

# Underestimated Seismic Hazard of the Ferghana Depression: New Archeoseismological Data

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**Abstract**—The results of archeoseismological investigations carried out for the first time at the Eylatan and Kuyul'tepe ancient settlements in the Ferghana Valley (Namangan oblast of Uzbekistan) are presented. Both settlements have traces of strong seismic effects. In Eylatan there is a systematic 4-m left-lateral displacement of sublongitudinal walls along a sublatitudinal seismogenic fault. In Kuyul'tepe, numerous ruptures and fissures have been revealed in an archeological trench. Eylatan was apparently destroyed in the 1st century BC by a strong ( $M_S = 7.6$ ,  $I_0 = X$ ) earthquake, whose seismogenic rupture reached the surface in the area of this settlement. After this seismic event, people have left the ancient city and to build comparatively small settlements around it. However, another strong earthquake ( $I = VIII$ – $IX$  in Kuyul'tepe) in the beginning of 1st millennium AD destroyed these settlements, too. The data can be used for a new seismic hazard assessment of the Ferghana depression.

**Keywords:** seismic deformations, seismogenic faults, Ferghana Valley, ancient earthquakes, Uzbekistan, Namangan oblast, western Tien Shan, Eylatan, Kuyul'tepe

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## INTRODUCTION

The Ferghana valley is an intermontane depression in the western part of the great Tien Shan mountain region (Fig. 1). The valley is surrounded by high ranges topped with glaciers, and the slopes of these ranges accumulate enough snow in winter to irrigate fields, gardens, and vegetable allotments when melting in the warm period. The valley bottom is filled predominantly with loess deposits, on which the highly fertile soils formed. Such favorable conditions attracted people since ancient times. However, natural disasters such as droughts, steady rains, floods, mud flows, landslides, and earthquakes have hit this region.

The long-term intensive seismic regime of this region is explained by rising of the Tien Shan mountain system as a result of the collision of the Indian and Eurasian lithospheric plates (see (Molnar and Tappanier, 1975; Chediya, 1986; Korzhenkov, 2006) and others). Unfortunately, the contemporary worldwide seismic network provides data on strong earthquakes (which are important for building) for only the last hundred years, whereas this time range is insufficient

for seismic hazard assessment in the case of designing such highly important objects as hydroelectric power stations and nuclear power plants: the parameters of strong earthquakes that have occurred in the region in the last hundreds and thousands of years (10 000 years for nuclear power plants) are necessary.

Note that these data can be obtained by paleo- and archeoseismologists, as well as by specialists in historical seismology. In various areas within the northern Tien Shan, both paleoseismological (Korzhenkov et al., 2013, 2015; Deev and Korzhenkov, 2016; *Sil'nye...*, 2018) and archeoseismological (Korzhenkov et al., 2016a, 2016b, 2017a, 2017b; Deev et al., 2016; *Sil'nye...*, 2018) studies have been successfully carried out. Certain data of paleoseismological studies are available for the Ferghana depression and the mountain ranges framing it (e.g., (Khodzhaev, 1985; Korzhenkov, 2006) and others), whereas historical sources are much scarcer and archeoseismological studies have never been carried out here. However, the lack of information mentioned above is important for a reliable seismic hazard assessment of the region.

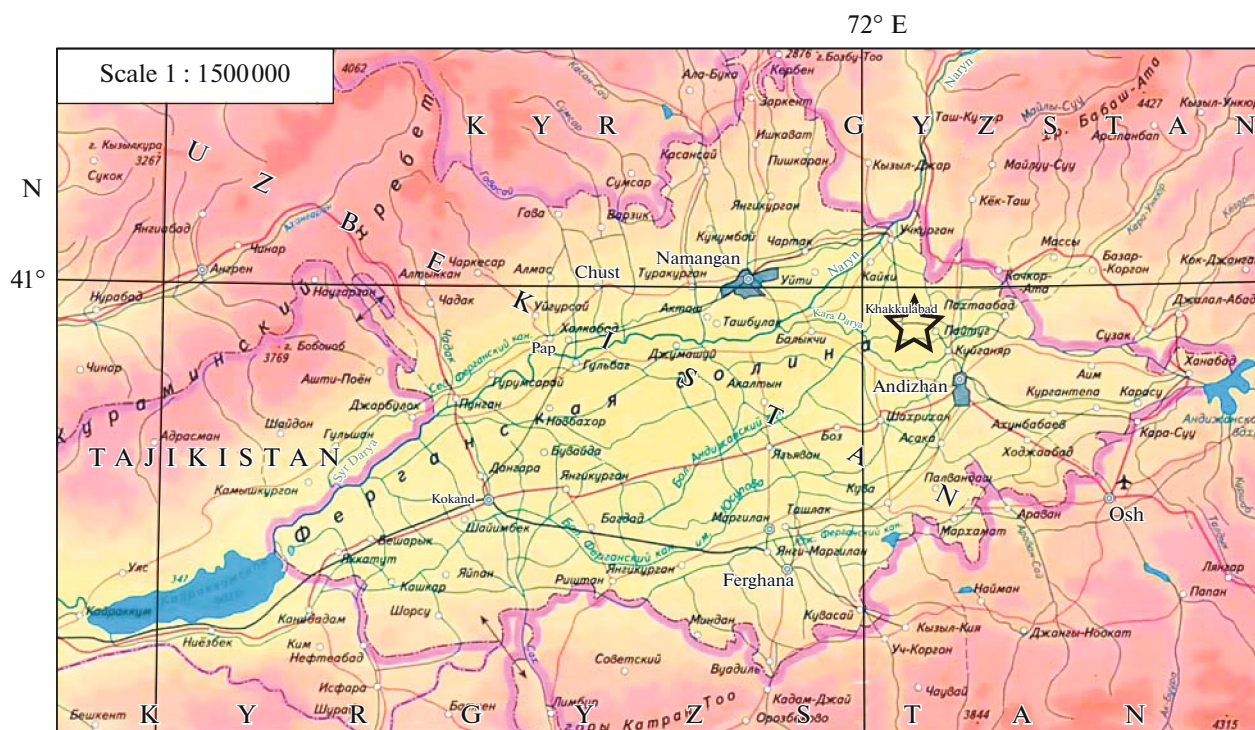


Fig. 1. Elevation map of Ferghana depression; the star denotes the location of studied archeological objects (Eylatan and Kuyul'tepe settlements).

The present work is the first attempt to infer seismological data from local archeological monuments.

### GEOLOGICAL–TECTONIC AND SEISMOLOGICAL KNOWLEDGE OF THE REGION

In April 2019, the first archeoseismological studies were carried out in the territory of Uzbekistan to reveal the traces of residual deformations of ancient strong earthquakes at archeological monuments of Namangan oblast, located within the limits of the Ferghana depression (Fig. 2). The geological structure of the Ferghana depression includes Paleozoic, Mesozoic, and Cenozoic deposits. Since our aim was to study ancient strong earthquakes of Neogene–Quaternary, only brief information about geology is provided below.

Upper Pliocene–Anthropocene deposits of the Ferghana depression start from rocks of the Bactrian Series, represented by gray conglomerates with interbeds of light brown siltstone–argillaceous rocks. In the direction toward the depression center, coarse-grained material changes to fine-grained. The age of the Bactrian Series is determined as the Upper Pliocene–Lower Pleistocene (Gramm, 1962).

Lower Pleistocene deposits (Sokh Fm., North Ferghana valley) are sands and loesslike clay loams; in the zone of the Chust-Pap anticline, they are clays and sandstones.

Middle Pleistocene deposits (Tashkent Fm.) are represented by gray conglomerates and thick loess cover.

Upper Pleistocene deposits (Golodnostepskaya Fm.) are represented by loesses with pebblestones occurring at their base. These deposits are common in terraces of Syr Darya River and its tributaries, as well as in recent fans (Ibragimov, 1970).

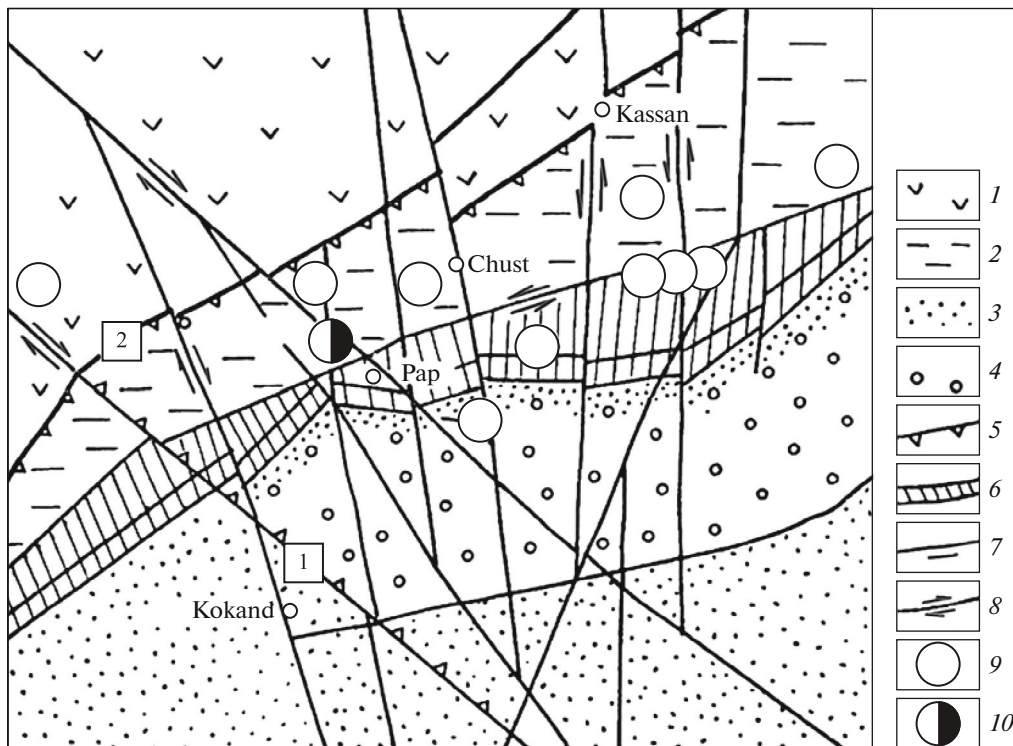
Holocene deposits (Syr-Darya Fm.) are represented by sands and gravel and, less often, pebblestones.

Namangan oblast is located between the North Ferghana fault and North Ferghana flexural fault zone, covering the piedmont zone of the Qurama Range (Fig. 3). It should be noted that the axes of juvenile folds are shifted here by 200–500 m (Yakubov et al., 1986), and this fact is explained by the constant thrusting of the Chatkal-Qurama Mountains along the North Ferghana fault towards the Ferghana depression. Another important reason for it is displacement of the North Ferghana fault toward anticlines such as Chust-Pap, Kasansai, and Namangan ones, as was supposed by V.I. Popov (1938) and O.A. Ryzhkov (1964). In other words, the fault is located in the contact zone of the Paleozoic and Mesozoic–Cenozoic deposits, but shifted by 6–8 km to the west-southwest.

As was noted above, the axes of juvenile folds are shifted to the southwest and south owing to the influence of the fields of tangential tectonic stresses forming as a result of the Chatkal-Qurama meganticline



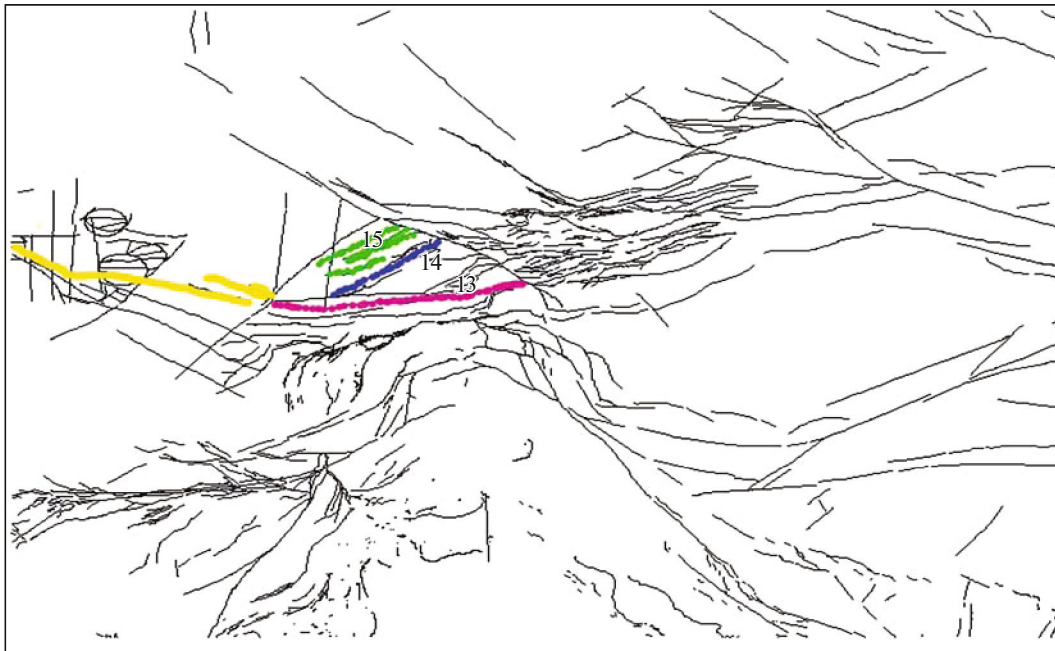
**Fig. 2.** Map of Naryn district of Namangan oblast and Isbaskent district of Andizhan oblast. Star denotes the locations of Eylatan (Isbaskent district) and Kuyul'tepe (near Khakkulabad, Naryn district) settlements. Lines denote tectonic faults.



**Fig. 3.** Structural geological position and schematic directions of recent tectonic movements in the epicentral zone of the 1984 Pap earthquake, after (Yakubov et al., 1986). Arbitrary notes: (1) uplift; (2) uplift dominating over subsidence; (3) weak relative subsidence; (4) clearly expressed relative subsidence; (5) regional faults (1, Kumbel-Kokand, 2, North Ferghana); (6) Ferghana fault zone; (7) ruptures and lineaments revealed by geodetic survey, deciphering aerial and satellite images, and morphometric analysis of topographic maps; (8) directions of motions along strike-slip faults; (9) epicenters of earthquakes with  $M > 5.0$ ; and (10) epicenter of the 1984 Pap earthquake.

growth. Under the condition of regional submeridional shortening of the Tien Shan, these stresses can lead to intensive deformations of crustal strata in the considered region with the renewal of the existing and formation of new faults, which may generate strong seismic events.

A review and analysis of publications on tectonic (geodynamic) zoning of the central part of the West Tien Shan (which incorporates the territory of Ferghana depression in East Uzbekistan) allow us to distinguish the main deep structure-controlling units, namely, the South Ferghana and North Ferghana



**Fig. 4.** Map of active faults of the Pamir–Tien Shan region, after (Trifonov et al., 2002): (13) South Ferghana fault, (14) North Ferghana fault, and (15) Karzhantau fault system.

faults and their flexural fault zones (Fig. 4). All strong regional earthquakes having magnitudes  $M \geq 5.0$  occurred at these faults, whereas the events in the magnitude range of  $M = 5.0–6.9$  occurred within the limits of seismogenic zones (Ibragimov, 1978). However, the earthquakes in the magnitude range of  $M = 7.0–7.9$  are associated to structures of lower order, namely, the Talas-Ferghana fault and the zone of intercept of the West and South Tien Shan faults (Usmanova et al., 2012).

Seismotectonic analysis of the geological–tectonic data and the data on earthquakes occurred in Namangan district of Uzbekistan allowed S.I. Ibragimov (1978) to distinguish the Namangan and North Ferghana (Ferghana fault zone) seismogenic zones as potentially hazardous in terms of the occurrence of strong earthquakes.

The Namangan seismogenic zone is a category-I zone, where earthquakes with magnitude  $M = 7.5$  and intensity  $I_0 = 9$  can occur (Ibragimov, 1978). Its activity is caused by its proximity to the North Ferghana zone and the Baubashata fault. The zone is 240 km long and 10–15 km wide. The northeastern part of the Namangan seismogenic zone is believed to have  $I = 9$ , because several of the strongest earthquakes have occurred there in the past: seismic events of 1494 and 1620 had  $I = 9$ , while those of 1927 and 1929 occurring in the southwestern part had  $I = 8$ . Below are the brief characteristics of these earthquakes.

(1) The 1494 Namangan earthquake,  $I_0 = 8–9$  (Novyi katalog..., 1977). The data on this earthquake are fragmentary and differ in details in various histor-

ical sources. Nevertheless, the very fact that the strong, destructive earthquake occurred in the vicinity of Namangan in 1494 has been supported by different studies of seismicity of this area (Novyi katalog..., 1977; Ibragimov et al., 1986; Butovskaya et al., 1961).

(2) The 1620 Akhsy earthquake near the town of Namangan. Resulting from this earthquake, the town of Akhsy (Akhsikent) was completely destroyed. Based on the descriptions of Muhammed-Tahiri ibn Abul Qasimi (quoted in (Novyi katalog..., 1977)), destructions of the walls and buildings in the town of Akhsy and morphological changes in the topography corresponded to shaking intensity of  $I_0 = 9$ , and the pleistoseismal zone was located in the North Ferghana seismogenic zone.

(3) The Namangan earthquake of August 12, 1927, occurred in the North Ferghana seismogenic zone and caused considerable destruction. The earthquake epicenter was located near the town of Namangan, where shaking intensity was  $I_0 = 8$  at maximum; it was  $I = 7–8$  in Namangan, Chust, Chartak, Yangikurgan, and Pap, and  $I = 4$  in Tashkent. In the vicinity of Chartak, large cracks with water pouring out of them formed in soil. The strong aftershock with  $I = 7$  occurred on August 19, 1927, to cause additional destruction in Namangan, Chartak, and Kum-Kurgan. A.G. Kon'kov (1964) and Ryzhkov (1964) attributed the occurrence of the 1927 Namangan earthquakes to the development of the aforementioned Namangan anticlines.

(4) The Namangan earthquake of March 8, 1929, occurred in the epicentral zone with intensity  $I_0 = 7$  and magnitude  $M = 7.5$ . The depth of the earthquake

**Table 1.** Strong earthquakes of Namangan oblast in 1400–2019

Earthquake	Date and time (hh:mm:ss)	Coordinates, deg		Source depth, km	Magnitude $M_L/M_w$
		N	E		
Namangan	1494	41.00	71.60	6	5.1/5.5
Akhsy	1620	40.90	71.40	6	5.8/6.0
Namangan	March 24, 1908, 22:07	40.90	71.00	26	5.4/5.7
Namangan	Jan. 23, 1912	41.00	71.70	12	5.2/5.6
Namangan	Aug. 12, 1927, 10:22:47.00	41.00	71.60	14	6.0/6.1
Namangan	Aug. 13, 1941, 00:55:53.00	40.80	71.30	20	5.1/5.5
Yartepe	Jan. 18, 1942, 16:36:31.00	41.10	71.60	21	5.9/6.0
Balykchi	Apr. 30, 1966, 13:41:10.00	41.15	71.97	18	5.0/5.4
Pap	Feb. 17, 1984, 23:26:52.90	40.85	71.06	20	5.5/5.6

The table is compiled on the basis of (*Novyi katalog...*, 1977), Aggregated Earthquake Catalog of Central Asia (also see (Abdrakhmatov et al., 2008)), and the catalog of earthquakes of Uzbekistan for the period since 2000 BC compiled and supplemented by researchers from the Mavlyanov Institute of Seismology, Academy of Sciences of the Republic of Uzbekistan.

source was 6 km, and it is what caused a strong effect on buildings and structures, despite moderate magnitude  $M = 5.0$  (*Novyi katalog...*, 1977).

(5) The Balykchi earthquake of April 30, 1966, occurred in the Balykchi district of Namangan oblast ( $M = 5.0$ ,  $I_0 = 6-7$ ) (Usmanova et al., 1981). Its epicenter was located in the zone of the Kasansai fold system. This earthquake was, in our opinion, was also related to the development of anticlines and to the tectonic regime of the region. In the localities of the Balykchi district, buildings and facilities designed without earthquake-resistant precautions were considerably damaged and destroyed (*Novyi katalog...*, 1978).

(6) The Pap earthquake of February 17, 1984, had magnitude  $M = 5.6$  and intensity  $I_0 = 8$ , and was also related to the development of the Chust-Pap anticline located near the town of Namangan. The Pap earthquake was followed by several earthquakes with moderate magnitudes  $M = 4.5-4.8$ , and these shocks released stresses in the area. However, this does not exclude the occurrence of strong earthquakes in the area of Namangan and its vicinities in future (Ibragimov et al., 1986).

The parameters of strong earthquakes in the study area are summarized in Table 1.

After an analysis of strong earthquakes occurring in the area of Namangan, it should be accepted that Kon'kov (1960) and Ryzhkov (1964) were correct about the seismogenic origin of local strong earthquakes. Based on geological–tectonic and geomorphic data (Kostenko, 1964), local seismicity of the town of Namangan is related to the formation of the Namangan anticline. The above is supported by a high crustal motion rate (15–22 mm/yr) in the area of Namangan based on GPS measurements (Zubovich et al., 2007), and this high rate is related to the growth of the Chust-Pap, Kasansai, and Namangan anticlines.

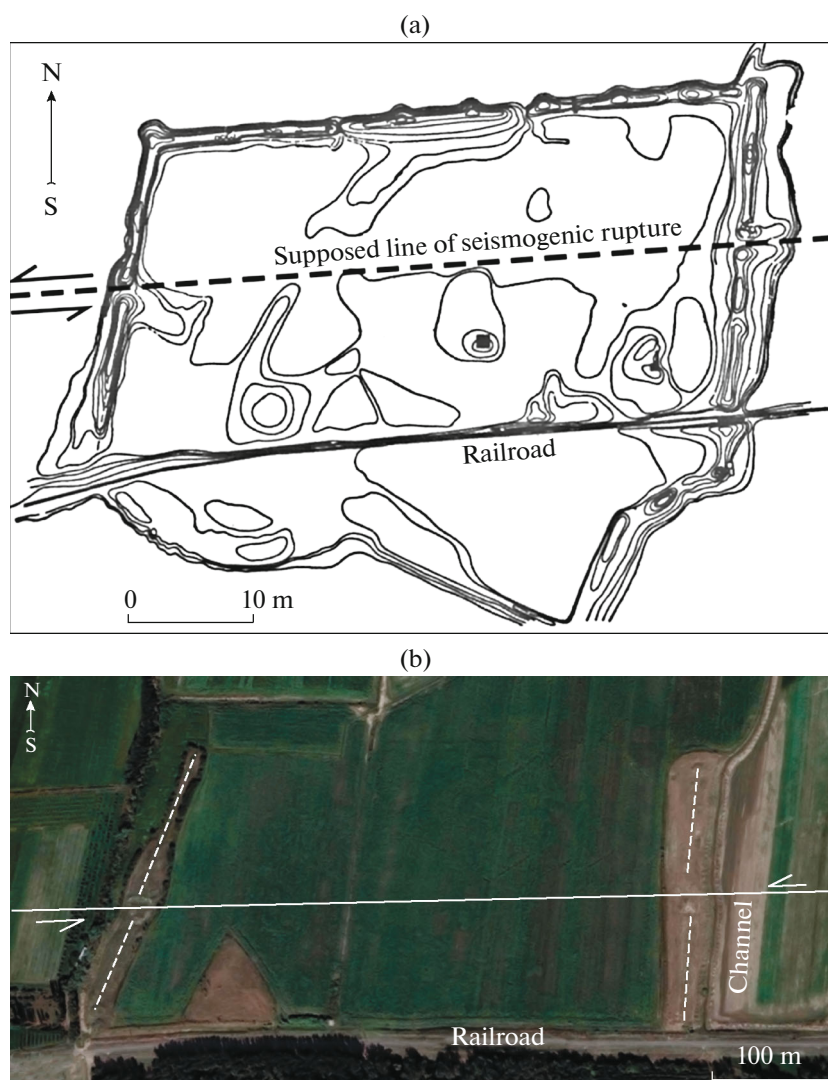
An analysis of the available geological–tectonic data on the area under study has allowed us to reveal the geo-

logical causes of seismic processes, which were determined by the recent tectonic evolution and the position of the North Ferghana seismoactive zone in the general structure of the West Tien Shan. An important factor that should be taken into account is the increase in seismic risk, because Namangan oblast is located in the piedmont area, immediately in the zone of the North Ferghana fault and its flexural fault zone of the same name, i.e., in the zone of their active influence.

To conclude here, let us note that, on the one hand, geodynamic processes related to the tectonic regime of the North Ferghana fault and its flexural fault zone of the same name continue to evolve. On the other hand, given the recurrence of strong earthquakes, the absence of a strong earthquake with  $M \geq 5.0$  in the Namangan seimsogenic zone for more than 35 years is a strong reason to expect it to occur here.

## HISTORICAL–ARCHEOLOGICAL STUDIES

The earliest known written data on the Ferghana valley are the Chinese chronicle records of the 2nd century BC mentioning the trip of the famous diplomat, Zhang Qian, to the Western Land in 138–128 BC. His report was presented to the Emperor Wu of Han in 126 BC. Later, several other ambassadors were sent to Ferghana (Dayuan). The Chinese emperor needed superior Ferghana horses, so his ambassadors to Ferghana followed one another. When it became clear that the horses could not be obtained through negotiations, a war was declared and won by the Chinese. These events were described in two chronicles, *Shiji* and *Hanshu* (Bichurin, 1950, vol. II, pp. 147–168; Khuzhaev, 2010, p. 63). The author of *Shiji*, Sima Qian, using the report by Zhang Qian and reports by other diplomats, which contained data on events in 138–90 BC, described Ferghana as a country of 70 cities and towns; however, only three of them were mentioned: Yuan, Yucheng, and Ershi. The capital city of confederation was Yuan (Ferghana), while Yucheng and Ershi were the regional central cities. In our opin-



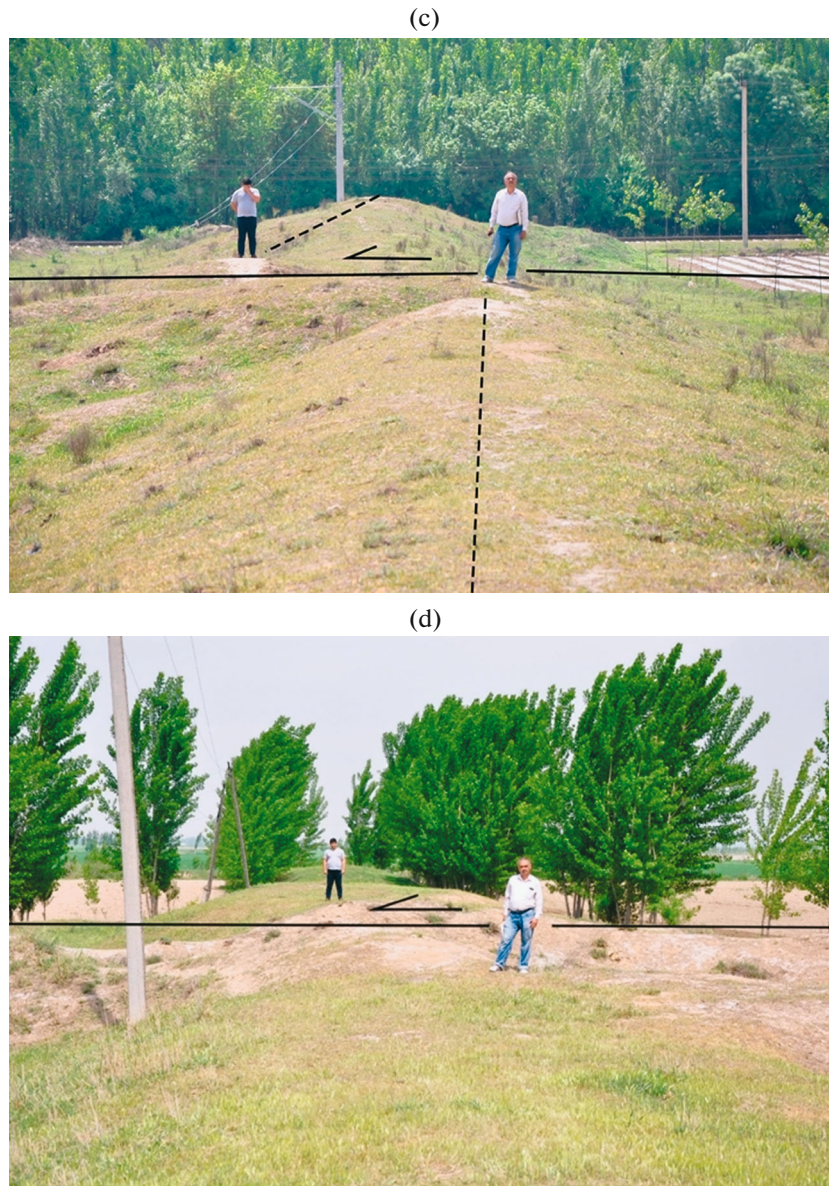
**Fig. 5.** Walls of the ancient town of Eylatan displaced along the seismogenic rupture: (a) schematic topographic drawing of the monument, after Yu.A. Zadneprovskii (1960) with modifications and additions; (b) satellite image; (c) eastern wall of the settlement; and (d) western wall of the settlement. Solid line in Figs. 5b and 5d denotes the rupture line (the direction of displacement is shown); dashed line denotes the central axes of the walls.

ion, proceeding from the geographic position and time of existence, the city of Yucheng can correspond to the city of Eylatan (see also (Anarbaev, 2013, pp. 358, 507–508; Anarbaev, 2019, p. 57)).

The city of Eylatan, which played a special role in the history of Ferghana, appeared in the eastern part of the Ferghana valley, in the Mailisu River delta, no later than the 5th century BC. There is no common opinion regarding the time of its foundation. Different researchers date it back to the 7th–4th (Zadneprovskii, 1960; Latynin, 1961), 3rd–2nd (Oboldueva, 1981; Kudratov, 1992), or 6th–3rd (Gorbunova, 1984; Matbabaev and Mashrabov, 2011) centuries BC. Analyzing the results of archeological works in 1988–1990 and 1994 at the Eylatan settlement, we came to the conclusions that the lower layers of the western part of this settlement and its defensive wall could be dated

back to the late 4th–first half of the 3rd centuries BC, whereas the upper layers and pottery kilns found within the area enclosed by the defensive wall referred to the second half of the 3rd–2nd century BC. People left Eylatan in the beginning of the 1st century BC.

In *Hanshu*, another Chinese written source, which dated later than *Shiji* (32–62 AD), the city of Yucheng (Eylatan?) is not mentioned (Anarbaev, 2013, p. 508); in this respect, the question is raised: what happened with the city of Yucheng (Eylatan?)? We think that the city was destroyed during the second Chinese military campaign or by some natural cataclysm. To recall, the archeological data also indicate that human activity in Eylatan ceased in the 1st century BC. In the same time, several small settlements appeared around Eylatan, and we have investigated one of them, Kuyul'tepe. The settlement of Kuyul'tepe, located near Eylatan,



**Fig. 5.** (Contd.)

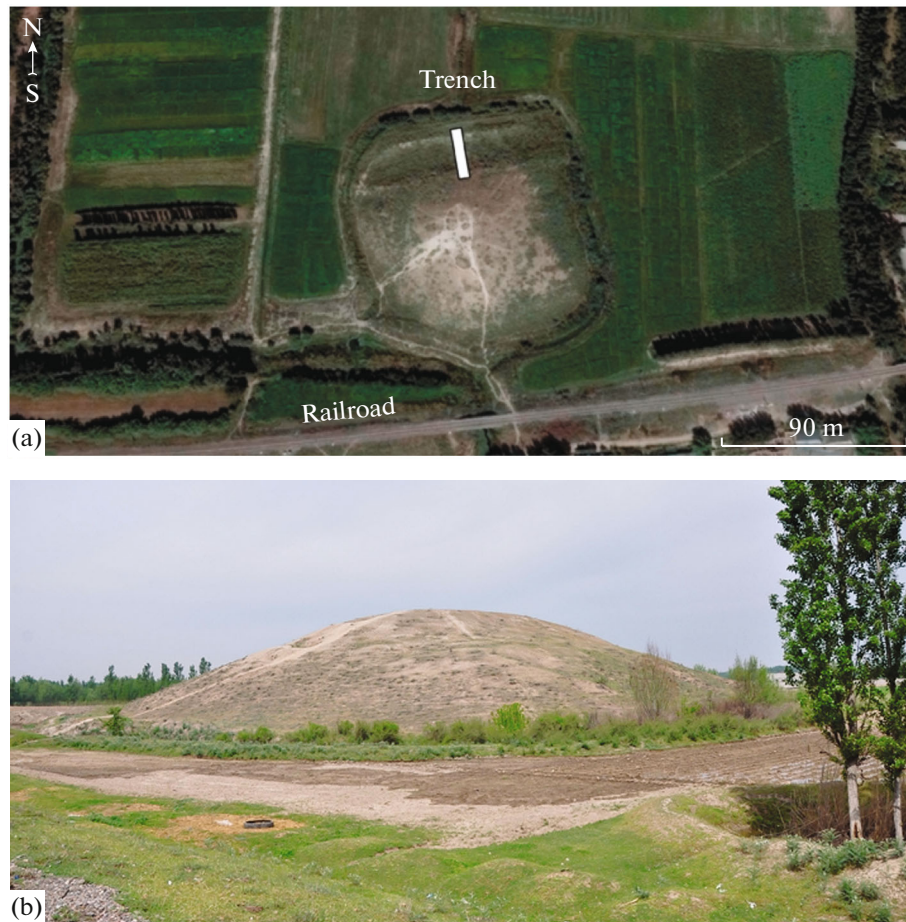
appeared ca. 1st century BC. The building remains that were revealed during the excavations dated back to the first centuries AD.

## RESULTS OF ARCHEOSEISMOLOGICAL STUDIES

Seismic waves generated by earthquakes travel in all directions from the epicentral zone, leading to movement of the lower parts of buildings and facilities simultaneously to the underlying soils, whereas the upper parts of constructions stay in place by inertia; as a result, parts of building constructs become tilted, ejected, and collapsed in the direction off the epicentral zone (see (Korzhenkov and Mazor, 1999, 2001)

and others). Wall fragments, or even entire walls, can rotate clockwise or counter-clockwise around a vertical axis when seismic waves arrived at some angle to the orientation of building structures. All these deformations serve as kinematic indicators useful for defining (a) direction to the epicentral zone and (b) local shaking intensity.

Archeoseismologists are extraordinarily lucky (at the expense of the unfortunate ancient inhabitants) when an earthquake source marked by a seismogenic rupture reaches the surface within the limits of a settlement, shifting and destroying walls of all buildings. Such cases are rare in archeoseismological literature (see (Rukieh et al., 2005; Korjenkov et al., 2006; Ovsyuchenko et al., 2019) and others). However, their



**Fig. 6.** Kuyul'tepe settlement: (a) satellite image; (b) surface image of 2019, view to the northwest.

importance is that there is no need to find the source of ancient seismic event. Additionally, one can infer earthquake-induced energy release from the values of displacements, namely, magnitude and epicentral shaking intensity. The role of archeologists in this case is to determine the age of catastrophe.

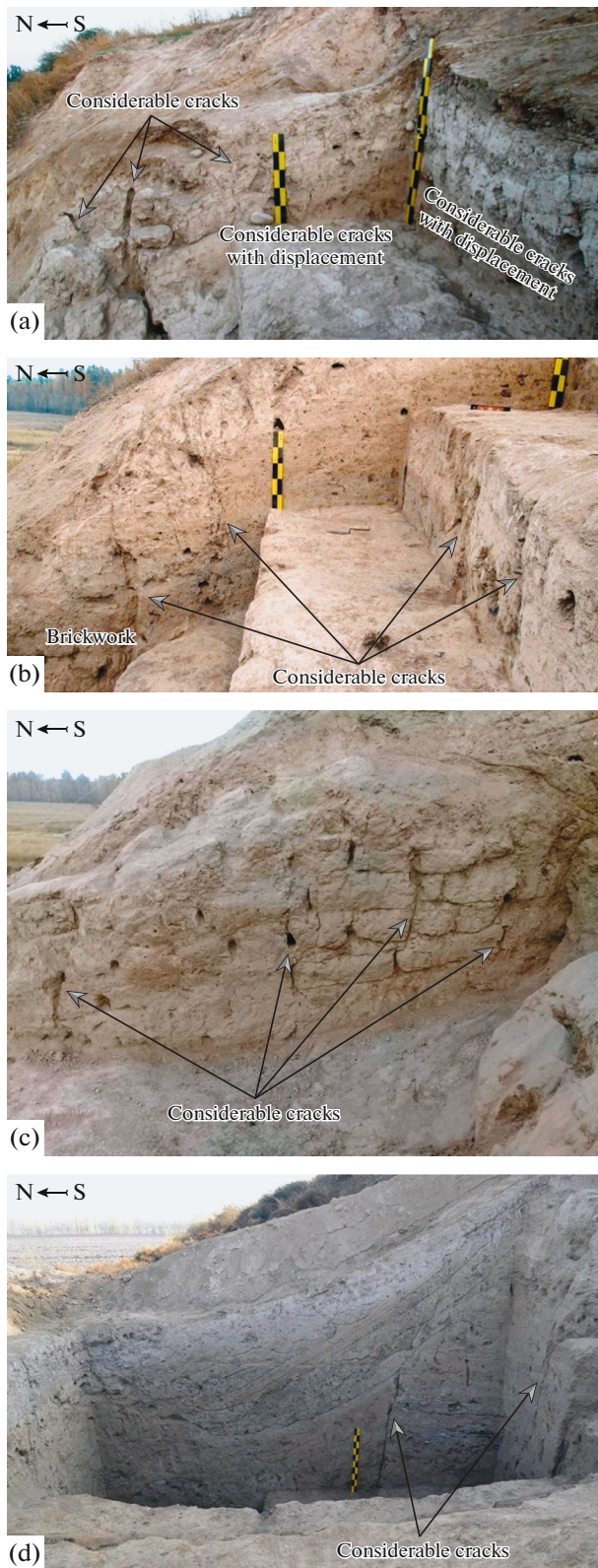
Such a fortunate situation was revealed when we investigated the Eylatan settlement. Although the only remains of the settlement are two highly crept submeridional walls, we can see that both of them are shifted by 4 m to the left along the exposed rupture of the ancient earthquake (Fig. 5). The eastern and western walls are oriented at  $5^\circ$  and  $10^\circ$ , respectively, while the rupture trends at  $85^\circ$ . The present-day height of the walls is up to 2–3 m, and their remained length is 250–300 m. Interestingly, in the zone where the seismogenic rupture shifts walls, we have found hollows representing archeological excavations of the 20th century. This is likely the seismogenic trench (hollow) which formed here and was interpreted by Soviet archeologists as an ancient town gate.

Interestingly, the present-day irrigation channel, which is dug to the east of the eastern wall, also has a

leftward bending. It should have been dug following a straight line, like the vast majority of irrigation channels in the area. However, this channel has been existing for a very long time and suffered the sinistral shift after the ancient earthquake, while modern people just clear this ancient channel from time to time, not changing its distorted shape.

At the distance of 1.5 km to the west of the western wall of Eylatan, there is another ancient settlement called Kuyul'tepe. Presently, only a crept mound of up to 15 m high remained after it (Fig. 6). In 2017, archeological excavations were carried out in its northern part, and we examined the eastern wall of the excavation more thoroughly (Fig. 6). It appeared to be cut by multiple ruptures and cracks. Judging by the presence of some parts carrying signs of extension, the main displacements on ruptures were horizontal, although a small vertical component is also present. It should be noted that developed ruptures and cracks are also reported in the southern wall (relatively small in area) of the excavation (Figs. 7a, 7b, 7d). This fact suggests the proximity of the studied settlement to the epicentral zone of the historical earthquake.





**Fig. 7.** Eastern wall of the trench dug on the northern slope of the Kuyul'tepe mound: (a) upper part of the trench, (b) middle part of the trench, (c) brick masonry in the middle part of the trench, and (d) lower part of the trench.

## CONCLUSIONS

The results obtained during our archeoseismological studies unambiguously indicate that the ancient town of Eylatan was destroyed by a strong earthquake in the 1st century BC. The magnitude of this event was determined from displacements along the seismogenic rupture in the remaining walls of the settlement. The formulas usually used for calculations are those from (Wells and Coppersmith, 1994); however, as was noted earlier (Korzhenkov, 2006), calculations by these formulas systematically underestimate magnitude values for the region of Tien Shan orogen. The best fit for Central Asia is obtained when calculations by formulas proposed by A.A. Nikonov (1988). We used one of them:

$$M_w = 7.09 + 0.79 \log D,$$

where  $D$  is the maximum displacement along the seismogenic rupture.

The magnitude is  $M = 7.6$ , suggesting that shaking intensity which led to the destruction of the ancient city of Eylatan was  $I_0 = X$  on the MSK-64 scale. These strong vibrations completely destroyed all buildings and caused heavy damages to the town walls or their destruction. Human activity in Eylatan ended in the beginning of the 1st century BC and the turn of millennia. People abandoned the town and built new settlements nearby, including Kuyul'tepe, where agricultural and craft activities continued. However, the later seismic event in the first centuries AD destroyed them, and Kuyul'tepe in particular. According to our estimates, the shaking intensity of this earthquake was  $I_0 = VIII-IX$ . In the end, people abandoned Kuyul'tepe settlement as well.

The results should be taken into consideration when assessing seismic hazard of the Ferghana depression.

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## CONFLICT OF INTEREST

The authors claim no conflict of interests.

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