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Traces of the Strong Devastating Earthquakes in the Hansaray and Its Vicinity, Bakhchysarai, Crimea

D. A. Moisieiev[a], *, A. M. Korzhenkov[b], **, A. N. Ovsyuchenko[b], *, E. A. Rogozhin[b], ****, †, and A. S. Lar'kov[b], *******

[a] *Bakhchysarai Historical, Cultural and Archaeological Museum-Reserve, Bakhchysarai, Crimea, 98405 Russia*
[b] *Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, Moscow, 123242 Russia*
*e-mail: ohota_d@ukr.net
**e-mail: korzhenkov@ifz.ru
***e-mail: ovs@ifz.ru
****e-mail: eurog@ifz.ru
*****e-mail: las119@yandex.ru

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Abstract—We study an ancient earthquake that significantly damaged the Hansaray (Khansarai) in Bakhchysarai, Crimea, at the end of the 17th century. However, to date, the traces of this catastrophic event can barely be found in the Khansarai walls. Our studies have shown that this is mainly due to the numerous repairs and restorations which have been continuously conducted at the monument. It is only due to the fact that one of the objects of the Hansaray (the "Eastern Building") was plundered in 2013 that we were able to identify the internal structure of its walls and to reveal a clearly expressed seismogenic deformation of the brick arch which underwent a subsequent repair. In order to accurately date the seismic event, we carried out a search for the analogies, which revealed similar damage in the walls of the Eski-Durbe mausoleum, the monuments of the first palace of the Crimean khans in Salachik (Zincirli medrese and Haci Giray durbe mausoleum) and the Great Kenassa of the Chufut-Kale fortress. By comparing the chronology of the Eastern Structure and other monuments and the peculiarities of their seismic deformations, we correlated the damage of these structures to the Salachik earthquake of April 30, 1698, whose epicentral area was located in the West Crimean seismogenic zone and which had local intensity in the Bakhchysarai region I_l = VIII–IX (on MSK-64 scale).

Keywords: Hansaray, earthquake, deformation, Eski-Durbe, Big Kenassa, kinetic identifier

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INTRODUCTION

Seismic hazard assessment of Crimea is primarily based on the data from a network of seismic stations. This network has existed for a relatively short time of about a hundred years starting from 1927 when the Yalta earthquakes producing ground shaking with intensity I_0 = VII–VIII in the zone of maximal damage occurred. The events that occurred on June 26 ($M = 6.0$) and September 11, 1927 ($M = 6.8$) have been to date most significant among the regional earthquakes over the last 150–200 years—the period of the seismic history of Crimea covered by instrumental data and documented in the periodical press and in the literary works of the contemporaries (Morozova and Shebalin, 1968; Pustovitenko et al., 1989; Nikonov and Ponomareva, 1991; Khapaev, 2012). Thus, the instrumental data leave no doubt of a high seismic potential of only one structure—the South Crimean seismogenic zone stretching along the southern coast of Crimea in the Black Sea.

However, the recent paleo- and archaeoseismological studies (Borisenko et al., 1995; 1999; Nikonov, 1994; 2016) and our works (Korzhenkov et al., 2016; 2017; 2018; 2019; Moisieiev et al., 2018a; 2019; Ovsyuchenko et al., 2017; 2019) have shown the high seismic potential of the entire Crimean Peninsula with possible devastating (I_0 = IX–X) earthquakes in this region to occur every few hundred years. The research continues to this day. This work is devoted to the study of deformations in the medieval monuments of the town of Bakhchysarai—the former capital of Crimea—and its vicinity (Fig. 1) aimed at accurate identifying the origin of the revealed failures and damages and subsequent parameterizing of seismic events.

METHODS

The archaeoseismological method has been used in seismic hazard assessment studies since relatively

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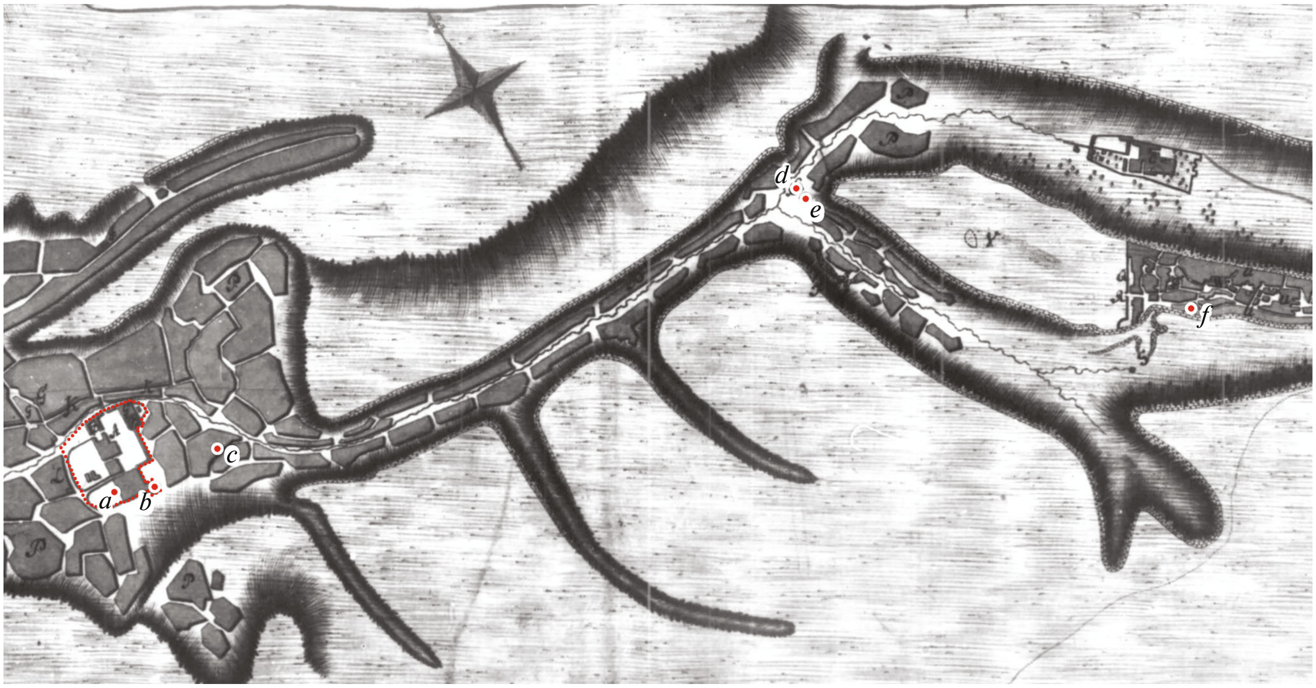

Fig. 1. Plan of town of Bakhchysarai as of 1775 (according to *Plan of the Crimea capital the town of Bakhchysarai* ... with changes and additions). Red line shows the complex of Hansaray: *a*, presumed Sahib Giray's Divan Hall; *b*, Dilara-Bikech durbe; *c*, Eski-Durbe; *d*, Zincirli Madrasah; *e*, Haci Giray Durbe; *f*, Great Kenassa in Chufut-Kale fortress.

recently. The interest of the specialists in these studies was drawn by the monograph (*Archeoseismology* ..., 1996). The cited publication was followed by an avalanche of the works on the study of failures and damages in the archaeological and historical sites all over the world. A bulk of these publications can be divided into two unequal parts:

(1) papers describing the displacement of ancient building structures along the fault scarps—occurrences of historical seismic sources on the surface. Only a few dozen papers on this issue were published to date (e.g., for the Kamenka fortress (Korzhenkov et al., 2006), Derbent fortress (Ovsyuchenko et al., 2019a; etc.));

(2) papers describing the failures and damages of the archaeological sites by strong ground shaking from the earthquakes. These so called seismoinertial deformations have been extensively published, e.g., for the monuments and objects in Israel (Korzhenkov and Mazor, 1999), Salachik (Korzhenkov et al., 2016), Cape Zyuk (Ovsyuchenko et al., 2019b), Ilka, Mangup and Chorgun (Moisieiev et al., 2019; etc.)).

In the first case, seismic origin of deformation is easily established and the ancient earthquake is also easily parameterized (by the displacement of the building structure). In the second case, one should initially (a) prove the seismic origin of the observed failures and damages, then (b) determine the local seismic intensity based on the special macroseismic scales; (c) determine the propagation direction of seismic oscillations (direction to the epicentral zone) using special kinematic indicators, and (d) determine the age of the ancient seismic event using the archaeological method or absolute dating methods.

The archaeoseismological method is described in detail and well known in the Russian historiography (Korzhenkov et al., 2016; Khapaev et al., 2016; Belik, 2017; Korzhenkov et al., 2006), and internationally (Korzhenkov and Mazor, 1999; Caputo and Helly, 2008; Galadini and Hinzen, 2006; Karakhanian et al., 2008; Kazmer and Major, 2015; Martín-González, 2018; Rodríguez-Pascua et al., 2011; Sintubin and Stewart, 2008; Stewart and Piccardi, 2017).

DATA

The territory of the back yards of the Hansaray, which is currently empty, accommodates several buildings which, for convenience, we denote as northern, southern, and eastern ones (Fig. 2, *b*). These three objects bear the traces of economic development and personal building of the 20th century—the so-called Khan's gardens in the southern flank of the palace complex. Our attention was attracted by the "eastern building" where the masonry technique was apparently coeval with the period when Khansarai was a functioning palace complex of the Crimean Khanate. Until autumn 2013, this building was faced with well-processed blocks (Fig. 3) which were subsequently taken out from it by local residents for their household needs (Fig. 4). As a result of significant damaging of the cultural heritage object, the internal structure of the "eastern building" was exposed. The object was constructed using several antiseismic techniques: duvar-kushak[1] (Fig. 4, *c*) and opus mixtum[2] (Fig. 5, *a*). Obviously, the plundered outer cladding had a later age because the only rectangular doorway (Fig. 3, *a*) which led inward covered the plinth (brick) arch of the earlier passage. It was located in a wall with a strike of 89°. The arch had a clearly expressed seismogenic deformation (Fig. 4, *a*) manifesting itself by the loss of the upper central part of the arch structure. The arc was subsequently repaired and the loss filled with rubble (Fig. 4, *b*). During the period when the protection of the objects of cultural heritage in the territory of the Hansaray complex was weakened, the "eastern building" was reinforced by a concrete armored belt (Fig. 3d) and covered by reinforced concrete slabs (Figs. 3, *b*, and 5, *b*). The passage under the arch was laid with rubble using modern building material apparently at the same time.

Such a deformation of an arched structure is a spectacular example of the effect of an earthquake on ancient buildings. In order for the plinth-brick arch of the "eastern building" to obtain such a damage, seismic vibrations should propagate parallel or slightly obliquely to the strike of the structure (*Archeoseismology* ..., 1996, pp. 129–152; Korzhenkov and Mazor, 1999). The ground shaking intensity sufficient for producing this damage is at least I_I = VII (MSK-64). However, the very design features of the building may suggest that the intensity estimate perhaps needs some correction. The "eastern building" was built using two antiseismic techniques: duvar-kushak and opus mixtum. Moreover, it is the duvar-kushak that was used to reinforce the arch that was damaged by seismic deformation (Fig. 4, *c*). Both these methods are systems with increased damping (Lipatov, 2006, p. 18). The most striking example of the use of these systems in a seismically active region can be observed in the Theodosian Walls or the Theotokos Pammacaristos Church—the Fethiye Cami Mosque, Istanbul. Despite having undergone numerous strong and devastating earthquakes (Khapaev, 2008, p. 97) there constructions have been fairly well preserved. The seismic stability assessment of the structures that were built using simultaneously the duvar-kushak and opus mixtum techniques indicates that the "eastern building" can be attributed to type B of the structures on MSK-64 scale and that the seismic intensity estimate for this building is higher, I_I = VII–VIII (MSK-64). The epicentral zone of the earthquake was located in the West Crimean seismogenic zone (or the Tarkhankut zone if seismic vibrations propagated somewhat obliquely to the strike of the walls) (Fig. 11, *a*).

The dating of the damage of the "eastern building" is directly related to its historical and architectural interpretation. According to the plan of the Hansaray complex compiled by J. Trombaro in 1798, there were the following objects in the place of the eastern building: "A big clothes-rinsing basin" and "Animal water fountain" (Figs. 2, *a*, 2, *b*). Captain K.V. Manshtein calls it "A stone building where a wide stone basin is constructed" (Manshtein, 1875, p. 352). O.Gaivoronskii in the popular science notes refers to this object as a water reservoir of the Khan's time (Gaivoronskii, 2015). However, in the final printed version of his work on Hansarai, the author does not mention this monument (Gaivoronskii, 2016, p. 184–187). In the Soviet times and during the Khan's period, the object was used as a water reservoir. In the photo of the "eastern building" taken before 2013, no seismogenic deformations are visible: they are hidden by the cladding of the well-processed stone blocks.

The use of the duvar-kushak technique is not very adequate to the hydraulic engineering purpose of the building. Wood exposed to humidity suffers strong damage causing an unnecessary danger to a building. The use of the duvar-kushak technologies combined with the extremely unique and rare opus mixtum technique points to the special significance of the object and importance of its durability and prestige. To date, only one object can be considered a geographically close historical, cultural and chronological analogy for the opus mixtum of the eastern building. This is the Zincirli Madrasah[3] (1500 A.D.) which was part of the palace complex in Salachik (Korzhenkov et al., 2016, p. 33). Seismic deformation in the walls of the building appeared before the madrasah was converted from a certain socially important facility into a water storage reservoir. This took place in 1736 at latest—the time when K.V. Manshtein saw this object in the form of a water reservoir. This suggests that the construction time of the "eastern building" can be highly accurately dated to the earliest construction period of Khansarai—the epoch of Sahib Giray (1532–1551) and Devlet Giray (1551–1577) khans (Ibragimova, 2016, p. 252) or by the 16th century overall. For example, it was Sahib Giray who began constructing Bakhchysarai (the Palace in the Gardens) but at the same time continued work on constructing the state-important buildings in the palace complex in Salachik (High Palace of Justice (Chelebi, 2008, p. 87)). It is the Salachik complex that accommodates the Zincirli Madrasah built by Mengli Giray—the predecessor of Khan Sahib Giray. Thus, it

[1] Duvar-kushak (Crimean Tatar) literally means belted wall. Duvar-kushak is a wall construction technology with laying wooden compensating beams inside the wall in order to increase earthquake resistance of building structures.

[2] Opus mixtum (Latin) literally means mixed work. Opus mixtum is a walling technology using a mortar of brick powder or ceramic chip (Crimean Tatar khorasan) with wall segments built of three-layer emplecton masonry alternating with rows of plinth (bricks).

[3] The Zyndzhirli Madrasah is constructed with a belt of one row of plinth bricks in the eastern, northern, and western walls of its courtyard, which is of course an example of the opus mixtum technique albeit in its reduced form.

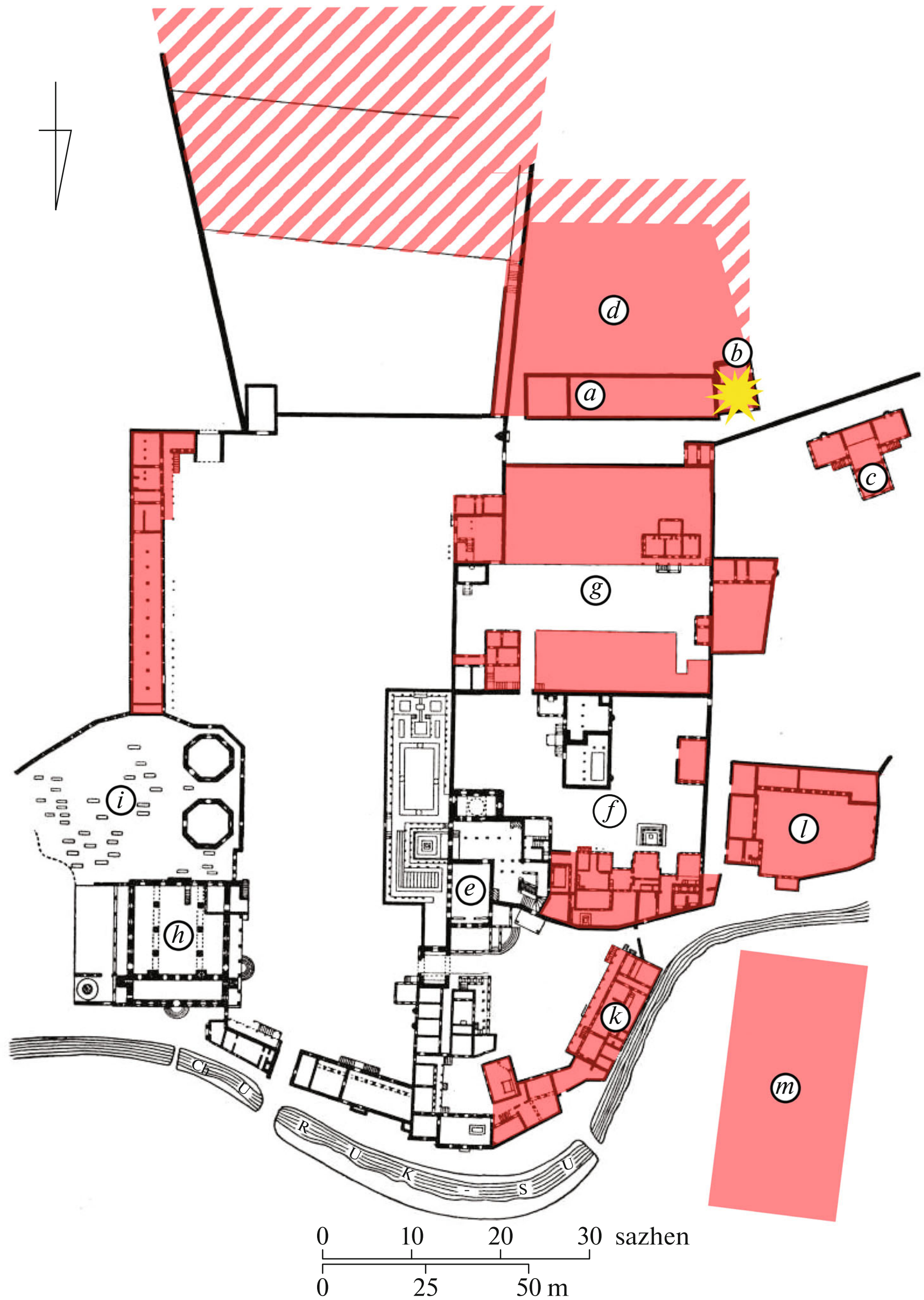

Fig. 2. Plan of Hansaray, late 18th century, according to A.L. Yakobson (Yakobson, 1964, p. 145, Fig. 47). Object designations and names according to plan of G. Trombara (Ibragimova, 2016, p. 27, Fig. 9), archaeological studies by A.I. Ibragimova (Ibragimova, 2016, pp. 197–218) and our analysis of historical site planigraphy: (*a*) "Big clothes-rinsing basin" (according to Trombara (Ibragimova, 2016, p. 27, Fig. 9)); (*b*) "Animal water fountain" or "eastern building" (according to Trombara (Ibragimova, 2016, p. 27, Fig. 9)); (*c*) Winter Palace ("Sahib Giray pavilion" according to O. Gaivoronskii (2016, pp. 185–187)); (*d*) ruins of presumed Sahib Giray's Divan building; (*e*) Islam Giray's Divan Hall and adjacent structures of Hansaray Main Building; (*f*) Harem courtyard; (*g*) Persian courtyard with ruins of "Persian Palace", baths, and Palace of Sultans; (*h*) Biyuk Khan-Jami (Big Khan Mosque); (*i*) Khan's cemetery with two durbe: Devlet I Giray and Islam III Giray; (*k*) Ambassador building; (*l*) bakery (khan's baths?); (*m*) Mehmed Giray's baths. Yellow asterisk marks eastern building. Nonextant buildings are indicated by red filling. Presumed nonextant buildings of Hansaray are shaded in red.

is the epoch of Khan Sahib Giray and its historical landscape that have the examples of the use of opus mixtum construction technique and can suggest the indirect age reference for the eastern building.

The building system of the Hansaray which was formed in the 16th–17th centuries degraded exactly during the repair and restoration work in the 1740s after the pogrom by Field Marshal Minnich. Archaeo-

Fig. 3. Hansaray. Eastern structure of presumed Sahib Giray Divan Hall (northern wall) before loss of cladding of well-processed stone (after (Gaivoronskii, 2015)). Black shading on white background shows sub-rectangular entrance to building on northern face of structure. Concrete ceiling slabs are indicated by white lines.

logical studies in the territory of Khansarai have shown that some buildings destroyed in 1736 have not been restored (Ibragimova, 2016, pp. 200–202). The fact that flower beds were laid out on their site indicates that these building were restructured for a different function. However, due to the detection of seismic deformations, the traces of yet another large-scale repair and restoration carried out between 1666 and 1736 were revealed in the eastern building.

What a kind of a purpose could this building have had? In the opinion of Gaivoronskii, adjacent to the "eastern building" had been the core of the formation of Khansarai at the Sahib Giray time (Gaivoronskii, 2016, pp. 184–187). E. Chelebi places the Eski-Keryunyush-Kapu gate (the Gate of the ancient Divan Hall) in this area. Moreover, Chelebi notes three Divan halls: the Sahib Giray's, Bahadir Giray's,[4] and Islam Giray's ones (Chelebi, 2008, p. 95–96).

The "eastern building" is part of the "Big clothes-rinsing basin" and "Animal water basin" according to Trombara and is part of a lengthy structure erected using the opus mixtum technique with plinth-brick arches above the passage(s?) in the northern face. Close to this architectural complex there is the southern wall of the fence surrounding the Persian yard, which is built using the duvar-kushak technique. This means that the wall was at some time part of a certain structure (Moisieiev, 2020, pp. 329–330). This fact, the size of the "Big clothes-rinsing basin" and "Animal water fountain" complex according to Trombara, the analogy of the construction technique to the buildings of the first palace of the Crimean khans in Salachik, and the closeness of the "old" Winter Palace and the Eski-Keryunush-Kapu Gate strongly suggest that the "eastern building" is part of the Sahib Giray's Divan Hall. This means that its destruction should be attributed to the time interval between 1666 (when seen by Chelebi and 1736 (when K.V. Manstein saw the consequences of its repair and restructuring).

ANALOGIES

Unfortunately, we lack information for more accurately dating the described earthquake. If its epicentral zone was located in the West Crimean seismogenic zone, then what we are dealing with is probably the consequences of the Salachik earthquake of April 30, 1698 (Korzhenkov et al., 2016, p. 44). However, the but one seismogenic deformation in the building is not conclusive for locating the epicentral zone of the event. Moreover, based on the existing data, we cannot state that this earthquake was a single event. If the "eastern building" was damaged in 1698, then the

[4] The extant Divan Hall.

Fig. 4. Hansaray. Eastern structure of presumed Sahib Giray Divan Hall (northern wall). Seismic deformation of plinth-brick arch with a strike 88°: (*a*) loss of upper central part of plinth-brick arch; (*b*) plinth arch repair with rubble stone; (*c*) signs of laying antiseismic compensation bar, duvar-kushak technology; (*d*) modification of "eastern building" in Soviet period (concrete armored belt).

Fig. 5. Hansaray. East building, western wall, inside view: (*a*) concrete floor slabs; (*b*) opus mixtum masonry technique.

strongest seismic vibrations should propagate from the southwest. The strike of the damaged arch generally does not rule out this scenario: the maximum seismic vibrations could propagate somewhat obliquely to the strike of the structure, i.e. from the southwest.

In order to more accurately delineate the epicentral zone of this seismic catastrophe and to test the hypothesis that the building was damaged by the Salachik earthquake of 1698, we surveyed the entire Hansaray. It was logical to assume that the ground shaking from the earthquake had affected the Khansarai in a systematic manner so that the synchronous damage of other parts of this complex could help dating the discussed event.

A similar set of deformations was revealed in the palace complex of Bakhchysarai. However, proving the seismic origin of these deformations is challenging because all structures of the complex have been slowly sliding down the slope toward the nearby river. This sliding is evident from the significant tilt of the walls in many buildings of the palace complex and from a saber-like bending of the trees. Besides, the buildings are constantly undergoing repairs and restorations. This is perhaps the central factor which should be taken into account in the archaeoseismological study of the Hansaray.

The repairs and restorations conceal significant seismogenic deformations of monuments thus creating difficulties in their detection. The situation is aggravated by the gravity-driven sliding of the architectural complex towards the floodplain of the Churuk-Su River. In order to overcome these difficulties, we thoroughly inspected the archival photographs and images of the 19th–20th centuries in order to find the elements of the Hansaray complex. This search yielded unexpected results which were used for more accurate dating of seismogenic damages in the "eastern building" of the supposed Sahib Giray's Divan Hall.

The spectacular example of how restorations and repairs of buildings obliterate traces of deformations is the Dilara Bikech durbe (Fig. 6). The durbe was built in 1763–1764 (Ibragimova, 2016, p. 175) but its condition at the beginning of the twentieth century called for repair and restoration work. In the photo taken in 1914 during the restoration, it can be clearly seen that the stone blocks move, are squeezed out, and experience rotations on the faces with the strikes 37° and 79°. The deformations in the building increase as the wall is raised. At present, the described damages in the facade of the durbe are absent (Fig. 6, panel 1). As of now, it is unclear what caused these deformations. Tracing their origin requires additional archival, historical, and archaeological studies. However, it is beyond question that the repair and restoration work can completely obliterate deformations in the walls of the Khansarai structures and other objects of the New Age in Crimea.

Eski-Durbe in the Old Town of Bakhchysarai

Given the latter, the main focus in our search for the analogies was placed on the analysis of archival photos, lithographs, and engravings. Previously, our team developed several methods and approaches for "archival" archaeoseismological studies (Moisieiev et al., 2018a), and these methods were efficiently used in this work. The most impressive results were obtained for Eski-Durbe (Old mausoleum). The durbe is located in the immediate vicinity of Khansarai (Fig. 1, *c*). In plan, it is a square with an inscribed octahedron which holds a dome. In the south, the durbe has a two-level courtyard fence attached to it. The lower part of the fence is a crenel wall and the upper part is a gallery. The fence was constructed later than the entire durbe overall (Naumenko et al., 2016, p. 236). The sagging of the keystone of the doorway arch in the durbe's southern wall with a strike of 95° (Fig. 7, *c*) is the most striking seismic deformation. The sagging is clearly visible in the photo of 1931 (Fig. 7, *c*) which captured the repair and restoration work made in 1927–1928. The systematic spalls of the crown blocks (Fig. 7, panel *a*2) and the closest blocks (Fig. 7, panel *a*1) in the gallery arches is another significant deformation. These deformations are clearly visible in the photos of 1928 (Fig. 7, panel *a*2) and 1931 (Fig. 7, panel *a*1): the latest restorations eliminated this seismic deformation and today it is unnoticeable. These spalls could be formed during a short interval when seismic vibrations passing through the arches caused their opening with insignificant northward displacement along the N–S axis.

The clockwise rotation of the blocks along horizontal axis in the western column (Fig. 7, panel *d*1) and the counterclockwise rotation of the blocks in the eastern column (Fig. 7, panel *d*2)/masonry of the eastern corner of the courtyard southern gallery (Fig. 7, panel *d*3) is yet another pictorial evidence of damage of the durbe building in an earthquake. This seismic deformation could appear as a result of short-term opening of the arches and tilting of the inter-arch columns towards the epicentral zone of the earthquake. The presence of opposite tilts (westward (Fig. 7, *d*1–*d*3) and eastward (Fig. 7, *d*1) suggests that they could probably be associated with two earthquakes. One earthquake (let us call it event 1[5]) also caused damage in the arch of the durbe's southern wall (Fig. 7, *c*) and in the arches of the courtyard gallery (Fig. 7, *a*2). The second earthquake (event 2) caused westward tilting of the blocks in the western column.

Next, damage in Eski-Durbe was tracked in the southern (Fig. 7, *b*) and eastern (Fig. 7, *e*) crenel walls of the courtyard. The better preservation of the walls of

[5] For simpler systematization of the earthquakes that caused seismic deformations in the walls of the buildings, here we conditionally refer to them as event 1, event 2, etc. Each individual monument has its own event 1 or event 2. These terms are only used in the context of the specific currently discussed object.

Fig. 6. Dilary Bikech durbe of Hansaray complex. Face striking 79°. Photo: 1, monument restoration, 1914 (clearly visible are movements of stone blocks in durbe cladding above arches of laid windows, enhanced by skyscraper effect towards building's dome); 2, present state.

one orientation may indicate that the strongest seismic vibrations were directed along the strike of walls. On the other hand, the breach in the eastern crenel wall of the courtyard fence could be formed when the strongest seismic vibrations approached the building along the bisectrix between the walls (Korzhenkov and Mazor, 1999, pp. 72–73, Fig. 23, *b*). That is, the epicentral zone of the event could be located in both the West Crimean (Fig. 11, *c*1) and the South Crimean (North Crimean?) seismogenic zones (Fig. 11, *c*2). Thus, as of now, we cannot definitely attribute the seismic deformation of the eastern crenel wall of the courtyard to event 1 or to event 2. Based on the engraving of 1838 by O. Raffe, we can confirm that these deformations are ancient, i.e., they were formed before 1783 (Korzhenkov et al., 2016, p. 32, Fig. 1).

The analysis of the seismogenic deformations of Eski-Durbe has shown an interesting situation: within less than 150 years, Bakhchysarai felt three earthquakes (events 1–3) and two of them (events 1 and 3) had a catastrophic effect. The earthquake that damaged the arches in the southern wall of the mausoleum and in the southern gallery of its courtyard, caused horizontal counterclockwise rotation of the blocks in the inter-arch pillars and in the masonry of the eastern corner of the courtyard southern gallery, and, probably, breached the eastern crenel wall in the Durbe courtyard (event 1) was most devastating. These deformations could be produced by the earthquake with intensity I_l = VII–VIII (MSK-64) with the epicentral region west of the monument (Fig. 11, *b*).

Event 2 caused clockwise rotation of the blocks in the western inter-arch column and probably broke the eastern crenel wall in the durbe courtyard. The epicentral zone of this event should have been located in the North Crimean or South Crimean seismogenic zones (Fig. 11, *c*2) and had the intensity I_l = VI–VII points (MSK-64).

Dating the event 3 which damaged the crenel of the southern fence of the Eski-Durbe courtyard (Fig. 7, *b*) is far more difficult. Undoubtedly, this earthquake occurred in the South Crimean seismogenic zone (Fig. 11, *d*). The probable time interval of this event is from the middle of the seventeenth century to 1783. As of now, one seismic catastrophe that could cause this damage is known—the Ai-Triada earthquake of 1776–1777 (Moisieiev et al., 2018a, p. 74). However, this hypothesis needs a more profound substantiation.

Great Kenassa of the Chufut-Kale Fortress

Our study of seismic deformations for finding a relevant set of analogies to the damages of the "eastern building" of the Hansaray included yet another monument, the Great Kenassa of the Chufut-Kale fortress. In the walls of this object, we revealed numerous seismic deformations which are detailed below.

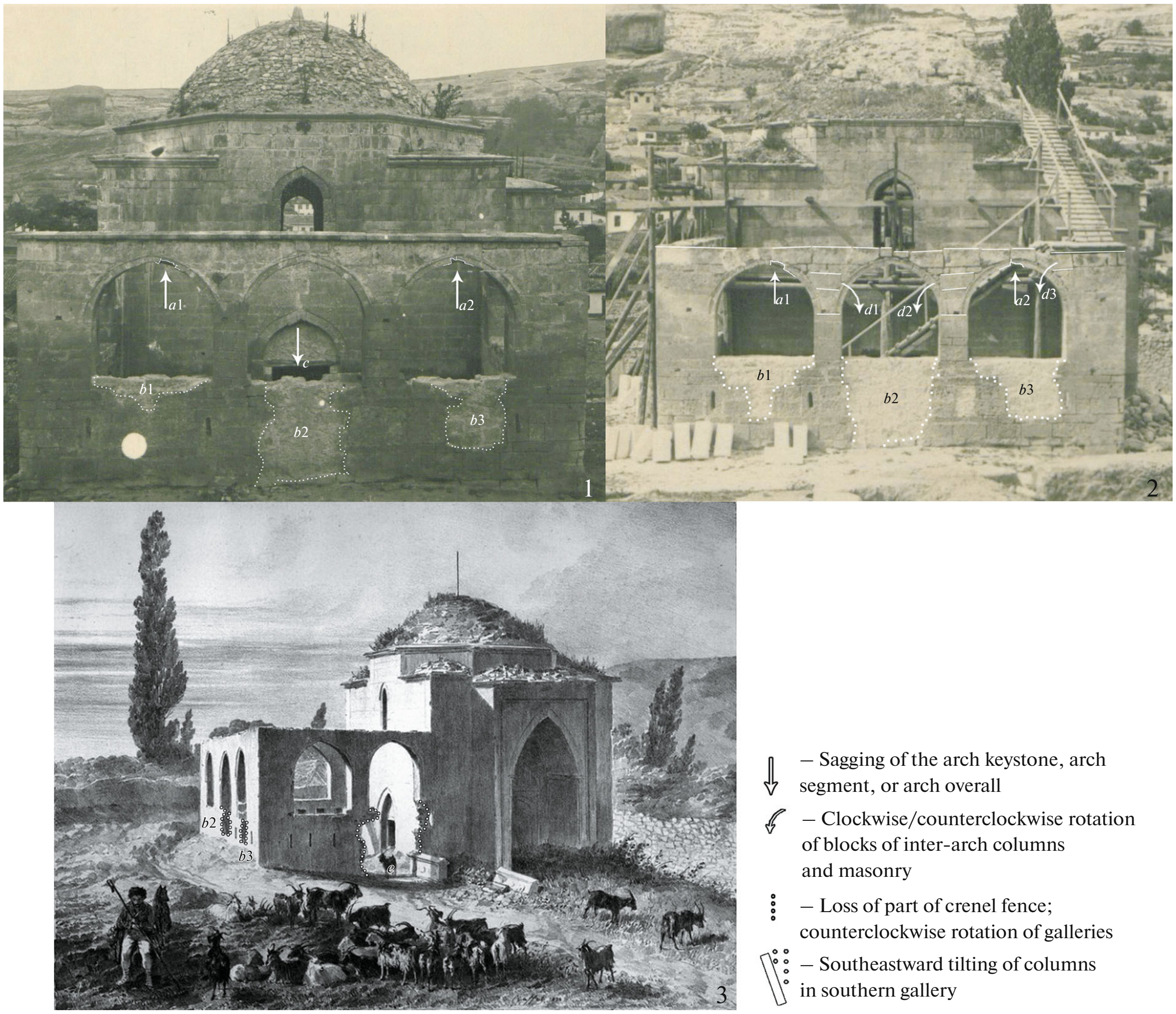

Fig. 7. Eski-Durbe in Old town of Bakhchysarai. 1, Photo of 1931, Durbe after restoration work of 1928; 2, photo of 1928, Durbe during restoration work in 1928; 3, engraving by O. Raffet, 1838: (*a*) break-off of crown blocks and closest blocks; (*b*) loss of part of crenel fence with strike 96°; (*c*) sagging of crown stone of arch with strike 95°; (*d*) clockwise (1) and counterclockwise (2), (3) rotation of blocks of inter-arch columns and masonry in eastern corner of courtyard southern gallery; (*e*) loss of northern part of fence with loopholes striking 3°.

After having undergone the impact from the seismic shock wave, the arch of the southwestern gallery failed to regain its original state and a small ledge was formed. Subsequently, attempts were made to plaster the ledge up to hide it (Fig. 9, 2). Besides, the columns in the gallery have a slight northeastward tilt which is not likely to be mostly due to their sloping towards the epicenter of the earthquake but, rather, due to the pressure exerted on their bases after the counterclockwise rotational displacements of the columns and fence slabs in the northwestern gallery which is described below. The sagging of the arch keystone could have been caused by an earthquake with intensity of at least I_l = VII points (MSK-64) and epicentral area in the South Crimean seismogenic zone (event 1, Fig. 11, *f*).

Next, the deformations are observed in the northwestern gallery. Here, an earthquake formed an ensemble of cracks in the stone slabs of the fence (Fig. 8, *c1*–*c3*; Fig. 9, 3), bases (Fig. 8, *e*; Fig. 9, *3*) and capitals of the columns (Fig. 8, *e1*; Fig. 10, *c*) (event 2). The cracks resulted from the counterclockwise rotation of individual elements of the gallery. Besides, the threshold stone of the entrance to the northeastern gallery was cracked (Fig. 8, *d*). These damages could have been formed under strong seismic vibrations directed along or slightly obliquely to the strike of the damaged elements. The gallery fence slab immediately right of the entrance and the base of the second right column are rotated counterclockwise by 5° (Fig. 10, *a1*) and 4° (Fig. 10, *a2*), respectively. This indicates that the most intense seismic vibrations propagated from the west at a certain angle to the strike of the colon-

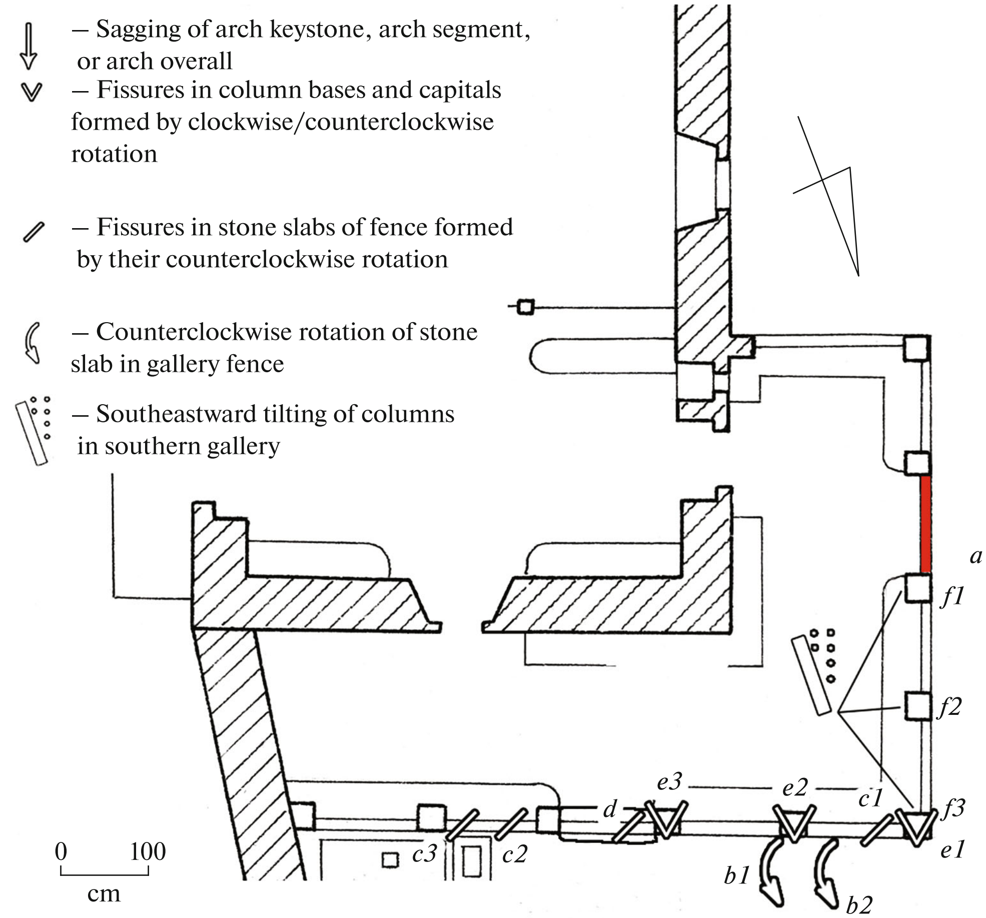

Fig. 8. Chufut-Kale Fortress. Big Kenassa. Plan of northeastern part of building with gallery: *a*, sagging of arch in southwestern gallery striking 20°; *b1*, counterclockwise rotation of column base by 4° in gallery; *b2*, counterclockwise rotation of stone slab by 5° in gallery fence; *c*, fissures formed in stone slabs of fence due to their counterclockwise rotation; *d*, fissure in sill stone at entrance to northeastern gallery; *e1*, fissures formed in column base and cap by counterclockwise rotation; *e2*, *e3*, fissures formed in column base by counterclockwise rotation; *f*, southeastward tilt of columns in southern gallery.

nade (Fig. 11, *e1–e2*). This also explains the throughgoing fissures in the fence slabs (Fig. 8, *c*; Fig. 9, 3). The difference is that in contrast to the intact slabs, the damaged ones were rotated counterclockwise only after the crack formation (it is clearly seen in the photo (Fig. 10, *a3*) that the slab sharply changes its strike after the appearance of the crack). A similar deformation was revealed in the capital of the corner column of the gallery (Fig. 10, *c*). Here, the counterclockwise rotation of the column around its axis resulted in the cracking of the capital itself and in a certain detachment of its southern corner. These deformations could have been produced by an earthquake (event 2) with intensity I_l = VII–VIII (MSK-64) with the epicentral area west of the monument (Fig. 11, *e1–e2*).

Thus, the walls of Great Kenassa on Chufut-Kale have two sets of seismic deformations left by two earthquakes originated in the different seismic zones. Their chronology is unclear since the archaeological and historical constraints only allow these events to be dated to a fairly wide period between the 14th century and 1783 (Gertsen and Mogarichev, 1993, p. 96; Korzhenkov et al., 2016, p. 32, Fig. 1).

Palace Complex in Salachik

Concluding our review of the possible analogies, we consider the palace complex of the first Crimean khans in Salachik—a monument that has already become an object of archaeoseismological research (Korzhenkov et al., 2016). Among the reliably and accurately dated seismic deformations in Zincirli Madrasah, we note the damage (sagging) of the plinth-brick arch of the courtyard gallery with a strike of 95°, the westward tilt of the column (with its subsequent repair) in the courtyard gallery, the counterclockwise rotation by 3° of a part of the madrasah southern wall with a strike of 65° and cracking of the gallery columns in the inner courtyard of the madrasah (Korzhenkov et al., 2016, pp. 35–36, 38–39, 41, 43, Figs. 3, 6, 7, *a*, 11, *a*). Seismic deformations in the

Fig. 9. Chufut-Kale Fortress. Big Kenassa: 1, southwestern gallery with strike 95°; 2, same, close-up view; 3, view of northeastern gallery (red filling shows fissures formed in column bases and fence stone slabs by their counterclockwise rotation): *a*, columns with stalactite echini on capitals; *b*, columns with echinus in form of round pillows and octagonal necks; *c*1, counterclockwise rotation of column base by 4° in gallery; *c*2, counterclockwise rotation of stone slab in gallery fence by 5°.

Haci Giray durbe manifest themselves in the form of the westward tilt of the durbe western face at an angle of 83° (Korzhenkov et al., 2016, pp. 35–36, Fig. 4). These deformations were formed during two earthquakes—the Salachik earthquake of 1698 (Fig. 11, *h*) whose traces are predominant and the Yalta earthquake of 1927 (Korzhenkov et al., 2016, p. 44). As of the date of publication of the monument, our estimate of the intensity of the Salachik (1698) earthquake was I_I = VIII–IX (MSK-64) (Korzhenkov et al., 2016, p. 44).

Dating the described seismic deformations in the local conditions of Bakhchysarai is extremely challenging. As noted above, the central factor impeding

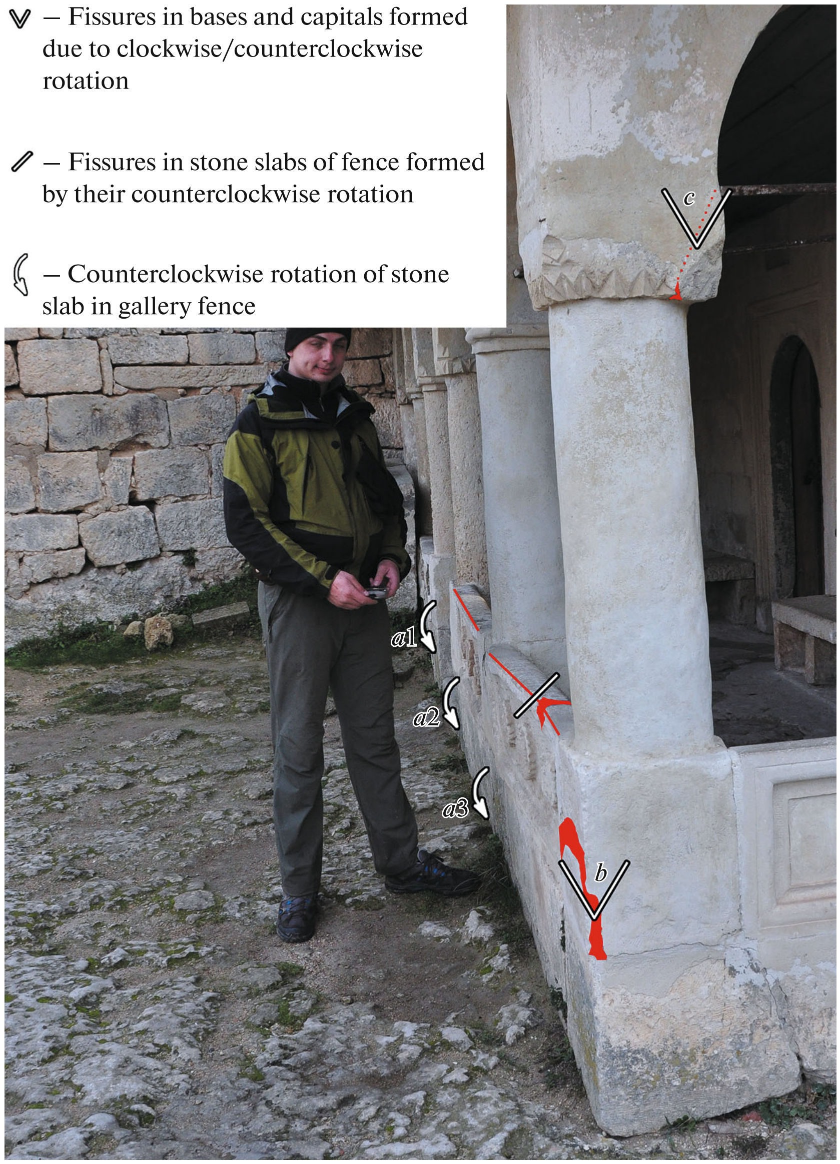

Fig. 10. Chufut-Kale Fortress. Big Kenassa. View of northeastern gallery: (*a*) columns with stalactite echini on capitals; (*b*) columns with round pillow echini with octagonal neck. Red filling shows fissures in column bases and fence stone slabs formed by their counterclockwise rotation.

the effective solution is the constant repair and restoration work at the archaeological objects which obliterates seismic deformations. The Dilara Bikech durbe is a striking example. In other words, Bakhchysarai with its vicinity is a living urban organism. Its historical and cultural landscape is carefully protected and preserved as an object bearing the marks of universal cultural value. The almost complete, with rare exception, absence of the archaeological studies and their published results for the territory of both the palace complex itself and the Old town and its outskirts is another factor complicating the dating of seismogenic deformations.

Therefore, the only possible solution for dating the earthquake that damaged the “eastern building” of the presumed Sahib Giray’s Divan Hall is to expand as much as possible the set of the discussed analogies in order to obtain the most relevant results. The set of the analogies considered in or study included the following monuments Eski-Durbe (a burial complex in the immediate vicinity of the Hansaray), the Great Kenassa of the Chufut-Kale fortress (the nearest outskirts of Bakhchysarai), and the palace complex in Salachik. The revealed seismic deformations grouped by the monuments and seismogenic zones accommodating the causal earthquakes are presented in Table 1.

Table 1. Revealed seismic deformations, their parameters and chronology

	Seismic deformations in monument walls in seismogenic zones	
	West Crimean	South Crimean
Eastern building of presumed Sahib Giray's Divan Hall	Plinth arch with a strike of 88°, I_l = VIII–IX (MSK-64)	
Eski-Durbe	Arch in the durbe's southern wall with a strike of 95°, I_l = VII–VIII (MSK-64)	(Southern) crenel wall of courtyard fence with a strike of 94°, I_l = VII–VIII (MSK-64)
	Arch in the courtyard gallery with a strike of 94°, I_l = VII–VIII (MSK-64)	
	Loss of part of (eastern) crenel wall of courtyard fence, strike 4°, I_l = VI–VII (MSK-64)	
Great Kenassa of Chufut-Kale Fortress	Rotations of fence slabs, column bases and capitals in northwestern gallery striking 110°, fissures in these elements, I_l = VII–VIII (MSK-64)	Southwestern gallery with a strike of 20°, $I_l \leq$ VII (MSK-64)
Zincirli Madrasah	Courtyard arch striking 95°, I_l = VIII–IX (MSK-64) (Korzhenkov et al., 2016, pp. 35, 38, 44, Fig. 6), earthquake of 1698	Cracking of columns in madrasah courtyard gallery, I_l = VI–VII (MSK-64), earthquake of 1927 (Korzhenkov et al., 2016, pp. 35–36, Fig. 3)
	Westward tilt of columns in courtyard gallery, I_l = VIII–IX (MSK-64) (Korzhenkov et al., 2016, pp. 35–36, 39, 44, Fig. 7, *a*), earthquake of April 30, 1698	
	Counterclockwise rotation by 3° of part of madrasah's southern wall with a strike of 65°, I_l = VIII–IX (MSK-64) (Korzhenkov et al., 2016, pp. 41, 43–44, Fig. 11, *a*), earthquake of April 30, 1698	
Haci-Giray Durbe	Westward tilt of the durbe's western face at an angle of 83°, I_l = VIII–IX (MSK-64) (Korzhenkov et al., 2016, pp. 35–36, 44, Fig. 4), earthquake of April 30, 1698	–

DISCUSSION

The azimuthal directions of the strongest ground motions reconstructed from the kinematic indicators suggest that the source of the earthquake that damaged the structures of the Hansaray in Bakhchysarai and the Great Kenassa in Chufut-Kale was located west of the Crimean peninsula. In this region, the West Crimean source (seismogenic) zone[6] was identified, skirting the western coast of Crimea and capable of generating earthquakes with $M \geq 6.5$ (Shebalin, 1972; Nikonov, 1994). Geologically, this zone corresponds to a poorly studied large strike-slip fault (*Stroenie* ..., 1992; Nakapelyukh et al., 2018). The intensity of the earthquake was I_l = VII–VIII (MSK-64). To date, besides Salachik, Bakhchysarai and Chufut-Kale, the traces of this seismic event have also been revealed in the Chorgun tower (Table 2) (Moisieiev et al., 2019, pp. 42–46) (Fig. 11, *g*). The previous intensity estimate of the earthquake based on the data for the Salachik palace needs to be revised and, given the new data, should be reduced by one point. The relative dating based on the archaeological and written sources constrains this event to between 1666 and the 1740s. According to the MSK-64 scale, a seismic event of such intensity should have had a severe effect on Bakhchysarai. Urban residential constructions should have been damaged significantly. At least half of the buildings should have had received large through deep cracks in their walls, and breaches should have had appeared in the constructions (Medvedev et al., 1965). Accordingly, almost all facilities coeval with the "eastern building" of the Hansaray should have been damaged. Table 1 shows that all monuments used in the comparison have seismogenic deformations from the events that originated in the West Crimean seismogenic zone.

[6] In this paper, as the main working hypothesis we assume that the epicentral area of the Salachik earthquake was located in the Western Crimean seismic zone. At the same time, is it is not excluded that the earthquake could have originated in the Tarkhankut seismic zone, which is the alternative hypothesis. The ultimate choice requires new data.

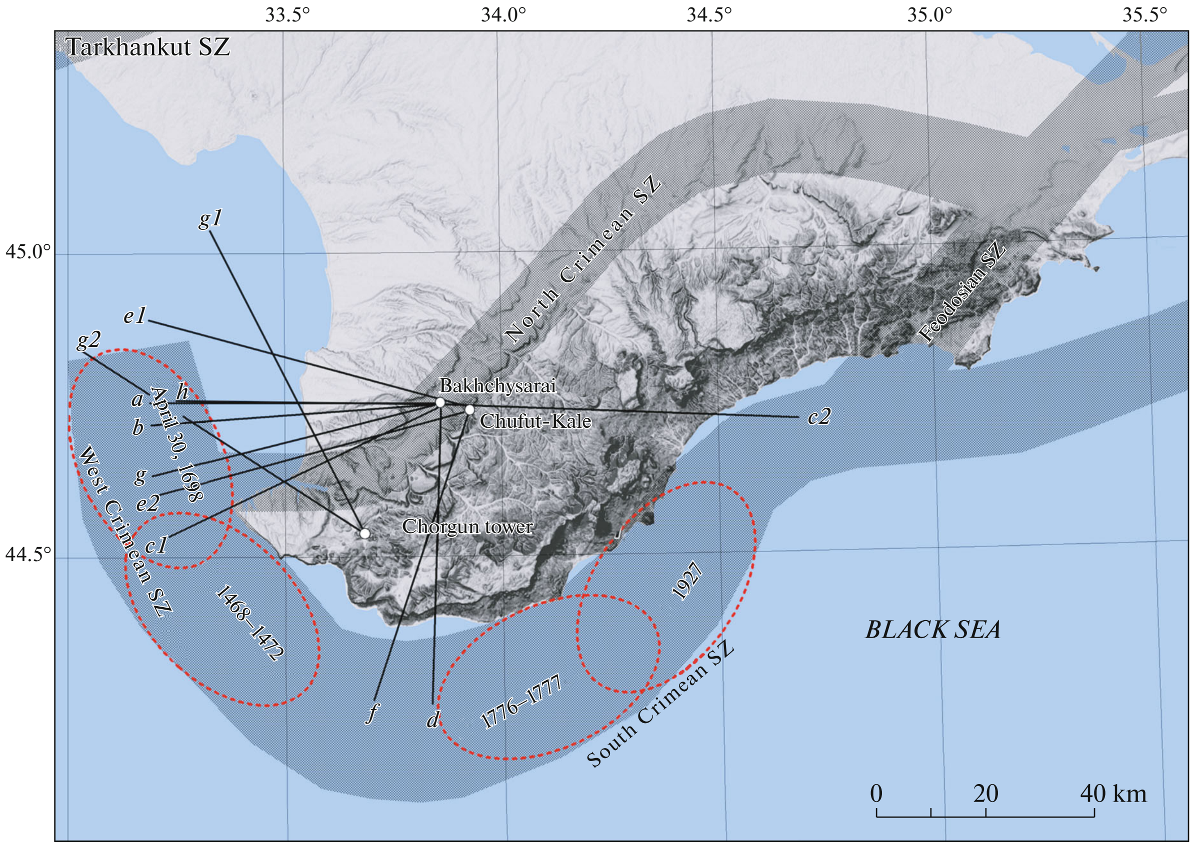

Fig. 11. Seismogenic zones (gray) of Mountainous Crimea according to instrumental, archaeoseismological, and paleoseismological data. Red lines show probable source zones of discussed historical earthquakes and Yalta earthquakes of 1927 (source zone dimensions of Yalta earthquake are shown conventionally, by analogy with Yalta earthquake zone, based on instrumental data for historical earthquakes). Black lines show reconstructions of seismic shock propagation axis (damaged objects): (*a*) Khansarai eastern structure; (*b*) Bakhchysarai Old town, Eski-Durbe, event 1; (*c1*) Bakhchysarai Old town, Eski-Durbe, probable event 1; (*c2*) Bakhchysarai Old town, Eski-Durbe, event 2; (*d*) Bakhchysarai Old town, Eski-Durbe, event 3; (*e1*, *e2*) Chufut-Kale, Big Kenassa, event 2; (*f*) Chufut-Kale, Big Kenassa, event 1; (*g*) Chorgun tower (event 2 according to (Moisieiev et al., 2019, pp. 45–46)); (*h*) Salachik, Zincirli Madrasah. SZ stands for seismogenic zone.

The damage of Eski-Durbe (event 1) was caused by the activation of the West Crimean seismogenic zone between the middle of the 17th century and 1783. Seismic deformations in Great Kenassa (event 2) were formed within wide chronological limits between the 14th century and 1783. The fact that the object had time to have had outlived the complete overhaul of the gallery suggests that this event perhaps occurred much later than the construction of the object (14th century (Gertsen and Mogarichev, 1993, p. 96)). The causes of the repair are unclear. The architectural volume of the gallery is enclosed between columns pertaining to two types: (1) the columns with stalactite echini on the capitals (Fig. 9, *a*) and (2) with an echinus in the form of a round pillow with octagonal neck (Fig. 9, *b*). It is reasonable to hypothesize that the columns pertaining to type I are original: increasingly more columns of this type have been found in the architectural context of the monuments (Miras ..., pp. 424–425, 441, 443, 470, Figs. 349, 365, 370, 394, 1; Sapunova, 2000, p. 43–44, 47). Both the first and second type of columns is damaged by the earthquakes that originated in the West Crimean (event 2) and South Crimean (event 1) seismogenic zones (Fig. 8, *a*, *e*, *f*; Fig. 9, *c*1; Fig. 10; Table 1). The buildings of the palace complex in Salachik have the most accurate chronology constrained by the seismic deformations from the April 30, 1698 earthquake[7] (Korzhenkov et al., 2016, p. 44). The plinth-brick arch with a seismic deformation in the

[7] The earthquake whose traces were first described in the monuments of the palace complex in Salachik and which was correspondingly named a Salachik earthquake was dated based on the record in the Kadiasker books of the Mangup kadylyk. We note the extremely high relevance of the historical information contained in the corpus of this type of sources. The books present dry and impersonal bureaucratic registries of court decisions, and that is why the information contained in them is so important and exclusive from the historical standpoint. Unfortunately, these artifacts had long been beyond the focus of the specialists and only recently have they come to be fully involved in the relevant research (Rustemov, 2017, pp. 4, 10–12, 15–17). This explains why this event was not addressed in the special literature on the subject (Khapaev, 2008, p. 89–95).

Table 2. Composite chronology of the traces of seismic events in the archaeological sites of southwestern Crimea known in the archaeoseismological literature

Archaeological site	Earthquake chronology and seismogenic zone	Damage type	Intensity estimate (MSK)	Data source
Palace complex in Salachik (Zincirli Madrasah, Haci Giray durbe, Mengli Giray mosque, town baths)	Salachik earthquake of April 30, 1698, West Crimean zone	Through-going fissures including those breaking through four building blocks in a row, significant tilt of a part of the wall against the terrain slope, counterclockwise rotation of part of wall masonry, deformations and collapses of arched structures, significant tilt of the column	VIII–IX	(Korzhenkov et al., 2016, pp. 35, 41, 44)
	Yalta earthquake June 26/September 11, 1927, South Crimean zone	Interblock fissures in gallery columns	N/A	(Korzhenkov et al., 2016, p. 41, 44)
Ai-Triada church	Ai-Triada earthquake of 1776–1777, South Crimean zone	Sagging of a significant part of the arched structure or the keystone, regular oriented tilting of columns, movements of blocks in the eastern wall, interblock cracks enhanced by skyscraper effect	VIII–IX	(Moisieiev et al., 2018a, pp. 73–74)
Mangup (Big Basilica, palace of 1425, castle-donjon, Cape Teshkli-Burun, fortification wall in the Gamam-Dere gully, Synagogue-Kenassa	Ilka earthquake of 1462–1475, South Crimean zone	Fissure in the threshold stone, detachment of the northwest corner of the building with clockwise rotation, rotations of central parts of western and eastern walls, significant eastward displacement of foundation (room H of the palace of 1425)	N/A	(Moisieiev et al., 2019, pp. 46–48)
	Earthquakes not defined, at least four events, chronology not defined, South Crimean zone	Sagging of the arch keystone, through-going fissures penetrating several blocks in a row, counterclockwise rotation of part of wall masonry, crack in window sill and window ceiling slab, splitting-off and knocking-out of the fragment of the meridional wall toward the east	VIII–IX	(Korzhenkov et al., 2020, pp. 326—331)
Ilka tile production center	Ilka earthquake of 1462–1475, South Crimean zone	Deformation (sagging) of furnace arch of the oven, deformation (sagging) of the middle part of the oven northwestern wall	N/A	(Moisieiev et al., 2019, pp. 39–40, 48)
Suatkan tile production center	Earthquake at the beginning of the 11th century, South Crimean zone	Systematic tilting of all arches in the furnace channel of the oven, stretching the arches and tilting of furnace walls from the center out perpendicular to the strikes of the described structures, counterclockwise rotation of a part of masonry in furnace channel	VII–VIII	(Moisieiev et al., 2018b, pp. 102–103, 111)
Chorgun tower	Ilka earthquake of 1462–1475, South Crimean zone	Sagging keystone in the arch, fissure in the window sill and window ceiling slab, interblock fissure	N/A	(Moisieiev et al., 2019, pp. 45, 48)
	Salachik earthquake of April 30, 1698, West Crimean zone	Interblock fissure, crack penetrating two blocks in a row, fissure in the window sill and window ceiling slab, collapsing of entrance arch	N/A	(Moisieiev et al., 2019, pp. 45–46)
	Ai-Triada earthquake of 1776–1777 or/and Yalta earthquake of June 26/September 11, 1927, South Crimean zone	Sagging keystone in the arch, opening of the interblock fissure from the arch upwards, fissure in the window ceiling slab. Probable collapse of the entrance to the tower and loophole pre-damaged by the Salachik earthquake	N/A	(Moisieiev et al., 2019, pp. 45–46)
Funa fortress	Earthquake of 1423, North Crimean (Feodosian?) zone	Partial or complete falling of the northern curtain wall and northern tower towards the north	N/A	(Kirilko, 2005, p. 50; Moisieiev et al., 2019, p. 42; Myts, 2009, pp. 78, 80, 85–86)
	Earthquakes not defined, at least two events, chronology not defined, South Crimean and West Crimean (North Crimean?) zones	Damage (fall) of the inner shell of the northern tower repaired after the earthquake of 1423, separation of the northern corner of the fortress with counterclockwise rotation by 3°, local destruction of the northwestern corner of the fortress and the repair of the damage by the buttress	N/A	(Moisieiev et al., 2019, p. 42)
Chersonesos	Earthquakes not defined, at least three events, chronology not defined (the earliest event is antique, two events after the 10th century), South Crimean, West Crimean zones	Splitting-off and pushing-out of wall fragments along a number of adjacent shear cracks, clockwise and counterclockwise rotations of whole walls/wall fragments/individual stone blocks, fractures of walls, through-going fissures penetrating several construction blocks in a row, deformations of well mouths	VIII ≤ I_o ≤ IX	(Khapaev et al., 2019, pp. 123–124, 126–127)

courtyard of the Zincirli madrasah has a strike close to the arches of the "eastern building" and Eski-Durbe: 95°/88°/95° versus 94°, respectively. However, it is only the counterclockwise rotation of a part of the madrasah' southern wall by 3° (Korzhenkov et al., 2016, p. 43, Fig. 11, *a*) that makes it possible to locate the epicentral zone of the Salachik earthquake (Fig. 11, *f*).

Besides the successful attribution of the seismic deformations of the eastern building, our search for the analogies has also revealed the traces of at least two other earthquakes. Firstly, at the beginning of the 20th century, the walls of the Dilara Bikech durbe perhaps still contained visible traces of seismogenic damage. Undoubtedly, the study of this monument should be continued and the proposed hypothesis tested with the accumulation of the new archival data or the archaeological results. In the walls of the Big Kenassa, we also revealed seismogenic deformations related to the seismic catastrophe that occurred in the South Crimean seismogenic zone (Fig. 11, *f*). The intensity of the event was $I_l \leq$ VII (MSK-64). The chronology of this earthquake is currently a subject of scientific discussion. Apparently, the event predated the Salachik earthquake as suggested by the absence of traces of this earthquake in the Zincirli Madrasah monument where professional gentle restoration work preserving the traces of two earthquakes was carried out (Korzhenkov et al., 2016, p. 35). On the other hand, Zincirli Madrasah has undergone profound restoration-conversion after the 16th century (Moisieiev, 2016, p. 135) which could remove the seismogenic deformations from the discussed earthquake. Attribution of event 1 which damaged the Great Kenassa is a subject of the future work. However, even now can it be noted that the epicentral zone of this event was close to the epicentral region of the earthquake of 1462–1472 described based on the seismic deformations of the Ilka tile production center (Moisieiev et al., 2019, p. 48, 50, Fig. 16). This is consistent with the overall chronology of Great Kenassa and with the intensity of this earthquake I_l = VIII–IX (MSK-64) at Mangup—the northernmost site known to date (Moisieiev et al., 2019, pp. 46, 48).

The damage of the crenel wall (the breach) in the southern fence of Eski-Durbe during event 3 (for the given monument) also occurred during an earthquake whose epicentral area was located in the South Crimean seismogenic zone (Fig. 11, *d*). However, dating this event is as of now extremely challenging. Perhaps this damage was left by the Ai-Triada earthquake of 1776–1777 (Moisieiev et al., 2018a, p. 74).

CONCLUSIONS

The new evidence of medieval strong earthquakes in Crimea expands the reference data for up-to-date seismic hazard assessment of Crimea. Our studies suggest that the four surveyed monuments—the "eastern building" of the Hansaray in Bakhchysarai, Eski-Durbe in the Old town of Bakhchysarai, Zincirli Madrasah in Salachik, and Great Kenassa in Chufut-Kale—were damaged by a single event of 1698 with the epicenter in the West Crimean seismogenic zone. This follows from the coincidence of the strikes of the damaged arches and the close relative chronology of the event (except for Great Kenassa with its wide chronology). Thus, the presumed Sahib Giray Divan Hall and its constituent "eastern building" are most likely to have been damaged on April 30, 1698 by a large Salachik earthquake. The intensity of this earthquake was approximately I_l = VII–VIII (MSK-64); based on the more extensive data, it will be possible to estimate the magnitude of this event. The revealed seismic deformations in the described objects have supported our previous results and the identified seismic events (which were not known before our studies).

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