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The Ming-Kush–Kökömeren Zone of Recent Transpression in the Middle Tien Shan

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Abstract—The Ming-Kush–Kökömeren Zone in the Middle Tien Shan is a transpressional structural unit, i.e., a longitudinal recent faultline depression, where manifestations of transverse shortening (intense folding, reverse and thrust faulting) are combined with left-lateral offset along the same faults; the left-lateral offset is commensurable to vertical separation along reverse and thrust faults or it even exceeds the latter. The complicated deformation within this zone has developed most intensely since the late Pliocene and reached a peak in the Pleistocene. However, the origin of this structural unit was at the onset of neotectonic stage, as evidenced from the Oligocene–lower Miocene conglomerate unit, which was formed as a product of the destruction of reactivated Hercynian thrust faults and nappes in the southern wall of the zone. The conglomerate filled a narrow ramp valley that formed in front of thrusts, probably due to the strike-slip offsets along boundary faults. Similar transpressional linear zones—Tessyk–Sary-Bulak, Uzunbulak–Oy-Kain, Kara-Köl, and Chong-Kemin (Kemin–Chilik)—are known in the Middle Tien Shan.

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INTRODUCTION

Most researchers of the neotectonics of the Middle Tien Shan have considered the major longitudinal structural elements—anticlines (ranges) and synclines (intermontane basins)—bounded and complicated by reverse and thrust faults as a result of transverse compression [3, 26, 27]. However, Rastsvetaev [19], Makarov [14], and Kopp [9], having recognized the leading role of transverse shortening but taking into account the en echelon arrangement of transverse structural elements, suggested that the offset of the left-lateral strike-slip should be taken into account as well. As was shown in [15, 17], the transverse compression that resulted in folding, reverse faulting, and thrusting was combined in the neotectonic evolution of the North Tien Shan with strike-slip displacements along oblique and longitudinal faults, which provided longitudinal stretching in addition to transverse shortening. The longitudinal strike-slip faults were defined as left-lateral, and the offsets were estimated at a few kilometers [4, 15]. The left-lateral components of displacement were documented for a number of active longitudinal faults, and their contribution to recent deformation of the mountainous edifice was estimated [1, 22, 23].

This paper is based on the data obtained during fieldwork in 2004–2006. A case story of the Ming-Kush–Kökömeren Zone is considered in the paper in order to show that the deformed narrow longitudinal depressions with left-lateral strike-slip component of neotectonic displacements, commensurable to transverse shortening or exceeding the latter, are a characteristic class of structural elements in the Middle Tien Shan. Such a structural assembly corresponds to the term *transpression* introduced by Harland [28], which we use hereafter in precisely this meaning.

Later on, this term was applied to designate the structural assemblies of lateral compression, where the structural elements of shortening oriented normal to the direction of compression and having a vertical component of separation (thrust and reverse faults, as well as tight folds) are combined with oblique or occasionally longitudinal right- and left-lateral strike-slip faults [29]. The lateral slip also results in shortening in the direction of compression and additionally in the horizontal stretching in the perpendicular direction. In this manner, the entire Tien Shan may be regarded as a region of transpression. The narrow synform suture zones of 3D deformation that comprise thrust faults, tight folds, packets of tectonic sheets, as well as both right- and left-lateral longitudinal shear zones, were established in the South Tien Shan to the west of the Talas–Fergana Fault [12, 18]. These suture zones are also a variety of transpressional structural assemblies. The Tien Shan is not unique in this respect. Similar structural assemblies with the participation of strike-slip faults are inherent to most collisional orogens, e.g., to the Altai, Pamirs,

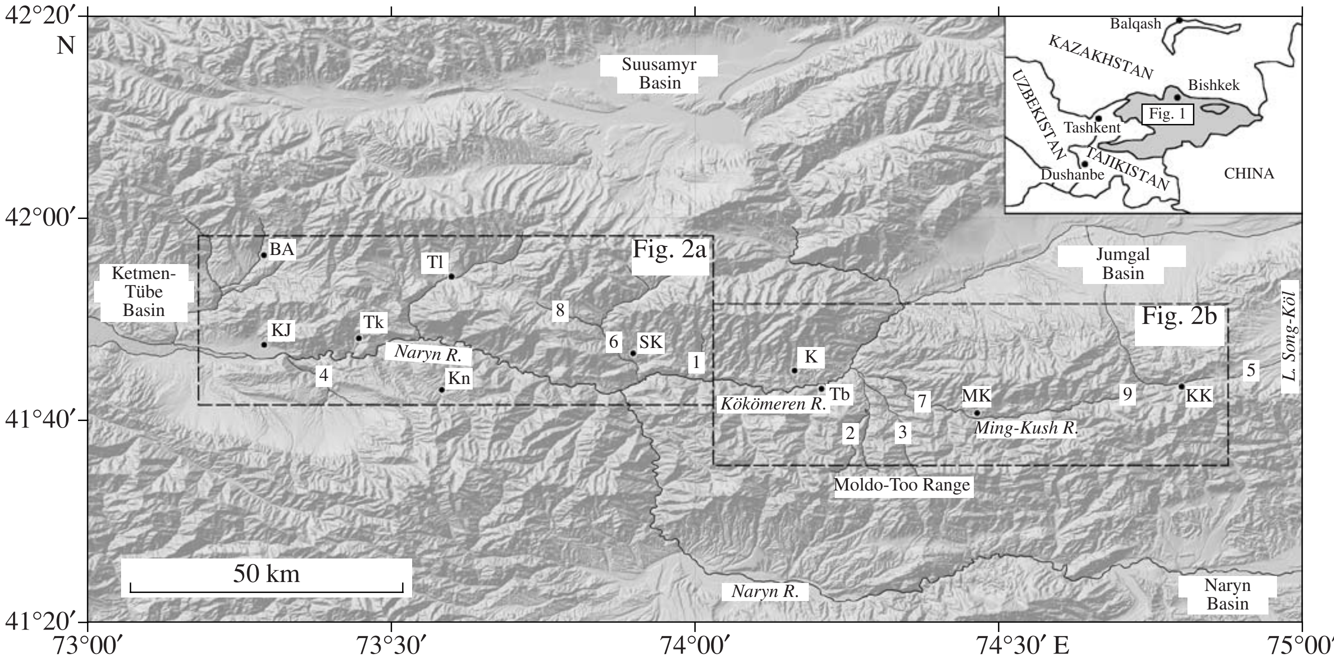

Fig. 1. Shaded-relief map of the Ming-Kush–Kökömeren Zone and its framework on the basis of the Shuttle Radar Topography Mission (SRTM) digital database (3″). Rectangles are contours of the maps shown in Figs. 2a and 2b. Settlements: (BA) Bel-Aldy, (K) Kichik-Jotash, (KK) Kara-Keche, (KJ) Kyzyl-Jasy, (Kn) Kaindy, (MK) Ming-Kush, (SK) Sary-Kamysh, (Tb) Tabylgyty, (Tk) Temirkent, (Tl) Toluk. Rivers (numerals in map): (1) Ak-Baltyrgan, (2) Ak-Köl (Keng-Say), (3) Dungurme, (4) Kambar-Ata, (5) East Kara-Keche, (6) Kovyuk-Suu, (7) Ming-Kush, (8) Terjailyak; (9) Donguz Pass.

Tibet, and the orogens of Iran and the Caucasus. This meaning of *transpression* is not used in this paper.

The Ming-Kush–Kökömeren Zone approximately coincides with the Nikolaev Line, extending from Lake Song-Köl westward for a distance of 160 km, where it merges with the Ketmen-Tübe Basin (Figs. 1, 2). The structure of the Ming-Kush–Kökömeren Zone was characterized in detail in the Geological Map of the USSR on a scale of 1 : 200000, map sheets K-43-XX, -XXI [6, 7] and by Sadybakasov [20, 21]. It was shown that this zone is a narrow ramp (up to 5 km wide in the east and 15 km in the west) that underwent folding and longitudinal faulting and is bounded by the North Kavak and South Kavak reverse-thrust faults.

According to the literature sources cited above, the ramp consists of the Paleocene–Eocene Kok-Turpak Formation (up to 40 m) with a flow of olivine basalt, with the mainly conglomerate sequence as thick as 2 km locally replaced by fine clastic sediments, as well as Pleistocene alluvium and proluvium. Near the Ming-Kush settlement, the conglomerate sequence consists of especially coarse clastic material. To the west of the mouth of the Ming-Kush River, sandstone, siltstone, clay, and less abundant silty marlstone and limestone appear as interlayers. A similar variation is observed in the eastern direction, in the Kara-Keche Depression and father toward Lake Song-Köl, where the thickness of this sequence is reduced to a few hundred meters. In the geological map on a scale of 1 : 200000, the Pliocene age of the conglomerate sequence is accepted on the basis of unconvincing correlation with sections of the adjacent recent depressions. At the same time, clays from this sequence contain remains of ostracodes *Cyprideis torasa littoralis* (Brady) abundant in the Neogene sediments of the Jumgal Basin.

Sadybakasov dated the conglomerate sequence in a broader range of Paleogene to Neogene and noted that the color of rocks changes upsection from red to gray. At the northern wall of the Ming-Kush–Kökömeren Zone he marked out the upper portion of the conglomerate sequence, which was composed of conglobreccia, as a special proluvial unit, which was compared with the Sharpyldak Formation of the upper Pliocene–Eopleistocene. Sadybakasov also pointed out the predominance of pebbles of Lower Carboniferous limestones in the lower portion of the section. These limestones are typical of the Middle Tien Shan, whereas only granitic fragments derived from the North Tien Shan occur in analogues of the Sharpyldak Formation.

STRATIGRAPHY OF MESOZOIC AND CENOZOIC ROCKS

Jurassic freshwater sedimentary rocks lie at the base of the Mesozoic to Cenozoic sections of the central and eastern segments of the Ming-Kush–Kökömeren Zone. They rest upon Lower Carboniferous red beds without visible angular unconformity, locally revealing a slight

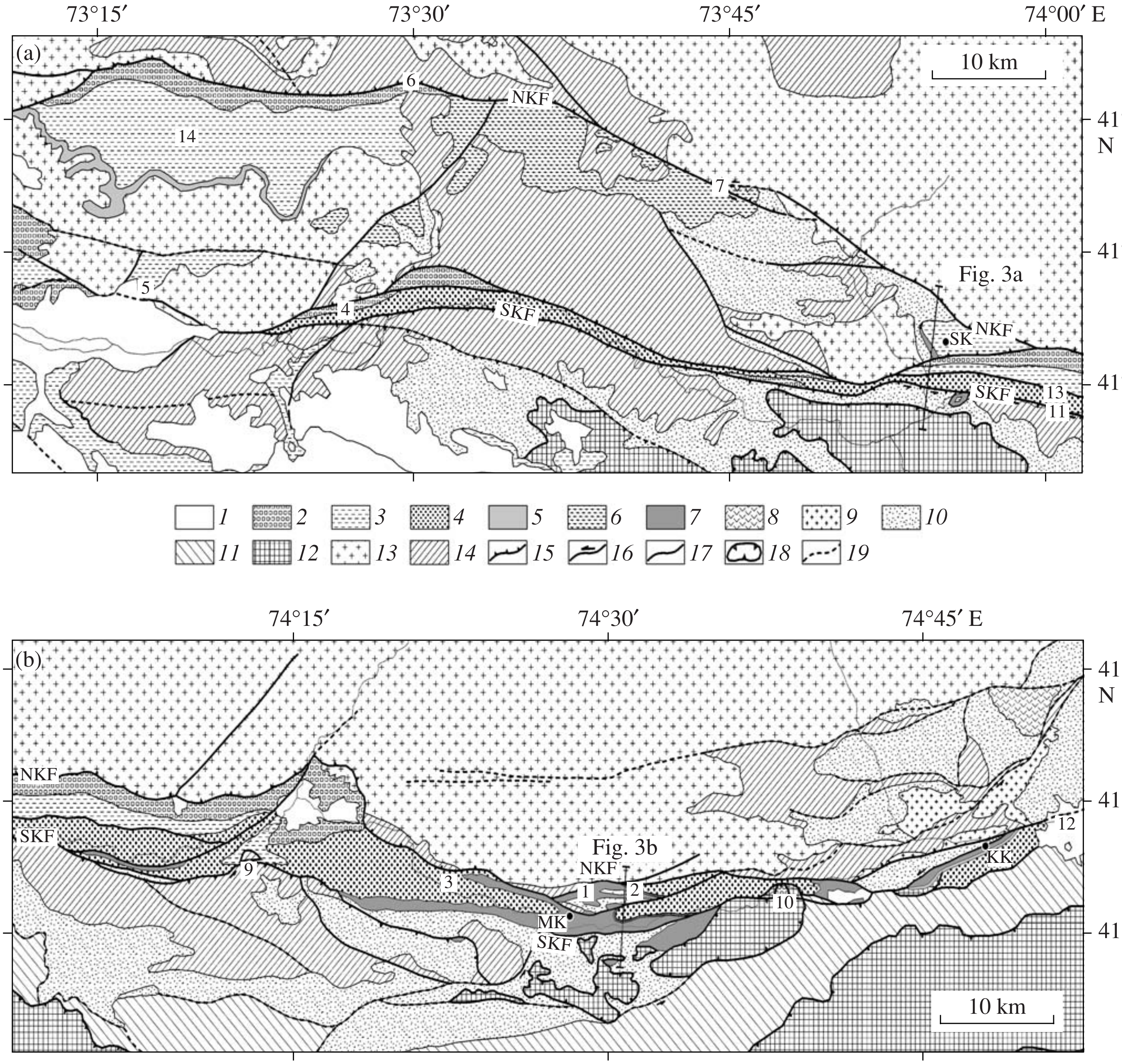

Fig. 2. Geological sketch map of the Ming-Kush–Kökömeren Zone and its framework without the cover of upper Quaternary sediments: (a) western and (b) eastern parts of the zone. (*1*) Lower to middle Pleistocene (Q_{1-2}), alluvial and proluvial sediments; (*2*) upper Pliocene to Eopleistocene (N_2^3–Q_E) Sharpyldak Formation; (*3*) Neogene (N_{1-2}) varicolored sequence, a probable analogue of the Naryn Formation; (*4*) Oligocene to lower Miocene (E_3–N_1^1) Ming-Kush Conglomerate, a probable analogue of the Kyrgyz Formation; (*5*) Paleocene to Eocene (E_{1-2}) Kok-Turpak Formation; the Kok-Turpak and thin Kyrgyz formations, unspecified (E–N_1^1) in the northwestern part of the map; (*6*) Paleogene to Neogene, unspecified; (*7*) Lower Jurassic (J_1); (*8*) Permian (?) Beletuk Formation (P?), volcanic rocks; (*9*) Late Paleozoic granitoids; (*10–12*) Early to Middle Carboniferous lithotectonic zones: (*10*) North Tien Shan Zone (Cn), (*11*) Transitional Zone (Cm), (*12*) Middle Tien Shan Zone (Cs); (*13*) Late Ordovician granitoids (γO_3); (*14*) Lower Paleozoic volcanic and sedimentary sequences (Sn–O_3); (*15–17*) faults reactivated or arisen during neotectonic stage (E_3–Q): (*15*) reverse and thrust faults, (*16*) strike-slip faults, (*17*) unspecified faults; (*18*) Late Paleozoic nappes; (*19*) other Late Paleozoic faults. Settlements and faults (letters in map): KK, Kara-Keche; MK, Ming-Kush; SK, Sary-Kamysh; SKF, South Kavak Fault, NKF, North Kavak Fault. See text for explanation of numerals in map.

Table 1. K–Ar age of igneous rocks from the Ming-Kush–Kökömeren Zone, the Middle Tien Shan, after I.V. Chernyshev and V.A. Lebedev, the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences

Sample	Location	Material	K, % ± σ	$^{40}Ar_{rad}$, ng/g ± σ	$^{40}Ar_{air}$, %	Age, Ma ± 2σ
13865	Kok-Turpak Formation	Basalt, whole-rock sample	1.42 ± 0.02	6.87 ± 0.07	24.7	68.4 ± 2.3
13866	Paleozoic basement	Diorite, whole-rock sample	1.80 ± 0.02	61.3 ± 0.6	5.3	434 ± 15

azimuthal unconformity. A more pronounced structural unconformity was documented in the core of the northernmost anticline in the Ming-Kush segment of the zone, where the Jurassic rocks directly overlap a dioritic intrusion of Late Ordovician age and nearby overlie Lower Carboniferous red beds of the Dungurme Formation.

The Jurassic sequence consists of quartz and polymictic sandstones, siltstone, and shale with interbeds of gravelstone, carbonaceous shale, and economic coal seams mined in the Ming-Kush and Kara-Keche open pits. At the western slope of the main Ming-Kush open pit, burnt varicolored siltstone and clay—products of underground fire in self-inflammable coal seams—are exposed. These rocks contain casts of Ginkgoales leaves (*Ginkgo* sp., *Sphenobaiera* sp., *Rseudotolleria* sp. ?), presumably Czekanowskiales (*Phoenicopsis* sp. ?), Coniferous (*Podozamites* sp., *Pityophyllum ex gr. angustifolium* (Nathorts) Moeller, *P. ex.gr. nordenskioldii* (Heer) Nathorst), and *Desmiophyllum* sp. and fern *Sphenopteris*. In the opinion of M.P. Doludenko and E.I. Kostina, who determined these plant remains at the Geological Institute, Russian Academy of Sciences (RAS), the prevalence of Ginkgoales and Coniferous *Pityophyllum* indicates the Jurassic age of the flora. With some uncertainty, the age is Early Jurassic, although some of the determined plants are known from Middle Jurassic rocks.

The total thickness of the Jurassic rocks in the Ming-Kush River valley attains 600–680 m. At the northern margin of the Ming-Kush–Kökömeren Zone, the thickness is reduced to 350 m and the clastic rocks become coarser. In the western direction (Sary-Kamysh settlement), the thickness decreases up to 100 m not only due to subsequent scouring, but also because of omission of the lower constituents of the section [20]. All this indicates that a structural topography existed in the Early Jurassic despite the suggestion that the initial area covered by the Jurassic sediments was undoubtedly larger that the region of their present-day occurrence. The depocenter was situated in the eastern segment of the zone near Ming-Kush and Kara-Keche settlements.

In some places, the Jurassic rocks are overlain without visible unconformity by the Kok-Turpak Formation up to 40 m thick, which is comprised of sandstone and unsorted clay with interlayers of sandy limestone and marlstone, and a flow of olivine basalt in the lower part of the section (Fig. 2b, locality 2). The K–Ar age of basalt is 68.4 ± 2.3 Ma (Table 1). This is the first evidence of the occurrence of Cenozoic volcanic rocks in the central part of the Middle Tien Shan. Previously, basalts were dated with isotopic methods only in the north and the south of the mountainous edifice within the Issyk-Köl, Chüy, and Ak-Say basins. On the basis of the isotopic age of the basalt and findings of the Eocene fauna in the Kok-Turpak Formation elsewhere in the Middle Tien Shan, we have referred this formation to the Paleocene–Eocene, although it cannot be ruled out that the bottom of this subdivision extends down to the Upper Cretaceous (Mikolaichuk et al., 2006).[1]

As concerns the post-Kok-Turpak Cenozoic sedimentary rocks of the Ming-Kush–Kökömeren Zone, our data substantially specified the previous views on their stratigraphy. It turned out that fine clastic, mainly varicolored rocks that were included into the conglomerate sequence overlie rather than replace it in the lateral direction. Thus, the previously recognized pre-Sharpyldak Paleogene–Neogene sequence must be divided into two units: the lower coarse clastic unit called the *Ming-Kush Conglomerate*, and the upper fine clastic unit called the *varicolored sequence* (Table 2).

The Ming-Kush Conglomerate extends from the headwater of the East Kara-Keche River westward along the Ming-Kush, Kökömeren, and Naryn rivers almost up to the mouth of the Kambar-Ata River, cropping out within a tract more than 125 km long and 3–4 km wide (up to 6 km near the mouth of the Ming-Kush River). This tract is interrupted only at the pass between the Kara-Keche and Ming-Kush valleys and near the Ming-Kush settlement. In the first locality, the interruption is caused by subsequent closing of walls of the Ming-Kush–Kökömeren Ramp, and in the second locality, by the uplifting of its bottom owing to recent deformation. However, the initial continuity of the area covered by the Ming-Kush Conglomerate removes any doubt.

This sequence is an alternation of lenticular conglomerate interlayers ranging from fine-pebble to boulder and block varieties (fragments up to 0.3 and occasionally 1.0 m across). The pebbles are rounded to various extents. The coarsest clastic material, poor sorting, and a high content of poorly rounded fragments are

[1] A. V. Mikolaichuk, V. A. Simonov, A. V. Travin, and E. R. Sobel, "Mesozoic and Cenozoic Plume-Related Magmatism of the Middle Tien Shan," in *Geodynamics and Geoecology of High-Mountain Regions in the 21st Century* (International Research Center—Geodynamic Testing Site in Bishkek. Scientific Station of the RAS, Moscow–Bishkek, 2006), No. 1, pp. 50–57.

Table 2. The Cenozoic rocks of the Ming-Kush–Kökömeren Zone, the Middle Tien Shan

<table>
<tr><th>Subdivisions, after [6, 7, 20, 21]</th><th colspan="2">Subdivisions accepted in this paper</th></tr>
<tr><td>Quaternary alluvial and proluvial sediments</td><td colspan="2">Quaternary alluvial and proluvial sediments</td></tr>
<tr><td>Upper Pliocene to Eopleistocene Sharpyldak Formation: proluvial sequence of conglobreccia and gravelstone consisting of fragments of granitic rocks from the North Tien Shan</td><td>Upper Pliocene to Eopleistocene Sharpyldak Formation: conglobreccia and gravelstone consisting of fragments of granitic rocks derived from the North Tien Shan, the northern facies of the Ming-Kush–Kökömeren Zone</td><td>Upper Pliocene to Eopleistocene Sharpyldak Formation: conglomerate and coarse-grained sandstone with fragments of granitic rocks from the North Tien Shan, the southern facies of the Ming-Kush–Kökömeren Zone</td></tr>
<tr><td rowspan="2">Pliocene [6, 7] or Oligocene to Miocene [20, 21] conglomerate sequence that consists of fragments of limestone from the Middle Tien Shan and locally replaced with fine clastic sedimentary rocks</td><td colspan="2">Lower to middle Miocene varicolored sequence as an analogue of the Naryn Formation</td></tr>
<tr><td colspan="2">Oligocene to lower Miocene Ming-Kush Conglomerate: coarse-clastic sequence consisting of fragments of limestone from the Middle Tien Shan</td></tr>
<tr><td>Paleocene to Eocene Kok-Turpak Formation: sandstone and unsorted clay with a basaltic flow</td><td colspan="2">Paleocene to Eocene Kok-Turpak Formation: sandstone and unsorted clay with a basaltic flow</td></tr>
</table>

characteristic of conglomerates that crop out in the Ming-Kush and Kara-Keche valleys. Gravelstone, sandstone, and siltstone interbeds are extremely rare and thin, occupying less than a few percents of the sequence volume. The number and thickness of fine clastic interbeds increase westward, e.g., southwest of the Sary-Kamysh settlement, but nowhere they becomes prevalent. The thickness of the Ming-Kush Conglomerate does not exceed one kilometer (~800 m southwest of the Sary-Kamysh settlement, ~600 m on the right bank of the Ming-Kush River west of the settlement bearing the same name, and 650–700 m south of the Kara-Keche settlement. In the first section, the bottom of the sequence is not exposed, while the roof has not retained in the other two sections. According to [20], the thickness of this conglomerate sequence reaches 1.5 km at the headwater of the Ming-Kush River. The paleomagnetic examination of the Ming-Kush Conglomerate on the right bank of the Ming-Kush River west of the Ming-Kush settlement (Fig. 2b, locality 3) performed by G.Z. Gurarii and N.Ya. Dvorova using the samples from our collection showed that the lower portion of the section has normal remanent magnetization, whereas the upper portion is characterized by inverse magnetization.

The pebbles of the Lower Carboniferous limestone are predominant in the Ming-Kush Conglomerate overall in the Middle Tien Shan. In the Ming-Kush River valley (Fig. 2b, locality 3), the pebbles consist of 55% Lower Carboniferous limestone, 36% red sandstone and siltstone of the Upper Ordovician or Lower Carboniferous, and 9% quartz and silicified rocks. Thus, we confirm the previous data that only the rocks from the southern wall of the Ming-Kush–Kökömeren Zone occur as pebbles; the granitic rocks of the North Tien Shan that dominate in its northern wall are absent. In the Kara-Keche and Ming-Kush valleys, the conglomerate sequence overlies without visible unconformity either the Kok-Turpak Formation or Jurassic rocks. On the right bank of the Kovyuk-Suu River southwest of the Sary-Kamysh settlement, the Ming-Kush Conglomerate is conformably overlain by a varicolored sequence (500–700 m) of alternating sandstone, siltstone, and clay with interlayers of gypsum, marlstone, gravelstone, and a less frequent conglomerate (Fig. 3a). The same relationships between the Ming-Kush Conglomerate and the varicolored sequence were established in the Tabylgyty River valley (southern bank of the Kökömeren River) and at the headwaters of the East Kara-Keche River.

Near the Sary-Kamysh settlement and at the headwaters of the East Kara-Keche River, a member (100–200 m) of brown gypsum-bearing clay with gypsum interlayers 10–20 cm thick occurs in the lower portion of the varicolored sequence. To the southwest of the Sary-Kamysh settlement, a few conglomerate beds similar to the Ming-Kush Conglomerate were observed at the base of this member. However, 1.5 km to the north of this outcrop, the conglomerate beds pinch out and the brown clay and overlying units of the varicolored sequence rest upon the Jurassic rocks (Fig. 4a). Farther northerly, where these rocks pinch out, the Lower Carboniferous red beds are underlying rocks. It is important to note that no angular unconformities are established between all the units listed above, and only a slight azimuthal unconformity is documented.

To the west of the Sary-Kamysh settlement, two types of sections that occupy different structural position are recognized in the Ming-Kush–Kökömeren Zone. In the southern branch of this zone, the Ming-Kush Conglomerate extends along the southern margin of the basin. Judging from the geological map, this tract continues on the right bank of the Kökömeren River and farther along the Naryn River for 40 km up to the

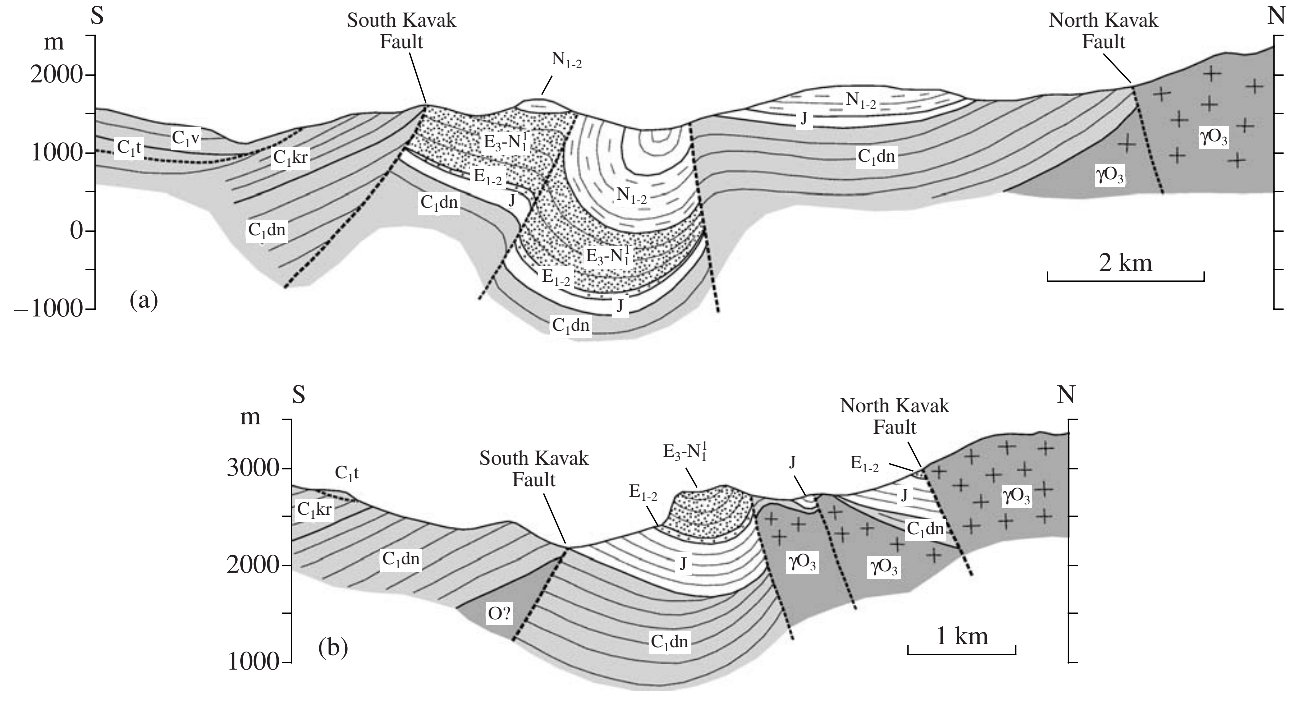

Fig. 3. Geological sections across the Ming-Kush–Kökömeren Zone: (a) near the Sary-Kamysh settlement, (b) east of the Ming-Kush settlement. See caption of Fig. 2 for indices of rocks.

Temirkent settlement (Fig. 2a, locality 4), where the same conglomerate with sandstone interbeds occurs likewise in the east (personal communication from A.L. Strom). In the northern branch of the Ming-Kush–Kökömeren Zone separated from the southern branch by an uplifted Paleozoic block, the Ming-Kush Conglomerate was not observed. In most outcrops, the varicolored sequence a few hundred meters thick lie at the bottom of the Cenozoic section. In the adjacent Ketmen-Tübe Basin, the thickness of this sequence attains 1 km and its upper portion becomes uniformly pale. The section 2 km north of the Kyzyl-Jasy settlement at the junction of the Ming-Kush–Kökömeren Zone with the Ketmen-Tübe Basin (Fig. 2a, locality 5) is indicative of this.

The lower brown clayey portion of the varicolored sequence (probably comparable in age to the Kyrgyz Formation) rests here upon grus of the weathered Late Ordovician granite up to a few meters thick (Fig. 4b). In some places, e.g., near the Bel-Aldy and Toluk settlements, the very thin Kok-Turpak Formation probably occurs at the bottom of the Cenozoic section. The gravelly inclusions in fine clastic material and calcareous nodules are characteristic of this formation. Red beds with a clay matrix (a few tens of meters) observed on the wall of the Bel-Aldy valley are similar to the Kyrgyz Formation of the adjacent basins.

In the northern segment of the Ming-Kush–Kökömeren Zone (Bel-Aldy, Sary-Kamysh, and Kichi-Jotash settlements), the varicolored sequence is overlain without visible unconformity by a unit of arkosic and polymictic gravelstones, coarse-grained sandstone, and conglobreccia. The gravelly material is predominant; however, cobblestones and boulders occur as well. The sequence is characterized by poor roundness of fragments and the predominance of granitic rocks in the clastic material, which was derived from a provenance situated to the north. In the Zyndin River valley, the pebbles consist of 56% Early Paleozoic granitoids, 20% silicified polymictic sandstone and siltstone of Ordovician (?) age, 13% basalt and basaltic andesite, 2% silicified acid lavas, and 9% veined quartz. The percentage of granitic material increases in gravelly and coarse sandy rocks consisting largely of granitic grus. On the basis of lithology and the position of the section, Sadybakasov [20] correlated this sequence of gravelstone and conglobreccia with the upper Pliocene–Eopleistocene Sharpyldak Formation.

This sequence is locally overlapped by pebbles, loesslike loam, and sandy loam of the lower and middle Pleistocene, which overlie Cenozoic rocks of various ages and a Paleozoic basement with a greater or lesser angular unconformity, filling paleovalleys in the northern Ming-Kush–Kökömeren Zone and comprising sporadic remnants of higher terraces of the Kökömeren River. The upper Pleistocene and probably Holocene lower terraces in the valleys of the Kökömeren River and its large tributaries are covered by sediments close in lithology to lower and middle Pleistocene sediments.

A characteristic sequence of gravelstone and conglomerate that overlies the varicolored sequence with a slight unconformity was recognized at the southern

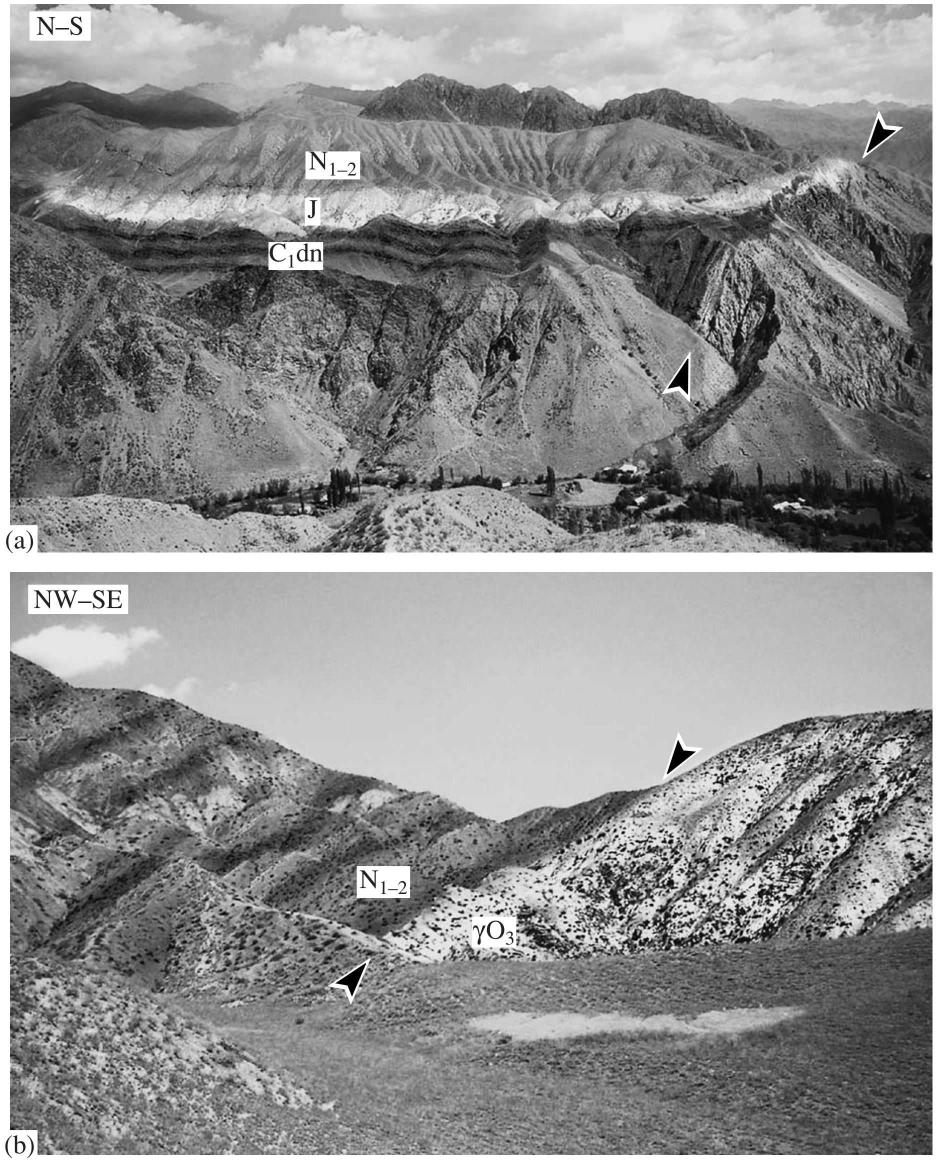

Fig. 4. The Neogene (N_{1-2}) sequence in the northwestern Ming-Kush–Kökömeren Zone: (a) overlapping of Jurassic (J) sedimentary rocks that rest on the Lower Carboniferous (C_1dn) red beds without visible unconformity near the Sary-Kamysh settlement and (b) overlapping of the weathered Late Ordovician (γO_3) granite northwest of the Kyzyl-Jasy settlement (Fig. 2a, locality 5).

margin of the Ming-Kush–Kökömeren Zone at the interfluve of the Tabylgyty and Keng-Say (Ak-Köl) rivers. With some outward similarity to the Ming-Kush Conglomerate, these rocks are distinguished by poorer roundness of pebbles, by intercalation of conglomerates and sandstones that occupy an appreciable portion of the section, and mainly by the occurrence of a considerable percentage of North Tien Shan granitoids along with limestone and other sedimentary rocks as pebbles. This sequence is likely a southern facies analogue of the unit of arkosic gravelstone and conglobreccia and may be referred to, as the latter, as the Sharpyldak Formation. To the east, in the Keng-Say and Dungurme valleys, this sequence apparently rests directly upon the Ming-Kush Sequence.

The correlation of the sequence, consisting of gravelstone, conglomerate, and conglobreccia, with the Sharpyldak Formation allows us to estimate the stratigraphic position of the underlying varicolored fine clastic sequence. In addition to the prevalence of fine clastic rocks, this sequence is characterized by a three-member structure: brown clay at the bottom, intercalation of variously colored beds in the middle, and a largely pale upper portion, which occurs most completely in the Ketmen–Tübe Basin. All these attributes are typical of the Neogene Naryn Formation, which is widespread in the adjacent Naryn and Jumgal basins.

In turn, the analogy between the varicolored sequence in the Ming-Kush–Kökömeren Zone and the

Naryn Formation provides insight into the stratigraphic position of the Ming-Kush Conglomerate that overlies the Kok-Turpak Formation and underlies the analogues of the Naryn Formation. We correlate the Ming-Kush Conglomerate with the Oligocene to the lower Miocene Kyrgyz Formation.

NEOTECTONIC STRUCTURE

The Ming-Kush–Kökömeren Zone is bounded in the north and south by active faults that have been named the North and South Kavak faults, respectively. Both faults are wavy in plan view and consist of extended segments that build one another up.

The North Kavak Fault is characterized by the overall uplifted northern wall. The fault plane dips to the north at angles up to 60–70° in the Zyndin River valley (Fig. 2a, locality 6) and to the northeast of the Ming-Kush settlement (Fig. 5a). At the Toluk–Terjailyak interfluve (Fig. 2a, locality 7), the North Kavak Fault Zone consists of three ruptures, along which the boundary of Caledonian granites with overlapping Upper Pliocene–Eopleistocene gravelstone and fine-pebble conglomerate subsides stepwise to the south (Fig. 5b). The Cenozoic beds and their soles are bent near the faults. The total vertical separation along reverse faults and near-fault flexures is greater than 100 m. The left-lateral offsets of the drainage pattern have been documented as well (Fig. 5c). They are greater than 30 m along the northern fault plane, attain ~30 m along the middle plane, and 30–40 m along the southern plane. Thus, the amplitude of Quaternary reverse and strike-slip displacements in the fault zone are commensurable. The left-lateral offsets have been documented for younger streams (up to 10 m along the southern fault). To the west (Fig. 2a, locality 6), the Zyndin River valley also bends to the left at the intersection with the North Kavak Fault. To the east, in the Kara-Keche River valley, the middle Pleistocene moraine is enclosed between the Permian (?) andesite of the northern wall and the Jurassic sequence. The moraine is cut by a fault that is inclined at an angle of 50° to the north. Furrows on its plane are inclined 25° to the east, indicating a combination of reverse and left-lateral strike-slip faulting.

The South Kavak Fault has an uplifted southern wall. The fault is inclined to the south at angles of 40–60° (Fig. 6a), although in the Kovyuk-Suu River valley southwest of the Sary-Kamysh settlement, the fault plane becomes almost vertical. The tectonic gypsum lenses of the Kara-Chauly Formation (Serpukhovian Stage of the Lower Carboniferous) extend here along the fault. Like the North Kavak Fault, the South Kavak Fault is a boundary of the present-day occurrence of the Mesozoic and Cenozoic sequences of the Ming-Kush–Kökömeren Zone. However, the fault branches of the Ming-Kush segment of this fault retreat southward on the slope of the Moldo-Too Range, and the northern wall of the fault embraces not only the Jurassic and Cenozoic rocks but also the Visean red beds of the Dungurme Formation and the Serpukhovian Kara-Chauly Formation.

In local segments, the frontal zone of the South Kavak Thrust Fault flattens out. For example, on the right bank of the Tabylgyty River (Fig. 2b, locality 9), the frontal zone of the southern wall of this fault, composed of the Ordovician shale, is separated as a small (hundreds of meters) tectonic nappe that overlies the Neogene varicolored sequence and probably upper Pliocene–Eopleistocene gravel and a conglomerate in the east. Together with these sediments, the nappe has subsided relative to the front of the thrust and deformed into a synform dipping somewhat more gently than the underlying beds (Figs. 6b, 6c).

A similar but larger nappe with amplitude of 1.2 km was described at the headwater of the Ming-Kush River [7, 20, 21] (Fig. 2b, locality 10). This nappe is composed of the Tournaisian limestone with relics of the Pliocene–Eopleistocene conglomerate on its surface. This conglomerate differs in outward appearance from the Oligocene to Miocene Ming-Kush Conglomerate that underlies the nappe and forms a synform together with the latter. With allowance for 4-km overlapping of the Jurassic rocks along the South Kavak Thrust Fault, the amplitude of the total Cenozoic thrusting is more than 5 km. The outcrops of the brecciated Tournaisian limestone in the west of the Kara-Keche segment of the Ming-Kush–Kökömeren Zone are remnants of tectonic nappe as well. These outcrops are located 4 km north of the front of the main allochthonous limestone massif in the Moldo-Too Range.

All nappes and thrusts on the northern slope of the Moldo-Too Range are hardly Cenozoic. The major phase of thrusting is Hercynian in age [16, 24, 25]. However, it is evident that the structural elements of the South Kavak Fault underwent neotectonic activation with recent thrusting for more than 5 km.

The left-lateral offset along the South Kavak Fault has been documented as well. For example, the Kovyuk-Suu River valley bends to the left for 50 m at its intersection with this fault. If the high right terrace downstream this intersection belongs to the Kovyuk-Suu valley, the slip may reach ~200 m. The Tabylgyty River valley curves to the left for ~250 m. The relationships between the vertical and lateral displacements on the left bank of the Ak-Baltyrgan River are especially interesting (Fig. 2a, locality 11). The lower reaches of this stream turned out to have been captured due to the tectonic uplift of its near-fault segment and have been retained as a middle Pleistocene paleovalley that cuts the Ming-Kush Conglomerate. The paleovalley abuts the South Kavak Fault, whose southern wall composed of Upper Ordovician tuff is raised for ~15 m above the valley bottom (Fig. 7c). Starting from this point, the paleovalley extends to the east along the fault and 700 m farther cuts the fault-line scarp and opens into the Kökömeren valley. The 700-m segment of the paleovalley that follows the fault may be regarded as the

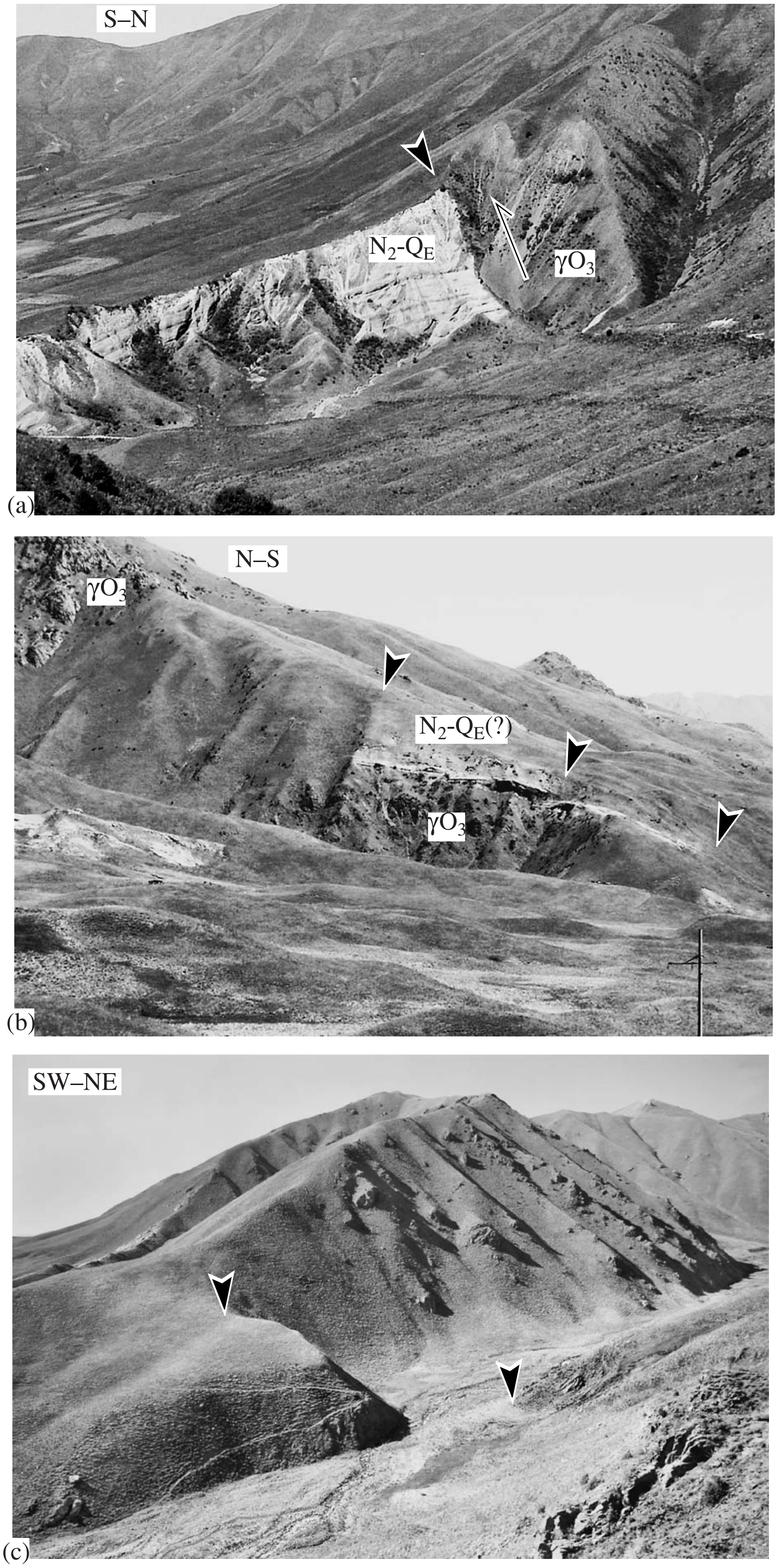

Fig. 5. The North Kavak Fault: (a) Paleozoic rocks upthrown on the Upper Pliocene to Eopleistocene (N_2^3–Q_E) gravelstone and conglomerate on the right (western) bank of the Zyndin River (Fig. 2a, locality 6), (b) upthrow separations along three branches of the fault at the Toluk–Terjailyak interfluve (Fig. 2a, locality 7), and (c) left-lateral offset of the valley along the northern branch of the fault, the same locality.

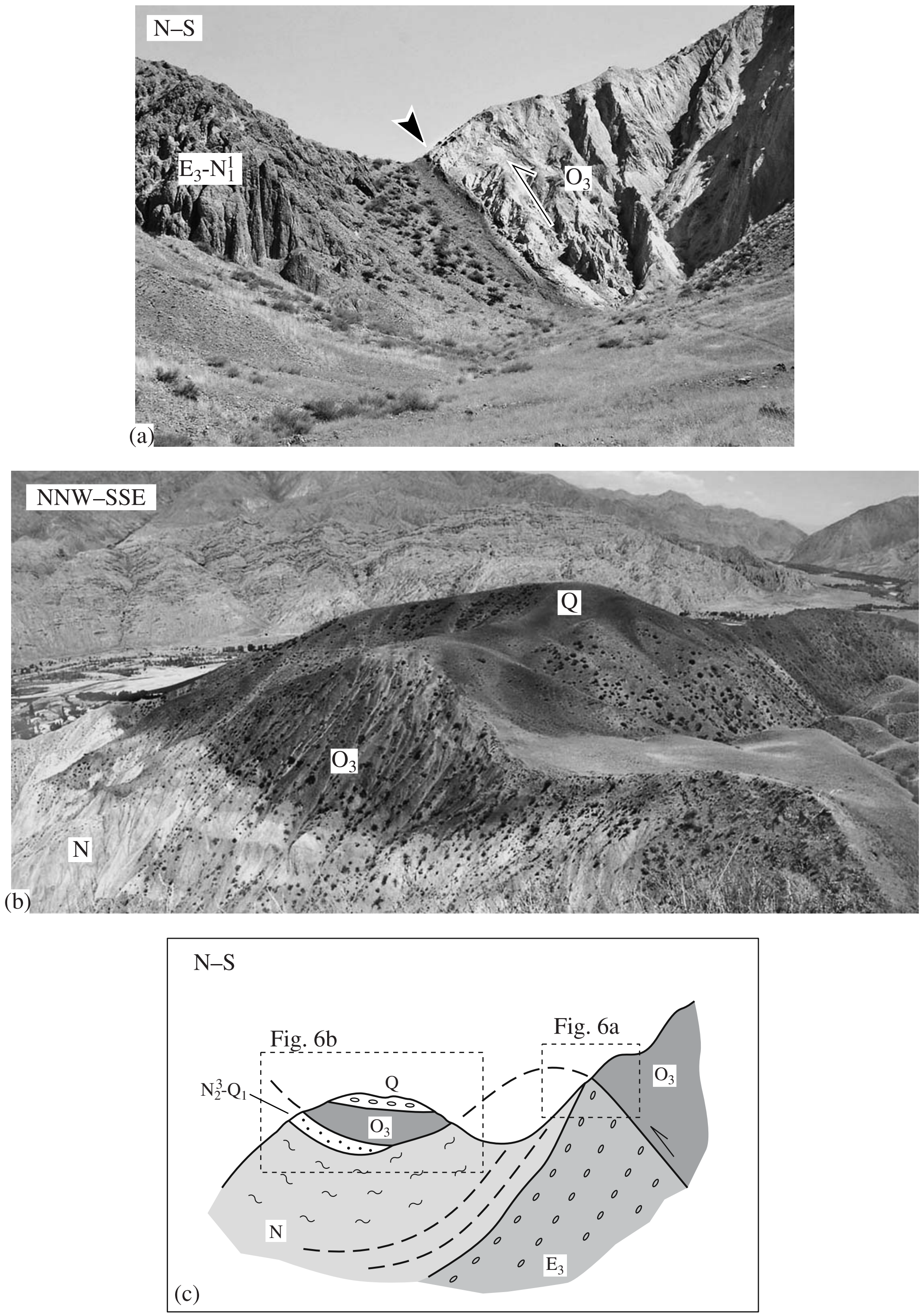

Fig. 6. South Kavak Fault on the right (eastern) coast of the Tabylgyty River (Fig. 2b, locality 9): (a) Ordovician shale thrust over Oligocene–Lower Miocene Ming-Kush Conglomerate and Neogene varicolored sequence, (b) tectonic nappe of Ordovician shale that overthrusts the Neogene varicolored sequence—both units are deformed into a synform—and (c) section across thrust fault (a) and nappe (b). See caption of Fig. 2 for indices of rocks.

result of the left-lateral offset, which is correlative to the vertical separation for 15 m. If this is the case, the late Quaternary left-lateral strike-slip offset could be much larger than the amplitude of thrusting.

The Ming-Kush–Kökömeren Zone is characterized by internal folding specific in each of its segments that are different in neotectonic uplifting and depth of erosion. The most uplifted segment is located near the pass

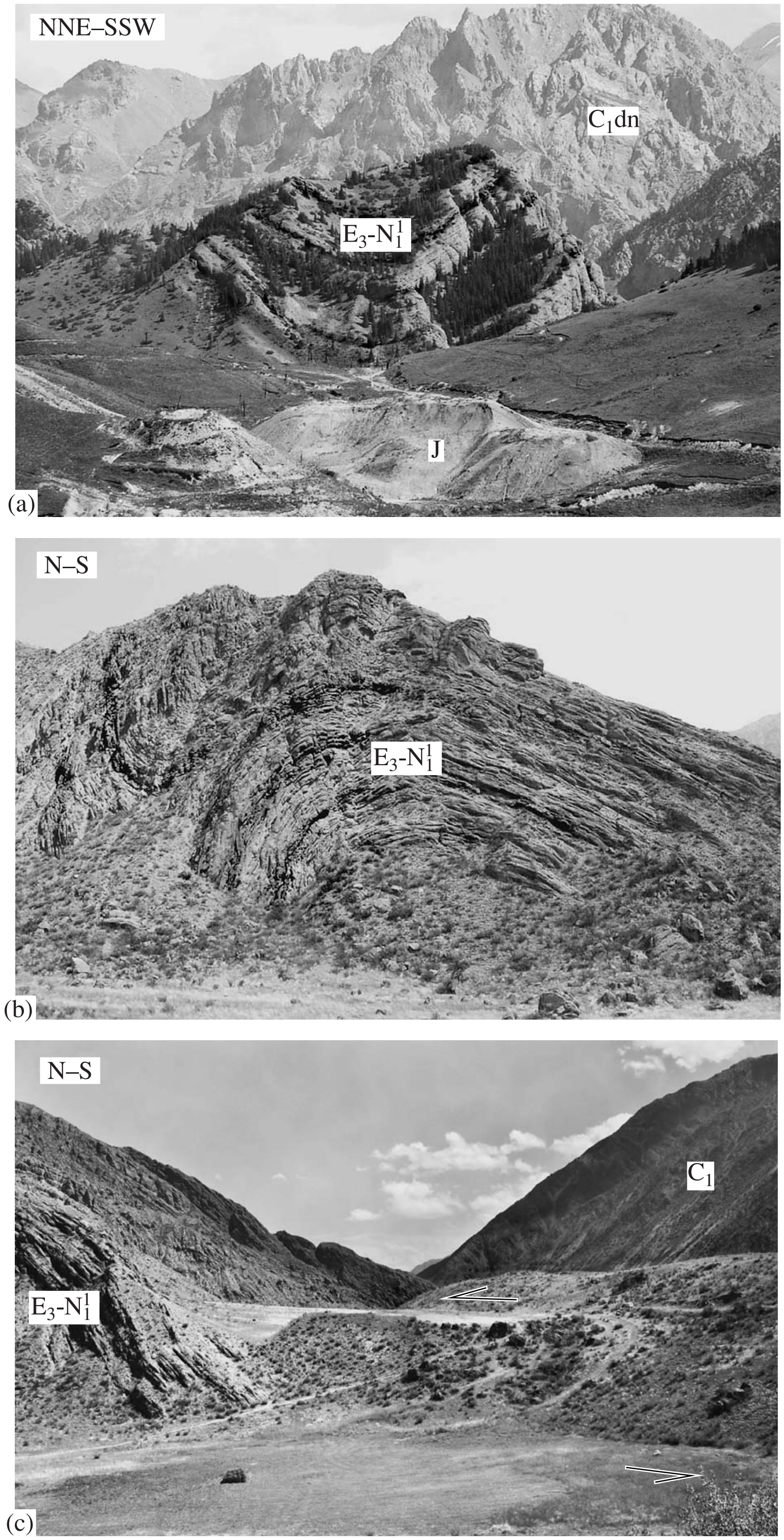

Fig. 7. The structure of the Ming-Kush–Kökömeren Zone: (a) syncline composed of the Oligocene–lower Miocene conglomerate in the Ming-Kush segment of the zone (Fig. 3b), (b) folded Oligocene–lower Miocene conglomerate in the Ak-Baltyrgan River valley (Fig. 2a, locality 13), and (c) left-lateral offset of the Middle Pleistocene paleovalley along the South Kavak Fault (Fig. 2a, locality 11). In the foreground—a closed depression at the abutment of the upper reaches of paleovalley on the fault; the paleovalley extends behind this depression between two fault branches; in the background—breaking of the southern uplifted wall of fault by the paleovalley at a distance of 700 m from the closed depression. See captions of Figs. 2 and 4 for indices of rocks.

between the Song-Köl Basin and the Kara-Keche River valley, which is higher by ~1 km than the Ming-Kush River valley. From the headwater of the Kara-Keche River, the surface descends toward the Ketmen-Tübe Basin in the west.

The Kara-Keche segment of the Ming-Kush–Kökömeren Zone is a syncline, whose NE–SW axis adjoins the South Kavak Fault to the south of the Kara-Keche settlement. Somewhat easterly, the northern limb and core of the syncline filled with the Ming-Kush Conglomerate are exposed near the fault. In the southern limb, this sequence dips north-northwest at angles of 65–80°. In the northern limb, the sequence is retained to a fuller extent; the dip angle increases from ~30° south-southeast close to the syncline core to 45–55° at the base of conglomerate sequence and 70–90° to the south-southeast azimuth in the Jurassic rocks. The lower portion of the conglomerate sequence is cut by a longitudinal fault inclined at 80° north-northwest. The furrows on the fault plane are inclined eastward at medium angles, indicating a combination of reverse and left-lateral strike-slip displacements.

The southeastern limb is developed more completely beneath the cover of the middle Pleistocene moraine at the headwater of the East Kara-Keche River (Fig. 2b, locality 12), where the varicolored sequence overlaps the Ming-Kush Conglomerate in the syncline core. In the southeastern limb of the syncline, the Ming-Kush Conglomerate is overturned up to 80–75° to the southeast, while the beds of the varicolored sequence flatten from 80–85° to 45–50° toward the syncline core. In the northwestern limb, the varicolored sequence dips at angles of 80–90° to the southeast.

In the west of the Kara-Keche segment, the only exposed northern syncline limb is composed of the Jurassic rocks overlain by a tectonic nappe of the brecciated Tournaisian limestone. The attitude of the Jurassic rocks changes southward from the overturned (90–70° north-northwest) to 65–90° and then 40–50° south-southeast. In the south, the Jurassic sequence is disturbed by two almost bedding-plane thrust faults with the threefold repetition of beds in the section. The Jurassic sequence is overlapped by middle Pleistocene (?) moraine inclined at angles of 20–30° north-northwest. To the south, the Jurassic section is built up by the Kok-Turpak Formation and the lower part of the Ming-Kush Conglomerate.

The structure of the Ming-Kush segment of the Ming-Kush–Kökömeren Zone is more complex (Fig. 3b). In its northern portion to the northeast of the settlement of Ming-Kush, the Kok-Turpak Formation and the Ming-Kush Conglomerate plunge beneath the North Kavak Reverse Fault at angles of 40–60°. To the south, the folded Jurassic rocks emerge from under these rocks. The southern limbs of two anticlines are disturbed by reverse faults conjugated with folds. The Lower Carboniferous red beds crop out in anticline cores. In the southern anticline, a diorite intrusion juts from under the red beds (Fig. 2b, locality 1). The K–Ar age of diorite was determined at 434 ± 15 Ma (Table 1), which corresponds to the terminal Ordovician. On the northern limb of this anticline, two recent reverse faults steeply dip to the north. The Quaternary roughly bedded rubble is displaced along each of these faults for 8–10 m.

A large syncline, which is situated to the south, is pinched near the Ming-Kush settlement, where it is filled with Jurassic rocks overlapped by the Kok-Turpak Formation, and widens and deepens to the west and the east, where the Ming-Kush Conglomerate appears (Fig. 7a). In the western expansion of the syncline, the conglomerate dips at angles of up to 70°, flattening toward the core. To the south of the eastern expansion, a fault extends along the Ming-Kush valley and separates the Jurassic rocks from the Lower Carboniferous red beds overlapped by the Jurassic sediments. The Tournaisian limestone is thrust over the Jurassic sequence along the South Kavak Fault.

In the central Ming-Kush–Kökömeren Zone (Fig. 2a, locality 13), the intense folding is retained (Fig. 7b); the folds are combined here with longitudinal faults. In the Sary-Kamysh segment of the zone (Fig. 3a) immediately to the north of the South Kavak Fault, a large anticline is composed of the Ming-Kush Sequence. The hinge of this anticline gently plunges to the northwest, and the crest is complicated by a small syncline with a varicolored sequence in the core. In the north, the anticline is bounded by a reverse fault inclined at an angle of ~65° to the south. The furrows on its plane are oriented updip. Near the reverse fault, the beds of the Ming-Kush and varicolored sequences turn at up to 85–70° to the south. In the south, the reverse fault bounds an asymmetric syncline with a steeply dipping and partly overturned southern limb and a gentle northern limb.

The syncline is bounded in the north by a steep (80° to the north) reverse fault, along which the Sharpyldak gravelstone that overlies the varicolored sequence is overturned up to 80° to the north. The reverse fault separates the syncline from the northern part of the Ming-Kush–Kökömeren Zone, where the Ming-Kush Conglomerate is absent, and a lower clayey member of the varicolored sequence rests directly on the Jurassic rocks or the Lower Carboniferous red beds without a substantial angular unconformity (Fig. 4a). The beds dip eastward and southeastward at angles up to 30–35°.

The same feature is typical of the Sara-Kamysh and Ming-Kush segments of the Ming-Kush–Kökömeren Zone. In the south of this zone, the reverse faults dip southward, whereas in the north, they dip northward, thus providing centripetal motion of rock masses relative to the axial plane of the most subsided syncline.

As mentioned above, to the west of the Sary-Kamysh segment, the Ming-Kush–Kökömeren Zone is divided into the southern branch, where the Ming-Kush Conglomerate occurs, and the northern branch, where this unit is absent, probably replaced by a thin member of red beds. The southern branch is a narrow (commonly no wider than 2 km) ramp bounded by the South

Kavak Fault in the south. Within the ramp, the Ming-Kush Conglomerate dips largely in the northern bearings [26]. Outcrops of Paleozoic rocks separate the southern branch from the northern one, which consists of a series shallow basins with irregular outlines, but which is generally elongated along the Ming-Kush–Kökömeren Zone. The Paleozoic inliers at their southern slopes delineate gentle arches. The locally retained thin red beds mentioned above may be tentatively correlated with the Kok-Turpak Formation or the fine clastic facies of the Kyrgyz Formation. The red beds lie almost horizontally. In the basins, the thin basal unit of red beds is overlain by the Neogene varicolored sequence and locally by the Sharpyldak Formation. They lie nearly horizontal, but in the Kara-Jigach Basin in the western Ming-Kush–Kökömeren Zone (Fig. 2a, locality 5), the beds gently dip northward, while the folded beds inclined at 25–30° have been noted in the largest Bel-Aldy Basin (Fig. 2a, locality 14).

The recent basins in the northwestern branch of the Ming-Kush–Kökömeren Zone reveal the same asymmetry as in the northern wall of this zone in the east. The reverse and reverse–strike-slip faults occasionally accompanied by the turning up of beds extend on the southern slopes of uplifts along the northern walls of the basins and dip steeply northward, whereas the southern boundaries of the basins are irregular in outlines and characterized by stratigraphic onlaping of Cenozoic sediments on the Paleozoic rocks. The ramp of the southern branch of the Ming-Kush–Kökömeren Zone is an axis of the countervergence in this fault system.

DISCUSSION

The Cenozoic sequences of the Ming-Kush–Kökömeren Zone are deformed into longitudinal folds often complicated by reverse faults. In the north and the south, the zone is bounded by reverse and thrust faults. The southern boundary thrust fault is commonly low-angle in comparison with the northern fault and in some places passes into small tectonic nappes. According to overthrusting of Jurassic and Cenozoic sequences by Paleozoic rocks, the minimum amplitude of thrusting in the Upper Ming-Kush segment of the South Kavak Fault reaches 5 km. All this testifies to the transverse shortening of the zone by 1.5–2.0 times, and thus to the substantial component of transverse compression. At the same time, many longitudinal faults reveal indications of the Late Quaternary left-lateral strike-slip offset, which is commonly commensurable to the amplitude of coeval inverse faulting and thrusting along the same faults, and it occasionally turns out to be greater. For example, the Middle Pleistocene paleovalley that formerly served as the lower reaches of the Ak-Baltyrgan River is displaced to the left for ~700 m, whereas the coeval vertical separation is about 15 m.

Thus, the neotectonic structure of the Ming-Kush–Kökömeren Zone is transpressional, i.e., combining manifestations of transverse shortening and longitudinal strike-slip offset.

To estimate the age of this structural unit, it should be kept in mind that the Lower Carboniferous red beds, the Jurassic coal-bearing sequence, the Eocene Kok-Turpak Formation, the Oligocene–Miocene Ming-Kush Sequence, and the Neogene varicolored sequence commonly give way to one another without visible unconformity. The first signs of unconformable relationships appeared at the bottom of the upper Pliocene–Eopleistocene gravelstone–conglomerate sequence. The more or less distinct unconformity is documented overall at the base of lower–middle Quaternary pebblestones. The outlier of tectonic nappe on the right bank of the Tabylgyty River is indicative of this. A synform together with underlying Neogene–Eopleistocene deposits is overlapped with sharp unconformity by the middle Pleistocene pebblestone and loam. Thus, the complex faulting and folding in the Ming-Kush–Kökömeren Zone started to form in the late Pliocene and became much more intense in Quaternary.

Such a young age of dislocation poses a question concerning tectonic conditions of the deposition of the Ming-Kush Conglomerate in the Oligocene and Miocene. The intense supply of coarse clastic material and its deposition in a narrow Ming-Kush–Kökömeren Zone should be explained. In this regard, the following facts should be taken into consideration.

(1) The Ming-Kush conglomerate is a sequence of clastic rocks varying from gravel and fine-pebble to boulder and block varieties up to 1.0–1.5 km in thickness. Now, this sequence occurs as a tract more than 125 km long and a few kilometers wide. To the east of the Kovyuk-Suu River, this tract occupies the entire Ming-Kush–Kökömeren Zone and only its southern branch to the west. In the northern branch, the Ming-Kush Conglomerate was not deposited and the relatively loose and thin sediments of the Kok-Turpak Formation, Jurassic rocks, and weathered granites overlain by clay of the Naryn Formation are retained therein. It is obvious that no Oligocene–early Miocene uplifts existed in the north, and a plain topography was predominant therein. The sandy–gravelly composition and relatively small thickness of the Kyrgyz Formation at the neighboring walls of the Jumgal and Naryn basins and the Ketmen–Tübe Basin in the east (Kaindy settlement) indicate that no high or eroded highlands existed near the Ming-Kush–Kökömeren Zone.

(2) Pebbles in the Ming-Kush Conglomerate are more or less rounded, indicating that the fluival process participated in the formation of this sequence. The coarsest composition and the poorest roundness have been established in the east within the Ming-Kush and Kara-Keche valleys. Sadybakasov established that the greatest thickness of this sequence (up to 1.5 km) is reached at the headwaters of the Ming-Kush River. Thus, a source of clastic material was situated in the east, from where this material was spread westward by streams.

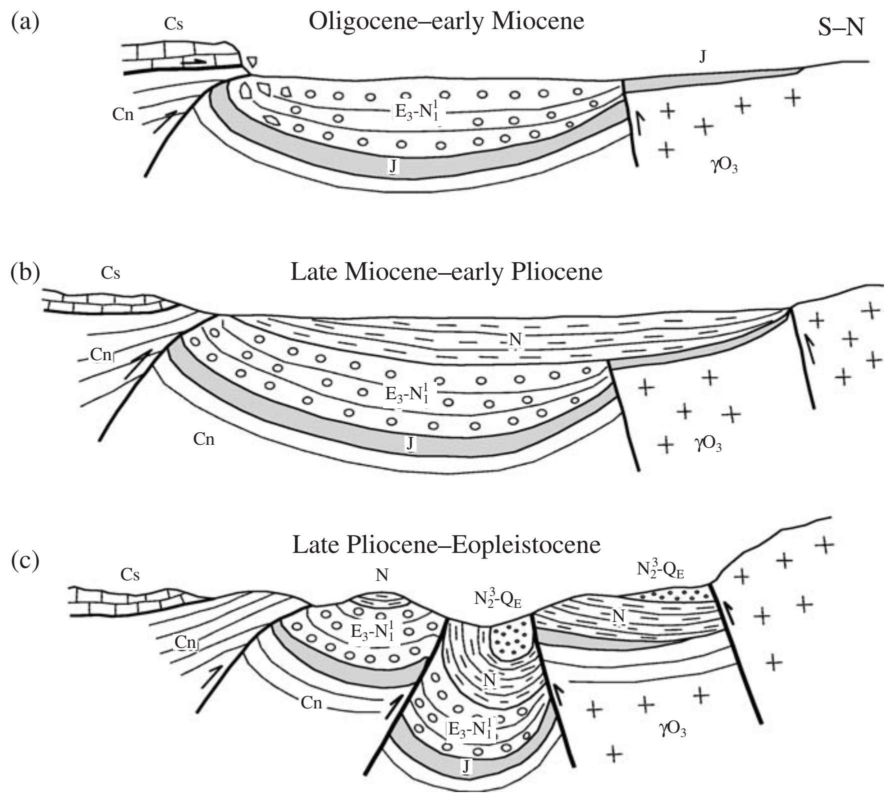

Fig. 8. Stages of the formation of the Ming-Kush–Kökömeren Zone: (a) Oligocene–early Miocene, (b) late Miocene–early Pliocene, and (c) late Pliocene–Eopleistocene. See caption of Fig. 2 for indices of rocks.

(3) The Ming-Kush Conglomerate does not contain a clastic material supplied from the northern framework of the Ming-Kush–Kökömeren Zone; in particular, no fragments of the Caledonian granites of the North Tien Shan are noted. The clastic material was derived from the south, and the Lower Carboniferous limestone is the most abundant rock observed in pebbles.

(4) Three Carboniferous lithotectonic zones are recognized in the Moldo-Too Range [16, 24, 25]. The northern zone pertaining to the Caledonian North Tien Shan is composed largely of Visean to Serpukhovian red beds and gypsum-bearing sequences. The southern lithotectonic zone separated from the northern one by a transitional zone is related to the Middle Tien Shan and is distinguished by the prevalence of the Tournaisian–Bashkirian limestones. The transitional zone is thrown up or thrust over the northern zone, and both these zones are overthrust by tectonic nappes of the southern zone. The minimum overlapping is ~20 km. The overthrusting is assumed to be Hercynian, because the nappe system is sealed to the east by the Late Carboniferous granite of the Song-Köl pluton. The Late Hercynian (Late Paleozoic–Early Mesozoic) left-lateral displacements made marks along the same reverse and thrust faults [16].

Taking into account the aforementioned data, the following history of the evolution of the Ming-Kush–Kökömeren Zone may be suggested. The Ming-Kush Conglomerate were formed under conditions of the initial neotectonic activation of the Middle Tien Shan, which started in the Oligocene and gave rise to low-mountain uplifts and deposition of relatively fine clastic and thin red beds of the Kyrgyz Formation in most intermontane basins. The abundance of the clayey matrix was caused by prevailing destruction of weathered rocks and redeposited products of weathering. On the northern slope of the Moldo-Too Range, the reactivation was expressed primarily in the resumed displacements of the Hercynian thrust sheets and nappes. Further, similar displacements resulted in overlapping of Cenozoic sequences by certain nappes. The frontal portions of nappes were actively destroyed, and they served as sources of clastic material for the Ming-Kush Conglomerate. Because the limestone nappes of the southern zone occupied the uppermost position in the Late Paleozoic structure of the Moldo-Too, their fragments are predominant in pebbles. The nappe-and-thrust hypothesis of the origin of the Ming-Kush Conglomerate explains its coarse-clastic appearance in combination with a relatively small emergence of the provenance.

The clastic material, which was supplied from the Moldo-Too Range, accumulated in a tectonic depression (asymmetric ramp) in front of the South Kavak thrust faults and nappes that were the main limitation of the ramp. The northern fault boundary of the ramp

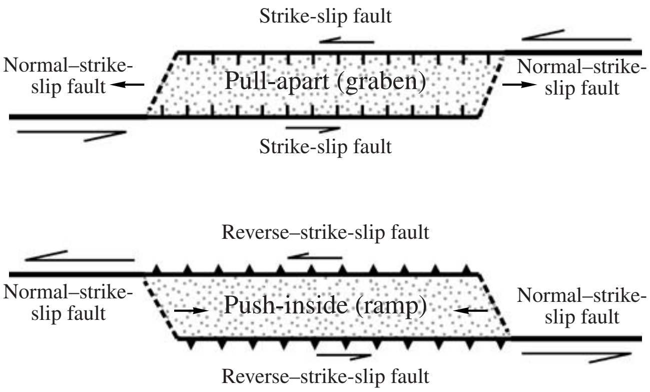

Fig. 9. Formation of pull-apart basins (grabens) under transtensional conditions and push-inside basins (ramps) under transpressional conditions: conceptual scheme.

existed as well, and the clastic material did not spread beyond this boundary. As judged from the section near the Sary-Kamysh settlement, the northern escarpment now marks a steep reverse fault, and it was the same in the Oligocene and early Miocene. According to the palinspastic reconstruction and possible overthrusting for a few kilometers in the south of the ramp, its initial width attained 10 and probably even 15 km (Fig. 8a).

The ramp evolved in the absence of substantial folding, and as a result, no angular unconformities between the deposited sequences have arisen. A stream valley where clastic material was deposited developed along the ramp. The near-channel part of the Naryn valley could have been a western continuation of this valley in the present-day Ketmen–Tübe Basin. Thus, the ramp filled with the Ming-Kush Conglomerate may be regarded as a paleovalley of the Pra-Naryn and Pra-Kökömeren.

The evolution of the ramp depression may be explained under the assumption that it arose in the Oligocene under transpressional conditions, i.e., along the boundary faults that underwent not only reverse and thrust faulting, but which also left-lateral strike-slip offsets that inherited similar but more intense movements that occurred in the Late Paleozoic and Early Mesozoic [4, 16]. This suggestion is based not only on relationships between the transverse shortening and left-lateral slip in the present-day structure of the Ming-Kush–Kökömeren Zone, which was formed largely in the Quaternary, but also supported by other evidence. As was shown above, the main provenance was likely situated in the Ming-Kush–Kara-Keche segment of this zone, where conglomerate sequence is the thickest and has the coarsest composition. The area of extensive tectonic nappes composed mainly of limestone of the southern lithotectonic zone of the Moldo-Too as the main source of clastic material is now located somewhat to the east, extending from the headwaters of the Ming-Kush River to the western Song-Köl Basin. This suggests a possible left-lateral offset of the main provenance for a distance of ~10 km. A detailed lithologic study could settle the question on the reality and distance of such an offset.

In most cases, the fault-bounded block that experiences transpression is uplifted along with centrifugal thrusting (flower structure, according to [30]). However, if such a block was initially a depression, it could have avoided inversion and developed as a basin of indentation (term proposed by Kuchai [11]). To distinguish the basins of indentation formed under transpressional conditions from the pull-apart basins as results of transtension, we have named the former push-inside basins [31]. The differences in their formation mechanisms are shown in Fig. 9.

An alternative mechanism of the evolution of the Ming-Kush–Kökömeren Zone during deposition of the Ming-Kush Conglomerate suggests that this zone evolved in the Oligocene under transtensional conditions as a pull-apart basin, and the transpressional setting that provided the formation of the present-day structure arose only by the late Pliocene. However, in this case the Ming-Kush–Kökömeren Zone would initially be bounded by normal and normal–strike-slip faults that did not leave indications in the present-day structure. All longitudinal faults have only a reverse or thrust component of separation, demonstrating the inherited character of neotectonic movements.

The intensity of tectonic movements decreased in the Neogene, and the fine clastic material of the varicolored sequence began to accumulate. The sedimentation embraced a vast territory, having spread over the northern part of the western Ming-Kush–Kökömeren Zone (Fig. 8b). In the late Pliocene and Eopleistocene, the vertical motions became more contrasting and led to the deposition of poorly rounded gravel and pebbles. The northern frameworks of the zone pertaining to the North Tien Shan were distinctly outlined as provenances. Both lateral and vertical tectonic movements reinforced in the Pleistocene formed the present-day structure of the Ming-Kush–Kökömeren Zone (Fig. 8c).

Thus, the major structural elements of this zone—the master faults with the recently retained character of displacements—had already originated in the Oligocene as the first manifestations of neotectonic activation, but the structure evolved most intensively and complexly in the Quaternary, when the velocity of movements became appreciably higher.

A number of recent longitudinal fault-line depressions more or less similar to the Ming-Kush–Kökömeren Zone have been identified in the Middle Tien Shan. These are the narrow Tessyk–Sary-Bulak Zone of small basins that adjoins en echelon to the Ming-Kush–Kökömeren Zone in the south and extends eastward along the Nikolaev Line; the Uzun-Bulak–Oy-Kain and Kara-Köl linear depressions between the Suusamyr and Kochkor basins; and the Chong-Kemin Zone north of Lake Issyk-Köl (Fig. 10).

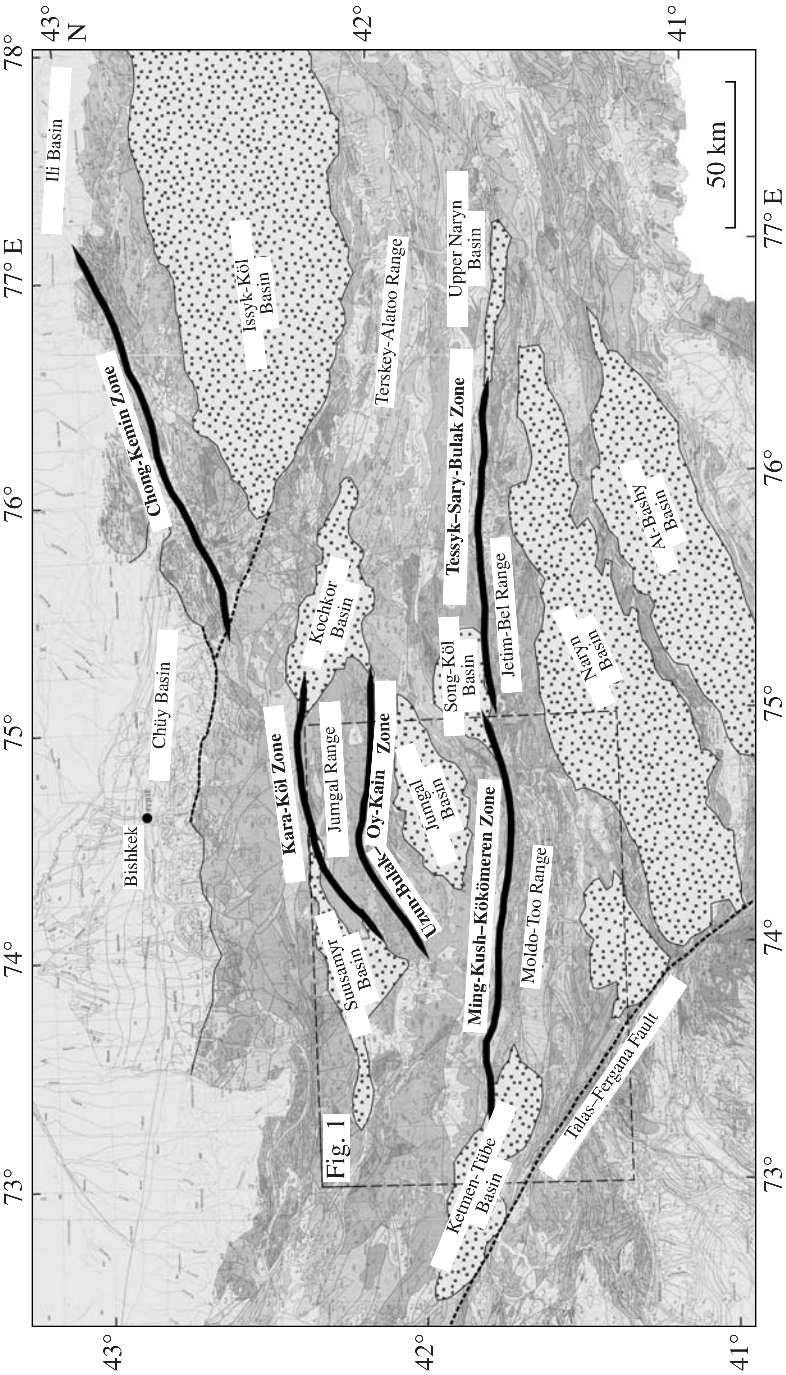

Fig. 10. Position of the Ming-Kush–Kökömeren Zone and similar transpressional zones in the structure of the Middle Tien Shan.

The Tessyk–Sary-Bulak Fault Zone extends for 200 km from the southern wall of the Song-Köl Basin to the northern end of the Upper Naryn Basin between the Moldo-Too and Jetim-Bel ranges in the south and the spurs of the Terskey Alatoo in the north. The fault that controls the formation of this zone is not uniform in its kinematics. At the southern margin of the Song-Köl Basin, its southern wall was uplifted in the Cenozoic and is expressed in topography as a smoothed escarpment up to 200 m high. However, to the east, the southern wall subsided with the formation of a chain of fault-line basins filled with deformed Cenozoic sediments from analogues of the Kyrgyz Formation to the upper Pliocene–Eopleistocene Sharpyldak Formation. These basins are asymmetric: their northern, near-fault portions have deeply subsided, whereas in the south the gently dipping Cenozoic beds overlap the Paleozoic basement. The fault cuts and offsets the Permian pluton of alkali granite to the left for 60 km. Most displacements pertain to the Late Hercynian; the neotetconic component is estimated at 5–8 km [4].

The Uzun-Bulak–Oy-Kain Zone extends from the southwestern end of the Kochkor Basin for 60 km in the west–northwestern direction. The formation of this zone is related to the movements along a large fault with the northern wall upthrown on the Cenozoic sediments of the subsided southern wall. The SW-trending splays divide the depression in the branches separated by blocks of the Paleozoic rocks, making up a horsetail structure, which gives grounds to suggest a left-lateral offset.

The analogues of all Cenozoic formations have been identified in the depressions. The Jurassic rocks emerge from under the Cenozoic cover in the central part of the zone. The Cenozoic sediments that plunge toward the northern boundary fault have been deformed in gentle folds. At the southern walls of depressions, the gently dipping Cenozoic beds overlap the Paleozoic basement. The westernmost and largest splay crosses the Kökömeren River valley. On the left bank, the Caledonian granite of the southeastern wall of the fault are upthrown on the Cenozoic sequences, which dip at angles of about 30° to the southeast. At the same time, the western continuation of the Uzun-Bulak–Oy-Kain Zone is an convex arc facing the north.

The Kara-Köl Zone is also arcuate and faces the north. The zone is traced from the northwestern end of the Kochkor Basin for a distance of 90 km toward the Suusamyr Basin along the East Kara-Köl and West Kara-Köl rivers. The Kara-Köl Zone is asymmetric as well, but in contrast to the Uzun-Bulak–Oy-Kain Zone, the master faults are confined here to the southern wall of the depression, whereas at the northern wall, the faults develop in a fragmentary manner and Cenozoic sediments transgressively overlap the Paleozoic basement. The Quaternary sediments overlie the varicolored Neogene sequence; analogues of the upper Pliocene–Eopleistocene sediments are likely present in some places.

The master fault consists of a left-lateral series of en echelon arranged segments. The Kara-Moynok Range is located between the two major segments, being separated from the Jumgal Range. In its westernmost part, the Kara-Köl Zone extends in the WSW direction and separates a narrow anticline composed of the Caledonian granite from the Suusamyr Basin. The relationships with Quaternary sediments and landforms bear indications of the recent activation of the fault, which are the most distinct in the west, where the small streams crossed by the fault reveal left-lateral offsets for tens of meters.

The Chong-Kemin (Kemin–Chilik) Zone of depressions extends for no less than 400 km in the east-northeastern direction and is conjugated in the west with another northwest-trending zone of active faults identified by Schulz [27] and Makarov [13]. Abdrakhmatov [2] interpreted this fault zone as a right-lateral strike-slip fault. From this locality, the Chong-Kemin Zone extends as a chain of Cenozoic fault-line depressions to the east, on the left bank of the Chong-Kemin River, and appears as a narrow ramp near its mouth. This ramp is composed of Cenozoic sedimentary rocks that deformed into a syncline. The fault that bounds the ramp in the north steeply dips north-northwest. The Caledonian granite and Proterozoic (?) metamorphic schists have been upthrown on the Neogene Chüy Formation (an analogue of the Naryn Formation), which tilts southward at moderate angles. The inclined striation on the fault plane indicates a left-lateral component of displacement. The southern boundary fault steeply dips to the south. To the east, the zone enters the Chong-Kemin valley, which widens into the small Shabdy Basin. The pre-Pleistocene Cenozoic rocks lie at low angles here. As in the ramp, all formations from Kok-Turpak to the Sharpyldak have been identified here.

Farther to the east, the zone extends along the Chong-Kemin valley. The pre-Pleistocene Cenozoic rocks occur here fragmentary, the section is incomplete and is often overlapped by the Pleistocene sediments (mainly moraines and fluvioglacial deposits). However, the boundary faults are clearly expressed in topography as young escarpments and linear depressions. The seismogenic faults of the Kemin earthquake of January 4, 1911, with a magnitude of 8.3 were confined to this segment of Chong-Kemin Zone up to 180 km long. The reverse faults with a separation up to 4–5 m and the left-lateral strike-slip component with an offset of 0.5–1.0 m are typical [5, 10]. The earthquake was accompanied by numerous landslides [8], which are the most expressive along the northern boundary fault in the vicinity of Mount Jaya (Figs. 11a, 11c).

On the northern slope of the Jaya Depression, one can see an almost vertical young fault trending in the east-northeastern direction, whose southern wall was uplifted 2 m in 1911 (Fig. 11b). On the small drainage divides crossed by the fault, the vertical separation reached 5 m. The total separation is related not only to

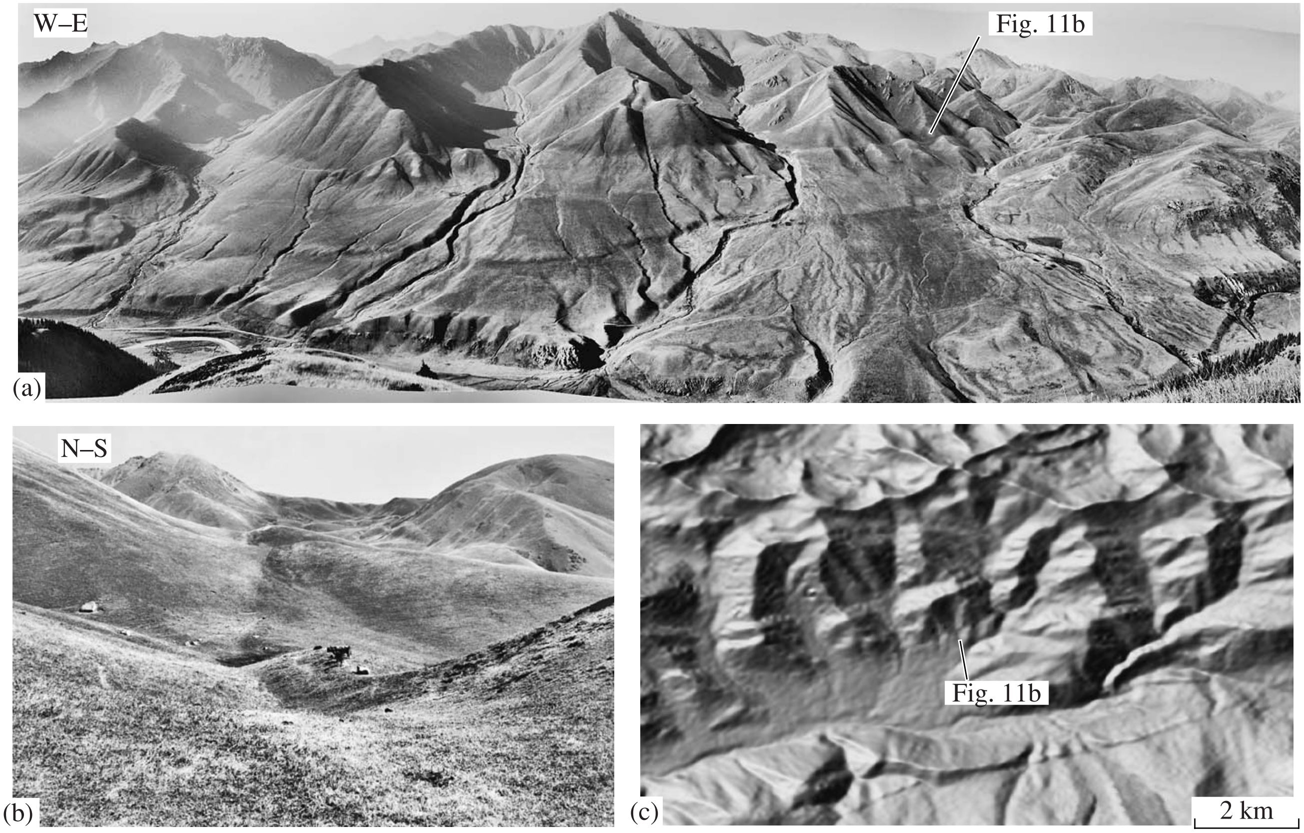

Fig. 11. The structure of the Chong-Kemin Zone near the Jaya Depression: (a) panorama photo of the northern wall of the Chong-Kemin valley—active faults are seen; (b) the fault on slope of the Jaya Depression reactivated by Kemin earthquake of 1911; location of this fault is shown in panels a and c; (c) SRTM (3″) digital topography model; lines of active faults and left-lateral offsets of landforms are seen.

the 1911 event, but also involves the preceding Holocene displacements. To the east, a valley crossed by the fault is displaced 2–3 m to the left. This offset is likely coeval with vertical separation for 5 m, so that their ratio is about 1 : 2. Somewhat upstream the Chong-Kemin River, two young faults were found on the southern slope of the valley. Along with uplift of the southern wall, expressed in a scarp a few meters high on the surface of the middle Pleistocene (?) moraine, the left-lateral bends of the channels that developed in the moraine indicate strike-slip offsets for 20–30 and 35–40 m along the southern and northern faults, respectively.

The Chong-Kemin Zone continues eastward along the Chilik River valley, where the Neogene–Quaternary vertical separation along the faults reaches 1.5 km (A.V. Timush, cited after [23]). The total recent left-lateral offset along the Chong-Kemin Zone is estimated at 3–4 km [4, 15, 17].

Thus, in the four considered depressions of the Middle Tien Shan the transverse shortening is combined with the longitudinal left-lateral offset like in the Ming-Kush–Kökömeren Zone. In all zones, this phenomenon is related to the Quaternary deformation, but as judged from the sequences of Cenozoic rocks, the evolution of these zones as depressions with transpressional structural grain was initiated still in Neogene or Oligocene. Hence, the transpressional nature of these zones was manifested at both the younger and later stages of recent tectogenesis.

The longitudinal left-lateral transpressional structural elements are conjugated (beginning from the early stage of neotectonic evolution) with the NW-trending right-lateral strike-slip faults. The largest faults of this kind (Talas–Fergana Fault, the faults that bound the Chong-Kemin Zone in the west, and the Main Junggar Fault) are characterized not only by considerable offsets, but they control the segmentation of the entire longitudinal structure of the present-day Tien Shan. The combination of strike-slip faults extending in different directions determines the regional neotectonic features, in particular, the angular outlines of basins.

CONCLUSIONS

A class of longitudinal recent depressions with the combination of transverse lateral shortening and longitudinal left-lateral strike-slip faulting has been identified in the Middle Tien Shan. These structural units are exemplified in the Ming-Kush–Kökömeren Zone at the boundary between the North and Middle Tien Shan. Its transverse shortening is expressed in thrust and reverse displacements along the boundary faults and in the internal folding complicated by longitudinal reverse faulting. The left-lateral strike-slip dislocations are manifested in offsets of landforms along the same longitudinal faults and oblique striation on fault planes. The transverse shortening and longitudinal strike-slip faulting mainly developed in the Quaternary. However, the framework of the transpressional structure started to evolve already in the Oligocene. The structure of the Oligocene–Lower Miocene conglomerate sequence was formed owing to the destruction of the frontal portions of the Hercynian thrust faults of the Middle Tien Shan reactivated recently. The sequence accumulated in a narrow ramp-type depression that was formed in front of thrust faults under conditions of the combined reverse and thrust faulting with left-lateral strike-slip offsets along the boundary faults.

Other longitudinal narrow depressions in the Middle Tien Shan, where indications of transverse shortening are combined with longitudinal left-lateral strike-slip faults, probably are analogues of the Ming-Kush–Kökömeren Zone. The Tessyk–Sary-Bulak Zone that adjoins en echelon the Ming-Kush–Kökömeren Zone in the south and serves as its eastern continuation, the Uzun-Bulak–Oy-Kain and Kara-Köl zones between the Suusamyr and Kochkor recent basins, as well the Chong-Kemin Zone to the north of the Issyk-Köl Basin, are examples.

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