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SWARM RECOGNITION ALGORITHM AS A PROMISING ARTIFICIAL INTELLIGENCE METHOD IN SEISMOLOGICAL RESEARCH

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Abstract. The article examines the current stage of seismic activity in the Northern Tien Shan region and adjacent territories in order to assess seismic hazard. Currently, there is another stage of seismic activity in the region, which necessitates the search for and application of new modern research methods and tools. The article presents an up-to-date method of pattern recognition as a promising approach to studying this problem. This is one of the applications of Artificial Intelligence (AI) in seismic research (related to assessing seismic hazard) based on recognizing the swarm activity of earthquakes in the region's seismicity. The paper considers the current stage of seismic activity in the Northern Tien Shan region and adjacent territories, focusing on the recognition of earthquake swarms (weak seismicity) and their thermodynamic parameters. The paper highlights the spatial and temporal distributions of earthquake swarms for the period 2017-2025 and by year. The paper also describes the physical and mathematical criteria for recognizing earthquake swarms and the thermodynamic conditions in their sources. The calculation of thermodynamic conditions in the foci of earthquake swarms

was carried out using a computational method that contains universal equations for calculating these parameters based on the magnitudes and energies of the occurring earthquakes. These studies will help to clarify the seismotectonic potential of the selected areas where earthquake swarms are concentrated, as well as provide a more accurate assessment of the seismic safety of the study area. The results obtained during the research and calculations play an important role in assessing the risks of severe earthquakes in the study area and potentially predicting their occurrence.

Key words: Artificial Intelligence (AI), pattern recognition, algorithm, seismicity, earthquake swarm, seismic hazard assessment, physical and mathematical criteria, thermodynamic parameters

The work was carried out at the National Scientific Center for Seismic Research within the framework of the BR24992763 Research Fund "Assessment of Seismic Hazard of the Territories of Regions and Cities of Kazakhstan on a Modern Scientific and Methodological Basis". The source of funding is the Ministry of Education and Science of the Republic of Kazakhstan.

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СЕЙСМОЛОГИЯЛЫҚ ЗЕРТТЕУЛЕРДЕГІ ЖАСАНДЫ ИНТЕЛЛЕКТІНІҢ ПЕРСПЕКТИВАЛЫ ӘДІСІ РЕТІНДЕ ҮЙІРЛІК ТАНУ АЛГОРИТМІ

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Аннотация. Мақалада сейсмикалық қауіпті бағалау үшін Солтүстік Тянь-Шань аймағының және оған іргелес аумақтардың сейсмикалығын жандандырудың қазіргі кезеңі қарастырылады. Бүгінгі таңда аймақта сейсмиканы жандандырудың кезекті кезеңі жүріп жатыр, бұл зерттеудің жаңа заманауи әдістері мен құралдарын іздеу және қолдану қажеттілігін тудырады. Мақалада осы мәселені зерттеудің перспективалық әдісі ретінде

үлгіні танудың өзекті әдісі келтірілген. Бұл сейсмикалық зерттеулерде (сейсмикалық қауіпті бағалауға байланысты) аймақтың сейсмикасындағы жер сілкіністерінің үйірлік белсенділігін тану негізінде жасанды интеллектті (АИ) қолдану бағыттарының бірі. Солтүстік Тянь-Шань аймағының және оған іргелес аумақтардың сейсмикалығын жер сілкінісі үйінділерін (әлсіз сейсмикалықты) және олардың кейбір термодинамикалық параметрлерін тану тұрғысынан жандандырудың қазіргі кезеңі қарастырылуда. 2017-2025 жылдар кезеңінде және Жылдар бойынша жер сілкіністерінің үйінділерінің кеңістіктік-уақыттық таралуы ерекшеленеді. Жер сілкінісі үйінділерін танудың физика-математикалық критерийлері және олардың ошақтарындағы термодинамикалық жағдайлар сипатталған. Жер сілкінісі ошақтарындағы термодинамикалық жағдайларды есептеу әдістемесі бойынша жүргізілді, онда болып жатқан жер сілкіністерінің магнитудасы мен энергиясының мәндеріне негізделген осы параметрлерді есептеудің әмбебап теңдеулері бар. Жүргізілген зерттеулер жер сілкінісі үйінділерінің шоғырланған аймақтарының сейсмотектоникалық әлеуетін нақтылауға, сондай-ақ зерттеу аумағының сейсмикалық қауіпсіздігін дәлірек бағалауды қамтамасыз етуге мүмкіндік береді. Жүргізілген зерттеулер мен есептеулер процесінде алынған нәтижелер зерттеу аумағында күшті жер сілкіністерінің пайда болу қаупін бағалауда және олардың пайда болу орындарын болжауда маңызды рөл атқарады.

Түйін сөздер: жасанды Интеллект (АІ), үлгіні тану, алгоритм, сейсмикалық, жер сілкінісі, сейсмикалық қауіпті бағалау, физика-математикалық критерийлер, термодинамикалық параметрлер

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АЛГОРИТМ РАСПОЗНАВАНИЯ РОЕВ КАК ПЕРСПЕКТИВНЫЙ МЕТОД ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В СЕЙСМОЛОГИЧЕСКИХ ИССЛЕДОВАНИЯХ

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Аннотация. В статье рассматривается современный этап активизации сейсмичности региона Северного Тянь-Шаня и прилегающих территорий с целью оценки сейсмической опасности. На сегодняшний день наблюдается очередной этап повышения сейсмической активности, что обусловливает необходимость применения новых современных методов исследования. В работе представлен актуальный метод распознавания образов как перспективный инструмент анализа данной проблемы. Это одно из направлений применения искусственного интеллекта в сейсмических исследованиях, основанное на распознавании роевой активности землетрясений в регионе. Рассматривается современный этап активизации сейсмичности региона Северного Тянь-Шаня и прилегающих территорий для распознавания роев землетрясений (слабой сейсмичности) и их термодинамических параметров. Выделены пространственно-временные распределения роев землетрясений за период 2017–2025 гг. и по отдельным годам. Описаны физико-математические критерии распознавания роев землетрясений и термодинамические условия в их очагах. Расчёт термодинамических условий в очагах роев землетрясений выполнен по вычислительной методике, содержащей универсальные уравнения, основанные на значениях магнитуд и энергии произошедших землетрясений. Проведённые исследования позволяют уточнить сейсмотектонический потенциал выявленных зон скопления роев землетрясений, а также обеспечить более точную оценку сейсмической безопасности исследуемой территории. Полученные результаты играют важную роль в оценке рисков возникновения сильных землетрясений и потенциальном прогнозировании мест их возможного проявления.

Ключевые слова: Искусственный интеллект (ИИ), распознавание образов, алгоритм, сейсмичность, рой землетрясений, оценка сейсмической опасности, физико-математические критерии, термодинамические параметры

Introduction. With the development of technology and engineering, scientists from various fields of science and applied disciplines, in particular mathematics, cybernetics and informatics, set themselves the task and goal of solving the problem of automatic pattern recognition. Historically, this problem arose from solving a specific problem - the creation of reading machines (Nguyen, 2019). Recognition is a task that processes and transforms incoming information and features of recognizable images into output, which is a conclusion about which class a particular recognizable image belongs to.

In terms of the history of the issue, we can note the work of R. Fisher, carried out in the 1920s and leading to the formation of discriminant analysis as one of the sections of the theory and practice of recognition. In the 40s, A.N. Kolmogorov and

A. Ya. Khinchin set the task of separating a mixture of two distributions. The most fruitful years were the 50s and 60s of the twentieth century. At that time, based on a mass of works, the theory of statistical decisions appeared. As a result, algorithms appeared that had the ability to classify a new object into one of the previously known classes, which became the beginning of a systematic scientific search and practical developments (Nguyen, 2019). Within the framework of cybernetics, a new scientific direction began to form, associated with the development of theoretical foundations and practical implementation of devices, and then systems designed to recognize objects, phenomena and processes. The new scientific discipline was called "Pattern Recognition".

And in the 60s, the problem of recognition became the leading one in attempts to apply mathematics in weakly formalized areas of science and practice. These included: practical geology, seismology, meteorology, biology, chemistry, medicine, etc.

Thus, the results of the classical theory of statistical decisions served as the basis for solving the problems of distributing objects into a particular class. Within the framework of this theory, algorithms were constructed that ensure, based on experimental measurements of the parameters (features) characterizing this object, as well as some similar data describing classes, the definition of a specific class to which the recognized object can be assigned. Subsequently, the mathematical apparatus of recognition theory was expanded due to the use of: graph theory; information theory; set theory; theory and methods of statistical analysis; methods of Boolean algebra; computer science; mathematical programming and systems engineering (Nguyen, 2019).

Research methodology. Today, the emergence of a large number of new recognition problems has led to the emergence of two directions with different research methods (Abdullaev et al, 2023). The first used standard mathematical methods. As a result, statistical recognition methods were introduced, created on the basis of the principles of mathematical statistics. The disadvantage of this direction was that the required degree of formalization in real problems was not met in most cases. The second, in turn, began to create new approaches, which required extensive mathematical experiments. With the advent of computers, mathematicians were able to conduct experimental studies. A mathematical experiment is essentially little different from a physical one. A real problem (situation) was studied, a hypothesis was put forward, then the experiment itself was conducted, which confirmed or refuted the hypothesis put forward.

The algorithm for the recognition problem can be represented as follows:

1. Study of a class of real problems (forecasting problems in geology, seismology, meteorology, etc.).

2. Study of locations and distributions of recognition objects (criteria for selecting objects that fit the given criteria).

- writing a program (implementation of an algorithm) or a set of programs

that, based on features and criteria, select objects described (suitable) for specified criteria.

In this case, the mathematician creates formal descriptions of classes of recognition procedures (models of recognition algorithms) and conducts their research using rigorous mathematical methods.

3. Classification of the recognized object and its placement in the final array, marked as "recognized" (array of recognized data).

- To classify a recognizable object, the object itself is placed in the data array in which recognition is being conducted; if all specified data recognition criteria match, the object is marked as recognized and placed in the array of recognized data.

4. Completing the recognition procedure

- At this stage, the recognition procedure is completed, the set of recognized objects is output as an array of "processed" recognized data, which can be subsequently worked with directly.

The procedure of pattern recognition in data arrays of any nature has always been a difficult and complex task. Data arrays can be not only one-dimensional (simple), two-dimensional, three-dimensional, but also multidimensional. So, in the case of a one-dimensional array, the data is arranged sequentially and does not require labor-intensive procedures for their selection and clustering. In the case of multidimensional arrays, the situation is different. The complexity of interpreting multidimensional arrays requires not only a large amount of computer memory, but also a complex mathematical multi-component analysis of each data set. In such cases, an algorithm written for a specific task comes to the rescue. Thus, for research in the field of seismology, the task is to apply a specific pattern recognition algorithm using data clustering for experimental seismological databases (catalogs).

Physical and mathematical criteria for recognizing earthquake swarms. Based on the assumption that the initial earthquake catalog does not contain events (earthquakes) of a man-made nature, that is, does not contain weak earthquakes caused by man-made or other events not related to natural processes and phenomena. In the presented algorithm, a swarm of earthquakes is taken to be weak seismicity with clear physical and mathematical criteria for its recognition (Kanamori et al, 2001, Abdullaev et al, 2024).

To identify the physical and mathematical criteria for recognizing earthquake swarms (weak seismicity) in the seismicity of the studied region, the graphical clustering method (GCM) was used (Celler, 1997, Lyutikova et al, 2017).

This method is used for pattern recognition as one of the AI methods that allows you to select from a large amount of information according to clear criteria the event that meets the specified selection criteria. In the graphical clustering method, such a criterion is the minimum distance between events. That is, for seismic events (earthquakes), this is the minimum distance between their epicenters. The time criterion is the minimum time between events (earthquakes), which has been

established experimentally (it is 15-26 days). The criterion for the number of events included in the sample was that only those events that were included in the previous two criteria and had more than 3 events were considered.

To recognize earthquake swarms, the following physical and mathematical criteria were obtained and introduced into the algorithm:

1. A swarm is a group in which the number of earthquakes N≥3, without limitation N by maximum value.

2. Spatial distance between adjacent events, forming a swarm L≤10' in angular measure.

An earthquake swarm can exist for minutes, hours, and can also exist for a longer period of time: months and even years. Therefore, swarms cannot be characterized by either the number of events N or the lifetime of the swarm.

3. Time between events (earthquakes) in a swarm (0<tswarm<15-26 days).

The radius of probable grouping of earthquake swarms was taken to be 18-20 km. The number of grouped earthquakes was 10% of the sample volume from the catalog [15]. Stable groups of clusters no larger than 20'-25' of angular measure (i.e. the size of focal zones of earthquakes with M=6-7 in the study area) are formed at a distance between events of L≤10'. Physical and mathematical criteria of earthquake swarms are related to the number of earthquakes in the swarm (group) itself. The probability of three random events falling into an area with a radius of L=10' is so small that it can be neglected.

Using these limiting physical and mathematical criteria, the images of earthquake swarms are recognized (using the graphical clustering method), and a detailed catalog of recognized earthquake swarms is compiled for the selected research area over a certain period of time (Levi et al, 1995, Kurskeyev et al, 2001, Lyutikova et al, 2017).

The process of swarm formation can be represented as a procedure of spatial grouping of seismic events.

The presented criteria and their numerical characteristics provide a more accurate physical and mathematical dependence in recognizing earthquake swarms in the seismicity of the study region. They are a specific application of AI methods and algorithms in seismological research.

Based on the physical and mathematical criteria for recognizing earthquake swarms, maps-schemes of the spatial distribution of swarms for the territory of the Northern Tien Shan and adjacent territories were constructed. Swarms presumably arise on the eve of strong earthquakes, the foci of which are formed in the earth's crust from structural inhomogeneities saturated with high-temperature masses for 1.5-2 years (Knopof, 1996, Litovchenko et al, 2020 Lyutikova et al, 2017, 2024).

Statement of the problem. To study seismicity in the Northern Tien Shan region and adjacent territories for the period 2017-2025 in order to recognize earthquake swarms (weak seismicity with K≥7) (Regional catalog, 2025, World earthquake catalog, 2025).

To identify zones of distribution and concentration of swarm activity in the study region.

Construct maps-schemes of the spatial-temporal distribution of strong earthquakes, taking into account the places of concentration of swarm activity.

To study the relationship between earthquake swarms (weak seismicity) and the stress-strain state of the environment.

To achieve the set objectives, it is necessary to apply an algorithm for recognizing earthquake swarms using the graphical clustering method.

In order to identify patterns in the spatial and temporal distribution of strong earthquake swarms, the graphical clustering method was used. Using generally accepted methods of cluster analysis, the correspondence of the row elements in the matrix to the specified rules was analyzed. If there is a spatial relationship and interdependence of events, it is expressed through "distances" (Euclidean or other) between events in n-dimensional space. If the geographic coordinates of an event are known, the geometric distance between the epicenters of earthquakes is chosen as a measure of the relationship. It is believed that the most interconnected events are those for which the inter-episocentral distances are minimal. The calculation time for GCM is proportional to the number of events in the sample that forms the matrix. Such situations may arise when analyzing time sequences of events, when there are clusters whose lifetime is less than the interval of the entire sample. Thus, for the territory bounded by coordinates 39-47°N and 70-85°E in 2017-2025. representative are earthquakes with $K \geq 7$. Some, the most general, qualitative characteristics of grouping for earthquakes with $K \geq 9$ ($M=2.8$) in the territory of the Northern Tien Shan are given in (Litovchenko et al, 2020, Lyutikova et al, 2024). Here, the radius of probable grouping was taken to be 15 km. In this case, the number of grouped earthquakes amounted to 10% of the sample size.

The obtained numerical characteristics of the swarms provide a more accurate mathematical dependence in the description of the recognition of their images in seismic data. Then, the spatial-temporal distribution of these events in the study area was carried out. In addition, strong earthquakes in the region were taken out (Figure 2).

Results and discussion. Based on the obtained characteristics of the swarms, maps-schemes of the spatial distribution of earthquake swarms were constructed (Figure 1-3). It was revealed that earthquake swarms are formed on the eve of strong earthquakes, the foci of which are formed in the earth's crust of structural inhomogeneities, the lithosphere of which in the latest stage of tectogenesis is destroyed and saturated with high-temperature masses. The obtained result is a high-quality confirmation of the algorithm's performance and can be used by specialists in further research.

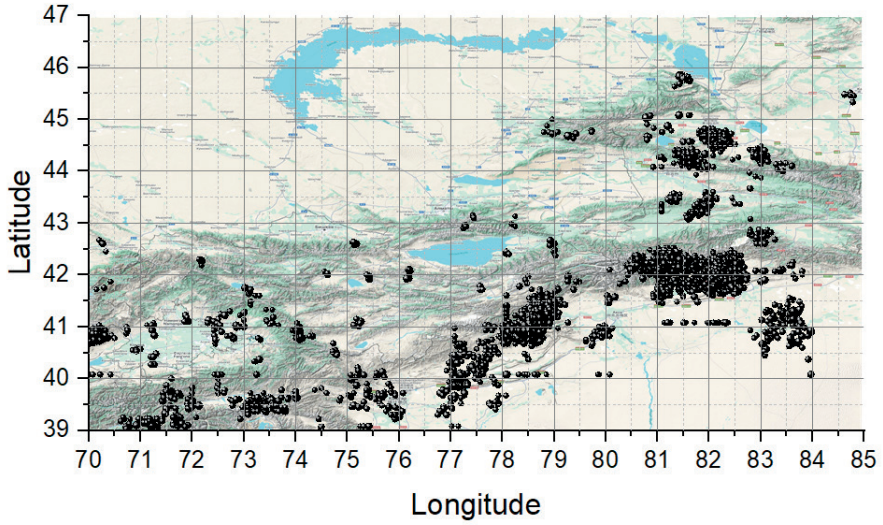


Figure 1. Map-scheme of the spatial-temporal distribution of swarm activity in the territory of the seismically active region of the Northern Tien Shan and adjacent territories for the period 2017-2025 (radius of swarms depending on K)

Figure 2 shows a schematic map of the spatiotemporal distribution of earthquake swarms for 2023 (Regional catalog, 2025). The epicenter of the strong earthquake that occurred in China in Aksu Province (01/23/2024, M=7.1, 41.19°N, 78.84°E) of the seismically active study region 39-46°N, 70-85°E is shown in red.

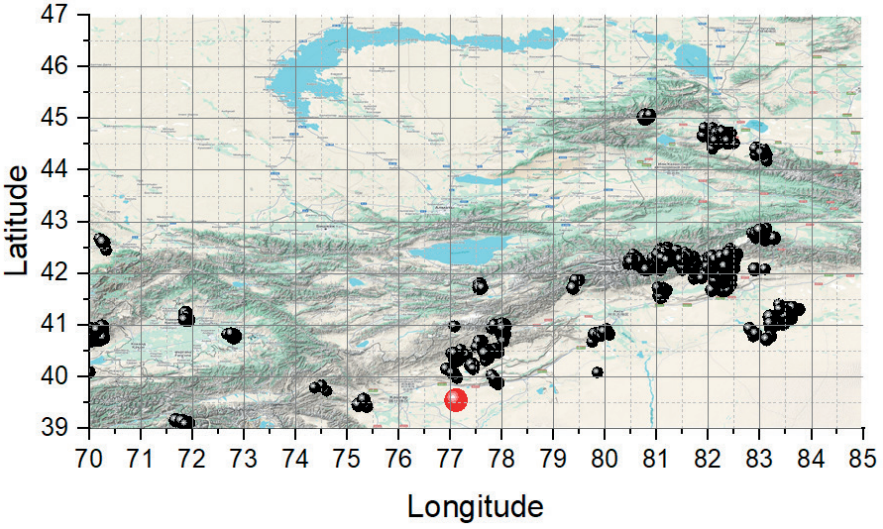
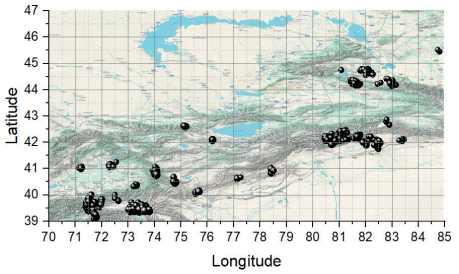
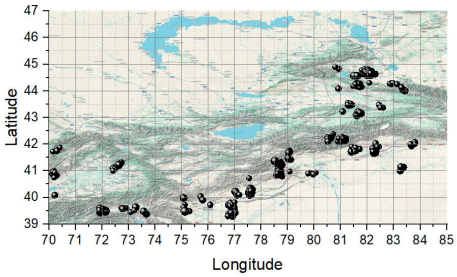


Figure 2. Map-scheme of distribution of earthquake swarms for 2023. In red is the epicenter of a strong earthquake that occurred in China in Aksu Province (01/23/2024, M = 7.1, 41.19°N, 78.84°E) of the seismically active study region 39-46°N, 70-85°E

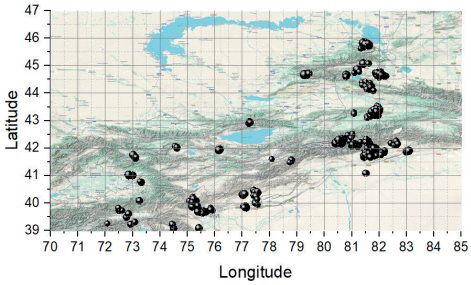
Below in Figure 3 are presented maps-schemes (by year) of the spatial-temporal distribution of earthquake swarms in the territory of the seismically active region of the Northern Tien Shan and adjacent territories for the period from 2017-2025 (Regional catalog, 2025). The radius of events is indicated depending on K.



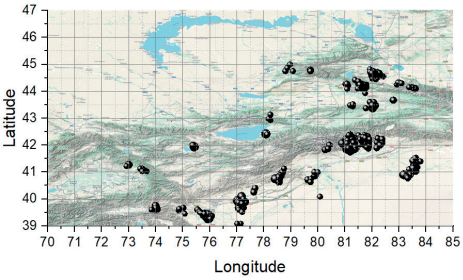
A) 2017



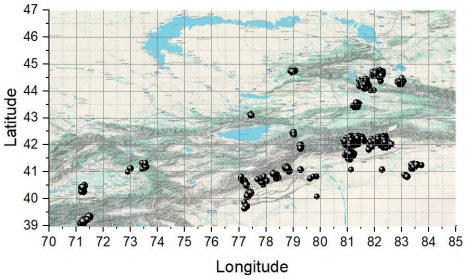
B) 2018



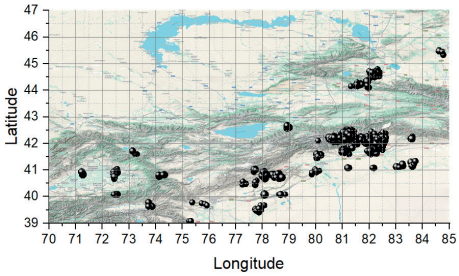
C) 2019



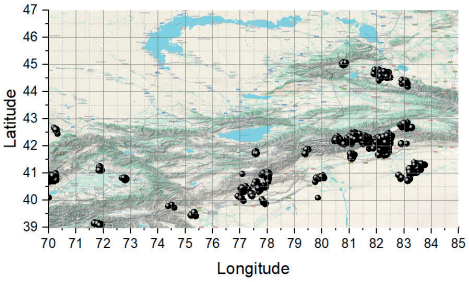
D) 2020



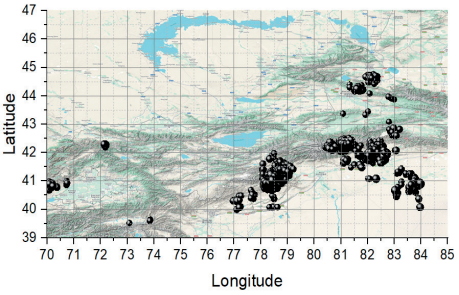
E) 2021



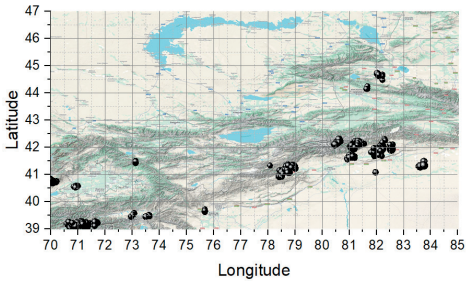
F) 2022



G) 2023



H) 2024



I) 2025

Figure 3. Maps-schemes of the distribution of earthquake swarms for 2017-2025 (A-I) by year in the territory of the seismically active region of the Northern Tien Shan and adjacent territories (radius of swarms depending on K)

The study of the relationship between earthquake swarms (weak seismicity) and the stress-strain state of the environment was carried out using the obtained numerical values of thermodynamic parameters in earthquake swarms for the period 2017-2025 (Regional catalog, 2025). Data on thermodynamic parameters in each of the swarm epicenters were calculated using a universal computational technique. The initial data for determining the thermodynamic parameters in earthquake swarms were the magnitude (M) and energy class (K) of earthquakes.

The calculations of the numerical values of the physical and mathematical parameters in the earthquake swarms of the Northern Tien Shan region and the adjacent territories are represented by the following equations (Tuliani, 1999):

$$\lg E = 9.257 + 2.7M - 0.1M^2 \quad (1)$$

$$\lg V(\text{км}^3) = 6.\text{б} + M(2.6 - 0.1M) \quad (2)$$

$$U = E / V \quad (3)$$

$$E_k = 2.7 + 0.1M \quad (4)$$

$$T(K) = 196.8K(\lg E_{\max} - \lg E) \quad (5)$$

$$\alpha_V = T(K)(\text{ 7733})^2 \quad (6)$$

$$G \approx k / V\alpha_V \quad (7)$$

$$\tau_{lp} = \sigma * \text{g}\varphi \quad (8)$$

$$\varepsilon = \alpha_V T(K) \quad (9)$$

$$\sigma = \varepsilon * G \tag{10}$$

$$\lg \eta = \lg \eta_{max} - \lg(E_{max} / E) \tag{11}$$

where 1 - E and M are the energy and magnitude of earthquakes, 2 - V is the critical value of the hearth volume, 3 - U is the potential energy density of seismic waves per unit volume (erg/cm^3), 4 – E_k is the specific energy of the hearth shape change, 5 - G is the volumetric modulus of elasticity, 6 -k – Boltzmann's constant, 7 – α_V is the coefficient of volumetric thermal expansion, 8 - τ_{cr} is the additional stresses discharged by the hearth, 9 - σ is the normal component of effective stresses, 10 - η is the viscosity of rocks in the hearth, 11 – η_{max} is the maximum value of the viscosity of the upper layers of the Earth.

Table 1 shows the numerical values of the parameters associated with some thermodynamic parameters in earthquake swarms, characterizing stresses and deformations in the foci (see Table 1).

Table 1.Numerical values of thermodynamic parameters of earthquake swarms

M	H	K	LgE	LgV	T°C	LgU	E_k	G*10^{11}	α_v	$\tau_{кр}$*10^8	ε	σ*10^9	lgη
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

As shown in Table 1, the parameters: E and M are the energy and magnitude of earthquakes, H (km) is the depth, K is the energy class, V is the critical value of the source volume, U is the density of the potential energy of seismic waves per unit volume (erg/cm^3), E_k is the specific energy of the change in the shape of the source, G is the volumetric modulus of elasticity, K is the energy class, αv is the coefficient of volumetric thermal expansion, τкр are the additional stresses released by the source, σ is the normal component of the effective stresses, Lgη is the logarithm of the viscosity of rocks in the source, η is the viscosity of rocks in the source (Poise).

Conclusion. The results obtained allow us to draw the following conclusions: based on the physical and mathematical criteria for recognizing earthquake swarms, it has become possible to identify areas of increased seismic activity in the study region. Earthquake swarms occur on the eve of strong seismic events, the foci of which are formed in the earth's crust from structural inhomogeneities saturated with high-temperature masses within 1.5-2 years. Due to the calculated physical and mathematical criteria, the algorithm for recognizing earthquake swarms is universal and can be applied to any seismically active region. The calculated thermodynamic parameters in the foci of earthquake swarms show more accurately the physical and mechanical conditions of the occurrence of earthquake swarms. In the course of the conducted research, an algorithm for recognizing earthquake swarms was applied, as one of the promising areas of application of AI. This algorithm allows for a more accurate assessment of the seismotectonic potential of the selected areas of earthquake swarm accumulation, and also provides the most accurate assessment of the seismic safety of the study area. The obtained scientific and practical results are of a research and applied nature and can be adapted to any seismically active region.

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