

Destruction of Medieval Archaeological Monuments by Strong Earthquakes in the Southwestern Issyk-Kul Basin, Tien Shan

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Abstract—The destruction of a major archaeological site in the 7th–9th centuries clearly demonstrates a lack of seismic knowledge of the region and, as a result, the neglected and underestimated seismic hazard assessment in the Alabash-Konur-Oleng Depression region near the southern border of the Issyk-Kul basin on the map of the Kyrgyz Republic. The aim of the field studies was to assess the consequences of a seismic event, to identify damage to the integrity of archaeological structures, and to estimate the strength of an earthquake in a given region. To search for archaeological sites, aerial photography of the site along the Akterek River was carried out—from the coast to the elevation of the Duvana Mountains. Field studies in the southern Issyk-Kul basin and the Alabash-Konur-Oleng Depression led to the discovery of an ancient destroyed complex on the southern slope of the Duvana Mountains. This structure, located on a seismotectonic scarp, was destroyed by it and absorbed by a seismotectonic graben. Most likely, a strong ($I_0 \geq 9$) earthquake occurred during the complex's existence, the 7th–9th centuries (?). There are other archaeological sites of various age in the Alabash-Konuroheng depression, bearing traces of the strongest seismic impacts, the study of which can help extend the seismic catalog for centuries and contribute to a more accurate seismic hazard assessment of the area of currently rising uplifts—the Adyrs (foothills) of the Terskey Ala-Too Range.

Keywords: earthquake, seismotectonic scarps, compensation graben, archaeoseismology, paleoseismology, seismic deformations, architectural and historical complex, Tien Shan, Issyk-Kul, Kyrgyzstan, Alabash-Konur-oleng depression, Duvana Mountains

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INTRODUCTION

The Issyk-Kul basin is attributed to seismically active territories: a large number of both weak and rather strong earthquakes are currently recorded here (Fig. 1). To assess seismic hazard, very strong earthquakes in the northern Issyk-Kul basin are of greatest interest. One of the strongest seismic events known here is the Kebin (Kemin) earthquake with a magnitude $M_S = 8.2$ and intensity $I_0 = 10-11$, which occurred in January 1911 in the valleys of the Chon-Kemin, Chilik, Aksuu, and Chon-Aksu rivers (Bogdanovich et al., 1914; Delvaux et al., 2001).

In 1970, in the eastern Issyk-Kul basin, the Sarykamysh earthquake with $I_0 = 8-9$ occurred (Nurmagambetov et al., 1975; Dzhanzakov and Ilyasov, 1976; Amankulov, 1979). From the length of the source and energy released during this event, it is the largest known instrumentally recorded event on the northern slopes of the Terskey Ala-Too Range. In the zone of maximum intensity, there were several settlements on an area of about 200 km² that suffered copious destruction of houses or damage to their struc-

tures. Mass wasting, landslides, and rockfalls were observed in the mountainous area.

In 1978, the Zhalanash-Tyup earthquake occurred, the intensity at the epicenter of which reached $I_0 = 8-9$ (Yerzhanov et al., 1978; *Zhalanash-Tyupskoe...*, 1981; Nersesov et al., 1981). More than 50 settlements in the Tyup region were badly damaged. Near the watershed parts of the Kyungei Ala-Too Range, landslides, rockfalls, and taluses occurred everywhere; numerous fissures in rocky soils were recorded.

All of the above strong earthquakes occurred in the northern and eastern Issyk-Kul region; at the same time, the available data in Fig. 1 clearly show the absence of strong earthquakes in the southern Issyk-Kul basin. However, since the tectonic activity of this region is quite high, this can be considered a temporary seismic quiescence within the southern Issyk-Kul basin. This assumption is supported by certain still insufficiently complete data from paleo- and archaeoseismological studies conducted recently in this region (Korzhenkov et al., 2015, 2016b, 2018a; Deev et al., 2016).

Thus, it can be concluded that the southern basin remains insufficiently studied in terms of seismic haz-

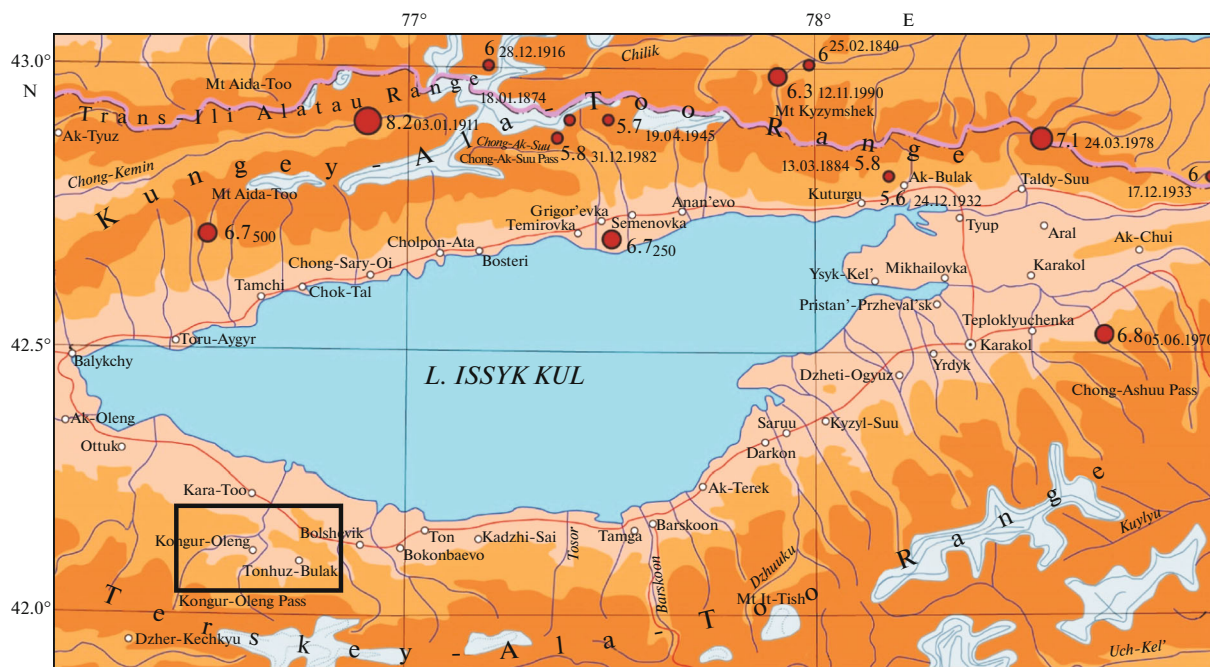


Fig. 1. Map of Issyk-Kul region, Circles indicate major seismic events; next to them are their magnitudes and dates of occurrence. Frame shows boundaries of study area, including Alabash-Konur-Oleng depression.

ard assessment. It is to eliminate the gaps in information on this region that we carried sought and parameterized paleoseismic events. The article presents some of these results.

RESEARCH METHODS

We used traditional paleo- and archaeoseismological methods. The paleoseismological method, the foundations of which in the former USSR were laid by studies by V.P. Solonenko (Solonenko, 1962; *Seismicheskoe raionirovanie...*, 1977; Solonenko and Khromovskikh, 1978), over the decades since its inception, it has become a powerful tool for identifying traces of paleoearthquakes, assessing their parameters, and dating them (*Paleoseismology*, 2009). The authors of this paper have long-term experience in paleoseismological studies since the 1980s (Korzhenkov and Chedia, 1986); they have repeatedly and successfully applied it in different regions of the world, having developed a system of criteria for identifying and parameterizing paleoseismic deformations (Chedia and Korzhenkov, 1997; Korzhenkov et al., 2010, 2018b; Rodkin et al., 2015; Smekalin et al., 2015; Deev and Korzhenkov, 2016; Ovsyuchenko et al., 2017; Vardanyan et al., 2018).

Although individual attempts at archaeoseismological studies have been known for a long time, archaeoseismology took shape as an independent scientific direction only in the 1980s (*Archaeoseismology*, 1996). The authors of this paper have experience in using the archaeoseismological approach in various

regions (Korzhenkov and Mazor, 1998; Vinokurov et al., 2015; Korzhenkov et al., 2016b, 2017a, 2018, 2019a, 2019b; Moiseev et al., 2018; Moiseiev et al., 2019). Archaeo- and paleoseismological methods complement each other (Stiros and Jones, 1996); therefore, in our studies, we widely combine the two (Korzhenkov, 2006; Korzhenkov et al., 2016c, 2018c; Ovsyuchenko et al., 2016, 2018, 2020; Gmyrya et al., 2019; Rogozhin et al., 2019). We acted similarly when carrying out the studies presented in this paper, using, among other things, the experience gained from previous studies in Issyk-Kul (Korzhenkov et al., 2015, 2016a, 2016b, 2016c, 2017a, 2018a, 2018b; Deev and Korzhenkov, 2016; Deev et al., 2016).

An important element of this work was aerial photography with a drone. This kind of work is rapidly being incorporated into various geological and geophysical studies (Aleshin et al., 2020a, 2020b, 2020c). In our research, aerial photography was done with a DJI PHANTOM 3 PROFESSIONAL (Fig. 2). The goal was to obtain a detailed image of the study area in the Alabash-Konur-Oleng valley, in the area between the Duvana foothills and Ak-Terek River.

To construct the drone's flight route, a reconnaissance of the area was carried out to find landmarks to simplify the procedure for linking images. As natural landmarks for this, we used civilian buildings in two areas within the study zone, as well as large rocks, power lines, and a road running parallel to the Ak-Terek River. A car was used as an artificial reference landmark. The height of the road was determined from topographic maps, and the coordinates of a condi-



Fig. 2. DJI PHANTOM 3 PROFESSIONAL drone used for aerial photography.

tional point (the actual horizontal center of the vehicle), from Garmin GPSMAP 64 GPS data. Civilian buildings also served as reference points for linking photographs. Aerial photography was performed with overlaps (transverse, 80% along the route; longitudinal, 90% across it) to obtain images without gaps and blurring and with maximum accuracy when stacked. Photographs were taken at a low speed (frame by frame) in good weather and a stable weak wind. As a result, the aerial photography stage yielded about 400 images.

After the images passed quality control, the data were saved in DXF format for export to AutoCAD and 3D MAX.

These data were processed automatically in 3D MAX. The position and orientation of the cameras were determined by selecting common points in overlapping photographs. Then, for ease of use, the resulting final image was exported in TIFF format. This was necessary for processing and applying the necessary conventional markings to the resulting image. The result of the work is an aerial view of the area (Fig. 3), which was converted into a vector map diagram for comparison with existing cartographic materials and other raster images with a corresponding coordinate reference (Fig. 4).

Aerial photography and the creation of this model made it possible not only to specify the location of the seismic graben and a series of scarps stretching along the river, but also to discover artificial landforms, which were later identified as objects resembling towers and walls (their foundations). These findings were confirmed during fieldworks.

FIELD STUDIES IN THE ALABASH-KONUR-OLENG DEPRESSION

As a result of research in the Alabash-Konur-Oleng depression, a large number of archaeological sites of various periods have been discovered. For example, the Alabash intradepression uplift in the western part of this mountain valley is known for its numerous petroglyphs, beginning with the Andronov culture of the 17th–9th centuries BC and up to modern times.

Paleo- and archaeoseismological research began here in 2013 and continues to this day. During this time, several cases of active faults that reached the surface, reflected in the relief in the form of fault scarps, and traces of destruction of archaeological monuments were discovered.

In the Alabash-Konur-Oleng valley, deformed mounds of the Saka-Usun period (7th century BC–V century BCE) were discovered, as well as stone foundations of walls of the Middle and Late Middle Ages (e.g., the Alabash fortress of the 10th–12th centuries, Figs. 5, 6) deformed by the last strong seismic event in the 18th century (Korzhenkov et al., 2018a).

Such gravestone monuments as 14th century kumbezoes proved no less interesting and informative; these were restored in the 19th century after the impact of a seismic event (Figs. 7, 8).

The aerial and satellite images were interpreted for illustrative and informative presentation of the fully studied, as it seemed earlier, operations area. As a result of analyzing the interpretation results and previous studies, as well as the published materials, unique information was obtained about ancient settlements in the Alabash-Konur-Oleng depression: a previously

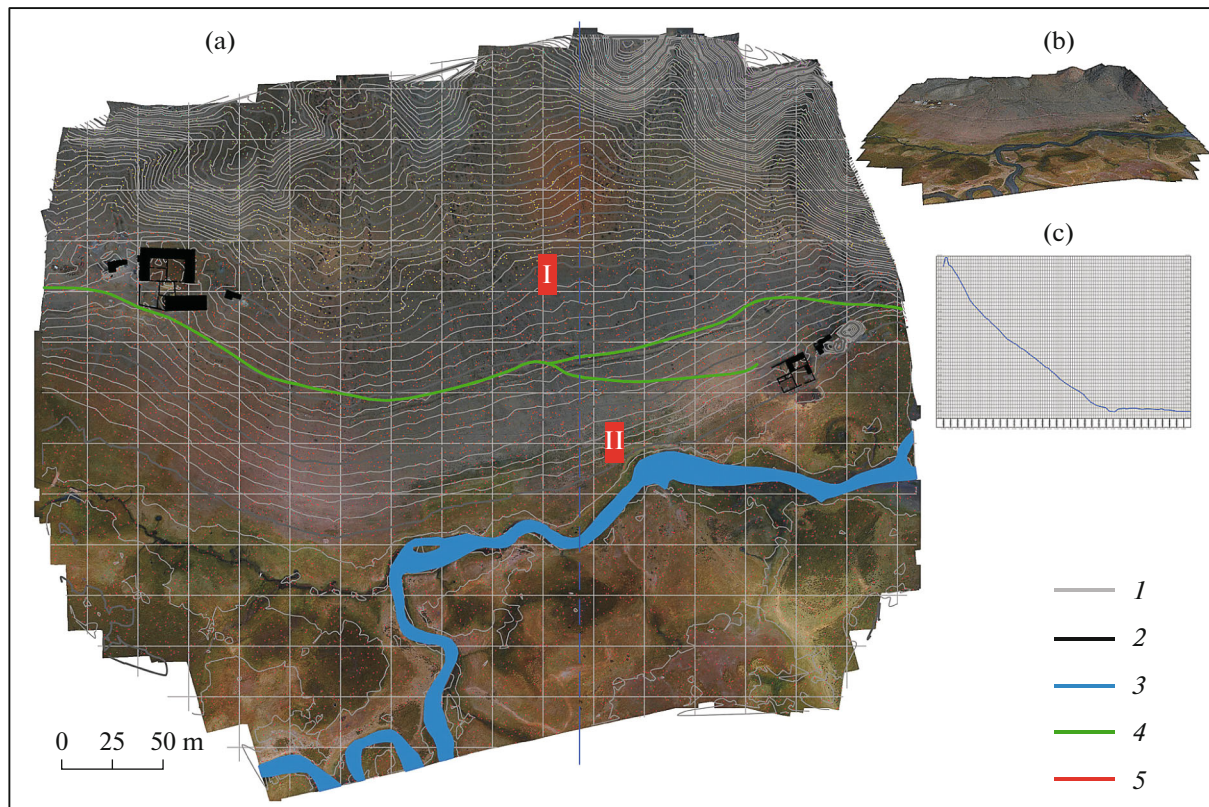


Fig. 3. Result of stitching and processing of obtained aerial photographs. (a) Aerial view of site of Duvana foothills section; (b) 3D terrain model; (c) the profile of relief surface along transect shown by dotted line between seismological trenches I and II; (1) topographic contours (step 1 m); (2) contours of building walls; (3) riverbed; (4) dirt road; (5) seismological trenches of 2016 (I) and 2017 (II).

unknown ancient architectural complex was discovered—a large settlement surrounded on three sides by mountains and wetlands, dammed by a fault scarp on the left bank of the Ak-Terek River. Near the river, in the lowland, are the remains of old defensive walls 1–1.5 m thick. They stretch as far as the terrace above the Ak-Terek floodplain, blocking the passage to the complex from the east, north, and west of the valley. In the central part of the complex are numerous archaeological sites: medieval stone walls and watchtowers, burial mounds, ritual temples, residential buildings, and barracks (?). The temple part of the complex is located on the slope of the Duvana Mountains; it is surrounded by modern pastures and a valley with ancient burial mounds in an area of about 2 km² (Fig. 9).

All this is located in a fairly large territory, while each of the levels is surrounded by its own defensive tier—a wall or rampart. The area on which the settlement stands is conveniently located, has sheltered rear areas, and is rich in watered pastures and meadows. This is due to the complex morphology of the relief, formed by the high tectonic and seismic activity in this region.

Presumably at the turn of the 8th–9th centuries BCE, a catastrophic earthquake occurred with a magnitude

$M = 7–8$, during which a section of an extended (several tens of kilometers) fault with a step compensation graben was activated, the “Dragon’s Footprint” (Korzhenkov et al., 2018a). During a strong paleoearthquake along the fault zone, several subparallel ruptures formed, which passed through the complex within the third, second, and first tiers and led to significant destruction of this sacred settlement.

We assume that, judging from the architectural details, the ruins of buildings once represented a Zoroastrian temple built by Sogdian settlers. This destructive event was the first and last for this Sogdian Zoroastrian temple: it was completely demolished. In the right part of the complex, near one of the forward defensive levels, a wall was horizontally displaced to the east by 1.2 m and vertically by 1.5 m. An observation tower was also destroyed. It ended up on the edge of a new structure and partially slipped with its foundation into the seismic graben that formed; the top collapsed in the opposite direction. In place of the once standing wall, a “saddle” with liquefied sands and small pebbles formed, and the platform with the tower was uplifted and displaced to the east. The total uplift of the structure in this part of the complex was 4 m (Figs. 10–13).

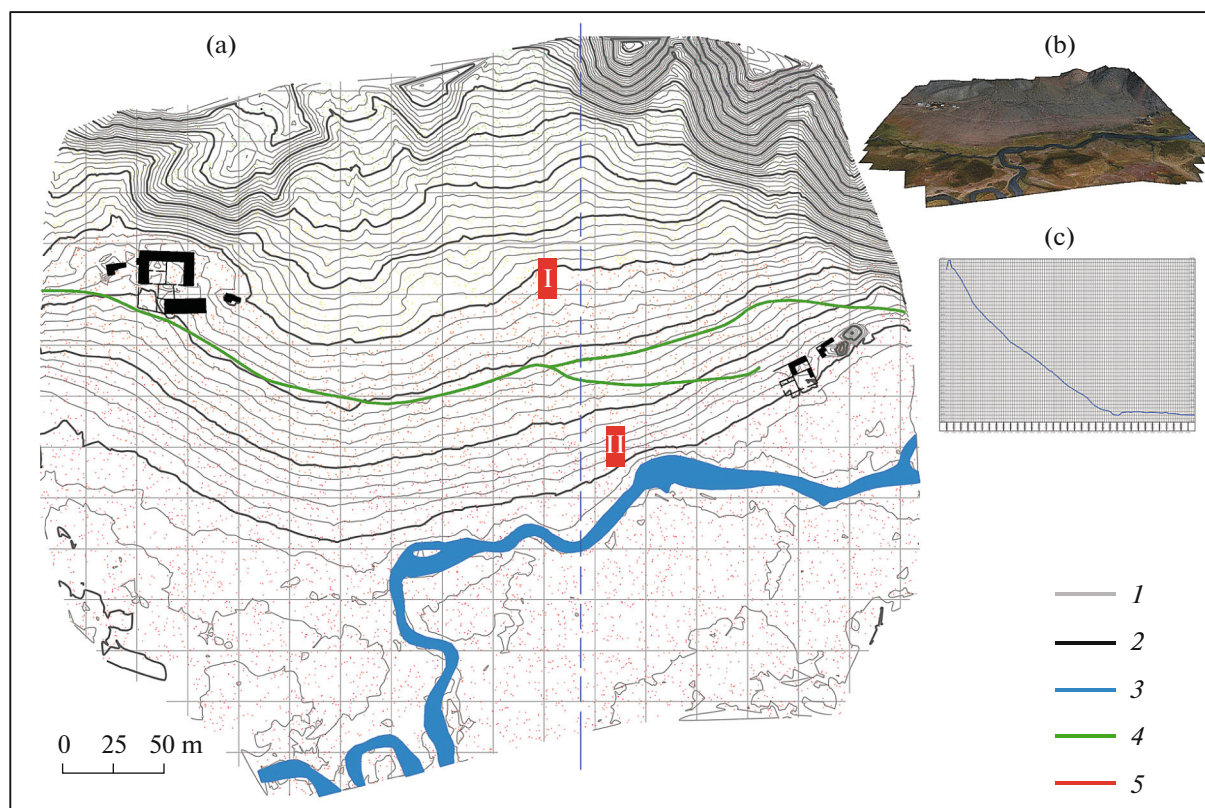


Fig. 4. Vector version of resulting aerial view (a), 3D elevation model based on aerial photographs (b), and profile of relief surface constructed from aerial photography data along transect shown by dotted line between seismological trenches I and II (c). (1) Topographic contours (step of 1 m); (2) contours of building walls; (3) riverbed; (4) dirt road; (5) paleoseismological trenches of 2016 (I) and 2017 (II).

The central part of the complex was destroyed to the same extent. A subsequent landslide (mudflow) not only strongly deformed, but also destroyed most of the tiers of the central part, forming a fan covering the entire central (possibly residential) part of the complex and the two tiers of walls protecting it. On the line of the third tier of the wall, we found small protrusions—extensions of walls blocking a pass through the mountain valley to the complex. Presumably, the third tier was the closing, uppermost wall and was connected to the towers on the edge of the Duvana Mountains, which were bonfire beacons of the Zoroastrian temple complex.

In the western—temple—part of the complex, significant changes also occurred in the structure of the relief and buildings. The lower tiers of the wall, due to copious damage, including anthropogenic intervention (leveling of the territory and clearing of the boulder-strewn area), hindered the interpretation and the identification of any architectural structures. The third, uppermost level of the building, presumably of religious significance, also suffered significant destruction, but of an exclusively seismic nature. Here horizontal displacement occurred to the east by 1.5 m, causing the wall to fail; there was also vertical displace-

ment by 1 m and partial destruction of the towers, as evidenced by the saddle, which ruptured the integrity of the wall; the towers collapsed counter to the displacement, despite buttressing of their rear parts (Figs. 14, 15).

HISTORICAL AND ARCHAEOLOGICAL HERITAGE OF THE SOGDIAN CIVILIZATION

Quite a lot of archaeological sites associated with the Sogdian civilization have survived to this day, in particular, such well-known ones as the Yamchun and Kakh-Kakha fortresses in Tajikistan (Figs. 16, 17, respectively). Apparently, the complex we discovered also belongs to this civilization.

During 4 years of studies in the Issyk-Kul basin, we examined and studied, together with archaeologists, many settlements that were fortified caravanserais (*tortkul's*). Before the arrival of the Karakhanids, Andronovites, Sakas (Scythians), Usuns, and Sogdians lived in this territory. After the arrival of the Turks and Karakhanids, numerous fortress settlements—caravanserais—developed in the territory, which, among other things, served as outposts along the entire extent of Kyrgyzstan's trade routes.



Fig. 5. Southern collapse of northern wall of Alabash Fortress (shown by long arrow). Dashed line, fragments of upper part of wall formed when it hit the ground. Western wall collapsed eastward (shown by short arrow). West view (after (Korzhenkov et al., 2018a), with changes).

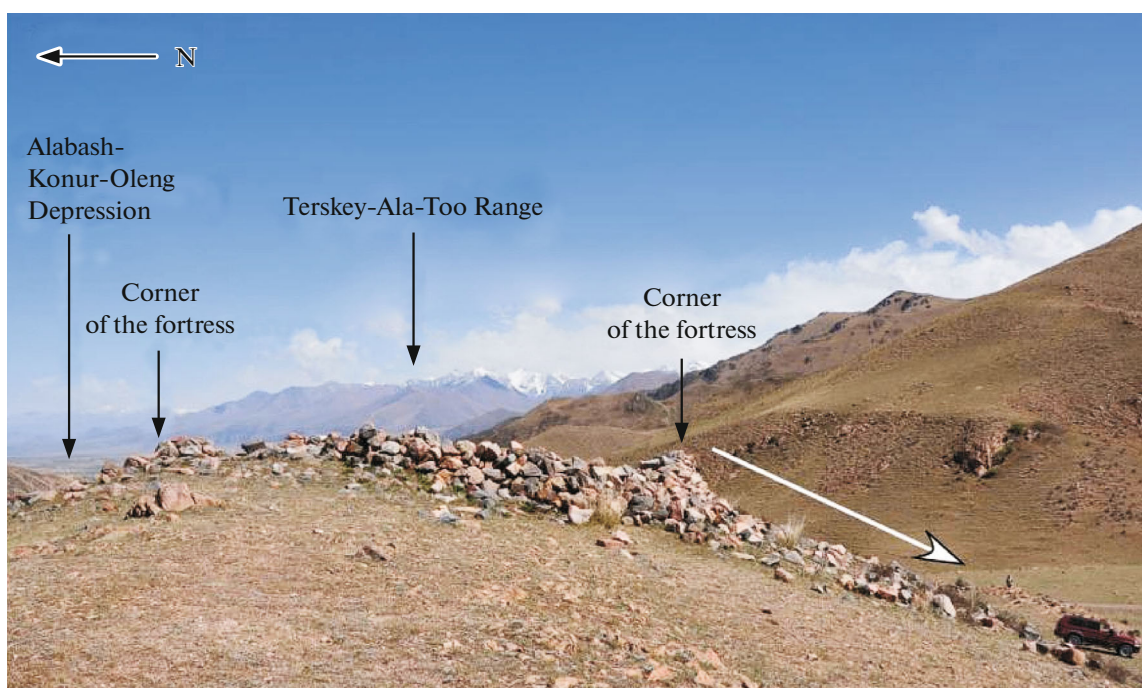


Fig. 6. Ruins of Alabash Fortress, east view. Northwest and southwest corners of fortress are marked with short arrows. Western wall of fortress collapsed to east, inside fortification (from observer viewpoint). Northern and southern walls collapsed to south. Direction of collapse of southern wall is shown by along arrow (after (Korzhenkov et al., 2018a), with changes).



Fig. 7. Kalmyk gravestones deformed in front of fault scarp. North view. Bold line is rear suture of fault scarp. In background, Duvana Range, a component of Kokonadyr-Tegerek uplift. A woman stands on the edge of the scarp (after (Korzhenkov et al., 2018a), with changes).



Fig. 8. Systematic oblique fissures (shown by arrows) are traces of ancient damage to northwestern column of grave monument, Konur-Oleng River (after (Korzhenkov et al., 2018a), with changes).

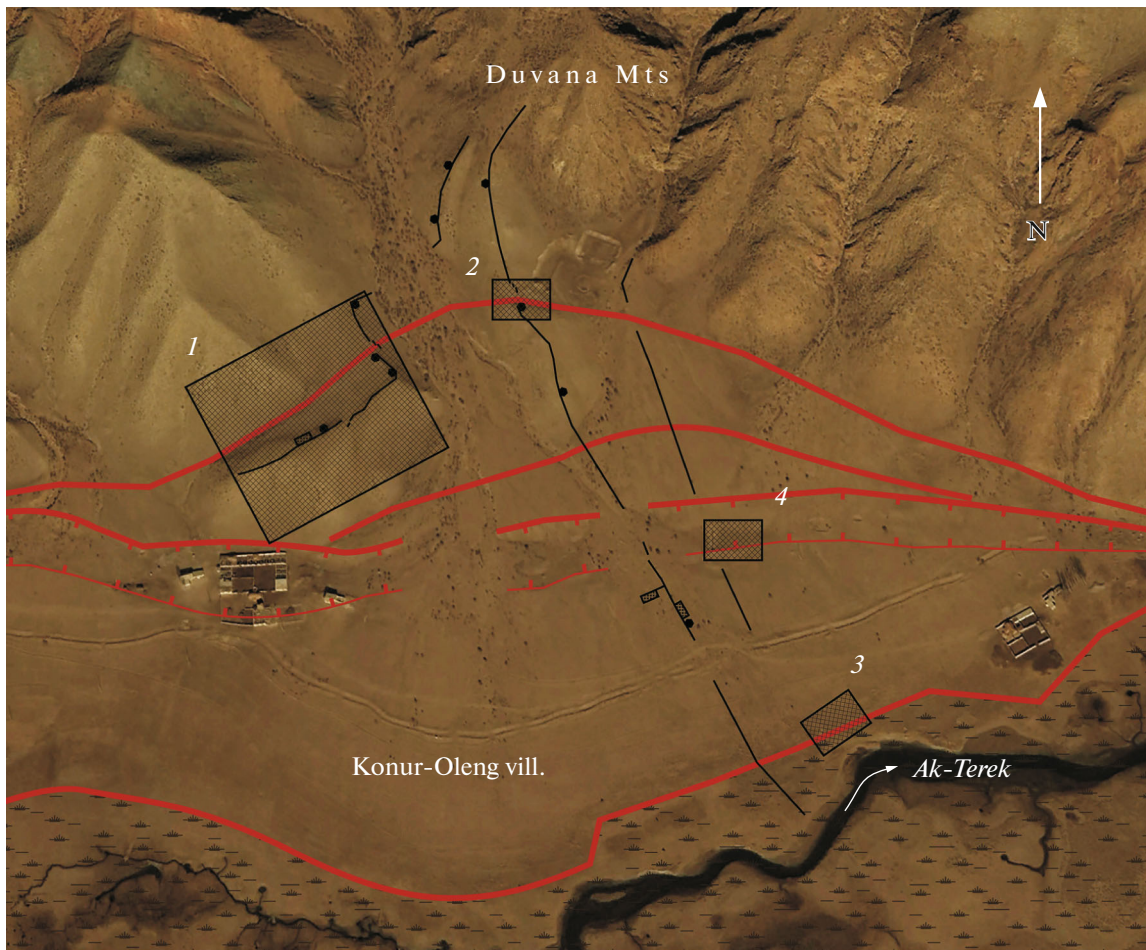


Fig. 9. Sketch map of investigated part of temple complex. (1) Ritual part of complex; (2) section where fault crosses observation tower and adjacent wall; (3) 18th century Kalmyk graves on edge of young fault scarp (trench 2017); (4) area of seismic compensation graben “Dragon’s Footprint” (2016 trench).

The complex we found is surrounded by caravanserais. However, it contains walls atypical of Karakhanid buildings, barracks-type buildings, residential buildings, Zoroastrian temples and burial structures, which distinguishes them from the main characteristic features of Karakhanid architectural monuments—armed fortresses and caravanserais. According to the data of archaeological finds in Central Asia, this structure more likely belong to Sogdian culture.

The Sogdians actively participated in trade across the Great Silk Road, which aided in spreading Zoroastrianism and later Buddhism. There is evidence that weapons produced in Sogd (in particular, chain mail) were exported to China and other countries (On the armament of Sogd..., 1952).

In the 4th–8th centuries, the Sogdians dominated trade between East and West; their trading colonies have been found far beyond Sogdia, in particular, on the territory of modern East China and along a large stretch of the Silk Road (Livshits, 1962).

In 1st–5th centuries CE Sogdians penetrated Kyrgyzstan and had a significant impact on the development of sedentary agricultural, crafts, and trade here. At this time, permanent settlements and towns with fortified centers grew up here; agriculture, artificial irrigation, and crafts developed.

Since the 4th century CE, merchant settlements with caravanserais began to appear in the most important trading points. These merchants were mainly natives of Sogdia, located along the Zeravshan River. The number of Sogdian colonists increased; they began to engage not only in trade, but also in agriculture, building irrigation facilities, etc. In the 7th century CE, in connection with the Arab invasion of Central Asia, the Sogdians began to move to the borders of modern Kyrgyzstan, especially the Chui and Talas valleys, where traces of their settlements have been found; they also clearly settled in the Issyk-Kul region.

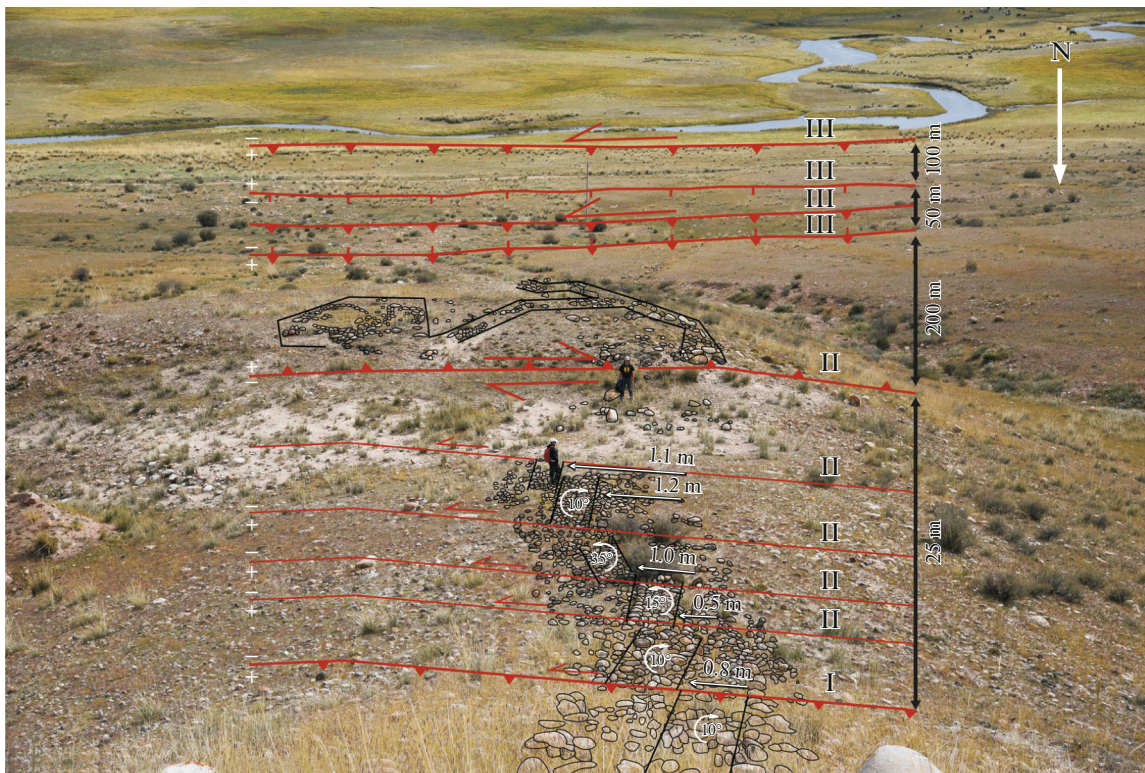


Fig. 10. Wall displacement and destruction of observation tower by fault.

STRUCTURAL POSITION OF THE EARTHQUAKE SOURCE

It is generally accepted that the formation of the neotectonic structure of the Issyk-Kul region as a part of the Tien Shan intracontinental orogen is due to collisional interaction of the Indian and Eurasian plates. The orogeny, according to geological and thermochronological data, began in the Late Oligocene (Schultz, 1948; Chedia, 1986; Trifonov et al., 2008; Glorie et al., 2010, 2011; Burtman, 2012; De Grave et al., 2013; Macaulay et al., 2013, 2014).

Crustal uplift has accelerated dramatically over the past 2–3 Ma. Since that time, the regional orography has grown systematically complex, and the formation of the high-mountainous relief of the Issyk-Kul region approached its modern appearance. This is clearly expressed as an increase in the rates of erosion, as well as in the growth of ridges due to depressions and degradation of recent molasses (Schultz, 1948; Chedia, 1986; Trifonov et al., 2008; Burtman, 2012). The formation of a young mountainous relief under conditions of general submeridional compression took place during the active development of sublatitudinal left-lateral strike-slip faults. The mountain ranges that formed in transpression mode are represented as “flower” structures (see Fig. 1), and the depressions between them on one or both sides are bounded by uplifts and thrusts and tend to shrink (Chedia, 1986;

Buslov et al., 2003; Burgette, 2008; Selander et al., 2012).

The Alabash-Konur-Oleng depression is located two dozen kilometers south of the lake Issyk-Kul and stretches in the sublatitudinal direction by 34 km with a width of up to 7.5 km. The lowest parts of the depression are at absolute elevations of 2000 m. From the south, the valley is bounded by the Terskey Ala-Too Range with maximum elevations up to 5200 m; from the north, by a series of Adyr uplifts (Tegerek, Kokon-Adyr, Ak-Bakshi mountains) with heights reaching 2500–3000 m.

According to the model proposed in (Burgette, 2008) (Fig. 18), the ridges framing the depression from the south and north have been thrust on it along reverse faults, but Delvaux et al. (2013) indicate the basin is only bounded by northern reverse fault. The onset of vertical movement of the Adyr uplifts along the Kokonadyr-Tegerek reverse fault is dated at the beginning of the Quaternary (Korzhenkov, 1987; Korzenkov et al., 2006).

The intensity of vertical movements along the reverse fault, the fault plane of which dips northward, and the formation of Adyr ridges are several meters per event. This is indicated by the antecedent areas of the Ak-Terek and Kel-Ter river valleys in places where the rivers cross the Adyr uplifts. West of the Ak-Terek river is a continuous valley, the antecedent part of the paleo river valley (the modern Duvana Pass) that remained

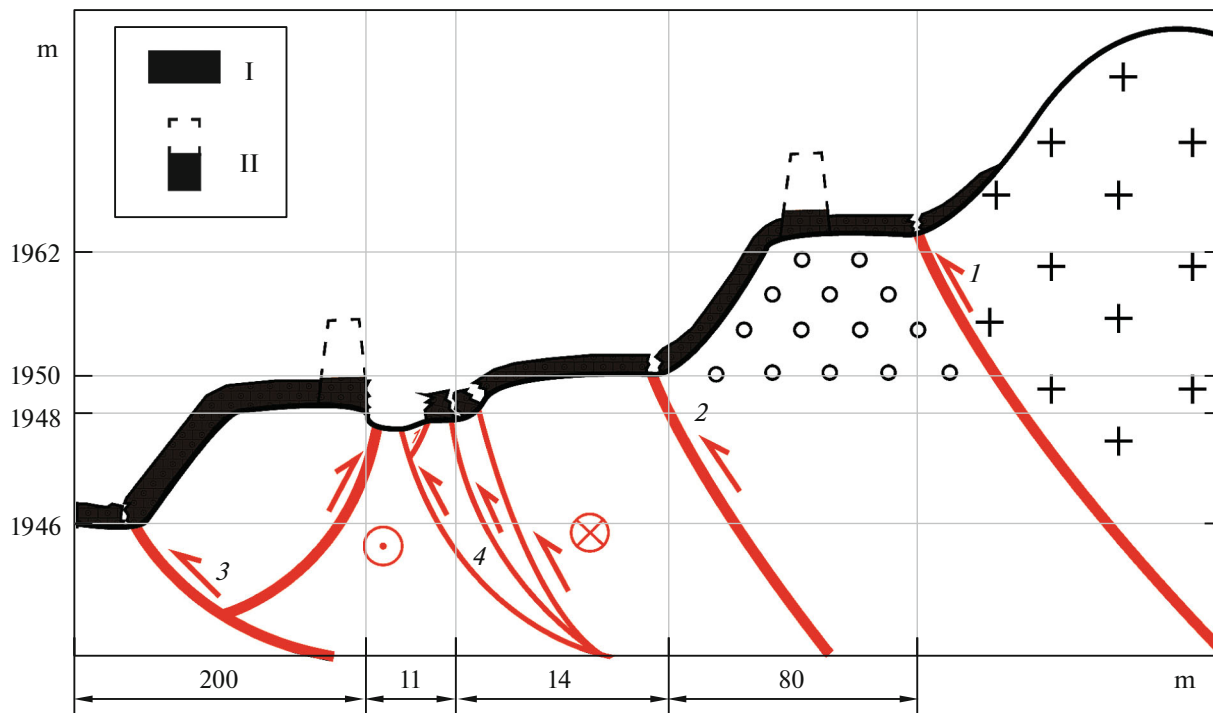


Fig. 11. Structure of fault at foot of Duvana Mountains. I, Wall; II, towers; (1–4) order of occurrence of seismotectonic scarps.

during uplifting of the ridge, where traces of Middle Pleistocene alluvium has been recorded (Makarov, 1977; Korjenkov et al., 2006).

Piedmont landscapes tending toward uplift contributed to the formation of a Holocene tectonically dammed lake in the depression, deposits of which are widespread in its northern part (*Geological Map...*, 1968). This process continues to this day, which inundates numerous areas in the mountain valley. The depression, widely flooded by the Konur-Oleng delta, is in fact divided into western (Ala-Bash) and eastern (Konur-Oleng) parts (Fig. 19).

In the field of distribution of epicenters of instrumentally recorded earthquakes within the study area, events with a magnitude no higher than 5 were recorded. Individual epicenters are located to the southeast, within the southern slope of the Terskey Ala-Too Range, facing the Balgart River valley (Kal'met'eva et al., 2009). In 2013, on the coast of Lake Issyk-Kul (between the villages of Kara-Talaa, Ulakhhol, Bar-Bulak, Ottuk, and Kara-Too), an earthquake occurred with $M_{PV} = 5.2$ and $I_0 = 4-5$ (Abdyraeva et al., 2014). Taking into account the indicated instrumental data, the research area on the seismic zoning maps of the territory of the Republic of Kyrgyzstan is located in the zone of expected earthquakes with a magnitude $M \leq 6.5$ (Fig. 20).

The results of paleo- and archaeoseismological studies carried out by the authors in the fieldwork seasons from 2014 to 2018 contribute to the overall pattern

of seismicity in the Alabash-Konur-Oleng intramontane depression and allow us to propose a higher seismic hazard assessment in the southern Issyk-Kul basin.

Parametrization of Seismic Activity of the Territory

Based on the results of paleo- and archaeoseismological studies of the Duvana foothills, as well as previous studies on the Alabash-Konur-Oleng depression, including the interpretation of satellite images, it was possible to identify a 50 km-long-scarp along the northern frame of the Alabash-Konur-Oleng depression, accompanied in some places by a step compensation graben formed by a series of strong earthquakes (Korzhenkov et al., 2018a; Deev et al., 2016).

Based on geomorphological analysis carried out according to the results of the interpretation, large-scale changes in the relief were noted. Out of all the identified areas, that between the southern foothills of the Duvana Mountains and the Ak-Terek River was the most striking and accessible, where there is a section of the compensation graben called the "Dragon's Footprint," weakly reworked by erosion processes.

Field research was carried out near this site using the trenching method, which revealed a series of seismic events clearly reflected in the walls of two trenches dug across the line of the scarp (Figs. 21, 22).

Close to the southern study site, near the bank of the Ak-Terek River, we discovered ancient graves of Kalmyk warriors of the 18th century. They are located

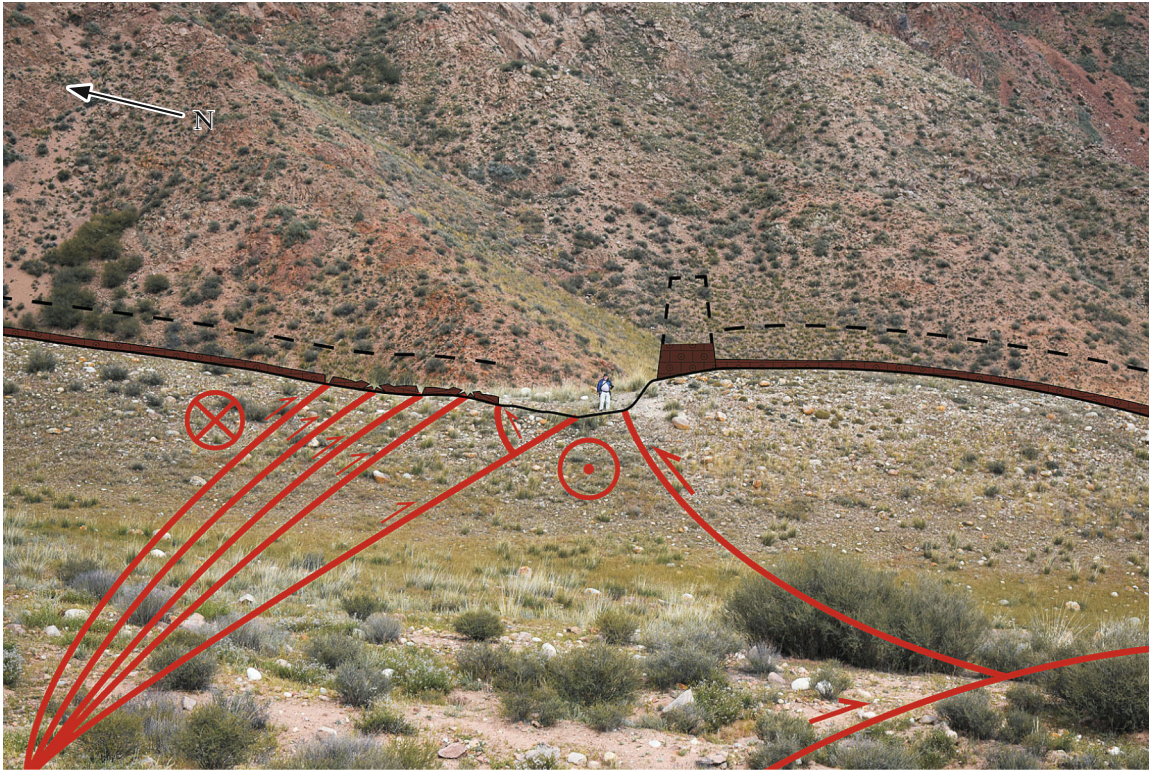


Fig. 12. Sketch map of graben at rear of reverse fault.

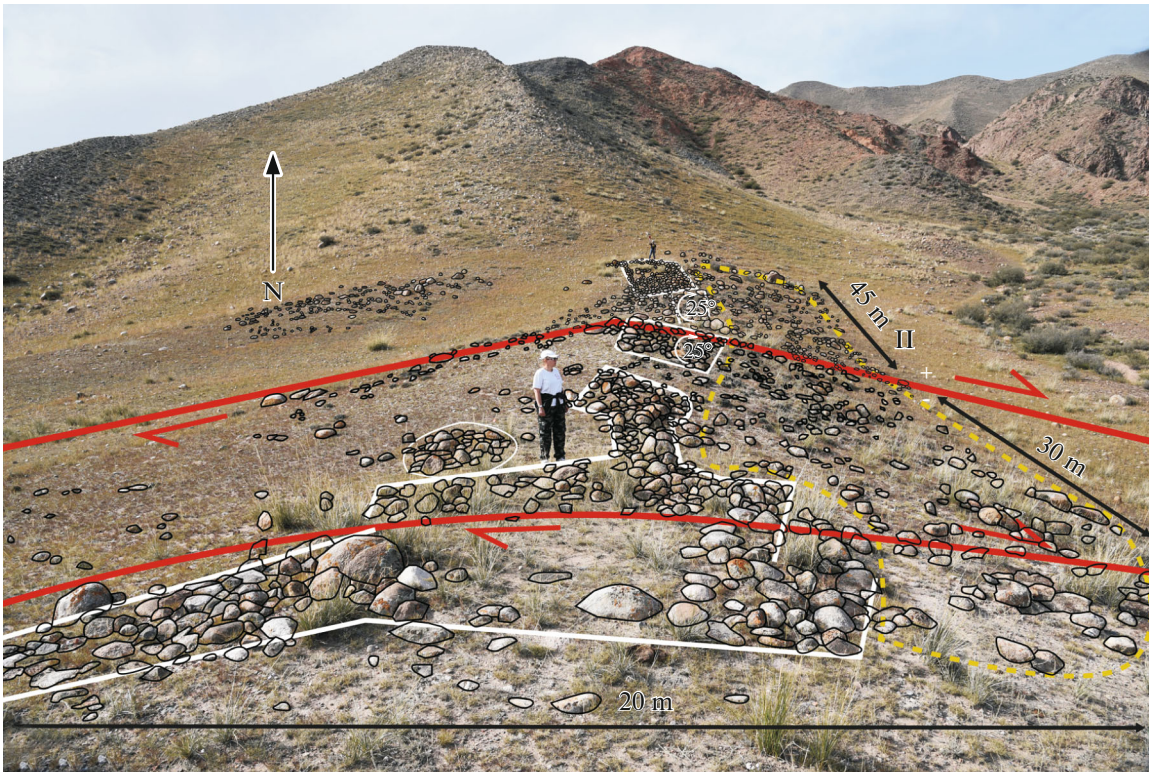


Fig. 13. Fault crossing central wall of temple part of complex and traces of its destruction.



Fig. 14. Fault crossing temple part of complex with destruction of building foundations. (1) Round building with entrance from west; (2) two buildings with inner walls dividing them into five separate rooms; (3) large round building; (4) towers; (5) walls.



Fig. 15. Parallel faults in temple part of complex with destruction of building foundations, top view.



Fig. 16. Badakhshan, Wakhan. Ancient Yamchun fortress on Pyanj is eastern stronghold of Kushan Kingdom. Photo from vostokphoto.ru.

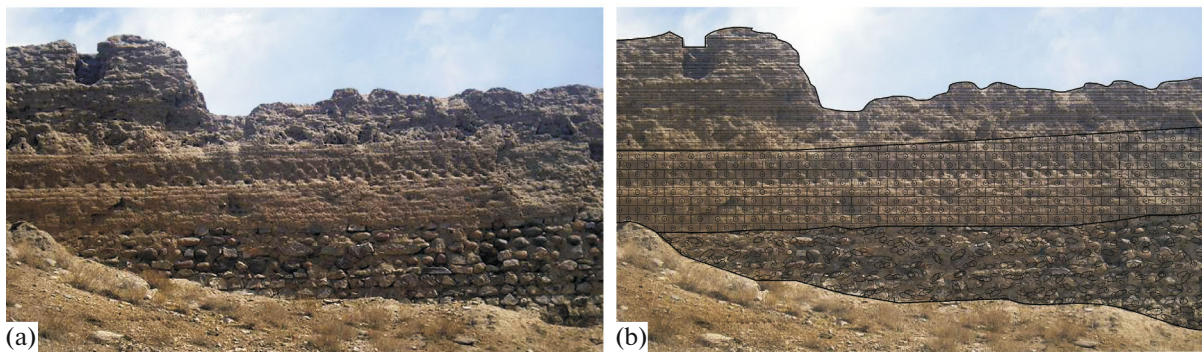


Fig. 17. Sample of preserved Kakh-Kakha wall in Namadgut, Tajikistan. (a) View of wall; (b) interpreted sketch map: upper layer, loam; middle layer, clay brick; bottom layer, foundation of boulders and clay. Shohi Mardon Namadgut Museum. Photo from vostokphoto.ru.

directly on the edge of a young scarp, which implies a seismic event that occurred after the burials, since the graves could not be located on the edge of the scarp and downslope. This is directly confirmed by the fact that the graves were deformed by this scarp: the stones overlapping the graves were displaced and thrown down the slope, and the graves themselves, which were originally circular, stretched from north to south—perpendicular to the strike of the reverse-fault scarp.

The next age indicator of the series of earthquakes is in the walls of the trenches themselves. Paleosols were discovered, buried under the sedimentary layer, the radiocarbon analysis of which indicated several successive seismic events with ages of 760–1020, 860–1155, 990–1185, and 1520–1595 CE in the northern trench near the Duvana foothills, and ages of 1270–1305, 1440–1515, and 1725–1785 CE in the southern, coastal trench (Korzhenkov et al., 2018b).

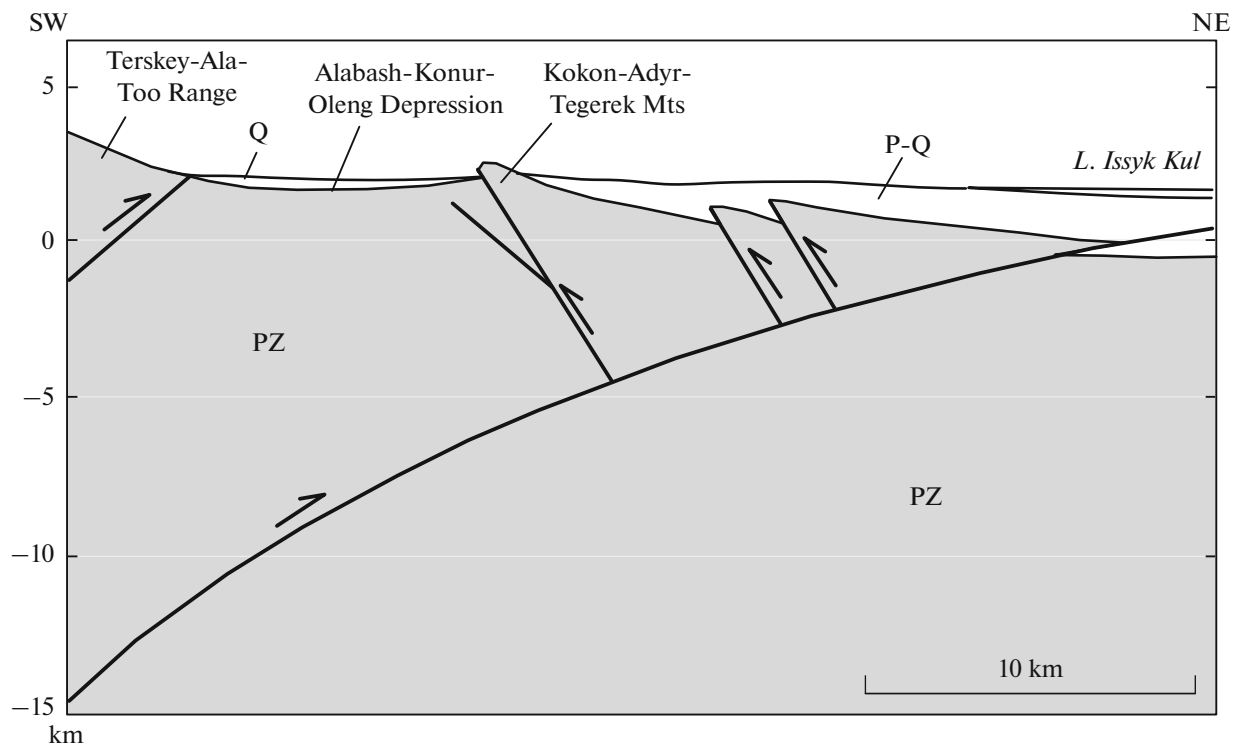


Fig. 18. Model of neotectonic structure of southern Issyk-Kul region (after (Burgette, 2008), with changes).



Fig. 19. Sketch map of Ala-Bash intramontane depression. (1) Kokonadyr-Tegerek Adyr fault; (2) swampy (dammed) territories; (3) Konur-Oleung River Delta.

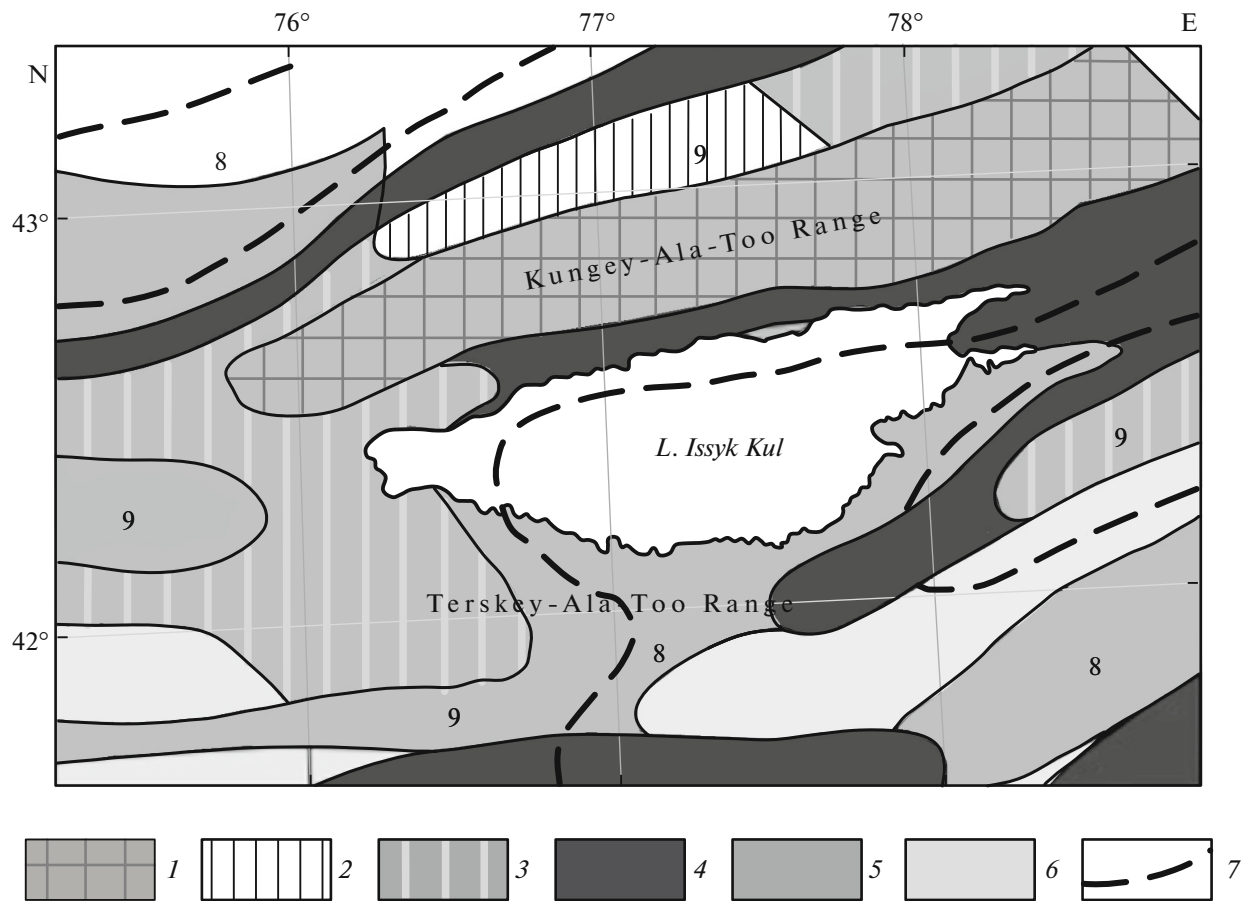


Fig. 20. Fragment of “General Map of Seismic Zoning of Kyrgyz Republic,” 2011 (after (Abdrakhmatov et al., 2012)). (1–6) Occurrence zones of earthquakes with different seismic intensity: (1) ≥ 8.0 ; (2) ≤ 8.0 ; (3) ≤ 7.5 ; (4) ≤ 7.0 ; (5) ≤ 6.5 ; (6) ≤ 6.0 ; (7) boundaries of zones with different initial scores. Numerals 8 and 9 indicate zones with a possible intensity of 8 and 9, respectively.

Later, approaching the foothills of the Duvana Mountains, some architectural structures were found in a satellite image that were difficult to interpret. During field works at this site, a temple complex with an area of about 2 km² was found, in the northeastern part of which eastward displacement of walls and parts of towers by 1–1.2 m were found with a large amount of destruction, up to destruction of the base of walls.

Ancient buildings were also discovered in the southeastern, central, central-southern, and southwestern parts of the Alabash-Konur-Oleng depression; however, due to the vigorous development of agriculture in Kirghiz SSR, these archaeological sites were destroyed in the leveling territories and the remaining foundations were eventually covered by mountain mudflows.

In the northwestern part of the complex, a large number of ritual structures have been discovered. The displacement of the foundations of religious, residential, and defensive buildings was of the greatest interest to us in this area. Thus, the displacements of the wall near the central part were 1.5 m to the east, and in the

area of a propeller fault, displacements from north to south reached 2 m with counterclockwise rotation of the wall by 45°–60°.

The already available data for the eastern part of the Alabash-Konur-Oleng depression showed that the minimum possible earthquake magnitude, according to archaeoseismological data on an event that occurred at the turn of the 16th (?) century was $M = 7.4$, with an intensity $I_0 = 8–10$ (Deev et al., 2016).

Because the archaeological monuments once located close to the southernmost, river bank fault scarp were destroyed and hence difficult to interpret, the main conclusion on the strength and intensity of the earthquake was drawn for the northern part of the temple complex. For this, we used the relations derived by A.A. Nikonov for the mountainous regions of Central Asia (Nikonov, 1988):

$M = 7.09 + 0.79 \log D$, where D is the amount of displacement along the rupture, m (in our case, 1.5 m) $\Rightarrow M = 7.2$;

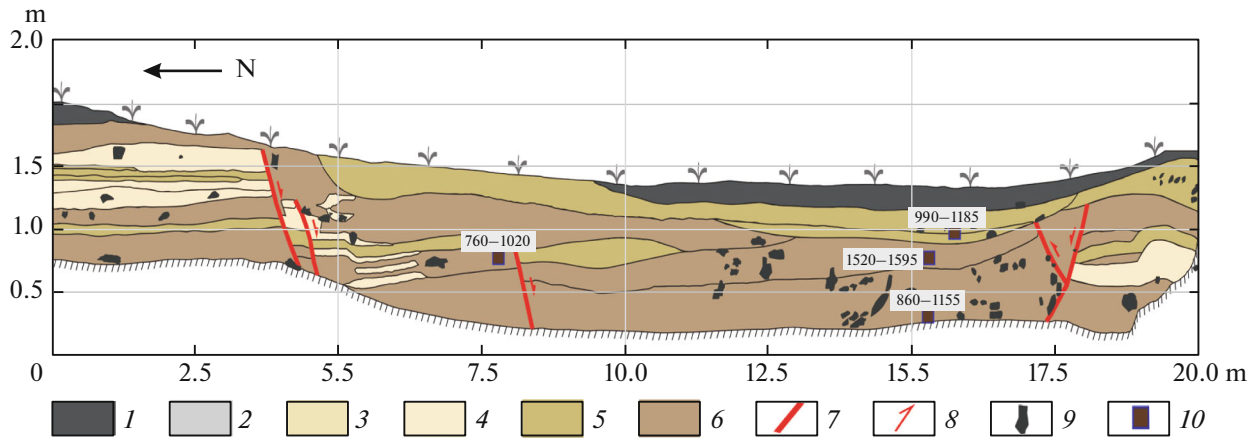


Fig. 21. 2016 trench in area of seismic compensation graben “Dragon’s Footprint” (after (Korzhenkov et al., 2018a), with changes). (1) Soils and paleosols; (2) clay; (3) loam; (4) sandy loam; (5) sand; (6) alluvium; (7) ruptures; (8) direction of displacement; (9) unrounded pebbles (granite); (10) sampling sites for radiocarbon analysis.

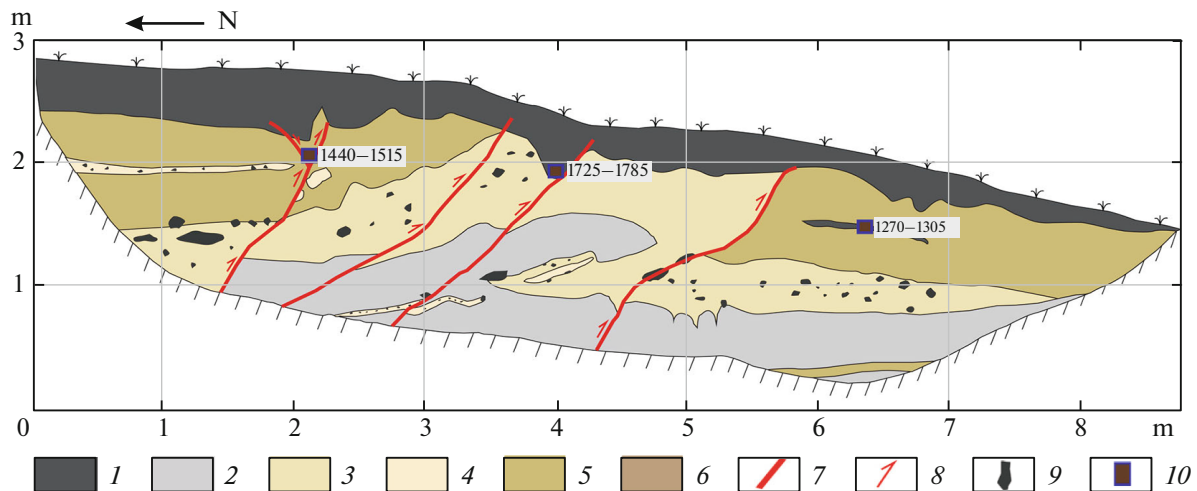


Fig. 22. 2018 trench in area of young fault scarp near high bank of Ak-Terek River (after (Korzhenkov et al., 2018a), with changes). Legend same as Fig. 21.

$M = 6.61 + 0.55 \log L$, where L is the length of the rupture zone on the surface, km (in our case, 48 km) $\Rightarrow M = 7.5$.

If we consider displacement of 1.5 m (in the central part of the temple complex) as the average along the fault scarp, then, according to (Wells and Copper-smith, 1994), we have

$M = 6.93 + 0.82 \log AD$, where AD is the average displacement, m $\Rightarrow M = 7.1$.

Also, according to (Solonenko and Khromovskikh, 1978):

$M = 0.51 \log h + 7$, where h is the height of the fault scarp (in our case, its minimum value is 2 m) $\Rightarrow M = 7.2$.

In the northeastern part of the temple complex, the height of the fault scarp reaches 2 m, which indicates significantly large vertical displacement of the planes, even if two to three recurring events were involved in formation of the fault scarp. This indicator substantiates the even greater increase in magnitude of the studied earthquake.

The results of aerial photography from the drone and the compilation of profiles of elevations made it possible to identify fragments of fault scarps adjacent to the study area that are similar in size and structural–geomorphological position to the east and west of the studied area. Judging from the results of interpretation and geomorphological analysis, these are segments of the primary deformation zone of the same

earthquake. In this case, according to (Nikonov, 1988):

$M = 7.26 + 0.32 \log l$, where l is the length of a single rupture, km (e.g., based on the example of our fault scarp, with a total length of 2 km) $\Rightarrow M = 7.4$.

Obviously, the minimum magnitude of the older earthquake that formed the fault scarp has a comparable value. Hence, according to the MSK-64 scale, the intensity of earthquakes with such a magnitude could be $I_0 = 8-10$.

CONCLUSIONS

Destruction of a major archaeological site of the 7th–9th centuries CE once again clearly demonstrates insufficient seismological study of the region and, as a consequence, an underestimated seismic hazard assessment. According to the results of archaeo- and paleoseismological studies presented in this work, the intensity in this region can reach values $I_0 > 9$. This exceeds the currently accepted level of seismic hazard assessment for the region on the general seismic zoning (GSZ) map of Kyrgyzstan.

Therefore, further research on paleo- and archaeoseismology are planned on the territory of the studied complex in tandem with archaeologists. Their main aim is to establish the age and carry out a more detailed study of the disasters that have occurred.

In other parts of the study area, additional investigation of the remaining parts of the complex will be carried out, where a new, young fault scarp has also been identified, which is of no less interest or hazard. This is because it crosses modern settlements and such critical infrastructure objects as schools, roads, power lines, irrigation ditches, and religious buildings.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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