

The Occurrence of Large Holocene Earthquakes in the Kultor Fault Zone, Northern Issyk-Kul Area, Tien Shan Based on Radioisotope Dating

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Received August 19, 2022; revised August 24, 2023; accepted September 4, 2023

Abstract—Structural-geomorphological and paleoseismological methods were used to study morphostructures on the southern slope of the Kungei Ala-Too mountain range and in its southern foothills (adyrs). An analysis of radioisotope dates (radiocarbon and infrared luminescence) in paleoseismological trenches shows a lateral migration of vigorous seismic activity along the Kultor fault zone in the northern Issyk-Kul region. It has been confirmed that the contemporary high seismic activity concentrates in the adyr zone, and is confined to adyr faults. At least seven morphogenic earthquakes have occurred along this fault zone during Holocene time. The repeat time of morphogenic earthquakes was 200–300 years in our era. It seems that this fault generated great seismic disasters with $M \sim 7.5$ ($I_0 = X$) in the 7th and 15th centuries, with the rupture zones emerging at the surface and producing fault scarps up to 70–80 km in length.

Keywords: paleoseismicity, adyr faults, fault scarps, trenching, “blind” faults, radioisotope dating, Kultor Fault, Issyk-Kul Depression, Kungei Ala-Too mountain range, Tien Shan

DOI: 10.1134/S074204632370032X

INTRODUCTION

No one can doubt that the northern part of the Issyk-Kul Depression generates high seismic activity. It is there, namely, along the east–west trending segments of the Chon-Aksuu and Kichi-Aksuu rivers, that one can see the surface trace of the rupture produced by the 1911 Kebin earthquake ($M_s = 8.2$, $I_0 = X-XI$) (Fig. 1). Also in this area, the seismic network has recorded the 1978 Zhalanash-Tyup seismic event with $M_s = 6.8$, $I_0 = VIII-IX$ and the 1990 Baisoorun earthquake ($M_s = 6.5$, $I_0 = VIII$) (Dzhanuzakov et al., 2003). Considering that such strong, morphogenic earthquakes have occurred in the 20th century only,

then one would ask what was the seismicity in this area some hundreds or thousands of years ago? The use of archeoseismological and paleoseismological methods (*Archaeoseismology*, 1996; *Palaeoseismology*, 1996, among others) will help answer the question.

It should be said that the impacts of strong older seismic events in the region of study have been examined previously: as an example, one knows the work of Ch.U. Utirov (1978, 1993) who identified localities of older seismic deformations during the surveys for detailed seismic zonation of the Issyk-Kul Depression. These surveys suffered from the following drawback: this researcher was using structural geomorpho-

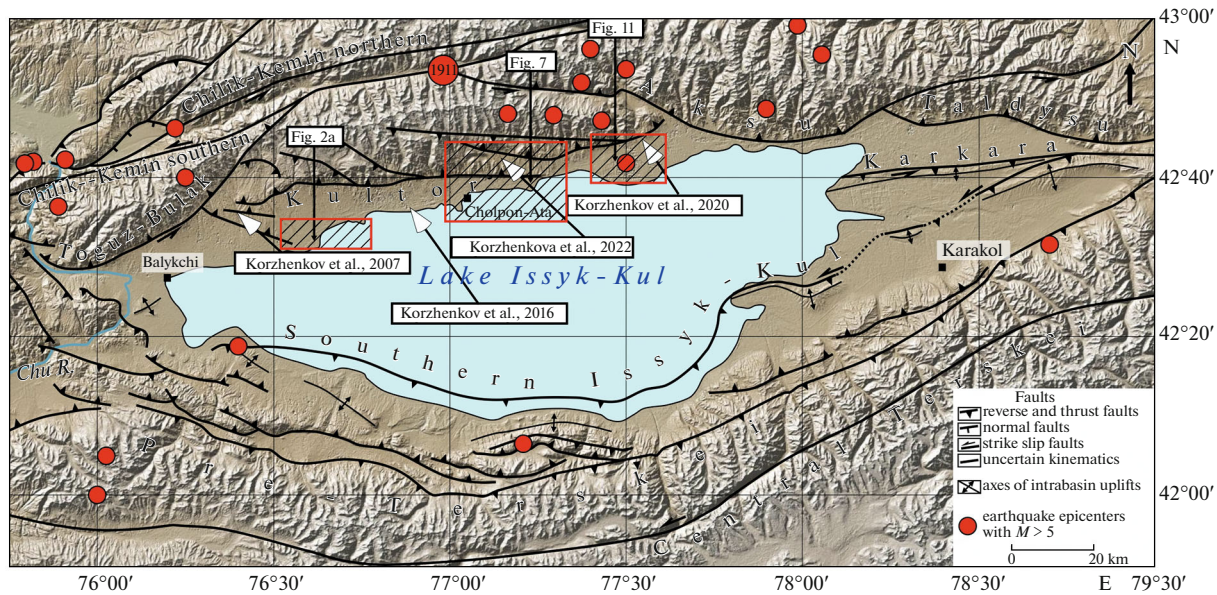


Fig. 1. The main active structures in the Issyk-Kul region (after Korzhenkov et al., 2019) with modifications and additions). The visualized relief was created using the GeoMapApp program package (<http://www.geomapapp.org>). Arrows indicate locations of trenches, the rectangles enclose references to the papers that provide descriptions of trench walls. The hatchured rectangles represent fragments of geological maps used in this paper.

logic techniques to detect traces of old earthquakes, while the internal structure of seismic deformations and their age remained unknown.

A breakthrough in the local paleoseismology took place in the 1990s, when international research teams came to the region. The study of earthquake-related convolutions in the Dead Sea sediments and the transfer of this experience to the Issyk-Kul Depression enabled descriptions of analogous liquefaction structures in the Holocene to Late Pleistocene deposits of this high-altitude lake (Korzhenkov et al., 1999; Bowman et al., 2004a; Povolotskaya et al., 2006). Studies of fault scarps by digging trenches and pits provided the key to understanding the internal structure of shallow parts of earthquake-generating fault zones, as well as to dating the earthquake-related movements (Korzhenkov et al., 2006a, 2006b; Korzhenkov et al., 2007, 2011, 2015, 2016, 2018, 2020; Abdakmatov et al., 2013; Deev and Korzhenkov, 2016; Deev et al., 2018; Korzhenkova et al., 2022). Tens of dates acquired using radiocarbon and luminescence techniques allow us to begin a study of strong ancient earthquakes in the northern Issyk-Kul region. It is with this issue that the present study is concerned.

MORPHOSTRUCTURES IN THE NORTHERN ISSYK-KUL DEPRESSION

The Issyk-Kul Depression lies in the northern part of the Tien Shan orogen, and is a complex-structured synclinorium. The depression is in tectonic contact to the south with the Terskei Ala-Too mountain range

(anticlinorium) along the Terskei fault zone. In the north, the Issyk-Kul Depression is adjacent to the Kungei Ala-Too mountain range (which too is an anticlinorium composed of several mega-anticline structures) along a sequence of border faults that are arranged en echelon, namely, the Toguz-Bulak, the Kultur, the Aksu, and the Taldy-Bulak fault (see Fig. 1). The Terskei and Kungei Ala-Too ranges are mostly composed of Paleozoic rocks displaced by Caledonian and Hercynian fold-and-fault deformations. The region in question was in a platform setting during Late Paleozoic, Mesozoic, and Early Cenozoic time, which resulted in the formation of a peneplanated denudation surface. Intense tectonic movements started to occur in the beginning of the Late Cenozoic (in the Oligocene), resulting in the formation of neotectonic uplifts and depressions, and in faulting. These movements culminated in the formation of a mountain relief and in the accumulation of coarse molasse. The Issyk-Kul Depression is a co-sedimentation depression, it is infilled with a 5-kilometer rock sequence of mostly Late Cenozoic deposits.

The Kungei circumference of the Issyk-Kul Depression consists of four recent mega-anticline structures. Of these, the West Kungei structure strikes NE, the Choktal-Agalatash structure strikes WNW, while the Central Kungei and East Kungei mega-anticlines are oriented approximately east-west (Chediya and Trofimov, 1978). The three last-mentioned mega-structures are situated in a system of right echelons. All of the four megastructures are obviously asymmetric: the southern limbs (slopes) of the uplifts dip at rela-

tively low angles with preserved fragments of pre-orogenic peneplain, while the northern limbs dip at steep angles and are cut short by faults, with these last serving to upthrust the limbs onto the structure that is adjacent to the north. The steep limbs are devoid of the peneplain; they show, with differing degrees of distinctness, layering of relief that was produced by sporadic (impulsive) orogenic movements.

Because of the ongoing crustal shortening between the Eurasian and Indian plates, the former areas of sedimentation in the Issyk-Kul Depression are being uplifted, hence each of the border faults listed above creates adyr (foothills) uplifts in front of itself with adyr faults serving as the southern boundary to these uplifts. These faults form a tectonic contact of the foothills zone mostly composed of Paleogene and Neogene rocks and Quaternary alluvial deposits. These deposits compose the slightly inclined plain descending under the lake.

It seems very likely that much of the crustal shortening in the region is at present accommodated by adyr faults with a staircase of fault scarps along them. We think that the scarps that align themselves along the adyr faults were largely produced by impulsive movements. This assertion is supported by the following facts: (1) the region of study is part of the North Tien Shan zone of high seismic activity characterized by great historical earthquake-induced disasters such as the 1911 Kebin earthquake with $M > 8$, which produced scarps up to 10–12 m in height (Bogdanovich et al., 1914; Arrowsmith et al., 2016); (2) the epicentral areas of these earthquakes and the areas around them contain widely abundant paleoseismic deformations, including large fault scarps (Utirov, 1978, 1993; Chediya and Korzhenkov, 1997; Korzhenkov, 2000; Korzenkov et al., 2004, among others); (3) the adyr zone in the Issyk-Kul area is characterized by a high rate of erosional downcutting and piedmont accumulation (Korzhenkov, 1988). That is to say, in case slow creep movements took place, the scarps must inevitably have been washed out by waters of consequent streams or overlain (buried) by a thick sequence of alluvial–coluvial deposits.

Apart from the above arguments, there are several characteristic features that can distinguish between seismotectonic and aseismogenic displacements (Solonenko, 1962, 1973, among others). These residual deformations are characterized by the following: (1) they are confined to zones of recently activated faults or are situated within actively developing morphostructures; (2) they are discordant with relief appearance along strike, disturbing geomorphologic surfaces of various kinds; (3) uplifted limbs of earthquake-generating faults form scarps; (4) these deformations persist in relief. The scarps considered here show all of the above features, so that we will call them fault scarps in what follows, and the movements on

adyr faults that have led to their formation will be referred to as seismogenic.

We are now going to analyze these data for the Kultor Fault in the northern Issyk-Kul area starting from west to east.

VIGOROUS PALEOSEISMICITY ALONG THE KULTOR FAULT ZONE

The western end of the Kultor fault zone is confined to the basin of the Toru-Aigyr River (Fig. 2). In this area, the river cuts through the antecedent part of its valley in the western periclinal termination of the Choktal-Agalash mega-anticline, which is overlain in the north and in the south by Paleogene deposits of the Kokturpak Formation which overlie conformably the older denudation surface. South of this area are the Ak-Teke and Tekren adyr uplifts, which are morphologic expressions of the eponymous adyr faults, branchings-out from the main Kultor Fault (see Fig. 2) (Korzhenkov, 2000; Bowman et al., 2004b; Korzhenkov et al., 2007, 2011).

We made a careful study of the Ak-Teke adyr fault zone (Korzhenkov, 2000; Bowman et al., 2004b; Korzhenkov et al., 2007). Of special significance in the context of the present study are traverses nos. 16–18 which were run over a Holocene terrace (Fig. 3). Seismic movements on the Ak-Teke adyr fault have displaced it through a height of 2.50–4.25 m (about 3 m on average). The age of the terrace in the hanging side of the fault was determined using infrared luminescence technique as 1.32 ± 0.21 ka (Korzhenkov et al., 2007). This age value means that the deposits of the uplifted Holocene terrace were still floodplain features before 1320 ± 210 years B.P. A large earthquake seems to have occurred in the Ak-Teke adyr fault zone during the 7th century (± 2 centuries). The floodplain deposits in the hanging side of the fault were uplifted to a height of a few meters and since then were never flooded by the Toru-Aigyr River. We said in the section *Luminescence Dating* (Korzhenkov et al., 2007) that these dates were the minimum age values. Recalling the uncertainty of the technique, we can say that the last earthquake must have occurred in the 6th, or even 5th century A.D., rather than in the 7th century. If that is the case, can this fault scarp mark the epicentral zone of a large earthquake that occurred in the northwestern Issyk-Kul area probably around 500 A.D. (see Fig. 1) on which our data are scanty (Dzhanuzakov et al., 2003)?

One can see in Fig. 4 that the deposits of the Q_{IV}^1 terrace (where traverses 17 and 18 were run) are disjunctured by two ruptures. The two ruptures reach the terrace top. These facts mean that two seismic events were responsible for the maximum displacement of 4.25 m on the Ak-Teke Fault, that is, an average of 2.12 m per one earthquake. These figures are quite realistic. As an example, the magnitude 7.3 1992 Suusamy

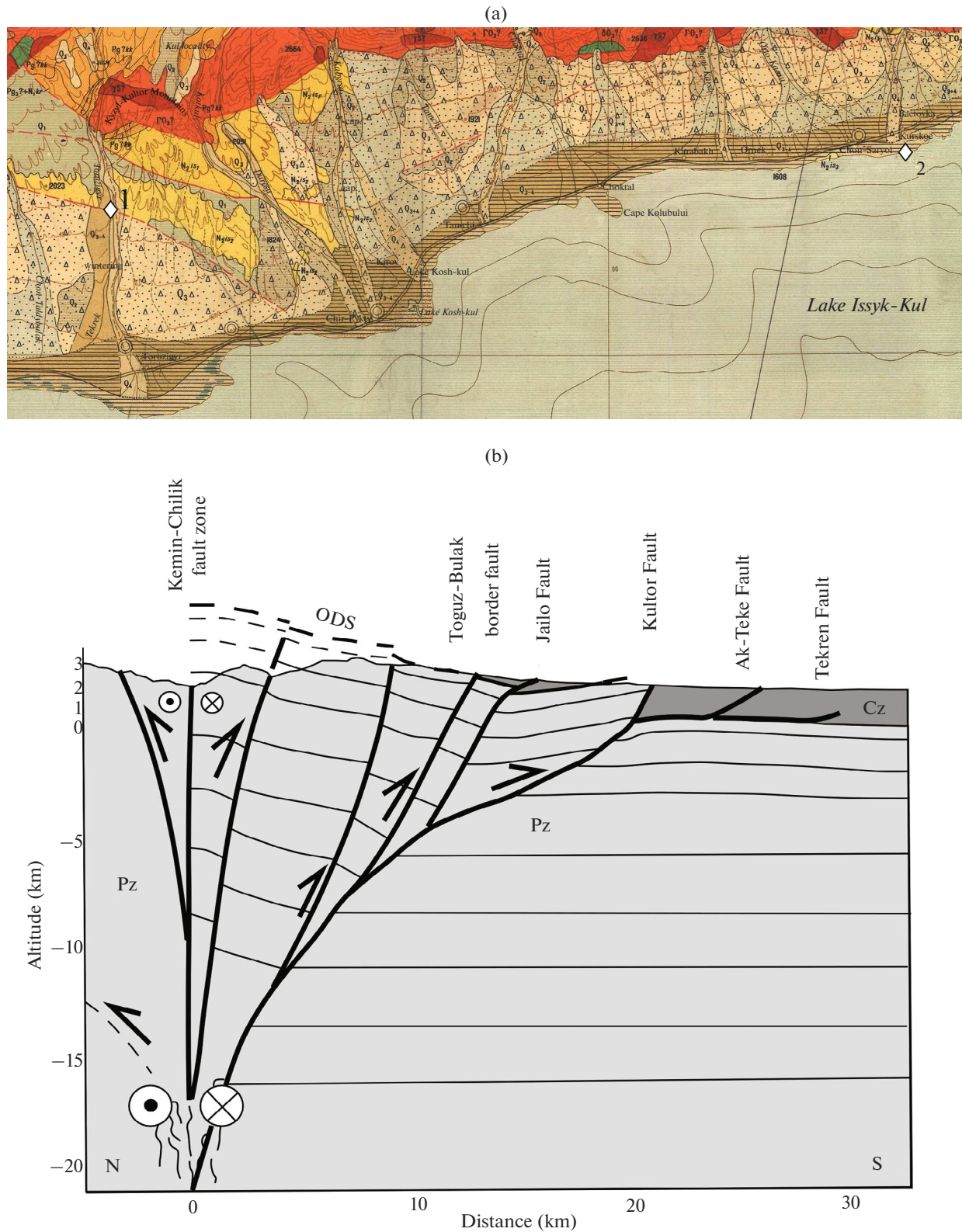


Fig. 2. A fragment of the 1 : 200000 geological map for the Northwest Issyk-Kul region (after Pomazkov, 1962 with additions) and a balanced section along the Toru-Aigyr R. valley. (a) map (green and shades of red show Paleozoic rocks, orange and yellow mark Paleogene and Neogene deposits, respectively, shades of grey show Quaternary deposits, and diamonds indicate locations of our surveys): (1) Ak-Teke fault cutting through the Toku-Aigyr R. valley, (2) submerged fortress of Emir Timur; (b) balanced section along the Toru-Aigyr R. valley after (Selander, 2008) with some modifications, with the main structures only being displayed. ODS stands for Older Denudation Surface.

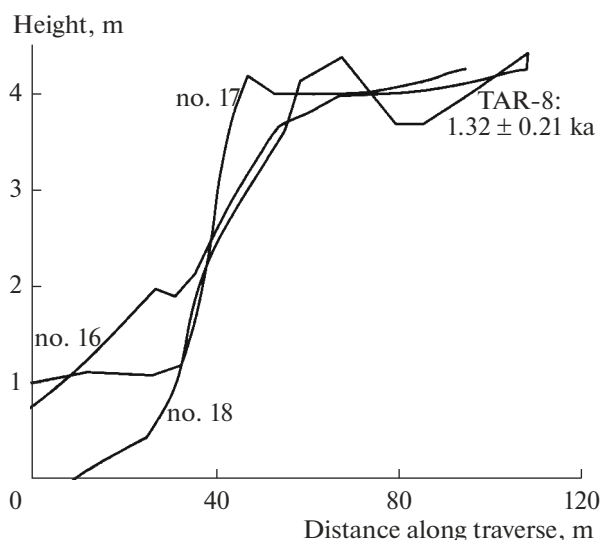


Fig. 3. A summary of leveling lines along a Holocene terrace of the Toru-Aigyr River through the Ak-Teke adyr fault (Korzhenkov et al., 2007).

earthquake in the northern Tien Shan produced two fault scarps whose maximum heights were 2.7 and 1.8 m (Bogachkin et al., 1997).

The youngest sample from the Toru-Aigyr valley was taken from the deposits of an uplifted high floodplain (TAR-8). Its age is 1.32 ± 0.21 ka, and it defines the last geologically recorded tectonic movement on the Ak-Teke adyrs. The fault in the deposits of the Toru-Aigyr high floodplain (see Fig. 4) along the

southern limb of the Ak-Teke anticlinal fold indicates a seismic movement during historical time and implies an ongoing tectonic activity along the Ak-Teke fault.

SURVEYS OF UNDERWATER BUILDINGS NEAR THE VILLAGE OF KURSKOE

These underwater buildings (see Fig. 2) were known long ago. As an example, the military Governor of the Semirechensk Oblast, general-major G.A. Kolpakovsky, who visited the location in 1869, wrote that "... two feet away from the shore, at a depth of a foot, one could see traces of buildings made of baked bricks. It would be difficult to see what was the purpose of these buildings, because the walls made of bricks do not enclose any space, but run in parallel rows spaced at the same distance, about two feet. One can now see three walls going away from the shore and under water so that they soon become invisible" (Kolpakovsky, 1870). The governor also reported about great numbers of bricks scattered around the walls. Just at waterline was a stone sculpture, *balbal*.

Academician V.V. Bartold while being a young staff member at the St. Petersburg University, did not find any of the buildings described above when visiting the Issyk-Kul Depression in 1894 (Bartold, 1897). Considerable regression affected the lake level for the last 25 years, by an amount of 4.5 m. Consequently, some of the buildings emerged from water, and were dismantled by local inhabitants for their household necessities. The future notable orientalist and a Russian academician searched the place to discover only

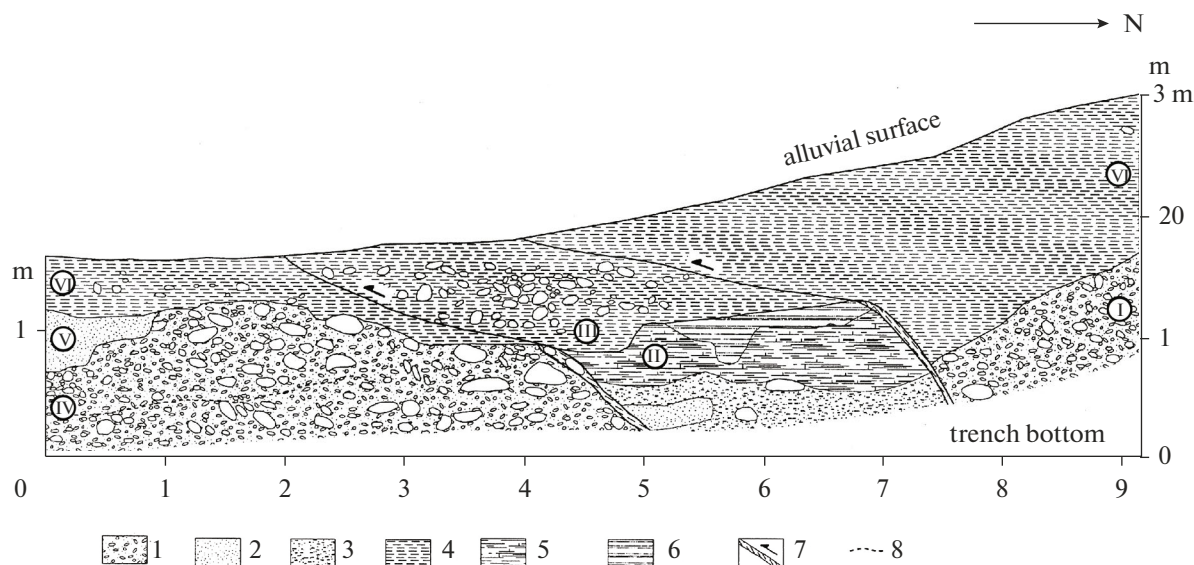


Fig. 4. A detailed picture of the Ak-Teke fault zone made by B. Shchasnyi (after Korzhenkov et al., 2007) with modifications). (1) pebble; (2) sand; (3) loam; (4, 5) clay (4 brown, 5 white); (6) organic matter; (7) rupture zone; (8) ferruginate rock streaks. I–VI stratigraphic units: (I) very dense, cemented shingle, (II) an irregular alternation of sand, loam, and clay with inclusions of organic matter, (III) clay with considerable amounts of pebble material, the so-called "colluvial wedge", (IV) unconsolidated shingle, (V) sand lens, (VI) compact clay with present-day soil on top.

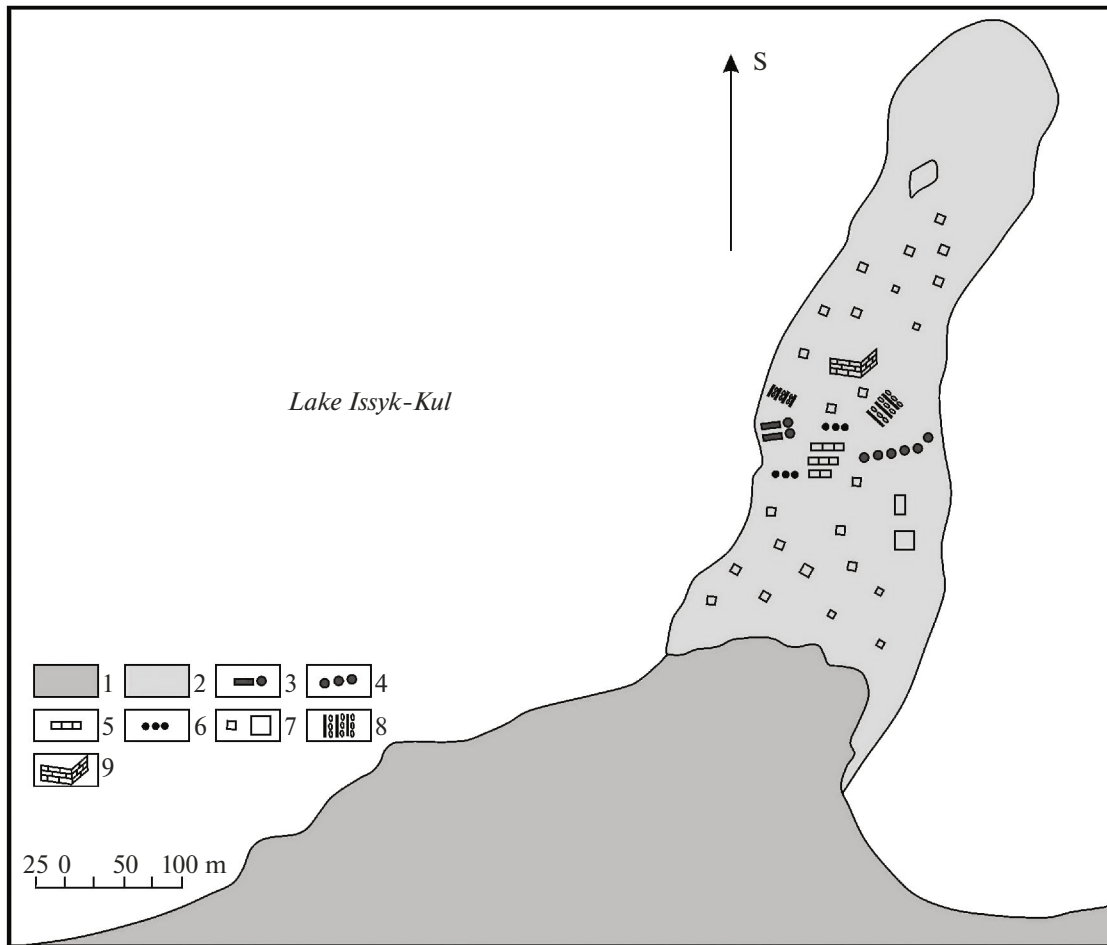


Fig. 5. A schematic map of a shoal that had existed near the contemporary Chaika resort in 1959 (based on Vinnik, 1961 with modifications). (1) shore, (2) shoal, (3) log flooring, (4) hedge, (5) wall remains, (6) wall substructure, (7) groups of scattered bricks, (8) stone pavement, (9) building.

some bricks lying on shore. Nevertheless, based on the information supplied by G.A. Kolpakovsky, V.V. Bartold hypothesized that the shambles covered by lake water are remains of a fortress that has long been known from some written sources. As an example, the Arabian writers Ibn-Arabshah in the 15th century and Mohammed Haidar in the 16th (Bartold, 1897) reported the existence, in the northern part of Lake Issyk-Kul, of a big island with numerous fortifications and residential houses. These buildings were used by Timur, the conqueror of the East, who according to some information kept his captives on the island, while other sources inform us that he himself took a rest there after his bloody campaigns.

The Issyk-Kul archeological team headed by D.F. Vinnik (Vinnik, 1961) has identified a considerable offshore sandbar, which is the older lake shore. The bar extends east–west, passing 400 m north of the present shoreline. It is 5–8 m high near the Chaika resort, gradually getting lower westwards. The bar is occasionally more than 100 m wide. Its surface occa-

sionally bears fragments of pottery. The staff of the archeological team have identified a long (reaching 1000 m) approximately north–south shoal (Fig. 5) whose width just offshore is 215 m. The shoal gets narrower southwards to widen again after some stretch. Owing to a considerable (2 m) lowering of lake level for the past 60 years, the shoal is now a long peninsula called Zmeinyi (Snake Peninsula).

While the Issyk-Kul archeological team was at work in 1959 (Vinnik, 1961), one could well see the NE corner of a wall on the shoal, with most of the wall being buried under sand and pebble. On top of the stone wall were ends of a log floor consisting of 18 poles. It was 5.2 m long and 3.3 m wide (Fig. 6). The poles were 7–15 cm thick. The poles were covered by a thick layer of travertine.

The poles did not float, because they were covered by a thick layer of earth and stones before the whole went under water. More than 20 radiocarbon dates were obtained for the absolute age of the poles (the work was done by a joint underwater archeological

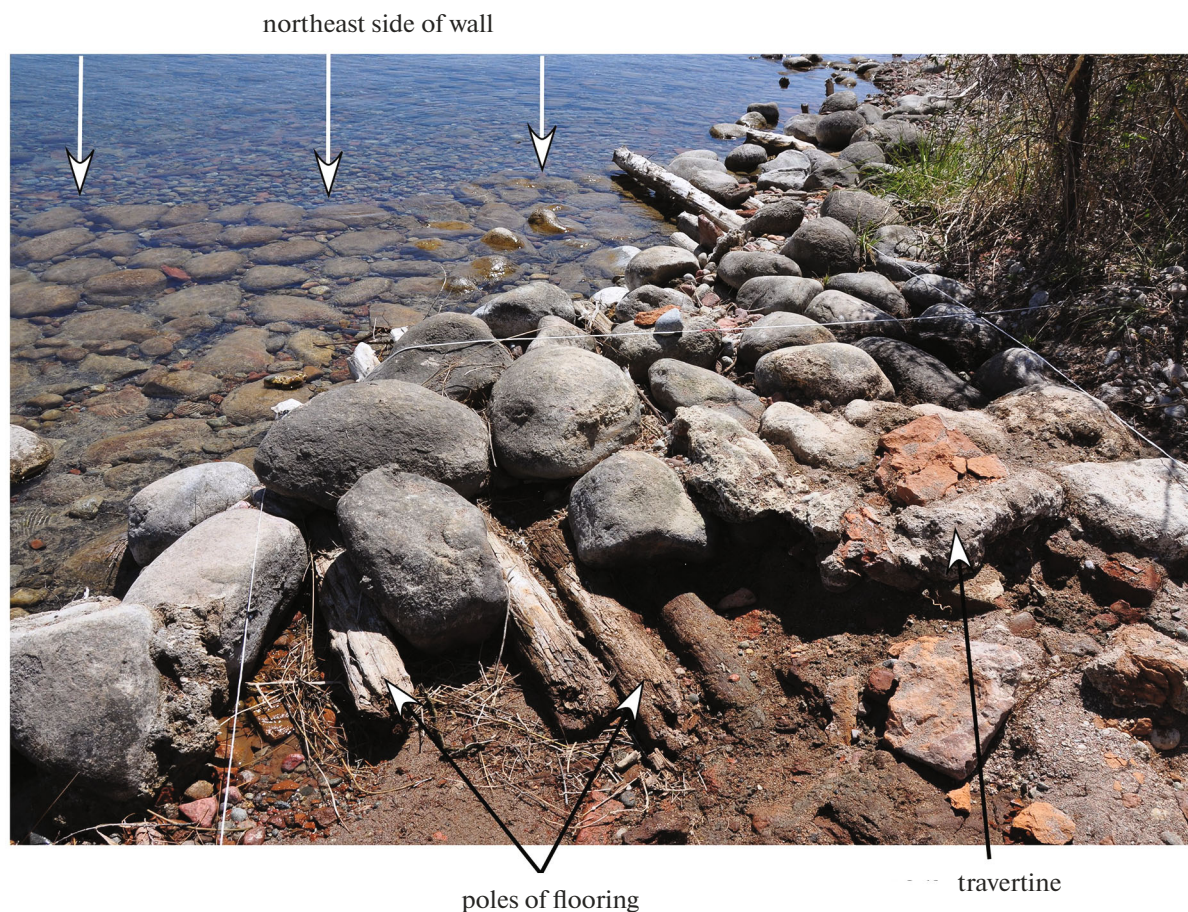


Fig. 6. A 2014 photograph of the eastern wall on the shoal near the modern Chaika resort as discovered by the team led by D.F. Vinnik in 1959 (Vinnik, 1961). View to northeast. One can see the 2-meter rope marking of the current archeological excavation made by the joint expedition organized by the Kyrgyz–Russian Slavic University and the American Geographic Society.

expedition of the Kyrgyz–Russian Slavic University and the US Geographic Society). All dates are within the same time span, viz., the late 14th to the early 15th century (personal communication by V.V. Ploskikh, who was co-head of the joint archeological expedition).

One can hardly imagine that large fortifications such as these (judging from the multimeter thickness of the stone walls unusual for the Issyk-Kul area) could be built in water. The natural hypothesis is that “a disaster occurred” (Vinnik, 1961), and all structures built in the place went under water. The layer of loose earth and stones was gradually washed away, and the poles were covered by a layer of travertine that cemented them.

A survey of the ruins near the village of Kurskoe carried out by underwater archeologists (Vinnik, 1961) showed that the shoal where the ruins stand was land in the Middle Ages. Bartold (1897) and P.P. Ivanov (1957) hypothesized that the island was submerged due to a catastrophic earthquake. The Issyk-Kul team made an exploratory survey of the lake bottom in

many places along the northern shore. However, they have not succeeded in discovering as many remains of medieval structures as in the Kurskoe area. It follows that this survey has confirmed the standpoint of V.V. Bartold and P.P. Ivanov.

Ivanov (1957) made a quite justified statement that the Zmeinyi Peninsula went under water in the manner of a disaster, during a strong earthquake. He agrees with Bartold (1897) and with L.S. Berg (1904) who pointed out that the subsidence was sudden, otherwise the inhabitants could have time to take away their numerous household utensils and valuable things which can be found underwater at present and which are cast ashore. Great amounts of human skeletons and bones are found under water, as well as on shore.

Archeologists provide materials to show that the shoreline subsided during strong earthquakes occurring in the late 19th and early 20th century. As an example, the “nearest shore of lake Issyk-Kul was lowered below its former level and went under water for a stretch of some hundreds of yards” on the northern shore of the lake near the Cholpon-Ata station during

the Vernyi earthquake of 1887 (*Turkestanskije Vedomosti*, 1887; Berg, 1904). Also for the Chilik earthquake of 1889, it was noticed that the shore was lowered and shrank in extent at some places, while the water level rose (Zeland, 1891; Bartold, 1897; Berg, 1904, among others). The above is supported by the (already mentioned) facts of considerable subsidence episodes in the shore zone occurring during the Kebin disaster of 1911 ($M = 8.2$, I = X–XI) (Bogdanovich et al., 1914).

We have cited instances of shore subsidence during distant earthquakes. Now what would happen to the lake shore, if a strong earthquake should occur at a distance of mere 5–7 km north of the shoreline?! We conclude that the subsidence of the Zmeinyy Peninsula/Island under water can be considered as proved. The question remains, when could the event have taken place?

We have pointed out that there are numerous radiocarbon dates obtained by the American Geographic Society for the log floorings on the Zmeinyy Peninsula. All of these fall into the time span of the late 14th to early 15th century A.D. It thus appears that the earthquake occurred later than this. Published and archival materials on the archeology of the Issyk-Kul Depression (Ivanov, 1957; *Biosfernaya ...*, 2002) indicate two periods when towns were founded in the depression during the 10–12th and 13–14th (occasionally as late as 15th) centuries A.D. *Kalmyks* went through the region in the 17–18th centuries, while the *Kyrgys* history of settlement began since the late 18th century. It is only the 16th century which remains “mute”. The *Mogol* era had ended, while the *Kalmyks* had not yet come. The scanty historical literature for the region contains no mention of a strong earthquake, neither before, nor after that time. It may be hypothesized that the strong earthquake occurring in the late 15th or the early 16th century (or a sequence of such events) had done away with the remains of agricultural civilization in the Issyk-Kul region. The earthquake completely destroyed the political, administrative, and military structure in the region, which allowed *Kalmyk* tribes to penetrate the region as a knife through butter, with no serious resistance from the local inhabitants.

PALEOSEISMOLOGICAL RESEARCH IN THE CHOLPON-ATA-KORUMDY INTERFLUVE AREA

Overall, one can state a general (northward) asymmetry (vergence) of the Kultor neotectonic mega-anticline: its northern limb is shorter and cut by the Chilik–Kemin fault zone, while the southern is longer and dips gently; it has preserved considerable fragments of a pre-orogenic peneplain. A sequence of Cenozoic deposits overlies conformably the peneplain formed on Paleozoic rocks. However, this is just an overall picture, since both limbs of the mega-anticline are cut through by numerous faults of various types

that frequently traverse the east–west mega-anticline obliquely (Fig. 7). The oblique faults provide evidence of a considerable shear component of the tectonic movements that have formed the Kultor mega-anticline. This mega-fold can be represented as a “flower” structure in cross section, while the tectonic suture is the “stem” which penetrates the crust deep, and branches out to both sides toward the ground surface as “lobes”, i.e., faults.

The main faults in the area of study are the Kultor border fault and adyr faults (I and II, see Fig. 7). These are classic faults. The former experiences southward thrusting of Paleozoic rocks (mostly granitoids) onto the Cenozoic deposits of the Issyk-Kul Depression, while the Kultor adyr fault consists in a thrusting movement of Paleogene–Neogene deposits onto the Quaternary deposits in the depression, southward as well. Both faults dip northward. However, all is not that simple there. There are other faults in between the faults described, with the faults being interpreted as reverse thrusts or underthrusts whose plane dips south (the Bozalatash fault, III, and the Akalatash fault, IV). There are also faults involving a considerable strike slip component; these are the Tegerek faults (V, VI, VII, see Fig. 7), which make an interesting two-sided ramp graben (Fig. 8). These underthrust and strike slip faults undoubtedly provide a telltale evidence for an intense north–south neotectonic compression, which leads to transpression besides thrusting.

The seismicity of the Tegerek ramp graben. This is a very interesting structural feature with recent seismicity recorded along it (see Fig. 8) (Korzhenkova et al., 2022). The movements in its southern part occur on the South Tegerek adyr underthrust fault, with the lower part of the slope moving north against the force of gravity. A small barrier mountain range has formed there whose growth can be inferred not only from the relief contrast, but also from a vertical deformation in the bed of an old *aryk* (irrigation ditch). The *aryk* was dug for irrigation of the agricultural lands south of the range, with the irrigation channel going around this barrier to the east. However, the earthquake-related movement uplifted the lower part of the *aryk*, so that water could no longer flow down. The people dug out another *aryk* above the first, but this “new” *aryk* is also dry at present.

We have dug a trench across the South Tegerek fault (Fig. 9). The GPS coordinates of its northern tip: $h = 2292$ m above sea level, $N = 42^{\circ}44'04.5''$, $E = 77^{\circ}10'58.7''$, the uncertainty in the coordinate determination is ± 4 m. The trench strikes at an azimuth of 3° , its maximum depth is 4.5 m, the width is 1.5 m, and the length 12 m. The trench walls show unconsolidated Quaternary deposits of different origins and grain size (from top to bottom):

(1) dark brown present-day humified loam soil up to 60 cm thick,

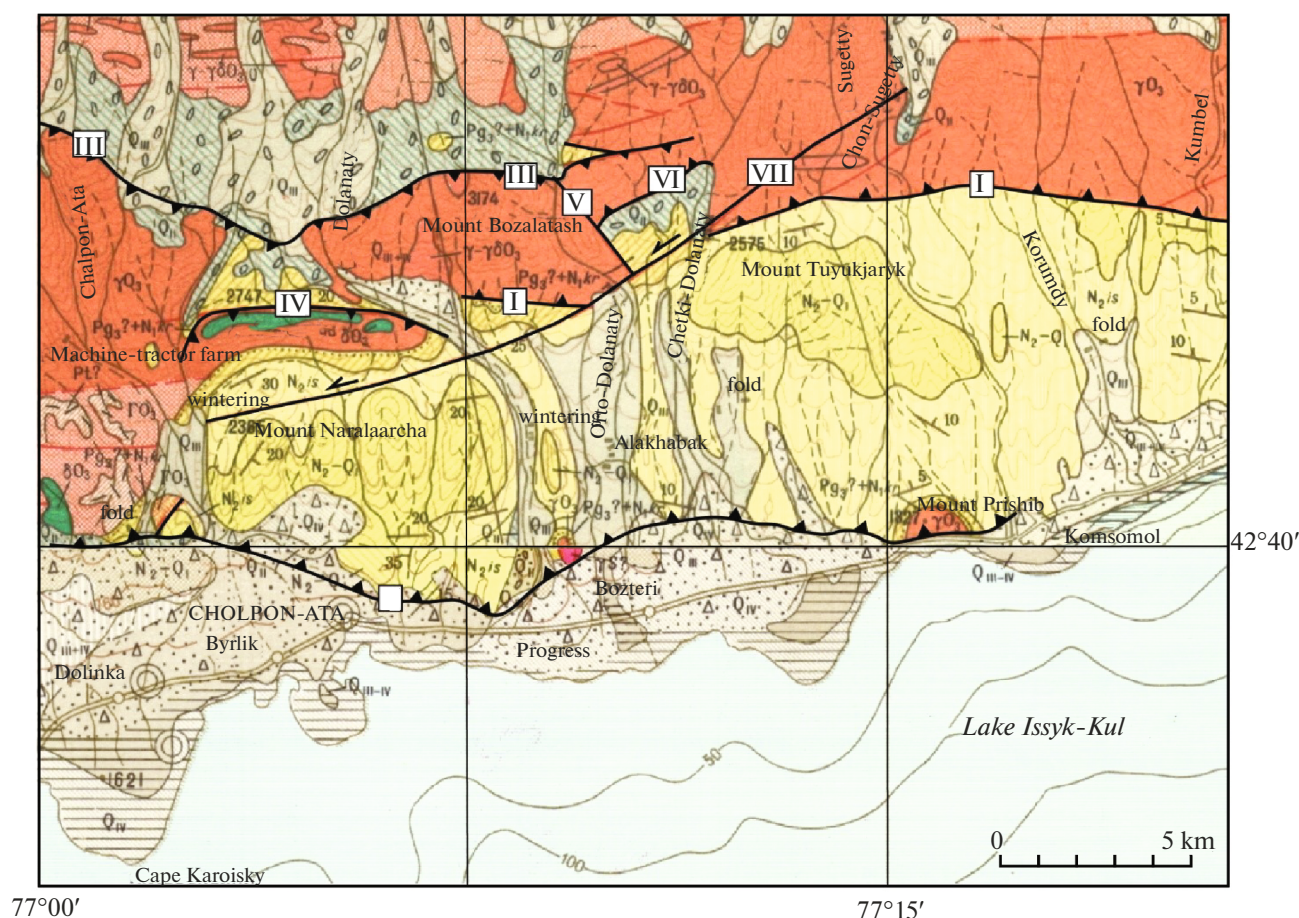


Fig. 7. Fragments of two 1 : 200000 geological maps (after Turchinsky, 1970; Zakharov and Chabdarov, 1975 with additions and modifications). Shades of red show Paleozoic granitoids, yellow marks Neogene rocks, and grey is for Quaternary deposits. Black lines indicate active faults, teeth show direction of slip dip, the arrow indicates lateral displacement on the fault. I–VII fault names: (I) Kultor border reverse or thrust fault, (II) Kultor adyr reverse or thrust fault, (III) Bozalatash underthrust fault, (IV) Akalatash underthrust fault, (V) West Tegerek reverse-oblique fault, (VI) North Tegerek reverse-oblique fault, (VII) South Tegerek strike slip fault.

(2) brown sandy loam with interbeds of large-grained sand, the maximum thickness is up to 120 cm,

(3) dark brown humified loam paleosoil up to 40 cm in thickness,

(4) grey–brown gruss–debris deposits up to 50 cm in thickness,

(5) reddish sandy loam with interbeds of large-grained sand up to 35 cm thick,

(6) light brown sandy loam with sand interbeds up to 95 cm thick,

(7) light brown to brown loam up to 70 cm in thickness; it is occasionally encountered as lenses in sandy loam (6),

(8) grey gruss–pebble deposits containing clasts (up to 20 cm across) of Paleozoic bedrocks of medium roundness. The visible thickness reaches 120 cm.

The section just described has been displaced by three reverse faults, with the southernmost being the oldest (I, see Fig. 9). It has displaced the layers in the

space from the gruss–gravel deposits (8) to the paleosoil (3). This is a reverse-faulting structure dipping south at angles reaching 50°. One can determine the vertical movement on the fault that amounts, e.g., based on the displacement of the paleosoil mentioned above, to 70 cm. However, the underlying layers have been displaced through a different amount, namely, 50 to 60 cm, which most likely provides evidence of the presence of a strike slip component on the rupture. It is important to note the presence of a colluvial wedge in the footwall of the northern fault consisting in its lower part of gruss–debris deposits (4) overlain by sandy loam (2).

The next in the order of age is the southern rupture plane of the reverse type (III, see Fig. 9). This rupture has displaced the layers in the space between the gruss–gravel deposits (8) and the loess-like loam (4). This reverse fault dips south at an angle of about 60°. It is important to note that the thicknesses and positions of unconsolidated layers displaced by the south-

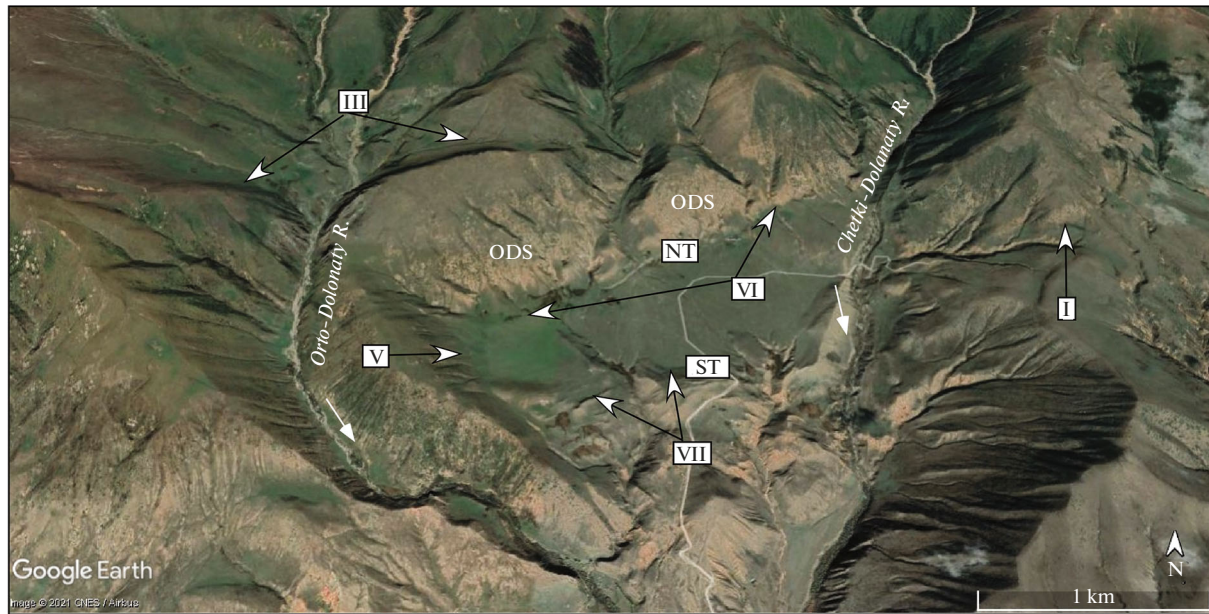


Fig. 8. A space image with indication of the faults that compose the Tegerek ramp graben in the Orto–Dolonaty and Chetki–Dolonaty interfluve area (Korzhenkova et al., 2022). I, III, V–VII are faults: (I) Kultor border fault, (III) Bozalatash fault, (V) West Tegerek fault, (VI) North Tegerek fault, (VII) South Tegerek fault. NT and ST denote our paleoseismological trenches (NT northern, ST southern); ODS are preserved fragments of an older denudation surface in the southern limb of the Bozalatash horst-anticline.

ern plane differ on the two sides of the fault, which most likely tells us that this fault involves a considerable strike slip component. This same circumstance also prevents us from determining the vertical displacement on this reverse fault.

The middle fault is the youngest in this section of the paleoseismological trench (II, see Fig. 9). The fault has displaced all deposits identified in the trench. In addition, a bend in the slope of the barrier ridge is confined to this discontinuity, namely, a young fault scarp 60 cm high. The middle fault dips slightly south in its upper part (80°), with the dip flattening towards the bottom to reach an angle of 65° . This is a reverse fault as well, although the associated vertical displacement is hard to calculate because of different thicknesses and positions of the layers on the two sides of the fault, which furnishes another piece of evidence for strike slip movements on each of the displacement planes in the South Tegerek adyr fault. It is important to note an increasing thickness of the present-day soil layer in the footwall of the middle fault (a colluvial wedge?), although one can interpret this as double layers of the present-day and former soils separated by a sandy loam layer in the hanging wall.

Researchers pointed, as far back as during the Soviet times, to considerable fragments of a pre-orogenic peneplain that has survived on the southern limbs of the anticlinal basement folds, including those on the neotectonic uplift of the Kultor mega-anticline (Utkina, 1978). The followers of S.S. Shults (1948) see

quite clearly that the folded basement deformations have northward vergence there: their northern limbs are short, steep, and displaced along faults, while the southern ones are long and dip at low angles, and are marked by a pre-orogenic denudation surface. There can be but insignificant faults there. It has been thought so earlier, these were pioneering small-scale surveys.

The use of the structural geomorphologic method showed a frequent presence of an earthquake-generating fault at the boundary between an uplift (mountain range) and the depression, including the situation on the low-angle long limbs of positive plicative features. As an example, the experienced eye of a geomorphologist and paleoseismologist will see a long line of swamped lows that give way to scarps higher up in the southern foot of the Bozalatash anticline in the Tegerek ramp graben. It is also seen that this is not a single line of rupture, but rather several parallel lines of scarps; that is, these relief forms mark a fault zone. This circumstance is best seen in the area where the waters of a nameless creek flow from the Bozalatash uplift into the Tegerek graben. There, one can see a whole set in the hanging wall of the fault: a staircase of fluvio-glacial and alluvial terraces uplifted along the fault to different heights. Measurements of heights and lateral displacements in terraces of different ages in this location showed that the lateral component of fault displacement is greater than the vertical by a factor of 3.

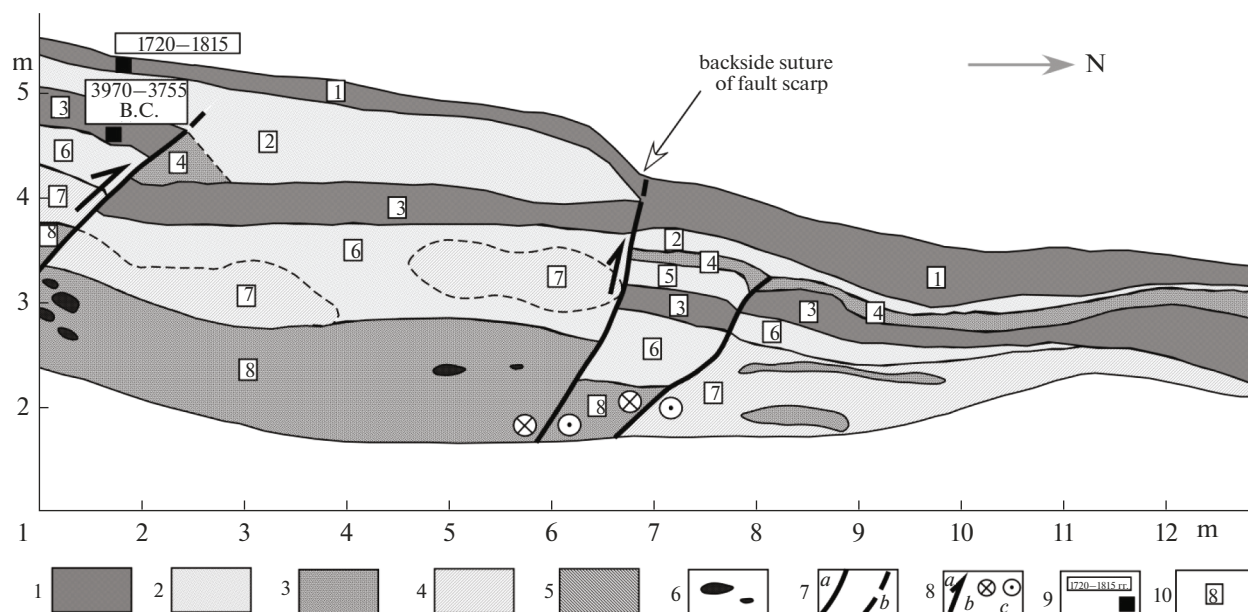


Fig. 9. Documentation of the west wall in the southern trench in the Tegerek graben going through the South Tegerek underthrust fault (Korzhenkova et al., 2022). (1) present-day and paleo soils, (2) sandy loam, (3) rock waste and gravel, (4) loess-like loam, (5) pattums (“waste deposits”, alluvium), (6) boulders and blocks, (7) ruptures (*a* certain, *b* uncertain), (8) sense of displacement on ruptures (*a* vertical, *b* from the viewer, *c* toward the viewer), (9) sampling sites for radiocarbon analysis, (10) identification number of the layer identified in the trench and described in main text.

We dug a paleoseismological trench across the North Tegerek fault (Fig. 10). The GPS coordinates of the southern part of the trench are as follows: $h = 2357$ m, $N = 42^{\circ}44'36.3''$, $E = 77^{\circ}10'53.1''$, with the uncertainty for coordinate determination being ± 4 m. The trench strikes at an azimuth of 150° , its maximum depth is 2 m, and the mean width is 1.5 m. We have documented the western wall of the trench. The trench runs along the uplifted alluvial fan where we expected to find numerous beddings that have been deformed to varying degrees depending on their ages. The deposits in the trench had a composition that reminded us of that encountered in the southern trench, with the only difference that the grain-size distribution was coarser.

The top of the section is present-day grey sandy loam mountain soil (1) up to 45 cm thick. This soil overlies a massive loam layer of the same color (2) 40 cm thick where interbeds of sandy loam and sand are encountered, in addition to half-rounded clasts of Paleozoic bedrock up to 30 cm across. Below this layer is a paleosoil (3) 20 cm thick, it is brown–grey in color and overlies a sandy loam substrate. This organic layer is underlain by grey gruss deposits (4) whose visible thickness reaches 40 cm. Still lower along the section is the alluvial pattum layer (a «waste sequence») (5) whose grain size rapidly increases from north to south, from large-grained sand to debris-gravel clasts up to 120 cm in thickness. The origin of these deposits is thought to be related to a mudflow. Under these deposits is another greyish-brown paleosoil (6) on a loam substrate up to 30 cm in thickness. This is under-

lain by a sandy loam layer (7) up to 70 cm thick, which gives way further south to lenses of debris and gravel. Still lower are gruss deposits (8), which remind one of a large-grained granite that has been crushed to get chippings; its thickness reaches 60 cm. Waste clasts are encountered in the northern part of the layer. Below is a thin (within 10 cm) lens of sandy loam (9). Farther downwards as far as the trench bottom is a layer of grey pattum (10), which is alluvial deposits up to 110 cm thick which includes individual half-rounded bedrock clasts, as well as a humic ovoid of uncertain origin (11, is it paleosoil?) 40×60 cm in size with a great amount of half-rounded pebble.

The wall of the northern trench (see Fig. 10) does not contain ruptures, except for some filiform cracks with no or little displacement. Nevertheless, the location was found to have several earthquake-induced plicative deformations: the earthquake-induced rupture has not reached the ground surface, but was near it. Especially spectacular is a bend in the lower paleosoil (6): the layer dips at angles of 15° – 20° in the northern part, while in the south the paleosoil is nearly vertical and separates into individual blocks. The middle paleosoil (3) has a similar tectonic bend, but with a smaller amplitude: the dip of the layer is 30° in the northern part and 3° – 5° in the southern. The present-day soil (1) is also deformed: its dip is 10° – 15° in the northern part and 2° – 3° in the southern. It is in the present-day soil that the backside suture of the present-day fault scarp is well expressed. One should also note the formation of the so-called colluvial wedges at

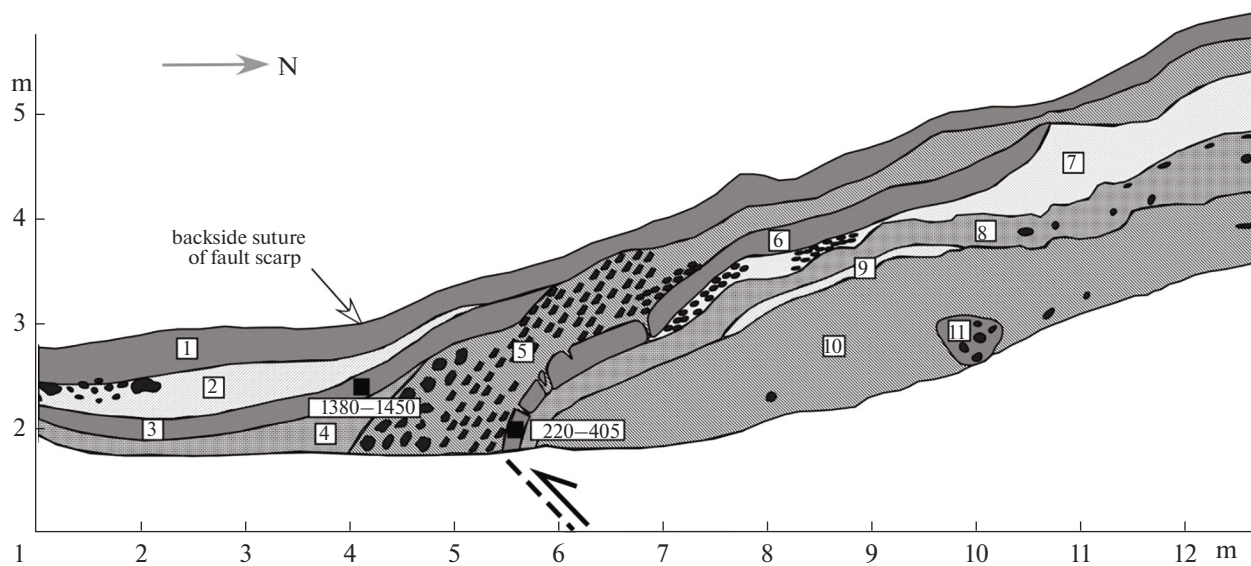


Fig. 10. Documentation of the western wall in the trench dug across the North Tegerek adyr fault, after (Korzhenkova et al., 2022). Flexural deformation in paleosoil (6) provides evidence of a “blind” character of the top of the fault zone. For notation see Fig. 9.

the base of the paleo-scarps: these are layers 4 and 5 after the first seismic event and layer 2 after the second earthquake. The colluvial wedge after the third, last, seismic event is still in its formative stage: it can be seen as the present-day soil layer increasing southward.

Examination of all discontinuities has revealed proofs of multiple and frequent earthquake-related displacements. This is shown primarily by data of structural geomorphology: nearly every fault zone contains one or two, or else a whole staircase of fault scarps. The best picture in this aspect is provided by the North Tegerek Fault: there are several uplifted Holocene and Late Pleistocene alluvial and fluvio-glacial surfaces in its hanging wall. The long-term regime in the occurrence of strong earthquakes along adyr faults is also supported by paleoseismological data, namely, by documented trenches dug across the faults. Both of the trenches dug and analyzed here across the South Tegerek and North Tegerek adyr faults “showed” the occurrence of at least 3 strong seismic events per each fault (see Figs. 9, 10).

In order to date these seismic events, we sampled the walls of the trenches (see Figs. 9, 10). For radiocarbon analyses we sampled paleosoils (TGR-1-3), including from the bottom of the present-day soil (TGR-4). The processing yielded the following results (Table 1).

The resulting radiocarbon dates enabled us to get the displacements for the fault zones which bound the Tegerek ramp graben, in space and over time. We will begin with the South Tegerek adyr fault (see Fig. 9). The oldest rupture plane identified in the trench wall is plane II. Its overthrusting (underthrusting) charac-

ter is beyond a doubt in the location: all layers in the southern side of the discontinuity are uplifted. This rupture has also displaced paleosoil (3) vertically by the amount 70 cm. The thick layer (2) in the northern side of rupture II may be the colluvial wedge of an old fault scarp. The maximum age of the first seismic event is determined from the absolute date of sample Vs-3100 (3970–3755 B.C.).

Rupture III (see Fig. 9) was activated next. This rupture is deformed and decays in layer (4) consisting of greyish brown gruss–debris deposits. The important fact consists in the circumstance that the rupture plane has displaced paleosoil (3) whose age is 3970–3755 B.C. (sample Vs-3100). It follows that the movement on this rupture took place after the paleosoil layer had been buried in the 4th millennium B.C. The kinematics of movement on rupture III is not quite clear. Judging from the southward dip of its plane, this must be a reverse overthrust/underthrust, similarly to its “brethren”, ruptures I and II. However, the trench wall only shows a persistent descent of the layers in the southern side of rupture III, which can well be treated as a normal fault. We would not give an unambiguous answer to the question what was the direction of the vertical component in the tectonic movement on rupture III, since we pointed out above that the tectonic movements on the Tegerek faults had a considerable lateral component that could be greater than the vertical by a factor of 3. It thus appears that several displacements on rupture III could push apart adjacent parts of a layer that were formerly adjacent to a considerable distance, thus producing the apparent effect of normal sense of movement in the southern side.

The last displacement occurred on rupture I that is part of the South Tegerek Fault (see Fig. 9). Its plane of slip has penetrated the present-day soil. Its thick layer in the northern side (footwall) of the rupture might be the colluvial wedge of the last seismic event. In addition, the back suture of the present-day 60-cm high fault scarp is also confined to rupture I. We hypothesize that the lowest age for this event is the age of our sample Vs-3102 (1720–1815), when the slope was stabilized in the hanging wall after the formation of the fault scarp, and the present-day mountain soil began to form.

Although no earthquake-related ruptures have been detected in the northern trench across the North Tegerek adyr fault zone (see Fig. 10), the flexural deformation in the layers of paleosoils and present-day soil provides evidence of the fact that the rupture was near and that the movement on the fault was “blind”. Nevertheless, we can use radiocarbon dates to decipher the history of strong seismic events that have occurred along the fault zone mentioned above.

The first seismic event took place in the time span 3970–3755 B.C. and was confined to the South Tegerek Fault. The event produced a fault scarp and disrupted the soil cover dated by sample Vs-3100. The paleosoil (6, see Fig. 10) in the North Tegerek fault zone was certainly forming in a quiet tectonic setting. The time of its strong deformation and burial is consistent with the age of our sample FTMC-FC63-1: 220–405 A.D. or with the age of the second earthquake that we have identified in the Tegerek ramp graben. The second paleosoil (3, see Fig. 10) has the age and the time of its burial in the time span 1380–1450 (sample Vs-3101). This is also the age of the third seismic event. The paleosoil layer (3) has only survived in the footwall of the rupture; it was buried under a massive loam layer with interbeds of sandy loam and sand encountered there (2). This paleosoil has been lost from the hanging wall, being washed away by erosion agents. The present-day mountain soil covers a fault scarp 2.0–2.2 m high. Judging from excellent morphologic expression, the age of the last seismic event must be a mere two or three hundred years.

Three strong morphogenic events have thus been identified on the South Tegerek Fault for the second half of the Holocene, and 3 strong earthquakes on the North Tegerek Fault. The highest ages of the first three events are 3970–3755 B.C., 220–405 A.D., and 1380–1450. The lowest age for the last event is 1720–1815. The thing to be cleared up consists in the question whether the seismic activation was occurring simultaneously on both walls of the Tegerek ramp graben or the faults were active independently of each other.

DATING THE OLD EARTHQUAKES AT THE EASTERN TIP OF THE KULTOR ADYR FAULT

Because of the ongoing crustal shortening between the Eurasian and Indian plates, the former areas of sedimentation in the Issyk-Kul Depression are being involved in an uplift, forming foothills (adyrs) along the mountain fronts that surround the Issyk-Kul Depression (Korzhenkov, 2000, 2006). The territory south of the Kultor border fault is no exception. The uplift involves deposits of Late Cenozoic molasse, which infilled the Issyk-Kul Depression since the start of orogeny (Fig. 11). The erosion exposures along the river valleys descending from the Kungei Ala-Too mountain range and cutting through the adyrs show ruptured Neogene sandstones, argillites, and finely clastic conglomerates and breccias (Fortuna, 1993). Their exposures at the ground surface can be explained, not only by the lateral pressure exerted by the southward moving mountain range composed of Paleozoic bedrock features, but also by uplifting of Neogene deposits in the Kultor adyr fault situated south of the border fault.

A quantitative estimate for the repeat times of strong earthquakes requires data of absolute dating of deformed sediments which are obtainable from paleoseismological trenches dug across fault zones. We have run two such trenches.

The first, or eastern, trench runs across the southernmost plane of the adyr fault half a kilometer west of the Tegermenty River (half kilometer west of the environs of the village of Kek-Debe) (Fig. 12). The trench strikes at an azimuth of 121°. The coordinates of the northern tip of the trench based on data of a GPS receiver: $h = 1717$ m, $N = 42^{\circ}45'47.7''$, $E = 77^{\circ}37'06.7''$, the uncertainty of coordinate determination is ± 4 m. The trench is 16 m long, its maximum depth is 2.5 m, and the width is within 2 m.

The eastern, approximately north–south striking trench has a relatively simple structure. The main type of deposit both in the hanging walls and in the footwalls was massive loess-like loam with no visible layering (see Fig. 12). Its visible thickness reaches 2 m in both walls of the fault. The zone of the earthquake-generated rupture looking as a very gentle-dipping thrust a few tens of centimeters in thickness is infilled with mixed gravel and gruss with a filler of large-grained sand. This was a spectacular sight, these comparatively large-grained deposits sandwiched between loess-like loam. The latter was probably “dragged in” along the fault from older deposits that compose the adyr uplifts, possibly from ground-up Late Quaternary fluvio-glacial deposits. It is hard to determine the total vertical displacement on the thrust, because we have not got any reference marks to estimate that. However, we have got the vertical component of the fault scarp, 1.25 m, and the angles of dip for the thrust plane, 20°, at the location where the fault plane emerges above the trench bottom and 0° in its southern flat part.

The structure of the hanging wall is of interest. At first sight one discerns strange rounded ovoidal bodies

Table 1. The results of radiocarbon dating for samples from the paleoseismological trenches traversing the Kultor fault zone

Sample no.	Laboratory index	Field identification number of sample	^{14}C age, years ($\pm 1\sigma$)	Calibrated age*, years for 68.2 and 95.4% probability
1	FTMC-AR90-1	KDB-1	1890 \pm 40	68.2% probability <u>60–170 AD (62.9%)**</u> 190–210 AD (5.2%) 95.4% probability 20–230 AD (95.4%)
2	FTMC-AR90-2	KDB-2	472 \pm 45	68.2% probability <u>1410–1460 AD (68.2%)</u> 95.4% probability 1320–1350 AD (3.8%) 1390–1520 AD (89.8%) 1600–1620 AD (1.9%)
3	FTMC-AR90-3	KDB-3	1688 \pm 40	68.2% probability 260–280 AD (7.4%) <u>320–410 AD (60.8%)</u> 95.4% probability 240–430 AD (95.4%)
4	FTMC-AR90-4	GRG-1	2117 \pm 50	68.2% probability <u>210–50 BC (68.2%)</u> 95.4% probability 360–280 BC (13.2%) 240–1 BC (82.2%)
5	FTMC-AR90-5	GRG-2	837 \pm 40	68.2% probability <u>1160–1250 AD (68.2%)</u> 95.4% probability 1050–1090 AD (5.3%) 1120–1140 AD (0.6%) 1150–1270 AD (89.5%)
6	FTMC-AR90-6	GRG-3	1495 \pm 40	68.2% probability <u>530–620 AD (68.2%)</u> 95.4% probability 430–500 AD (15.2%) 520–650 AD (80.2%)
7	FTMC-FC63-1	TGR-1	1764 \pm 40	68.2% probability 240–265 A.D. (16.0%) 275–350 A.D. (52.3%) 95.4% probability <u>220–405 A.D. (95.4%)</u>
8	Vs-3101	TGR-2	540 \pm 50	68.2% probability 1325–1355 (23.9%) 1390–1435 (44.4%) 95.4% probability 1300–1370 (39.1%) <u>1380–1450 (56.4%)</u>

Table 1. (Contd.)

Sample no.	Laboratory index	Field identification number of sample	¹⁴ C age, years ($\pm 1\sigma$)	Calibrated age*, years for 68.2 and 95.4% probability
9	Vs-3100	TGR-3	5066 \pm 50	68.2% probability 3950–3895 B.C. (25.7%) 3880–3800 B.C. (42.5%) 95.4% probability 3970–3755 B.C. (91.9%) 3745–3710 B.C. (3.6%)
10	Vs-3102	TGR-4	230 \pm 50	68.2% probability 1635–1685 (27.8%) 1735–1805 (33.6%) 1925–... (6.9%) 95.4% probability 1510–1595 (12.2%) 1615–1700 (32.3%) 1720–1815 (37.5%) 1835–1885 (3.7%) 1910 AD–... (9.7%)

Ages were estimated at the Radiocarbon Laboratory of State Research “Center for Research in Nature”, Vilnius, Lithuania; the determination method is ¹⁴C: LSC; the date of analysis is December 23, 2021 to January 30, 2022; The data of protocol is January 31, 2022; * software for calibration was OxCal 4.4 (Bronk, 2008); ** calibration curve was IntCal2020 (Reimer et al., 2013).

of different colors and composition in the trench wall (see Fig. 12). These are primarily reddish lumps of paleosoil that had been torn away from their original place to be involved in the thrusting movement. Most likely, the rounded shape of these paleosoil blocks, as well as of isolated ovoids consisting of light grey sandy loam, can be explained by multiple displacements of the entire material in the hanging wall, which has led to rotatory movements and rounding of originally rough fragments of the deposits.

One can see secondary normal-faulting planes in the back of the thrust (see Fig. 12). The displacements on these planes reaching 1 m have produced “pockets” that caught deposits of reddish paleosoil and present-day grey–brown loam soil. These normal-faulting planes dip at angles of 55°–60°.

The footwall of the fault scarp has a much simpler structure. It is composed of the massive loess-like loam mentioned above. In its lower part (above the trench bottom) one can see the top of a ball consisting of red paleosoil and a lens composed of pebble layers—pebble in grey sandy loam in front of the thrust front (see Fig. 12). The lens is most likely part of the deposits due to a small temporary stream that flowed parallel to the adyr front before the formation of this fault scarp.

The second, western paleoseismological trench was dug by us through the southernmost fault scarp in the Kultor fault zone east of the Chon-Aksuu River. The GPS coordinates of its northern tip: $h = 1773$ m, $N = 42^{\circ}44'02.7''$, $E = 77^{\circ}29'48.5''$, the uncertainty of coordinate determination was ± 5 m. The trench

strikes at 4°, its length is 21 m and width within 2.5 m (Fig. 13). The trench shows similarities and differences compared with the trench described above. Here also, the structure of both walls of the fault zone involves yellowish massive loess-like loam without any visible stratification. Here too, there are balls of unconsolidated rocks or fragments of these, but this time in both walls of the thrust; as well, there are fragments of reddish paleosoil, but here one sees ovoids of a light brown paleosoil instead of the light grey sandy loam detected in the walls of the eastern trench. One new thing consists in the presence of elongate lenses of black paleosoil in the bottom of the trench section. One also sees there small half-rounded clasts of Paleozoic rocks and fragments of pottery.

The fault scarp is small, its height is a mere 0.5 m. Its size might have been somewhat diminished in the wide trough-looking valley of a dry creek (*sai*) due to erosion. Nevertheless, the scarp has a clear expression in the relief (see Fig. 13). The plane of the rupture that has produced this earthquake-induced relief form has an angle of 25° in its lower visible part. Toward the top the dip increases to reach 40° (see Fig. 13). It was impossible in this trench to estimate the amplitude of displacement on the thrust because there was no reliable reference that had been displaced by the earthquake. The thrusting displacement on the main fault plane is confirmed by upward wrapping (dragging) of the southern part of the black soil layer.

The compression that was created during the earthquake in the front of the fault scarp also led to hummocking of soil blocks in the footwall of the fault zone.

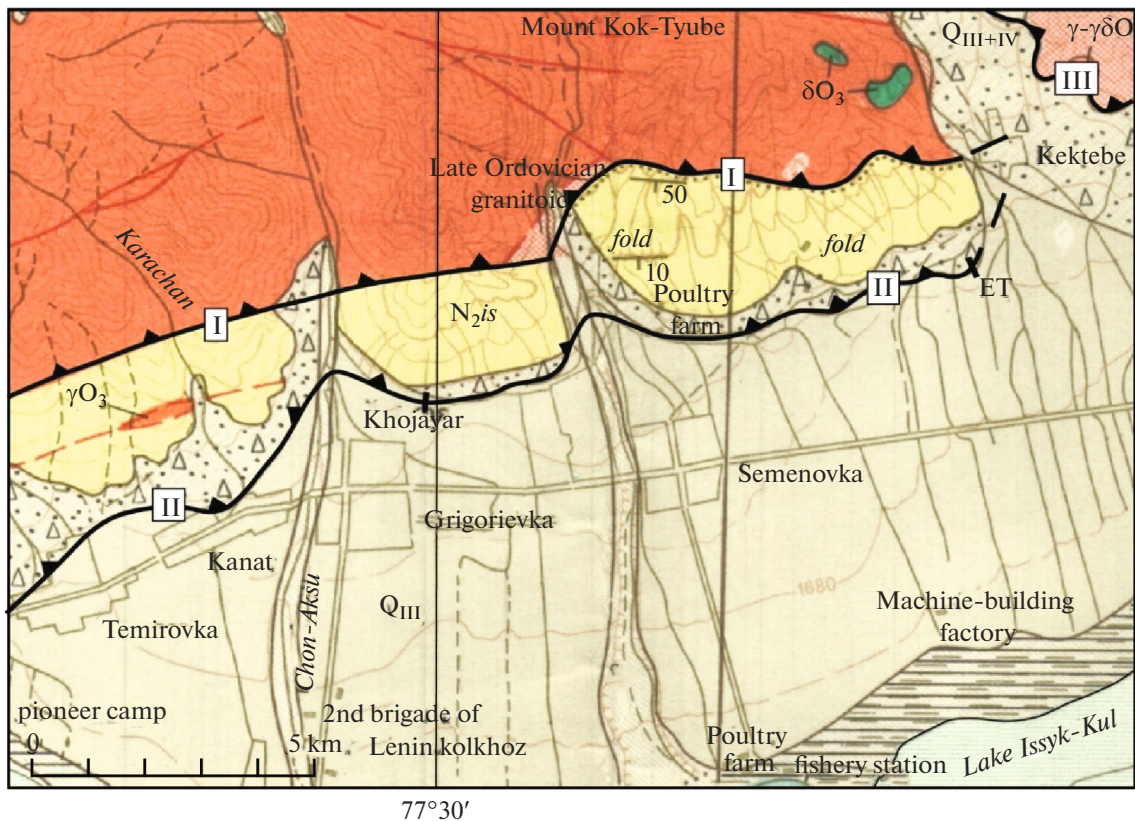


Fig. 11. A fragment of a 1 : 200000 geological map (after Zakharov and Chabdarov, 1975 with additions and modifications). Ordovician granitoids are shown in red, Neogene deposits in yellow, and Quaternary formations in grey. Heavy black lines mark main active thrust-oblique faults: (I) Kultor border fault, (II) Kultor adyr fault, (III) Aksu border fault. Teeth are in the direction of dip for fault planes. The locations of our paleoseismological surveys: WT western trench, ET eastern trench.

Strong ground motion has produced a reverse fault and a cut (see Fig. 13), which have divided the wall into blocks whose southern sides were uplifted by pressure from the north by amounts between a few centimeters and a few tens of centimeters. Such systematic displacements have led to a small counterclockwise rotation of all the blocks. In addition to the structures in the footwall just described, there is a graben infilled with grey pebble deposits of alluvial genesis. These deposits are overlain by a red paleosoil (see Fig. 13).

In the back part of the hanging wall we see tension too leading to the formation of a graben-shaped pocket filled with paleosoil. The ongoing movement of the entire thrust part toward the axis of the Issyk-Kul Depression has led to rotation of the light brown paleosoil block.

When the trench walls have been documented, we began to look for organic remains to help us date the deposits described in the walls of the trench. Unfortunately, the massive loess does not contain any organic remains. To perform dating we had to sample considerable amounts of soil material.

The eastern trench has yielded the most information. We have written about pockets that were formed in the back of the thrust zone (see Fig. 12). One of these pockets caught a considerable amount of pres-

ent-day soil during an earthquake. Radiocarbon dating of a sample of present-day dark brown loam soil from 80 cm depth gave the calibrated date 1410–1460 A.D. (FTMC-AR90-2) (see Table 1). This seems to be the lowest age for the formation of the fault scarp. The age of that sample coincides with our estimate of a strong earthquake that we identified earlier and whose traces we found in the western part of the Kultor fault zone (Korzhenkov et al., 2016a).

We took two samples from the eastern wall to determine absolute age from the reddish paleosoil, which gave the following calibrated dates: 60–170 A.D. (FTMC-AR90-1) and 320–410 A.D. (FTMC-AR90-3) (see Table 1). The first sample was taken from a pocket near the normal-faulting plane. By analogy with the preceding case we assume that the paleosoil age reflects the lowest age of the paleo-earthquake, 60–170 A.D. The presence of reddish soil blocks in the section tells us that, also after this ancient earthquake, subsequent seismic movements took place and fragmented the reddish paleosoil layer. That event took place later than 320–410 A.D.

The western trench gives us a calibrated age for the black paleosoil deposit, 210–50 B.C. (FTMC-AR90-4). The black soil in the footwall is overlain by a block of light brown paleosoil whose age is 530–620 A.D.

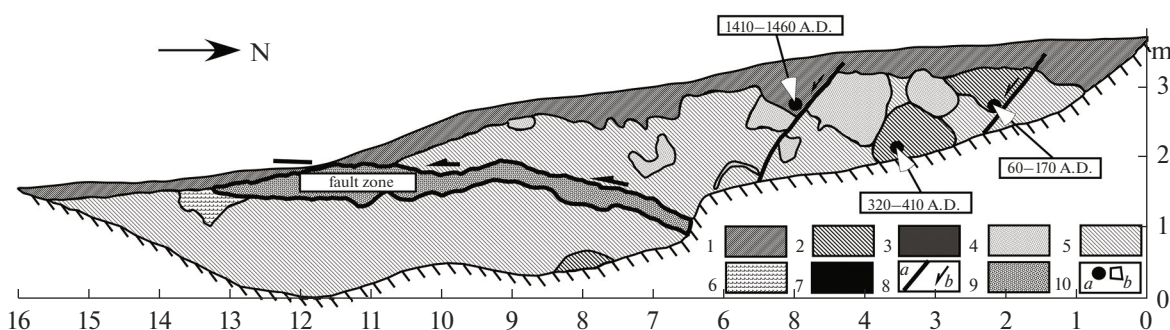


Fig. 12. The paleoseismological trench dug across the southernmost fault scarp of the Kultor adyr fault, west of the village of Kek-Debe (Korzhenkov et al., 2020). Section through the western wall. (1) present-day soil, (2) reddish paleosoil, (3) light brown paleosoil, (4) sandy loam, (5) loess-like loam, (6) debris–grass deposits, (7) black paleosoil, (8) earthquake-related faults (*a* planes, *b* sense of displacement), (9) unconsolidated deposits (granules and grass) infilling the fault zone, (10) sampling sites (*a* for radiocarbon analysis, *b* pottery). For trench location see Fig. 11.

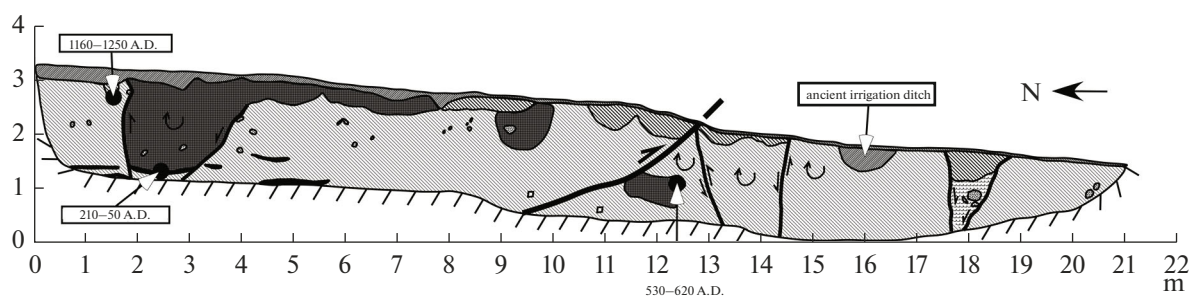


Fig. 13. The paleoseismological trench running across the southernmost fault scarp of those on the Kultor adyr fault east of the Chom-Aksuu River (after Korzhenkov et al., 2020 with modifications). This is the documentation for the eastern wall. For notation see Fig. 12.

(FTMC-AR90-6). The light brown paleosoil infills the graben in the hanging wall. For this reason its age can be the lowest age of a historical earthquake. Another date for a sample from this trench taken in the reddish paleosoil has a calibrated age of 1160–1250 A.D. (FTMC-AR90-5). That fragment of the reddish soil also lies in a “pocket”, and could have been buried during a strong past earthquake.

Summing up, we have radiocarbon dates that may be the lowest ages of strong earthquakes on the Kultor adyr fault: 60–170 A.D., 530–620 A.D., 1160–1250 A.D., and 1410–1460 A.D. The time difference between the dates (the repeat time for strong earthquakes on the fault) is 200–600 years. These data are fairly well consistent with materials concerning the repeat times of strong seismic events on the Aksuu border fault (Korzhenkov et al., 2018), which separates the Issyk-Kul Depression from the Kungei Ala-Too mountain range and extends the Kultor fault to the east. One may wonder about an absence of same-age dates in trenches separated by a distance of 20 km. There can be two explanations.

(1) Organic remains that could be used to date earthquakes have survived in one trench, but have been destroyed by erosion in the other.

(2) The two trenches run through different segments of the Kultor fault, which behave differently in the tectonic and seismological sense. This too need not be a subject for wonder: the combined 200-km zone of the Chilik–Kemin and Aksuu faults which became active during the 1911 earthquake ($M_s = 8.2$, $I_0 = X-XI$) was subdivided by us into 14 segments by the character of structural behavior (Arrowsmith et al., 2016).

THE REGIME OF STRONG HOLOCENE EARTHQUAKES ALONG THE KULTOR FAULT ZONE

Summing up, we can say that we have studied four areas of seismic deformations at the western termination, in the northwestern part, in the northeastern part, and at the eastern termination of the Kultor fault. All of these segments are part of the zone affected by the influence of the Kultor border fault which separates the Issyk-Kul Depression and the Kungei Ala-Too mountain range. It should be noted that it was not at all easy to find suitable material for radiocarbon analysis (bones, wood, charcoal, or humus-rich soil) in a natural exposure or in a paleoseismological trench under the conditions of mountain relief and intense

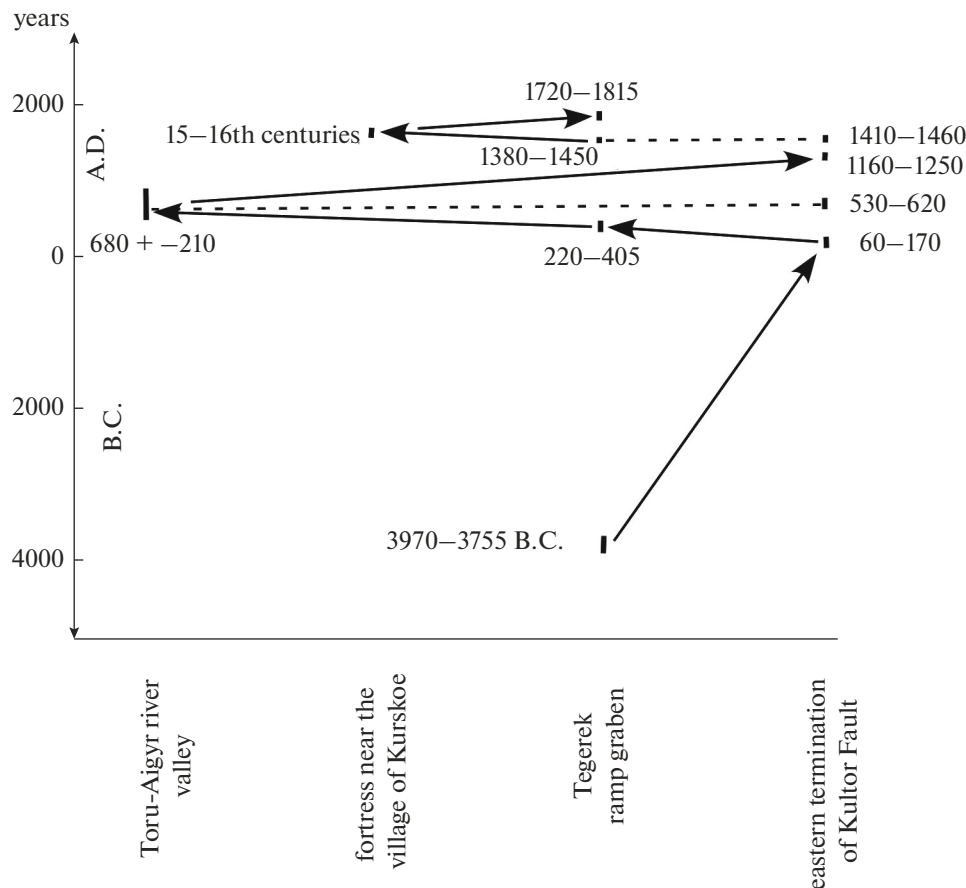


Fig. 14. Schematic correlation of strong earthquakes along the Kultor fault zone in the northern Issyk-Kul region based on (Korzhenkov et al., 2007, 2016, 2020; Korzhenkova et al., 2022).

erosional processes. It is for this reason that a summary review of absolute dates for extensive areas is a significant event for the geological community, with the materials of such a review being sought after by many researchers.

We have collected the available 10 radiocarbon dates and 1 luminescence date that we listed in a table (see Table 1), and calculated on this basis the ages of seismic events in the Holocene, which we also plotted (Fig. 14). We have succeeded in identifying a total of 7 strong earthquakes.

The first seismic event occurred in 3970–3755 B.C. on the South Tegerek Fault, producing a fault scarp and a rupture of soil cover, with the date being based on sample Vs-3100 (Korzhenkova et al., 2022).

We sampled the wall of the paleoseismological trench near the village of Kek-Debe (Korzhenkov et al., 2020), from the reddish paleosoil in a pocket near the normal-faulting plane for absolute age determination. The calibrated date was 60–170 A.D. (FTMC-AR90-1) (see Table 1). We therefore think that the age of this paleosoil reflects the lowest age of the second paleo-earthquake, viz., 60–170 A.D.

The paleosoil (6, see Fig. 10) above the North Tegerek Fault was certainly formed under quiet tectonic conditions (Korzhenkova et al., 2022). The time of its strong deformation and burial is the age of our sample FTMC-FC63-1: 220–405 A.D. This is just the age of the third earthquake that we have identified to have occurred in the Kultor fault zone.

The wall of a trench near the village of Semenovka contains a block of light brown paleosoil in the foot-wall of the rupture; the paleosoil has an age of 530–620 A.D. (FTMC-AR90-6) (Korzhenkov et al., 2020). This paleosoil infills the graben, hence we infer that its age is the lowest age for the 4th historical earthquake. The rupture length due to the earthquake described above may have been very considerable (80 km). This is shown by the luminescence date for TAR-8, the sample for which was taken at the western termination of the Kultor fault zone. There, the seismic displacements on the South Akteke adyr fault have displaced the Holocene terrace to a height of 2.50–4.25 m. The age of the terrace was determined by the infrared luminescence method as 1.32 ± 0.21 ka (Korzhenkov et al., 2007). The last age means that the

deposits in the uplifted Holocene terrace were still floodplain features before the period 1320 ± 210 B.P. Another strong earthquake occurred in the South Akteke adyr fault in the 7th century (± 2 centuries). The floodplain deposits in the hanging wall of the fault were uplifted to a height of a few meters and were never flooded by the waters of the Toru-Aigyr River.

Another date from the trench near the village of Semenovka concerns a sample of the reddish paleosoil. Its calibrated age is 1160–1250 A.D. (FTMC-AR90-5) (Korzhenkov et al., 2020). This fragment of the reddish soil also lies in a “pocket”, and was buried during the 5th strong earthquake.

We have written about “pockets” that were formed in the back of the thrust zone in the trench near the village of Kek-Debe (see Fig. 12) (Korzhenkov et al., 2020). One of such pockets caught a considerable amount of the old soil during the earthquake. Radiocarbon dating of a sample of dark brown loam soil from a depth of 80 cm gave a calibrated date of 1410–1460 A.D. (FTMC-AR90-2) (see Table 1). This is just the lower age for the formation of the fault scarp and for the 6th strong earthquake along the Kultor Fault. It is important to note that the second paleosoil (3, see Fig. 10) in the northern trench in the Tegerek Graben has a similar age within the uncertainty of the radiocarbon method: the time it was buried is 1380–1450 A.D. (sample Vs-3101) (Korzhenkova et al., 2022). This is also the age of the 6th seismic event. The paleosoil (3) layer has only survived in the footwall where it is buried under a massive loam layer with interbeds of sandy loam and sand (2). This paleosoil was not preserved in the hanging wall, being washed out by erosional agents. In addition, the age of the 6th seismic event coincides with the radiocarbon dates (the late 14th to early 15th century) obtained by American and Kyrgyz archeologists for the medieval fortress of Emir Timur on the Zayachy Peninsula flooded by the waters of Lake Issyk-Kul (Korzhenkov et al., 2016) west of the region under study here. If this is the case, then the earthquake-generating fault was also rather long, 70 km.

The last movement on the South Tegerek Fault (Korzhenkova et al., 2022) occurred on fault I (see Fig. 9): its plane penetrates the present-day soil, and its thick layer in the northern wall (footwall) of the rupture is the colluvial wedge of the last, 7th earthquake. In addition, fault I is also near the back suture of a present-day fault scarp 60 cm high. Our hypothesis is that the lower age for this event is the age of our sample Vs-3102 (1720–1815), when the formation of the fault scarp was followed by stabilization of the slope in the hanging wall and the present-day mountain soil began to form.

CONCLUSIONS

Structural-geomorphologic and paleoseismological methods were used to study morphostructures in the northern slope of the Kungei Ala-Too mountain range and in its southern foothills (adyrs). An analysis of radioisotope dates (radiocarbon and infrared luminescence techniques) in geological trenches shows migration of high seismic activity along the Kultor fault zone in the northern Lake Issyk-Kul region. It has been confirmed that the present-day high seismic activity concentrates in the adyr zone and is confined to adyr faults. At least seven morphogenic earthquakes have occurred along the fault zone during Holocene time. The repeat time for morphogenic earthquakes was 200–300 years in our era. Great seismic disasters with $M \sim 7.5$ ($I_0 = X$) seem to have occurred along the Kultor fault in the 7th and 15th centuries, with the seismic ruptures reaching the ground surface and producing fault scarps 70–80 km long. Subsequent paleoseismological surveys in the Issyk-Kul Depression will supplement and refine the above scheme showing the migration of vigorous seismicity in the north of the basin.

ACKNOWLEDGMENTS

We wish to thank A.R. Agatova, D. Bauman, E.V. Deev, A.S. Kichutkin, D.V. Luzhansky, T. Liu, E. Mamyrov, M.Yu. Menshikov, I.E. Povolotskaya, N. Porat, E.A. Rogozhin, S.N. Rodina, A.Yu. Starikova, I.V. Turova, M.T. Usmanova, T.A. Charimov, D. Shen, B. Shchasnyi, and A.S. Yudakhin for the help during our work in the field and in the laboratory.

FUNDING

This research was conducted for the state program of research at Laboratory 304 of the Shmidt Institute of Physics of the Earth for 2019–2021 “Refining the Assessment of Seismic Hazard for Tectonically Active Crimea–Caucasus and Tien Shan Mountain Belts and for Relatively Stable Territories of the East European Platform and the Baltic Shield Based on Paleoseismological and Geodynamic Data”.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

- Abdrakhmatov, K.E., Strom, A.L., Delvo, D., Khavenit, Kh.V., and Vittori, E., Temporal clustering of large earthquakes in North Tien Shan, *Vestnik Instituta Seismologii NAN KR*, 2013, no. 1, pp. 3–9.
- Archaeoseismology*, Stiros, S. and Jones, R.E., Eds., British School at Athens; Fitch Laboratory Occasional Papers, 1996. 268 p.

- Arrowsmith, J.R., Crosby, C.J., Korzhenkov, A.M., Mamyrov, E., Povolotskaya, I., Guralnik, B., and Landgraf, A., Surface Rupture of the 1911 Kebin (Chon-Kemin) Earthquake, Northern Tien Shan, Kyrgyzstan, in *Seismicity, Fault Rupture and Earthquake Hazards in Slowly Deforming Regions*, Landgraf, A., Kuebler, S., Hintersberger, E., and Stein, S., Eds., Geological Society, London, Special Publications, 2016, vol. 432.
- Bartold, V.V., *Otchet o poezdke v Srednyuyu Aziyu s nauchnoi tselyu v 1893–1894 godakh* (A Report on a Trip to Middle Asia for Scientific Purposes in 1893–1894), St. Petersburg, 1897.
- Berg, L.S., *Lake Issyk-Kul, Zemlevedenie*, 1904, vol. 11, Books 1–2.
- Biosfernaya territoriya Issyk-Kul: Kulturno-istoricheskie pamyatniki* (The Issyk-Kul Biosphere Territory: Cultural and Historical Monuments), Bishkek, 2002.
- Bogachkin, B.M., Korzhenkov, A.M., Mamyrov, E., Nechaev, Yu.V., Omuraliev, M., Petrosyan, A.E., Pletnev, K.G., Rogozhin, E.A., and Charimov, T.A., The structure of the rupture zone in the 1992 Susamyr earthquake based on an analysis of its geological and seismological manifestations, *Fizika Zemli*, 1997, no. 11, pp. 3–18.
- Bogdanovich, K.I., Kark, I.M., Korolkov, B.Ya., and Mushketov, D.I., The earthquake of December 22, 1911 (January 4, 1911) in the northern mountain ranges of Tien Shan, *Trudy Geol. Kom., Nov. Ser.*, Issue 89, St. Petersburg, 1914.
- Bowman, D., Korjenkov, A.M., and Porat, N., Late-Pleistocene seismites from Lake Issyk-Kul, the Tien Shan Range, Kyrgyzstan, *Sedimentary Geology*, 2004a, vol. 163, pp. 211–228.
- Bowman, D., Korjenkov, A., Porat, N., and Czassny, B., Morphological response through competing of thrusting and erosion, at basin foothills, the northern Tien Shan, Kyrgyzstan, *Geomorphology*, 2004b, vol. 63, pp. 1–24.
- Bronk, R.C., Deposition models for chronological records, *Quaternary Science Reviews*, 2008, vol. 27, nos. 1–2, pp. 42–60.
- Chediya, O.K. and Korzhenkov, A.M., On long-term preservation of traces of ancient seismic disasters in relief: The Chilik–Kemin earthquake-generating zone in North Tien Shan, *Geomorfol.*, 1997, no. 3, pp. 88–98.
- Chediya, O.K. and Trofimov, A.K., Neotectonics, in *Geologicheskie osnovy seismicheskogo raionirovaniya Issyk-Kulskoi vpadiny (Severnyi Tyan-Shan)* (Geological Principles for the Seismic Zonation of the Issyk-Kul Depression (North Tien Shan)), Kalmurzaev, K.E., Ed., Frunze: Ilim, 1978, pp. 66–76.
- Deev, E.V. and Korzhenkov, A.M., Paleoseismological research in the epicentral zone of the 1911 Kemin earthquake in North Tien Shan, *Geol. Geofiz.*, 2016, vol. 57, no. 2, pp. 421–430.
- Deev, E., Korzhenkov, A., Turova, I., Pavlis, T.L., Luzhanskii, D., Mažeika, J., Abdieva, S., and Yudakhin, A., Large ancient earthquakes in the Western Issyk-Kul basin (Kyrgyzstan, Northern Tien Shan), *J. Asian Earth Sci.*, 2018, vol. 166, pp. 48–65.
- Dzhanuzakov, K., Omuraliev, M., Omuralieva, A., Iliasov, B., and Grebennikova, V.V., *Silnye zemletryaseniya Tyan-Shanya v predelakh territorii Kyrgyzstana i prilegayushchikh raionov stran Tsentralnoi Azii* (Large Earthquakes in Tien-Shan within the Area of Kyrgyzstan and Adjacent Areas of Central Asian Countries), Bishkek: Ilim, 2003.
- Fortuna, A.B., Mesozoic and Paleogene–Neogene deposits, in *Detalnoe seismicheskoe raionirovanie Issyk-Kulskoi vpadiny* (Detailed Seismic Zonation of the Issyk-Kul Depression), Abdрахmatov, K.E., Ed., Bishkek: Ilim, 1993, pp. 11–15.
- Ivanov, P.P., *Materials for the archeology of the Issyk-Kul Depression*, Tr. Instituta Istorii AN KirgSSR, no. III, Frunze, 1957.
- Kolpakovsky, A., On ancient structures found in Lake Issyk-Kul, *Izv. RGO*, 1870, vol. VI, Section 2.
- Korzhenkov, A.M., The Structure and Formation of Morphostructures in Northeast Tien Shan, *Extended Abstract of Cand-Sci. (Geol.-Mineral.) Dissertation*, Frunze: FPTI, 1988. 21 p.
- Korzhenkov, A.M., Cenozoic tectonics and seismicity in the northwestern Issyk-Kul Depression, Tien Shan, *Geol. Geofiz.*, 2000, vol. 41, no. 7, pp. 971–982.
- Korzhenkov, A.M., *Seismogeologiya Tyan-Shanya (v predelakh territorii Kyrgyzstana i prilegayushchikh raionov)* (The Seismogeology of Tien Shan: The Area of Kyrgyzstan and Adjacent Areas) Bishkek: Ilim, 2006.
- Korzhenkov, A.M., Bauman, D., Omuraliev, M., and Khaselton, K., Traces of past strong earthquakes in the deposits of Lake Issyk-Kul, *Izv. RGO*, 1999, vol. 131, no. 4, pp. 48–55.
- Korjenkov, A.M., Kovalenko, V.A., and Usmanov, S.F., Long-term preservation of paleoseismic deformations as a tool for revealing of ancient seismic catastrophes (on example of Chon-Kemin Valley, Kyrgyzstan), in *Proceedings of the 7th International Symposium on High Mountain Remote Sensing Cartography*, Buchroithner, M.F., Ed., Bishkek, Kyrgyzstan, July 2002, Dresden: *Kartographische Bausteine*, Band 23, 2004, pp. 137–153.
- Korjenkov, A.M., Arrowsmith, J.R., Crosby, C., Mamyrov, E., Orlova, L.A., Povolotskaya, I.E., and Tabaldiev, K., Seismogenic destruction of the Kamenka medieval fortress, Northern Issyk-Kul region, Tien Shan (Kyrgyzstan), *J. Seismol.*, 2006a, no. 10, pp. 431–442.
- Korjenkov, A.M., Michajljow, W., Wetzell, H.-U., Abdybashaev, U., and Povolotskaya, I.E., *Field Excursion Guidebook: International Training Course “Seismology and Seismic Hazard Assessment”*, Bishkek, Potsdam: GFZ-ZAIAG, 2006b.
- Korzhenkov, A.M., Povolotskaya, I.E., and Mamyrov, E., The morphologic expression of Quaternary deformation in the northwestern foothills of the Issyk-Kul Depression, Tien Shan, *Geotektonika*, 2007, no. 6, pp. 53–72.
- Korzhenkov, A.M., Abdieva, S.V., Vakhrameeva, P.S., Dzhumabaeva, A.B., Mamyrov, E., Morozova, E.A., Orlova, L.A., and Fortuna, A.B., Strong historical earthquakes in the northwestern Issyk-Kul Depression, North Tien Shan, *Geol. Geofiz.*, 2011, vol. 52, no. 9, pp. 1276–1286.
- Korzhenkov, A.M., Abdieva, S.V., Fortuna, A.B., Charimov, T.A., and Yudakhin, A.S., Seismically mobilized

- moraines in Tien Shan, *Geol. Geofiz.*, 2015, vol. 56, no. 10, pp. 1871–1881.
- Korzhenkov, A.M., Deev, E.V., Luzhansky, D.V., Abdieva, S.V., Agatova, A.R., Mazeika, J.V., Menshikov, M., Rogozhin, E.A., Rodina, S.N., Rodkin, M.V., Sorokin, A.A., Fortuna, A.B., Charimov, T.A., Shen, D., and Yudakhin, A.S., A strong medieval earthquake in the northern Issyk-Kul region, Tien Shan: Results of paleoseismological and archeoseismological research, *Geofiz. Pro. Biosf.*, 2016, vol. 15, no. 4, pp. 43–63.
- Korzhenkov, A.M., Abdieva, S.V., Agatova, A.R., Arrowsmith, R., Bauman, D., Vakhrameeva, A.S., Gladkov, A.S., Guralnik, B., Deev, E.V., Dzhumabaeva, A.B., Kazmer, M., Kerimbaeva, D.P.S., Kolchenko, V., Crossby, K., Lobova (Kazantseva), E.Yu., Luzhansky, D.V., Mazeika, J.V., Mamyrov, E., Menshikov, M.Yu., Morozova, E.A., Muraliev, A.M., Nurmanbetov, K., Orlova, L.A., Pavlis, T.L., Povolotskaya, I.E., Porat, N., Rogozhin, E.A., Rodina, S.N., Rodkin, M.V., Sorokin, A.A., Tabaldiev, K., Turova, I.V., Usmanov, S.F., Fortuna, A.B., Charimov, T.A., Shen, D., and Yudakhin, A.S., *Silnye istoricheskie i paleozemletryaseniya Priissykkulia i ikh polozenie v strukture Severnogo Tyan-Shanya (Strong Historical and Paleo Earthquakes in the Issyk-Kul Region and their Setting in the Structure of North Tien Shan)*, Nikolaev, A.V., Editor-in-Chief, Moscow: IFZ RAN, 2018.
- Korzhenkov, A.M., Abdieva, S.V., Gladkov, A.S., Deev, E.V., Liu, J., Mazeika, J.V., Rogozhin, E.A., Rodkin, M.V., Sorokin, A.A., Turova, I.V., and Fortuna, A.B., Paleoseismicity of Adyr faults: The Kokonadyr–Tegerek Fault, Southwestern Issyk-Kul region, the Tien Shan, *J. Volcanol. Seismol.*, 2019, vol. 13, no. 5, pp. 305–322.
- Korzhenkov, A.M., Strelnikov, A.A., Deev, E.V., Korzhenkova, L.A., Liu, J., Mazeika, J.V., Rogozhin, E.A., Rodina, S.N., Turova, I.V., Usmanova, M.T., and Fortuna, A.B., Adyric faults as generators of strong earthquakes in the Issyk-Kul Depression: The Kultor fault zone, *Vopr. Inzh. Seismol.*, 2020, vol. 47, no. 2, pp. 19–40.
- Korzhenkova, L.A., Korzhenkov, A.M., Strelnikov, A.A., Starikova, A.Yu., Kichutkin, A.S., Makeev, V.M., Mazeika, J.V., and Fortuna, A.B., Strong earthquakes on the southern slope of the Kungei Ala-Too mountain range in North Tien Shan and their structural setting in the crust, *Geofiz. Pro. Biosf.*, 2022, vol. 21, no. 1.
- Paleoseismology*, McCalpin, J., Ed., 2nd edition, International Geophysics, vol. 95, N. Y.: Academic Press, 2009. ISBN: 9780123735768
- Pomazkov, K.D., *Geologicheskaya karta SSSR (A Geological Map of the USSR)*, Scale 1 : 200 000, Series North-Tien-Shan, 1968, Sheet K-43-XVII.
- Povolotskaya, I.E., Korzhenkov, A., and Mamyrov, E.M., Traces of strong earthquakes in lacustrine sediments of the Kok-Moinok Depression, North Tien Shan, *Geol. Geofiz.*, 2006, no. 10, pp. 1024–1035.
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Bronk, Ramsey, C., Buck, C.E., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hafliadason, H., Hajdas, I., Hatte, C., Heaton, T.J., Hoffman, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D.A., Scott, M., Southon, J.R., Staff, R.A., Turney, C.S.M., and van der Plicht, J., IntCal13 and Marine13 radiocarbon age calibration curves 0–50000 years cal BP, *Radiocarbon*, 2013, vol. 62, no. 4, pp. 725–757.
- Selander, J., *Inherited Strike-Slip Faults as an Origin for Basement-Cored Uplifts: Example of the Kungey and Zailikey Ranges*, Northern Tien Shan, M.S. Thesis, North Carolina: University, Chapel Hill, 2008.
- Shults, S.S., *Analiz noveishei tektoniki i relief Tyan-Shanya (An Analysis of Neotectonics and Relief of Tien Shan)*, Moscow: Geografiz, 1948.
- Solonenko, V.P., Determining the epicentral zones of earthquakes from geological criteria, *Izv. AN SSSR, Ser. Geol.*, 1962, no. 11, pp. 57–71.
- Solonenko, V.P., Paleoseismology, *Izv. AN SSSR, Fizika Zemli*, 1973, no. 9, pp. 3–16.
- Turchinsky, V.P., *Geologicheskaya karta SSSR (A Geological Map of the USSR)*, Scale 1 : 200 000, Series North-Tien-Shan, Sheet K-43-XVIII, Leningrad: Kartfabrika VAGT, 1970.
- Turkestanskije Vedomosti*, 1887, no. 31.
- Utirov, Ch.U., Seismic deformations, in *Geologicheskie osnovy seismicheskogo raionirovaniya Issyk-Kul'skoi vpadiny (Severnyi Tyan-Shan)* (Geological Principles for the Seismic Zonation of the Issyk-Kul Depression (North Tien Shan)), Kalmurzaev, K.E., Ed., Frunze: Ilim, 1978, pp. 91–111.
- Utirov, Ch.U., Seismic deformations and paleoseismic deformations, in *Detalnoe seismicheskoe raionirovanie Issyk-Kul'skoi vpadiny (Detailed Seismic Zonation of the Issyk-Kul Depression)*, Abdrakhmatov, K.E., Ed., Bishkek: Ilim, 1993, pp. 113–125.
- Utkina, N.G., Principal features of the geomorphologic structure of the region, in *Geologicheskie osnovy seismicheskogo raionirovaniya Issyk-Kul'skoi vpadiny (Severnyi Tyan-Shan)* (Geological Principles for the Seismic Zonation of the Issyk-Kul Depression (North Tien Shan)), Kalmurzaev, K.E., Ed., Frunze: Ilim, 1978, pp. 52–57.
- Vinnik, D.F., The work of the Issyk-Kul archeological team in 1959, *Izv. AN KirgSSR, Ser. Ob. Nauk*, 1961, vol. III, no. 3, pp. 83–102.
- Zakharov, I.L. and Chabdarov, N.M., *Geologicheskaya karta SSSR (A Geological Map of the USSR)*, Scale 1 : 200 000, Sheet K-43-XI, Moscow: Gosgeoltekhizdat, 1975.
- Zeland, N., From the shores of Issyk-Kul, *Turkesk. Vedom.*, 1891, nos. 35–36.

Translated by A. Petrosyan

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