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Original paper

Ismayilli earthquake on February 5th, 2019

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Abstract: Relevance. The Shamakhi-Ismailli seismogenic zone is known as the zone of the most powerful earthquakes in the Caucasus, which has been characterized by high seismic activity for centuries. Analysis of seismicity over the past 15 years has shown an increase in activity in this region. In October 2012, there was a devastating earthquake with a magnitude of 5.3. It is this earthquake that can be considered a trigger of activity in this region in subsequent years. In view of this, the task of studying seismicity, as well as the stress fields of the lithosphere of the region under study, seems to be especially urgent. The study of the seismicity of the Shamakhi-Ismailli zone provides additional information on the deep tectonic processes occurring in this region, which is important for seismic zoning. **Aim.** The article analyzes the seismic activity of the Shamakhi-Ismailli region, which began with an earthquake on February 5 at 19 h 19 min, with ml = 4.4, which occurred 11 minutes before the main shock with an intensity of 6 points, which occurred on February 5, 2019 at 19 h 31 m. **Methods.** The epicentral field was studied, as well as the distribution of foci in depth, solutions of the mechanisms of foci of the main shock and the most noticeable aftershock were constructed and analyzed. A diagram of the main elements of the rupture tectonics of the Shamakhi-Ismailli focal zone has been drawn, on which the mechanisms of the focal points of the lakes of the Ismailli field are plotted. **Results.** It has been established that the source area is located in the zone of intersection of the Vandam longitudinal fault with the West Caspian and transverse Akhsu strike-slip faults, which additionally characterizes the high seismic activity and deep penetration of the West Caspian right-sided orthogonal fault. Thus, it can be seen that, in terms of epicenters, they tend to the basement faults and the nodes of their intersection, i.e. The main shock that occurred on February 5, 2019, shows the agreement of the second nodal plane NP2 with the right-lateral Akhsu and West-Caspian transverse faults characterized by the type of displacement right-lateral strike-slip. An analysis of the orientation of the compression axes showed the NE-SW orientation, and the extension axes of the NW-SE orientation.

Keywords: Shamakhi-Ismayilliseismogenic zone, southeastern part of the Greater Caucasus, landslides, mud volcanoes, earthquake source mechanism, Ismayilli earthquake.

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ГЕОТЕКТОНИКА И ГЕОДИНАМИКА

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Оригинальная статья

Исмаиллинское землетрясение 5 февраля 2019

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Резюме: Актуальность работы. Шамахи-Исмаиллинская сейсмогенная зона известна как зона самых сильных землетрясений на Кавказе, которая на протяжении веков характеризовалась высокой сейсмической активностью. Анализ сейсмичности за последние 15 лет показал рост активности в этом регионе. В октябре 2012 года произошло разрушительное землетрясение магнитудой 5,3. Именно это землетрясение можно считать триггером активности в этом регионе в последующие годы. В связи с этим задача изучения сейсмичности, а также полей напряжений литосферы изучаемого региона представляется особенно актуальной. Изучение сейсмичности Шамахи-Исмаиллинской зоны дает дополнительную информацию о глубинных тектонических процессах, происходящих в этом регионе, что важно для сейсмического районирования. **Цель работы.** В статье проанализирована сейсмическая активность Шамахы-Исмаиллинского района, начавшаяся землетрясением 5 февраля в 19 ч 19 мин, с ml = 4,4, произошедшим за 11 минут до главного толчка с интенсивностью 6 баллов, произошедшего 5 февраля 2019 в 19 час 31 мин. **Методы работы.** Изучены эпицентральное поле, распределение очагов по глубине, построены и проанализированы решения механизмов очагов главного толчка и наиболее заметного афтершока. Составлена схема основных элементов разрывной тектоники Шамахы-Исмаиллинской очаговой зоны, на которой нанесены механизмы очагов озер Исмаиллинского месторождения. **Результаты работы.** Установлено, что очаговая область расположена в зоне пересечения Вандамского продольного разлома с Западно-Каспийским и поперечным Ахсуйским сдвигами, что дополнительно характеризует высокую сейсмическую активность и глубокое проникновение Западно-Каспийского правостороннего ортогонального разлома. Таким образом, видно, что в плане эпицентров они стремятся к разломам фундамента и узлам их пересечения, т.е. главный толчок, произошедший 5 февраля 2019 г., показывает совпадение второй узловой плоскости NP2 с правосторонним Ахсуйским и Западно-Каспийским поперечным разломом, характеризующимися правосторонним сдвиговым типом смещения. Анализ ориентации осей сжатия показал ориентацию СВ-ЮЗ, а оси растяжения – ориентацию СЗ-ЮВ.

Ключевые слова: Шамахы-Исмаиллинская сейсмогенная зона, юго-восток Большого Кавказа, оползни, грязевые вулканы, механизм очага землетрясений, Исмаиллинское землетрясение.

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Introduction

The Shamakhi-Ismayilli seismogenic zone is known as the zone of the most powerful earthquakes in the Caucasus, which for centuries has been characterized by high seismic activity. These studies have been reflected in the works of many scientists [Gasanov et al., 1984,1997]. The first information about earthquakes that occurred in Shamakhi and its environs dates back to ancient times. One of the earliest destructive earthquakes according to Georgian sources occurred in 1192. In the zone of the southern foothills of the Greater Caucasus near the city of Shamakhi in 1667, a catastrophic earthquake with a magnitude of 6.9 occurred, which is one of the largest earthquakes in the Greater Caucasus. The

geodynamic processes in its source caused intense changes in the geomorphological situation in the region (failure of mountain ranges) and huge human casualties (more than 80.000 people died) [Tibaldi et al., 2019]. In the same source in 1828, 1859, 1869, 1872, destructive earthquakes of M = 5.7-7.0 were repeated, and in 1902 a catastrophic earthquake of magnitude M = 6.9 occurred, which claimed many lives. The first scientific description of the Caucasian earthquakes was made by G. Abikh, who examined the consequences of the Shamakhi earthquake of 1859. An analysis of macroseismic and instrumental material over the past 150 years suggests that more than 200 earthquakes in the Shamakhi zone of various magnitudes occurred from sources that are located in four almost parallel latitudinal bands. The two southern epicentral bands give rise to catastrophic earthquakes, while the northern bands mainly generate 6 and 7-point shocks. One of the characteristic features of this zone is the elongation of macroseismic fields in the general Caucasian direction. (Fig. 1) [Agamirzoev, 1987; Akhmedbeili, Gasanov, 2004; Shempelev et al., 2017].

Over the past 15 years, one of the strongest earthquakes in this region is the earthquake that occurred on October 7, 2012, at $15^{h}42^{m}$, 17 km southeast of the Ismayilli seismic station in the Ismayilli region with ml = 5.3.

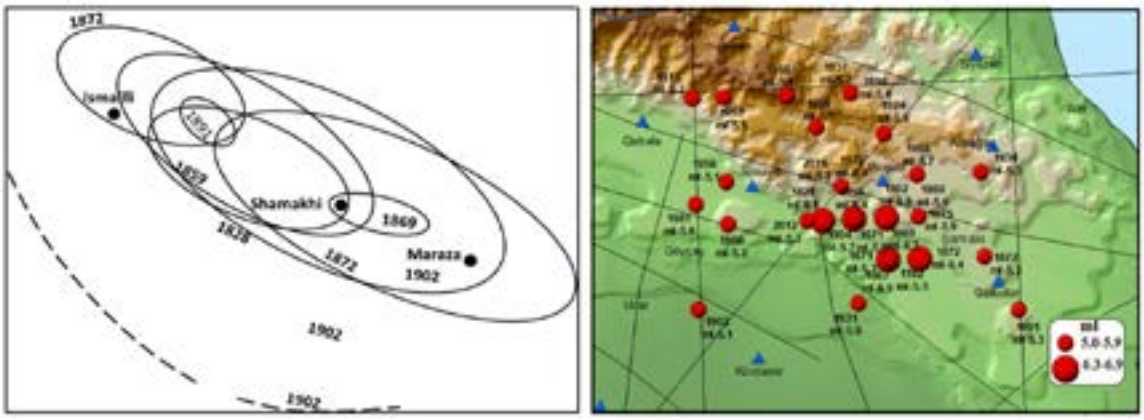

Fig. 1. Diagram of the pleistoseist zones of the devastating Shamakhi earthquakes [Agamirzoev, 1987] and map of the epicenters of strong earthquakes that occurred in the Shamakhi-Ismailli seismogenic zone for the period 427-2019 with ml≥5.0

The intensity at the epicenter of this earthquake on a 12-point scale was estimated at 6 points; in the nearby settlements of Pirkulu, Shamakhi, Ismaili and Akhsu, the earthquake was felt up to 4-2 points. In Figures 2 a map of the epicenters of strong catastrophic earthquakes with magnitude greater than 5that occurred in the Shamakhi-Ismayilli seismogenic zone for the period 427-2019 is shown. Historical data was taken from [Shebalin, Kondorskaya, 1977].

Tectonics

As is known, the West Caspian Fault was identified by V.E. Khain (1966) by the presence of a hidden at a depth the gravity ledge along the eastern side of the Talish-Vandam (now Saatli-Kurdamir) maximum, stretching from the coast of the Caspian Sea at the Kura Spit to the north-north-western direction and before it intersects with the river Girdimanchay at the Baku-Tbilisi highway. To the north, this fault runs along the middle course of the Girdimanchay river to the village of Lagich and further north-east through

the watershed of the Main Range to the village of Qonakhkend and further through the village of Khachmaz to the Caspian Sea. It turns out that the West Caspian fault has an arcuate shape or two strike directions: north-north-west and north-east.

East of the Akhsu-Astrakhan line with the simultaneous expansion of the propagation fields of the Upper Cretaceous sediments, there is an expansion of negative ones, narrowing and complication by thrust disturbances of positive structures in the upper reaches of the Girdimanchay-Kozluchay River; and near the village of Astrakhanovka the amplitude of cover-thrust formation increases significantly. These data clearly illustrate the presence of an ancient northeastern fault along the Akhsu River, reflected both in the pre-Alpine basement and in the Cenozoic deposits of the Adjinour and Langebiz ridge. From this, it follows that the Sigirly-Buinuz and Padar-Akhsu-Baskal north-northwest faults of the basement are reflected in the Mesozoic-Cenozoic deposits of the northern part of the Kura Depression, Adjinour and the Vandam zone of the Greater Caucasus. Probably, the northeastern part of the West Caspian fault corresponds to a wide strip enclosed between the Ismayilli-Babadag and Akhsu-Chagan-Khaltan faults [Aliev et al., 2002; Akhmedbeili et al., 2002; Giorgobiani, 2020; Khain, Alizade, 2005; Shikhalibeili et al., 1989; Shikhalibeili, 1996].

Research methods

Seismicity. The seismic conditions of the Shamakhi zone, as well as the entire South-East Caucasus, which is distinguished by significant amplitudes of the latest, Quaternary and modern movements, complex morphological and structural differentiation, are typical for focal zones of strong earthquakes. Based on the statistical data on the seismic zoning map, the Shamakhi region is identified as a zone of 8-9 point earthquakes, as the ground conditions, as well as the quality of buildings in the Shamakhi region, significantly affect the degree of destruction during earthquakes that occur in this region [Khain, Alizade, 2005].

The seismicity of the Shamakhi epicenter zone is associated with the presence of two differently oriented structural elements: submerged transverse uplift and folded structures of the Greater Caucasus. The length of this zone, as indicated by a number of researchers, is 60-70 km, the width is from 15 to 25 km. immediately outside the specified territory, the force of oscillations of the earth's surface decreases sharply, and already in the area of Ismailli village never exceeds 5-6 points. It should be noted that each of the destructive earthquakes that occurred in the Shamakhi region almost always covered the same area, and the phenomena accompanying the earthquake – landslides, eruptions of mud hills, formation of cracks in the soil, etc., also almost always occurred in the same places [Khain, Alizade, 2005]. The earthquake that occurred on February 5, 2019 at 19^h31^m with ml=5.2, h=8 was no exception. The seismic activity in this zone began with the February 5 earthquake at $19^h\ 19^m54^s$, with ml=4.4 which occurred 11 minutes before the main shock and is considered to be its strong foreshock, felt up to 3-4 points. In addition, a large number of weak foreshocks with ml<3 were recorded. Aftershock activity was also high. Figures 3 show the waveforms of the main shock and aftershocks at both Pirgulu station and at all digital stations.

An analysis of the map of epicenters showed that foreshocks are located mainly northeast and southeast of the main shock, and the maximum of them is boundary on the left. The main shock on February 05, 2019 at 04^h40^m caused a rather active aftershock process. On the first day after it,142 aftershocks were recorded (Fig. 2). In total, the

number of earthquakes that occurred in the Ismailli region in February amounted to 19 foreshocks and 413 aftershocks, and the released energy was $125 \cdot 10^{11}$J.

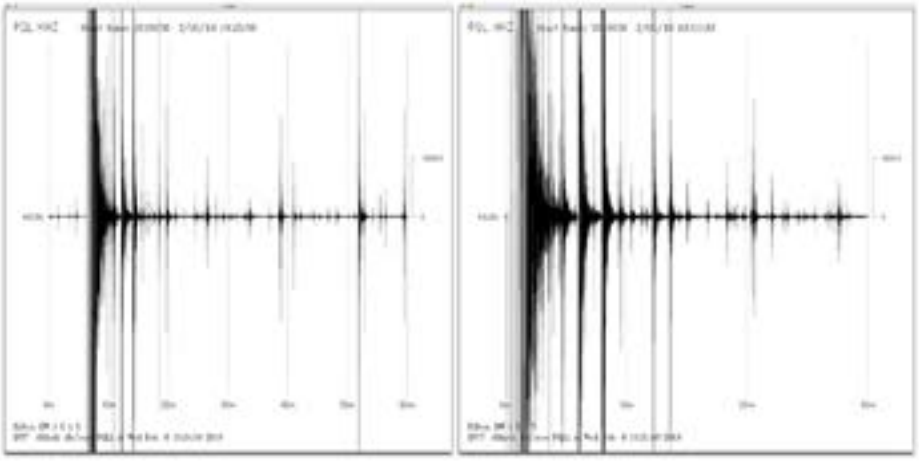

Fig. 2. Image of waveforms of the Ismayilli earthquakes of February 05, 2019 at Pirgulu station

In order to study the peculiarities of the spatiotemporal distribution of seismicity within the Shamakhi-Ismayilli region, a map of the epicenters of earthquakes that occurred in the studied region for 2019 was compiled. 5. This is primarily the area of aftershocks near the main shocks, which have a shape similar to the shape of the letter ("Г"), stretched out in the general Caucasian direction (Fig. 3).

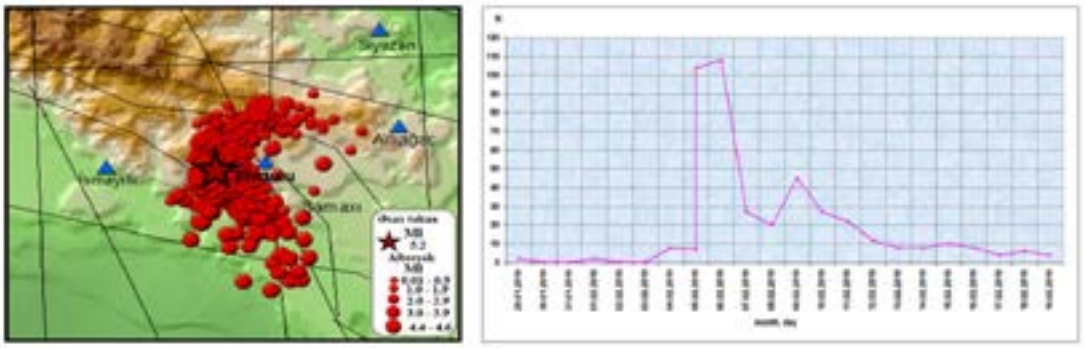

Fig. 3. Map of the main shock and aftershocks epicenters and distribution of the aftershocks of the February 5, 2019 earthquake by day

In order to monitor the swarm process from February 5-15 in the epicenter zone, temporary portable stations were installed in the earthquake area. The statistics of aftershocks within the focal zone for the following days indicate their sharp decline already in early March, in the number of aftershocks no more than 2-3. In order to study the distribution of the depth of earthquake sources, two seismological profiles were constructed – NW-SE and SW-NE strike. This makes it possible to identify zones of intersection of faults in different directions, to which the densest sections of hypocenters gravitate. Figure 4 shows a section along the I-I profile of NW-SE direction, coinciding with the strike of longitudinal deep faults (Fig. 4).

As can be seen, two groups of earthquake hypocenters (earthquake sources) are distinguished here – presumably, the sources associated with the strike of the Vandam fault with an angle of incline of 45° and the Akhsu fault with an angle of incidence of

30º. The depth of the location of the centers of the main mass of earthquakes varies from 5-15 km; more are established deep sources with depths up to 35 km. The main number of earthquakes is concentrated in the zone of intersection of multidirectional faults in the central part of the profile. From the northwest to the southeast, an arcuate occurrence of the basement surface is observed. Considering that the basaltic layer lies in the Shamakhi-Ismailli zone at depths of 20–25 km, it can be assumed that the earthquake source is located in the sedimentary layer, on the surface of the pre-alpine basement. It should be noted that the sources of relatively strong earthquakes with ml = 4.4-5.2 are located at a depth of 8-10 km.

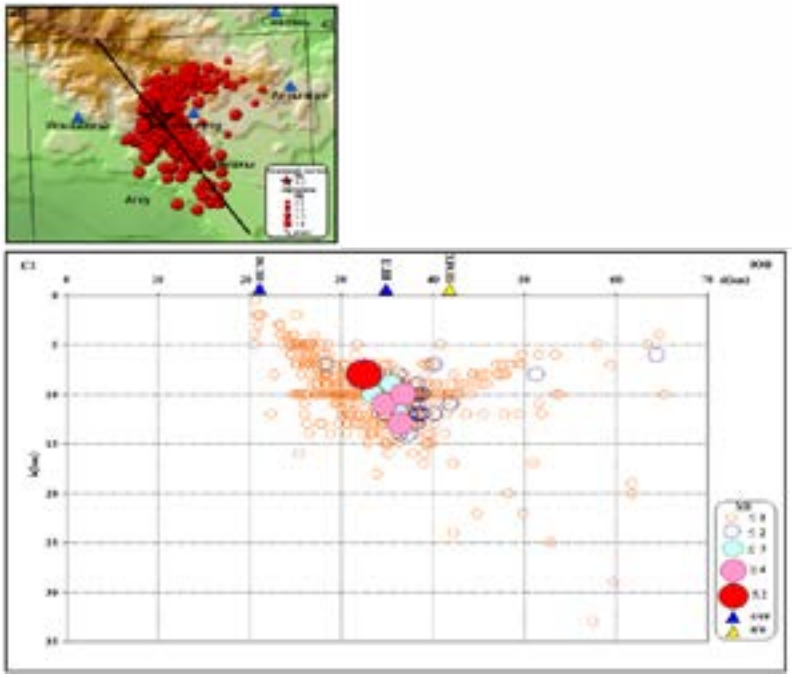

Fig. 4. Seismic-geological section I-I of the Shamakhi-Ismailli seismogenic zone of the NW-SE strike

As was noted earlier, a unique feature of the surface structure of the Shamakhi seismically active zone is tectonic coverings, whose contacts with underlying younger formations are characterized by clearly expressed angular and structural disagreements and create conditions for the occurrence of weak earthquakes. A high density of sources in the central part of the profile is connected, concentrated mainly at an epicentral distance of 30-50 km. The depths of the sources also vary from 5 to 15 km. [Kazimova, 2020].

Macroseismic studies

For the purpose of macroseismic research of earthquakes, the macroseismic expedition of the RSSC ANAS conducted work in the territories where the earthquake was felt. The buildings in these villages that suffered the most vulnerability and destruction are mainly associated with the construction of torn stones, cubes and local river stones. During strong vibrations, which lasted up to 10 seconds, residents in a panic ran out into the street. The earth fluttered. The houses creaked, hanging objects swayed violently, and other objects fell from shelves. Light, heavy, and very heavy objects moved from their places (Fig. 5). Cracks appeared in the house; the plaster fell off. Along the entire perimeter, which covered a number of buildings, there were longitudinal, cruciform, and transverse cracks, stone fences were destroyed. Electricity has been cut off.

The macroseismic field of this earthquake is extended in a northwest direction. The pleistoseist zone covers the regions of Akhsu and Shamakhi with an area of 13×20=260 km^2. The coordinates of the macroseismic epicenter are φ = 40.78ºN, λ = 48.46ºE [Kuliev, 1977]. Based on these studies, it was revealed that the most intense earthquake was felt in the territories of such villages as Chukhuryurd, Nagarakhan, Madras, Shamakhi and Pirgulu. Here, the intensity of the earthquake was estimated at 6 points. In Baku, an earthquake was felt up to 3 points.

Fig. 5. Damaged buildings in the village of Shamakhi district

After the earthquake, landslides of considerable size arose. Disturbances in the relief, a change in the flow rate of springs and hum from the bowels are noted. According to the research conducted by the RSSC staff, the activity of two sections of landslide processes on the 4 km section of the Gizmeydan road in the Shamakhi district was identified (Fig. 5). After the first landslide process, cracks 5-10 mm wide were formed on the asphalt road, and 15-25 mm wide along the road. After the second landslide process, cracks 5-10 mm wide were also formed on the asphalt road, and 20-30 mm along the road. In addition, cracks and dips are observed on asphalt at 154 km of the Akhsu pass road.

Analysis of the accumulated factual material about the eruptions of mud volcanoes and seismic events in Azerbaijan with full confidence shows that a significant part of the mud volcanoes erupts after a strong earthquake (M=5 or more).As noted earlier [Aliev et al., 2001, 2002; Aliev, Keramova, 2002], a surely causal relationship between the eruption of mud volcanoes and tremors is established when the earthquake source and mud volcano are within the same fault structure, and if the volcano has accumulated sufficient energy for paroxysmal activity, i.e. earthquakes play, as it were, the role of the “trigger” in the mud volcanic process [Yetirmishli et al., 2019; Kangarli, 2007].

On February 13, local time, 06^{h}25^m, the Gushchu mud volcano erupted within the Shamakhi region (Fig. 6). The ejection height reached 4-5 meters. The eruption occurred 150 meters from the village, closer to the sown areas, and lasted 1.5 minutes (Table 1). As a result of the eruption, a layer of volcanic mud covered an area of approximately two hectares. So far, 14 eruptions of this volcano have been recorded. This time during the eruption, no flame or characteristic cracks were observed.

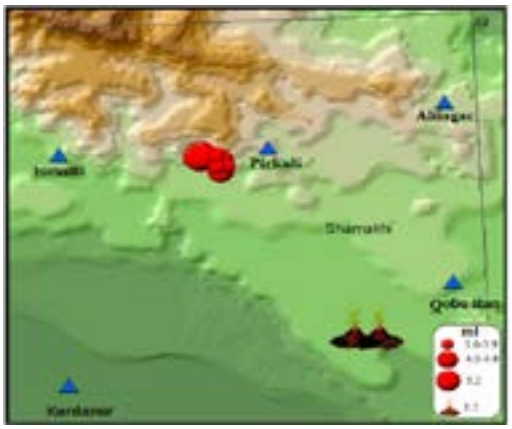

Fig. 6. The location map of the main shock of the Ismayilli earthquake with the strongest aftershocks, as well as the epicenters of 2 eruptions of the Gushchu mud volcano

Table 1

Main parameters of the eruption of the mud volcano "Gushchu"

№	Data	Time UTS	Coordinates		h, Δ km	ml	Duration of the eruption
			φ	λ			
1	13.02.2019	02:25:55	40.44	48.74	4	1.1	1m.30 sec
2	13.02.2019	02:38:29	40.44	48.74	3	1.1	1 m.30 sec

Results of work

An indispensable condition for the occurrence of strong earthquakes is increased mobility, i.e. contrasting tectonic movements, which are characteristic of zones dividing areas with different, and sometimes sharply changing, directions of tectonic movements. In this regard, the mechanisms of the sources of the Ismayilli earthquakes were constructed and analyzed: 2019.02.05 19^h19^m (foreshock), 2019.02.05 19^h31^m (main shock), 2019.02.05 19^h37^m, 2019.02.05 22^h34^m, 2019.02.06 02^h25^m, 2019.02 .09 16^h35^m, 2019.02.11 15^h29^m (aftershocks) (Table 2). Magnitude Mw was taken from the catalog (http://www.emsc-csem.org/Earthquake/earthquake.php).

Table 2

Parameters of the mechanisms of foci of the Ismayilli earthquake in February 2019

№	Data, *d m y*	t_0, *hms*	*h*, *км*	Magni-tude		Major stress axes						Nodal plane					
				ml	*Mw*	*T*		*N*		*P*		*NP1*			*NP2*		
						PL	*AZM*	*PL*	*AZM*	*PL*	*AZM*	*STK*	*DP*	*SLIP*	*STK*	*DP*	*SLIP*
1	20190205	19:19:54	11	4.4		71	104	19	284	0	14	266	48	65	122	48	116
2	20190205	19:31:37	8	5.2	5.0	7	297	82	90	4	207	72	88	8	342	82	177
3	20190205	19:37:24	11	3.4		54	139	6	238	36	333	237	81	84	93	11	125
4	20190205	22:34:05	9	3.0		5	306	82	180	7	36	171	89	-172	81	82	-1
5	20190206	02:25:50	10	3.9		18	297	72	117	0	27	340	77	167	73	77	13
6	20190209	16:35:09	11	2.9		41	102	20	353	41	244	-110	90	353	0	20	263
7	20190211	15:29:31	13	4.0	3.9	31	325	28	74	46	197	258	82	-62	3	29	-164

Based on the works [Rzaev et al., 2013], a diagram of the basic elements of the discontinuous tectonics of the Shamakhi-Ismayilli source zone (Fig. 7) was drawn up, on

which the mechanisms of the sources of the Ismayilli earthquakes are plotted. Here we see that the focal region lies in the zone of intersection of the Vandam longitudinal fault with the West Caspian and Akhsu transverse fault shifts, additionally characterizing high seismic activity and deep penetration of the West Caspian right-lateral orthogonal fault. Thus, it can be seen that, in terms of epicenters, they tend to the foundation faults and the nodes of their intersection, i.e. it can be concluded that the faults that cut the foundation, and even more so penetrate the upper mantle, are fraught with a constant seismic hazard.

The main shock on February 5, 2019 at 23:31:37, local time in the Ismayilli district with ml=5.2, was characterized by near horizontal (PL_P=4°) compressive southwest orientations and tensile northwestern orientations (PL_T=7°). The type of movement along both steep (DP_1=88°, DP_2=82°) planes is a shift. The *NP1* plane has a northeastern (STK_1=72°) strike with a slip type of left-lateral strike-slip, and *NP2* has a northwest (STK_2=342°) with a slip type of right-lateral strike-sli. A comparison of the strike of the nodal planes with the fault lines shows the agreement of the second nodal plane NP2 with the right-lateralAkhsu and West Caspian transverse faults, which allows us to consider the NP2 plane as active [Akhmedbeili et al., 2002].

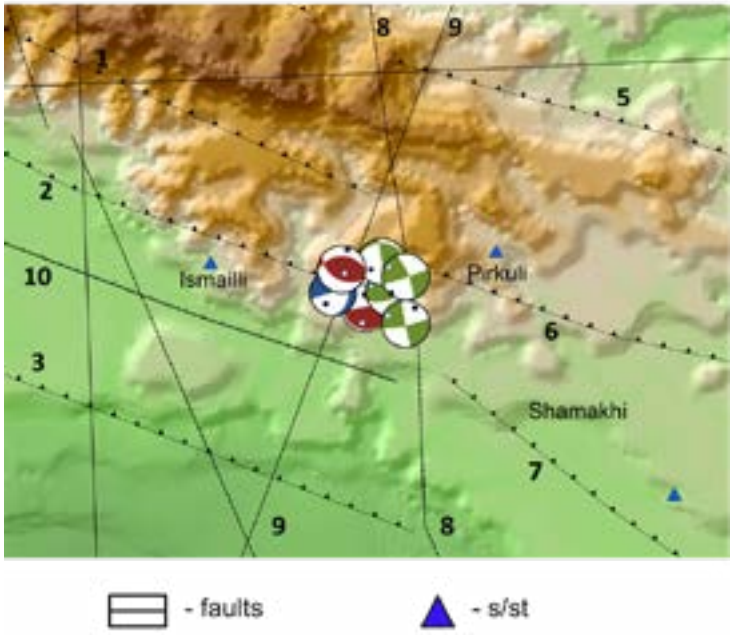

Fig. 7. Diagram of the main elements of the discontinuous tectonics of the Shamakhi-Ismayillisource zone and the mechanisms of the earthquake sources for 2019.
Tectonic faults: 1-Dashgil-Mudrese, 2-Vandam, 3-Geokchay, 4-Siyazan, 5-Zangi-Kozluchay, 6-Germian, 7-Adjichay-Alyat, 8-West-Caspian, 9 – Akhsu; 10 – North-Adjinour
[Metaksas et al., 2011;Rzaev et al., 2013]

The mechanisms of the aftershock earthquake sources are mainly of two types: uplifts and shifts. An exception is the earthquake that occurred on February 6 at 02:34:05 local time on the territory of the Akhsu district (ml=3.0). The earthquake was characterized by near-horizontal (PL_P=7°) compressive NE orientations and tensile NW orientations (PL_T=5°). The type of movement along both steep (*DP*=89-82°) planes is a strike-slip with normal fault elements. The *NP1* plane is near-vertical (STK_1=171°), and *NP2* is near-horizontal (STK_2=*81*°). A comparison of the strike of the nodal planes with the fault lines in Fig. 18 shows the agreement of the first *NP1* nodal plane with the North-Adjinour longitudinal fault.

Based on the results obtained, the orientations of the compression and extension axes of the studied strong earthquakes were analyzed. An analysis of the orientation of the compression axes showed the NE-SW orientation, and the extension axes of the NW-SE orientation.

Conclusions

The source zone of the Ismayilli earthquake is located on the southeastern subsidence of the meganticlinorium of the Greater Caucasus, composed of thick volcanic and sedimentary strata of the Meso Cenozoic and extended in the general Caucasian direction. Between the Shamakhi-Gobustan and Alazan-Agrichay synclinoria stands out the Baskal tectonic cover, with a thickness of 1.5-2 km, a width of 10-12 km, a length of 20-25 km.

The high seismicity of the Shamakhi zone is associated with the presence of gravitational anomalies, of which the largest and most interesting is the positive anomaly located along the Astara-Astrakhan-Bazar-Kurdamir line and further north-north-east to the latitude of Ismaili.

The Ismayilli source zone is associated with the presence of two differently oriented structural elements: submerged transverse elevation and folded structures of the Greater Caucasus. The length of this zone is 60-70 km; the width is from 15 to 25 km. On February 5, 2019 at 19^h31^m with ml=5.2, an earthquake occurred at a depth of h=8in this zone. Seismic activity in this zone began with the February 5 earthquake at $19^h19^m54^s$, with ml=4.4 which occurred 11 minutes before the main shock and is considered to be its strong foreshock, felt up to 3-4 points. In addition, a large number of weak foreshocks with ml<3 were recorded. Aftershock activity was also high. The most powerful aftershocks had magnitudes with ml>3.4, 3.0, 3.9.

An analysis of the deep distribution of the sources showed that the sources are presumably related to the strike of the Vandam fault with an angle of inclination of 45 and the Akhsu fault with an angle of incidence of 30. The depth of the location of the sources of the main mass of earthquakes varies from 5-15 km, and deeper sources with depths of up to 35 km have been established. The main number of earthquakes is concentrated in the zone of intersection of multidirectional faults in the central part of the profile. From the northwest to the southeast, an arcuate occurrence of the basement surface is observed. The earthquake source is located in the sedimentary layer, on the surface of the pre-alpine basement. It should be noted that the sources of relatively strong earthquakes with ml=4.4-5.2 are located at a depth of 8-10 km. An analysis of the mechanisms of the earthquake sources showed that the source region is located at the intersection of the Vanda longitudinal fault with the West Caspian and Akhsu transverse fault-shifts. The main shock that occurred on February 5, 2019, shows the agreement of the second nodal plane NP2 with the right-lateral Akhsu and West-Caspian transverse faults characterized by the type of displacement right-lateral strike-slip. An analysis of the orientation of the compression axes showed the NE-SW orientation, and the extension axes of the NW-SE orientation.

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