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FAULTS OF MIDDLE ASIA

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ABSTRACT. The heterogeneous territory of Middle Asia includes regions of Caledonian, Variscan, and Alpine folding and is covered by a uniform regional net of faults that consists of faults of six directions.

Within the Tien-Shan Variscides, three stages of deformations can be distinguished. The regional fault net of Middle Asia includes faults of the second and third stages of deformation. The Talas-Ferghana fault, the largest in Middle Asia, first moved in the Permo-Triassic during the third stage of deformation of the Variscides. At that time its strike-slip movement reached an amplitude of 180 km. Both horizontal and vertical displacements along the fault continued during the Mesozoic and Cenozoic and are still going on at the present time.

Relative to brittle deformation, the Earth's crust is characterized by a property that can be called discreteness. This property confines the number of fault directions in a net of continental faults to four or six directions; a system of such faults is completely saturated and thereafter remains invariant (uniform) under any further alterations of the stress field, which can only produce a change in the directions of displacements along the existing faults. The fault net of a continent originates in an existing block of continental crust under the influence of any stress peculiar to that block. Later on, the fault net spreads from areas of earlier consolidation into orogens. The saturated fault net within an orogen forms at the end of the mountain-building epoch during the last stage of orogenic deformation.

INTRODUCTION

Middle Asia covers the territory of the basins of the Syr-Darya and Amu-Darya rivers, which fall into the Aral Sea. The Tien-Shan and Pamir mountain ranges and the Kyzyl-Kum and Kara-Kum deserts are located in this territory. The tectonic structure of Middle Asia was formed at various times (fig. 1).

The northern part of the Tien-Shan belongs to the Caledonides. To both south and north are vast territories of Variscides. The Tien-Shan mountain ranges and the uplands within the Kyzyl-Kum desert are composed of Paleozoic rocks; Mesozoic and Cenozoic deposits of platform type are distributed in the intermontane valleys. South of the Tien-Shan lie various tectonic units. In the southeast, the Tien-Shan Variscides border on the Precambrian Tarim platform, in the south, with the Alpine structure of the Pamirs, and in the southwest, with the Tadjik Caledonides. The Caledonides of Middle Asia were repeatedly deformed during the Variscan and Alpine epochs and the Variscides during the Alpine epoch.

FAULT NET OF MIDDLE ASIA

The heterogeneous territory of Middle Asia is covered by a single net of faults (fig. 2, opp. p. 734; fig. 3). This net consists of six components, that is, faults of six directions: meridional (I), two northeastern (II and III), latitudinal (IV), and two northwestern (V and VI). The faults forming this net have steep fault surfaces and both horizontal and vertical recent displacements. Studies of slickensides showed that northeast-striking faults (rays II and III of the net) have left-lateral displacements, whereas northwest-striking faults (rays V and VI) have right-lateral displacements.

In the mountain regions, the vertical amplitude of recent displacements exceeds the horizontal amplitude, but horizontal displacements prevail on plains. Where northwest and northeast faults intersect, mutual displacements take place. The latitudinal faults of ray IV are reverse faults and normal faults and are generally displaced along the faults of rays II, III, V, and VI. The meridional faults of ray I are normal faults; they are short faults, systems of fractures, and micrograbens. Faults of all other rays of the net displace faults of ray I (Burtman, Legoshin, and Shvolman, 1979).

The directions of displacement along the faults show that the present-day net of faults of Middle Asia expresses conditions of meridional compression and latitudinal extension.

HISTORY OF FAULT NET FORMATION

While studying the geological history, one can see how some faults originated at certain stages of the tectonic process, functioned for a period of time, and then either died away or were preserved and revived again under new geological conditions.

During the Middle Paleozoic, the rocks of present-day Middle Asia included some continental blocks (fig. 1) divided by basins with oceanic crust, in which deep-water deposits accumulated. The Turkestan oceanic basin lay between the Kirghiz and the Alai-Tarim microcontinents; the South-Gissar oceanic basin between the Alai-Tarim and Tadjik micro-

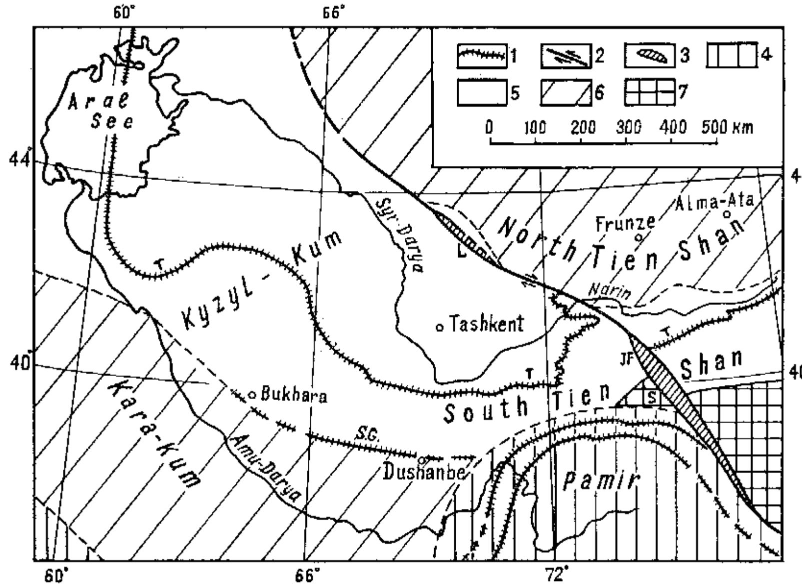


Fig. 1. Tectonic scheme of Middle Asia. 1, sutures of Paleozoic oceanic basins (T—Turkestan, SG—South Gissar); 2, Talas-Ferghana fault; 3, Jurassic depressions situated along the Talas-Ferghana fault (L—Leontiev, JF—Jarkend-Ferghana); 4, area of Alpine folding; 5, of Variscan foldings; 6, of Caledonian folding; 7, Tarim platform (S—Suluterek massif).

continents. Paleozoic and pre-Paleozoic rocks of the Pamirs composed the Kurghovat microcontinent (Ruzhentsev, Pospelov, and Sukhov, 1977) and the northern margin of Gondwana. At the end of the Early Carboniferous, subduction began to reduce the oceanic basins, and during the Middle Carboniferous, they were completely closed. In the process, the faults that had developed on the bottoms of the oceanic basins disappeared together with the oceanic crust, and their continuations are known nowhere within the continental blocks. It follows that the faults existing in the Paleozoic oceanic crust took no part in forming the fault net of Middle Asia.

Formation of the fault net in the Variscides.—Folds and faults in the present Variscides began to form under the influence of stresses caused by the collision of continental blocks; three stages of deformation can be recognized (Burtman, 1975, 1976). How do the faults formed in the separate deformation stages participate in the development of the regional fault net visible in the Tien-Shan Variscides?

Stage D-1. In the Middle Carboniferous (Morrowan-Desmoinesian), during the closing of the Turkestan oceanic basin, a system of nappes was thrust over the Alai-Tarim continent (fig. 4). The rocks in these nappes had formed on the bottom of the oceanic basin and on its

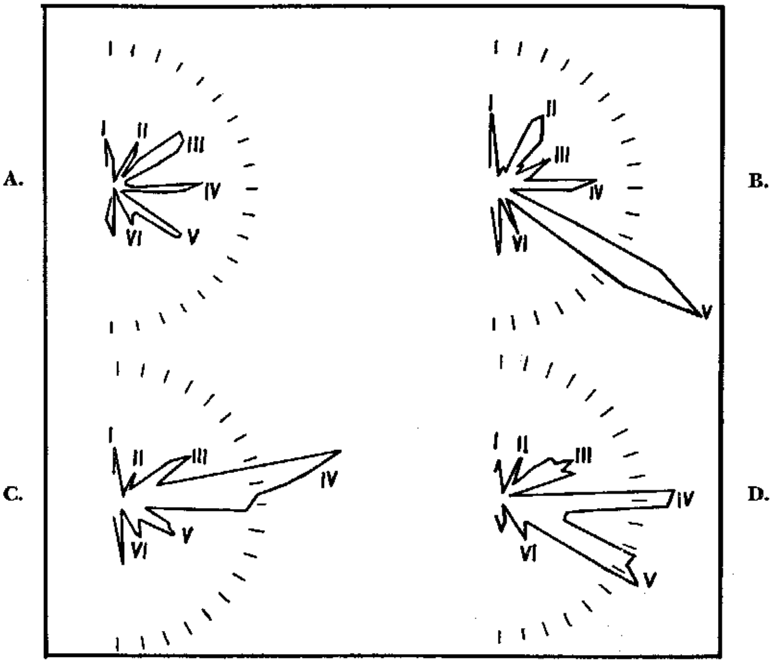


Fig. 3. Diagrams of faults (Burtman, Legoshin, and Shvolman, 1979). The diagrams are compiled by using a pallet with circles of 50 km radius. A. faults in Meso-Cenozoic deposits in the territory contiguous with the Aral Sea; B. faults in Phanerozoic and older rocks in the central part of the Kyzyl-Kum desert; C. faults in the Southern Tien-Shan Variscides; D. faults in the Northern Tien-Shan Caledonides.

continental slopes. The overthrust faults separating the nappes are the earliest Variscan faults preserved in the region. They are widespread in the uplands of the Kyzyl-Kum desert and in the Tien-Shan ranges (Burtman, 1973, 1975, 1976, 1977a). The overthrust surfaces formed horizontally, or almost horizontally, for almost everywhere they are parallel to layering that rested almost horizontally on the sea bottom before the overthrusting.

Stage D-2. At this stage, as the continental blocks collided, their margins were warped, and mountainous uplifts were formed. As a result, the D-1 overthrust surfaces were folded into synforms and antiforms, and the overthrust surfaces acquired substantial dips, frequently steep and in places overturned. No new movement took place along the folded overthrust surfaces, however, and they were not utilized in forming the regional fault net, which includes only fragments of D-1 overthrust surfaces that had become steeply inclined during D-2 deformation.

The second stage of deformation produced faults along with folds (fig. 5), under conditions of transverse compression of a plastic geosynclinal system. Reverse faults and overthrusts striking parallel to the fold axes predominate.

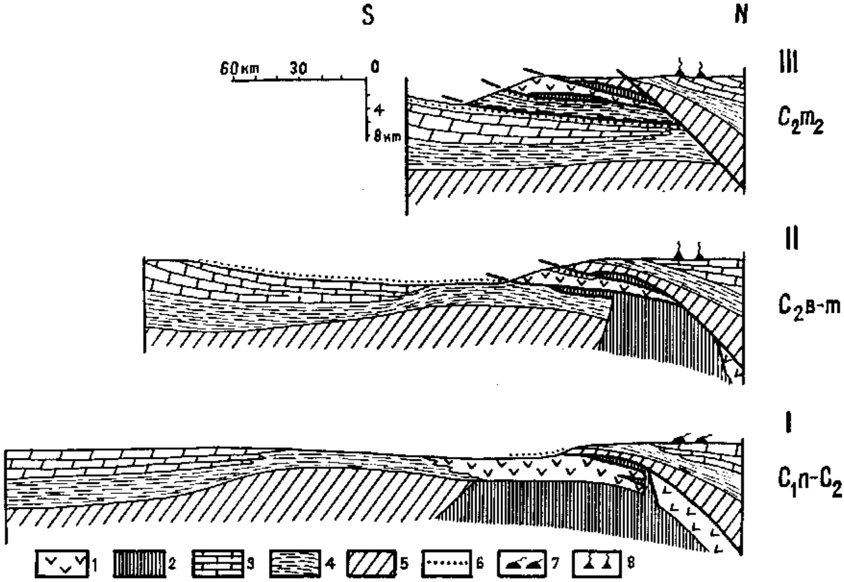


Fig. 4. Scheme showing the closing of the Turkestan oceanic basin and collision of the Altai-Tarim and Kirghiz continents.

I. Namurian-Bashkirian time (Chesterian-Morrowan); II. Bashkirian-Moscovian time (Morrowan-Atokan); III. Late Moscovian time (Desmoinesian).

1.-2. rocks of the Turkestan oceanic basin: 1, volcanogenic and cherty-volcanogenic deep-water sediments, Ordovician, Silurian, Devonian, and Early Carboniferous, 2, ultrafamic and gabbroid rocks of the oceanic basement; 3 to 5. rocks of the Alai-Tarim and Kirghiz continents: 3, Devonian and Early Carboniferous carbonate deposits, 4, Silurian, Devonian, and Early Carboniferous clastic deposits, 5, Early Paleozoic and Precambrian rocks; 6. flysch and olistostrome deposits of the overthrust epoch; 7. andesitic volcanism; 8. felsic volcanism.

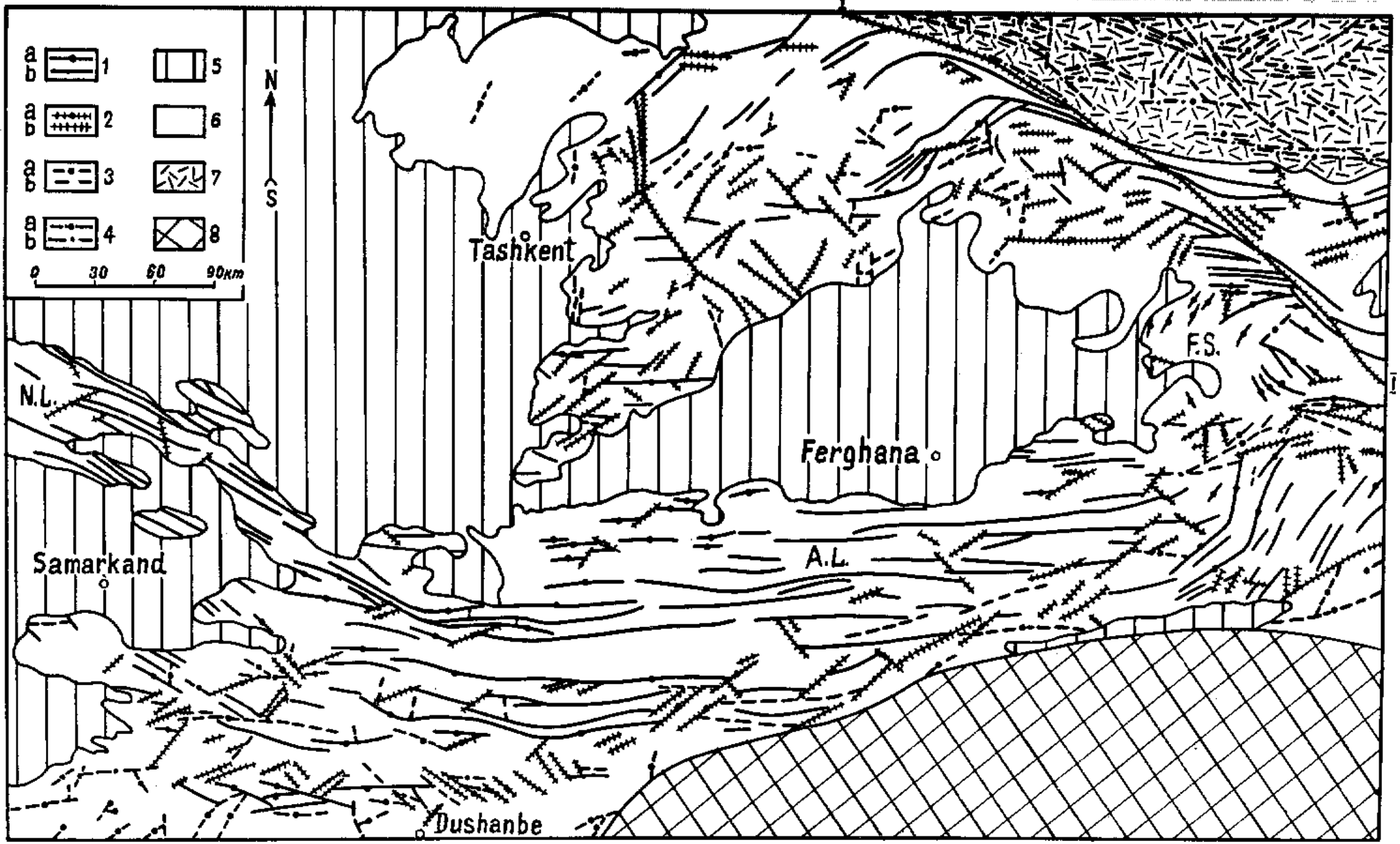


Fig. 5. Major faults of the Tien-Shan active in the Mesozoic and Cenozoic. Map based on field data.

1. to 3. faults in the Variscides: 1, faults of D-2 of Variscan deformation (Upper Carboniferous-Permian), 2, faults of D-3 of Variscan deformation (Permian-Triassic), 3, faults of Alpine time or of unknown age; 4. faults in the Caledonides (1a, 2a, 3a, 4a—faults with proved movements in the Mesozoic or Cenozoic; 1b, 2b, 3b, 4b—faults with supposed movements in the Mesozoic or Cenozoic); 5. and 6. Variscide territory: 5. Quaternary deposits, 6, pre-Quaternary rocks; 7. Northern Tien-Shan Caledonides; 8. Pamir area of Alpine folding.

N. L.—Nuratau limb of the Nuratau-Alai arc; A. L.—Alai limb of the Nuratau-Alai arc; F. S.—Ferghana sector of the Tien-Shan; I-I—Talas Ferghana fault.

The second stage of deformation was spread through the late Carboniferous and a large part of the Permian; it produced a Variscide structure consisting of folds and faults oriented along the east-west strike of the Variscan folded belt.

Stage D-3. In Permo-Triassic time, the Variscan folded system was subjected to deformations during which displacements were horizontal. At this stage of deformation, strike-slip faults and large horizontal folds (folds with horizontal a-c planes, that is, nearly vertical axes) with steep hinges appeared, the faults of stage D-2 being bent into arcs and cut and displaced along the strike-slip faults.

Deformations of stages D-1 and D-2 resulted from collision of the Early Paleozoic continents and were confined to the Variscan folded belt. Deformations of stage D-3 were caused by more general factors. After the Variscan oceanic basins were closed in the Middle Carboniferous, synchronous deformation of the same type (fig. 6) covered a vast territory of the Late Paleozoic continent, parts of which are at present in Eurasia and America (Burtman, 1976, 1977b). This deformation spread throughout Middle Asia as well, being most intense within the Variscan Tien-Shan folded system.

The structural plan of the region formed by Variscan tectogenesis was characterized by folds and faults of the D-2 and D-3 stages. The regional fault net was formed on the basis of this very structural plan which included faults of two major types: D-2 faults (mainly reverse) striking along folded arcs, and D-3 strike-slip faults cutting them. Within

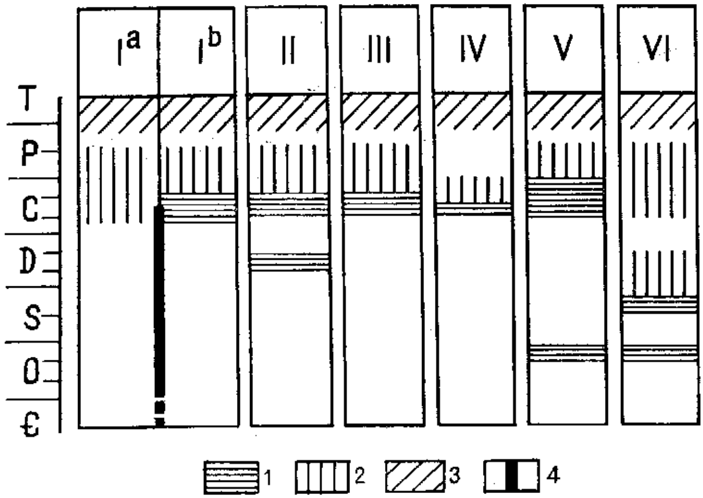


Fig. 6. Times of deformation in Variscan mountain ranges. I. Variscan Tien-Shan, successions of deformations: Ia—Kirghiz, Ib—Alai; II. Urals; III. Cantabrian zone, Spain; IV. Harz; V. Southern Appalachians; VI. Northern Appalachians.

1. first stage of deformation: formation of nappes; 2. second stage of deformation: formation of dip-slip faults, synforms, and antiforms; 3. third stage of deformation: formation of strike-slip faults, thrusts, horizontal flexures (sigmoids), and horizontal folds with steeply plunging hinges; 4. time of existence of the Turkestan oceanic structure in the Tien-Shan Variscides.

the Variscan Tien-Shan structural plan, two sectors having different structural patterns can be distinguished: the Nuratau-Alai and the Ferghana sectors (figs. 2, 5).

The Nuratau-Alai sector is an arc consisting of two rectilinear limbs (Alai and Nuratau) and a relatively narrow zone in which these limbs join (fig. 5). Within the Alai, limb folds and faults of the D-2 stage strike east-west persistently for 300 km. D-2 structures are cut and displaced by northwest- and northeast-striking D3 faults at angles of 30° to 50°. The D-3 faults are short — some kilometers and, less frequently, some tens of kilometers long. Within the Nuratau limb, the D-2 structures have a general northwest strike (300°) for 450 km. The D-3 faults strike northwest and northeast and are up to 25 km long.

Where the limbs of the arc join, the faults curve and pass from one limb into the other. When the regional fault net formed, the synchronous structures in the different limbs of the Nuratau-Alai arc made up parts of different rays of this net. Longitudinal D-2 faults in the Alai limb formed ray IV of the regional net, whereas continuations of the same faults in the Nuratau limb became part of ray V. Cross-cutting D-3 strike-slip faults compose rays II, III, V, and VI of the net. The map of the present-day fault net (fig. 2) shows that, where the arc limbs join, straight faults branch from the curvilinear faults and cross the structures of the other limb. Such faults with the Nuratau strike within the Alai limb can be readily seen on cosmic photographs. These branches of lengthwise faults cutting straight from one limb of the arc into the other were formed later than the Nuratau-Alai arc as the regional fault net functioned.

The structural plan of the Ferghana sector was described in the author's paper published in this journal (Burtman, 1975). In the Ferghana sector D-2 folds and faults were bent into broad curves at stage D-3 to form steep horizontal folds. Paleomagnetic studies (Burtman and Gurariy, 1973) confirm the secondary origin of these curves (fig. 7).

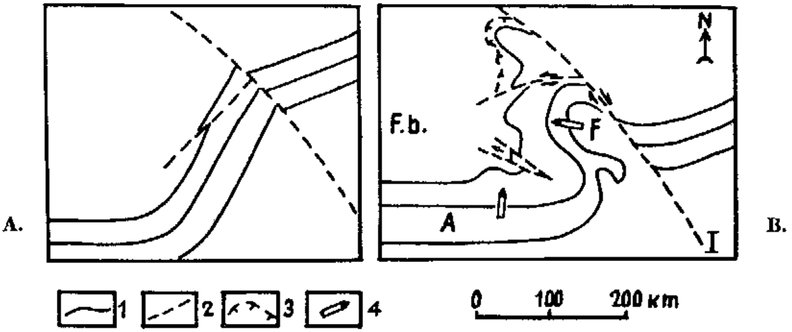


Fig. 7. Scheme of formation of the structure of the Ferghana sector at D-3 stage. A. beginning of D-3 stage; B. end of D-3 stage.

1. strike of D-2 folds; 2. and 3. D-3 faults: 2—strike-slip faults, 3—thrusts; 4. direction of paleomagnetic vectors in Upper Paleozoic rocks.

Symbols: A—Alai ridge; F—Ferghana ridge, F.b.—Ferghana depression.

After the regional fault net formed, movements along the faults of the net resulted in segmentation of these curved faults, young branches developing along the strike of each segment. Differently oriented parts of such a segmented fault together with their branching continuations made up a part of various components (rays) of the regional fault net.

The D-3 faults differ sharply from the D-2 faults, described above. They are rectilinear strike-slip faults and strike mostly northwest and northeast. The fault system of stage D-3 is superimposed on all other structures. It formed when the arcs in both sectors were already partly formed. Movements along the strike-slip faults were accompanied by further compression of the arcs (fig. 7). The strike-slip faults, with few exceptions, compose the diagonal rays of the regional fault net. Most of them extend for kilometers or tens of kilometers, the Talas-Ferghana strike-slip being noteworthy for its great length. Special studies of this fault show that movements along it were renewed repeatedly during Mesozoic and Cenozoic, as discussed below.

History of the Talas-Ferghana fault.—The Talas-Ferghana fault (figs. 1, 5) crosses Middle Asia and goes beyond its limits; its total length is over 1500 km, and it stretches over 600 km of the Tien-Shan territory. To the northwest it extends along the boundary between the Caledonides and the Variscides; southward it crosses the Variscides and continues southeast along the boundary of the Tarim platform, cutting off from it the Suluterek Precambrian massif. In the Tien-Shan Variscides studies of the relationships between this fault and Paleozoic, Mesozoic, and Cenozoic rocks and structures show that Paleozoic rocks of various age have slipped dextrally over the same horizontal distance (up to 180 km) all along the fault. This right-lateral displacement of the fault limbs was accompanied by plastic deformation of the fault limbs; allowing for the plastic deformation, the horizontal displacement along the zone of the Talas-Ferghana strike-slip fault reaches 250 km. This large strike slip was established by studying the facies of Early and Middle Paleozoic deposits, plutonic massifs of Late Paleozoic age, and Late Paleozoic tectonic and metallogenic zones (Burtman, 1964). For instance, figure 8 shows the relation between the Talas-Ferghana fault and rocks of the Givetian and Frasnian stages of the Devonian. Four types of sections have been distinguished in these deposits: Tayalmysh, Akkapchigay, Alabuka, and Buzbutau. Sections of Tayalmysh type are composed of marine quartz standstones of the Frasnian stage; in Givetian time they were areas of erosion. Sections of Akkapchigay type have proluvial, alluvial, and near-shore coarse deposits in the Givetian and mature quartz sandstones in the Frasnian. Sections of the Alabuka type are composed of marine shallow-water clastic and carbonate deposits. Sections of Bozbutau type consist of limestones interbedded with mafic lavas. All these sections are autochthonous, but where deposits of the Bozbutau type are developed, allochthonous ophiolites compose nappes (not shown on fig. 8).

The youngest rocks that were displaced 180 km along the Talas-Ferghana strike-slip fault are plutonic massifs of Permian age, which cut folds of D-2 stage but were deformed at stage D-3. No data available indicate the existence of the Talas-Ferghana fault before stage D-3. Moreover, analysis of the history of Variscan deformations of stage D-3 (Burtman, 1976) shows that the main strike-slip displacement took place at the end of this stage (fig. 7).

In Jurassic time two basins appeared along the line of the Talas-Ferghana fault in which terrigenous deposits accumulated (fig. 1). In the northwest is the Leontiev basin, which has the shape of a graben, 180 km long and 10 km wide, and contains Jurassic deposits over 2 km thick. In the southeast is the Jarkend-Ferghana basin, over 400 km long. These two narrow and deep depressions lie along segments of the Talas-Ferghana fault that strike northwest (320°); between them is a part of the fault oriented west-northwest (300°). Thus their disposition suggests that they formed by extension resulting from right-lateral displacement along the west-northwest segment of the Talas-Ferghana fault.

No data on movements of the Talas-Ferghana fault in the Cretaceous and Paleogene have been obtained. The present morpho-structural plan of the Tien-Shan began to form in the Neogene, and by the beginning of the Quaternary the present mountainous relief had been created. Numerous data on horizontal displacement of the relief forms along the Talas-Ferghana fault show that in the Quaternary horizontal movements were proceeding along several parallel faults located in a zone 3 to 10 km wide (fig. 10); the most active displacements were recorded in a band 1 to 2 km wide. In the strike-slip zone the river and creek valleys were bent to the right and Quaternary deposits were displaced (Rantsman, 1963; Rantsman and Pshenin, 1963, 1967). Pliocene-Quaternary horizontal displacement along the strike-slip zone ranges from 5 to 14 km in various places, that is on the average 0.5 cm per yr, although

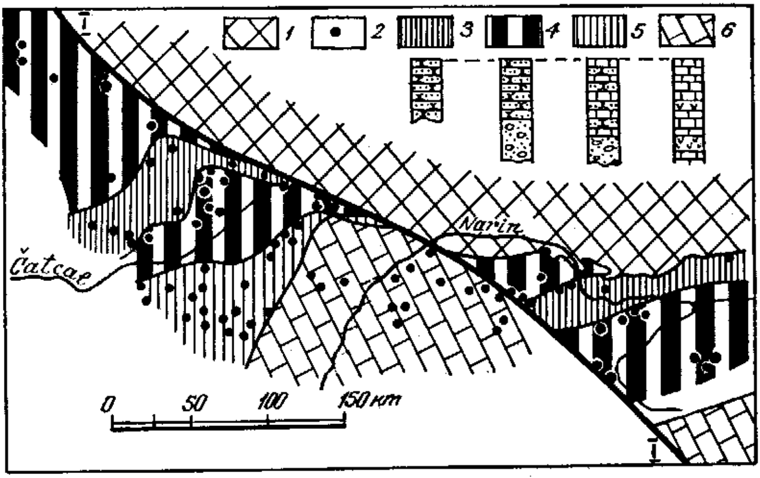


Fig. 8. Givetian-Frasnian deposits and Talas-Ferghana strike-slip fault (I-I). 1. area of erosion; 2. locality of stratigraphic sections; 3. to 6. types of sections: 3—Tayalmysh, 4—Akkapchigay, 5— Alabuka, 6—Bozbutau.

displacement along single faults was less than 2 km. Thorough studies carried out in the Ferghana ridge (fig. 11, segment a) enabled us to follow the course of this movement (Rantsman and Pshenin, 1963). Displacement along the strike-slip zone during the Pliocene and Early Pleistocene is 4 to 7 km and during Middle Pleistocene-Holocene, 5 to 6 km. For single strike-slip faults it reaches 700 m for the Late Pleistocene and Holocene. Trough-valleys and moraines of the Middle Quaternary glaciation in locality 5 (fig. 11) were displaced the same amount. Holocene displacements along some faults reached 200 to 250 m.

Miocene-Quaternary movements in the zone of the Talas-Ferghana fault also had a vertical component, ranging from 0 to 2.5 km in various segments of the fault zone (Kuchai, 1972).

Right-lateral displacements of recent relief forms are seen throughout the Talas-Ferghana fault (Burtman, 1964; Wallace, 1976). At locality 1 (fig. 11) 25 valleys of small temporary streams with an interval of 5 km are cut and shifted horizontally over 30 m. Plate 1 and figure 12 show the northwestern part of this area. Displacement of the courses and valleys of recent streams over the same distance are seen in localities 7, 8, 9, and 10 (fig. 11).

In localities 2 and 11 (fig. 11) the amplitude of the horizontal displacement of valleys reaches 50 m. In locality 4 (fig. 11) the fault cuts moraines of the recent mountain glaciation, shifting them 30 m horizontally.

In localities 3, 4, and 5 (fig. 11) a strike-slip displacement of watershed ridges over 30 to 50 m is seen.

Where the valley of a temporary stream descends toward the line of the strike-slip fault along the steep slope, a new valley was sometimes

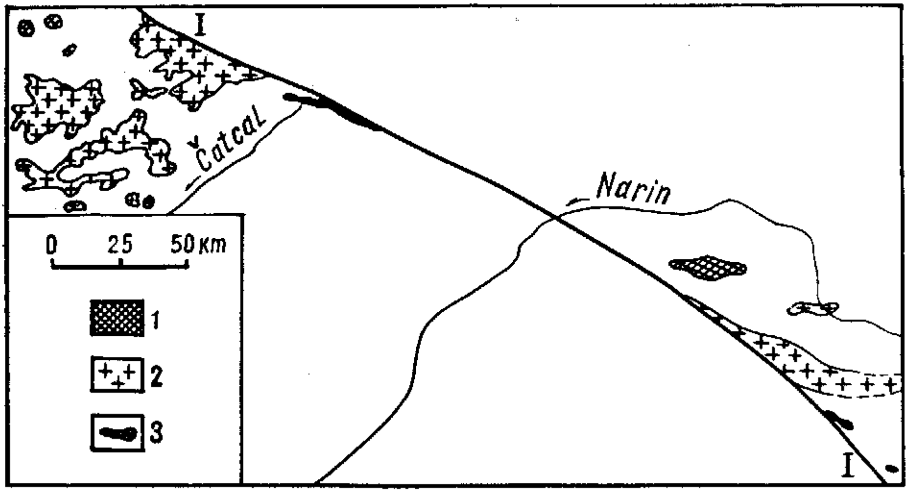


Fig. 9. Late Paleozoic plutons and Talas-Ferghana strike-slip (I-I). 1. to 3. Late Paleozoic plutons: 1—alkaline rocks (syenites, shonkinites), 2—granites, 3—granodiorites.

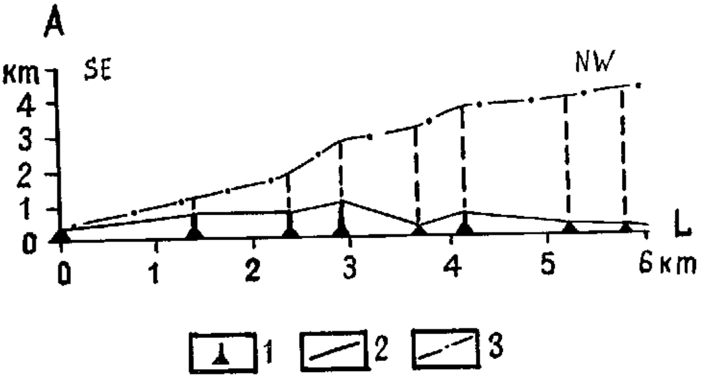


Fig. 10. Graph showing the amplitudes of Quaternary strike-slip dislocations in the Talas-Ferghana fault zone in the Kuldama river valley, Ferghana range, at locality 4, figure 11 (after Rantsman and Pshenin, 1963, with alterations). A. amplitude of strike-slip; L. distance across the Talas-Ferghana fault zone.

1. locality and value of strike-slip displacements along particular faults within the Talas-Ferghana fault zone; 2. graph of strike-slip displacements along particular faults; 3. graph of sums of strike-slip displacements in the Talas-Ferghana fault zone.

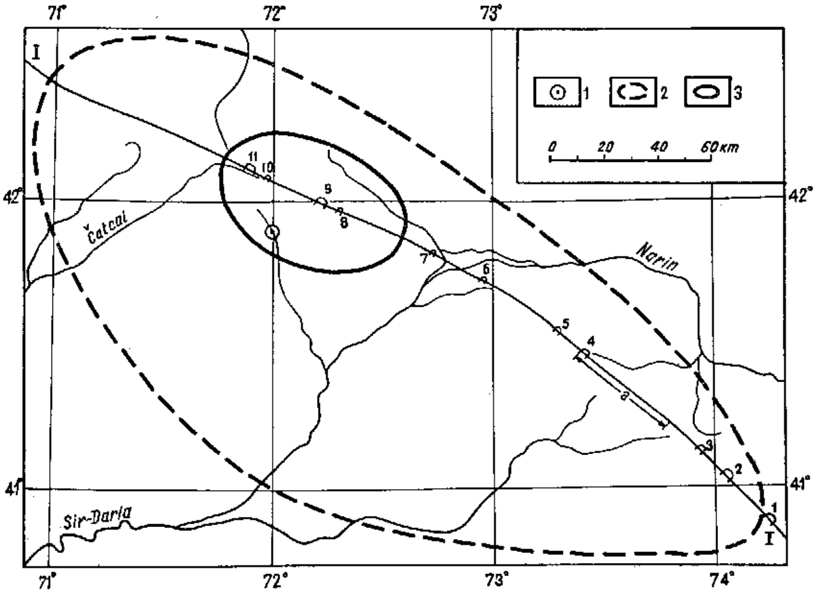
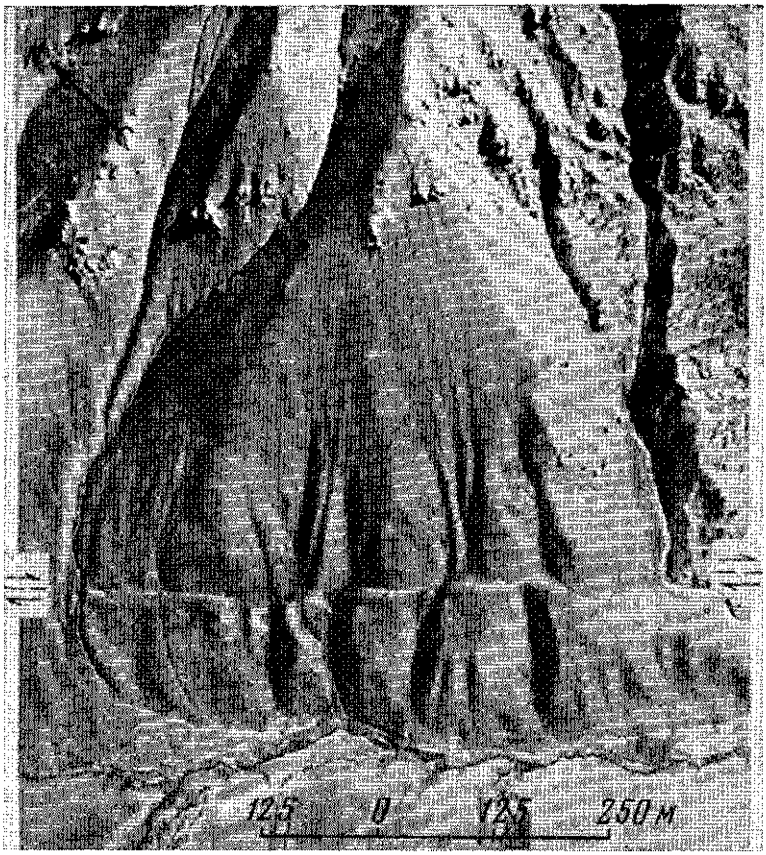


Fig. 11. Map showing the localities (1-11) where recent horizontal displacements along the Talas-Ferghana fault (I-I) were recognized. The epicentral zone of the Chatcal earthquake aftershocks also shown.

1. epicenter of the Chatcal earthquake on 2th November, 1946 (according to the Atlas of USSR Earthquakes, 1962); 2. territory within which the epicenters of the Chatcal earthquake aftershocks are located (Rozova and Chernyavkina, 1949); 3. territory within which 75 percent of the Chatcal earthquake aftershocks are located.

PLATE 1



Channels of recent streams showing right-lateral strike-slip displacement along the Talas-Ferghana fault. Airplane photograph, Ferghana ridge, locality 1 in figure 11.

formed on its continuation to take the place of the displaced part of the valley (pl. 1). If the strike-slip displacement were slow, the continuation of the valley beyond the line of the fault should be wider than the upper part of the valley, so that the valley would widen in the direction of displacement. However, young continuations of valleys beyond the line of the Talas-Ferghana fault are much narrower than their older upper parts. Thus the observed 30-m strike slip did not accumulate during hundreds of years of slow movements but must have been a rapid process, that is, due to earthquakes. If the 30-m displacement of the valleys were the sum of displacements during several earthquakes, we should observe below the fault line some continuations of the same valley shifted to various distances. The picture observed is, however, quite different; each valley has only one old continuation, displaced over 30 m along the strike-slip fault. We can therefore assume that the

30 m of strike slip is the result of one strong earthquake taking place in the historical past.

The zone of the Talas-Ferghana fault has high seismicity at present as well. The epicenter of the magnitude 7.5 Chatcal earthquake (intensity 9 according to the 12-unit scale) of November 3, 1946, was located near the Talas-Ferghana fault. Determinations of stress orientation in the focus of this earthquake (Shirokova, 1974) testify to a lateral displacement, probably along a fault that accompanies the Talas-Ferghana fault (fig. 11).

The major shock was followed by numerous aftershocks, over 100 of them during the first 24 hrs and 300 during the first month (Rozova and Chernyavkina, 1949). The zone of aftershock epicenters is elongated along the Talas-Ferghana fault, and the epicenters of many aftershocks lie on the line of the fault. Near the earthquake epicenter, in the vicinity

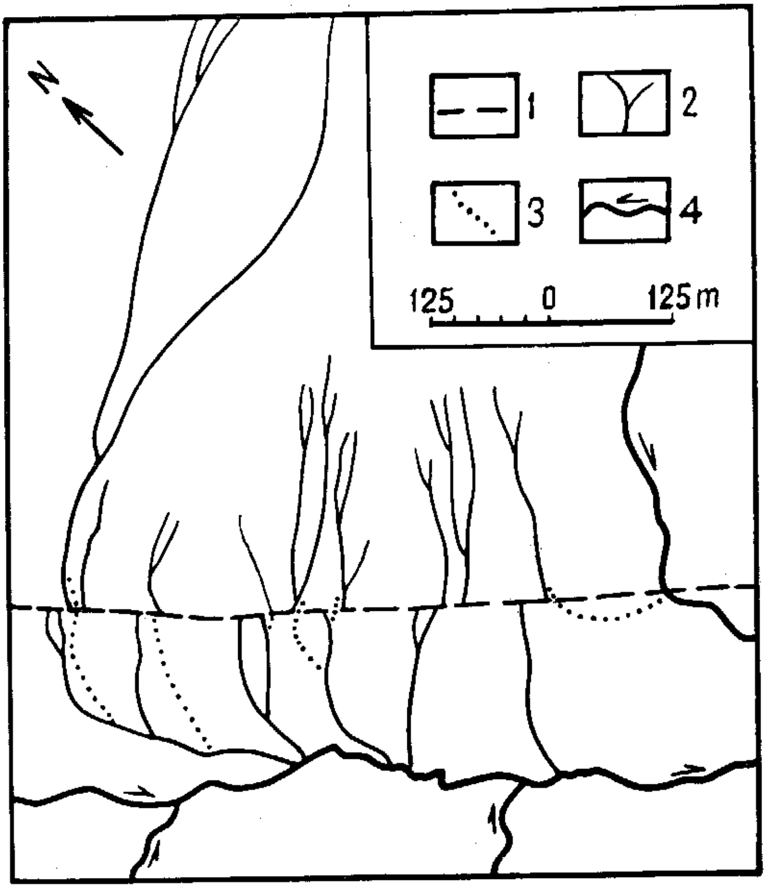


Fig. 12. Diagram of horizontal displacements seen in plate 1. 1. line of the Talas-Ferghana faults; 2. channels of recent streams shifted along the fault; 3. channels of recent streams originated after strike-slip displacement; 4. rivers.

of Sarythelek Lake, right-lateral displacements up to 1.5 m took place along small faults of east-west strike (Fedorenko, 1968). Numerous gravitational dislocations resulted from the Chatcal earthquake: large rockfalls and landslides, and also open fissures on the slopes of valleys (Leonov, 1965). In the same area, Upper Pleistocene and Holocene dislocations record strong earthquakes that took place approx 10,000 and 50,000 yrs ago (Kuchai, 1971). Rockfalls and landslides produced by Late Pleistocene and Holocene earthquakes are recorded in many places along the Talas-Ferghana fault (Rantsman and Pshenin, 1963).

This study of the history of movements along the Talas-Ferghana fault shows that the fault appeared during the D-3 stage of Variscan deformation as a strike-slip fault cutting the Variscan folded area in a fresh place. The diagonal fault joined two previously existing tectonic lines — the boundary of the Caledonides in the north and that of the Tarim platform in the south (fig. 1). The main strike-slip displacement took place at the end of the D-3 stage in the Permian-Triassic time. There were insignificant horizontal dislocations in the Jurassic. The fault was an active strike-slip fault in Neogene-Quaternary time and is seismically active at present. Besides horizontal displacements along the Talas-Ferghana fault, vertical dislocations took place as well, but their amplitude is relatively low.

Conclusions.—The regional fault net utilized faults of different ages for its formation. The faults of the first stage of Variscan deformation took almost no part in forming the regional net. The faults of the second stage had a different structural pattern in various parts of the folded area and different strikes within a single sector by the time they had become a part of the regional fault net. They are included in all components (rays) of the regional system. The plan of the faults originating in the third stage of deformation is the same all over the territory of the Variscides. With a few exceptions, all the faults of the third stage made up parts of the diagonal rays of the regional net.

The fault net of Middle Asia was formed at the end of the Paleozoic. In the territory of the Variscan folded system, it appeared during the third stage of deformation. At this stage the folded system was subjected to deformation together with older parts of the continent. The Chingiz strike-slip fault in Kazakhstan extends from the Variscides into the Caledonides (Samygin, 1974); the Talas-Ferghana strike-slip fault cuts the Variscides and the old Tarim platform. Where older continental crust was present, a fault net already existed by the time of formation of such strike-slip faults, and the new strike-slip faults utilized one or several older faults with suitable directions, whereas they cut the young folded system in a fresh (new) place. Thus, the fault net from the area of earlier consolidation spread into the young folded area during the final stage of its deformation.

The faults present during this final stage of deformation of the geosynclinal system did not die away at the end of the epoch but went on functioning during the ensuing platform regime. The fault net of

Middle Asia was present in the Mesozoic; it was enriched in the newest epoch and is still living nowadays.

CONDITIONS FOR THE EXISTENCE OF A FAULT NET

Study by various researchers of the distribution of faults on the continents led them to the conclusion that most regions are characterized by four directions of faults with an interval of 30° to 60° (45° in the ideal case) between them. In some regions six directions of faults have been described[1], Southern Siberia (Kheraskov, 1977) and Middle Asia being among them. That such regularities have been established on various continents led many to believe in a universal global fault net of the Earth's crust produced by a stress field of constant orientation (Katterfeld and Charushin, 1970; Moody, 1966; Sonder, 1947; Suvorov, 1968; Tchebanenko, 1963; Voronov, 1968). These ideas are contradicted by the paleomagnetic data showing that the continental blocks have migrated and rotated. At the same time, the fact that such fault nets exist on various continents requires explanation.

The questions to be considered here are as follows: What will become of the fault net of a continent if the orientation of the stress field changes or if the continent rotates in an invariant stress field? Will faults continuously appear in new directions corresponding to each new position of the continent relative to the stress field?

S. G. Ghosh and H. Ramberg (1968) carried out an experimental study of such a situation, relative to plastic deformation. The minimal angle between the axes of folds appearing successively in the models, when the applied stresses were altered, was 30°. Thus the largest number of possible strikes of folds is six. It is quite possible that the minimal angle ($\gamma_{\min}$) between the faults in a fault net is also close to 30°, since the greatest number of faults known in continental fault nets is 6.

The stress field orientation can change in two ways. First, the orientation can change gradually if a lithosphere plate or part of it rotates in the global stress field. In this case new fault systems will appear with an interval equal to $\gamma_{\min}$. If $\gamma_{\mathrm{imn}} = 30°$, the maximum possible number of fault systems is six. Second, the orientation of the stress field can change abruptly by an angle α. If $\alpha < \gamma_{\min}$, no new fault systems will appear. If $\alpha = \gamma_{\min} = 30°$, a fault net consisting of six components is possible. If $\alpha > \gamma_{\min} = 30°$, the number of possible directions can only be 4 or 5, but a 5-component fault net is hardly possible, because fault systems more frequently appear in pairs. One can assume that 6-component fault nets are formed in the continental crust by gradual changes in the orientation of the stress field, whereas 4-component fault nets are formed by abrupt changes.

It seems probable that 4- and 6-component fault nets are entirely *saturated,* that is, after such a fault net has formed, further changes in

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[1] D. Moody and M. Hill (Moody and Hill, 1956; Moody, 1966) believe that strike-slip faults of eight directions are developed in the Earth's crust. This eight-component net was obtained by combination of data on several continents into one diagram. The material below shows that such a method of summarization is erroneous.

orientation of the stress field will not result in the appearance of new fault systems; only the direction of displacement along the existing faults will change. Such changes of movement direction along faults are known in Middle Asia (Afonichev and others, 1976; Gzovsky, 1975; Suvorov, 1968; Vyrovlyansky, 1960) and in other regions (for instance, Illies and Greiner, 1976). The following conclusions can be drawn: (1) A continental fault net that remains invariant does not prove that the stress field remained constant. (2) Rotation of the continent relative to the stress field or change in the orientation of the stress field does not result in reconstruction of a saturated fault net.

As shown by the history of the fault net of Middle Asia, the formation of an invariant fault net took rather a long time, the net spreading episodically into younger parts of the continental crust. The direction of each component of the fault net can vary within a certain range; with a 6-component fault net this range is close to 30°, with a 4-component net 45°. Therefore, as the fault net expands over a new territory, it can be distorted (fig. 13). As a result, the fault net may prove to be different in areas with heterochronous continental crust.

Arcuate faults are widespread in folded areas. Such faults enter the invariant fault net in distinctly different ways; two types can

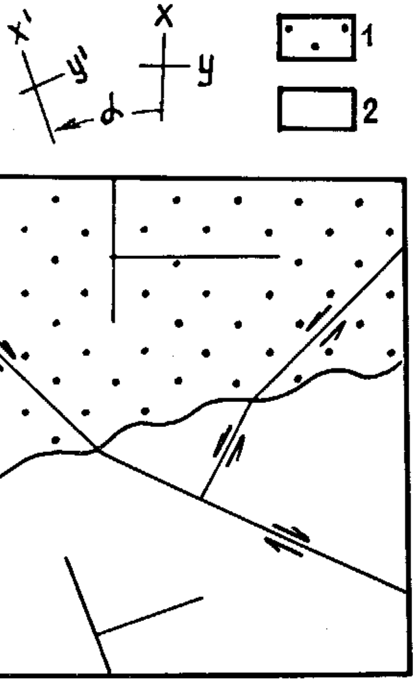

Fig. 13. Diagram of the distortion of a fault net during its expansion into younger crust (plan view). 1. old continental crust; 2. young continental crust; x, y—main axes of the stress field in which a fault system was formed in the old crust; x′, y′—main axes of the stress field at the time of the fault-net expansion (angle α less than 30°).

be distinguished. In the first type the arcs have rectilinear limbs, as, for example, the Nuratau-Alai arc described above. Faults developed on the limbs of such an arc are part of the invariant net from the very beginning. Rectilinear parts of single faults having different strikes form different rays of the invariant net and subsequently act as independent faults. Young strike continuations cut the zone where the two limbs of the arc join and also the structures in the other limb of the arc.

The other type includes faults that are curvilinear throughout, such as the faults in the Ferghana sector of the Tien-Shan or the faults of the Pamir arc. In order for such a fault to fit into the invariant net, it must be segmented; moreoever, the curvature of curvilinear segments of the faults must not exceed certain limits. In the 6-component invariant net the strike of a fault within one ray can range up to about 30°. This limit on the range, combined with the curvature of the arc, determines the length of the segments of the arcuate fault; farther along, young branches develop on contination of the segments, and the arc structure decomposes.

Probably arc faults are segmented by the influence of an already functioning invariant fault net; that is, arc faults of the second type are parts of a completed invariant net, whereas those of the first type participate in creating such a net.

The main sources of oriented stresses embracing the crust of an entire or several continents are as follows:

1. If the speed of the Earth's rotation rate fluctuates, the polar compressive stresses in the body of the Earth periodically relax. If the movements along the faults were influenced by such variable stresses, the displacement direction would change frequently along the same faults, but no such changes have been observed on recent faults. At the same time, the stresses in question could be prominent in the origination of the invariant fault net in any continental block.
2. Stresses appear where the continental margins of lithosphere plates collide, producing a strong regional stress field embracing both the colliding continents. Such a stress field persists for a long period of time, since the forces that caused the movement of the continents are still active after their collision.
3. The stresses associated with centrifugal forces about the pole of rotation and the ellipsoidal shape of the Earth tend to shift the continents toward the equator. This stress field is very persistent in time, varying slightly with longtitude but equally oriented on all the continents at any given movement.

The two latter sets of stress can best explain both the coincidences and non-coincidences in the direction of displacement along the faults of invariant nets of various continents. Where a strong regional stress field is absent, the displacement along faults is probably controlled by the centrifugal forces and is uniform on different continents. Where continental margins of lithosphere plates collide, the stress field produced by the collision affects the directions of displacements along the faults.

In some cases these two stress fields act in the same direction, as in the stress field that resulted from the Oligocene collision of the Indian plate with Eurasia. The youngest displacements along the faults of the invariant fault net of Middle Asia take place in this overall stress field.

GENERAL CONCLUSIONS

By studying the history of the invariant net of Middle Asia and discussing the conditions of its existence in a moving and rotating continental block, we can reach the following conclusions.

1. The Earth's crust has the property of discreteness relative to deformations; that is, it is able within certain limits to transmit stresses without any deformation, and the number of possible directions of faults and folds is restricted. The minimal angle between the directions of fold axes appears to be 30° and that for fault systems is probably the same.

2. Because of the discreteness of the Earth's crust, the invariant fault net of a continent, once formed, is preserved; that is, the saturated fault net remains invariable despite changes in the stress field, although such changes can cause a change in the directions of displacements along the faults of the net. If the continent or a part of it rotates relative to the global stress field, the changes of the field and the appearance of regional force fields do not result in reconstruction of the invariant fault net. If the net is not saturated (that is, there are vacant directions), the rotation can supplement the existing fault net with rays oriented along the vacant directions.

3. The invariant fault net of the continents originates in older blocks of the crust under the influence of any stresses acting in these blocks. Subsequently, it spreads from areas of earlier consolidation into orogens. The invariant fault net within an orogen is formed at the end of the mountain-building epoch in the last stage of orogen deformation and continues to be active during the platform epoch of development.

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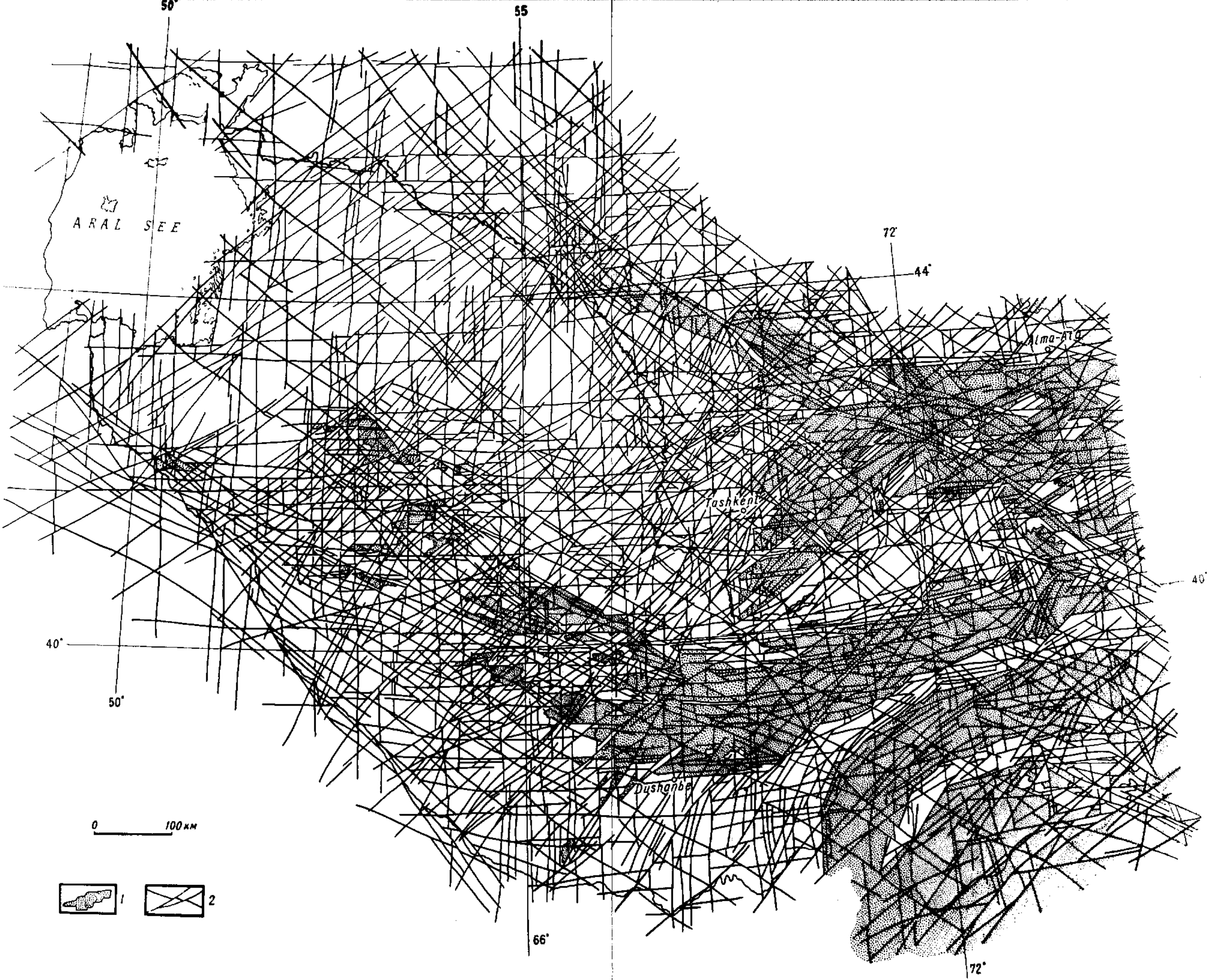
50°
55
ARAL SEE
72
44°
Alma-Ata
Tashkent
40°
40°
50°
Dushanbe
0
100 км
1
2
66°
72°

Fig. 2. Fault net of Middle Asia. The map was compiled from cosmic scanning pictures and from photographs taken from satellites and planes (Burtman, Legoshin, and Shvolman, 1979). 1, Paleozoic and pre-Paleozoic rocks; 2, faults; Mesozoic and Cenozoic rocks blank.