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Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
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GEOLOGICAL-AND-TECTONIC CONDITIONS OF FORMATION AND FOCAL MECHANISM OF TORAIGYR-SOGUETY EARTHQUAKE, May 30, 2012

Abstract. The seismic characteristic of Toraigyr-Soguety earthquake is presented. The significant seismic events of the area are demonstrated including Chilik catastrophic earthquake. Geological-and-tectonic conditions of the epicentric areas of Chilik and Toraigyr-Soguety earthquakes are described. Kinematics of neotectonic faults is considered with respect to directions of main stress axes. Two models of focal mechanism of Toraigyr-Soguety earthquake compare with tectonic deformations of the area.

Key words: earthquake, epicentric area, geological-and-tectonic conditions, neotectonic fault, kinematics of fault, main stress (deformations) axes, models of earthquake focal mechanism, fault planes.

Introduction. The epicenter of earthquake with energy class K = 13.7÷14.2 and hypocentral depth H = 20 km was fixed by seismographs of the Seismological Experimental and Methodical Expedition (SEME) of the Ministry of Education and Science of Republic of Kazakhstan at a point on the surface with the coordinates 43° 23` N and 78° 46` E on May 31, 2012, at 3 o'clock, 20 min., 56.7 sec of the local time (On May 30, 2012, at 21 o'clock, 20 min., 56.7 sec of GMT). The surface wave magnitude been measured by a seismograph of the medium-term period amounts to $M_S = 5.0$, but the longitudinal wave magnitude been measured by a short-period seismograph amounts to Mpva = 6.0. From the GCMT data the surface wave magnitude M_S is equal to 5.4, and the hypocentral depth is equal to H = 27 km [1]. Regarding of geological-and-tectonic conditions the epicenter of the earthquake is projected onto the southern limb of Soguety graben syncline, in 3-5 km to the north from Toraigyr uplift (figure 1). Therefore we are proposing to name that earthquake Toraigyr-Soguety. In the source [2], this earthquake is barely named Soguety, so it does not allow distinguishing between it and others, which would occur in Soguety depression.

It is possible to judge about kinematics of movements along possible planes of ruptures in the focus of Toraigyr-Soguety earthquake using the interpretations of the earthquake focal mechanism of the SEME or the GCMT earthquake catalog. It would be interesting to know, what is the link between parameters of earthquake focal mechanism (EFM), tectonic structure, directions of main stress axes and type of modern movements along active faults in the area of Toraigyr-Soguety earthquake focus? The investigation of formation of Toraigyr-Soguety earthquake attracts particular interest also in connection with one more circumstance. That earthquake is considered to be the strongest in energy (K = 13.7) among all earthquakes recorded by seismographs of SEME in the territory bounded with the coordinates 43° – 44° N and 78° – 80° E since 1950 till 2017 (see table 1).

Table 1 – The earthquakes with energy class 12 and more, which occurred since 1950 till 2017
in the territory bounded with the coordinates 43-44° N and 78-80° E (from the SEME data)

Year	Month	Day	O'clock	minutes	Seconds	Lat.	Long.	Kp	H, km	Mpva
1950	8	8	13	14	0,0	43°12’	79°12’	12,0	?	?
1951	2	17	11	46	14,1	43°18’	78°54’	12,0	?	?
1957	12	20	11	1	26,0	43°00’	78°30’	12,0	30	?
1974	3	4	14	3	56,8	43°53’	78°15’	12,2	?	?
1975	2	12	13	34	52,4	43°10’	78°47’	12,6	25	5,1
1982	8	12	10	39	57,6	43°03’	79°48’	12,1	?	4,5
1986	2	14	1	52	1,0	44°00’	78°12’	12,7	20	4,3
1986	5	10	12	47	41,0	43°53’	78°11’	12,4	10	3,8
1986	7	17	8	15	34,2	43°17’	78°00’	12,4	13	3,9
2012	5	30	21	20	56,7	43°23’	78°46’	13,7	20	6,0

Notes: 1 Dates of the earthquakes are of GMT (Greenwich Mean Time) in table 1 and hereunder.
2 The designations of K, H, Mpva parameters are explained in the text.

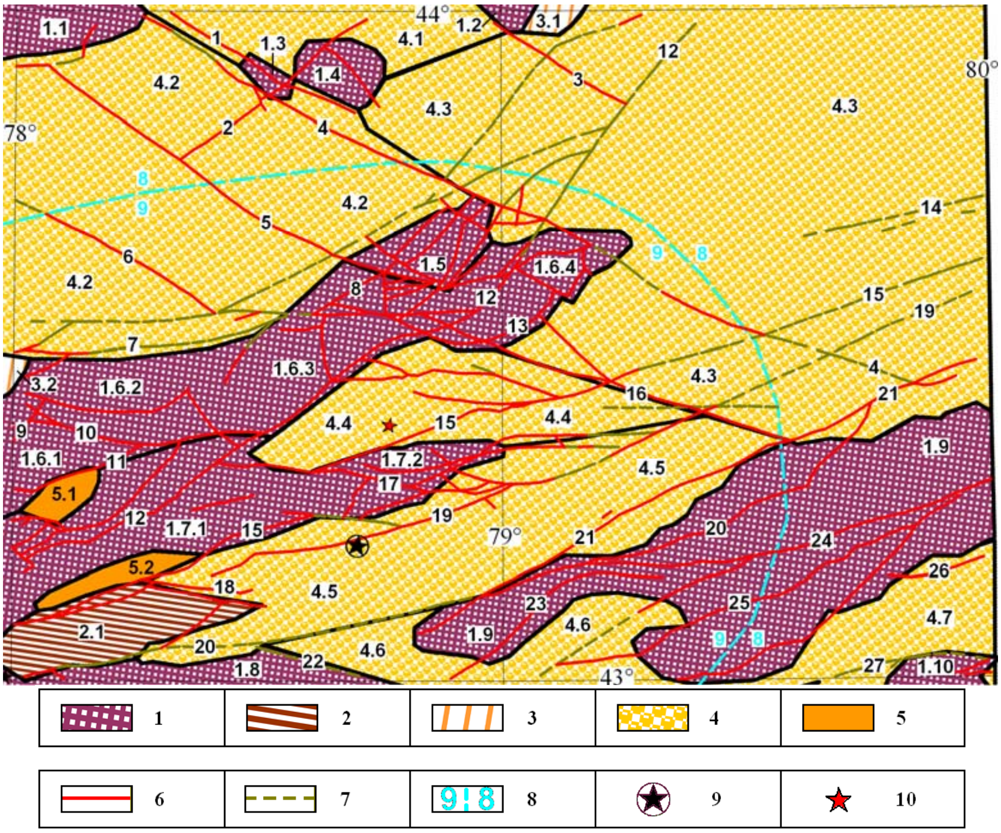

Figure 1 – Neotectonic zoning and seismicity of the area of the epicenter of Toraigyr-Soguety earthquake.
Compiler: A. R. Zhdanovich

Neotectonic zoning [3]: **1-5 – epiplatform region, subregion of intense Alpine orogenesis**: 1 – ***arched block uplifts*** (1.1 – 1.4 – uplifts of Dzungar Alatau: 1.1 – Sholak, 1.2 – Katutau, 1.3 и 1.4 – the western and eastern Ulken Kalkans; the orogens of North Tien Shan: 1.5 – 1.7 – uplifts of Zaili Alatau: 1.5 – Balaboguty, 1.6 – Karachin (ridges: 1.6.1 – Karash, 1.6.2 – Bakaidyntau, 1.6.3 – Soguety, 1.6.4 – Ulken Bogetty), 1.7 – Donzhailau (1.7.1 –Sarytau Mountains, 1.7.2 – Toraigyr Mountains), 1.8 – East Kungei, 1.9 – West Ketmen, 1.10 – El’shyn-Buiryk), 2 – ***highlands and mountain plateaus***: 2.1 – Dalaashyk Highland, 3 – ***foothill steps and adyrs*** (3.1 – South Dzungar, 3.2 – Zaili), 4 – ***intermountain troughs*** (4.1 – Konurolen Basin, 4.2 – West Ili graben syncline, 4.3 – Panphilovsk

(East Ili, Dzharkent) graben syncline, 4.4 – Soguety Basin, 4.5 – Zhalanash Basin, 4.6 Karkara (West Kegen) Basin, 4.7 – East Kegen Basin), 5 – ***intermontane depressions*** (5.1 – Asy, 5.2 – Zhinishke); 6-7 – **neotectonic faults** (1 – Kalkan Shift, faults: 2 – Kalkan, 3 – West Katutau, 4 – Chundzha-Dubun (Chundzhin), 5 – Karasai, 6 – Bas-Boroldai (Sorkol'), 7 – Karaturuk, 8 – Balaboguty, 9 – Tauturgen, 10 – Kiikbai-Zhumak, 11 – northwestern branch of Chilik-Kemin Zone, 12 – southeastern branch of Chilik-Kemin Zone, 13 – Boguty, 14 – Ili, 15 – North Dalaashyk, 16 – Boguty-Charyn, 17 – Toraigyr, 18 – Beskaragai, 19 – Karadala-Charyn, 20 – North Kuluktau (Baisorun-Chilik), 21 – North Ketmen, 22 – Zhalanash, 23 – South Kuluktau, 24 – Central Ketmen Zone, 25 – Tuyuk, 26 – South Ketmen, 27 – Chul'adyr Zone): 6 – ***manifested on the surface***, 7 – ***disguised under the sediment cover***; 8-10 – **seismic elements**: 8 – ***boundaries of the zones of normative MSK-64 seismic intensity*** (intensity 8 and 9) ([4], simplified), 9-10 – epicenters of earthquakes: 9 – ***Chilik*** (11.07.1889), Ms 8,1, K 17,9, H 40 km [5], 10 – ***Toraigyr-Soguety*** (30.05.2012), Ms 5,0, K 13,7, H 20 км (from the SEME data)

As is clear from table 1, during the last 68 years the maximal energetic class of sampled earthquakes did not exceed 12.0 over a period of 1950 – 1957 years, 12.6 over a period of 1974 – 1975 years, 12.7 over a period of 1982 – 1986 years. Periods of 1958 – 1973 years, 1976 – 1981 years, 1987 – 2011 years, and 2013 – 2017 years are characterized by relative seismic lull.

Examining the seismic history of the area, we don't have to omit mention of Chilik catastrophic earthquake that occurred on July 11, 1889 in 20 km towards the south-southwest from the focus of Toraigyr-Soguety earthquake at a point on the surface with the coordinates 43° 12` N and 78° 42` E (see figure 1).

Chilik earthquake was of the surface wave magnitude Ms = 8.1, energy class Kp = 17.9, and seismic intensity I_0 = 10 on the International MSK-64 Scale [5-7]. Pleistoseistal area of the Chilik earthquake captured the eastern spurs of the Zaili and Kungei Alatau Ridges, and meridian distance from the eastern coast of Lake Issyk Kul up to the Ili River [5, p. 497]. Widespread rock falls, screes, and lineal seismic dislocations were formed in the mountains. Sizeable damages of the Earth surface were observed on the beach of Lake Issyk Kul, between settlements Uital and Sazonovka. A tsunami wave formed straight in Lake Issyk Kul had flooded the western beach. Pleistoseistal area of the Chilik earthquake is practically the same as the zone of seismic intensity 9 established by I. V. Mushketov on the ground of 60 questionnaires with description of macroseismic destructions of buildings [7, p. 27].

Chilik earthquake had shown itself in such significant scale of macroseismic effect, which was never surpassed by subsequent earthquakes. So the intensity zone of 9 on a statutory map of seismic risk zoning (SRZ) of Kazakhstan Republic of 2006 (see Fig. 1) in many respects repeats the intensity zone of 9 of Chilik earthquake [8].

On the SRZ map the epicenter of the Toraigyr-Soguety earthquake is located within the intensity zone of 9, a bit towards the North from the boundary of the eastern segment of Zaili seismogenerating zone of M ≤ 7,0 [4,8].

The intensity of earth tremor in the epicenter of Toraigyr-Soguety earthquake is estimated by 6 points of the MSK-64 scale, according to the SEME data of macroseismic observation. During earthquake no serious destructions were observed. Only fissures were formed and plaster crumbled in some buildings of Kok-Pek settlement and near Bartogai reservoir.

Geological-and-tectonic conditions of the earthquake area. In figure 1 some neotectonic structures [3] and faults of the epicentric areas of Chilik and Toraigyr-Soguety earthquakes are shown. The Toraigyr uplift, which is nearby to the Toraigyr-Soguety earthquake epicenter, constitutes the eastern termination of the system of Zaili Alatau Ridges. The arches of the Northern Tien Shan – Zaili and Kungei Alatau – are the members of the region of Caledonian folding [9, p. 10]. Ili graben syncline and spurs of Dzungar Alatau are situated northward and present the part of the Zhongar-Balkhash Folding Region with Hercynic basement which arose in the late Paleozoic marginal sea's place during the late Paleozoic and the early Triassic epoch [10, p. 7, 256]. Faults trending to the east-northeast, north-west and north-east had arisen at the times of Hercynic, Caledonian and former cycles of tectogenesis. They are the boundaries of blocks of the consolidated basement [11, p. 187]. Most of the modern morphostructures are inherited from Paleozoic structures [12]. For example, West Ili Graben Syncline is inherited from the eastern part of Ili

Synclinorium of Hercynic age [13, p. 36]. Kungei and Zaili uplifts, and their eastern prolongation – Ketmen uplift – are inherited from Caledonian anticlinoria of the same names. Outcrops of folded Caledonian basement consisting of Cambrian and Ordovician formations stretch in the form of a narrow belt along the fold axis of Ketmen uplift [11, p. 154].

In the regard of features of formation of morphostructures during the Alpine tectonic cycle the Ketmen, Kungei and Zaili uplifts are wholly allocated within the area of the North-Eastern Tien Shan segregated by the Talas-Fergan fault from the South-Western Tien Shan. Vertical movements revealed themselves more actively in the North-Eastern Tien Shan than in the South-Western Tien Shan where horizontal movements prevail [14, p. 62]. In general block-and-folding structures of the Tien Shan Mountains the block faulting and movements along faults are more significant than folding and plicated dislocations [15]. Mountain ridges and depressions (basins) correspond to horst-anticlines and graben-synclines. Territory of the Ketmen, Kungei and Zaili ridges, where seismicity is the highest in Kazakhstan, is referred to as the Almaty Seismically Dangerous Area [16].

O. K. Chediya has singled out in the eastern pericline of the Zaili morphostructure, called him megafold, the third-order structures from south to north: Ili, Donzhailau, and Karachin horst-anticlines [9, p. 187-190]. The same three eastern branches of the Zaili morphostructure were named the Dalaashyk, Sarytau-Toraigyr, and Karash-Boguty uplifts by K. T. Kulikovski and V. F. Shlygina earlier [11, p. 181].

The Ili Horst-Anticline corresponds to the Dalaashyk Highland. The Donzhailau Horst-Anticline is represented by Sarytau and Toraigyr Mountains. The Karachin Horst-Anticline consists of Karash, Bakaidyntau, Soguety, Ulken Bogetty ridges from west to east (see Fig. 1). The Sarytau Mountains are edged by intermontane depressions: the Asy in the north and the Zhinishke in the south. To the east the Zhinishke depression is extended by the large intermountain trough Zhalanash.

That was in the Zhalanash trough, in and around of the Karadala-Charyn fault, on a site of the closest approach of the riverbeds of the Charyn and the Chilik where the epicenter of Chilik catastrophic earthquake was identified by I. V. Mushketov [5,7].

The Soguety Basin and the Toraigyr uplift, like the most neotectonic structures of the region, strike to the east-northeast. The epicenter of Toraigyr-Soguety earthquake, as shown in Fig. 1, is located on the southern limb of Soguety graben syncline, near its axis. The North Dalaashyk fault is the nearest to the epicenter of the Toraigyr-Soguety earthquake and passes at the distance of 3 km to the southeast, setting the southern limb of Soguety graben syncline apart from the Toraigyr uplift. The position of the North Dalaashyk Fault in figure 1 was specified from [17]. Authors of the article [2, p. 144,148] associate the source of Toraigyr-Soguety earthquake with the zone of Kapchagai-Chilik fault striking to the northwest but it isn't confirmed by the current research.

The strike azimuth of the North Dalaashyk fault is equal to 70° both near the epicenter of Toraigyr-Soguety earthquake and over the greater part of the own manifestation. The north limb of the Soguety graben syncline is separated from the Karachin uplift by the southeastern branch of Chilik-Kemin Zone of faults.

Thickness of the Cainozoic deposits amounts to 100 – 400 m, which is based on the data of drilling in the area of the Soguety graben syncline, near epicentre. The Cainozoic sediments are underlain by acid volcanic rocks of the Upper Paleozoic [18]. The bottom of the Cainozoic sedimentary rock sequence of Soguety and Zhalanash graben synclines consists of the Miocene nonsegmented red clay with basal marl exposed in the Charyn canyon. To the north from the Toraigyr Mountains, in the Soguety depression the Miocene is overlaid by Ili strata (N_2^3 *il*). Ili strata are represented by conglomerates, detritus, sandstones by thickness of 40-50 m and siltstone, which changes the sequence to the north from the mountains [19, p. 43,48].

There was a lake in the Soguety depression where lacustrine sediments were accumulated before the end of the Middle Pleistocene (B.C. 110,000) [20]. Starting from the Upper Pleistocene, after a debacle of the lake dam, deluvial, alluvial, and proluvial facies have been forming the upper part of the Quaternary sequence.

As shown in figure 1, first-rate arched block uplifts, intermountain and intermontane basins strike according to the azimuth about 70°-80°, towards the east-northeast. This direction is referred to as the

Tienshan [12]. Neotectonic faults of the Tienshan direction are marked in the relief in the form of tectonic scarps, which divide slopes of the Zaili Alatau into longitudinal latitudinal steps.

Previously we have executed statistical analysis of fault systems of Northern Tien Shan and Dzhungariya [21]. The average strike azimuth of neotectonic faults of the Tienshan system, being calculated like a weighted average, taking into account the length of each fault, equals to 74.89° [22, p. 67].

Such regional faults as the Central Ketmen, North Kuluktau (Baisorun-Chilik), North Ketmen, Karadala-Charyn, North Dalaashyk, Chilik-Kemin, and Karaturuk (see figure 1) edge limbs of horst-anticlines at the margins with neighbouring parts of depressions or pass across the paraxial parts of horst-anticlines and graben-synclines, and also strike towards the east-northeast. Listed above faults are tectonically movable; they stretch for a hundred kilometers and are surrounded by intensively fissured rocks of about several km wide. Chilik-Kemin fault is a crust-cutting disjunctive structure cutting the Earth's crust up to its floor, up to depth of 50 km [23]. The other faults are plunged down into the Earth's crust, as a rule, up to depth of 10-15 km, keeping within limits of granite-gneiss layer.

Majority of the earthquake focuses of the Almaty Seismically Dangerous Area is distributed in the range of 5-20 km of depths and is confined within some deep faults and large-scale branch faults, being renovated at the newest time [16,23,24]. According to Kurskeyev A. K., geological medium at a depth of 5-20 km is in brittle-elastic condition and is capable of accumulation of great tectonic strain, promoting the strongest earthquakes such as historical ones: Vernyi (1887, M_{LH} = 7.3), Chilik (1889, M_{LH} = 8.3), Kemin (1911, M_{LH} = 8.2), Suusamyr (1992, M_{LH} = 7.3) and others. The plastic-viscous layer of the Earth's crust (below 25 km) is good to form the sources of smaller dimensions and, conformably, of less energy [24, p. 63-65].

The system of strike-slip faults trending towards NW exerts appreciable influence on the neotectonic structures of Northern Tien Shan and Dzhungariya. Statistical analysis of this strike-slip faults' system, which is referred to as the Chu-Ili [23, p. 62], reveals that the average strike azimuth of that system, being calculated like a weighted average, taking into account the length of each fault, equals to 302.37° [22, p. 67]. In the area of investigation such NW faults as West Katutau, Chundzha-Dubun (Chundzhin), Karasai, Boguty-Charyn, Bas-Boroldai (Sorkol'), Kalkan Shift, and others (see figure 1) are considered to be strike-slip faults with right-lateral component [12, 21-23]. NW shifts by length of 20 - 150 km become morphologically apparent in periclines of arched block uplifts, highlands, intermountain and intermontane depressions. Some right-lateral strike-slip faults crossing morphostructures displace their parts in different directions. At the neotectonic stage a reconstruction of the ancient tectonic plan ensues from forcing of NW shifts.

The Kalkan Shift situated on the south periphery of uplifts of Dzungar Alatau (see in the upper (northern) part of figure 1) strikes towards the north-west (azimuth 300°) and crosses Permian stratovolcano Kalkan, which was active in the Eocene and the Oligocene, during its Alpine regeneration [20]. At the present time stratovolcano is divided by the Kalkan Shift into 2 parts: the western and eastern Ulken Kalkans.

As shown in figure 1, the Kalkan Shift is characterized by right-lateral (dextral) component of shifting and displaces the parts of the puy (stratified cone) made of Permian dacite and andesite tufas in different directions over a distance of 10 km.

Analyzing the geological structures of Dzungar Alatau and adjacent depressions including Ili one, L. K. Didenko-Kislitsina has established that Dzungar Alatau is the autonomous epiplatform Pliocene-Quaternary orogen [13].

If we connect the beginning of displacement of stratovolcano Kalkan with the beginning of the Pliocene (B.C. 5.8m), the strike-slip rate along the Kalkan Shift is estimated at 10 km / 5.8 m years = 1 000 000 cm / 5 800 000 years = 1.7 mm/a.

If to consider system of NW shifts from the north to the south in the following sequence: the West Katutau fault, Kalkan Shift, Chundzha-Dubun fault, Karasai fault, et cetera, it is easy to determine that they are located regularly every 20-30 km (see figure 1). This indicates that segment of the Earth's crust covering front ranges of the South Dzungaria and the eastern virgations of the Zaili Alatau are in the condition of tangential compression.

We can find out from the right-lateral shifting along the Kalkan Shift striking to the azimuth 300° that the azimuth of axis of tangential compression is equal about 345°. For this purpose it is enough to combine the azimuth of striking 300° and theoretical corner 45° between a plane of a fault and an axis of compression, as it takes place for both fault planes and main axes of compression and stretching [25]. It is obvious that any faults being perpendicular to the axis of compression, striking to the azimuth 345°-270° = 75°, will develop like thrusts and underthrust faults. Consequently, the component of a motion down and upward along the dip line should prevail among faults with the Tienshan direction (75±5°). Really, as appears from [11, p. 187], the faults with the Tienshan direction and more scarce faults striking to the NE develop like upthrow-shifts with the left-lateral displacement and quite often are transformed into upthrusts. Planes of faults, striking towards ENE and NE, often dip under mountain structures at angle about 70-80°.

Earthquake focal mechanism (EFM). Let's consider two solutions of focal mechanism of Toraigyr-Soguety earthquake represented in figure 2. The first EFM is from the SEME data (see figure 2, A). The second EFM is from the Global Catalog of earthquakes (see figure 2, B) [1]. After that we'll compare two solutions of EFM with each other and collate them with kinematics of the nearest neotectonic faults. Table 2 includes parameters of three Main (Principal) Stress Axes and two possible fault planes for each variant of two EFM.

Additionally, we have estimated a shear angle and components of unit vector of movement on the plane (D_x and D_θ) by applying the method stated in [25].

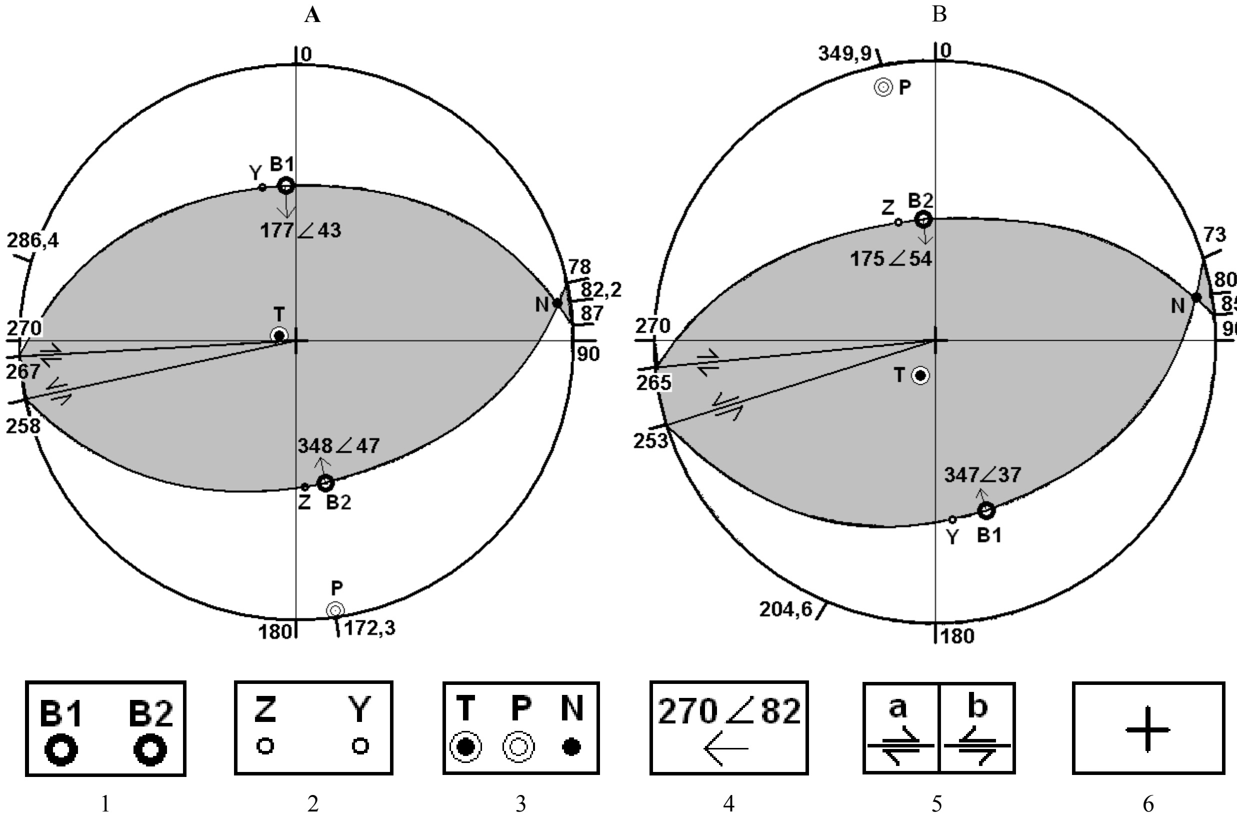

Figure 2 – The stereograms of focal mechanism of Toraigyr-Soguety earthquake (30.05.2012) on the upper hemisphere of the Schmidt's net: from the SEME data (A) and from the GCMT data [1] (B). Compiler: A. R. Zhdanovich
1 – vertices of fault planes: of the first one (B1), of the second one (B2); 2 – poles of fault planes (Motion Axes): of the first one (Z), of the second one (Y); 3 – Principal Axes of Strain: Axis of Tension (T), Axis of Pressure (P), Neutral Axis (N); 4 – direction of dip and dip angle of a fault plane; 5 – directions of shifts on a map: of right-lateral (dextral) shift (a), of left-lateral (sinistral) shift (b); 6 – the center of the diagram

Table 2 – The solutions of focal mechanism of the Toraigyr-Soguety earthquake (30.05.2012).
Compiler: A. R. Zhdanovich

Data source	Parameters of the Principal Axes of Strain, being calculated from the positions of the fault planes						The fault planes							
	Pressure, P		Tension, T		Neutral, N (B)		Parameters from the data sources					Calculated parameters		
	Azm	α	Azm	α	Azm	α	№	STR	Ψ	θ, Dip	SLIP	SHEAR	D_x	D_θ
SEME	172,3	88,0	286,4	4,9	82,2	85,5	1	87	177	43 S	98	6,6	0,1146	0,9934
							2	258	348	47 NW	84	-6,1	-0,1069	0,9943
GCMT [1]	349,9	81,5	204,6	10,4	80,8	84,2	1	73	343	37 NW	80	-9,7	-0,1683	0,9857
							2	265	175	54 S	97	7,2	0,1253	0,9921

Note. The designations listed in Table 2: Azm – azimuth of the extremity of an axis in the upper hemisphere; α - angle of approach (α = 90 – pl, where pl – angle of plunge); STR – strike azimuth of a fault plane; Ψ – direction of dip of a fault plane; θ, Dip – angle of dip of a fault plane; SLIP – a slip angle (Rake [1]); SHEAR – a shear angle; Dx – component of movement in the direction of the strike line; Dθ – component of movement in the direction of the dip line.

As follows from figure 2 and table 2 two solutions of focal mechanism from the SEME and GCMT data are practically the same. In the regard of kinematics of the motion, two possible fault planes are interpreted like upthrow-shifts with dominance of component of movement in the direction of the line oriented up-rake (D_θ = 0.99, see table 2) and with circumvertical axis of tension (angle of approach α is 4.9° (SEME) and 10.4° (GCMT)). The significant fluctuations of the azimuth of the tension axis (286.4° (SEME) and 204.6° (GCMT)) are related to its circumvertical position and sensitivity of the azimuth to deviation of the axis from the vertical position even over a small angle.

The axis of pressure P is close to horizontal (angle of approach is 88.0° (SEME) and 81.5° (GCMT)), with its extremity directed in the upper hemisphere towards SSE (Azm 172.3° (SEME)) or in an opposite direction, towards NNW (Azm 349.9° (GCMT)). The Neutral Axis N is the most stable; it's striking towards ENE (82.2° (SEME) and 80.8° (GCMT)) at an abrupt angle to the vertical (85.5° (SEME) and 84.2° (GCMT)).

In table 2, from directions of dip (Ψ) we can realize that the first fault plane from the SEME data with Ψ = 177° corresponds to the second fault plane from the GCMT data with Ψ = 175°, and inversely, the second fault plane from the SEME data with Ψ = 348° corresponds to the first fault plane from the GCMT data with Ψ = 343°. The discrepancy of numbers of fault planes is due to the fact, that the fault planes are numbered in ascending strike azimuths of planes. But strike azimuth of plane is being determined by various ways in SEME or GCMT practice. To get a strike azimuth of a fault plane in SEME practice they use the direction of that extremity of a strike line, along which an observer sees a perched block on the right [25, p. 54]. In the GCMT catalogue they mean that a perched block is located on the left of an observing line.

The fault plane dipping to the SSE (177° or 175°) has got positive estimate of component of movement in the direction of the strike line Dx (0.1146 (SEME) or 0.1253 (GCMT)), and therefore, includes the right-lateral motion. The other fault plane dipping to the NNW (348° or 343°) has got negative estimate of component of movement in the direction of the strike line Dx (-0.1069 (SEME) or -0.1683 (GCMT)) and includes the left-lateral motion.

The first fault plane from the SEME data or the second fault plane from the GCMT data is the right-lateral upthrow-shift striking to the azimuth 87° or 265° (in northern bearing: 85°). The second fault plane from the SEME data or the first fault plane from the GCMT data is the left-lateral upthrow-shift striking to the azimuth 258° (in northern bearing: 78°) or 73°. It is the fault plane that is close to the striking azimuth 70° of the North Dalaashyk fault.

It's possible to estimate only theoretically an average absolute size of displacement along the fault (d) [25] in the focus of the Toraigyr-Soguety earthquake due to there is no information about opening of the fault on the surface. In the capacity of an estimate of the absolute size of displacement they can exploit average amplitude of displacement along the fault (a) calculated according to correlation dependence between amplitude and magnitude.

For example, the formula of V. S. Khromovskikh [5]:

$$M_{LH} = \lg a + 7, \tag{1}$$

where M_{LH} – is a magnitude, being measured according to maximal horizontal amplitudes of the surface waves, implies that

$$a = 10^{(M-7)}, \text{ m.} \tag{2}$$

Magnitudes M_{LH} и M_S are linking by simple relation [21]:

$$M_{LH} = M_S + 0{,}1. \tag{3}$$

For example, for $M_S = 5.4$ from the data of [1], we'll get $M_{LH} = 5.5$. The average amplitude of displacement along the fault amounts to:

$$d = a = 10^{(5{,}5-7)} = 10^{(-1{,}5)} = 3.2 \text{ cm.} \tag{4}$$

Absolute values of motion along the fault in the direction of the strike line (d_x) and in the direction of the dip line (d_θ) can be calculated formulaic by using values of components of movement in the direction of the strike line (D_x) and in the direction of the dip line (D_θ), being listed in table 2:

$$d_x = D_x \times d = \sin \text{SHEAR} \times d, \tag{5}$$

$$d_\theta = D_\theta \times d = \sin \text{SLIP} \times d. \tag{6}$$

For example, absolute values of motion along the first fault plane (from the GCMT data [1]), which is the left-lateral upthrow-shift striking to the azimuth 73°, oriented closely to the azimuth 70° of the North Dalaashyk fault, are estimated by formulas (5) and (6), taking into account the values of D_x and D_θ from the table 2:

$$d_x = -0.1683 \times 3.2 \text{ cm} = (-5) \text{ mm}, \; d_\theta = 0.9857 \times 3.2 \text{ cm} = 3.2 \text{ cm}.$$

Evidently, displacement of 3.2 cm at the hypocentral depth (H) of 20 ÷ 27 km could not be manifested on the surface.

Conclusions. 1. In the area of Toraigyr-Soguety and Chilik earthquakes spatial orientation of modern morphostructures (ridges and depressions) and faults, inherited from Paleozoic structures, coincides with Tienshan, ENE direction (weighted average is 74.89°). Movements along the shifts of Chu-Ili, NW direction (weighted average is 302.37°) take the second place by influence on the morphology and dynamics of neotectonic structures.

2. The epicenter of the Toraigyr-Soguety earthquake that happened on May 30, 2012 is located on the southern limb of Soguety graben syncline, to the north from the Toraigyr uplift, at the distance of 3 km towards North from the central axis of the North Dalaashyk fault, striking to the azimuth of 70°.

3. Two solutions of focal mechanism from the SEME and GCMT data are practically the same. Two possible fault planes are interpreted like upthrow-shifts with dominance of positive component of movement in the direction of the line oriented up-rake (0.99). The one fault plane trending to the ENE (85÷87° in northern bearing) and dipping at angle of about 43° ÷ 54° towards SSE (175÷177°) has got positive estimate of component of movement in the direction of the strike line (0.1146÷0.1253) and is considered to be the right-lateral upthrow-shift. The other fault plane trending to the ENE (73÷78° in northern bearing) and dipping at angle of about 37÷47° towards NNW (343 ÷348°) has got negative estimate of component of movement in the direction of the strike line ((-0.1069) ÷ (-0.1683)) and is considered to be the left-lateral upthrow-shift.

4. The focal mechanism of the Toraigyr-Soguety earthquake reveals that the fault plane trending to the azimuth of 73÷78° and dipping at angle of about 37÷47° to the azimuth of 343÷348°, interpreted like the left-lateral upthrow-shift, is close to the striking azimuth 70° of the North Dalaashyk fault located near to the epicenter. Therefore, the North Dalaashyk fault trending towards ENE is able to be the left-lateral upthrow-shift with dominance of the motion oriented up-rake. If taking the left-lateral upthrow-shift trending to the azimuth of 73° (the first fault plane from the GCMT data [1]) as corresponding rupture in the source, the absolute value of motion in the direction of the line oriented up-rake is estimated at 3.2 cm.

5. Analysis of two focal mechanisms of the Toraigyr-Soguety earthquake, brought to your attention in this article, reveals that the axis of pressure P is close to horizontal (angle of approach is 88.0÷81.5°) and strike azimuth ranges between 349.9 and 352.3° in northern bearing.

6. Displacement of the western and eastern Ulken Kalkan uplifts in different directions along the Kalkan Shift with striking azimuth of 300° is characterized by right-lateral (dextral) component of shifting and the average strike-slip rate is estimated at 1.7 mm / a during the last 5.8m years. To satisfy the progress condition of shifting towards the azimuth of 300° the most probable value of striking of the axis of compression (pressure) is 345°.

7. An assumption of the left-lateral shifting and motion oriented up-rake along the first-rate faults striking towards ENE and the right-lateral shifting along the faults striking towards NW fits the geological-and-tectonic and seismological data being set in this paper and testifies to existence of circumhorizontal tangential compression directed approximately from NNW towards SSE (azimuths of 345-353°) in the area of the epicenters of Chilik and Toraigyr-Soguety earthquakes.

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ТОРАЙҒЫР-СӨГЕТІ ЖЕР СІЛКІНІСІ ОШАҒЫНЫҢ МЕХАНИЗМІ МЕН ГЕОЛОГИЯЛЫҚ-ТЕКТОНИКАЛЫҚ АХУАЛЫНЫҢ ҚАЛЫПТАСУЫ, 2012 ж. 30 мамыр

Аннотация. Торайғыр-Сөгеті жер сілкінісінің эпиорталығы Қазақстан Республикасының Алматы облысында 2012 жылдың 30 мамырында, нүктедегі 43° 23` с. е. және 78° 46` ш. б. координаттарымен, Гринвич бойынша 21 с. 20 мин. 56,7 сек. тіркелді. Жер сілкінісінің энергетикалық сыныбы (Кр) 13,7 ÷ 14,2, магнитудасы (М) 5,0 ден 6,0 дейін, гипоцентр тереңдігі 20-27 км деп бағаланып, топырақты соғу үдемелілігі (I_0) MSK-64 халықаралық сейсмикалық шкала бойынша 6 балды құрады. Жер сілкінісі энергиясы бойынша осы аумақта 1889 жылдың 11 шілдесінде Торайғыр-Сөгеті жер сілкінісі эпиорталығынан 20 км-де өткен Шелек жер сілкінісінен (Кр = 17,9, М = 8,1, I_0 = 10) кейінгі 43° – 44° ендік пен 78° – 80° бойлық арасында болған қатты жер дүмпуі болып есептеледі. Шелектегі жер сілкінісі кезінде Іле және Күнгей сілемі жоталарында көптеген жарықшақ, жылжыма мен бойлық сейсмикалық дислокациялар, ал Ыстықкөл көлінде цунами толқыны орын алды. Торайғыр-Сөгеті жер сілкінісінің эпиорталығы Сөгеті опырықты-синклинінің оңтүстік қанатындағы, Торайғыр көтерілімінен 3,5 км солтүстікке қарай, азимут бойынша 70° созылып жатқан және эпиорталыққа жақын Солтүстік Далаашық жарылымынан солтүстік-батысқа қарай 3-5 км-де орналасқан. Сөгеті ойпаты мен Торайғыр көтерілімі Іле Алатауы жоталар жүйесінің шығыс жақ аяғында орналасқан. Іле көтерілімі солтүстік-шығыс Тянь-Шанға енеді де, каледонды антиклинорияға ұласады. Ең үлкен күмбезді-бұдырлы көтерілімі, тауаралық және тауішілік ойпаттар азимут бойымен шамамен 70°-80°, ШСШ бағытында созылып жатыр, оны тяньшандық деп атайды. Тяньшандық бағытының неотектоникалық өңірлік жарылымдары рельефте Іле Алатауының беткейін бойлық дерлік ендік сатыларға бөлетін тектоникалық кертпештер түрінде байқалады. Шелек-Кемін жарылымы жер қыртысын түбіне дейін 50 км тереңдікке дейін кесіп өтеді; тяньшандық бағытының басқа жарылымы гранит-гнейс қабатынан аспай, жер қыртысынан 10-15 км тереңдікке түседі. СБ Шу-Іле жүйесінің оң жақ бүйірлік ығысу әсерінен ежелгі құрылымдық жоспардың неотектоникалық қайта құрылуы орын алып, неотектоникалық құрылымдар морфологиясы өзгереді. Батыс және шығыс Үлкен-Қалқан көтерілімдерінің түрлі бағыттағы 10 км Қалқан бойынша 300° азимутпен сырғып созылуы соңғы 5,8 миллион жыл ішінде шамамен орташа 1,7 мм жылдамдықпен оң жақ қозғалысымен сипатталады. 300° созылған жылжыманы дамыту үшін сығу өсін 345° азимут бойынша созу тууы ықтимал. Торайғыр-Сөгеті жер сілкінісі жарылымының нодальді жазықтығы (ЖНЖ) құлама-өрлеме сызығы бойындағы араласу векторының оң компоненттері басымдылығымен ығысу-жылжуы деп түсіндіріледі (0,99). Бір

ЖНЖ ШСШ (85° ÷ 87° солт румбке) созылуы, ООШ азимутты құламасы (175° ÷ 177°), 43° ÷ 54° құлау бұрышымен оң жаққа қарай ығысып жылжиды және созылу сызығы бойындағы араласудың оң компонентті векторы 0,1146 ÷ 0,1253 диапазонды қамтиды. Екінші ЖНЖ ШСШ (73° ÷ 78° солт румбке) созылуы, ССБ азимутты құламасы (343° ÷ 348°), (37° ÷ 47°) құлау бұрышымен сол жаққа қарай ығысып жылжиды және оның созылу сызығы бойындағы араласудың теріс компонентті векторы – (-0,1069) ÷ (-0,1683). Бұл нодальді жазықтық Солтүстік Далаашық жарылымының 70° созылу азимутына жақын. Сондықтан да Солтүстік Далаашық жарылымы ығыспалы араласу компоненттері басымдығымен сол жақтық ығысу-жылжу жағдайы орын алады. Ошақтағы 73° созылмалы жарылым жазығының сол жақтық ығысу-жылжуды қабылдау барысында құлама-өрлеме сызығының бағыты бойынша араласудың абсолютті шамасы 3,2 см деп бағаланады. Сығу өсі субгоризонтальді болса, оның бұрышы тігінен 88,0° ÷ 81,5°, құрайтындығы, ал солтүстік румбтағы созу азимуты 349,9°-дан 352,3° дейін құбылатындығы анықталды. Созудың ШСШ ірі жарылымы бойынша сол жақтағы ығысу-жылжу қозғалысына және созудың СБ ығысуы бойынша оң жақтық қозғалыстың орын алуы үшін мақалада баяндалған геологиялық-тектоникалық және сейсмологиялық мәліметтер арқылы нақтыланады, сонымен қатар олар осы ауданда 345° – 353° азимут бойынша бағытталған, субгоризонтальді тангенциалды сығылудың Торайғыр-Сөгеті және Шелекте болған жер сілкінісі эпиорталығының болатынын айғақтауы мүмкін.

Түйін сөздер: жер сілкінісі, эпиорталық аудан, геологиялық-тектоникалық ахуал, неотектоникалық жарылым, жарылым кинематикасы, кернеудің басты өсі (деформация), жер сілкініс ошағының механизм моделі, жарылымның нодальді жазықтығы.

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Республики Казахстан, Алматы, Казахстан

ГЕОЛОГО-ТЕКТОНИЧЕСКИЕ УСЛОВИЯ ФОРМИРОВАНИЯ И МЕХАНИЗМ ОЧАГА ТОРАЙГЫР-СОГЕТИНСКОГО ЗЕМЛЕТРЯСЕНИЯ 30 мая 2012 г.

Аннотация. Эпицентр Торайгыр-Согетинского землетрясения зафиксирован 30 мая 2012 г., в 21 ч. 20 мин. 56,7 сек. по Гринвичу в Алматинской области Республики Казахстан в точке с координатами 43° 23` с. ш. и 78° 46` в. д. Энергетический класс землетрясения (Кр) оценивается в 13,7 ÷ 14,2, магнитуда (М) – от 5,0 до 6,0, глубина гипоцентра – от 20 до 27 км, интенсивность сотрясения грунта (I_0) по международной сейсмической шкале MSK-64 составила 6 баллов. Это землетрясение является самым сильным по энергии на территории, заключенной между широтами 43° – 44° и долготами 78° – 80°, после Чиликского землетрясения (Кр = 17,9, М = 8,1, I_0 = 10 баллов), которое произошло 11 июля 1889 г. в 20 км к ЮЮЗ от эпицентра Торайгыр-Согетинского землетрясения. Во время Чиликского землетрясения в восточных отрогах Заилийского и Кунгейского хребтов сформировались многочисленные обвалы, осыпи и линейные сейсмодислокации, а в оз. Иссык-Куль – волна цунами. Эпицентр Торайгыр-Согетинского землетрясения расположен на южном крыле Согетинской грабен-синклинали, в 3-5 км к северу от Торайгырского поднятия, в 3 км к северо-западу от Северо-Далаашикского разлома, ближайшего к эпицентру и простирающегося по азимуту 70°. Согетинская впадина и Торайгырское поднятие расположены на восточном окончании системы хребтов Заилийского Алатау. Заилийское поднятие входит в Северо-восточный Тянь-Шань и унаследовано от одноименного каледонского антиклинория. Крупнейшие сводово-глыбовые поднятия, межгорные и внутригорные впадины простираются по азимуту около 70°-80°, в ВСВ (тяньшаньском) направлении. Неотектонические региональные разломы тяньшаньского направления выражены в рельефе в виде тектонических уступов, которые разделяют склоны Заилийского Алатау на продольные субширотные ступени. Чилик-Кеминский разлом рассекает земную кору до подошвы на глубину 50 км; остальные разломы тяньшаньского направления погружаются в земную кору на глубину 10-15 км, не выходя за пределы гранито-гнейсового слоя. Под воздействием правосторонних сдвигов чу-илийской системы СЗ простирания происходит неотектоническая перестройка древнего структурного плана, изменяется морфология неотектонических структур. Смещение на 10 км в разные стороны западного и восточного Улькен-Калканских поднятий по Калканскому сдвигу с азимутом простирания 300° характеризуется правосторонним движением приблизительно со средней скоростью 1,7 мм / год на протяжении последних 5,8 млн. лет. Для развития сдвига с простиранием 300° наиболее вероятно простирание оси сжатия по азимуту 345°. Нодальные плоскости разрыва (НПР) Торайгыр-Согетинского землетрясения интерпретируются как сдвиго-взбросы с преобладающей положительной компонентой вектора смещения вдоль линии восстания-падения (0,99). Одна НПР является правосторонним сдвиго-взбросом с простиранием на ВСВ (85° ÷ 87° в северных румбах), с азимутом падения на ЮЮВ (175° ÷ 177°), углом падения 43° ÷ 54° и положительной компонентой вектора смещения вдоль линии простирания в диапазоне 0,1146 ÷ 0,1253. Другая НПР является левосторонним сдвиго-взбросом с простиранием на ВСВ (73° ÷ 78° в северных румбах), с азимутом падения на ССЗ (343° ÷ 348°), углом падения 37° ÷ 47° и отрицательной компонентой вектора смещения вдоль линии простирания в диапазоне (-0,1069) ÷ (-0,1683). Эта нодальная плоскость близка по азимуту простирания 70° к Северо-Далаашикскому разлому. Поэтому Северо-Далаашикский разлом может являться левосторонним сдвиго-взбросом, с преобладающей взбросовой компонентой смещения. При принятии левостороннего сдвиго-взброса с простиранием 73° плоскостью разрыва в очаге абсолютная величина смещения по направлению линии падения-восстания оценивается в 3,2 см. Выявлено, что ось сжатия субгоризонтальна, ее угол с вертикалью составляет 88,0° ÷ 81,5°, а азимут простирания в северных румбах колеблется от 349,9° до 352,3°. Допущение левосторонних сдвиго-взбросовых движений по крупнейшим разломам ВСВ простирания и правосторонних движений по сдвигам СЗ простирания согласуется с геолого-тектоническими и сейсмологическими данными, изложенными в статье, и может свидетельствовать о наличии в районе эпицентров Торайгыр-Согетинского и Чиликского землетрясений субгоризонтального тангенциального сжатия, направленного по азимуту 345° – 353°.

Ключевые слова: землетрясение, эпицентральный район, геолого-тектонические условия, неотектонический разлом, кинематика разлома, главные оси напряжений (деформаций), модель механизма очага землетрясения, нодальные плоскости разрыва.

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