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THERMODYNAMIC PARAMETERS OF EARTHQUAKE SWARMS

Abstract. This article describes a method for recognizing earthquake swarms in seismicity and new data on their thermodynamic parameters. Earthquake swarms of the Northern Tien Shan and adjacent territories, recognized in the seismicity of this region for 2017-2024, are considered. Numerical values of thermodynamic parameters in the sou rces of swarms are obtained. This article is devoted to the first obtained results of calculating the thermodynamic parameters in the sources of earthquake swarms, which are made using a universal method. It is also shown that the behavior of thermodynamic parameters over time corresponds to the calculation model.
Keywords: earthquake swarms, seismicity of the Northern Tien Shan region, thermodynamic parameters

Introduction. Currently, the Earth's seismicity is actively increasing on a global and regional scale. Strong earthquakes occur in seismically active regions of the Earth, such as Turkey, Syria, Afghanistan, China, Taiwan, Japan, Russia, etc. Strong seismic events, for example, in January 2024y. in China, Aksu province, M = 7.1, numerous aftershocks had a magnitude of more than 4.0 [1]. Thus, on 03/04/2024 in Almaty there was a noticeable earthquake with M = 4.7. Along with historical catastrophic earthquakes: Vernenskoye, Keminskoye, Chilikskoye and others [2,3], the forecast and prevention of strong earthquakes is a priority task of seismology. The swarms of earthquakes recognized in the seismicity of the Northern Tien Shan region and adjacent territories for 2017-2024 are considered. [1-3, 4-7,10] The need for research is dictated by the current stage of seismicity activation in the entire region. Swarms are background, impulsively arising and also impulsively disappearing shocks, and vibrations of the earth's surface in certain areas of the study region. The spatio-temporal distribution of earthquake swarms in the region allows us to identify their concentration and location (Figure 1).

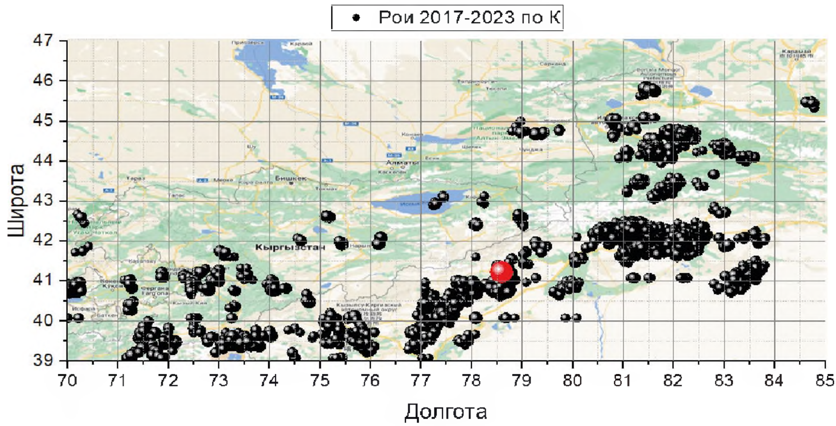

Figure 1. Spatio-temporal distribution of earthquake swarms recognized in the seismicity of the Northern Tien Shan and adjacent territories for 2017-2024 (the size of the radius of the swarms depends on the magnitude, in red is a strong earthquake on 03.04.2024 with a magnitude of M=7.1) [1]

Method and methodology of calculation. Method **The MGKI** method [8,11] was used to recognize swarms in the seismicity of the region. More details about it can be found in [7, 8,11]. Calculations of thermodynamic parameters in the foci of weak earthquakes (M>1.6) were carried out using the computational method from [4,9,10,13-15], which makes it possible to study in more detail the nature of the occurrence of earthquake swarms. For this purpose, swarms (with a magnitude greater than 1.6) of earthquakes were recognized using modern seismic data from the earthquake catalog [1] , in particular, an algorithm and method for recognizing swarms [4,5,7,8,10] were used, and their thermodynamic parameters were calculated [13,14,15] .

The calculation was carried out using a universal method [2-4,7-14], which resulted in obtaining numerical values of the thermodynamic parameters of earthquake swarms for 2017-2024. Note that earthquakes are sources of information about the physical parameters of the earth's crust and its stratification [2-4,5-7,9,13, 14]. The initial data for determining the thermodynamic parameters of earthquake swarms are the magnitude and energy class of the earthquake. Table 1 shows the numerical values of some thermodynamic parameters of earthquake swarms.

Thermodynamic parameters in earthquake swarms are calculated using known and original equations from [2-4, 7-10, 13].

The thermodynamic parameters of swarms were considered in the following sequence: seismic wave energy (lgE); temperature of the source environment (T°C); temperature stresses, deformation of the volume and shape of the source; density of deformation energy; potential energy of source deformation; ultimate strength of the medium in the destruction volume; determination of the ratio of the value of potential energy of deformation; destruction energy, etc. [2,7,13]. The presentation of the thermodynamic parameters of swarms is of great theoretical and practical importance for the quantitative assessment of geodynamic processes in the crust, as well as for the purposes of detailing seismotectonic zoning and clarifying the nature of the swarm. As shown in Table 1, parameters E and M are the energy and magnitude of earthquakes, V is the critical value of the source volume, U is the density of potential energy of seismic waves in a unit volume (erg/cm^3), E_k is the specific energy of change in the shape of the source, G is the bulk modulus of elasticity, K is the energy class, α_v – coefficient of volumetric thermal expansion, τ_{cr} - additional stresses released by the source, σ is the normal component of effective stresses, Lg η is the logarithm of the viscosity of rocks in the source of swarms.

Table 1 – Thermodynamic parameters in the foci of earthquake swarms in the Northern Tien Shan region and adjacent territories for 2017-2024 [1]

Longitude	Latitude	Magnitude	Depth	Energy class	LgE	LgV	T(°C)	LgU (E rg / cm ^{3})	Ek	G $*10^{11}$ dynes/cm ^{2}	α_v 10^{-5} K^{-1}	τ_{cr} $*10^8$ dynes / cm ^{2}	ε	$\sigma*10^9$ dynes/cm ^{2}	lgη (P)
83.37	41.4	1.89	10	7.4	14	11.1	2381.7	2.8858	2.88	1.03615	4.44E-05	0.0015	0.1178	0.122	14.51
81.55	42.22	1.94	5	7.5	14.1	11.2	2356.4	2.891	2.89	1.04613	4.40E-05	0.00152	0.1156	0.120	14.63
83.43	41.3	2.5	5	8.5	15.3	12.4	2109.8	2.947	2.95	1.1544	3.99E-05	0.00167	0.0949	0.109	15.89
83.48	41.18	2.33	10	8.2	15.0	12.0	2182.5	2.930	2.93	1.12022	4.11E-05	0.00162	0.1008	0.112	15.52
80.08	40.82	2	25	7.6	14.2	11.3	2331.2	2.897	2.9	1.05626	4.36E-05	0.00153	0.1134	0.119	14.76
80.6	42.18	2.17	20	7.9	14.6	11.7	2256.3	2.913	2.91	1.08753	4.23E-05	0.00158	0.1069	0.116	15.14
80	40.82	1.89	20	7.4	14	11.1	2381.7	2.885	2.88	1.03615	4.44E-05	0.0015	0.1178	0.122	14.51
83.38	41.3	1.72	10	7.1	13.6	10.7	2458.51	2.869	2.87	1.00705	4.57E-05	0.00146	0.1247	0.125	14.12
80.63	42.25	1.89	15	7.4	14	11.1	2381.7	2.885	2.88	1.03615	4.44E-05	0.0015	0.1178	0.122	14.51
81.57	42.22	1.94	20	7.5	14.1	11.2	2356.46	2.891	2.89	1.04613	4.40E-05	0.00152	0.1156	0.120	14.63
81.55	42.27	1.72	20	7.1	13.6	10.7	2458.51	2.869	2.87	1.00705	4.57E-05	0.00146	0.1247	0.125	14.12
81.6	42.15	1.94	10	7.5	14.1	11.2	2356.46	2.891	2.89	1.04613	4.40E-05	0.00152	0.1156	0.120	14.63

Table 1 – Thermodynamic parameters in the foci of earthquake swarms in the Northern Tien Shan region and adjacent territories for 2017-2024 [1] *(continuation)*

79.97	40.87	2.06	15	7.7	14.3	11.4	2306.17	2.902	2.90	1.06653	4.31E-05	0.00155	0.1112	0.118	14.89
81.6	42.22	1.94	5	7.5	14.1	11.2	2356.46	2.891	2.89	1.04613	4.40E-05	0.00152	0.1156	0.120	14.63
80.67	42.25	1.83	10	7.3	13.8	10.9	2407.24	2.880	2.88	1.02631	4.48E-05	0.00149	0.1201	0.123	14.38
82.38	44.57	1.89	5	7.4	14	11.1	2381.79	2.885	2.88	1.03615	4.44E-05	0.0015	0.1178	0.122	14.51
82.2	44.67	2.06	20	7.7	14.3	11.4	2306.17	2.902	2.90	1.06653	4.31E-05	0.00155	0.1112	0.118	14.89
81.73	42.22	2.22	15	8	14.7	11.8	2231.64	2.919	2.92	1.09827	4.19E-05	0.00159	0.1049	0.115	15.27
81.62	42.13	2.11	10	7.8	14.5	11.6	2281.2	2.908	2.91	1.07696	4.27E-05	0.00156	0.1091	0.117	15.02
82.33	44.63	2.28	20	8.1	14.8	11.9	2207.04	2.924	2.92	1.10916	4.15E-05	0.00161	0.1028	0.114	15.39
81.62	42.15	2.17	10	7.9	14.6	11.7	2256.36	2.913	2.91	1.08753	4.23E-05	0.00158	0.1069	0.116	15.146
82.42	44.57	2.39	15	8.3	15.1	12.2	2158.2	2.935	2.93	1.13144	4.07E-05	0.00164	0.0988	0.111	15.64
82.93	44.45	1.67	20	7	13.4	10.6	2484.3	2.863	2.86	0.99762	4.61E-05	0.00145	0.1271	0.126	13.98
82.08	44.42	2.06	15	7.7	14.3	11.4	2306.1	2.902	2.90	1.06653	4.31E-05	0.00155	0.1112	0.118	14.89
81.6	42.18	2.11	15	7.8	14.5	11.6	2281.2	2.908	2.91	1.07696	4.27E-05	0.00156	0.1091	0.117	15.02
82.08	44.42	1.78	15	7.2	13.7	10.8	2432.8	2.874	2.87	1.01661	4.53E-05	0.00147	0.1224	0.124	14.25

Results. For each magnitude greater than 1.6, the values of the given thermodynamic parameters were calculated using the corresponding formulas from [2,7,13,14]. In this case: the logarithm of the specific (volume) energy density of seismic waves (lgU), unlike (lgV), is in a linear dependence on the magnitude. The value of the potential energy of seismic waves depends on the volume of the source and is practically independent of the specific energy density U, which follows from the differences in the changes in V and U for the range of magnitudes (see Table 1). When considering the relationships between energy and temperature in the sources of earthquake swarms, in theoretical terms, the probability of a relationship between the energy and magnitude of an earthquake with the thermodynamic parameters of the source of the swarms can be assumed from the very nature of the accumulation of thermoelastic stresses in the upper shells of the Earth.

Accumulation of stresses, according to the authors [2-4,5,6,7-14,15] is a consequence of uneven temperature distribution and differences in the physical properties of the geological environment. An indicator of stress concentration at depth is their discharge in the form of an earthquake. Empirical equations of the relationship according to [2,7-13] between the temperature in the earthquake source at the moment of release of additional elastic stresses and the energy in the swarm source: T(K)=196.8 K (lgE_{max} – lgE), where 196.8 K is a constant that determines the number of degrees corresponding to a change in energy (Erg) by one order of magnitude; lgE is the logarithm of the energy of seismic waves. A comparison of the values of the logarithm of the energy of seismic waves calculated using the computational method [2,13,14] and the temperatures in the swarm source calculated using the equations reveals, first of all, an inverse relationship between E and T, as well as between the magnitudes and temperatures. As the temperature in the swarm source increases, the magnitudes and, accordingly, the energy values of seismic waves decrease. A comparison of the calculated values of α_V with the data of its measurement under atmospheric pressure reveals the same nature of the increase in the value of α_V depending on the increase in temperature (T), although with the unambiguity of the order of magnitude, some discrepancy is noted in the value of the coefficient itself. The increase in the values of α_V with increasing temperatures is caused by the fact that the orientations of maximum thermal expansion and maximum compressibility are usually close. At the same time, a change in temperature and pressure in a unit volume leads to a partial mutual destruction of their effect, which determines the parameter α_v as the average value of the thermoelastic change in volume. The change in deformation ε, bulk modulus of elasticity G and normal component of effective stresses σ in earthquake swarms are determined by equations [2,13,14] with substitution of the obtained values of α_v and corresponding temperatures T(K). Comparison of the calculated data of the sizes ε, σ and G with temperature reveals that the first two of them increase with increasing temperatures, and the third one – bulk modulus of elasticity G – on the contrary, decreases. The relationships between the values of magnitude, seismic wave energy and shear modulus, on the one hand, and temperature and effective stresses, on the other, are in inverse proportions. With increasing temperature and, accordingly, effective stresses, the values of magnitude, seismic wave energy and shear modulus decrease. These relationships in the areas of seismically active orogens create a favorable geodynamic environment for the development of neotectonic deformations and partial melting of crustal matter. As can be seen from Figure 1, the contours of earthquake swarms are distributed unevenly throughout the study region in 2017-2024.

Conclusion. Based on the results of the conducted research on modern seismic data, numerical values of thermodynamic parameters in some sources of weak earthquakes (swarms) in the Northern Tien Shan region and adjacent territories for 2017-2024 were calculated. Thermodynamic parameters characterize the physical conditions in the sources of weak earthquakes, which gives a clearer idea of the nature of the occurrence of swarms.

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ТЕРМОДИНАМИЧЕСКИЕ ПАРАМЕТРЫ РОЕВ ЗЕМЛЕТРЯСЕНИЙ

Аннотация. В статье описывается метод распознавания рои землетрясений в сейсмичности и новые данные об их термодинамических параметрах. Рассмотрены очаги землетрясений Северного Тянь-Шаня и прилегающих территорий, распознанные в зоне сейсмичности этого региона за 2017-2024 гг. Получены численные значения термодинамических параметров в рои землетрясений. Статья посвящена впервые полученным результатам расчета термодинамических параметров в рои землетрясений, выполненным с использованием универсального метода. Также показано, что поведение термодинамических параметров во времени соответствует расчетной модели.
Ключевые слова: рои землетрясений, сейсмичность Северного Тянь- Шаня, термодинамические параметры

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ЖЕР СІЛКІСУ ТОБЫНЫҢ ТЕРМОДИНАМИЯЛЫҚ ПАРАМЕТРЛЕРІ

Түйіндеме. Бұл мақалада сейсмикадағы жер сілкінісі ошақтарын тану әдісі және олардың термодинамикалық параметрлері туралы жаңа мәліметтер сипатталған. 2017-2024 жылдары осы аймақтың сейсмикасында танылған Солтүстік Тянь-Шань және оған жақын аумақтардың жер сілкіністерінің ошақтары қарастырылды. Ошақтардағы термодинамикалық параметрлердің сандық мәндері алынды. Бұл мақала әмбебап әдісті қолдана отырып жасалған

жер сілкінісі ошақтарындағы термодинамикалық параметрлерді есептеудің алғашқы нәтижелеріне арналған. Уақыт бойынша термодинамикалық параметрлердің әрекеті есептеу моделіне сәйкес келетіні де көрсетілген.
Түйінді сөздер: жер сілкіністерінің ошақтары, Солтүстік Тянь-Шаньның сейсмикалығы, термодинамикалық параметрлер.

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