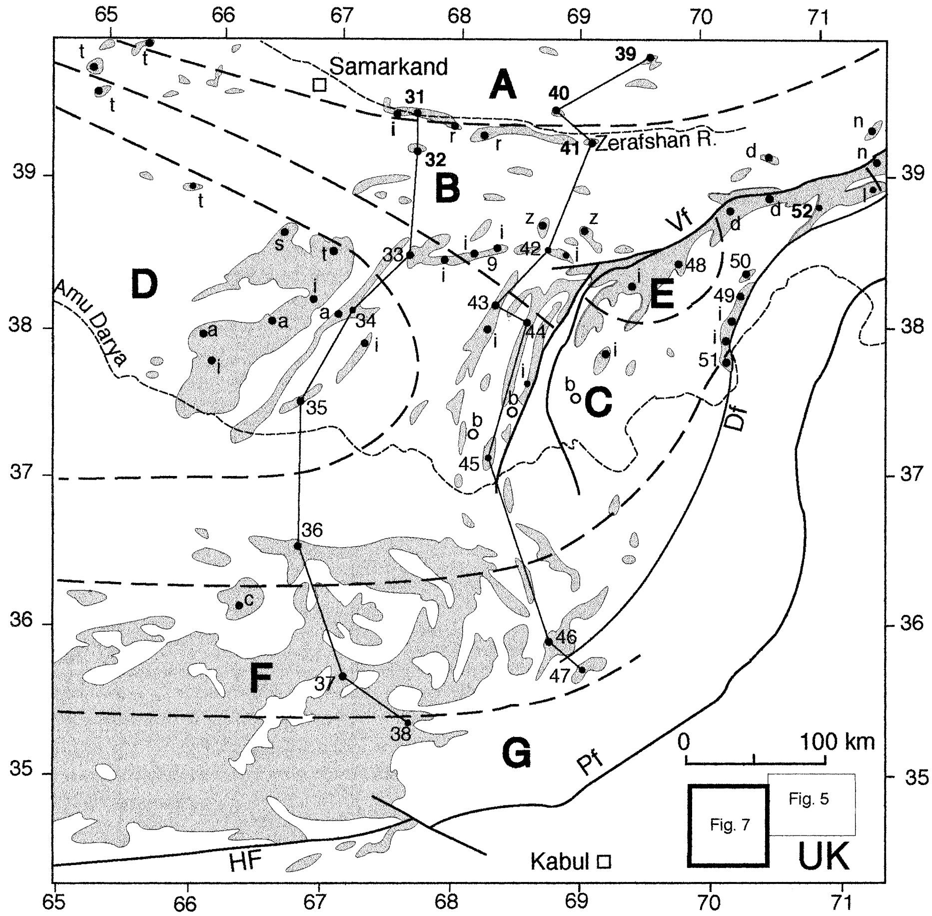

Fig. 7. Upper Cretaceous facies zones (A–J) of the Afghan–Tadjik Basin and mountain frame. The stratigraphic sections (31–52) are shown in Fig. 8. The notation is explained in Fig. 3.

and the west. The Vakhsh ramp basin (IV in Fig. 12) is an axis of convergence.

Palaeomagnetic data show that the angles of rotation of the tectonic units differ. Generally, the angle of rotation in the Tadjic Depression increases from west to east towards the Pamir. Units II and III together are rotated $16° \pm 5°$ counterclockwise. The main part of units V and VI are rotated over $50° \pm 9°$ counterclockwise and the angle of rotation of unit VII is the same. The northern part of unit V (situated near South Hissar strike–slip fault) and unit VIII were rotated slightly. This rotation pattern is in good agreement with the data on the Pamir–Tien Shan Cenozoic interaction which resulted from the India–Eurasia convergence (Burtman and Molnar, 1993).

4. Reconstruction of the prefolding structure of the Tadjik Depression

The first unconformity (with an angle up to 50°) appears in the Cenozoic stratigraphic section of the Tadjik Depression in Middle Miocene continental coarse grained deposits near the border of the depression with the Pamir (in the Darvaz area). The inner part of the Tadjik Depression was folded in the Pliocene and Quaternary. An arc system of

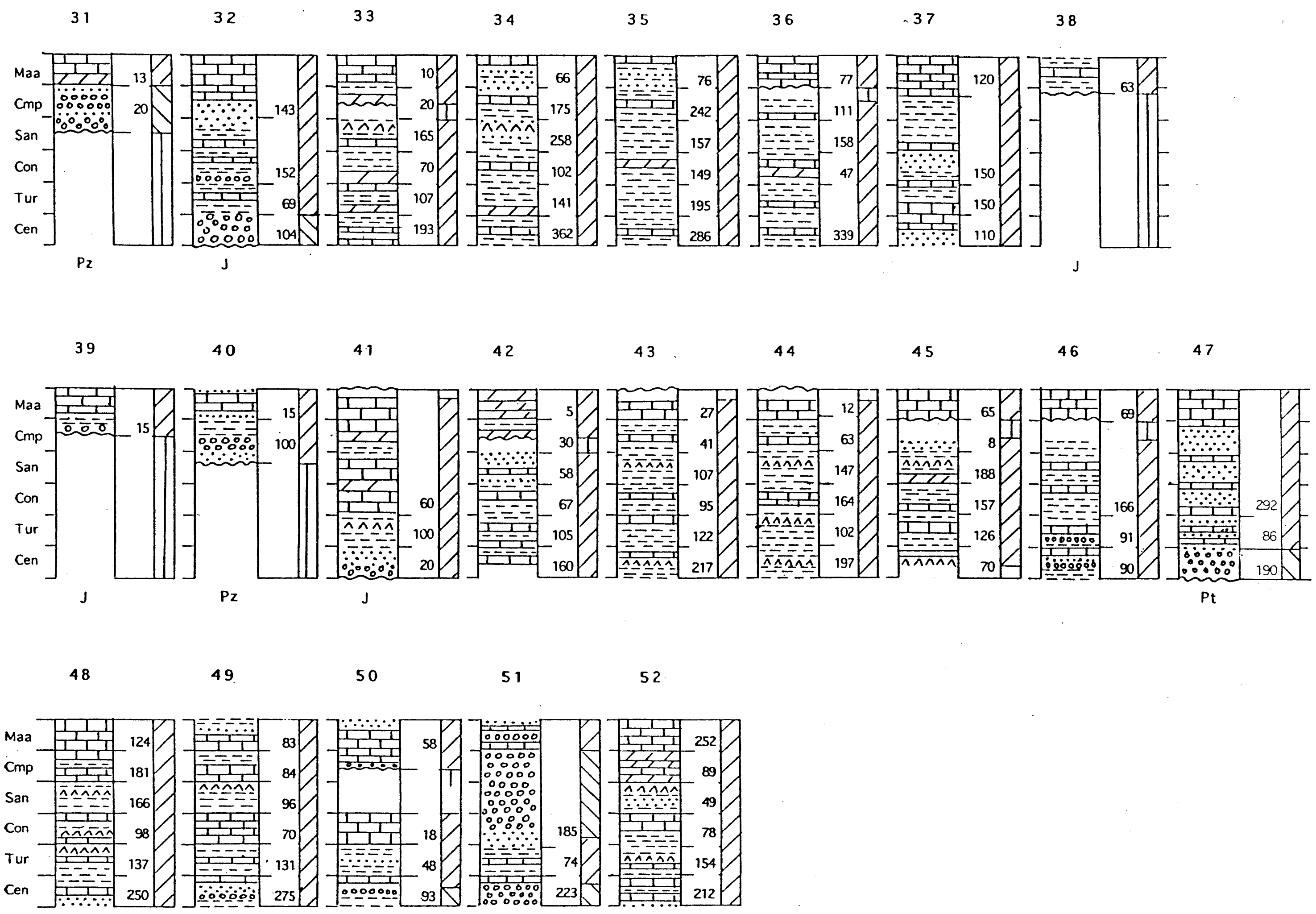

Fig. 8. Stratigraphic columns of the Upper Cretaceous deposits of the Afghan–Tadjik Basin along lines 31–38, 39–47 and 48–52 in Fig. 7. Legend as in Fig. 4. Localities 31, 39 and 40 are in zone A, localities 32, 41 and 42 are in zone B, localities 33, 36, 43–45, 49, 50 and 52 are in zone C, localities 34 and 35 are in zone D, locality 48 is in zone E, localities 37, 46, 47 and 51 are in zone F and locality 38 is in zone G. Source of data: 31, 32, Pojarkova (1959); 33–35, 42–45, 48, 50, Djalilov (1971); 36, 46, 47, Dronov (1980); 37, 38, Bratash et al. (1970); 39, Pojarkova (1969); 40, Djalilov et al. (1971); 41, Starshinin (1972); 49, Djalilov (1963, 1971); 51,52, Djalilov (1963).

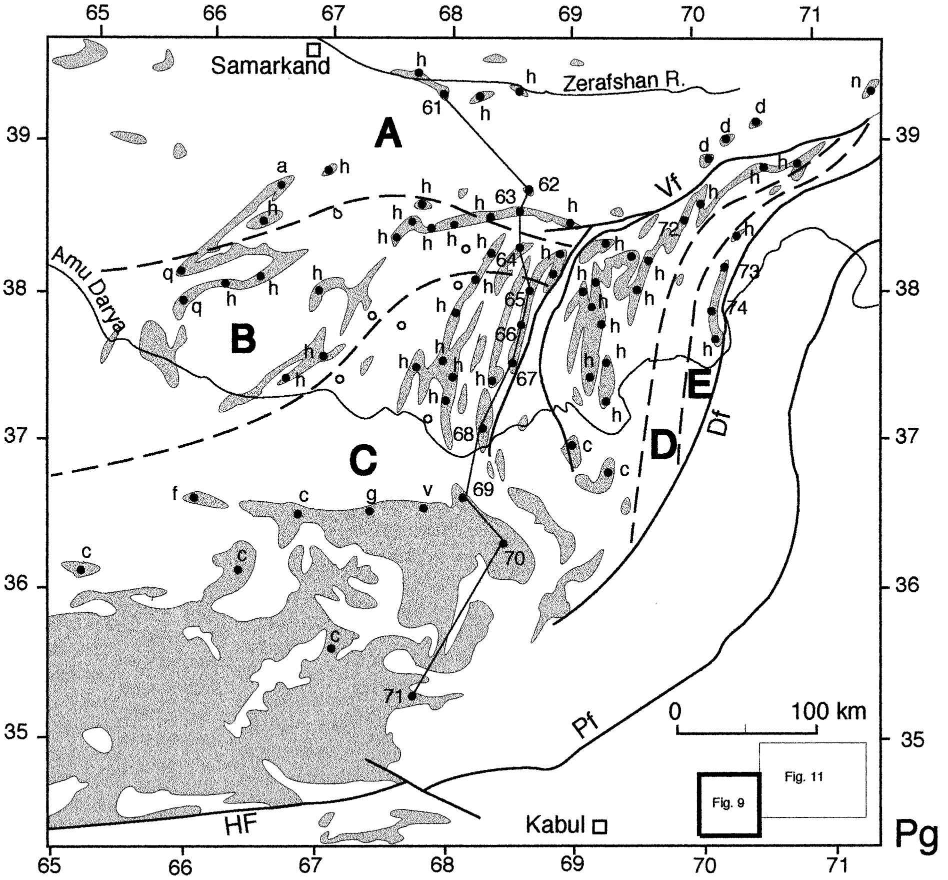

Fig. 9. Palaeogene facies zones (A–E) of the Afghan–Tadjik Basin. Distribution of Palaeogene deposits is shown by outlines and grey shading. Undivided Upper Cretaceous–Palaeocene deposits are included in areas to the South from the Amu-Darya river. The open circles mark the holes described by Minakova et al. (1975). Other notation as in Fig. 3. Stratigraphic sections (61–74) are shown in Fig. 10.

folds and faults was built around the Pamir (Fig. 2) as result of the Pamir–Tien Shan interaction. This arc system was formed by thin-skinned folding of sediments detached over Jurassic salt (Zaharov, 1964; Bekker, 1996).

A way of determining the amount of shortening is to use the cross-sections to reconstruct the structure of the Tadjik Depression before folding began. The overthrust faults were lacking in cross-sections of the depression that were constructed before it was deep drilled. Such cross-sections supplemented the geological map of Tadjikistan (Vlasov and Diakov, 1984) and were used in a recent reconstruction (Thomas et al., 1996). A convergence of 100 km between the Pamir and Tien Shan was determined, which is not in agreement with the pattern of facies zones and palaeomagnetic constraints on the magnitude of the tectonic rotations in the Tadjik Depression. A convergence of 240 km was determined (Bourgeois et al., 1997), using a more realistic cross-section prepared by the Moscow Institute of Oil Geology (VNIGNI). It was also concluded that a combination of thrusting, wrenching and block rotation implies a non-plane deformation which cannot be restored properly using two-dimensional balanced cross-sections (Bourgeois et al., 1997).

Geological cross-sections across the Tadjik

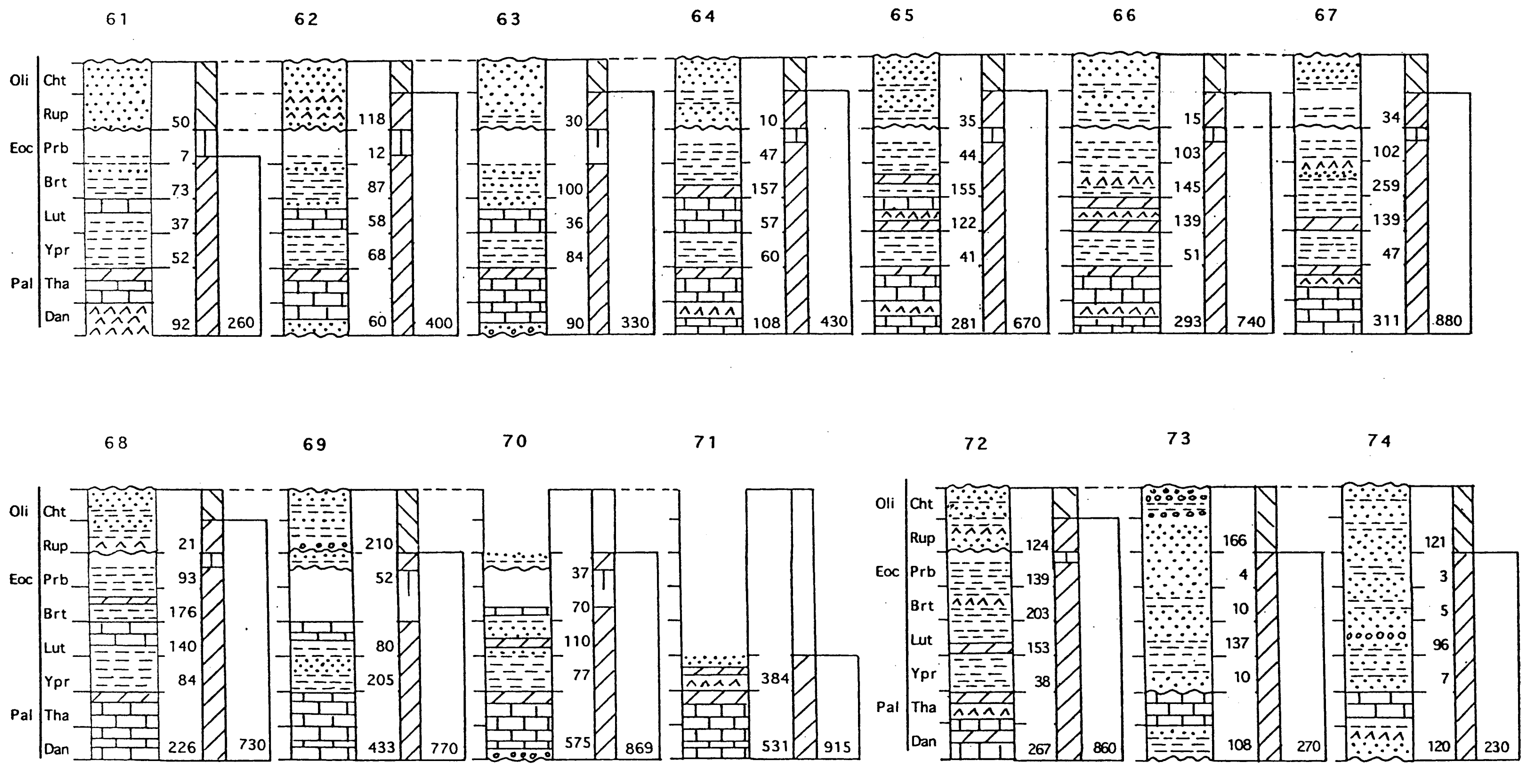

Fig. 10. Stratigraphic columns of Palaeogene deposits of the Afghan–Tadjik Basin along lines 61–71 and 72–74 in Fig. 9. Legend as in Fig. 4. Localities 61–63 are in zone A, locality 64 is in zone B, localities 65–72 are in zone C and localities 73 and 74 are in zone E. Sources of data: 61–68, 72–74, Davidzon et al. (1982); 69–71, Bratash et al. (1970).

Table 1
Correlation of Cretaceous stratigraphic subdivisions

General stages	Local formations of the Tadjik Depression
Maastrichtian	Bulgarin
	Udantau
Campanian	Daralitau
	Sarykamysh
Santonian	Kattakamysh
Coniacian	Akrabat
	Modun
Turonian	Muzrabat
	Disgiryak
	Talhab
Cenomanian	Gazdagan
	Tagarin
	Karikansau
	Tubegatan
Albian	Shirabad
	Akkapchigay
	Babatag
	Derbent
	Karakuz
Aptian	Koligrek
Barremian	Okuzbulak
	Kyzyltash
Hauterivian	Alymurad
Valanginian, Berriasian	Karabily

Local formations of the Tadjik Depression according to Djalilov (1971) and Djalilov et al. (1971).

Depression based on detailed maps, geophysical investigations and results of drilling have been published by Bekker (1996). They were used to prepare structural cross-sections (Fig. 13). A base of Palaeogene deposits was used for determination of the crustal shortening by unfolding the structure (Table 5). The palinspastic reconstruction of the Tadjik Depression (Fig. 14) is based on the data of the shortening of cross-sections A–D from Table 5. A restoration was made manually. As the magnitude of the shortening increases from cross-section A to cross-section D and varies along the cross-sections, so all units in the reconstruction were deformed and rotated. This counterclockwise rotation, determined by structural data, conforms to angles of rotation of tectonic units determined independently in palaeomagnetic studies (Table 4). The crustal shortening between the Pamir and Tien Shan (the distance between points a and a′ in the reconstruction in Fig. 14) was ca. 300 km.

A wide gap (>100 km) appeared on the reconstruction. Shortening this area (the black area on the reconstruction in Fig. 14) was not compensated by the observed structures. Arguments for the subduction of the continental crust beneath the Pamir were advocated by Hamburger et al. (1992) and Burtman and Molnar (1993). It was anticipated that the main part of crust was subducted,

Table 2
Correlation of the Palaeogene stratigraphic subdivisions

	European scale	Central Asia[a]	Tadjik Depression[b]
Oligocene	Chattian	Shurysay	Shurysay
	Rupelian		Hissarak
Eocene	Priabonian	Sumsar	Songlak
		Hanabad	Kushan
		Isfara	
	Bartonian	Rishtan	Tohar
		Turkestan	Beshkent
	Lutetian	Alay	Jukar
	Ypresian	Suzak	Givar
Palaeocene	Thanetian	Buhara	Karatag
			Aruktau
			Tabakcha
	Danian	Akdjar	Akdjar

[a] Regional stratigraphic scale of Central Asia — according to Vialov (1940), Simakov (1952a) and Kreydenkov and Raspopin (1972).
[b] Local stratigraphic scale of the Tadjik Depression — according to Davidzon et al. (1982).

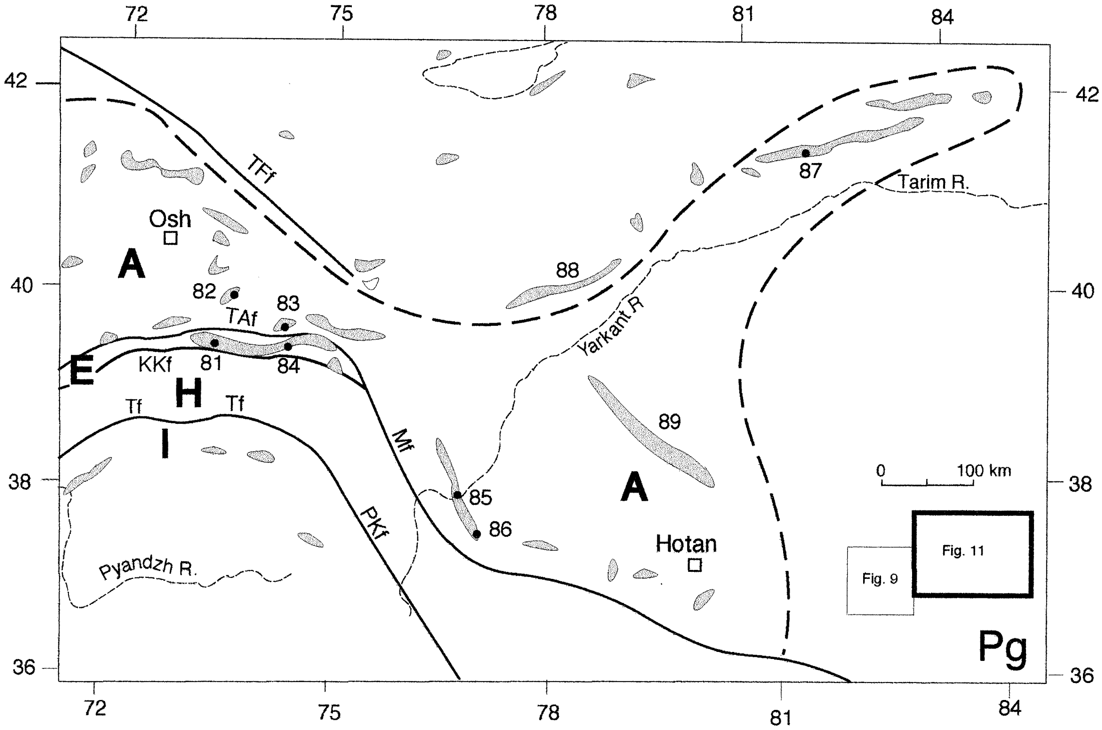

Fig. 11. Palaeogene facies zones (A–I) of the Pamir–Alay area and the Western Tarim. The distribution of Palaeogene deposits is shown in grey. 81–87, stratigraphic sections in Fig. 6. Main faults: KKf, Karakul; Mf, Momuk; PKf, Pamir–Karakorum; f, Tanymas; TAf, Trans-Alay; TFf, Talas–Ferghana. The other notation is as in Fig. 3.

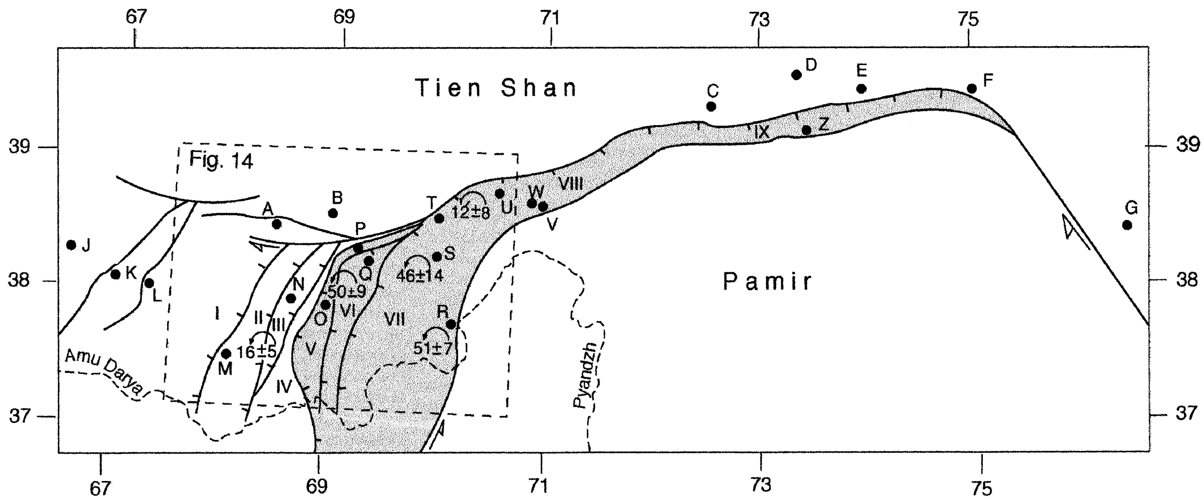

Fig. 12. Tectonic units (I–IX) and palaeomagnetic localities (A–Z). The bold lines mark main faults. Arrows show the Late Cenozoic rotation of the tectonic units. Tectonic units [after Bekker (1996) with some changes]: I, Babatag; II, Rengan–Kyzymchek; III, Daganakiik–Aruktau; IV, Vakhsh; V, Karatay; VI, Sarsaryak–Sanglak; VII–IX, Kuliab–Trans-Alay (VII, Kuliab; VIII, Peter; IX, Trans-Alay). External Belt of the Pamir is shown shaded in grey.

Table 3
Palaeomagnetic data from localities which are unrotated or rotated slightly: these localities restrict the significantly rotated territories determined from data in Table 4

Locality	Point in Fig. 12	Bibliography	Age of magnetization	$I°$ Inclination	$D°$ Declination	α_{95} (°)
Gissar	A	Pozzi and Feinberg (1991)	L.K	44	6	5
Takob	B	Bazhenov et al. (1994)	L.K	52	2	4
Kyzyleshme	C	Bazhenov (1993)	L.K	59	0	5
		Bazhenov and Burtman (1990)	L.K	51	359	8
Sugut	D	Bazhenov (1993)	L.K	47	9	6
		Bazhenov and Burtman (1990)	L.K	50	9	5
Taldybulak	E	Bazhenov (1993)	L.K	49	14	5
		Bazhenov and Burtman (1990)	L.K	45	14	6
Wuqua	F	Chen et al. (1992)	L.K	40	12	7
			E.K.	33	12	4
Yingjisha	G	Chen et al. (1992)	L.K	37	8	10

E.K, Early Cretaceous; L.K, Late Cretaceous; α_{95}, radius of circle of confidence.

Table 4
Palaeomagnetic data from the SW Hissar, Tadjik Depression and external zone of the Pamir

Locality	Point in Fig. 12	Bibliography	Age	$I°$	$D°$	α_{95} (°)	¥ (°)
Dekhanabad	J	Chauvin et al. (1996)	E.Mio	30	3	9	(±)*0
Derbent	K	Bazhenov et al. (1994)	L.K.	49	6	3	(+)5±5
			E.K.	37	6	6	
Pulkhakim	L	Thomas et al. (1994)	E.Mio	35	349	13	(+)* 14±15
Pyryagatau	M	Thomas et al. (1994)	E.Mio	30	336	12	(+)* 27±14
Aksu..	N	Thomas et al. (1994)	E.Mio	33	347	15	(+)* 17±16
		Bazhenov et al. (1994)	L.K.	49	356	3	(+)16±5
		Bazhenov et al. (1994)	E.K.	23	356	17	
Kalininabad	O	Thomas et al. (1994)	L.Oli–E.Mio	33	310	9	(+)* 53±11
Nurek Pass	P	Pozzi and Feinberg (1991)	E.K	54	355	12	(+)17±15
Nurek Dam	Q	Pozzi and Feinberg (1991)	E.K	56	324	9	(+)48±7
S. Darvaz	R	Thomas et al. (1994)	M.Eoc – E.Mio	32	312	11	(+)* 51±13
		Bazhenov and Burtman (1990)	M.Eoc–E.Mio	29	305	7	
		Bazhenov et al. (1994)	L.K.	41	321	5	(+)51±7
		Bazhenov and Burtman (1990)	L.K.	44	314	3	
Tukaynaron	S	Thomas et al. (1994)	L.Oli–E.Mio	33	317	11	(+)* 46±14
Rogoon	T	Pozzi and Feinberg (1991)	E.K	60	359	4	(+)13±8
Chilydara	U	Bazhenov and Burtman (1990)	Oli–E.Mio	30	352	7	(+)* 11±8
Hipshun	W	Bazhenov and Burtman (1990)	L.Eoc–E.Mio	40	329	7	(+)* 34±9
Mionadu	Y	Bazhenov and Burtman (1990)	L.K	44	8	3	(+)4±3
Kyzylart	Z	Bazhenov and Burtman (1990)	M.Eoc–E.Mio	39	37	5	(–)* 34±7

Age, age of magnetization: E, Early; M, Middle; L, Late. ¥°, angle of counterclockwise (+) and clockwise (–) rotation of measured paleomagnetic declination versus Cretaceous Pole (Besse and Courtillot, 1991) or <*> versus Early Miocene Dekhanabad mark, calculated according to Demarest (1983). Other notation as in Table 3.

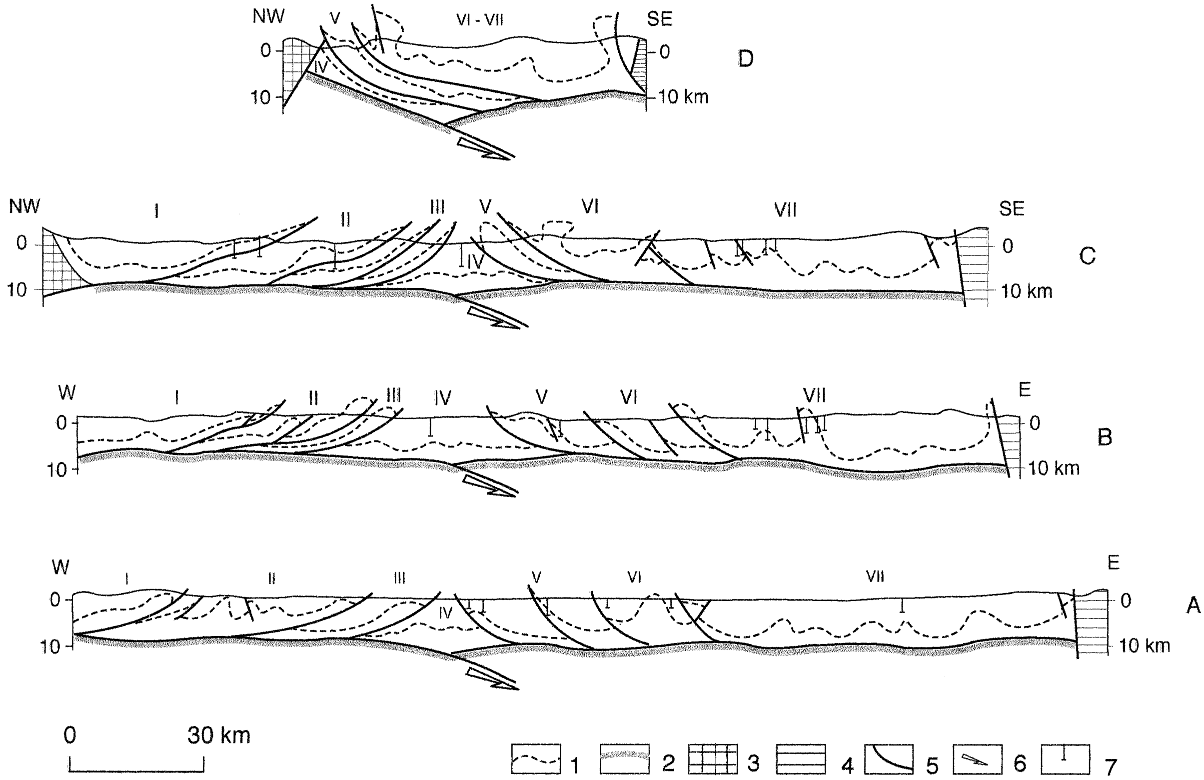

Fig. 13. Structural cross-sections of the Tadjik Depression based on data from Bekker (1996). Positions of cross-sections are indicated in Fig. 14. 1, The base of Palaeogene deposits; 2, basement under Jurassic salt and gypsum; 3, Palaeozoic rocks of the Tien-Shan; 4, Palaeozoic rocks of the Pamir; 5, faults; 6, direction of subduction of continental crust; 7, drill holes.

but the Cretaceous–Cenozoic sedimentary cover was scrapped off and folded. The gap in the reconstruction (Fig. 14) implies that the sedimentary cover was also partly underthrusted beneath the Pamir.

A palinspastic map of the Tadjic Depression (Fig. 14) and maps of the facies zones (Figs. 3, 5, 7, 9 and 11) allows the palinspastic reconstruction of facies zones for the transitional zone between the Pamir and Tien Shan (Fig. 15). Late Cretaceous latitudes in Figs. 15 and 16 are based on palaeomagnetic data from Table 4. Palaeomagnetic inclination anomalies in lower Cretaceous and Palaeogene rocks are found in the region. They have been discussed by Bazhenov (1981), Bazhenov et al. (1994), Thomas et al. (1994) and Chauvin et al. (1996). In Figs. 15–17 the Early Cretaceous and Palaeogene latitudes deduced from Eurasian palaeomagnetic poles from Besse and Courtillot (1991) have been used.

5. Palaeogeography

Red-coloured clastic and clay non-marine sedimentary rocks were deposited in the Afghan–Tadjik Basin in the Early Neocomian. Marine transgression began in the Hauterivian. The sea came from the West. Non-marine conditions returned to the depression in the Early Barremian. The next transgression began in the Late Barremian and reached a maximum in the Late Albian when most of the depression and its surroundings were occupied by the Tadjik Sea.

In the Hauterivian, a shoreline of the Tadjik Sea was on the boundary of zone D [Fig. 15(A)];

Table 5
Shortening of tectonic units in Late Cenozoic time

Cross-section	Unit	LQ (km)	Shortening (km)			LR (km)	*S* (%)
			Folds	Faults	Σ		
A	1	19	4	–	4	23	17
	II	40	11	10	21	61	34
	III	14	2	15	17	31	55
	I–III	73	17	25	42	115	37
	IV	6	3	16	19	25	76
	V	31	6	6	12	43	28
	VI	18	5	2	7	25	28
	VII	85	11	2	13	98	13
	V–VII	134	22	10	32	166	19
	I–VII	213	42	61	103	316	33
B	I	39	3	3	6	45	13
	II	19	4	20	24	43	56
	III	7	3	25	28	35	80
	I–III	65	10	48	58	123	47
	IV	25	3	21	24	49	49
	V	21	4	5	9	30	30
	VI	19	3	11	14	33	42
	VII	68	26	1	27	95	28
	V–VII	108	33	17	50	158	32
	I–VII	198	46	85	131	329	40
C	I	48	9	–	9	57	16
	II	23	3	30	33	56	59
	III	11	9	42	51	62	82
	I–III	82	21	72	93	175	53
	IV	6	2	39	41	47	87
	V	9	7	16	23	32	72
	VI	29	15	–	15	44	34
	VII	66	10	12	22	88	25
	V–VII	104	32	28	60	164	37
	I–VII	192	55	139	194	382	51
D	IV–VII	69	43	58	101	170	59

LQ, Modern width of tectonic units (on sea level); LR, reconstructed width of tectonic units before their shortening; S, transverse shortening of tectonic units in respect of LR. Cross-sections are shown in Fig. 14.

in the Late Barremian it was on the border of zone C with zones B, E and F. In the Aptian and Albian, the boundary of the sea migrated into the territory of zones B, C, E and F in transgressions and regressions. In the Late Albian, it reached the boundary between zones A and B. The eastern boundary of Late Albian marine sediments is situated near 72°E in the External Pamir Belt, and it nearly reaches the meridian 75°E in the Central Pamir Belt (27 in Fig. 5). The southern boundary of marine sediments is placed in the Central Pamir [I in Figs. 5 and 15(A)], from which it extends south-westward to the Western Hindu Kush Mountains.

The Upper Cretaceous Tadjik Sea was open to the West. The northern boundary of the sea migrated across zone A [Fig. 15(B)] between the present-day Zeravshan, Alay and Chatkal Ranges. Marine Upper Cretaceous deposits extended eastward from the Afghan–Tadjik Basin through the Pamir–Alay area to the western part of the Tarim Basin, where the marine deposits became continen-

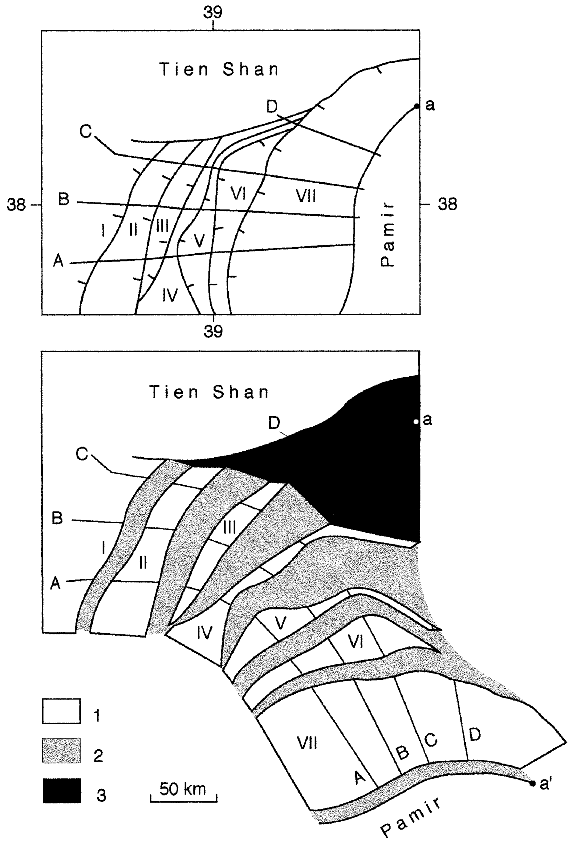

Fig. 14. Modern tectonic units of the Tadjik Depression (above) and palinspastic reconstruction of its territory (below), based on the conclusion about the shortening of cross-sections A–D (Table 5). 1, Modern tectonic units I–VII (from Fig. 12); 2, territories which were shortened; 3, tectonic gap: shortening of the territory cannot be measured from the observed structures.

tal ones (25 in Figs. 5 and 6). Continental deposits are distributed in northern and southern Tarim father to the East (Sinitsyn, 1957; Hendrix et al., 1992).

Upper Cretaceous coarse grained rocks are distributed near the southern and eastern margins of the Afghan–Tadjik Basin and indicate nearby uplift. That upland was situated on the territory of the Northern Pamir [H in Figs. 5 and 15(B)] and the Central Mountains of Afghanistan. It was a barrier between the Tadjik Sea and Tethys Marine Basin. It is not certain, however, whether this barrier was permanent.

In the Palaeocene and most of the Eocene epochs, a shallow sea occupied the modern Afghan–Tadjik Basin and the surrounding mountains [Fig. 15(C)]. The sea left this territory in the Late Eocene and returned in Early Oligocene. After the Rupelian, the sea left this region permanently.

The Tadjik Palaeocene–Eocene Sea was open to the west and north. In the eastern part of the Alay Range [82, 83 in Figs. 6 and 11), Pamir–Alay area (81, 84) and in the foothills of Western Kunlun (85, 86), there are neritic sedimentary rocks which are similar to strata in the marginal part of the Afghan–Tadjik Basin. Marine sediments are widespread in the northern part of the Tarim Basin (87 in Figs. 6 and 11). They are known (Norin, 1935) in the inner part of the Tarim Basin in the Mazartag Mountains (89 in Fig. 11). Farther eastward, however, there are no Palaeocene and Eocene deposits according to borehole and seismic data (Wang et al., 1992). In the southern part of the Tarim basin, marine sedimentary strata graded into a continental strata eastward of Hotan. Continental sedimentation was common in the foothills of the Tien Shan (88) and further northward.

The southern marginal zone of the Palaeogene marine basin (E in Figs. 8, 9 and 11) is preserved in External Belt of the Pamir. There are no Palaeogene rocks in the Northern Pamir (H in Fig. 11), and coarse grained continental rocks are known in the Central Pamir (I in Fig. 11). In the Afghan–Tadjik Basin, marine deposits of the inner part of the Tadjik Sea spread southward as far as the Western Hindu Kush and the Central Mountains of Afghanistan. Clastic and volcanic continental deposits are common in southern Afghanistan. Hence, the southern boundary of Palaeogene marine sedimentation is in the territory of the modern high mountain belt of the Central Afghanistan–Western Hindu Kush–Northern Pamir–Western Kunlun or the boundary is covered by Late Cenozoic overthrust faults in front of that mountain belt.

6. Conclusion: palaeogeographic palinspastic reconstruction of the Pamir–Tien Shan transition zone for the Cretaceous and Palaeogene

Facies zones (Figs. 5, 7, 9 and 11), palaeomagnetic data on block rotation (Tables 3 and 4;

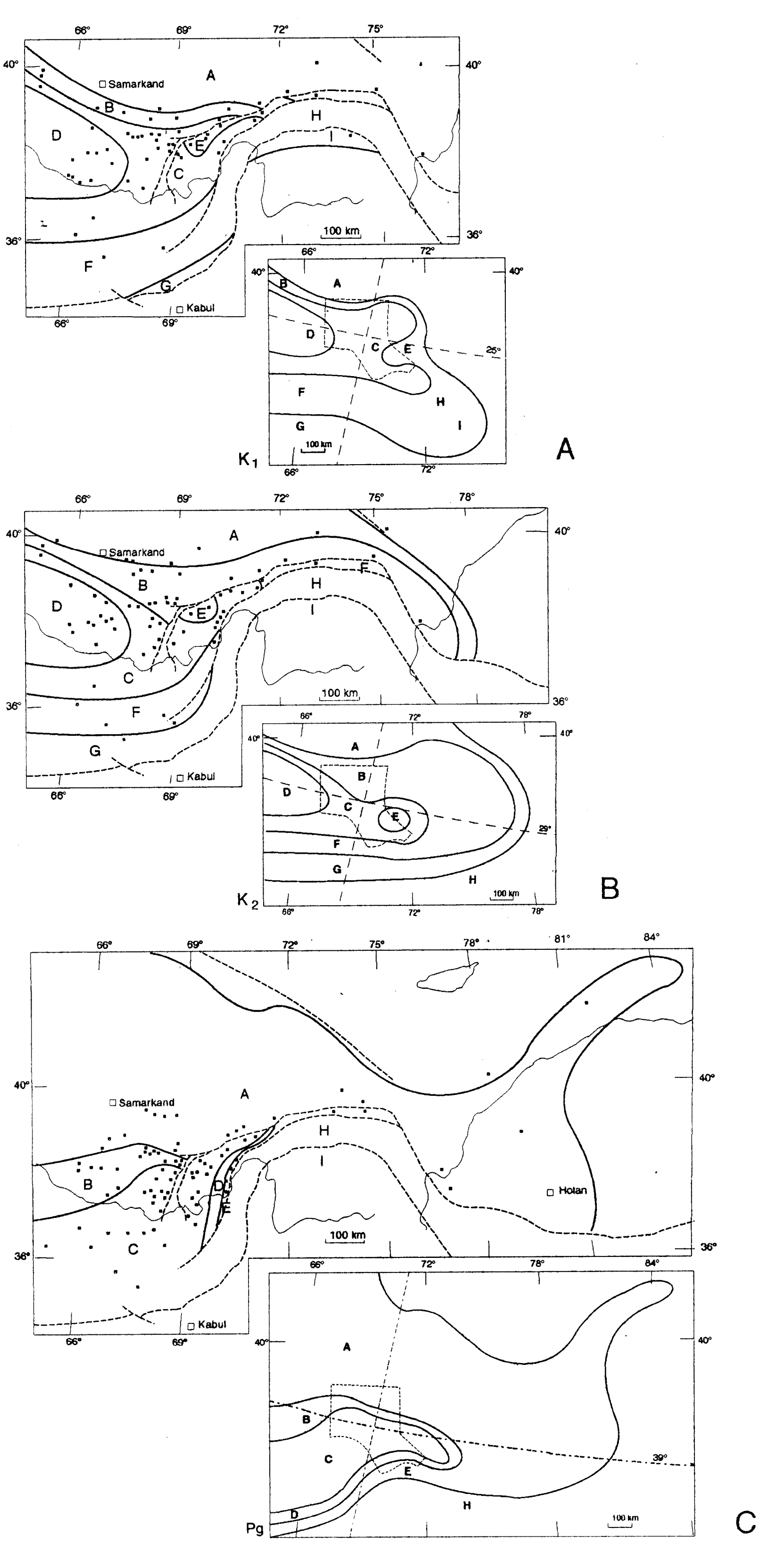

Fig. 15. Modern position of the facies zones and palinspastic reconstruction for Early (A) and Late Cretaceous (B) and Palaeogene (C). The bold lines mark the main faults and the dots mark the stratigraphic sections. Palaeolatitudes and palaeolongitudes are indicated by dashed lines and the territory of reconstruction in Fig. 14 is marked by thin dashed lines.

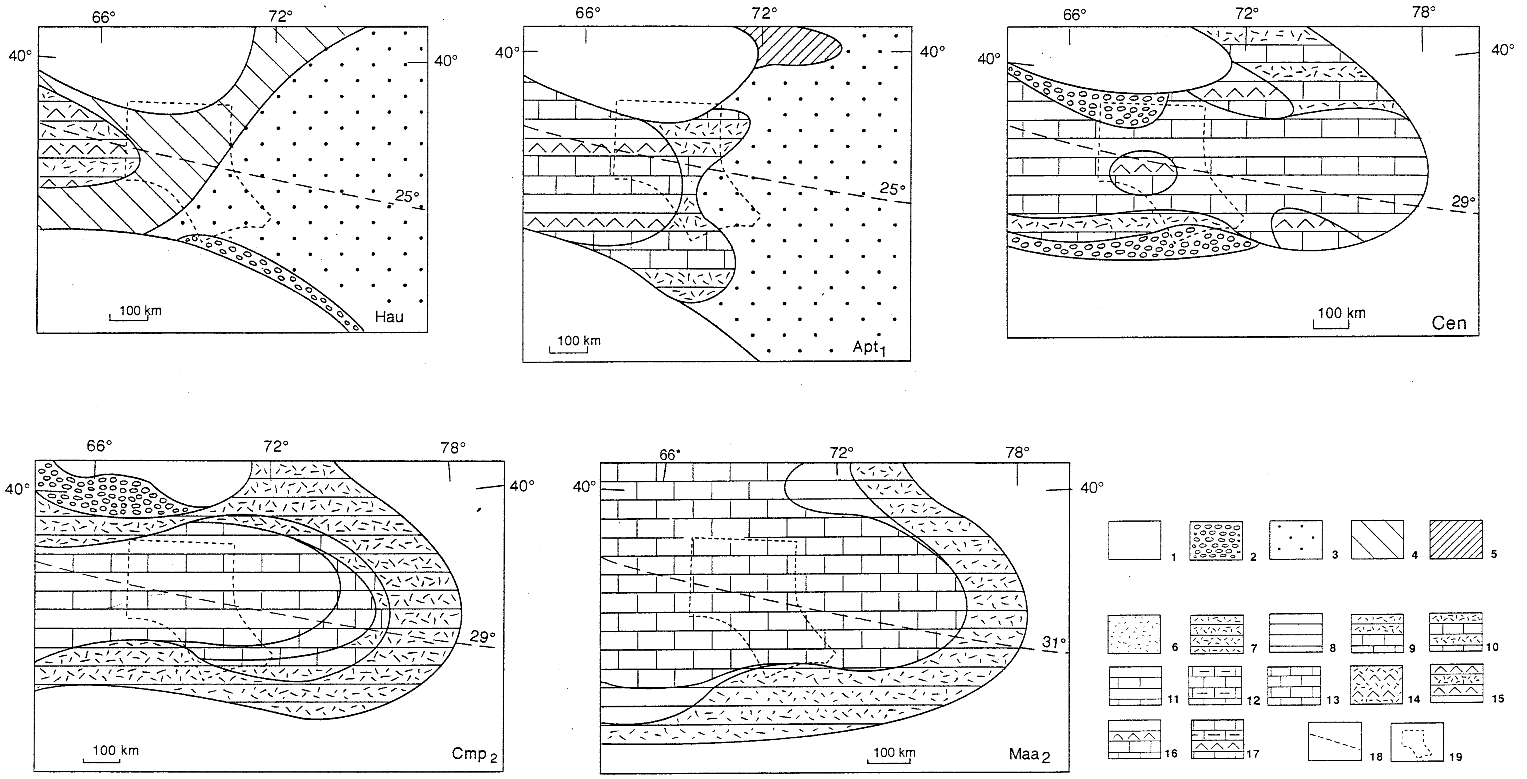

Fig. 16. Palaeogeographic palinspastic reconstruction for the Cretations. 1, Erosion area. Continental sedimentation: 2, proximal coarse clastics; 3, fluviatile sand and silt; 4, fluviatile clay, sand and silt; 5, lacustrine clay. Marine neritic sedimentation: 6, sand and silt; 7, clay, sand and silt; 8, clay; 9, limestone, clay, sand and silt; 10, limestone, sand and silt; 11, limestone and clay; 12, limestone and marl; 13, limestone; 14, gypsum, sand and silt; 15, gypsum, clay, sand and silt; 16, gypsum, limestone and clay; 17, gypsum, limestone and marl; 18, palaeolatitudes; 19, territory of reconstruction as in Fig. 14.

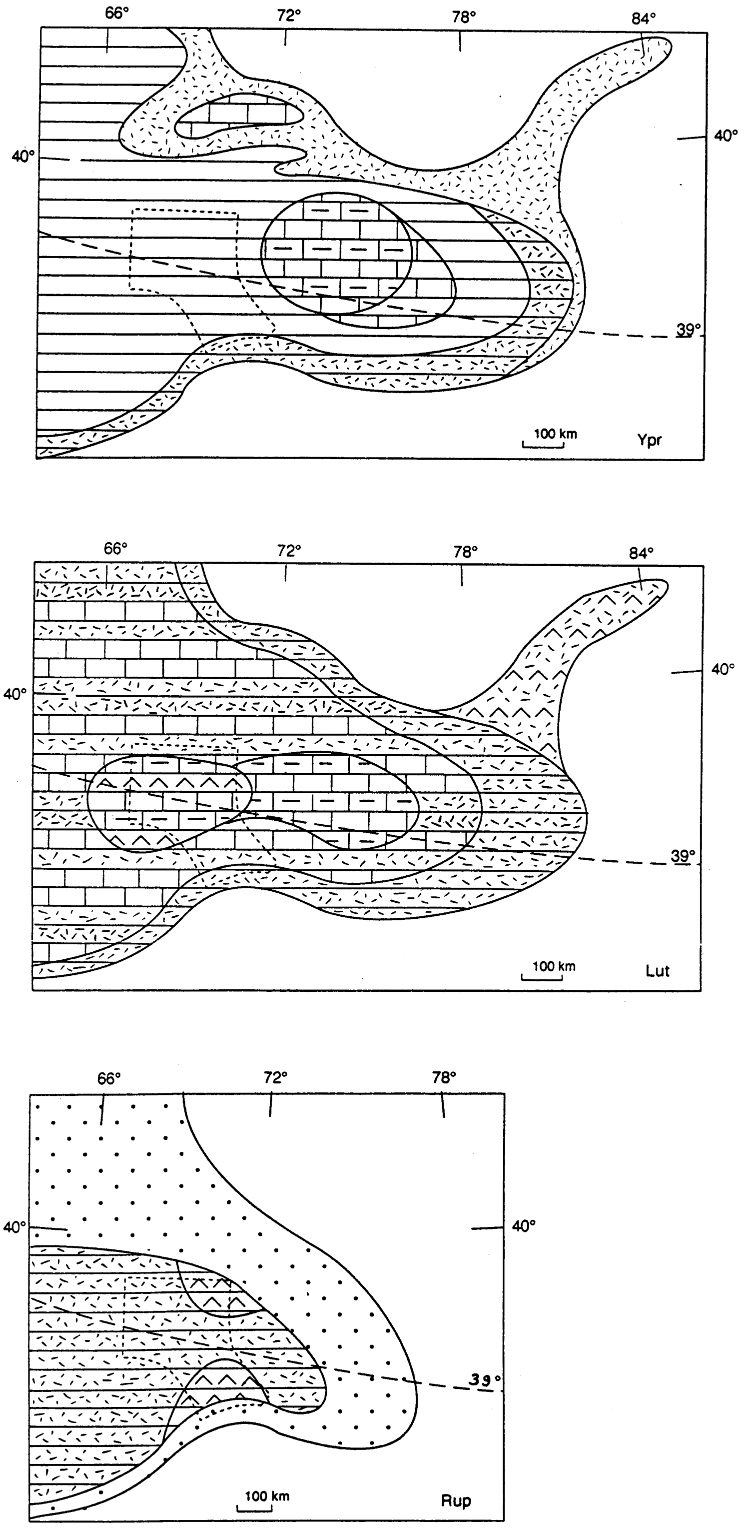

Fig. 17. Palaeogeographic palinspastic reconstruction for the Palaeogene. The notation is as in Fig. 16.

Fig. 12) and data about the Late Cenozoic structure of the Afghan–Tadjik Basin (Figs. 13 and 14) allowed the determination of Cenozoic crustal shortening and to restore the dimensions of the transition zone between the Pamir and Tien Shan in the Cretaceous and Palaeogene. This allows the preparation of palinspastically-restored palaeogeographic and sedimentary facies maps for a basin between the Pamir and Tien Shan before convergence in the Late Cenozoic. Such maps were constructed for eight stratigraphic levels of the Cretaceous and Palaeogene (Figs. 16 and 17). The reconstructions are based on the correlation of stratigraphic and lithological data and their palaeoenvironmental interpretation. Palinspastic maps of facies zones (Fig. 15) are the basis for palaeogeographic reconstruction.

The palinspastic palaeogeographic maps (Figs. 16 and 17) allow determination of the size of the basin and the routes of transgression and regression on the margins. The Tadjik Sea was a bay of the enormous Turan Sea. In the early Aptian the bay was ca. 400 km wide (from north to south) and its main part was located over the modern Afghan–Tadjik Basin. In the Late Cretaceous, the eastern shore of the bay was 600–700 km east of the Early Cretaceous shoreline. In the Eocene, marine conditions extended further eastward. After the Rupelian, continental environments occupied the entire region and surrounding areas (Sinitsyn, 1957, 1962; Sobel and Dumitru, 1997).

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