Deep structure of the Turkestan paleoocean suture: (Northeastern Fergana)

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DEEP STRUCTURE OF THE TURKESTAN PALEO-OCEAN SUTURE

(northeastern Fergana)

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Talas-Fergana and East Fergana faults are considered, the zone has a low-density inversion layer in the lower crust (35-50 km). Rock densities are calculated by an empirical formula with the use of seismic tomography data on P and S wave velocities. This territory is remarkable in the geological aspect as it involves the southern Tien Shan ophiolite belt notching a suture which resulted from the closure of the Turkestan paleo-ocean in the Middle Carboniferous. In the Earth's crust section the suture is traceable to a depth of 15-20 km, is cone-shaped, and is characterized by an increased density of rocks. Analysis of the gravimetric field and density sections suggests that within this cone the Earth's crust is saturated with rocks of ophiolite association.
Inversion layers, density of rocks, Turkestan paleo-ocean, suture

INTRODUCTION

An important line of geodynamic research is study of the deep structure of the Earth's crust, character of the crust-mantle transition, and tectonic layering of the crust. In recent years, the density and velocity heterogeneities of the Tien Shan crust have been actively studied on the basis of seismotomographic data [1-4]. The Kyrgyz part of the Tien Shan has been zoned according to types of density sections, and the recognized zones differ in character of the crust-mantle transition (Fig. 1): The first type of density section includes a low-density inversion layer in the lower crust (35-50 km), whereas the second type of section has no layer of this type. The second-type density section has been recognized within the Fergana depression and northeast of the Talas-Fergana fault. Of special interest is the territory bounded by the Talas-Fergana and East Fergana faults, which are characterized by the first-type section.

A remarkable geologic feature of this territory is the Fergana sigmoid structure (sinistral horizontal flexure). The sublatitudinal Hercynian complex of the Alai Ridge turns in East Fergana northward, then northwestward, and in North Fergana it again has a sublatitudinal strike. The central position in the Hercynian structure of the region is occupied by the southern Tien Shan ophiolite belt, which, together with high-pressure metamorphic complexes marks the suture of the Turkestan paleo-ocean. The east end of this belt offset for 200 km along the Talas-Fergana dextral strike-slip fault occurs on the northern slope of the At-Bashi Ridge. There, the ophiolite belt gradually pinches out along the At-Bashi-Inylchek sinistral strike-slip fault. The intense horizontal deformations of the Hercynian complexes of the southern Tien Shan are considered the result of Late Paleozoic movements [5, 6], but Bazhenov [7], relying on generalized paleomagnetic data, suggests that the maximum offset along the Talas-Fergana fault is due to the rotation of the Fergana block for the last 10 mln. years.

MAIN FEATURES OF DENSITY SECTION OF THE FERGANA DEPRESSION AND ITS MOUNTAINOUS FRAMING

To calculate the rock density, we used an empirical formula by Khalevin [8], relating density to velocities of compressional *(V_p)* and shear (V_s) waves. The reliability of calculated density increases owing to the combined use of velocities of both longitudinal and shear waves. Asynchronous variation in V_p and V_s is often

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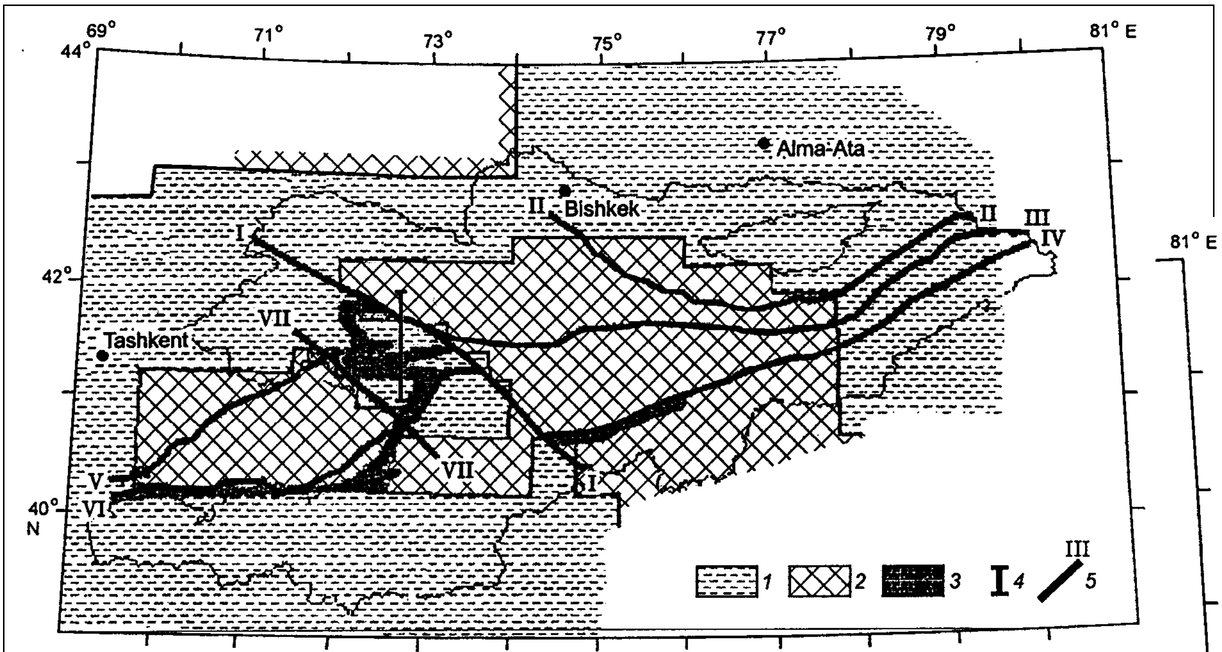

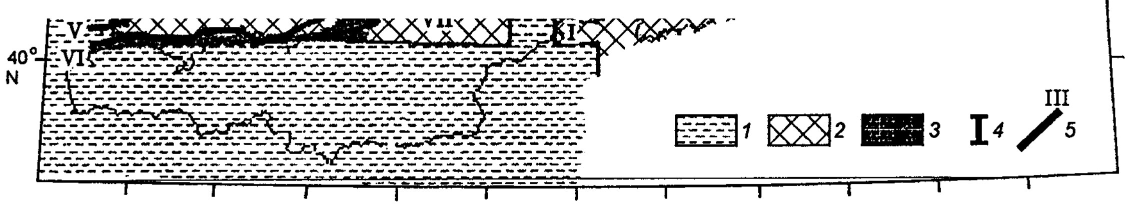

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observed in the Tien Shan region. This seems to be connected with the fact that the velocities of *P* waves are controlled chiefly by the chemical composition of rocks, while the velocities of *S* waves characterize, as a rule, their physical condition (viscosity, gas- and water-saturation, etc.). As a result, V_p and V_s display an intricate dependence on rock density. Initial velocity data were from a 6-layer seismotomographic model for the Tien Shan lithosphere [1]: the size of unit cells, 15'xl5', and the crust thickness, 50 km.

The central part of the Fergana depression displays a normal type of density section: Density increases with depth. The middle and lower parts of the Earth's crust (20-35 and 35-50 km) are made up of high-density rocks, 3.00 and 3.14 g/cm^3, respectively. In the mountaneous framing of the Fergana depression, the density section is characterized by a high degree of layering: Layers with density of 2.95-3.19 g/cm^3 occur at different levels of the Earth's crust — in the lower, middle, and upper parts of the section. They are intensely mixed with lower-density rocks to form in places a sandwich-type section (with two low-density layers). This type of the Earth's crust is characterized by gravitational instability, which favors interlayer offsets under present-day geodynamic conditions.

The presence of heavy dense rocks is mirrored in the gravity field. Figure 2 shows an anomalous gravity field characterizing the density inhomogeneities of the Earth's crust (the thickness of the crust is 50 km). In the mountainous framing of the Fergana depression, the most intense positive anomalies correspond to the exposed suture of the Turkestan paleo-ocean. The internal structure of this zone is shown in the density section (Fig. 3, a). A small segment of the profile situated north of the Talas-Fergana fault characterizes the northern Tien Shan Caledonides. In the zone situated between the Talas-Fergana and East Fergana faults, the density section contains two layers with high density of rocks: one lies beneath the surface *(p* = 2.87—2.88 g/cm^3), and the other *(p* — 2.95—3.14 g/cm^3) dips from north to south, from a depth of 5 km to the base of the crust. Both high-density layers are underlain by low-density inversion layers: in the interval of 5-10 km *(p* = 2.60—2.66 g/cm^3) and at the base of the crust *(p* = 2.86 g/cm^3). Figure 3, *b* gives a geological interpretation of the density section. The calculations show that basic-ultrabasic composition of the upper part of the Earth's crust ("granite geophysical layer") is quite probable if a considerable bulk of these complexes is composed of serpentinites [9]. The initial calculated density is the mean-weighted density of ophiolite association on the

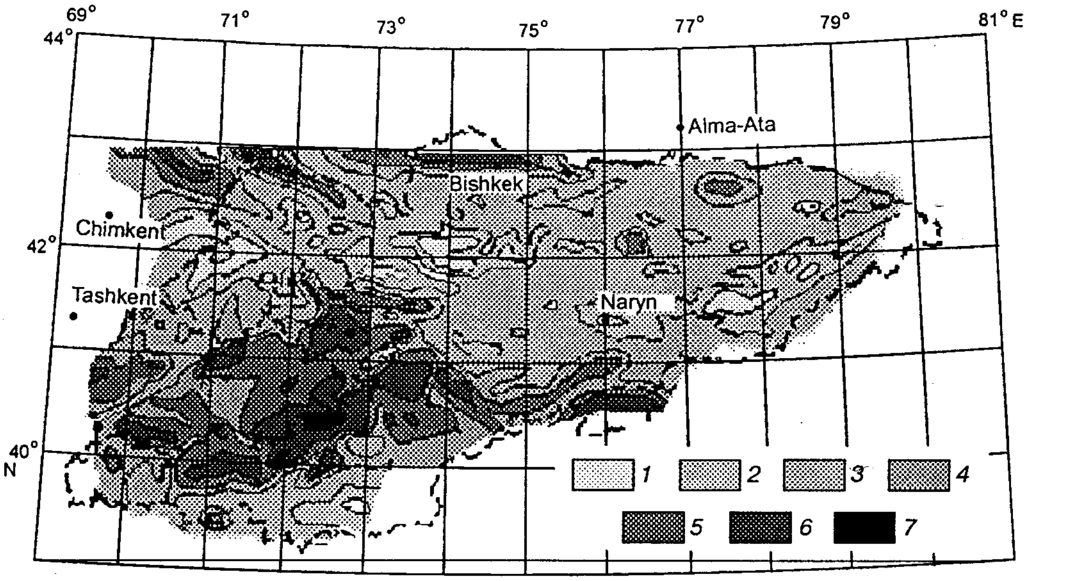

Fig. 2. Map of transformed gravity field reflecting density inhomogeneities in a 50 km thick layer (with data by Z. I. Revenkova and A. N. Lobanchenko). Negative field: 1 — intense, 2 — moderate, 3 — weak. Positive field: 4 — weak, 5 — moderate, 6 — intense, 7 — very intense.

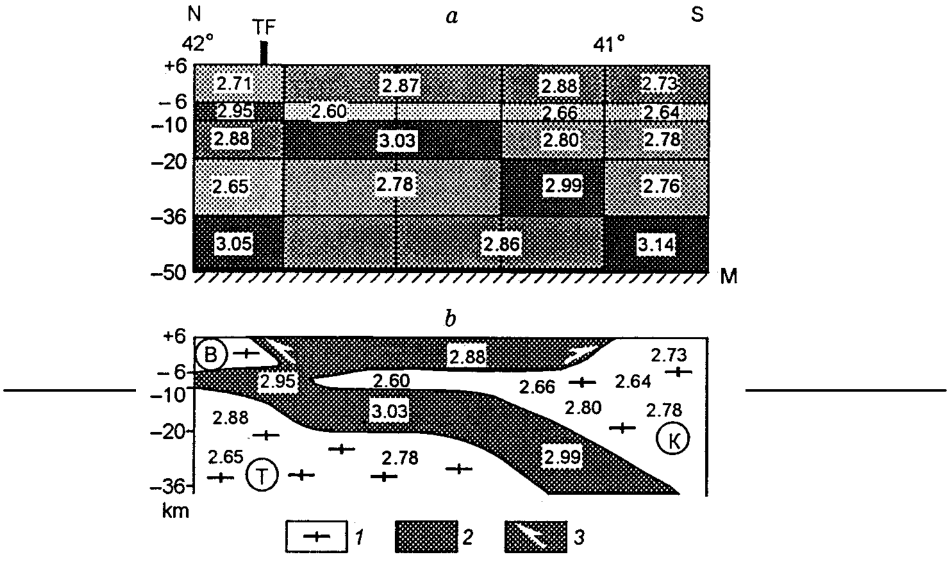

Fig. 3. Deep strucure of the suture of the Turkestan paleo-ocean. a — Density section; TF — Talas-Fergana fault, M — Moho. b — Geological-geophysical section: 1 — microcon-tinents: K — Kyrgyz-Kazakh, T — Tarim, B — Baubashata block of the Tarim microcontinent; 2 — complexes of the Turkestan paleo-ocean; 3 — direction of movement of tectonic covers.

day surface, with corrections for the effect of geothermal gradient on dehydration of ultrabasic rocks introduced at certain depths, as tabulated:

Geological model of section	Depth, H_1 - H_2 , km	Density, *p* (g/cm^3)
Volcanosedimentary layer Ophiolite	0-9 9-	2.72
association: a) with serpentinized	18 18-	2.95
ultrabasic rocks b) with unaltered	32 32-	3.02
ultrabasic rocks	57	3.15

A qualitatively new idea of predominantly basic-ultrabasic composition of the Earth's crust along the southern Tien Shan ophiolite belt was formulated as early as the 1980s. This conclusion was based on analysis of the final stages of development and closure of the Turkestan paleo-ocean. The history of the southern Tien Shan Hercynides is given below, with the recentmost geological and geophysical data taken into account.

THE MAIN STAGES OF EVOLUTION OF THE SOUTHERN TIEN SHAN HERCYNIDES

The Late Paleozoic collision of the Kyrgyz-Kazakh and Tarim microcontinents resulted in the southern Tien Shan nappe-folded belt at the site of the Turkestan paleo-ocean. This belt consists of the north-dipping package of tectonic nappes composed of continental slope and foot complexes, within-plate basalts, and carbonate-volcanogenic rocks of oceanic uplifts [5, 6, 10]. The highest structural position in this sequence is occupied by an ophiolite tectonic nappe. Unlike the underlying splinter-type nappes, this tectonic unit is an intricate antivergent structure, whose northern wing within Northeastern Fergana is thrust over the complexes of the Kyrgyz-Kazakh microcontinent. We have in mind the structure orientation preceding the Late Paleozoic horizontal deformations. Within the Fergana sigmoid feature, the deposits of the Kyrgyz-Kazakh microcontinent may also occur south of the suture, as shown, for example, in the section (see Fig. 3).

The internal structure of this fold is very intricate: It consists of a series of higher-rank nappe folds [11]. The ophiolite belt is more intensely sheared eastward and completely overrides the China-bordering spurs of the Inylchek Ridge, while the complexes of the Kyrgyz-Kazakh and Tarim microcontinents are brought in contact [12].

Many researchers of this region share the opinion that the Turkestan paleo-ocean originated in the Vendian or Early Paleozoic as a consequence of extension and destruction of the Tarim microcontinent [13]. The spreading zones in which the oceanic crust formed existed for a long time, from early Ordovician through Early Carboniferous [14].

Different scenarios are proposed to describe the final stages of the paleo-ocean. According to Burtman's model [5], adopted and developed by researchers of the western Tien Shan [15-19], the newly formed oceanic crust descended beneath the Kyrgyz-Kazakh microcontinent for the greatest part of the Paleozoic. The long-lived subduction is inferred from the Early Silurian, Early-Middle Devonian, and Middle-Late Carboniferous subduction magmatic complexes found within the southern margin of the microcontinent. The closure of the paleo-ocean in the late Late Carboniferous ended with the collision of continents [16-18].

Khristov, whose investigations formed the basis for modern concepts of the geological structure of the eastern Kyrgyz Tien Shan [20], believes that the subduction was subordinate and the closure of the Turkestan paleo-ocean was accompanied by the heaping of large volumes of ophiolites in the upper horizons of the Earth's crust and their obduction onto approaching microcontinents. This conclusion is based on the following arguments: (1) The oceanic complexes of the eastern part of the southern Tien Shan Hercynides from the side of both the Tarim and the Kyrgyz-Kazakh microcontinents are framed by passive margins, with no calc-alkaline series of island arcs found there; (2) southern Tien Shan ophiolites coincide, within the area of their occurrence, with the positive gravimetric anomaly caused by the occurrence of high-density rocks in the upper part of the Earth's crust [11, 12, 20, 21].

The existing discrepancy in understanding of the final stages of development of the Turkestan paleo-ocean is due to objective reasons, chiefly, because of the fact that the Kyrgyz-Kazakh microcontinent is heterogeneous in strike. The western segment of the Turkestan paleo-ocean is associated with the Paleozoic complexes of active margin developed within the Kuramin Ridge, whereas its eastern segment borders the terrigene-carbon-ate deposits of passive margin traceable to the eastern frontier with China [22]. The boundary between complexes of active and passive margins of the Kyrgyz-Kazakh microcontinent lies west of the Talas-Fergana fault and is subparallel to it. At present, the nature of this boundary cannot be interpreted unambiguously, but we think that it is, most likely, of strike-slip fault (transform) character [23].

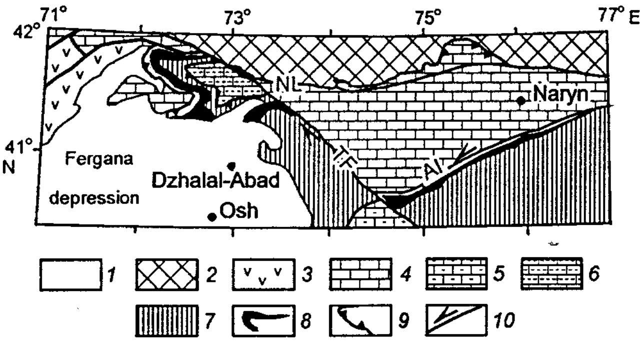

Fig. 4. Scheme of occurrence of precollision complexes of Northeastern Fergana and adjacent territories. 1 — Meso-Cenozoic deposits of the Fergana trough; 2-4 — Kyrgyz-Kazakh microcontinent: 2 — northern Tien Shan Caledonides, 3 — volcanic belt of western Tien Shan, 4 — passive margin of East Tien Shan; 5, 6 — Tarim microcontinent: 5 — Suluterek massif, 6 — Baubashata Massif; 7 — accretionary prism; 8 — southern Tien Shan ophio-lite belt; 9 — frontal Hercynian nappes; 10 — Late Paleozoic strike-slip faults: TF - Talas-Fergana, NL - Nikolaev line, AI - At-Bashi-Inylchek.

At the same time, convincing proof of the subduction that took place in the eastern segment of the southern Tien Shan Hercynides comes from eclogites present among the schists of the At-Bashi Ridge [24] and from blueschists developed after the basalts of the ophiolite belt. Glaucophane and lawsonite are developed sporadically, as relict minerals, for in most cases they have been exterminated by superposed greenschist metamorphism [25]. The time of manifestation of subduction has been established by the formation of an accretion prism in the period from Early Bashkirian to Late Carboniferous. The subsequent thrust of a nonvolcanic arc (accretion prism) over the Late Carboniferous flysch marks the beginning of a continental collision [6].

But, as established in Northeastern Fergana, the earliest nappes are related to the obduction of greenschist-altered ophiolites onto the Kyrgyz-Kazakh microcontinent (Fig. 4). The formed ophiolitoclastic olistostromes include the breccias made up chiefly of apovolcanic greenschists and serpentinites. The host carbonate-siliceous deposits are characterized by Late Visean-Serpukhovian foraminifers and goniatites [11]. The tectonic nappes of Bashkirian age, composed of ophiolites, volcanogenic and terrigene-siliceous rocks of Lower and Middle Paleozoic age, show an inverse vergency. They thrust over the Baubashata Massif, a fragment of the Tarim microcontinent, split off it at the stage of paleo-ocean opening [10]. The successive formation of the structure of the North East Fergana ophiolite belt has been explained by analog modeling of subduction zones in multilayer sand-mica environments [26, H. P. Echtler (oral communication)].

Results of these studies show that an asymmetric anticlinal structure (nonvolcanic arc) overturned toward the continent was formed above the subduction zone at its early stages. Later on, the overturned wing of the anticline was complicated by overthrust (retrowedge thrust), the displacement along which compensates the reduction of the ocean basin. As the thrust comes to the surface, its leading edge becomes destroyed and retrowedge syntectonic sediments form. As late as the end of this stage, basal decollement forms beneath the prowedge region, leading to the formation of an accretion wedge during the further contraction of the basin.

Thus, the avolcanic subduction of oceanic crust that lasted most of the Early and Middle Carboniferous led to a nonvolcanic arc in Northeastern Fergana, made up of heaped nappes, chiefly of ophiolite composition. The total thickness of the nappes evidently reached tens of kilometers, which has been reflected in magnetic and gravimetric fields. As a result of the Late Carboniferous collision, the thick continental crust of the-southern Tien Shan orogen retained large phenocrysts of Early Paleozoic oceanic crust. A principal scheme of the formation of the crust of this kind is given in Fig. 5, *a, b*.

DISCUSSION AND CONCLUSIONS

Recent seismotomographic data on velocities of shear seismic waves permitted us to calculate the density parameters of the medium, to pattern the distribution of density inhomogeneities in the Earth's crust, and to infer the chemical composition of the Earth's crust.

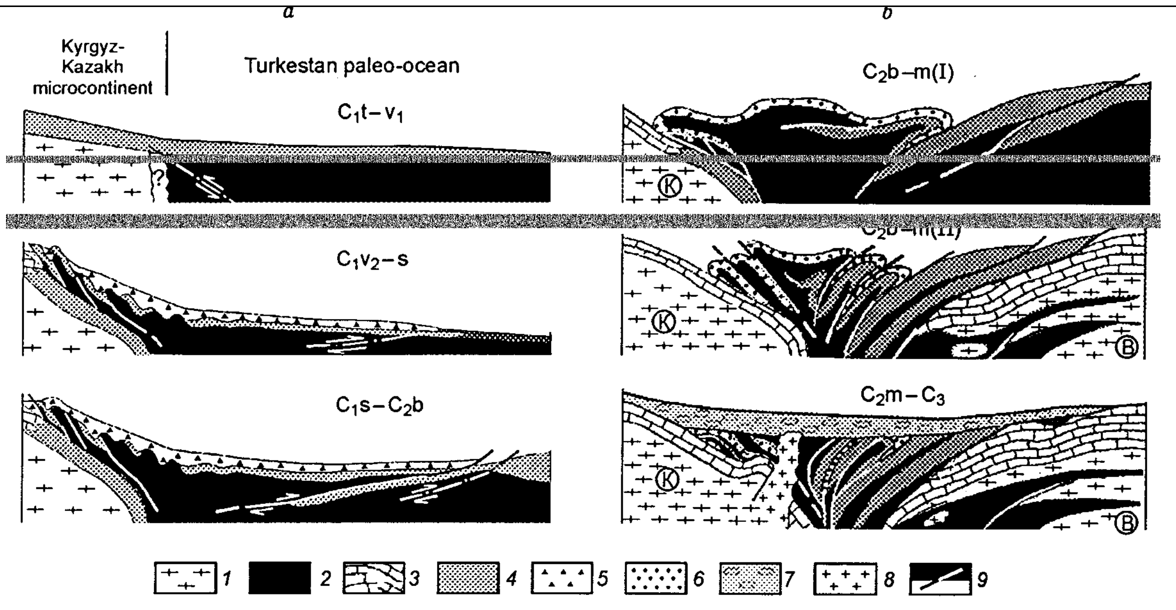

Fig. 5. A principal scheme of development of the collision zone of the southern Tien Shan Hercynides. 1 — granite-gneiss complex of microcontinents: K — Kyrgyz-Kazakh, B — Bauba-shata massif of the Tarim microcontinent; 2 — ultrabasic-gabbro base of the Early Paleozoic oceanic crust; 3 — terrigene-carbonate cover of microcontinents (PZ_{1_2}); 4 — terrigene-sili-ceous deposits of the continental sole and oceanic effusions, silicites, and pelitomorphic limestones *($PZ_{l\text{-}2}$);* 5 — ophiolitoclastic olistostrome (C_1v-s); 6 — ophiolitoclastic olisto-strome and underlying deposits of the continental sole, combined; 7 — collisional flyschoid-molassa complex ($C_{2\text{-}3}$); 8 — collisional granitoids (C_3); 9 — faults.

Analysis of the gravimetric field and density sections has shown that the southern Tien Shan ophiolite belt is a deep-seated structure rather than a package of rootless overthrust tectonic nappes. Along this suture zone, the Earth's crust is a tectonic mixture of large blocks of basic-ultrabasic and granite-gneissic composition (see Fig. 3). The lower layer with a density of 2.95-3.14 g/cm^3 seems to be a relict zone of subduction remaining between two, Kyrgyz-Kazakh and Tarim, microcontinents brought into contact. The upper layer with a density of 2.88 g/cm^3 characterizes the ophiolites thrust over the approaching continental masses. The resolution of initial seismotomographic data is not sufficient to interpret details of its internal structure, but the antivergent structure of the ophiolite belt within Northeastern Fergana suggests that the upper layer has a conical shape and at a depth of 15-20 km is conjugate with the lower layer.

At the collision stage, this deep-seated feature was drastically restructured, which can be observed east of the Talas-Fergana fault. In the northeastern direction, along the At-Bashi-Inylchek fault, the gravimetric anomaly wedges out (see Fig. 2). Geological data completely agree with geophysical materials.

Longitudinal folding and Late Paleozoic thrusts led to the exposure of deep horizons of the subduction zone, represented by eclogites. The northern part of the cone-like body of the ophiolite belt was eroded. The age of retrograde metamorphism of the exhumed At-Bashi eclogites is estimated by the Rb-Sr method at 267±5 Ma (Early Permian) [24]. The isotope dates are somewhat overestimated, since the metamorphic rocks of the At-Bashi Ridge as well as the Northeastern Fergana ophiolites are overlapped, with a drastic angular discordance, by flyschoid-molassa suites of a back-arc trough with the basal layers of Moscovian age.

Thus, within the Northeastern Fergana region, the suture of the Turkestan paleo-ocean is traceable to a depth of 15-20 km, is cone-shaped, and is characterized by a higher density of rocks. Analysis of a gravimetric field and density sections suggests that within this cone the Earth's crust is saturated with rocks of ophiolite association.

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REFERENCES

[I] S. W. Roecker, T. M. Sabitova, L. P. Vinnik, et al., /. *Geophys. Res.*, vol. 98, p. 15779, 1993.

[2] T. M. Sabitova, O. M. Lesik, and A. A. Adamova, *Pure Appl. Geophys.,* vol. 151, p. 539, 1998.

[3] O. M. Lesik, in: *Proceedings of the 31st Tectonic Meeting "Tectonics and geodynamics: general and regional aspects"* [in Russian], Moscow, vol. 1, p. 303, 1998.

[4] A. B. Bakirov, O. M. Lesik, A. P. Lobanchenko, et al., *Indications of modem deep magmatism in the Tien Shan,* Geologiya i Geofizika (Russian Geology and Geophysics), vol. 37, no. 12, p. 42(40), 1996.

[5] V. S. Burtman, *Structural evolution of Paleozoic folded systems* [in Russian], Moscow, 1976.

[6] Yu. S. Biske, *Geotektonika,* no. 1, p. 31, 1995.

[7] M. L. Bazhenov, *Tectonophysics,* vol. 221, p. 251, 1993.

[8] N. I. Khalevin, A. L. Aleinikov, E. N. Kolupaeva, et al., *Joint application of P and S waves in deep seismic sounding,* Geologiya i Geofizika (Soviet Geology and Geophysics), vol. 27, no. 10, p. 94(85), 1986.

[9] A. V. Mikolaichuk, in: *Typical geological and geophysical models of seismic and aseismic regions* [in Russian], Bishkek, p. 78, 1992.

[10] E. V. Khristov and A. V. Mikolaichuk, *Geotektonika,* no. 3, p. 76, 1983.

[II] E. V. Khristov and A. V. Mikolaichuk, in: *Tectonics of the Pamirs and Tien Shan* [in Russian],
Moscow, p. 98, 1983.

[12] E. V. Khristov, *Dokl. AN SSSR,* vol. 306, no. 1, p. 166, 1989.

[13] A. B. Bakirov and V. S. Burtman, in: *Tectonics of the Tien Shan Variscides: trip guidebook of the 27th International Geological Congress* [in Russian], Frunze, p. 55, 1984.

[14] S. A. Kurenkov and V. A. Aristov, *Geotektonika,* no. 6, p. 22, 1995.

[15] Yu. S. Biske, *Geotektonika,* no. 1, p. 41, 1991.

[16] A. B. Bakirov, M. D. Ges', and E. V. Khristov, *Izv. NAN Kirgizskoi Respubliki,* no. 2, p. 79, 1991.

[17] M. D. Ges' and K. V. Seliverstov, *Geologiya Rudnykh Mestorozhdenii,* vol. 37, no. 2, p. 132, 1995.

[18] P. A. Mukhin, Kh. A. Abdullaev, V. E. Minaev, et al., *Sov. Geologiya,* no. 10, p. 47, 1989.

[19] Yu. S. Savchuk, P. A. Mukhin, and L. V. Meshcheryakova, *Geotektonika,* no. 4, p. 70, 1991.

[20] E. V. Khristov and M. P. Khristova, *Geotektonika,* no. 5, p. 72, 1978.

[21] E. V. Khristov, in: *Relationship of geological processes in the Paleozoic folded buildings of Central Asia (Proceedings of the Central Asian regional tectonic conference, 6-8 December, 1978)* [in Russian], Frunze, p. 72, 1981.

[22] D. V. Alexeiev, H. E. Cook, A. V. Mikolaichuk, and A. V. Dzhenchuraeva, in: *Permo-Carboniferous Carbonate Platforms and Reefs. A Research and Field Conference Sponsored by SEPM and MS: Program and Abstracts Volume,* p. 19, 2000.

[23] E. V. Khristov, K. S. Ivanov, A. V. Mikolaichuk, et al., *Izv. NAN Kirgizskoi Respubliki. Ser. Problemy Geologii i Geografii* v *Kirgizii,* p. 65, 1999.

[24] M. Tagiri, T. Yano, A. Bakirov, et al., *The Island Arc,* no. 4, p. 280, 1995.

[25] A. B. Bakirov and K. S. Sakiev, *Izv. NAN Kirgizskoi Respubliki. Ser. Problemy Geologii i Geografii v Kirgizii,* p. 14, 1999.

[26] F. Storti, F. Salvini, and K. McClay, *Tectonics,* vol. 19, no. 2, p. 378, 2000.

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