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Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

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PATTERNS OF FORMATION OF PHYSICAL AND MECHANICAL PARAMETERS OF STRONG EARTHQUAKE FOCI IN THE NORTHERN TIEN SHAN

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Abstract. *Relevance*. Identifying the zones where strong and destructive earthquakes originate remains a major challenge in modern seismology because the mechanisms controlling earthquake nucleation and localization within active fault systems are not fully understood. A key unresolved issue is the role of the spatial heterogeneity of the physical and mechanical properties of the Earth's crust in tectonic stress accumulation and the formation of strong earthquake sources. *Objective*. This study aims to identify the spatial and depth-related patterns of the physical and mechanical properties of the Earth's crust controlling the localization of strong earthquake sources in the Northern Tien Shan and to evaluate the role of mechanical heterogeneity in earthquake preparation. *Methods*. A comprehensive analysis of regional seismic data and elastic modeling results was performed. Distributions of P-wave (Vp) and S-wave (Vs) velocities were analyzed, dynamic elastic parameters, including shear, bulk, and Young's moduli,

were calculated, and their spatial gradients were determined to characterize crustal heterogeneity. *Results*. The strongest earthquake foci are localized mainly within transition zones characterized by pronounced mechanical contrasts rather than extreme elastic parameter values. These zones exhibit reduced S-wave velocities, lower shear modulus values, and elevated elastic parameter gradients at depths of 8–20 km, indicating stress concentration and increased rock deformability. The results demonstrate that spatial heterogeneity is a more reliable indicator of potential focal zones than the absolute values of elastic parameters. *Conclusions*. The study substantiates the decisive role of spatial gradients of elastic parameters as geophysical markers of strong earthquake localization in the Northern Tien Shan. A conceptual physico-mechanical model of earthquake source formation is proposed, accounting for the rheological structure of the seismically active belt and the distribution of mechanical contrasts within the crust.

Keywords: Northern Tien Shan; strong earthquakes; seismically active belt; seismogenic layer; physical and mechanical properties; earthquake source mechanics

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СОЛТҮСТІК ТЯНЬ-ШАНЬДАҒЫ КҮШТІ ЖЕР СІЛКІНІСІ ОШАҚТАРЫНЫҢ ФИЗИКАЛЫҚ-МЕХАНИКАЛЫҚ ПАРАМЕТРЛЕРІНІҢ ҚАЛЫПТАСУ ЗАҢДЫЛЫҚТАРЫ

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Аннотация. *Өзектілігі*. Күшті және жойқын жер сілкіністерінің ошақ аймақтарын анықтау қазіргі сейсмологиядағы негізгі мәселелердің бірі болып табылады, себебі белсенді жарылымдар бойындағы жер сілкінісі ошақтарының қалыптасуы мен орналасу механизмдері әлі толық зерттелмеген. Маңызды ғылыми мәселелердің бірі – тектоникалық кернеулердің жинақталуы мен күшті жер сілкіністері ошақтарының қалыптасуындағы Жер қыртысының физикалық-механикалық қасиеттерінің кеңістіктік әртектілігінің рөлін анықтау. *Зерттеудің мақсаты.* Жұмыстың мақсаты – Солтүстік Тянь-Шань аймағындағы күшті және жойқын жер сілкіністері ошақтарының орналасуын анықтайтын Жер қыртысының физикалық-механикалық қасиеттерінің кеңістіктік және тереңдік заңдылықтарын анықтау және сейсмикалық процестерді дайындаудағы механикалық әртектіліктің рөлін бағалау. *Әдістері*. Аймақтық сейсмологиялық деректер мен серпімді модельдеу нәтижелері негізінде P- және S-толқындардың жылдамдықтары, серпімділік модульдері және олардың кеңістіктік градиенттері зерттелді. Vp және Vs таралуы талданып, ығысу модулі, көлемдік сығылу модулі және Юнг модулі есептелді. *Нәтижелері*. Күшті жер сілкіністерінің ошақтары серпімді параметрлердің экстремалды мәндерінде емес, механикалық контрасттары жоғары өтпелі зоналарда орналасатыны анықталды. Бұл аймақтар 8–20 км тереңдікте төмен Vs мәндерімен, төмен ығысу модулімен және жоғары серпімділік градиенттерімен сипатталады. Кеңістіктік әртектілік әлеуетті ошақ аймақтарын анықтауда абсолюттік серпімді параметрлерге қарағанда ақпаратты көрсеткіш болып табылады. *Қорытынды*. Зерттеу нәтижелері Солтүстік Тянь-Шаньдағы жер сілкінісі ошақтарының орналасуында серпімділік параметрлері градиенттерінің маңызды рөлін дәлелдейді.

Түйін сөздер: Солтүстік Тянь-Шань, күшті жер сілкінісі, сейсмикалық белсенді белдеу, сейсмогендік қабат, физикалық-механикалық көрсеткіштер, ошақты механика

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ЗАКОНОМЕРНОСТИ ФОРМИРОВАНИЯ ФИЗИКО-МЕХАНИЧЕСКИХ ПАРАМЕТРОВ ОЧАГОВ СИЛЬНЫХ ЗЕМЛЕТРЯСЕНИЙ СЕВЕРНОГО ТЯНЬ-ШАНЯ

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Аннотация. *Актуальность*. Выявление зон возникновения сильных и разрушительных землетрясений остаётся одной из главных задач современной сейсмологии, поскольку механизмы формирования и локализации очагов в зонах активных разломов изучены не в полной мере. Одним из наиболее важных и дискуссионных вопросов является роль пространственной неоднородности физико-механических свойств земной коры в процессах накопления тектонических напряжений и формирования очагов сильных землетрясений. *Цель*. Выявить закономерности пространственного распределения физико-механических свойств земной коры, определяющих локализацию очагов сильных и разрушительных землетрясений Северного Тянь-Шаня, а также оценить роль механической неоднородности геологической среды в процессах подготовки сейсмических событий. *Методы*. Исследованы пространственные и глубинные закономерности формирования физико-механических свойств зон возникновения землетрясений. На основе региональных сейсмических данных и результатов упругого моделирования проведён комплексный анализ скоростей P- и S-волн, модулей упругости и их пространственных градиентов. Исследованы распределения скоростей продольных (Vp) и поперечных (Vs) волн, а также рассчитаны динамические упругие параметры, включая модуль сдвига, модуль объёмной упругости и модуль Юнга. *Результаты*. Установлено, что очаги наиболее сильных землетрясений локализуются преимущественно в переходных зонах с выраженными механическими контрастами, а не в областях

экстремальных значений упругих параметров. Эти зоны характеризуются пониженными скоростями Vs, сниженными значениями модуля сдвига (G) и повышенными градиентами упругих свойств на глубинах 8–20 км, что свидетельствует о концентрации напряжений и высокой деформируемости пород. Пространственная неоднородность физико-механических свойств является более информативным индикатором потенциальных очаговых зон, чем абсолютные значения упругих характеристик. *Выводы*. Научная новизна исследования заключается в обосновании роли пространственных градиентов упругих параметров как геофизических маркеров локализации очагов сильных землетрясений Северного Тянь-Шаня. Предложена концептуальная физико-механическая модель формирования очага землетрясения, учитывающая реологическое строение сейсмоактивного пояса и распределение механических контрастов в земной коре.

Ключевые слова: Северный Тянь-Шань, сильные землетрясения, сейсмоактивный пояс, сейсмогенный слой, физико-механические параметры, механика очага

Introduction. The generation of strong earthquakes remains a central problem in modern seismology, tectonophysics, and geodynamics. Despite significant progress in the study of spatiotemporal patterns of seismicity, the physical mechanisms that initiate focal failure remain the subject of active debate. In intracontinental orogenic regions such as the Tien Shan, earthquake processes are determined not only by the regional stress field but also by the complex mechanical structure of the earth's crust, including rigid blocks, weakened fault zones, and areas of intense fracturing (Abdullaev, 2002).

The seismogenic layer in such regions represents a mechanically heterogeneous environment within which tectonic stresses accumulate and redistribute. The Northern Tien Shan is one of the most seismically active inland regions of Central Asia. Numerous strong earthquakes with moment magnitudes Mw ≥ 6.5 are recorded here, posing a serious seismic hazard (Abdullaev et al., 2025). Despite a significant number of studies, the role of the physical and mechanical parameters of the Northern Tien Shan seismic belt and the seismogenic layer in influencing the processes of strong earthquake foci has not been sufficiently studied, especially quantitatively.

The aim of this work is to identify fundamental patterns in the formation of physical and mechanical parameters of the foci of the strongest earthquakes in the Northern Tien Shan and to assess their role in the mechanisms of initiation and development of focal destruction.

Literary review. Foreign and domestic researchers have studied the formation of strong earthquake foci in continental orogenic regions. This research is a key objective of modern seismology and geophysics. Particular attention has been paid to regions with high tectonic and seismic activity, such as the Northern Tien Shan, where complex interactions between deep and near-surface processes occur.

Research into the source zones of strong earthquakes has historically focused primarily on the analysis of macroseismic manifestations and seismic wave parameters. Today, with the development of instrumentation and digital data processing methods, it has become possible to study the internal structures of seismogenic belts and zones in greater detail, including the distribution of longitudinal and shear wave velocities. Variations in the elastic parameters of the medium have been studied in greater detail within the framework of elasticity theory, which has shown that wave propagation parameters are closely related to the physical and mechanical properties of rocks.

Modern research has demonstrated the important role of the rheological properties of the lithosphere in the formation of strong and catastrophic earthquake foci. Therefore, within the framework of rock rheology, the processes of stress accumulation and relaxation, which determine the conditions for the transition from an elastic state to brittle failure, have been examined. Numerous studies have established that the seismogenic layer (seismically active belt) is confined to depths of 5–25 km, where conditions of maximum tectonic stress concentration are realized.

In this regard, the concept of mechanical heterogeneity of the environment as a key factor in the localization of strong and catastrophic earthquake foci has received significant development. A number of studies have shown that zones with reduced shear wave velocities (Vs) and contrasting shear modulus values are potential areas for the accumulation of deformation energy. Publications (Tuliani, 1983; Tuliani, 1999) present a computational method for calculating the physical and mechanical parameters at earthquake foci of varying magnitudes, which made it possible to obtain numerical values for these parameters. It is also noted that such heterogeneities can be caused by both lithological features and the presence of fault structures and fluids (Tuliani et al.,2003).

The regions of Central Asia, particularly the Tien Shan, are characterized by a high degree of tectonic segmentation, a complex block structure of the crust, and high seismic activity, which determines the diversity of earthquake focal mechanisms and the spatial variability of their physical and mechanical parameters. Currently, numerical and elastic modeling methods are actively used. These methods allow us to reconstruct the distribution of stresses and strains in the lithosphere, as well as assess the influence of geomechanical and physical processes during the destruction of the environment and the occurrence of a strong earthquake.

Ultimately, although progress has been made in research into the patterns of physical and mechanical parameters at the foci of strong earthquakes, a number of unresolved issues remain. First, the spatial distribution of elastic parameters and their gradients within seismically active belts remains insufficiently studied. Second, their role in the occurrence of strong and catastrophic earthquakes has not been clearly elucidated. Third, the contributions of absolute values of physical and mechanical parameters to understanding the nature of their occurrence, compared to their spatial variability, require further clarification.

Thus, an analysis of existing research has shown that a key focus in modern seismicity research today is the transition from descriptive analysis of earthquake foci, strong earthquakes, and catastrophic events to identifying patterns of their formation based on a comprehensive consideration of the physical and mechanical properties of the environment. This is particularly relevant for the Northern Tien Shan, where high seismic hazard requires a deeper understanding of the mechanisms of focal processes.

Geological and tectonic structure of the Northern Tien Shan in terms of the development of major earthquake foci. As is well known, the Northern Tien Shan is an actively deforming intracontinental orogen formed as a result of the ongoing collision of the Indian and Eurasian lithospheric plates. Current deformations are driven by a system of deep Paleozoic faults, reactivated in the Cenozoic. The main structural elements of the region are large crustal blocks separated by a system of northeast- and sublatitudinal-trending reverse-thrust and strike-slip faults. These structures control the spatial distribution of seismicity and earthquake focal depths.

The seismogenic layer of the Northern Tien Shan spans depths from a few kilometers to approximately 25 km. Below this boundary, a transition from brittle failure to ductile rock flow occurs, corresponding to the brittle-ductile transition zone. Most strong earthquakes are concentrated in this deep region. Figure 1 shows a map of the main active faults (slips, thrusts, and normal faults) of continental Asia and the Northern Tien Shan, which form modern seismically active belts and zones. Figure 1 shows that all modern fault zones in Asia, fully activated during the Holocene, define the main seismically active belts and zones where catastrophic events are currently occurring, representing a region of geodynamic instability. While tectonic processes in the Earth's crust occur continuously, geodynamic processes, particularly seismic ones, occur intermittently, with a certain cyclicity and periodicity (Abdullaev, 2002).

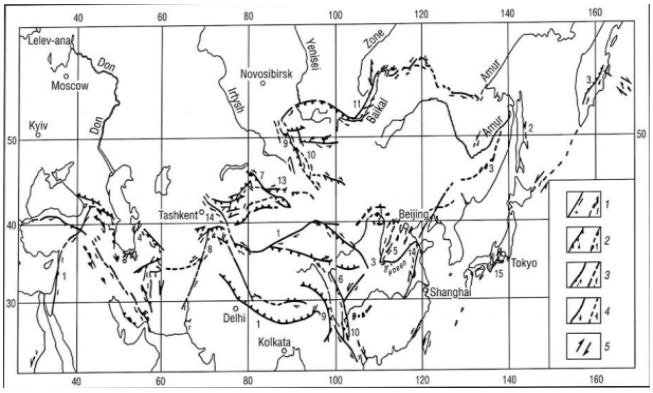

Figure 1. Map of the main active faults (slips, thrusts and normal faults) of continental Asia, which form modern seismically active belts and zones (according to Trifonov V.G., 1987) 1 - strike-slips, 2 - thrusts and reverse faults, 3 - normal faults, 4 - with an unknown direction of displacement, 5 - zones of shear deformations.

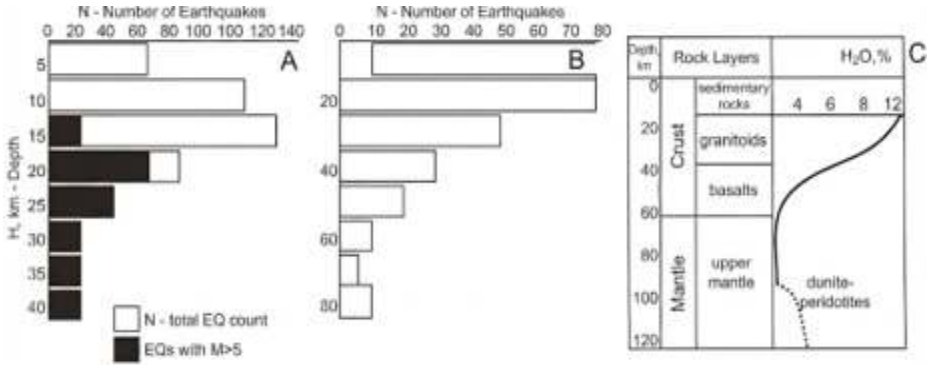

Figure 2. Histogram of the distribution of hypocenters of earthquakes in the Northern Tien Shan (A); continental Asia with M ≥6.0 (B) and a model of free water distribution by depth in the Earth's lithosphere (B).

While numerous weak seismic events in the upper crust (up to 10 km) are caused by a simple, widespread mechanism called "hydraulic fracturing," the confinement of major and strong seismic events to the granite layer is explained by two phenomena: the exceptionally strong physical and mechanical properties of granitoids, with their high shear and shear resistance and therefore high load-bearing capacity, and the simultaneous presence of significant amounts of free fluids, which create anomalous stresses in dislocation zones. Due to their increased plasticity and "creep," basaltic layers do not accumulate sufficient stresses to generate strong earthquakes.

Figure 2 shows that the maximum number of strong earthquakes (M > 5.0) and the main seismic energy are confined to depths of 15-30 km, less often 40 km, i.e. to the granite layer. From a physical point of view, this is an area of rapid transition of a certain volume of the geological environment from one quasi-stable state to another, which can be called a region of instability or a focus of tectonic or seismic stress development. Such a transition is accompanied by the transformation of a certain potential energy of the elastically deformable medium into kinetic and thermal energy. This results in multidirectional rapid rupture displacements, which are usually called an earthquake focus. An earthquake focus is a local linear region in the earth's crust or upper mantle, where elastic stresses accumulate and are suddenly released in the form of a rupture along a fault. The main physical and mechanical parameters of the source include: seismic moment (M_0) - a measure of the overall "size" of an earthquake; The source radius, shear, and stress, and the released stress—the reduction in stress at the source during rupture; the propagation velocity of longitudinal (P) and shear (S) waves, reflecting the elastic properties of the medium; the quality factor (Q) and spectral parameters associated with internal friction and energy dissipation in the source and surrounding medium. These quantities determine the seismic radiation spectrum and the mechanical energy of the rupture.

Materials and Methods. The study utilized regional and global earthquake catalogs, including events with magnitudes Mw ≥ 4.0 over a long period of instrumental observations, as well as those with magnitudes greater than 6.0. The arrival times of longitudinal (P) and shear (S) waves recorded by local and regional seismic networks were used to analyze the velocity structure of the Earth's crust. Recent laboratory measurements of crustal rocks recovered from deep levels of seismic zones (e.g., subduction complexes) show that P- and S-wave velocities, low porosity, and material density are closely related to the zone's susceptibility to rupture: stiffer regions can serve as zones of strong tremors. These elastic parameters are critical for estimating the critical length of faults on which large earthquakes can initiate. One of the key parameters of focal mechanics is the released stress—the measurable change in the stress state before and after rupture. Analysis of dynamic parameter catalogs (source radius, released stress, seismic energy) shows that: stress-drop can vary in different regions and depends on geodynamic conditions (e.g., Tien Shan); before strong earthquakes, average values of released stress often decrease, and the b-value (a characteristic parameter of the frequency distribution) increases, indicating non-stationarity of the seismic regime before a major event. Modern seismic tomography and models show that sources are not simple flat faults; their structure can be complex, three-dimensional, and include multiple segments. In subduction zones: large sources are located in areas of high seismic wave velocities, reflecting rigid blocks; The presence of low-velocity anomalies and elevated Poisson's ratio may indicate fluid accumulations and mechanical heterogeneity, which influences the initial excitation of a rupture. Recent reviews emphasize that fluid pressure, permeability, and hydrogeology of fault zones significantly influence the mechanical stability of a fault source: fluids can act as triggers for the onset of slip or, conversely, increase friction with changes in pore pressure; models incorporate changes in permeability and fluid pressure during fault preparation and recovery cycles. This area of research is considered one of the most relevant in earthquake physics, as interfacial processes (solid-liquid) can significantly alter rupture dynamics.

Modern dynamic models take into account the nonlinear mechanical properties of the fault surface and the surrounding medium: fault propagation is considered as a complex dynamic process with deviations from simple linear mechanics, taking into account plastic elastic behavior, multiscale fracturing and cohesive properties; multi-peak dynamic responses and mixed mechanisms (tension + shear) are observed in experimental dynamic loading models, which reflects the complex nature of the material failure and the rupture process under load (Afonso et al., 2013; Aki, Richards, 2002). Source parameters (seismic moment, stress drop, source radius, spectral features) are fundamental characteristics closely related to the mechanical properties of the source and the surrounding medium. New measurements of wave velocities and structural anomalies allow us to refine the models of stress distribution and rupture readiness. The role of fluids, hydrogeology and mechanical heterogeneities increases the focus on complex source models

that go beyond linear mechanics. Further development of 3D dynamic models that link large-scale geodynamics with small-scale fault mechanics; integration of observational data (seismic tomograms, stress-strain measurements) with source parameters; in-depth study of the role of fluids, temperature effects and mechanical heterogeneities in the cycle of earthquake preparation and failure. Velocity models were used to calculate the main elastic parameters under the assumption of an isotropic linear-elastic medium. The shear modulus (G), Young's modulus (E) and Poisson's ratio (ν) were determined by the standard relationships: $G = \rho V_s^2$, (1); $\upsilon = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)}$, (2); E = 2 G (1+ υ), (3), where (Vp) and (Vs) are the velocities of longitudinal and shear waves, (ρ) is the density of the medium.

To identify zones of mechanical contrasts, spatial gradients of elastic parameters were calculated. The relationship between mechanical characteristics and seismicity density was assessed using correlation analysis with verification of the statistical significance of the results. Other key criteria for localizing large earthquakes include: an increase in crustal thickness, an increase in the plane of ruptures per unit block volume, and the intensity of neotectonic movements (± displacements mm/year). To calculate other physical and mechanical parameters, a computational methodology published in [2-4, 21-22] and the formulas provided therein were used. These formulas were used to calculate the physical and mechanical parameters at the foci of the strongest earthquakes in the Northern Tien Shan; the calculations are presented in Table 1 (Abdullaev et al., 2025).

In this work, machine translation of text was used to better understand the essence of the research problem.

Results and discussion. Numerical values of the physical and mechanical parameters of the foci of the strongest earthquakes in the Northern Tien Shan for the period 1900-2026 were obtained (see Table 1). Velocity models reveal pronounced lateral and vertical heterogeneity within the seismogenic layer. The foci of strong earthquakes are predominantly localized in zones of reduced shear-wave velocities, where the reduction in Vs reaches 12-18% compared to the surrounding blocks. Minimum Vs values are observed at depths of 10-15 km, which corresponds to the region of maximum concentration of strong earthquake foci. The shear modulus (G) and Young's modulus (E) are characterized by significant variability both with depth and in plane. It has been established that strong earthquakes are not confined to zones with uniformly low or high elastic parameters, but are localized near the boundaries between mechanically rigid blocks and weakened fault zones. A statistically significant correlation was revealed between the density of earthquake foci and the shear modulus gradients (r = 0.65–0.72). This indicates that spatial contrasts in mechanical properties play a key role in the initiation of focal failure. Table 1 below presents the numerical values of the physical and mechanical parameters at the foci of the strongest earthquakes in the Northern Tien Shan, showing the temperature (T ° C) values at the foci, viscosity (η), shear and normal stresses, strains, elastic modulus, etc. By analogy with computer technology

in (Abdullaev et al., 2025), similar calculations of physical and mechanical parameters for the strongest earthquakes with M≥7 were carried out. Table 1 shows the numerical values of the obtained parameters. These values were obtained for the first time and can serve as a guide in the numerical assessment of other strong earthquakes. The obtained results confirm the model according to which the accumulation of tectonic stresses occurs within mechanically rigid crustal blocks, while rupture initiation occurs in adjacent weakened fault zones. Reduced values of the shear modulus and increased Poisson's ratio (ν) promote unstable sliding and the development of focal failure. Similar patterns of earthquake foci localization near elastic contrasts have been identified for the San Andreas Fault System, the forearc regions of Japan, and the Tibetan Plateau. This indicates the universal nature of the identified mechanical patterns. Based on the obtained data, a conceptual model of the focal point of a strong earthquake is proposed, in which rupture is initiated in a zone of mechanical weakening located at the boundary with a rigid crustal block in the brittle-ductile transition region. This structure ensures the simultaneous accumulation of stresses and the conditions for their unstable release.

Conclusions. Strong and very powerful earthquakes of the Northern Tien Shan are localized within the seismogenic layer at depths of 8–20 km.

The foci of strong and powerful earthquakes are confined to zones of sharp spatial gradients of physical and mechanical parameters.

Reduced shear wave velocities and reduced shear modulus values are reliable indicators of mechanical weakening of the medium.

Mechanical contrasts between rigid blocks and fault zones play a decisive role in the initiation of focal destruction.

The identified patterns are universal in nature and can be used in seismic hazard assessment.

Table 1. Table of physical and mechanical parameters in the foci of the strongest earthquakes of the Northern Tien Shan seismogen for 1900-2026.

Data	La	Lo	h	M	K	IgE	lgV	lgU	Ek	T©	G*10 ^{11}	a_n 10^{-5} K^{-1}	t_{cr} *10^8	e	p* 10^9	lgη (II)	η
1902-08-22T03:00:00.000	39,8	76,2	30	7,7	17,86	24,12	20,65	3,467	3,47	390,6096	4,14516	0,0000111	6,01	0,00736	3,053	24,628	4,2462E+24
1906-12-22T18:21:12.800	43,98	84,93	15	7,95	18,22	24,35	20,86	3,487	3,49	345,7391	4,44576	0,0000104	6,45	0,0064	2,846	24,856	7,1779E+24
1911-01-03T23:25:49.300	42,91	76,8	20	8,02	18,4	24,46	20,96	3,497	3,5	323,8942	4,60847	0,00000998	6,68	0,00596	2,746	24,967	9,2683E+24
1938-06-20T23:50:36.630	42,71	75,94	15	7,03	16,6	23,26	19,86	3,397	3,4	560,0544	3,30203	0,0000139	4,79	0,01161	3,832	23,767	5,8479E+23
1944-03-09T22:12:57.760	43,29	83,87	10	7,28	16,96	23,51	20,1	3,417	3,42	509,6735	3,51458	0,0000131	5,1	0,01024	3,6	24,023	1,0544E+24
1946-11-02T18:28:35.510	41,79	71,82	25	7,54	17,5	23,88	20,43	3,447	3,45	437,0544	3,87402	0,0000119	5,62	0,00843	3,266	24,392	2,466E+24
1949-02-23T16:08:11.420	41,92	84,23	10	7,36	17,14	23,64	20,21	3,427	3,43	485,0735	3,62863	0,0000127	5,26	0,00961	3,487	24,148	1,406E+24
1949-07-10T03:53:41.220	39,17	70,83	20	7,5	17,5	23,88	20,43	3,447	3,45	437,0544	3,87402	0,0000119	5,62	0,00843	3,266	24,392	2,466E+24
1961-04-13T16:34:44.590	39,76	77,71	35	7,04	16,6	23,26	19,86	3,397	3,4	560,0544	3,30203	0,0000139	4,79	0,01161	3,832	23,767	5,8479E+23
1974-08-11T01:13:55.500	39,45	73,83	9	7,3	17,14	23,64	20,21	3,427	3,43	485,0735	3,62863	0,0000127	5,26	0,00961	3,487	24,148	1,406E+24
1978-03-24T21:05:48.200	42,83	78,6	33	7,1	16,78	23,39	19,98	3,407	3,41	534,6672	3,40582	0,0000135	4,94	0,01091	3,715	23,896	7,8705E+23
1985-08-23T12:41:56.160	39,43	75,22	6,8	7	16,6	23,26	19,86	3,397	3,4	560,0544	3,30203	0,0000139	4,79	0,01161	3,832	23,767	5,8479E+23
1992-08-19T02:04:37.410	42,14	73,57	27,4	7,3	17,14	23,64	20,21	3,427	3,43	485,0735	3,62863	0,0000127	5,26	0,00961	3,487	24,148	1,406E+24
2024-01-22T18:09:04.340	41,25	78,65	13	7	16,6	23,26	19,86	3,397	3,4	560,0544	3,30203	0,0000139	4,79	0,01161	3,832	23,767	5,8479E+23

References

Abdullaev A.U. (2002) Flyuidniy regim zemnoy kory seismoaktivnyh oblastey. [Fluid regime of the earth's crust in seismically active regions] — Almaty: Evero. – 352 p. (in Russ.).

Abdullaev A.U., Lyutikova V.S., Litovchenko I.N. (2025) Machine learning for intelligent pattern recognition methods for seismic safety (using earthquake swarms as an example). Seismoprognosis Observations in the Territory of Azerbaijan. – Vol. 27. – No. 1. – P. 3-9. DOI: 10.59849/2219-6641.2025.1.3. (in Eng.).

Abdullaev A.U., Lyutikova V.S., Litovchenko I.N. (2025) Swarm recognition algorithm as promising artificial intelligence method in seismological research. News of National academy of sciences of the Republic of Kazakhstan, series of geology and technical sciences. – Vol. 6. – No. 474. – P. 8-21. DOI: 10.32014/2025.2518-170X.567 (in Eng.).

Abdullaev A.U., Sylkanova A.O., Yesenzhigitova E.Zh., Khachikyan G.Ya. (2023) Ob ocenke sejsmotektonicheskogo potenciala: prakticheskij aspect v svyazi s geoekologiej. [On the assessment of seismotectonic potential: Practical aspects and seismic hazard analysis]. Geography and Water Resources. – No. 1. – P. 42-47. DOI: 10.55764/2957-9856/2023-1-42-49.5 (in Russ.).

Afonso J.C., Ranalli G., Allen M.B. (2013) The mechanical structure of continents: Constraints from lithospheric strength and seismic data. Earth and Planetary Science Letters. – No. 375. – P. 1-9. DOI: 10.1016/j.epsl.2013.05.011. (in Eng.).

Audet P., Bostock M.G., Christensen N.I., Peacock S.M. (2009) Seismic evidence for overpressured subducted oceanic crust and megathrust fault sealing. Nature. – Vol. 457. – No. 7225. – P. 76-78. DOI: 10.1038/nature07650. (in Eng.).

Burov E.B. (2011) Lithospheric rheology and orogenesis: Mechanisms and tectonic implications. Tectonophysics. – Vol. 490. – No. 1-2. – P. 1-17. DOI: 10.1016/j.tecto.2010.03.001. (in Eng.).

Chen C., Gao S.S., Lee C.T.A. (2017) Mantle transition zone discontinuities beneath the Tien Shan region. Geophysical Journal International. – Vol. 211. – No 1. – P. 80-92. DOI: 10.1093/gji/ggx287. (in Eng.).

Das S., Aki K. (1977) Fault zone trapped waves in the presence of shallow crustal heterogeneity. Bulletin of the Seismological Society of America. – Vol. 67. – No 3. – P. 771-794. DOI: 10.1785/BSSA0670030771. (in Eng.).

Kawakatsu H., Watada S. (2006) Seismic structure of subcontinental lithosphere. Nature. – Vol. 441. – P. 333-337. DOI: 10.1038/nature04754. (in Eng.).

Lei J., Zhao D. (2007) Teleseismic P wave tomography beneath the central Tien Shan. Physics of the Earth and Planetary Interiors. – Vol. 161. – No. 1-2. – P. 141-151. DOI: 10.1016/j.pepi.2007.05.002. (in Eng.).

Li X., Chen Y., (2006) Seismic anisotropy of the crust and upper mantle in central Asia. Earth and Planetary Science Letters. – Vol. 253. – No. 1-2. – P. 237-249. DOI: 10.1016/j.epsl.2006.10.015. (in Eng.).

Litovchenko I.N. (2009) Phizicheskie parametry ochagovih zon silnyh zemletryasenij na Severnom Tyan-Shane [Physical parameters of focal zones of strong earthquakes in the Northern Tien Shan]. Bulletin of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. – P. 59-67. (in Russ.).

Litovchenko I.N., Lyutikova V.S. (2025) Thermodynamic parameters of earthquake swarms. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. – No. 3. – P. 81-90. DOI: 10.53939/1560-5655_2025_3_81 (in Eng.).

Liu Y., Rice J.R. (2007) Spontaneous failure of rate-state faults: Nucleation and aftershock sequences. Journal of Geophysical Research. – Vol. 112. B09404. DOI: 10.1029/2007JB004930. (in Eng.).

Lyutikova V.S., Litovchenko I.N. (2019) Tekhnologija raspoznavanijz obrazov (v vyjavlenii roev zemletrjaseniy) [Pattern recognition technology in detecting earthquake swarms] In: Proceedings of the International Conference of Young Scientists and Students. Bishkek, Kyrgyzstan. – P.104-108. (in Russ.).

Makeyeva L.I., Vinnik L.P., Roecker S.W. (1992) Shear-wave splitting and small-scale convection in the continental upper mantle. Nature. – Vol. 358. – P. 144-147. DOI: 10.1038/358144a0. (in Eng.).

Tuliani L.I. (1983) Svyaz' mezhdu magnitudoy zemletryaseniya i termodinamicheskimi parametrami v zone ochaga. [Relationship between earthquake magnitude and thermodynamic parameters in the focal zone]. Reports of the Academy of Sciences SSSR. – Vol. 270. – No.1. – P. 74-77. (in Russ.).

Tuliani L.I. (1999) Seysmichnost' i seysmicheskaya opasnost' na osnove termodinamicheskikh i reologicheskikh parametrov tektonosfery. [Seismicity and Seismic Hazard Based on Thermodynamic and Rheological Parameters of the Tectonosphere]. The scientific world, Moscow. (in Russ.).

Tuliani L.I., Levin L.E. (2003) Opyt prognozirovaniya zemletryaseniy na Kavkaze [Experience of earthquake prediction in the Caucasus]. Reports of Earth Sciences. – Vol. 389. – No. 1. – P. 108-110. (in Russ.).