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ON THE AFTERSHOCKS OF SOME STRONG EARTHQUAKES IN THE SOUTH-EAST OF KAZAKHSTAN

The proposed article presents the results of a comprehensive study of the aftershocks of some strong earthquakes in the south-east of Kazakhstan during the period 1960-2023.

Strong earthquakes in the studied region are accompanied by numerous aftershocks, therefore it is very important to consider the behavior of aftershock attenuation processes in more detail. The relevance of this topic determines the subject, the object, as well as the choice of the method of research. Special attention was paid to the spatial and temporal distribution of aftershocks relative to the epicenters of strong earthquakes during the period 2016-2023. For the research, an earthquake catalog was used for the territory of 39-47°N, 70-85°E with an energy class K≥7.

The results of the research are schematic maps of strong earthquakes and their aftershocks that occurred in the last few years in the selected study area. The statistics of the number of aftershocks after strong earthquakes have occurred are presented, the time dependence of strong earthquakes (main aftershocks) and their aftershocks in the time interval 2016-2023, which occurred on the territory of 39-46°N, 70-85°E is constructed. A qualitative analysis of the results obtained makes it possible to more clearly understand the physical and mechanical conditions of the occurrence of aftershocks after strong earthquakes and to understand in detail the law of attenuation of aftershocks.

Key words: seismicity, strong earthquakes, aftershocks, geological structures, the law of attenuation of aftershocks.

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Қазақстанның оңтүстік-шығысындағы кейбір күшті жер сілкінісінің салдары туралы

Ұсынылған мақалада 1960-2023 жылдар кезеңінде Қазақстанның оңтүстік-шығысындағы кейбір күшті жер сілкіністерінің афтершоктарын кешенді зерттеу нәтижелері берілген.

Зерттелетін аймақтағы күшті жер сілкіністері көптеген жер сілкіністерімен бірге жүреді, сондықтан жер сілкінісінің әлсіреу процестерінің әрекетін толығырақ қарастырған жөн. Бұл тақырыптың өзектілігі тақырыпты, объектіні, сондай-ақ жүргізілетін зерттеу әдісін таңдауды анықтайды. 2016-2023 жылдар кезеңінде болған қатты жер сілкіністерінің эпицентрлеріне қатысты жер сілкіністерінің кеңістіктік және уақытша таралуына ерекше назар аударылды. зерттеу үшін K≥7 энергетикалық класы бар 39-46°СБ, 70-85°ШБ, аумақтары үшін жер сілкіністерінің каталогы қолданылды.

Зерттеу нәтижелері соңғы бірнеше жылда таңдалған зерттеу аумағында болған қатты жер сілкінісі мен олардың жер сілкіністерінің диаграммалары болып табылады. Күшті жер сілкіністерінен кейінгі жер сілкіністерінің саны туралы статистика ұсынылған, 39-46°СБ, 70-85°ШБ аумағында болған 2016-2023 жылдар аралығындағы күшті жер сілкіністерінің (негізгі дүмпулердің) және олардың жер сілкіністерінің уақытша тәуелділігі салынған. Алынған нәтижелерді сапалы талдау үлкен жер сілкіністерінен кейін жер сілкіністерінің пайда болуының физикалық-механикалық жағдайларын неғұрлым нақты түсінуге және жер сілкіністерінің әлсіреу Заңын егжей-тегжейлі түсінуге мүмкіндік береді.

Түйін сөздер: сейсмикалық, күшті жер сілкіністері, дүмпулер, геологиялық құрылымдар, дүмпулердің әлсіреу заңы.

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О последствиях некоторых сильных землетрясений на юго-востоке Казахстана

Предлагаемая статья представляет собой результаты комплексного исследования афтершоков некоторых сильных землетрясений юго-востока Казахстана за период 1960-2023 гг.

Сильные землетрясения в исследуемом регионе сопровождаются многочисленными афтершоками, поэтому весьма актуально рассмотреть поведение процессов затухания афтершоков более подробно. Актуальность данной темы определяет предмет, объект, а также выбор метода проводимых исследований. Особое внимание было обращено на пространственное и временное распределение афтершоков относительно эпицентров произошедших сильных землетрясений за период 2016-2023 гг. Для исследований применялся каталог землетрясений для территории 39-46°СШ, 70-85°ВД, с энергетическим классом K≥7.

Результатами исследований являются карты-схемы сильных землетрясений и их афтершоков, произошедших в последние несколько лет на выбранной территории исследования. Представлена статистика количества афтершоков после произошедших сильных землетрясений, построена временная зависимость сильных землетрясений (основных толчков) и их афтершоков в интервале времени 2016-2023 гг., произошедших на территории 39-46°СШ, 70-85°ВД. Качественный анализ полученных результатов позволяет более четко понять физико-механические условия возникновения афтершоков после сильных землетрясений и детально понять закон затухания афтершоков.

Ключевые слова: сейсмичность, сильные землетрясения, афтершоки, геологические структуры, закон затухания афтершоков.

Introduction

The current stage of activation of the Earth's seismicity dictates the need to conduct research on the processes of occurrence and attenuation of aftershocks after strong earthquakes. Strong earthquakes (two strong earthquakes with a magnitude of more than 7.8) that occurred in Turkey on February 6, 2023, after which many aftershocks were recorded, can serve as a vivid confirmation and example. So [1,3]: "On February 6, 2023, with an interval of nine hours, two powerful earthquakes occurred in southeastern Turkey. The epicenter of the first with a magnitude of 7.8 (± 0.1) was located in the Shehitkamil area in Gaziantep (Turkey), the epicenter of the second with a magnitude of 7.5 (± 0.1) was located in the Ekinozu area in Kahramanmaras (Turkey)." Therefore, modern studies of aftershocks after strong earthquakes have occurred are becoming very relevant. On September 9, 2023, a strong earthquake with M=7 occurred for the first time in Morocco.2. Aftershocks with a magnitude of M = 4.5 occurred after it. According to the US Geological Survey, the earthquake occurred about 72 kilometers east of the Moroccan city of Marrakech. The second aftershock, magnitude 3.9, was recorded at a depth of 10 km also near the city of Marrakech [1,3].

Strong earthquakes are always accompanied by numerous aftershocks. Their number and intensity decrease over time, and the duration of manifestation can last for months. The probability of strong aftershocks is especially high in the first hours after the main shock. There are many cases when buildings damaged by the main impact were destroyed precisely by repeated, less violent tremors. Aftershocks pose a threat during rescue operations. An aftershock is a repeated seismic shock of lower intensity compared to the main seismic event.

Therefore, special attention in this study was paid to the aftershocks of strong earthquakes in the South-East of Kazakhstan, in order to comprehensively study the spatial and temporal distribution of aftershocks after strong earthquakes and the law of their attenuation.

Materials and methods

The materials of the research and analysis were scientific sources [1-12]. A catalog of earthquakes for the period 1960-2023 was used for the territory of 39-46°N, 70-85°E, [4]. Special attention was paid to the current stage of activation of the seismicity of the region for the period 2016-2023.

In order to understand the physico-mechanical meaning of the process and the nature of the occurrence of aftershocks, some strong earthquakes in the region and their aftershocks have been studied. The whole process can be described as follows. The presence of aftershocks is associated not so much with residual stresses directly in the hearth, as with a rapid (during the main shock of the earthquake) increase in stresses in the vicinity of the hearth of the earthquake, due to the redistribution of stresses. When the main impact of an earthquake is plastic (and brittle) deformation of the earth's crust in the earthquake site, the hard surface of the earth's crust shifts in general from tens of centimeters to several meters. At the same time, the mechanical stresses in the hearth decrease from the maximum (from the level of ultimate strength) to the minimum residual ones. On the other hand, stresses in the vicinity of the hearth (source of rupture) increase significantly (as a result of displacement of the Earth's crust), sometimes bringing this stress closer to the ultimate strength. When the strength limit is exceeded (near the source of the main shock), aftershocks occur. With this displacement of the earth's surface, mechanical stresses increase at a great distance from the epicenter (source) (similar to how it happens near the epicenter). The essence of the concept of aftershocks is always associated with major aftershocks (strong earthquakes). After the main shock, not only residual stresses arise directly in the hearth, but also quickly (during the main earthquake) stresses increase in the vicinity of the hearth of the earthquake due to the redistribution of stresses. During the main shock (strong earthquake) – plastic (and brittle) deformation of the earth's crust in the earthquake site, the hard surface of the earth's crust shifts, from several tens of centimeters to several meters.

A comprehensive study of the processes of occurrence and attenuation of aftershocks, and the application of the law and the Omori method [2] revealed some statistical patterns. According to the law proposed by Swedish seismologist M. Bot, the magnitude of the strongest aftershock is less than the magnitude of the main shock by one. Aftershocks can occur over a long period of time (months and years). A statistical pattern is also found in the time sequence of their occurrence [3]. The mechanical stresses in the hearth decrease from the maximum (from the level of ultimate strength) to the minimum residual stresses. Stresses in the epicenter area increase significantly, sometimes approaching the ultimate strength. When the strength limit is exceeded (near the focus of the main shock), repeated aftershocks occur. Mechanical stresses also increase at a great distance from the epicenter. Stress increases at the plate boundaries may approach the limit of strength of the earth's crust along its perimeter, then after strong earthquakes – displacements along the plate boundary, a series of man-made earthquakes may occur. Thus, in [5], the time statistics of the strongest aftershocks were considered relative to the moments of the corresponding main shocks. It follows from the considered material that the occurrence of the strongest aftershocks in time obeys the power law of distribution. This is similar to Omori's law [2] for the sequence of all aftershocks (see Fig. 1). As the authors note [6]: "the hypothesis of the independence of times and magnitudes in aftershock sequences has been confirmed." After strong earthquakes, aftershocks usually occur, which can cause significant additional damage, sometimes even exceeding the damage from the main shock. Strong aftershocks are often accompanied by a temporary increase in the number of events per unit of time. Presumably, a strong aftershock is likely to occur at the beginning of a series of events. A more likely scheme is the occurrence of aftershocks due to stresses accumulated before the main shock [6]. Figure 1 shows the time dependence of aftershocks on the main shock, which occur in the time interval 2017-2023. Taking into account all the features of the occurrence of aftershocks after strong aftershocks, special attention was paid to their spatial distribution.

Results and discussion

According to the catalog of aftershocks, major aftershocks (SOMS) [4], it can be concluded that aftershocks do not occur instantly, but with some delay after the main (main) shock. It is obvious that small impacts similar in strength to direct impacts from seismic events, for example, tides or even surface waves from the main shock that rounded the Earth, can also act as triggers that increase the likelihood of aftershocks [6]. At the same time, a trigger is understood as a specific cause of events, conditions under which a prescribed action should occur-an event, an event that sets in motion, a provoking factor, a signal that causes predetermined conditions. Let's take a closer look at the analysis of the occurrence of a sequence of aftershocks. For this purpose, the temporal sequence of major aftershocks (strong earthquakes) and their aftershocks is considered (see Fig. 1) for the period 2017-2023. Figure 1 shows how the sequence of aftershocks is distributed over time after the main shock.

According to the accumulated data on the aftershocks of the earthquake catalog (SOME) [4] for 1960-2023, it can be assumed that the assessment of the probability of subsequent aftershocks is based on the assumption that the magnitude of aftershocks does not depend on time; under this assumption, the maximum magnitudes depend only on the intensity of the aftershock flow (the number of events per unit of time) or do not depend directly on the time elapsed since the main shock [6]. Each aftershock can be characterized by a pair of quantities: time relative to the main shock and magnitude, which can be considered as a two-dimensional random variable. It can be assumed that if the magnitudes are independent of time, any of the aftershocks may be equally likely to be the strongest. There are 34 main aftershocks in the catalog of strong earthquakes, each of which may or may not have its own sequence of aftershocks (see Table 1). Provided reliable estimates of parameters based on data on the interval from the main (main) shock, it is possible to estimate such characteristics as the maximum magnitude, the waiting time for shocks of a given force, the occurrence of events of a given force in a given interval. The corresponding parameters were identified in the sequence of aftershocks of each of the 34 main aftershocks. In the earthquake catalog, the main (main) tremors are marked -3, the corresponding aftershocks are marked – 40-41 [4]. Table 1 shows the sequences of the main aftershocks and the number of their aftershocks for 1970-2023. Some strong earthquakes in the studied region, their coordinates, magnitude, depth and number of aftershocks are given. For the spatial representation of aftershocks, the main aftershocks with K>14.0 and the number of their aftershocks were taken from the indicated table. 1. K is the energy class. For example, some strong earthquakes (major aftershocks and their aftershocks) were considered starting from 2016-2023. The results of the spatial distribution of aftershocks of some strong earthquakes in the studied region are shown in Figures 2-5. In the sequence of aftershocks of each strong earthquake, there are sufficiently strong events of class K = 9.7, 9.2, they are timed to the main shock and obey the law of attenuation of aftershocks.

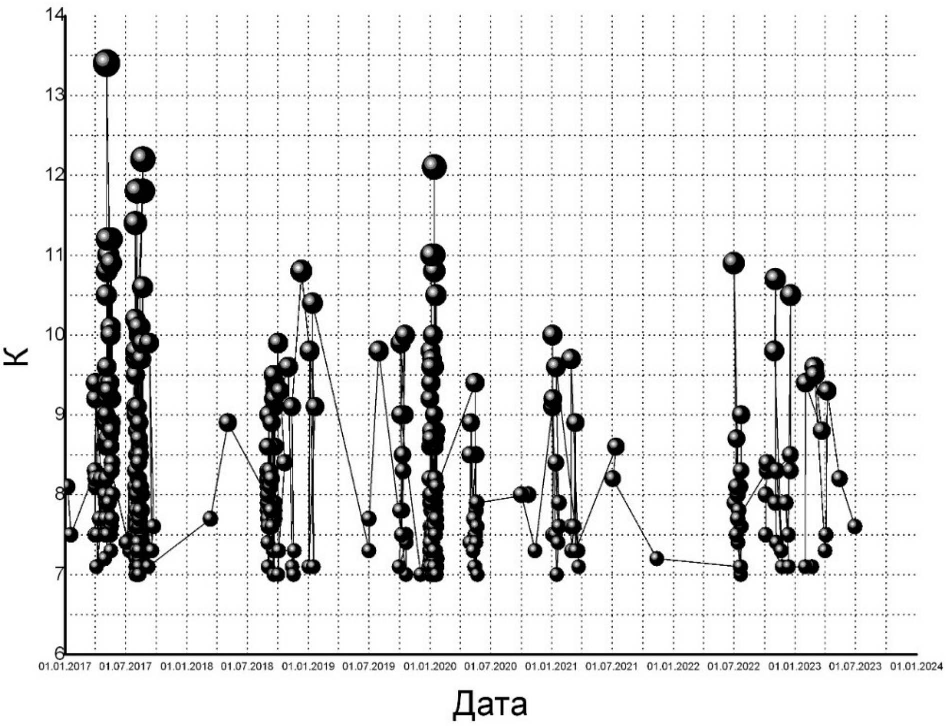

Figure 1 – Time dependence of the main aftershocks and their aftershocks in the time interval 2017-2023, which occurred on the territory of 39-46°N, 70-85°E

Table 1 – List of strong earthquakes (K≥14) and the number of their aftershocks in the south-east of Kazakhstan in 1970-2023. (compiled from materials [4])

№	Дата, время	Координаты		Энергетический класс, *K*	Магнитуда, *M*	Глубина гипоцентра, *H*, км	Количество афтершоков
		Широта	Долгота				
1	05.06.70 4:53	42.47	78.80	15.6	6.3	15	4
2	10.05.71 14:51	43.00	71.20	14.2	-	-	4
3	15.06.71 22:04	41.52	79.12	14.2	6	11.9	71
4	15.01.72 20:21	40.28	79.38	14.4	6.2	10.2	6
5	24.03.78 21:05	42.87	78.58	16.0	7.1	33	95
6	25.09.79 13:05	45.00	77.00	14.0	5.9	40	0
7	13.02.83 1:40	40.13	75.15	14.6	6.2	16.1	401
8	23.08.85 12:42	39.15	75.30	17.5	7	6.8	271
9	24.08.85 20:46	39.45	75.80	14.9	-	-	181
10	24.01.87 8:09	41.40	79.17	15.3	6.2	28.9	301
11	12.11.90 12:28	42.93	77.93	14.6	6.4	19.1	87
12	25.02.91 14:30	40.33	78.92	14.4	6	20.6	23
13	15.05.92 8:07	41.10	72.42	15.0	6.2	49.5	43
14	19.08.92 2:04	42.07	73.63	17.0	7.3	27.4	141
15	30.12.93 14:24	44.82	78.77	15.0	5.5	14.9	62
16	19.03.96 15:00	40.22	76.58	14.6	6.3	28.2	3
17	09.01.97 13:43	41.17	74.20	14.2	5.8	22.2	3
18	21.01.97 1:47	39.43	76.98	14.4	5.9	33	3
19	01.03.97 6:04	39.72	76.82	14.2	5.6	22.4	2
20	11.04.97 5:34	39.60	76.93	14.6	6.2	15	1
21	14.02.05 23:38	41.80	79.18	14.3	6.1	22	125
22	19.04.09 4:08	41.32	78.18	14.0	5.4	39	11
23	19.07.11 19:35	39.92	71.45	14.3	6.1	20	3
24	28.01.13 16:38	42.52	79.67	14.7	6.1	15	836
25	26.06.16 11:17	39.75	73.73	14.2	6.4	13	45
26	25.11.16 14:24	39.25	74.27	14.4	6.6	17	2
27	03.05.17 4:47	39.45	71.58	14.3	6	11	42
28	08.08.17 23:27	44.40	82.48	16.7	6.3	20	130

To analyze the number of strong aftershocks, a series of aftershocks that occurred in 2016-2023 was taken. Figures 2-5 show the spatial and temporal distributions of aftershocks after strong earthquakes. As you can see, in space, aftershocks are grouped in the epicentral region of the main shock. The number of aftershocks for each strong earthquake is different. There are single aftershocks after a strong earthquake, and there are numerous aftershocks, up to 100 and more.

Thus, the aftershocks of some strong earthquakes in the south-east of Kazakhstan that occurred during the observation period were considered.

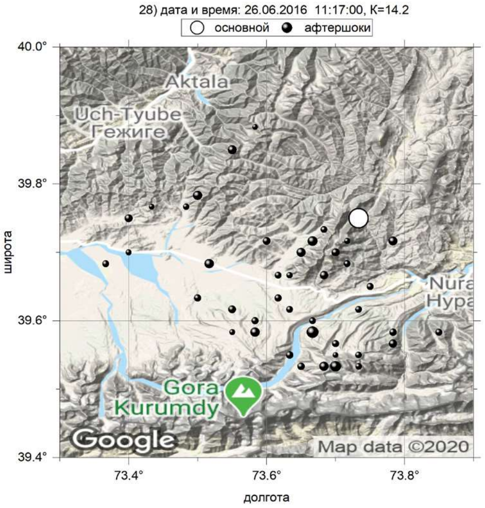

Figure 2 – Aftershocks of a strong earthquake on June 26, 2016, K = 14.2 [4]

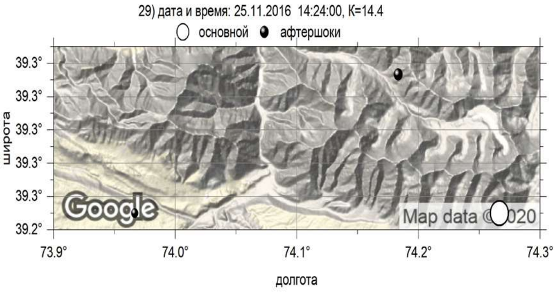

Figure 3 – Aftershocks of a strong earthquake on November 25, 2016, K = 14.4 [4]

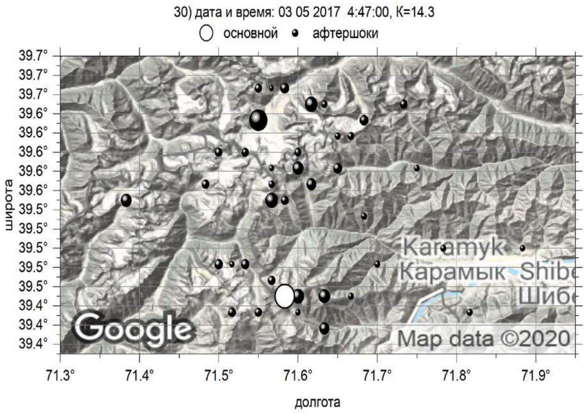

Figure 4 – Aftershocks of a strong earthquake on May 03, 2017, K = 14.3 [4]

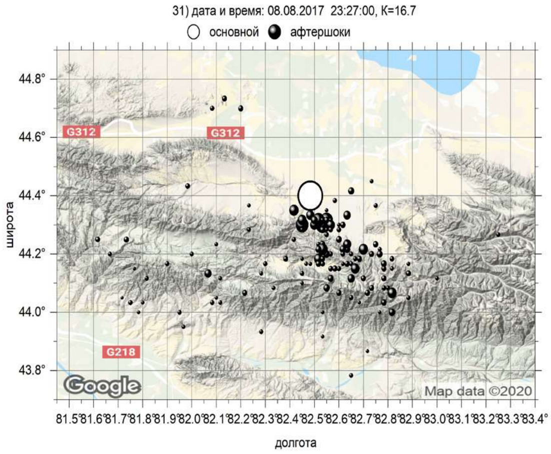

Figure 5 – Aftershocks of a strong earthquake on 08.08.2017, K=16.7 [4]

Conclusion

The following conclusion can be drawn as conclusions. During the period of intensification of seismicity in the Southeastern Kazakhstan research region for 2016-2023, maps-diagrams of the spatial and temporal distribution of aftershocks after strong earthquakes (K≥14) were obtained. The time dependence of the main aftershocks and their aftershocks in the time interval 2016-2023, which occurred on the territory of 39-46 °N, 70-85°E, showed graphs of curves that obey the law of attenuation of Omori aftershocks. The obtained research results made it possible to better understand the physico-mechanical conditions of the occurrence and attenuation of aftershocks after strong earthquakes and showed the need for timely study of aftershocks after strong earthquakes in connection with recent strong earthquakes in different parts of the globe.

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