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Seismogenic Rockfalls and Landslides in the Mountain Areas of the South-East Kazakhstan

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ABSTRACT: There are given the data on landslides and rockfalls caused by strong earthquakes in the territory of the South-East Kazakhstan. More than 60 large seismogenic landslides and rock falls were recorded. 25 of them had a volume of 10 to 100 million m^3, and the volume of the four largest rock falls exceeded 100 million m^3. The highest density of seismogenic landslides (1/5 km^2) is recorded in the low-mountain zone of the northern slope of the Ile Alatau Ridge. The percentage of areas affected by landslides reaches 5 %. In the mid-mountain and high-mountain zones of the Zhetysu, Ile and Kungey Alatau Ridges, the density of seismogenic landslides ranges from 1/100 km^2 to 1/50 km^2, and the share of affected areas is from 1 to 1.5 %. There are 26 lakes dammed by seismogenic rockfalls. The volumes of nine lakes exceed 10 million m^3.

KEYWORDS: dangerous seismogenic processes, landslides, rockfalls, seismogenic risk.

I. INTRODUCTION

In the mountainous areas one of the main geological hazard are exogenous processes: landslides, rockfalls, mudflows and avalanches [1, 2]. In seismically active areas a strong earthquake with a magnitude more than 6.0 often causes formation of these processes [3]. During such earthquakes, intensity of exogenous processes increases in many times. A huge rockfall of the volume of 2,200 million m^3 overloaded the village of Usoy in the Pamir in Tajikistan during the earthquake of 1911. The Sarez Lake with a depth of 500 m and a volume of 17 km^3 was formed above the dam [4]. In the Northern Tien Shan in the territory of Kazakhstan and Kyrgyzstan catastrophic seismogenic landslides and rock falls occurred in 1887 and 1911 [5, 6]. The most destructive earthquake was in 1920 in the province Gansu in China. About 100 000 people were killed from landslides [7]. The landslide of the Khait earthquake in Tajikistan in 1949 hit several villages and killed 26 000 people [8]. A giant landslide from Huascaran Mountain destroyed the city of Yungay and several villages during Peru earthquake with M 7.75 in 1970. More than 18 000 people were killed [9]. The Kashmir earthquake in Pakistan in 2005 caused formation of 25 500 landslides, 87 500 people were killed [10]. The Sichuan earthquake in China in 2008 with M 7.9 induced almost 200 000 landslides in the area of 110 000 km^2. The volume of the largest landslide amounted to 750 million m^3. Almost 70 000 people were killed [11].

Disasters related to seismogenic exogenous processes were recorded in many seismically active mountain regions of the world: in the Pamir [4], Tien Shan [5, 6[, Karakorum [10], Himalayas [11], in Japan [12], New Zealand [13], and the Andes [9].

Seismic landslides and rockfalls often create dams and lakes at the bottom of a valley. Landslides that occurred during the Sichuan earthquake in 2008 in China formed 250 dams [11]. Breakthroughs of these lakes lead to formation of catastrophic mudflows and floods.

Many researchers note that large landslides are possible only with intensive earthquakes [3]. The largest deformations of slopes are usually associated with zones of tectonic faults. Other factors affecting formation of seismogenic rockfalls are

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depth of the relief and steepness of the slope. Most often seismic dislocations occur at the depth of the relief dissection of more than 500 m and the slope steepness of more than 30 degrees.

In Kazakhstan, the impact of earthquakes on exogenous processes was studied in the late 19th – early 20th centuries by I. Mushketov [5] and K. Bogdanovich [6], in the middle of the 20th century – by N. Kolotilin [14], in the late 20th – early 21st centuries – by A. Medeu [15] and V. Blagovechshenskiy [16].

II. RESEARCH AREA AND USED MATERIALS

The research area is located in the southeast part of Kazakhstan between 42-46^{o} N and 76-82^{o} E. These are the mountain ranges of the Zhetysu Alatau, Ile Alatau, Kungey Alatau, Teriskey Alatau and Uzynkara. The ridges have a sublatitudinal direction. The height of the watershed part of these ranges is: in the ridge of Uzynkara – 3300-3400 m, in the Zhetysu Alatau – 4000-4100 m, in the Ile and Kungey Alatau – 4100-4300 m, in the Teriskey Alatau – 4300-4500 m, and in the basin of the Bayankol River – up to 5000 m.
The mountain ridges of the South-East Kazakhstan are roof block uplifts formed in the era of Alpine folding on the site of the Paleozoic Peneplain. The newest total amplitudes of the uplifting are 3000-4000 m. In creation of the modern relief, the main role was played by tectonic movements in the Neogene-Quaternary period, accompanied by erosion and glacial exaration processes. Seismicity of the territory is due to the presence of a number of seismogenerating zones confined to geological faults, oriented mainly in the latitudinal direction. The maximum magnitude of earthquakes in the Ile and Kungei Alatau may reach 8.0, in the Zhetysu and Teriskey Alatau – 7.0 [17].
The study uses the data on earthquakes given in the literature [5, 6, 18-20] and Internet [21]. The distribution and characteristics of modern seismic dislocations are taken from the works of Mushketov and Bogdanovich [5, 6]. The data on paleoseismic dislocations are obtained from the results of interpretation of Google satellite images and large-scale topographic maps.

III. RESULTS AND DISCUSSION

The map of seismogenic landslides and rockfalls was compiled on the basis of the ground-based survey materials, aero visual observations and interpretation of Google Earth space images. As comparison of the results of decoding of space images with the results of the ground-based and aero visual surveys showed, these images allow us to identify seismic dislocations with confidence and sufficient accuracy and measure their sizes.

A zone of caving and an accumulation zone of rockfalls or landslides as well as dammed lakes were distinguished on the space images (Figure 1). The parameters of dislocations and lakes were measured by using topographical maps.
The map of seismic dislocations was compiled at the scale of 1:1 000 000 (Figure 2).

Based on the materials of Mushketov and the results of space images' decoding, a catalog of large seismic dislocations in the mountain regions of Kazakhstan (see table) was compiled.

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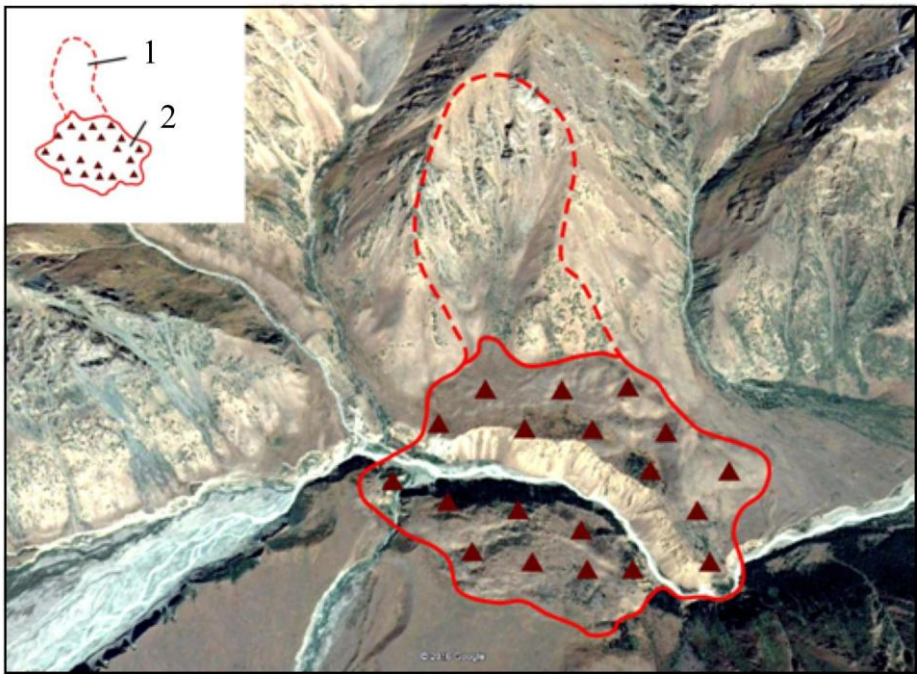

Figure 1. A space image with the contours of the seismogenic rockfall in the valley of the Shelek River. The volume of the rockfall is 36 million m^3.
1 – caving zone, 2 – accumulation zone.

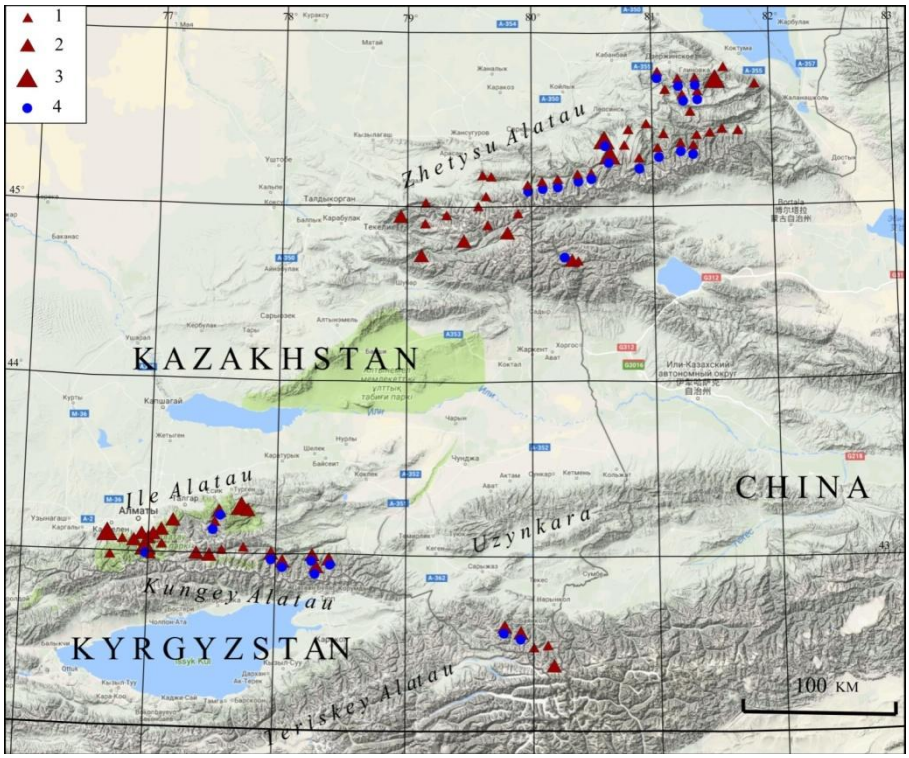

Figure 2. Distribution of large seismogenic landslides, rock falls and dammed lakes in the mountain areas of the South-East Kazakhstan.
The volume of the displaced rocks in million m^3: 1 – 1-10; 2 – 10-100; 3 – more than 100; 4 – dammed lakes.

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Table. Seismogenic rock falls, landslides and dammed lakes in the mountainous regions of Kazakhstan

River basin	Height, m above sea level	Fall height, m	Type of a dislocation	Volume, million m^3	Volume of a dammed lake, million m^3
The Ile Alatau Ridge					
Ulken Almaty	2500	1050	Rockfall	380	14
Ozyornaya	2700	600	Rockfall	15	-
Prokhodnaya	1300	900	Rockfall	54	-
Kokcheka	1300	600	Rockfall	24	-
Oizhailau	1200	500	Landslide	6,0	-
Zhamanbulak	1000	500	Landslide	30	-
Tastybulak	1200	400	Landslide	6,5	-
Essik	1750	800	Rockfall	24	15
Essik	3100	700	Rockfall	7,0	3,0
Aksai	1400	600	Rockfall	40	-
Aksai	1300	400	Landslide	25	-
Aksai	1500	500	Landslide	1,5	-
Kaskelen	1400	500	Landslide	2,0	-
Koturbulak	1300	600	Landslide	5,4	-
Pryamaya Shchel	1200	550	Landslide	84	-
Shirokaya Shchel	1300	500	Landslide	1,5	-
Kishi Almaty	1400	300	Landslide	12	-
Remizovka	1500	400	Landslide	6,0	-
Turgen	1600	1200	Rockfall	150	-
The Kungey Alatau Ridge					
Chon Uryukty	2200	1000	Rockfall	22	2,4
Kaiyndy	1850	900	Rockfall	15	1,2
Kolsai	1800	900	Rockfall	50	16
Kolsai	2430	800	Rockfall	20	20
Shelek	1800	880	Rockfall	30	-
Shelek	1750	780	Rockfall	5	-
Shelek	2400	750	Rockfall	3	-
Shelek	1970	1310	Rockfall	8	-
Shelek	2120	1080	Rockfall	6	-
Shelek	3330	480	Rockfall	1,5	-
Shelek	2800	800	Rockfall	36	-
Shelek	3230	1060	Rockfall	2,4	-
Shelek	3360	770	Rockfall	4,5	-
The Teriskey Alatau Ridge					
Bayankol	3100	750	Rockfall	30	12
Bayankol 1	2600	560	Rockfall	21	-
Bayankol 2	2720	950	Rockfall	5,0	-
Ulken Kokpak	3050	600	Rockfall	25	20
The Zhetysu Alatau Ridge					
Aganakty	1700	750	Rockfall	120	35
Aganakty	2500	800	Rockfall	140	44
Baskan	2200	650	Rockfall	25	6,0
Korgas	2300	1000	Rockfall	50	15
Orta Tentek	2450	930	Rockfall	46	2,0
Orta Tentek	2440	410	Rockfall	34	0,22
Orta Tentek	2370	750	Rockfall	58	0,72

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Tentek	2790	690	Rockfall	20	4,0
Tastau	2340	600	Rockfall	1,5	-
Tastau	2010	610	Rockfall	2,1	-
Zhamanty	1940	680	Rockfall	34	1,3
Zhamanty	1820	780	Rockfall	1,0	0,49
Zhamanty	1410	570	Rockfall	7,2	1,6
Zhamanty	2260	320	Rockfall	3,5	0,7
Zhamanty	2160	430	Rockfall	2,4	0,55
Zhamanty	2000	540	Rockfall	1,0	-
Zhamanty	1200	460	Rockfall	1,6	0,32
Zhamanty	1080	580	Rockfall	12	-
Zhamanty	1490	650	Rockfall	27	-
Zhamanty	1680	740	Rockfall	10	-
Koksuat	1080	430	Rockfall	2,2	-
Koksuat	1100	300	Rockfall	2,3	-
Koksuat	1420	1280	Rockfall	9,6	-
Bolshoi Baskan	2740	660	Rockfall	2,1	0,42
Bolshoi Baskan	2550	850	Rockfall	28	19
Koksu	1820	440	Rockfall	68	-
Koksu	1910	580	Rockfall	6,6	0,21
Kora	1410	700	Rockfall	3,9	-

More than 60 large seismogenic landslides and rockfalls were identified in the mountain regions of the South-East Kazakhstan.

There are 19 large seismogenic landslides and rockfalls in the Ile Alatau Ridge. Many of them were formed during the Verny earthquake M 7.3, which intensity was 9 points. The epicenter of the earthquake was at the foot of the northern slope of the ridge. According to I. Mushketov, the volume of individual seismic dislocations exceeded 50 million m^3, and the total volume of the displaced masses was 440 million m^3 [5].

In addition to the seismic dislocations of 1887, there are many ancient rockfalls in the Ile Alatau. The size of some of them exceeds the size of the rock falls in 1887. The largest one is the seismogenic rockfall at the Ulken Almaty Lake in the central part of the Ile Alatau. Its volume is 380 million m^3, which makes it one of the largest seismic dislocations on the Earth. The rockfall extends down the valley on the length of 5.2 km. The area of the rockfall is 2.5 km^2, the area of accumulation is 2.1 km^2, and the total area of disturbed lands is 4.6 km^2.

Seismogenic rockfalls in the Ile Alatau are mainly formed in the mid-mountain zone (from 2 000 to 3 200 m above sea level), where rocks and mainly granites are widespread. This zone is characterized by a steeply sloping, deeply dissected relief. Steepness of the slopes here is more than 30 degrees, the valleys' depth is more than 500 m. Seismogenic landslides are confined to the low-mountain zone (from 1 000 to 2 000 m above sea level), where loesslike loams are widespread. Steepness of the slopes is lower here, and the valleys' depth is less than in the mid-mountain zone.

In the mid-mountain zone of the central part of the northern slope of the Ile Alatau density of seismic dislocations is 1/100 km^2. The total area of disturbed lands is 15 km^2. This is about 1.5 % of the area of the mid-mountain zone. Density of seismogenic landslides, formed from loess-like loams, is very high in the low-mountain zone. Here, one seismogenic landslide accounts for 5 km^2. The total area of disturbed lands for seismogenic landslides is 25 km^2, which corresponds to approximately 5 % of the area of the low-mountain zone.

In the Zhetysu Alatau Ridge the two largest seismogenic rockfalls are in the central part of the northern slope of the ridge, in the valley of the Aganakty River in the Lepsy River basin. One rock fall is located at the altitude of 1 700 m above sea level. Its volume is 120 million m^3; the area of disturbed land is 4.5 km^2. The Lower Zhasylkol Lake with the volume of 35 million m3 was formed above the rockfall. The second rockfall is at the altitude of 2 500 m above sea

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level. The volume of this rockfall is 140 million m^3; the area of disturbed land is 3.4 km^2. The Upper Zhasylkol Lake with the volume of 44 million m^3 is dammed with a rock fall.
However, the most seismogenic rockfalls were recorded in the western part of the Zhetysu Alatau, in the basins of the Tentek, Zhamanty and Tastau Rivers. Twenty seismogenic rockfalls were discovered there. Eight of them have the volume of more than 10 million m^3. Here, one rockfall occurs in 70 km^2 of the area. The share of lands disturbed by seismic dislocations is 1.5 %.

There are six large seismic dislocations in the central part of the Zhetysu Alatau, in the basins of the Big Baskan, Baskan, Sarkan and Aksu Rivers. The volume of two of them exceeds 100 million m^3. Density of seismogenic rockfalls is 1/250 km^2. The share of the area of disturbed lands is 0.5 %.

The least seismic dislocations were recorded in the western and southern parts of the Zhetysu Alatau, in the basins of the Karatal, Osek and Korgas Rivers. There are four large seismic dislocations with the volume of 25 to 68 million m^3. Density of seismic dislocations is 1/500 km^2. The share of the area of disturbed lands is 0.1 %.

Thirteen big seismogenic rockfalls were recorded in the Shelek River basin in the Kungei Alatau Ridge. The largest ones are the rock falls of Chon Uryukty, with the volume of 22 million m^3, Lower Kolsai (50 million m^3), Upper Kolsai (20 million m^3) and Kaiyndy (15 million m^3). All these rockfalls have lakes, which repeatedly broke through [18]. In this area, one seismic dislocation falls on 70 km^2, and the share of disturbed land area is 1 %.

In the Kazakh part of the Teriskey Alatau Ridge, four seismic dislocations were discovered on the area of 400 km^2. Three of them have the volume of more than 10 million m^3. Two rockfalls have dammed lakes. Density of seismic dislocations is 1/100 km^2. The share of the area of disturbed lands is 0.5 %.

There are no seismic dislocations in the Uzynkara Ridge.

Territorial differences in density of seismic dislocations are in good agreement with the seismic zoning map. Areas with a high density of seismic dislocations are confined to the areas where earthquakes of 9 points intensity are possible. However, in the central and eastern parts of the Zhetysu Alatau, there is a high density of seismic dislocations, while this area is marked on the seismic zoning map as an area where earthquakes of 7 points intensity only are possible. This discrepancy is explained by the fact that the seismic zoning map was compiled from the data on earthquakes for the period of instrumental observations (about 130 years). Paleoseismic dislocations carry information on earthquakes for several thousand years. Therefore, they are more reliable sources of information on earthquakes of rare occurrence, and they must be taken into account when assessing the maximum intensity of earthquakes.

IV. CONCLUSIONS

Seismogenic landslides and rockfalls occur during earthquakes of a magnitude greater than 6 in an area where intensity of an earthquake exceeds 8 on the MSK-64 scale. Probability of formation of seismogenic landslides, rockfalls and mudflows should be taken into account when assessing natural risk in seismically active mountainous areas.

In the mountains of the South-Eastern Kazakhstan, the 9-point earthquake area, marked on the seismic zoning map, coincides with the territory of spread of strong earthquakes, revealed from the data on large gravity seismic dislocations, only for the Ile and Kungey Alatau Ranges. The Zhetysu and Teriskey Alatau Ranges are referred to the region of 7-point earthquakes. However, high density and large dimensions of paleoseismodislocations show that intensity of earthquakes in these ridges should be increased to 9.

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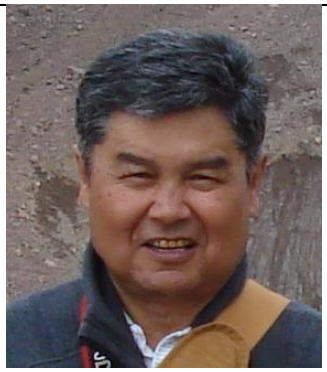

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