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SEISMOPROGNOSIS OBSERVATIONS IN THE TERRITORY OF AZERBAIJAN

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SEISMOLOGICAL-GEOPHYSICAL RESEARCH CONDUCTED IN DASHKESAN SKARN-IRON ORE GROUP BED AND ASSESSMENT OF THE RISK OF LANDSLIDE THAT MAY OCCUR IN THE AREA

G.J.Yetirmishli[1], R.B.Muradov[1], N.B.Khanbabayev[1], E.S.Garaveliyev[1], E.M.Bagyrov[1]

Annotation

1. In the article, it is noted that the value of the average transverse wave speed parameter varies between 400-515 m/s in the seismic profiles developed in the waste and landslide areas of Dashkasan skarn-iron ore group beds up to a depth of 30 m. In the left wing of the resulting landslide, a geological disturbance was determined in the direction of the fault-falling layer. A layer with a low transverse wave speed (350-441 m/s) is observed in the landslide area in seismic profiles No. 4 and 5 at a depth of 30-44, 30-47 m, respectively. This layer is assumed to be a clay layer. Inside the clay layer, a lens with a value of transverse wave speed varying between 263-351 m/s is observed. It is assumed that this lens has a layer of watery clay and the sliding plane corresponds to this layer.

2. In the direction of Mollahasanli village, a layer with low transverse wave speed (305-425 m/s) is observed at a depth of 30-45 m, and a lens with low wave speed is not observed inside this layer. From this point of view, the current condition of the retaining dam is considered stable compared to the landslide area.

3. In the waste and landslide area of Dashkasan skarn - iron ore group beds, the geodynamic regime was evaluated, the tension dynamics of the gravity and geomagnetic field were studied, and tectonic fault zones were found. These areas are assumed to be prone to landslides.

4. In the area of the new landfill, the observed gravity and geomagnetic stress are at background levels. For this reason, the new dump site is more durable and stable from the geological point of view than the previous (slid on 03.09.22) dump site.

Keywords: *SME-seismomagnetic effect, nT- nanotesla, mechanism of earthquake source, geodynamic mode, geomagnetic field stress, ml-magnitude, gravity force, gravimetric field stress, local anomaly, engineering-seismic exploration.*

DAŞKƏSƏN SKARN-DƏMİR FİLİZ QRUPU YATAQLARINDA APARILMIŞ SEYSMOLOJİ-GEOFİZİKİ TƏDQİQATLAR VƏ ƏRAZİDƏ BAŞ VERƏ BİLƏCƏK SÜRÜŞMƏ RİSKİNİN QİYMƏTLƏNDİRİLMƏSİ

Q.C.Yetirmişli, R.B.Muradov, N.B.Xanbabayev, E.S.Qaravəliyev, E.M.Bağırov

Annotasiya

1. Məqalədə Daşkəsən skarn-dəmir filiz qrupu yataqlarının tullantı və sürüşmə sahələrində işlənmiş mühəndisi- seysmik profillərdə 30 m dərinliyə qədər orta eninə dalğanın sürət parametrinin qiymətinin 400-515 m/s arasında dəyişdiyi qeyd olunur. Nəticədə baş vermiş sürüşmənin sol qanadında qırılıb-düşmə tipli layın yatım istiqamətində geoloji pozulma müəyyən edilmişdir. Sürüşmə sahəsində 4 və 5 saylı seysmik profillərdə uyğun olaraq 30-44, 30-47 m dərinlikdə aşağı eninə dalğa sürətinə (350-441 m/s) malik lay izlənilir. Bu layın gil qatı olması güman edilir. Gil qatının daxilində eninə dalğa sürətinin qiyməti 263-351 m/s

[1] *Republican Seismic Survey Center of Azerbaijan National Academy of Sciences*

arasında dəyişən linza izlənilir. Bu linzanın sulu gil layı olması və sürüşmə müstəvisinin də bu laya uyğun olması ehtimal edilir.

2. Mollahəsənli kəndi istiqamətində dayaq bəndində isə 30-45 m dərinlikdə aşağı eninə dalğa sürətinə malik (305-425 m/s) lay izlənilir və bu lay daxilidə aşağı dalğa sürətinə malik linza müşahidə edilmir. Bu baxımdan dayaq bəndinin mövcud durumu sürüşmə sahəsinə nisbətən stabil qəbul edilmişdir.

3. Daşkəsən skarn - dəmir filiz qrupu yataqlarının tullantı və sürüşmə sahəsində geodinamik rejim qiymətləndirilərək qravitasiya və geomaqnit sahəsinin gərginlik dinamikası öyrənilmiş risk təhlükəsi olunan tektonik pozulma zonaları aşkar edilmişdir. Bu sahələrin sürüşməyə meyilli olduğu güman edilir.

4. Yeni tullantıxana ərazisində qravitasiya və geomaqnit sahəsində müşahidə olunan gərginlik fon səviyyəsindədir. Bu səbəbdən yeni tullantıxana sahəsi əvvəlki (03.09.22-ci ildə sürüşmüş) tullantıxana sahəsinə nisbətən geoloji nöqteyi nəzərdən daha davamlı və stabil xarakterlidir.

Açar sözlər: *SME-seysmomaqnit effekt, nT- nanotesla, zəlzələ ocağının mexanizmi, geodinamik rejim, geomaqnit sahə gərginliyi, ml-maqnituda,ağırlıq qüvvəsi, qravimetrik sahənin gərginliyi, lokal anomaliya, mühəndisi-seysmik kəşfiyyat.*

СЕЙСМОЛОГО-ГЕОФИЗИЧЕСКИЕ ИССЛЕДОВАНИЯ, ПРОВЕДЕННЫЕ В ДАШКЕСАНСКОЙ СКАРНОВО-ЖЕЛЕЗОРУДНОЙ ГРУППЕ ЗАЛЕЖЕЙ И ОЦЕНКА РИСКОВ ВОЗМОЖНЫХ ОПОЛЗНЕЙ НА ТЕРРИТОРИИ

Г.Д.етирмишли, Р.Б.Мурадов, Н.Б.Ханбабаев, Э.С.Гаравелиев, Э.М. Багиров

Аннотация

1. В статье определено изменение значения среднего параметра скорости поперечных волн до глубины 30 м в разработанных инженерно-сейсмических профилях на отваловых и оползневых участках месторождений Дашкесанской скарново-железорудной группы в пределах 400 -515 м/с. В результате в левом крыле образовавшегося оползня установлено геологическое нарушение в направлении слоя сбросопадения. В зоне скольжения на сейсмических профилях № 4 и № 5 на глубинах 30-44 и 30-47 м соответственно наблюдается слой с низкой скоростью поперечных волн (350-441 м/с). Предполагается, что эти породы представляет собой слой глины. Внутри слоя глины наблюдается линза со значением скорости поперечных волн, варьирующимся в пределах 263-351 м/с. Предполагается, что эта линза представляет собой водянистый слой глины и что этому слою соответствует плоскость скольжения.

2. У подпорной дамбы в направлении села Моллагасанлы на глубине 30-45 м наблюдается слой с низкой скоростью поперечных волн (305-425 м/с), внутри этого слоя не наблюдается линза с низкой скоростью волн. С этой точки зрения существующее состояние подпорной дамбы можно считать стабильным по сравнению с оползневой зоной.

3. В отбросно-оползневом районе Дашкесанской скарно-железорудной группы месторождений оценен геодинамический режим, изучена динамика напряженности гравитационного и геомагнитного поля, выявлены зоны тектонических нарушений. Эти области склонны к скольжению.

4. Наблюдаемая гравитационная и геомагнитная напряженность на территории нового полигона находится на фоновом уровне. По этой причине новая свалка геологически более прочна и устойчива, чем предыдущая (сползла 03.09.22) свалка.

Ключевые слова: *SME-сейсмомагнитный эффект, nT-нанотесла, механизм очага землетрясения, геодинамический режим, напряжение геомагнитного поля, ml-магнитуда, сила тяжести, напряжение гравиметрического поля, локальная аномалия, инженерно-сейсмическая разведка.*

INTRODUCTION

In Dashkasan skarn-iron ore group deposits, since the middle of the last century, blasting and geophysical exploration related to exploitation works have been carried out. During the search and exploration works, geodynamic activity is observed in areas with the risk of avalanches, subsidence and landslides due to the impact of explosions carried out in the exploitation process. On September 3, 2022, a landslide occurred in the waste field near Mollahasanli village of Dashkasan district and the road was closed as a result of the avalanche.

Ensuring the safe conduct of blasting operations, studying the effect of blast shock and other seismic waves is a very urgent problem.

The purpose of the work: assessment of the geodynamic conditions of the area and the effect of impact and other seismic waves generated during blasting operations on the environment, including the stability of the landslide area, using complex seismological-geophysical methods in the South-East area of Dashkasan skarn-iron ore group bed.

The following seismological, engineering-seismic and geophysical research works were carried out in order to solve the issues raised by RSXM:

Engineering-seismological research works in the South-East field;

- Investigation of the geological-tectonic structure of the sliding area with gravi-magnetometric studies, determination of the location and direction of tectonic faults, geological disturbances;
- Detection of other landslide-prone areas by seismological-geophysical methods;
- Assessment of the stress-deformation state of the geological environment with magnetometric and gravimetric studies, construction of a schematic map and 3D model in 2D format.

Brief overview of Dashkasan skarn-iron ore group deposits

The Dashkasan skarn-iron ore group beds are located in the northeast of the Lesser Caucasus at an altitude of 1500-2000 m, 36 km from the city of Ganja, 8 km from the Gushchu railway station, in the immediate vicinity of the city of Dashkasan (Figure 1.).

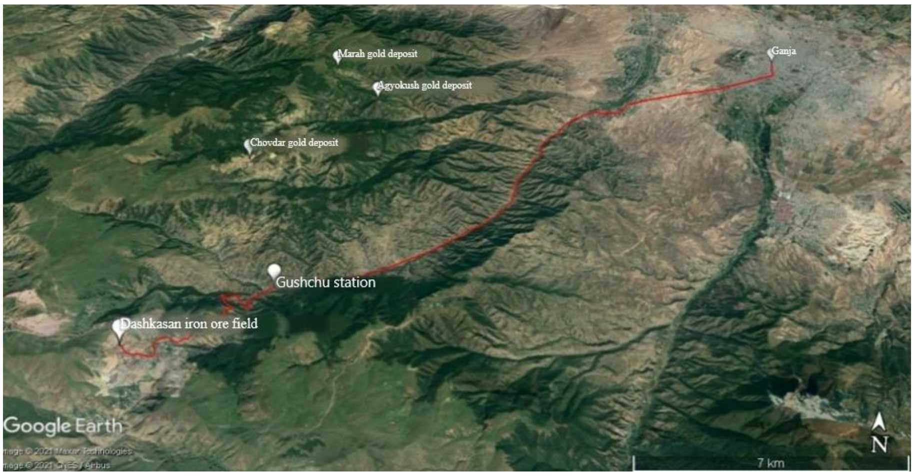

Figure 1. Aerial view of Dashkasan iron ore group deposits

The geological structure of Dashkasan skarn-iron ore group beds includes sedimentary rocks of Middle and Upper Jurassic age. Upper Jurassic sediments are more widespread in the Dashkesan area. The ores of the Dashkasan deposit were mainly formed in the Upper Jurassic sediments. Upper Jurassic sediments begin with agglomerate tuffs, calcareous tuffites and tuff breccias, limestones (up to 250 m thick), argillites with tuffs and tuffites, sandstone and marl.

Tectonically, the area containing the Dashkasan skarn-iron ore group beds is located in the Lok-Karabakh structural-formation zone of the Lesser Caucasus. The tectonic movements after the intrusion caused the formation of a large number of faults in the direction of northwest extension. These faults are more widespread between the northwest in the Gushchu area and the southeast of the village of Dardara. In the northwest, the relatively largest fault extends from the Kamargaya river valley to the North Cobalt mine [1].

Table of earthquakes (ml≥2.0) that occurred in Dashkasan region during 2021-2023

Date	hour	lat	lon	h	Ml
22.05.2021	13:15:17.178	40.63	46.05	2	2.31
31.05.2021	14:03:32.667	40.61	46.01	9	2.40
11.01.2021	10:55:24.277	40.33	45.96	9	2.22
05.01.2022	9:27:20.007	40.48	46.20	10	2.23
21.01.2022	10:03:40.480	40.65	46.21	18	2.21
19.05.2022	18:53:10.516	40.35	46.43	12	2.93
31.08.2022	8:08:04.557	40.21	46.49	17	2.37
26.09.2022	5:22:47.894	40.43	46.38	1	3.54
28.10.2022	7:09:16.700	40.30	46.46	11	3.03
19.01.2023	14:35:33.408	40.34	46.18	12	2.55

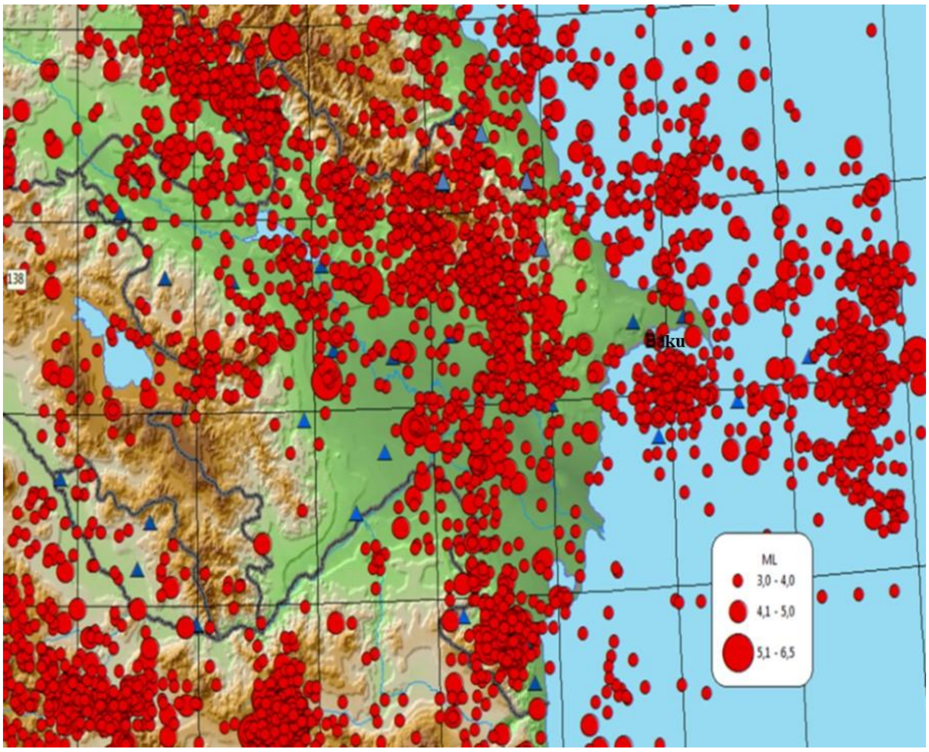

Figure 2. Map of epicenters of M≥3.0 earthquakes that occurred in Azerbaijan and adjacent territories during 1980-2022

This map shows the uneven distribution of weak and moderate earthquakes as well as strong earthquakes in the territory of Azerbaijan.

Strong earthquakes that create a seismic hazard occur in the study area, although not often. In the past, quite strong and moderate earthquakes have occurred in these areas, including Dashkasan region and Ganja region, and seismic events will be repeated in the future.

The method of engineering seismic exploration works

The GEODE-24 engineer seismic station, 24 seismic receivers, a 115-meter seismic survey wire and a 12 kg impact hammer were used to study the tested microseisms. Noises from the environment and microvibrations created by the impact method are considered as a seismic source.

The method of data acquisition and collection consists of obtaining 12 microvibration recordings of 30 seconds. The transformed wavefield of the received recordings shows the dispersion curve of the transverse waves. The transverse wave dispersion curve is selected from the transformed wave field and modeled to calculate the velocity profile of the underground transverse waves.

In order to obtain recordings in the research area, software such as ReMiVspect4.0 and ReMiDisper4.0 were used during the processing of recording results obtained from the Seismodule Controller software package.

Seismic data processing and interpretation

While performing engineering-seismic exploration works, the research area is divided into 2 areas. In the first stage, the research works were carried out in the 1st area, which includes the area where the landslide occurred.

In the second stage, the researches were carried out around the next possible landslide in the direction of Mollahasanli village on the border of the landslide area.

The total volume of works done in both areas was 2645 sq m.

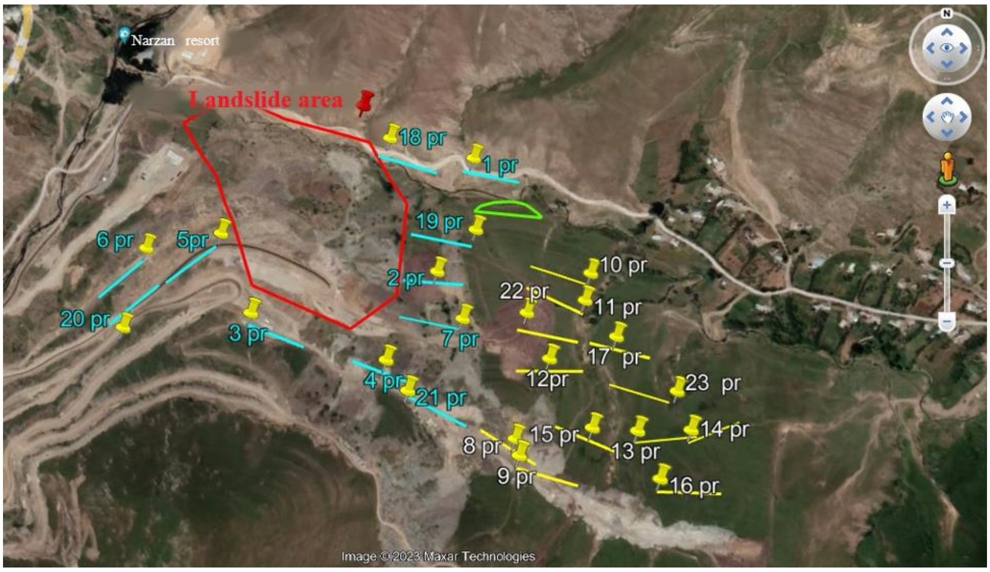

Figure 3. Location scheme of seismic profiles around the sliding area

In the field, cross-sections of the speed change depending on the depth were established for each profile.

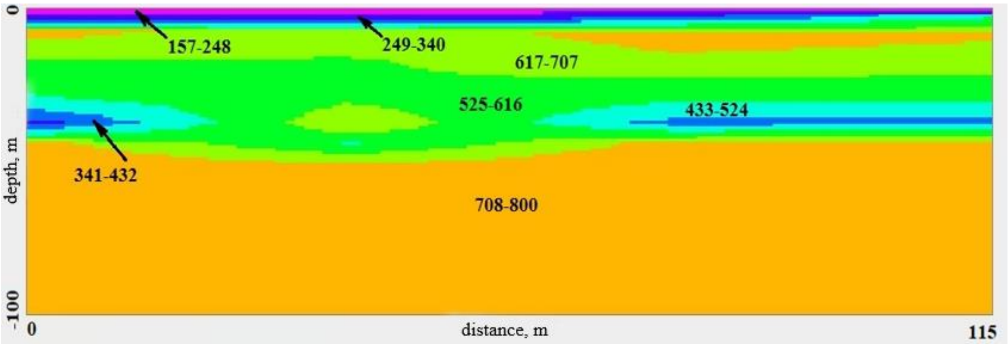

Figure 4. 2-dimensional velocity cross section of transverse waves on seismic profile #1 (in m/s).

In profile #1, the average transverse wave velocity parameter was calculated up to a depth of 30 m. The average transverse wave speed parameter is calculated by the following formula:

$$V_{s30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{V_i}}$$

where hi and Vi are the thicknesses of the layers up to a depth of -30 m and their corresponding transverse wave velocities. Based on the calculation, we get:

Vs30= 490 m/s.

As can be seen from the profile, a layer with a low wave speed (341-432) is observed within the high-velocity layer (525-616) at a depth of 36.5-42 m. At these depths, the transverse wave propagation speed in the layer is 300-459 m/s.

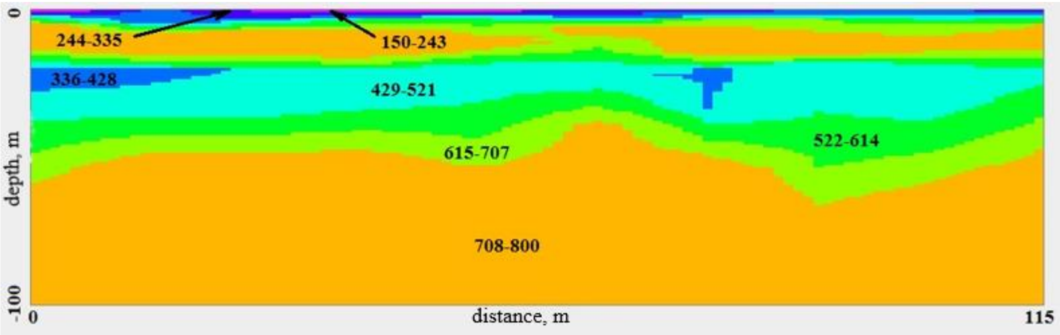

Figure 5. 2-dimensional velocity cross section of transverse waves on seismic profile No. 3

The average transverse wave velocity parameter up to a depth of 30 m was calculated on profile No. 3

Vs30= 510 m/s.

As can be seen from the profile, 20 At the depth of -32 m, the layer with low wave speed has penetrated into the high-velocity layer in the form of a lens at the beginning of the cut (left wing). At these depths, the transverse wave propagation speed in the layer is 336-428 m/s. At a depth of about 50-60 m, the top of the layer recorded at a speed of 708-800 m/s has a rise shape in the center of the profile and penetrated the bottom of the fast layer of 615-707 m/s, and a completely opposite picture was observed on the right wing of the profile. This indicates geological disturbances in the stratification within the section.

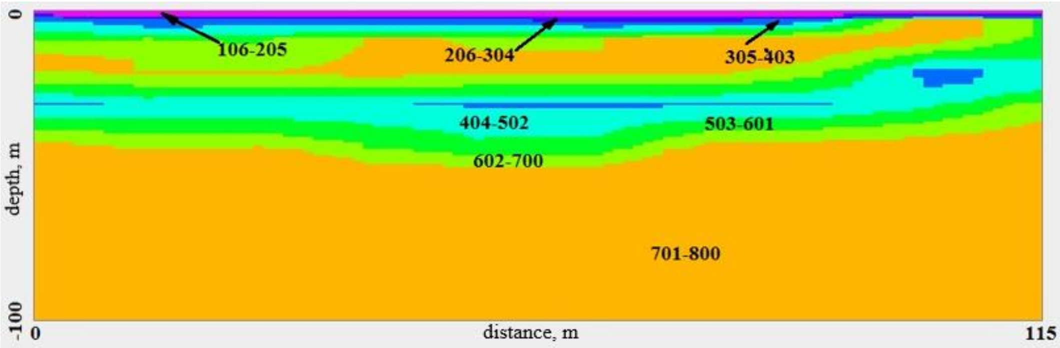

Figure 6. 2-dimensional velocity cross section of transverse waves on seismic profile No. 10

In profile No. 10, the average transverse wave speed parameter up to a depth of 30 m was calculated

Vs30= 440 m/s.

In this profile 30- A layer with a low wave speed is observed at a depth of up to 45 m. At these depths, the transverse wave propagation speed in the layer is 305-403m/s.

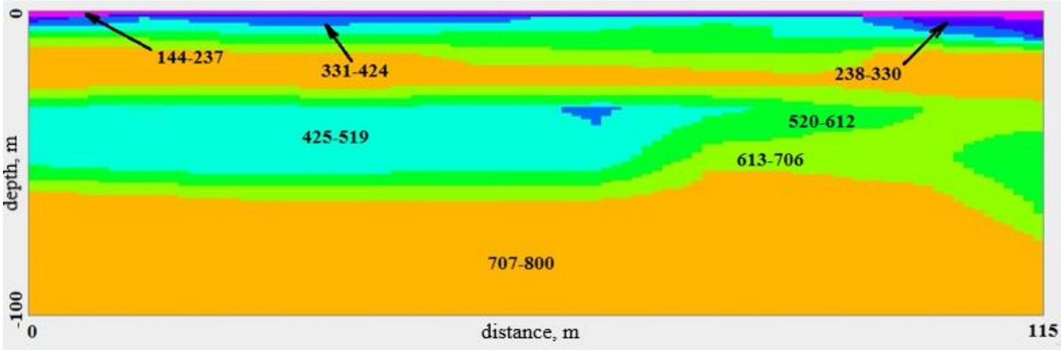

Figure 7. 2-dimensional speed cut of transverse waves on seismic profile No. 14

In profile No. 14, the average transverse wave speed parameter up to a depth of 30 m was calculated Vs30= 490 m/s. On the left wing of the profile, the 20 m thick fast layer of 425-519 m/s disappeared completely, despite the increase in speed at the end of the profile. On the contrary, at the end of the profile, the ceiling of the 707-800 m/s high-speed layer penetrated the bottom of the low-speed layer lying above it in the form of an ascent.

Methodology of conducting magnetometric research

The results of the magnetometric research carried out in the waste and landslide areas of the skarn-iron ore group beds in the Dashkasan region of the Republican Seismological Service Center were investigated. The magnetometric research works carried out for the purpose of landslide risk assessment were carried out by fully covering the area. A network of profiles was created in the research area and the goal was set to determine the probable voltage dynamics of the magnetic field.

The mentioned method made it possible to monitor tectonic disturbances (cracks) at different depth intervals in the area and to evaluate the geodynamic regime of the mineral bed.

Processing and interpretation of magnetometric data.

Magnetometric observations in the waste and landslide-prone areas of the Dashkasan field were performed by an operator on foot along the profiles with a G-856 proton-type magnetometer made in America (Figure 8).

Figure 8. The appearance of the proton-type magnetometer G-856, manufactured in America.

Magnetometric observation works were carried out in the above-mentioned areas and the measurement data received on the developed profiles were initially analyzed. The research works were carried out in six parallel and two profiles that cross them in the north-south direction with a distance of 250 m between the points and profiles (Figure 9)

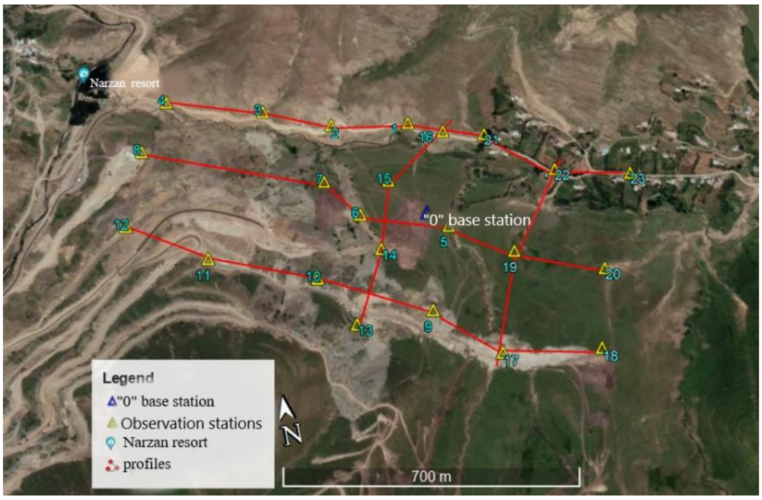

Figure 9. Layout scheme of gravi-magnetometric profiles performed in waste and landslide areas of Dashkasan skarn-iron ore group beds.

Based on the analysis and interpretation of magnetometric data, the anomalous areas that may be at risk of landslides have been outlined (Figure 10) and the depth of the planes that can cause landslides according to the lithological composition of geological sections in these areas has been determined (Figure 11). A schematic map and a 3D model were prepared in 2D format.

As can be seen from the prepared maps, it is observed that the geomagnetic field voltage is almost unevenly distributed in Dashkasan skarn-iron ore beds and waste areas.

In this local area, the geomagnetic field voltage varies with gradient increases and, albeit episodic, decreases.

The geomagnetic field gradient is characterized by sharp changes in the 2D map of the area.

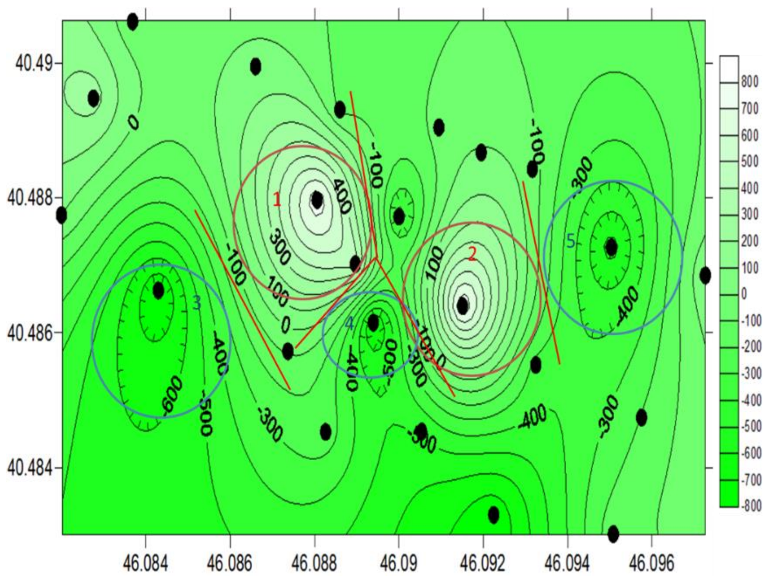

Figure 10. Map of the stress-deformation state of the geomagnetic field in the waste and landslide areas of Dashkasan skarn-iron ore group beds in 2D format

Conventional signs:

Geological fault lines

Magnetic observation points

Geomagnetic anomaly (maximum) 1-2

Geomagnetic anomaly (minimum) 3-4-5

In the south and southwest wing of the map, geomagnetic anomalies of minimum type 3, 4, and 5 are observed in the east. All three minimum-type anomalies are elongated in the south-north direction. The intensity of the noted anomalies is around -400 ÷ -500 nT.In the center of the research area, intense anomalies of maximum type 1 and 2 are observed in the geomagnetic field. The mentioned maximum-type anomalies are stretched in the south-north direction, just like the minimum-type anomalies. In the contact zone of the maximum and minimum type anomalies observed on the map, there were sharp gradient changes related to the stress in the geomagnetic field (Figure 11). These are areas of transition from intense maximum No. 1 and No. 2 to minimum No. 3-4-5.

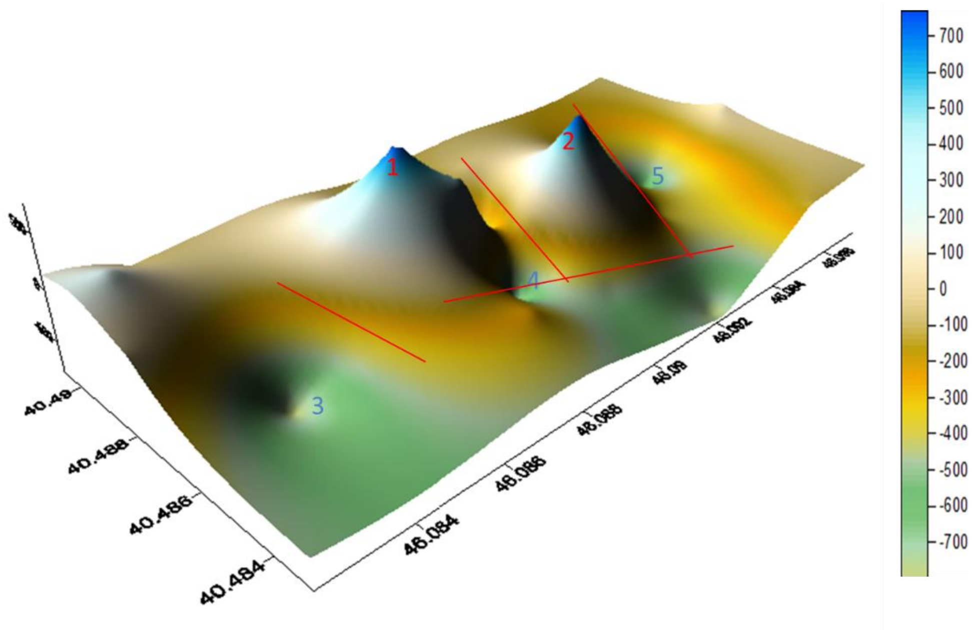

Figure 11. The model of the stress-deformation state of the geomagnetic field in the waste and landslide areas of Dashkasan skarn-iron ore group beds in 3D format

1-2 Maximum
3-4-5 Minimum
Geological fault lines

The above-mentioned maximum and minimum type of local geomagnetic anomalies are more precisely expressed in the schematic model drawn up in 3D format. Maximums 1 and 2 observed in the geological structure of the area with gradient changes in the geomagnetic field (surges) occur here in the lower layers of the earth's surface. It is assumed to be related to complications (Figure 12). On the basis of the results of complex geological, hydrogeological, seismological, engineering-seismic and geophysical data, anomalies are contoured in the study area, and there is a risk of landslides, it can be said that Dashkasan skarn iron ore group beds It shows that the dynamics of activation in the area is intense and it is important to take measures that can reduce the risk of landslides.

The method of gravimetric research.

A gravimetric network has been established to investigate the geological-tectonic structure of the landfill and the adjacent landslide zone, and to determine the location and direction of tectonic faults and disturbances (Figure 9).

Gravimetric studies have drawn up a schematic map, vector scheme and 3D model reflecting the tension of the gravity field, depth dynamics, and the distribution of gravity in the landfill and its adjacent areas.

The obtained data allowed to monitor the tectonic disturbances in different depth intervals in the area and to evaluate the geodynamic regime of the area. It was performed with a high-precision gravimeter of the CG-5 AutoGrav type, manufactured in Canada (Figure 12).

Figure 12. View of the Canadian-made CG-5 AutoGrav type gravimeter under research.

Processing and interpretation of gravimetric data

A 2-dimensional isoanomaly map (Figure 13), a 3-dimensional model (Figure 14) and a vector scheme (Figure 15) of the gravity field according to the results of calculations and changes of the gravity field on each profile in the waste and landslide areas of Dashkasan skarn - iron ore group deposits were drawn up.

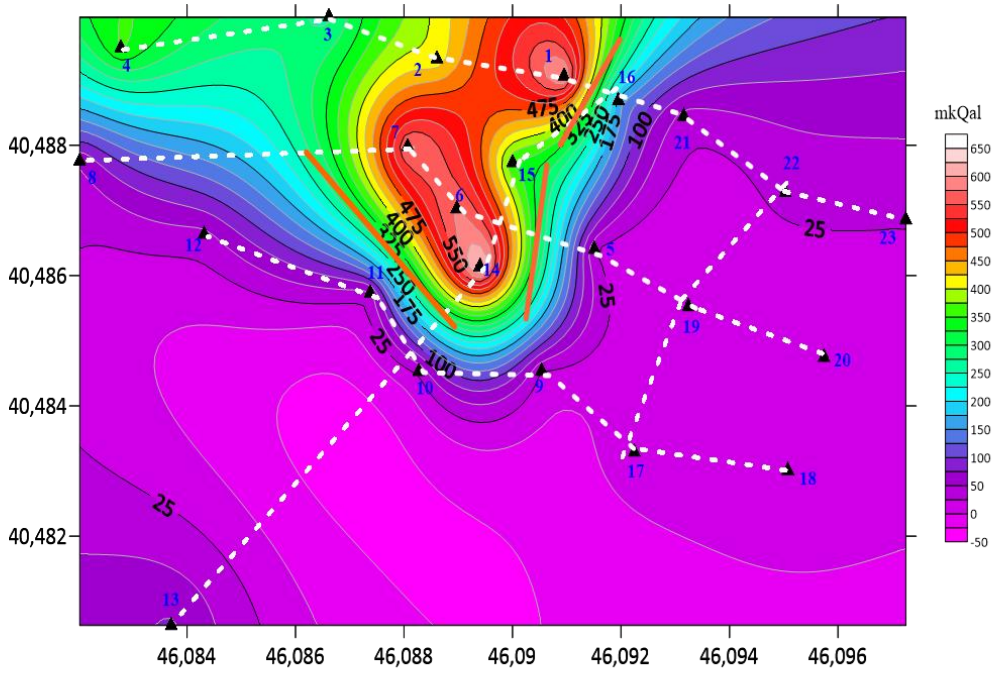

Figure 13. General isoanomaly map of the gravity field reflecting the stress-deformation state in the waste and landslide area of Dashkasan skarn - iron ore group beds.

As can be seen from the isoanomaly map of the gravity field, the anomalous zones accompanied by the variable value of the relative gravity force are precisely covered has been done. Thus, the relative gravity varies between 400 and 650 μGal, spreading to the south-west and south of the study area with a maximum value. This mentioned anomaly is spread from north to south and is closed in both directions.

In the southern wing of the map, there is a complication in the gravity field, which is exactly the opposite of the anomaly in the north-south direction. An anomalous zone is observed with a decrease in the gravity field from 250 μGal to 175 μGal with a minimum value.

The presence of this type of anomalies in the area suggests that there is a geological disturbance in the local area, where the gradient has changed sharply, resulting in a landslide.

The fact that the gravity field anomalies of the area are so sharply opposite means that the research area has a complex geological structure. The results of the above-mentioned interpretation are more clearly visible in the 3D model and vectorial map of the stress-deformation state of the geological environment based on the data of the gravity field in the waste and landslide area of Dashkasan skarn - iron ore group deposits (Figures 14-15).

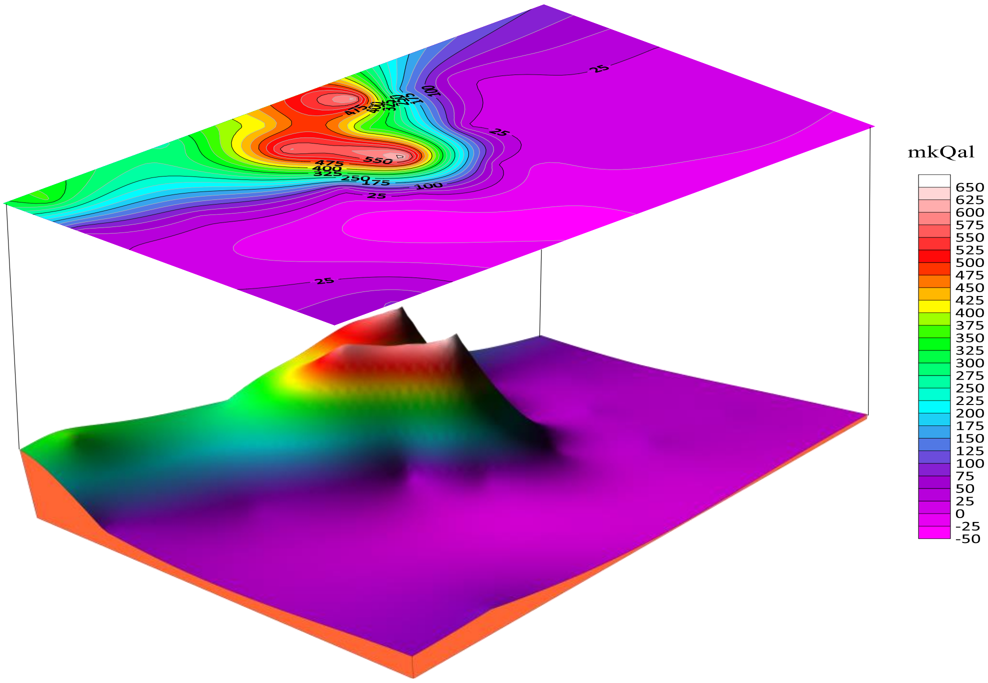

Figure 14. Dashkasan skarn - a model built in 3D format reflecting the stress-deformation state of waste and landslide area of iron ore group beds.

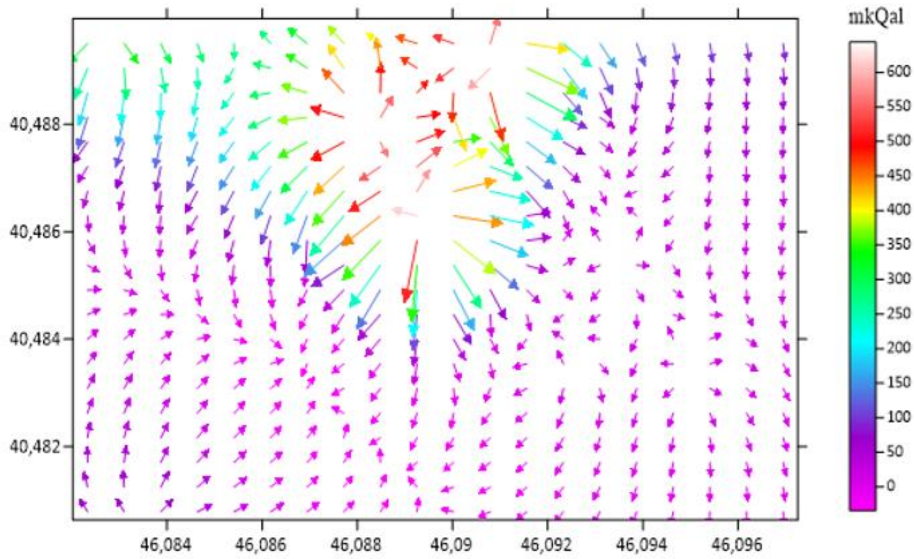

Figure 15. Vector map of the gravity field reflecting the stress-strain condition in the waste and landslide area of Dashkasan skarn - iron ore group beds.

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STATISTICAL ASSESSMENT OF THE SEISMICITY OF AZERBAIJAN AND SURROUNDING REGIONS IN 2021 BASED ON THE DATA OF "KINEMETRICS" SEISMIC STATIONS

G.J. Yetirmishli[1], S.S. İsmailova[1]

Annotation

The territory of Azerbaijan is one of the most seismically active regions of the world. For this, a fairly extensive study of information about the current state of seismicity in a certain region is required. The analysis of seismicity based on digital data of 2021 is reflected in the article. Along with earthquakes, explosions were also analyzed. From these studies, it is known that an increase in the number of earthquakes and the released seismic energy is observed in 2021. Seismic activation is mainly observed along the Western Caspian, Ajichay-Alat, Ganjachay-Alazan, Gazakh-Sygnakh, Front Talish, Talish, Sharur-Ordubad, Sangachal-Ogurchu, Garabogaz-Safidrud, Agrakhan-Krasnovodsk deep faults.

Keywords: *analysis of seismicity, earthquakes, seismic activity, tectonic faults.*

“KİNEMETRİCS” SEYSMİK STANSİYALARIN MƏLUMATLARI ƏSASINDA 2021-Cİ İL ƏRZİNDƏ AZƏRBAYCAN VƏ ƏTRAF BÖLGƏLƏRİN SEYSMİKLİYİNİN STATİSTİK QİYMƏTLƏNDİRİLMƏSİ

Q.C.Yetirmişli, S.S.Ismayilova

Annotasiya

Azərbaycan ərazisi – dünyanın ən seysmoaktiv bölgələrindən biridir. Bunun üçün müəyyən bir bölgədə seysmikliyin mövcud vəziyyəti haqqında məlumatın kifayət qədər geniş öyrənilməsi tələb olunur. Məqalədə 2021-ci il üçün rəqəmsal məlumatlar əsasında seysmikliyin analizi öz əksini tapmışdır. Zəlzələlərlə yanaşı partlayışların da analizi aparılmışdır. Bu araşdırmalardan məlum olur ki, 2021-ci ildə zəlzələlərin sayında və ayrılan seysmik enerjidə artım müşahidə olunur. Seysmik aktivləşmə əsasən Qərbi Xəzər, Acıçay-Ələt, Gəncəçay-Alazan, Qazax-Sığnax, Talış, Öntalış, Şərur-Ordubad, Sangaçal-Oğurçu, Qaraboğaz-Safidrud, Aqraxan-Kasnavodsk dərinlik qırılmaları boyunca müşahidə olunur.

Açar sözləri: *seysmikliyin analizi, zəlzələlər, seysmik aktivlik, tektonik qırılmalar.*

СТАТИСТИЧЕСКАЯ ОЦЕНКА СЕЙСМИЧНОСТИ АЗЕРБАЙДЖАНА И ПРИЛЕГАЮЩИХ РЕГИОНОВ В 2021 ГОДУ НА ОСНОВЕ ДАННЫХ СЕЙСМИЧЕСКИХ СТАНЦИЙ "KINEMETRICS"

Г.Дж.Етирмишли, С.С.Исмаилова

Аннотация

Территория Азербайджана является одним из самых сейсмически активных регионов мира. Для этого требуется достаточно обширное изучение информации о современном состоянии сейсмичности в определенном регионе. В статье отражен анализ сейсмичности на основе цифровых данных 2021 года. Наряду с землетрясениями анализировались и взрывы. Согласно исследованиям в 2021 году

[1] *Republican Seismic Survey Center of Azerbaijan National Academy of Sciences*

наблюдается рост числа землетрясений и выделившейся сейсмической энергии. Сейсмическая активизация в основном наблюдается на территории Западно-Каспийского, Аджичай-Алатского, Гянджачай-Алазаньского, Газах-Сигнахского, Переднего Талыша, Талышского, Шаруд-Ордубадского, Сангачал-Огурчинского, Гарабогаз-Сафидрудского, Аграхан-Красноводского глубинных разломов.

Ключевые слова: *анализ сейсмичности, землетрясения, сейсмическая активность, тектонические разломы.*

INTRODUCTION

Earthquakes are one of the most dangerous natural processes on Earth. The Caucasus, including Azerbaijan, as well as the Caspian Sea, are part of the Alpine-Himalayan rift system, located in the collisional contact zone of the Eurasian and Arabian tectonic plates, and are characterized by fairly high seismic activity.

In 2021, an analysis of seismicity was carried out based on digital data. Earthquakes in neighboring states and the Caspian Sea also affect the territory of Azerbaijan. On 02.01.2021, an earthquake with a magnitude of ml=4.8 was recorded in the territory of Dagestan at 04:05 local time. The earthquake was felt in the border regions of Azerbaijan up to magnitude 4-3; On March 11, 2021, an earthquake with a magnitude of ml=4.5, h=7 km occurred in the territory of Iran at 05:46 local time, which was felt up to 3 points in the territory of Azerbaijan. 4 earthquakes were registered on the territory of Armenia. The most powerful of these earthquakes, with magnitude ml=5.2 and ml=5.5, depths h=2 and 4 km occurred. These earthquakes were felt in the border regions of Azerbaijan up to 5-3 points.

A map of the epicenters of the earthquakes that occurred in the region of Azerbaijan has been constructed (Figure 1).

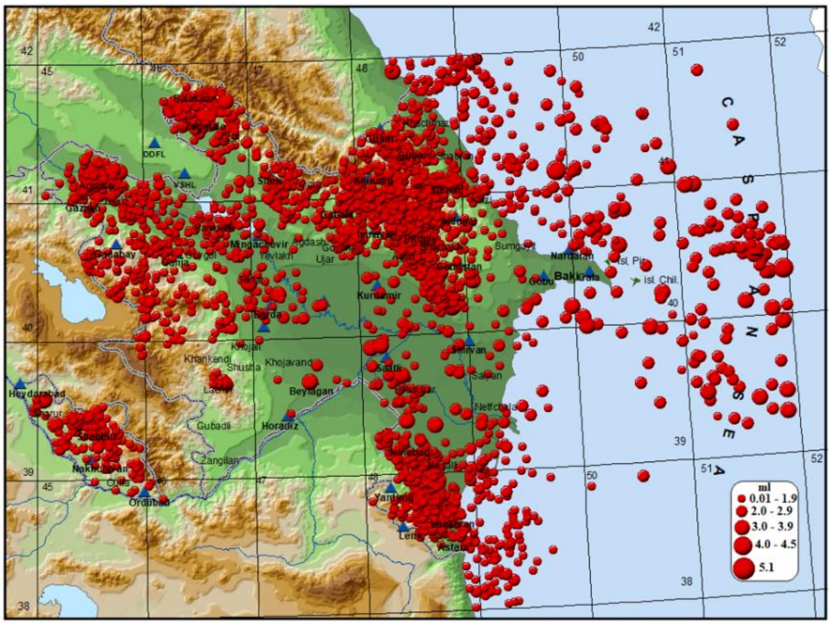
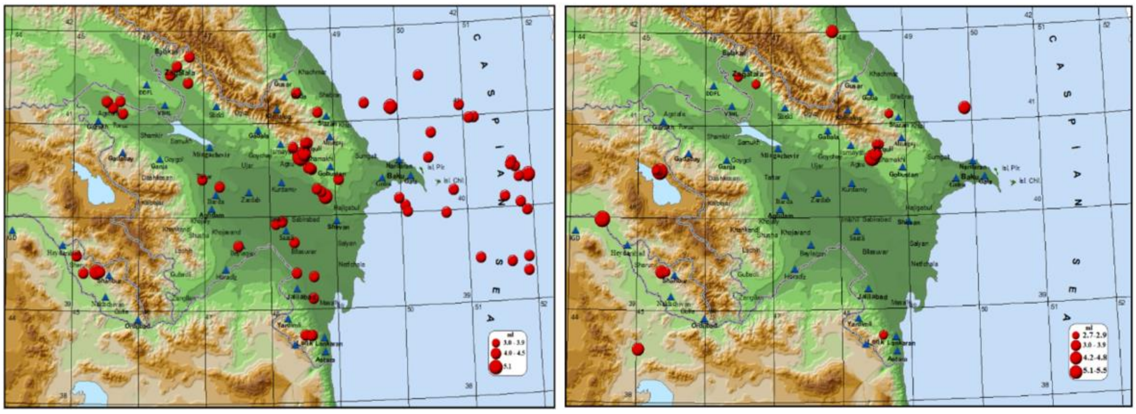


Figure 1. Map of epicenters of earthquakes that occurred in the territory of Azerbaijan

In 2021, an earthquake with a magnitude ml≥3 was recorded in the territory of Azerbaijan and 17 perceptible earthquakes were recorded in Azerbaijan and its adjacent territories (Figures 2a and 2b).



2a 2b

Figure 2. a) Map of epicenters of earthquakes with magnitude ml≥3 in the territory of Azerbaijan during 2021; b) Map of epicenters of earthquakes felt in Azerbaijan and adjacent areas during 2021.

The analysis of the number of earthquakes and released seismic energy in the territory of Azerbaijan during 2010-2021 shows that in 2020, the number of earthquakes in the territory of Azerbaijan is 4030, the amount of released seismic energy is ∑E=13.1 • 1011C, while the highest magnitude is ml=4.9, in 2021 the number of earthquakes was 4184, the amount of released seismic energy was ∑E=14.3•1011C, the highest magnitude was ml=5.1 From the results of the analysis, it is known that the analysis of the number of earthquakes and the released seismic energy in the territory of Azerbaijan for 12 years (Figure 3) shows that the amount of seismic energy released in 2012 reached its maximum. This is related to the occurrence of strong (ml=4.0÷5.7) earthquakes in the territory of the republic in recent years.

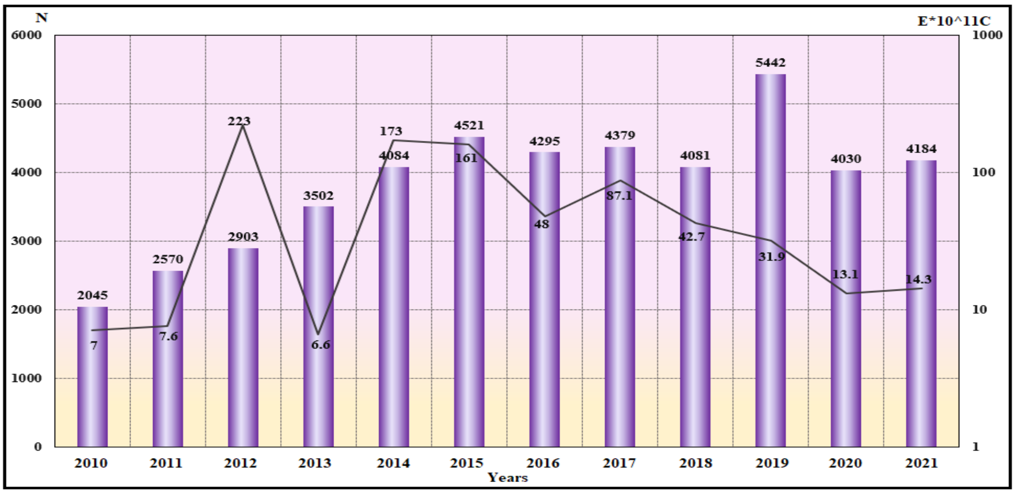


Figure 3. Histogram of the distribution of the number of earthquakes and the released seismic energy in the territory of Azerbaijan during 2010-2021

The analysis of the number of earthquakes and the release of seismic energy in Azerbaijan and adjacent areas by month (Figure 4) shows that the release of seismic energy was higher in February and November.

The high level of seismic energy released in February is related to the occurrence of earthquakes with ml≤5.5 on the territory of Armenia. The high energy in November is related to the earthquake with the magnitude ml-5.1 that occurred in the Shamakhi region.

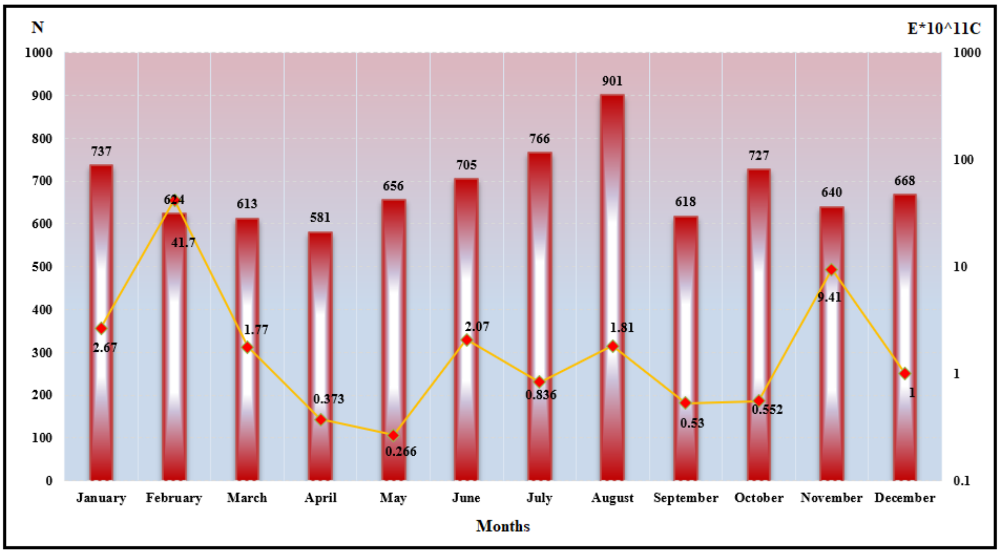


Figure 4. Histogram of the distribution of the number of earthquakes and the released seismic energy in Azerbaijan and adjacent areas in 2021 by month

A histogram and a map of the distribution of the depth of the earthquakes that occurred in Azerbaijan and adjacent areas in 2021 in space and time have been constructed (Figure 5). The analysis of the distribution of earthquakes according to depth shows that 40% of them occurred at a depth of ≤10 km.

The depths of earthquakes in the land area of Azerbaijan are 2-54 km, in the Caspian water area 2-62 km, and in the regional areas mainly between 2-35 km changes.

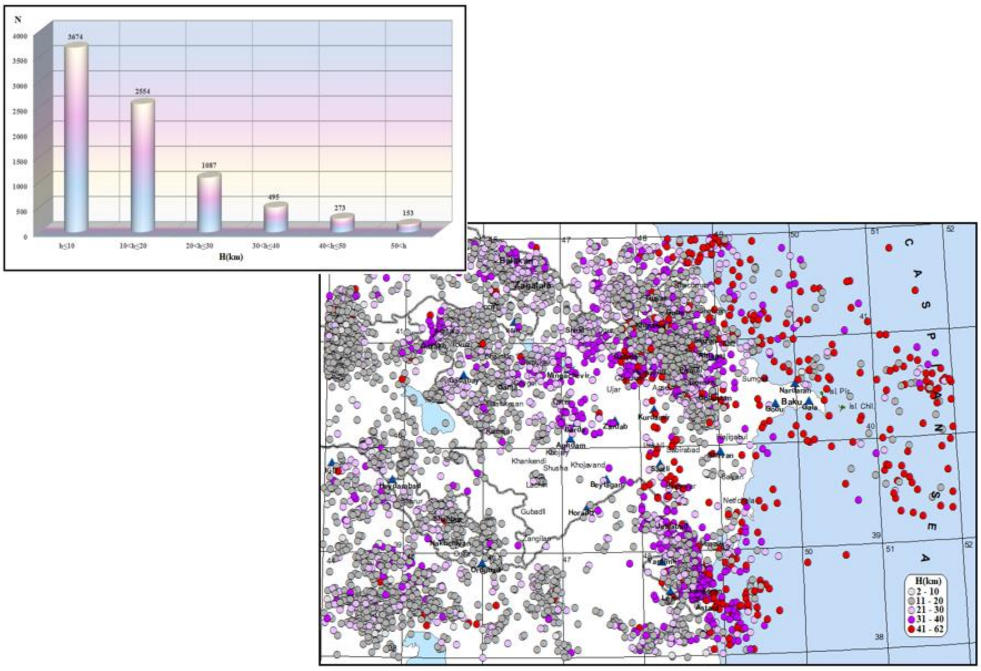


Figure 5. Histogram and map of the depth distribution of earthquakes that occurred in Azerbaijan and adjacent areas in 2021

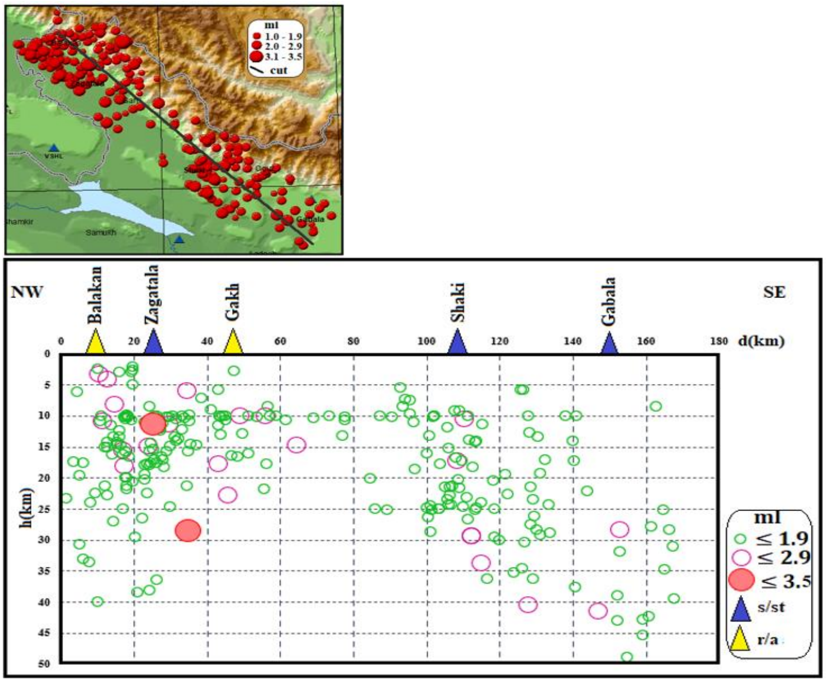


Figure 6. Balaken-Gabala I-I seismological section

In order to study the seismicity of the territory of Azerbaijan, seismological profiles were established for separate seismoactive regions.Seismological traction was established along the Balaken-Gabala II profile passing through the seismoactive zone of Azerbaijan (Figure 6). The profile extends along the Ayrichay-Alat deep fault in the pan-Caucasus direction.

As can be seen from the section, as in 2020, weak seismicity is observed along the profile.In the Zagatala area, 2 shocks with a magnitude of ml≤3.0 were recorded. An earthquake with a magnitude of ml-2.8 was recorded on August 18 at 13:37 local time in Zagatala district, 15 km southwest of Zagatala station. The earthquake was felt by some people. In the Zagatala-Balakén area, the pits are mainly distributed at a depth of 2-25 km. Magnitude ml-2.8 and ml-3. 1 imperceptible shock occurred within the sedimentary layer at a depth of 11 km.Earthquakes with a magnitude of ml≤2.9 were recorded in the territory of Gakh. An earthquake with a magnitude of ml-2.9 was registered in Gakh region on March 31 at 13:04 local time, 23 km south of Zagatala station. The earthquake was felt by some people. As can be seen from the cut, the earthquake occurred at a depth of 10 km. The earthquakes that occurred in the Zagatala-Balakan areas are located at the intersection of the Vandam and Sharur Zagatala faults. Weak seismicity is observed in the area of

In order to study the geodynamic conditions of the Shamakhi-Ismayilli zone and the Lower Kura basin, the northwest, southeast II-II profile was constructed (Figure 7) and the seismicity was higher than the background level. 2 strong perceptible tremors were recorded in this zone. First, on 20.11.2021 at 16:46 local time, an earthquake with a magnitude of ml-5.1 was recorded in Shamakhi area, 17 km south of Pirgulu station. The earthquake was felt up to 5 in the epicenter and 4-3 in the surrounding regions. Aftershocks were recorded after the earthquake. The magnitude of aftershocks varies in the range of ml=0.8-4.5. Second, an earthquake with a magnitude of ml=4.5 was recorded on 20.11.2021 at 16:48 local time in Shamakhi area, 13 km south of Pirgulu station. The earthquake was felt up to 4 in the epicenter and 3 in the surrounding regions. As can be seen from the cut, density of hypocenters is observed in the north-west direction. The strong aftershocks and aftershocks that occurred in the Shamakhi area were located in the zone of influence of the Achichay Alat and Western Caspian deep faults.

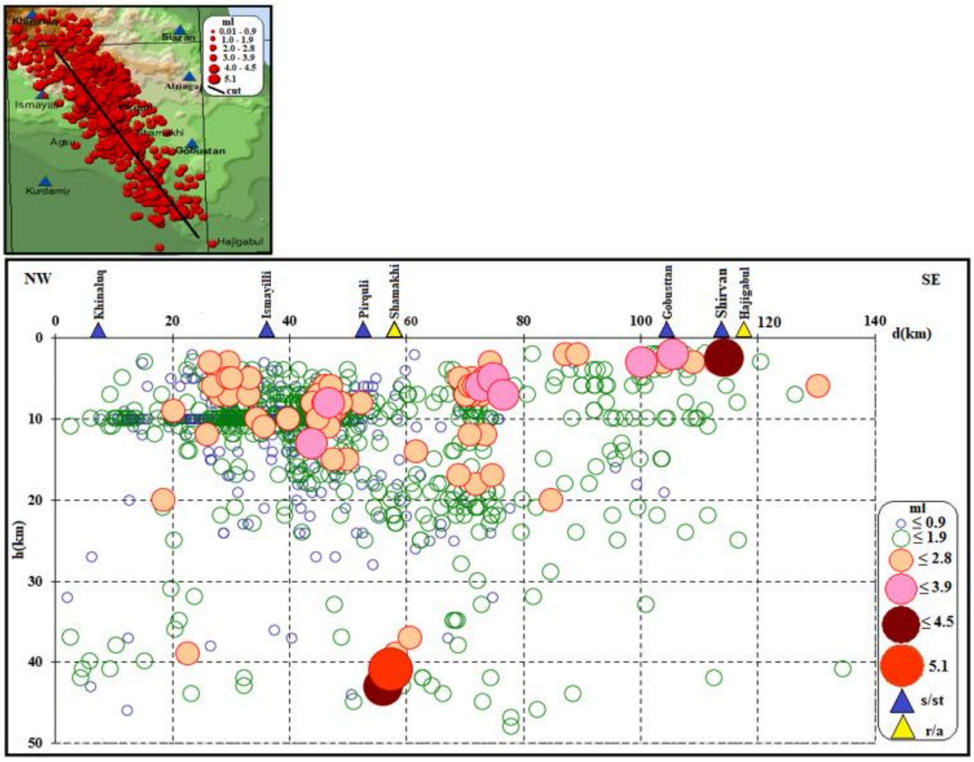


Figure 7. Seismological section of Shamakhi-Ismayilli seismogenic zone II - II profile

During the entire section, distribution is mainly observed at a depth of 2-48 km. Earthquakes with magnitude ml≥3.0 are distributed within the sedimentary layer at a depth of 2-12 km. As can be seen from the cross section, earthquakes with magnitude ml≥3.0 occur in the deep layer as well. The earthquake with a magnitude of ml-5.1 and its aftershocks were spread at a depth of 38-43 km. The main thrust occurred at a depth of 41 km.

The magnitude of the reduction of the hypocenters is ml≥3 as the section passes through the Lower Kura plain. 0 earthquakes are increasing. In the area, the hearths are distributed at a depth of 2-20 km. Earthquakes with magnitude ml≥3.0 occurred within the subsidence layer.

In 2021, seismicity was higher in Nakhchivan AR than in other years. In order to study the geodynamic conditions of the Nakhchivan area, a seismological cross-section (Figure 8) was constructed on the III-III profile in the northwest and southeast directions. Hypocenters were distributed along the cross-section at a depth of 3-25 km. Intensification of earthquakes is observed in the north-west direction. As can be seen from the section, mostly weak earthquakes occurred in the area. An increase in tremors with a magnitude of ml≥3.0 was recorded in the Shahbuz area.

The highest magnitude earthquake occurred in Nakhchivan area was ml=4.2. On January 23, at 17:22 local time, an earthquake occurred in Shahbuz district, 15 km west of Shahbuz station. The earthquake was felt at the epicenter with a magnitude of 5 and in the surrounding regions up to 4-3. Before the earthquake, on January 21 at 23:23 local time, an earthquake with a magnitude of ml=3.8 was recorded in Shahbuz district, 11 km northwest of Shahbuz station. The earthquake was felt up to 4 in the epicenter and 3 in the surrounding regions. The occurrence of earthquakes is related to the activation of the Sharur Ordubad fault. In 2021, 130 weak tremors (by a single station) were recorded at the Shahbuz station. Earthquakes with magnitude ml≥3.0 are observed to occur within the sedimentary layer at a depth of 3-10 km.

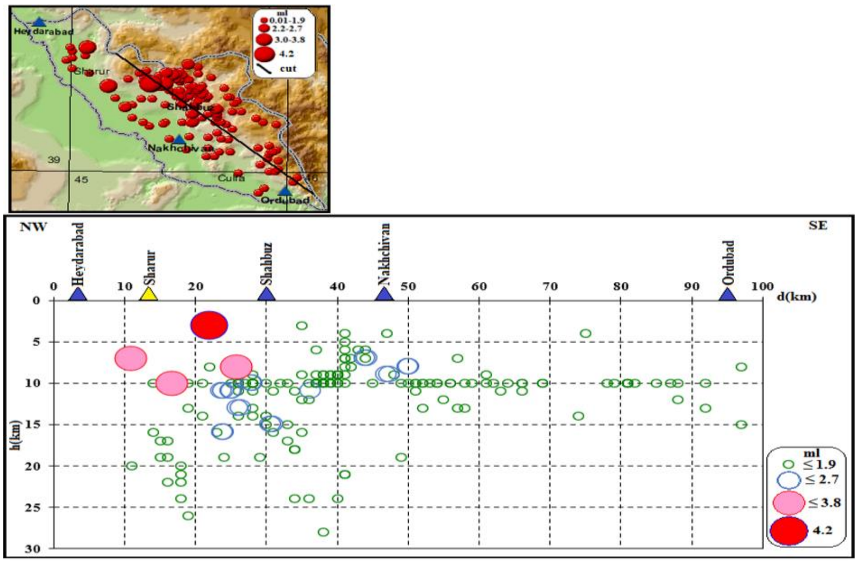


Figure 8. Seismological section of the Nakhchivan area on the III-III profile

If we look at the Caspian water area, we can see that the level of seismic activity has increased, 25 tremors with a magnitude of ml≥3 have been recorded (Figure 9). The highest magnitude earthquake recorded in the Caspian water area was ml=4.5. The earthquake was felt up to 3 points in Siyazan, Khizi regions, Sumgayit city.

The occurrence of earthquakes with magnitude ml≤4.5 in the Northern and Central Caspian waters is related to the activation of the Makhachkala-Krasnovodsk fault. The concentration of earthquakes in the center is observed at the intersection of the Agrakhan-Krasnovodsk and transverse Karabogaz Safidrud faults. The main mass of earthquakes with magnitude ml≥3.0 in the Caspian water area was recorded at a depth of 40-62 km, as well as at a depth of 12-14 km. Magnitude ml≥3 in the South Caspian Sea. The occurrence of earthquakes with 0 is related to the activation of the Sangachal-Ogurchu deep fault.

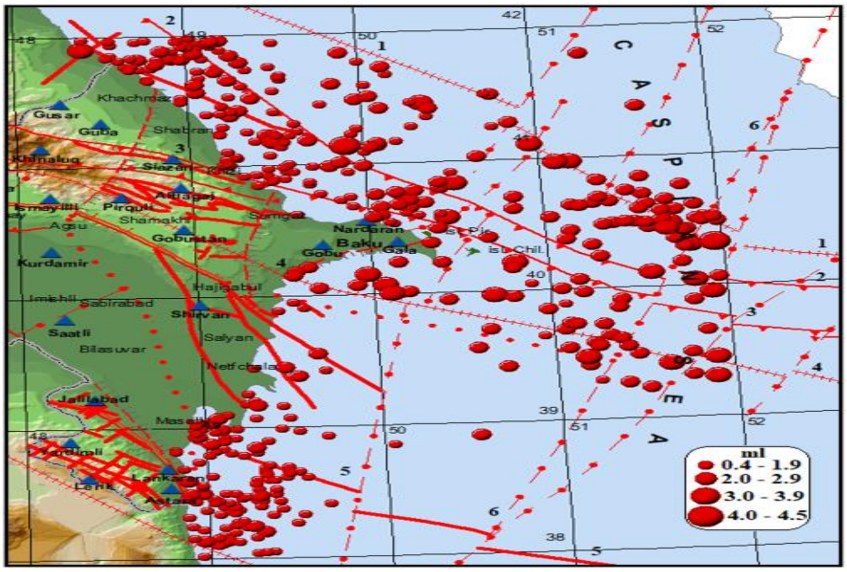


Figure 9. Map of earthquakes, faults and epicenters of the Caspian watershed in 2021
Faults: 1- Agrakhan-Krasnovodsk; 2 – Makhachkala-Krasnovodsk; 3- Absheron-Near Balkhan;
4 – Sangachal-Ogurchu; 5- Mil-Chikhishlar 6 - Karabogaz-Safidrud; 7 - Lahiridcan.

Earthquakes with a magnitude of ml≤2.8 that occurred in the Talysh coastal zone in the South Caspian basin were concentrated between the Mil-Chikhishlar and Lahiridjan marginal faults passing through the territory of Iran.

Seismic activity

Analysis of the seismic activity of the researched area, the earthquakes that occurred in 2021 were used from the catalog of the RSSC ANAS, and based on this, a seismic activity map was drawn up to monitor the change of the seismic regime over time (Figure 10).

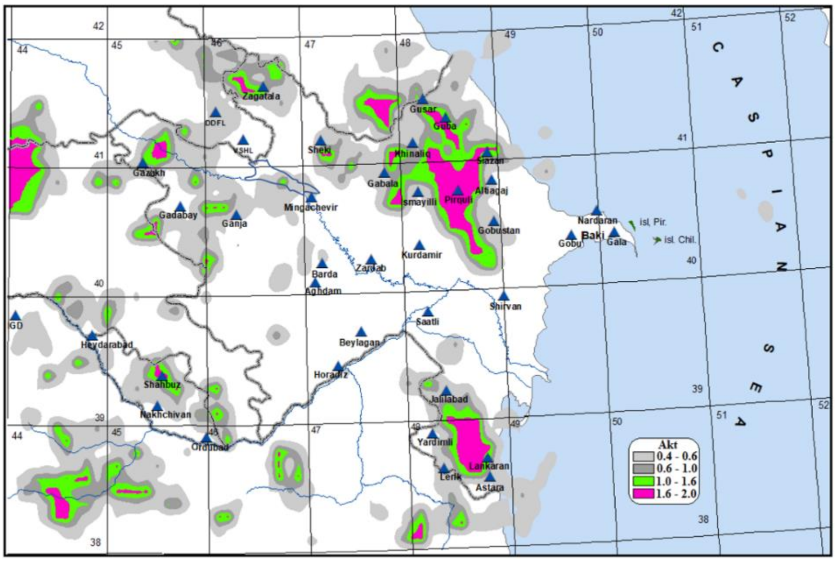


Figure 10. Seismic activity map of Azerbaijan and adjacent territories in 2021

In 2021, activity was high in Shamakhi-Ismayilli, Gusar-Guba, Talish zones. Zagatala-Balaken seismicity is weak on the southeastern slope of the Greater Caucasus. In 2021, unlike other years, seismic activity increased in Shahbuz district of Agstafa, Nakhchivan AR. Weak seismicity in the Lesser Caucasus and an increase in earthquakes within the Mingachevir reservoir are recorded. The southern and northern parts of the Caspian Sea are relatively calm, while the central part has been highly active. Seismicity was high on Iran-Turkey border and Georgia-Armenia border.

CONCLUSION

During 2021, an increase in seismicity is observed in the northwestern region of Azerbaijan in the Shamakhi-Ismailli seismogenic zone, in the Talish mountainous zone, in the central part of the Caspian Sea, on the Iran-Turkey border, and on the Georgia-Armenia border. Seismicity was higher in Shahbuz district of Nakhchivan AR in 2021, unlike other years. Seismic activity is observed along the Western Caspian, Achichay-Alat, Ganjachay-Alazan, Gazakh-Sighnakh, Talish, Front Talish, Sharur-Ordubad, Akhvay, Sangachal-Ogurchu, Garabogaz-Safidrud, Agrakhan-Krasnovod deep faults. In 2021, an increase in the number of earthquakes and the released seismic energy is observed. During the year (ml=2.7-5.5) 17 perceptible earthquakes were registered. The analysis of the distribution of earthquakes by depth shows that the depths of earthquakes in the land area of Azerbaijan are 2-54 km, It varies between 2-62 km in the Caspian water area, and mainly between 2-35 km in regional areas. 40% of the foci at a depth of ≤10 km were deposited within the layer.

There is tension in the Caspian Sea. The southern and northern parts of the Caspian Sea are relatively calm, but the central part is in a tense situation. The largest part of hypotents occurs in the basalt layer and upper mantle at a depth of 40-62 km.

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MODERN SEISMOGEODYNAMICS OF THE NORTH-WESTERN PART OF AZERBAIJAN

G.J. Yetirmishli[1], S.E. Kazimova[1], A.Sh. Mammadova[1], S.E. Mehtiyeva[1]

Annotation

The article presents an analysis of the seismicity of focal zones in the northwestern part of the Republic of Azerbaijan. Using a geodynamic model of a pair of right-lateral strike-slip faults, an interpretation of the focal mechanisms of the Zagatala, Balakan, Oghuz, Gabala and Sheki earthquakes was given, and a mechanism of the Caucasian fault with a left-sided strike-slip component was established. A connection between the observed seismicity and the tectonic structure of the region was revealed. The nature of movements in the active parts of deep faults has been revealed. An analysis of the orientation of the main stress axes of earthquake focal mechanisms was carried out. Depth profiles of displacements in the sources of strong earthquakes were constructed.

Based on the orientation data of the compression and tension axes, a map of the distribution of the Lode-Nadai coefficient was constructed. As can be seen on the maps, the Zagatala, Balakan and Gabala regions are mainly characterized by tensile stresses. Compressive stresses are observed in the Sheki and Oghuz regions. Thus, in 2003-2023, the displacement values were determined in the foci of earthquakes with magnitude ml≥4 in the Balaken, Zagatala, Sheki, Oguz and Gabala regions. In the Sheki, Oguz, Gabala regions at a depth of 12-19 km, the displacement is 0.26-0.35 m, and in the Zagatala and Balakan regions 0.15-0.27 m at a depth of 3-15 km. The smallest displacement of 0.1-0.12 m was recorded in the Sheki region.

***Key words**: geodynamics, deep faults, focal mechanisms, Zakatala, Balakan, Okhuz, Gabala and Sheki earthquakes.*

AZƏRBAYCANIN ŞİMAL-QƏRB BÖLGƏSİNİN MÜASİR SEYSMOGEODİNAMİKASI

Q.C.Yetirmişli, S.E. Kazımova, A.Ş. Məmmədova, S.E. Mehtiyeva

Annotasiya

Məqalədə Azərbaycan Respublikasının şimal-qərb hissəsində seysmogen zonalarının aktivliyi təhlili təqdim olunur. Sağ yana doğru sürüşmə-sürüşmə cütünün geodinamik modelindən istifadə etməklə Zaqatala, Balakən, Oğuz, Qəbələ və Şəki zəlzələlərinin ocaq mexanizmlərinin analizi nəticəsində ümumqafqaz qırılmalar üzrə sol tərəfli hərəkətlər müəyyən olunub. Müşahidə olunan seysmiklik ilə rayonun tektonik strukturu arasında əlaqə və dərin qırılmaların aktiv hissələrində hərəkətlərin xarakteri aşkar edilmişdir. Zəlzələ ocaq mexanizmlərinin əsas gərginlik oxlarının oriyentasiyasının təhlili aparılmışdır. Güclü zəlzələ mənbələrində yerdəyişmələrin dərinlik profilləri qurulmuşdur.

Sıxılma və gərginlik oxlarının istiqamətləndirilməsi nəticəsində Lode-Nadayi əmsalının paylanma xəritəsi qurulmuşdur. Xəritədən göründüyü kimi, Zaqatala, Balakən və Qəbələ rayonları əsasən gərilmə gərginliyi ilə xarakterizə olunur. Şəki və Oğuz rayonlarında sıxılma gərginliyi müşahidə olunur. Belə ki, 2003-2023-cü illərdə Balakən, Zaqatala, Şəki, Oğuz və Qəbələ rayonlarında maqnitudası ml≥4 olan zəlzələlərin ocaqda yerdəyişmə giymətləri müəyyən edilmişdir. Şəki, Oğuz, Qəbələ rayonlarında yerdəyişmənin dəyəri 12-19 km dərinlikdə 0,26-0,35 m, Zaqatala və Balakən rayonlarında isə 3-15 km dərinlikdə 0,15-0,27 m müşahidə olunur. Ən aşağı yerdəyişmə 0,1-0,12 m Şəki ərazisində qeydə alınıb.

***Açar sözlər:** geodinamika, dərin qırılmalar, ocaq mexanizmləri, Zaqatala, Balakən, Oğuz, Qəbələ və Şəki zəlzələləri.*

[1] *Republican Seismic Survey Center of Azerbaijan National Academy of Sciences*

СОВРЕМЕННАЯ СЕЙСМОГЕОДИНАМИКА СЕВЕРО-ЗАПАДНОЙ ЧАСТИ АЗЕРБАЙДЖАНА

Г.Дж Етирмишли, С.Э.Казымова, А.Ш.Маммадова, С.Э.Мехтиева

Аннотация

В статье представлен анализ сейсмичности очаговых зон СЗ части Азербайджанской республики. С использованием геодинамической модели пары правосторонних сдвигов дана интерпретация механизмов очага Закатальских, Балаканских, Огузских, Габалинских и Шекинских землетрясений, установлен механизм общекавказского сброса с левосторонней сдвиговой компонентой. Выявлена связь наблюденной сейсмичности с тектоническим строением региона. Выявлен характер подвижек в активных частях глубинных разломов. Проведен анализ ориентации основных осей напряжений механизмов очагов землетрясений. Построены глубинные профили смещений в очагах сильных землетрясений.

По данным ориентаций осей сжатия и растяжения была построена карта распределения коэффициента Лоде-Надаи. Как видно на карте, Загатальский, Балаканский и Габалинский районы в основном характеризуются растягивающими напряжениями. Напряжения сжатия наблюдаются в Шекинском и Огузском районах. Так, в 2003-2023 годах были определены величины смещений в очагах землетрясений с магнитудой ml≥4 в Балакенском, Загатальском, Шекинском, Огузском и Габалинском районах. В Шекинском, Огузском, Габалинском районах на глубине 12-19 км величина смещения составляет 0,26-0,35 м, а в Загатальском и Балаканском районах 0,15-0,27 м на глубине 3-15 км. Наименьшее смещение 0,1-0,12 м зафиксировано в Шекинском районе.

Ключевые слова: *геодинамика, глубинные разломы, механизмы очагов, Закатальские, Балаканские, Огузские, Габалинские и Шекинские землетрясения.*

INTRODUCTION

The long-term study of earthquakes shows that the vast majority of them occur due to the sudden release of tension accumulated over a long period of time in the tectonically active parts of the earth's crust. The Caucasus, including Azerbaijan, as well as the Caspian Sea, are part of the Alpine-Himalayan rift system, are located in the collisional contact zone of the Eurasian and Arabian tectonic plates, and are characterized by fairly high seismic activity. The Arabian plate is moving northward, breaking away from the African megaplate along the Red Sea and Gulf of Aden rift zones. As a result of the collision of the Arabian plate with the Eurasian megaplate, the lithosphere area between them is divided into the Anatolian, Iranian, Black Sea, southern Caspian microplate and the Caucasian megablock. [3] These microplates, including the southern Caspian microplate, which includes the territory of Azerbaijan, and the Caucasian megablock are characterized by their own directions of movement and are bordered by systems of deep faults with high seismic activity.

Zagatala-Balakan, Sheki and Okhuz-Gabala seismoactive zones are located in the northwestern zone of the Azerbaijani part of the Greater Caucasus. The Zagatala seismically active zone is located in the extreme north-west of the Azerbaijani part of the Greater Caucasus. Conventionally, its border in the east should be considered the Zagatala-Shamkhor transverse uplift. In the north, west and south, the zone merges with the potentially highly active seismic zones of Southern Dagestan and Western Georgia. The area of the Zakatala seismically active zone within Azerbaijan does not exceed 3500 km^2. The first information about earthquakes in this zone dates back to 1853. From 1853 to 1933 in the Zagatala seismically active zone, only 55 earthquakes were recorded, felt in one or more populated areas (Malinovsky, 1940). The intensity of these earthquakes does not exceed 5-6 points. [2, 10]

The epicenters of earthquakes in this zone are localized along three parallel lines of latitudinal strike. The most powerful earthquakes, the intensity of which reaches 7 points, occur in the extreme northern epicentral line.

One of the characteristic features of the Zakatala zone is the high frequency of earthquakes from the same source zone and their low intensity. From a tectonic point of view, the earthquakes that occurred in the Balaken seismogenic zone are located in the southwest of the Azerbaijani part of the Greater Caucasus, surrounded by the Ayrichay-Alyat and Vandam deep faults. Note that the Tfan anticlinorium stands out as the central uplift of the Mesozoic core of the Greater Caucasus meganticlinorium, in the arch of which the most ancient Aalenian and Toarcian formations for the region are exposed. On the southern wing of the Tfan anticlinorium, the Zakatala-Kovdag synclinorium is distinguished, filled with Cretaceous formations. The southernmost structural element of the Mesozoic core of the Greater Caucasus meganticlinorium on the territory of Azerbaijan is the Vandam anticlinorium, composed of volcanic bajos in the core. This work is devoted to the study of the modern geodynamic situation in the northwestern part of Azerbaijan according to the earthquake source mechanism data [14, 15].

Mechanisms of earthquake sources in the study area

In order to study the stress and deformation areas of the earth's crust, the parameters of the focal mechanisms were established, evaluated, the conditions of their formation, and the dynamic parameters of mechanisms and earthquake foci were analyzed (Figure 1). Source mechanisms are supposed to be subjected to what type of displacement movements (horizontal displacement, breaking and falling, breaking and lifting) of the rocks in the source during an earthquake. The source mechanisms were built on the basis of P waves of 35 digital stations of earthquakes with ml≥4.0 in "Fa_major" and Moment Tensor software.

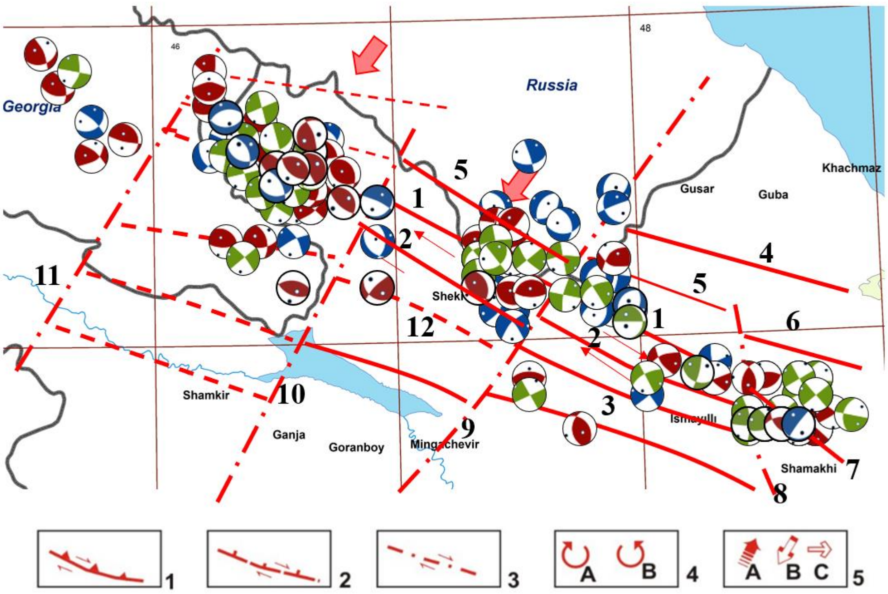

Figure 1. Scheme of the fault structure and features of the geodynamic regime of the southern slope and southeastern subsidence of the Greater Caucasus and the mechanisms of earthquake foci for 2003-2023.
Symbols: The main seismogenic faults that determine the features of the geodynamic regime of the earth's crust: 1-reverse faults, 2-normal faults, 3-slip faults (arrows indicate the direction of horizontal movements). Reverse faults: 1-Dashgil-Mudresa, 2-Vandam, 3-Geokchay, 4-Siyazan, 5-Zangi-Kozluchay, 6-Germian, 7-Adzhichay-Alyat. Shifts: 8-West-Caspian, 9-Arpa-Samur, 10-Ganjachay-Alazan, 11-Kazakh-Signakh. Faults: 12-North Adzhinour,
(Faults map compiled by: (Shikalibeyli [15])

Focal mechanisms of 49 earthquakes with magnitude ml≥4.0 and depth h=2-42 km were established in the North-Western part of Azerbaijan during 2003-2023. As can be seen from the map, faults and horizontal displacements are dominant in the Zagatala-Balakén zone, and horizontal displacement-type movements prevail in the Sheki, Oguz, and Gabala zones. 11 earthquakes with magnitude ml≥4.0 were recorded in Sheki, Oguz, Gabala zones. 9 of these earthquakes are dominated by horizontal displacement type movements and are aligned between the Pan-Caucasus right-sided Dashgil-Mudrasa, Vandam and Northern Acinohur faults, and are located at a depth interval of 11-21 km [8,13].

In 2012, 2014, 2015, earthquakes occurred in Zagatala, Gabala, and Okhuz territories with a magnitude of ml>5 (table 1). In 2012, an earthquake with a magnitude of ml=5.7 occurred in Zagatala region. On May 7, at 04:40:25, earthquakes occurred in Zagatala, Balaken, Gakh, Sheki, Okhuz, with a focal depth of ml=5.6, H=9 km, and an intensity of I0=7.0 at the epicenter at 14:15:13. It was determined that the first Zagatala earthquake (GMT 4:40, M=5.6) was a fault-slip type, and the second earthquake (GMT 14:15, M=5.7) was a fault-slip type.[6, 7]

On June 29, 2014, at 17:26:07, an earthquake occurred in Zagatala region with a magnitude of ml=5.3 km, a focal depth of H=9 km, and an intensity of I_0=5 at the epicenter. As can be seen from the table, the direction of the compression axis P is vertical (PL=3), and the direction of the tension stress axis T is oriented in the plane close to the horizon (PL=18). A sharp drop was determined for the nodal plane (DP=79-75). The value of displacement in the hearth (SLIP=-15-(169)) indicates that displacement, fracture-falling type of movement prevails. Based on the above, as a result of the tension states, it was determined that the earthquake is of the fault-thrust-displacement type and coincides with the Gazakh-Signakh transverse fault. The Balakan earthquake on October 14, 2012 was characterized by horizontal (PLP=0°) tensile stresses with a southwestern orientation (AZM=239°) and near-vertical compressive (PLT=48°) with a northwestern orientation (AZM=329°) stresses (fig. 10, table 4). The type of movement on both (DP=57°) planes is normal fault with shear elements. Plane NP1 has an eastern strike (STK_1=115°), NP2 – a northern strike (STK_2=2°). Comparison of the strike of nodal planes with fault lines shows agreement of the second nodal plane NP2 with two transverse Kazakh-Signakh and Sharur-Zagatala faults [9].

Table 1.

Focal mechanisms of earthquakes felt in Balakan, Zagatala, Sheki, Oguz, Gabala areas in 2003-2023 Ml≥5.0

№	Data	Time	Coordinates		Principal stress axes						Nodal planes						ml	H, km
					T		N		P		NP1			NP2				
			φ°N	λ°E	PL	AZM	PL	AZM	PL	AZM	STK	DP	SLIP	STK	DP	SLIP		
1	20030601	6:09:43	40.96	47.32	0	252	90	8	0	162	207	90	0	297	90	-180	5.2	10
2	20120507	4:40:25	41.5	46.58	14	79	71	296	10	171	152	87	162	216	72	2	5.6	9
3	20120507	14:15:13	41.56	46.63	0	240	20	150	69	330	130	48	-117	349	48	-62	5.7	12
4	20120518	14:47:20	41.52	46.64	5	251	78	135	10	343	117	87	-169	27	79	-4	5.0	10
5	20120518	14:46:33	41.53	46.62	0	69	15	159	74	339	354	47	-68	144	47	-111	5.0	13
6	20140629	17:26:07	41.54	46.54	3	288	72	27	18	197	241	79	-15	334	75	-169	5.2	9
7	20140929	1:38:07	41.13	47.94	7	323	41	59	48	225	265	64	-43	17	53	-146	5.5	11
8	20141004	4:59:32	41.11	47.94	11	317	64	72	23	222	268	82	-25	1	65	-171	5.0	6
9	20150904	4:49:36	40.97	47.43	0	288	90	172	0	18	153	90	-180	63	90	0	5.9	16
10	20180605	18:40:25	41.55	46.62	0	284	19	194	71	14	176	48	-116	32	48	-64	5.5	10

In 2014, at 06:38:07 local time, a strong (ml=5.5) earthquake was recorded 22 km north-east of the city of Gabala. After the earthquake (ml=5.5), 79 aftershocks were recorded within a day. The sources are located at a depth of 5-19 km. It should be noted that the strong earthquake that occurred in Gabala region coincides with the Ismailli-Sighirli orthogonal fault. After that earthquake, at 08:55:52 and 09:19:08 local time, earthquakes of ml>3.0 were recorded 22 km northeast of Gabala city. The focal mechanisms of both earthquakes are aligned with the pan-Caucasus trend and the Dashgil-Mudrasa fault [8].

In 2015, the earthquakes of magnitude ml=5.9 at 04:49:36 on September 4 and ml=4.0 at 00:13:32 on October 13, 2015, show that the movement of the left side displacement type prevails. As can be seen from the table, the direction of the compression axis P is vertical (Pl=10) and the direction of the tension stress axis T is oriented in the plane close to the horizon (Pl=5). A sharp drop was determined for the nodal plane (DP=86-90). The value of displacement in the furnace (Slip=0-(-10)) indicates that displacement-type movement is predominant. According to the above, as a result of tension conditions, left-lateral horizontal displacement type movements are formed in NE directions and coincide with the Arpa-Samur transverse fault.

In the Balakan-Gabala seismogenic zones of Azerbaijan, earthquakes with a magnitude of ml≥3.0 share the core more closely at a depth of 3-25 km. 8 earthquakes with magnitude ml≥5.0 were registered. These earthquakes are recorded at a depth of 8-15 km.

On September 4, 2015, an earthquake occurred near the Oghuz region with an observed intensity of I0=7 points at the epicenter and I_0=7-3 points in nearby areas. In accordance with the map of epicenters of seismic events for 1900-2003 in the area of the earthquake, a number of strong earthquakes were recorded, with an intensity of 6 or more at the epicenter. The most significant of them are the earthquakes of 1953 and 1968 with I0=6-7 points, 1980, 1986, 1991 with I0=5-6 points, March 5, 2000 I0=5 points. The last noticeable event in this area was the earthquake on June 1, 2003 with I0=6 points at the source and 3-4 points in the Mingachevir and Kurdamir regions (Table 2).

Table 2.

Strong earthquakes in Oghuz and nearby areas with an intensity of 5 or more at the epicenter.

Data			Time			Coordinats		Depth	Ml	Io points
year	mounth	day	hours	min	sek	lat	lon	км		
1953	9	2	00	36	01	41.10	47.40	5	5.1	7
1953	9	16	11	15	29	41.20	47.40	28	5.0	6
1968	5	11	11	29	40	41.00	47.60	15	4.7	6
1980	4	1	07	33	41	40.70	47.80	20	4.7	6
1986	6	02	15	16	13	40.97	47.77	22	4.6	5
1991	10	21	11	58	23	40.92	47.34	16	4.5	5
2003	06	01	06	09	42	41.05	47.27	22	5.0	6
2015	04	09	04	49	36	40.97	47.43	16	5.9	7

Based on macroseismic studies, it was revealed that the earthquake was felt with the greatest intensity in the territories of Oghuz and Sheki regions. Here, the intensity of the earthquake according to table MSK-64 was estimated at 7 points. The earthquake was accompanied by more than 80 aftershocks with a magnitude from 0.5 to 4, 33 of which occurred in the first day [3, 4]. The aftershock cloud spread up to 23 km in the south-north direction and 9 km in the west-east direction, but the area of the main mass of the earthquake cluster was 88 km^2. Despite the fact that the main source is located at a depth of 16 km in the granite layer, the depth of the aftershocks ranges from 11-34 km. As can be seen in Fig.2, the epicenter of the earthquake is confined to the intersection zone of the longitudinal Dashgil-Mudresa and transverse Arpa-Samur faults [5]. It should be noted that the Arpa-Samur deep fault of ancient origin at all times from the Paleozoic to the present day has been a zone of active manifestation of tectonic movements, a conductor of magmatic melts, ore-bearing solutions and seismicity. According to Shikhalibeyli E.Sh. [6] The Arpa-Samur Trans-Caucasian seismically active metal-bearing fault zone unites the Mrovdag-Zod, Terter and Khachin faults of deep origin.

Analysis of the focal mechanisms of the earthquakes on 09/04/2015 with ml=5.9 (main shock) and on 10/13/2015 with ml=4.0 showed the predominance of two types of movements. The earthquakes that occurred in the Oghuz region on September 4 at 04:49 am and on October 13 at 00:13 am occurred under the influence of tensile and compressive stresses of similar magnitude.

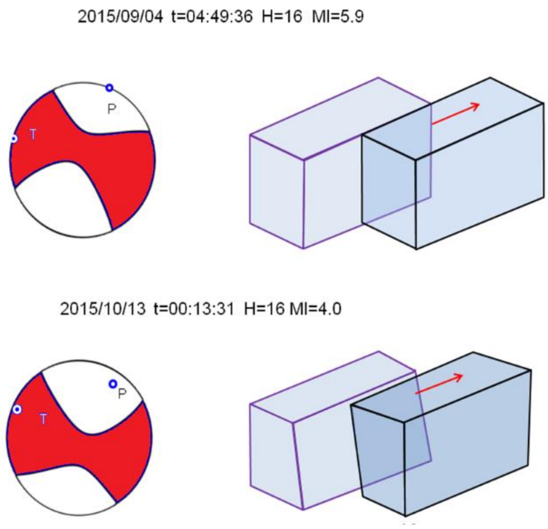

Figure 2. Earthquake source mechanisms, as well as block diagrams of displacement along the NP2 plane

From Table 2 it can be seen that the first nodal plane of the rupture extends in the SE direction (153º) with a dip to the southwest at an angle of 86-90º, the second nodal plane has a NE strike (63º) with a dip to the southeast at an angle of 83-90º. In this case, the compression stresses in the earthquake source were oriented in the northeast direction (azimuth 18) and acted near-horizontally (angle with the horizon 0-7), and tensile forces were directed in the west-southwest direction (287-288) at an angle of 0-2 to the horizon. The type of movement of these earthquakes is strike-slip with a left-lateral horizontal component.

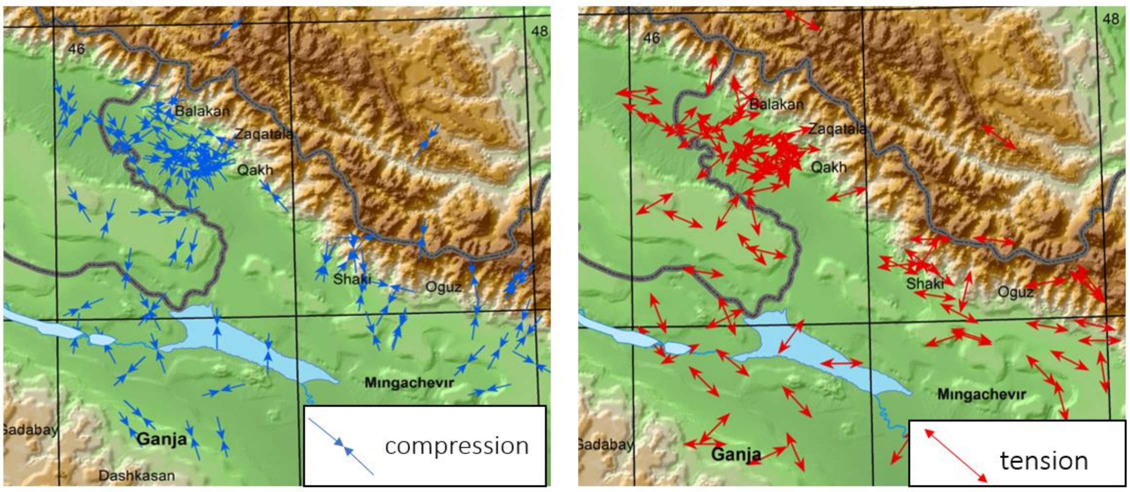

Figure 3. Scheme of compression-tension axes of focal mechanisms of earthquakes with ml≥4.0 in Zagatala-Gabala area during 2003-2023

Stress and deformation areas of the Earth's crust in the North-Western part of Azerbaijan

During 2003-2023, the scheme of compression-tension axes was established based on the data of focal mechanisms of earthquakes with ml≥4.0 in Balakan, Zagatala, Sheki, Oghuz and Gabala areas (Figure 3).

On the map, blue color-compression, red color-tension arrows. The analysis of the orientation of the compression and extension axes showed the SW-NE orientation of the compression axes in the Sheki and Gabala-Oghuz seismogenic zones. A chaotic distribution is observed in the Zakatala-Balaken zone. This is due to the complexity of the tectonic structure. The main seismic tremors with a magnitude of more than 4.0 are associated with the following tectonic zones: the node of intersection of the Zagatala, transverse with the Ganyh-Ayrichai longitudinal fault; 2 - node of intersection of Zagatala with Shambul-Ismailly longitudinal fault. All these tectonic nodes are located in the Mazymgarishan-Sarybash sublatitude fault zone and are controlled by this fault. As a result of the orientation of the compression and tension axes, a distribution map of the Lode-Nadayi coefficient was constructed. On the map, the blue color shows the tension arrows, the red color shows the compression arrows. As can be seen from the map, the Zagatala, Balakan, Gabala region of the republic is characterized by tension. Compression stress is observed in Sheki and Oghuz regions (Figure 4).

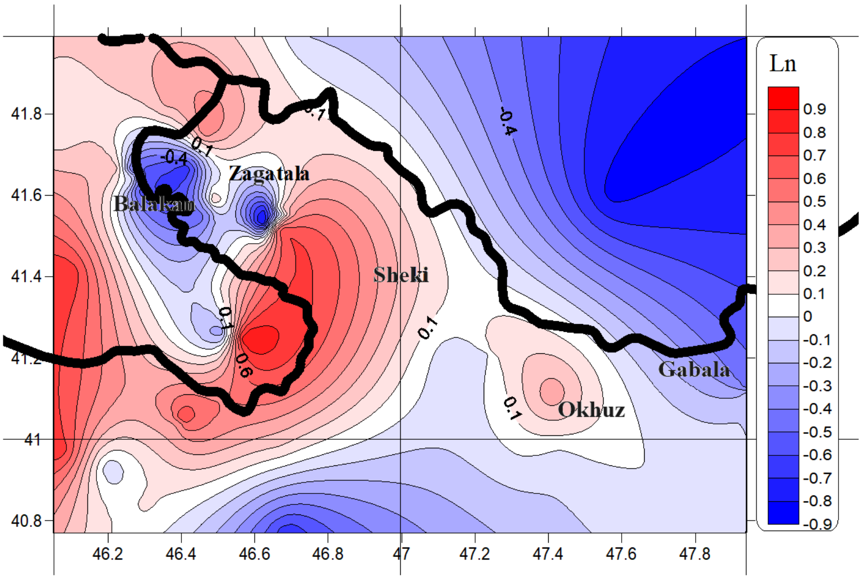

Figure 4. Distribution map of the Lode-Nadai coefficient calculated on the basis of the focal mechanisms of the earthquakes that occurred in Zagatala, Sheki, Oghuz and Gabala in 2003-2023

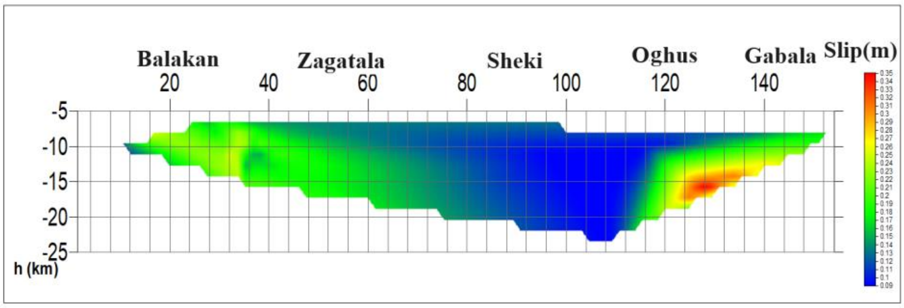

Figure 5. In 2003-2023, the depth section of displacement values calculated based on the mechanisms of earthquakes with ml≥4 in Balakan, Zagatala, Sheki, Oghuz and Gabala regions

Thus, on the basis of the USA USGS Coulomb 3 program, a depth section of the displacement values of earthquakes with magnitude ml≥4.0 in Balakan, Zagatala, Sheki, Oghuz and Gabala regions in 2003-2023 was established (Figure 5). As can be seen from the cross-section, the values of displacement in the Oghuz, Gabala, Zagatala and Balaken zones are high and vary in the range of 0.25-0.35 m. In Sheki, Oghuz, Gabala regions, the value of displacement is 0.26-0.35m at a depth of 12-19 km, and 0.15-0.27m is observed at a depth of 3-15 km in Zagatala and Balakan regions. The lowest value of displacement was recorded in Sheki area of 0.1-0.12m.

In the section of the Zagatala and Balaken zones, displacement values are characterized by higher values in the range of 0.18-0.26m at a depth of 6-16 km (Figure 6).

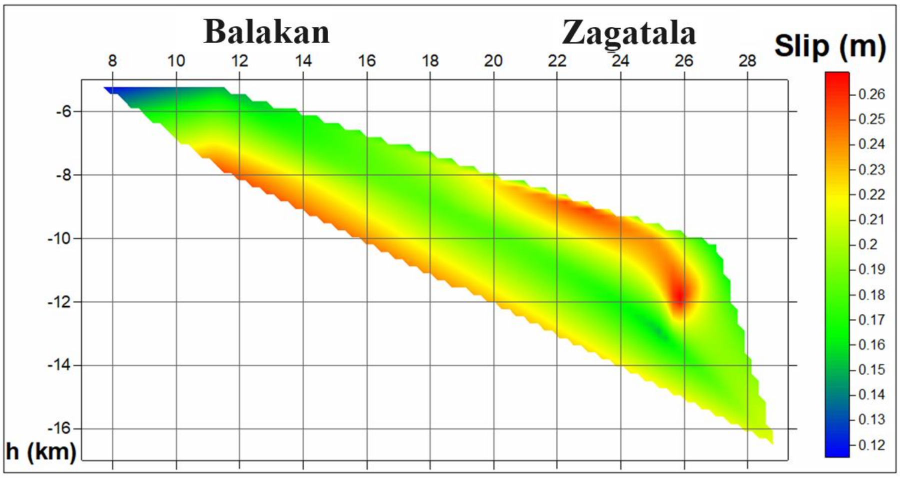

Figure 6. Depth cut of displacement values calculated on the basis of mechanisms of earthquakes with ml≥4 in Balakan and Zagatala regions in 2003-2023

In Sheki, Oghuz, Gabala regions, the value of the displacement at a depth of 13-19 km is higher and is observed in the interval of 0.23-0.34m (Figure 7).

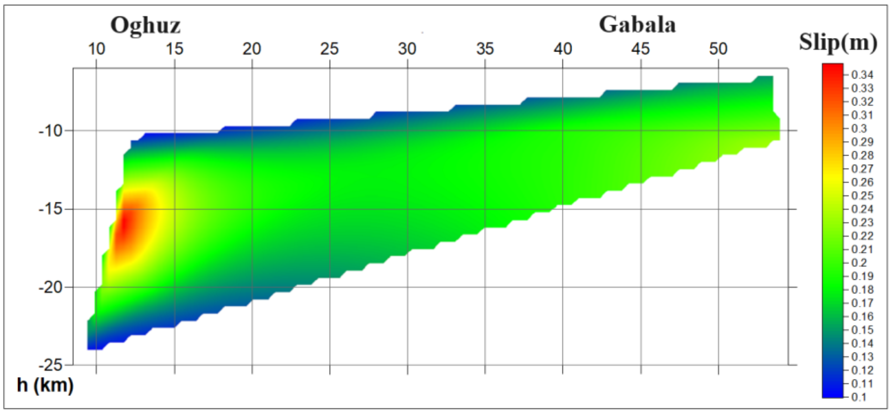

Figure 7. Depth cut of displacement values calculated on the basis of mechanisms of earthquakes with ML≥4 in Oguz and Gabala regions in 2003-2023

RESULTS

The study of the spatio-temporal sequence of seismic shocks of various magnitudes in each seismic focal zone leads to conclusions about the similarity of individual seismically active zones of the Azerbaijani part of the Greater Caucasus, observed not only in their tectonic conditions, but also in the nature of the manifestation of seismicity. The epicentral zones of most of the listed earthquakes are located in the foothills in the Vandam structural zone. The spatial distribution of epicenters demonstrates that the events of 2014-2015 with ml≥5.0 are confined to transverse (northeast-trending) disjunctive dislocations, but the epicentral zones generally have a "pan-Caucasian" elongation and are located along the Vandam tectonic zone along the Ganykh-Ayrichay-Alyat deep thrust. It can be assumed that the sources of the Gabala, as well as Oghuz earthquakes are confined to the extension zone and their mechanism is determined as the result of right-sided shear deformation in the zone of geodynamic influence of the left-sided Arpa-Samur fault. The structure of the Kura Basin is observed to shift under the structure of the Greater Caucasus.

Analysis of the orientation of the compression and extension axes showed the SW-NE orientation of the compression axes in the Sheki and Gabala-Oghuz seismogenic zones. On the territory of the Zakatala-Balaken zone, a chaotic distribution is observed. This is due to the complexity of the tectonic structure. The main seismic tremors with a magnitude greater than 4.0 are associated with the following tectonic zones: the intersection of the Zagatala transverse fault with the Ganykh-Ayrichay longitudinal fault; 2 - intersection point of the Zagatala with the Shambul-Ismayilli longitudinal fault. All these tectonic nodes are located in the zone of the Mazymgaryshan-Sarybash sublatitudinal fault and are controlled by this fault.

As a result of the orientation of the compression and tension axes, a distribution map of the Lode-Nadayi coefficient was constructed. As can be seen from the map, the regions of Zagatala, Balakan, and Gabala are mainly characterized by tensile stress. Compression stress is observed in Sheki and Oghuz regions.

Thus, in 2003-2023, depth sections of displacement values of earthquakes with magnitude ml≥4 in Balaken, Zagatala, Sheki, Oghuz and Gabala regions were established. As can be seen from the cross-section, the values of displacement in the Oghuz, Gabala, Zagatala and Balaken zones are high and vary in the range of 0.25-0.35 m. In Sheki, Oghuz, Gabala regions, the value of displacement is 0.26-0.35m at a depth of 12-19 km, and 0.15-0.27m is observed at a depth of 3-15 km in Zagatala and Balakan regions. The lowest value of displacement was recorded in Sheki area of 0.1-0.12m.

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SEISMOGEODYNAMICS OF THE GREATER CAUCASUS FROM GNSS DATA

G.J. Yetirmishli[1], I.E. Kazimov[1], A.F. Kazimova[1]

Abstract

The article provides an analysis of modern seismogeodynamics of the Azerbaijan part of the Greater Caucasus. The purpose of the research was to reveal how complex geodynamic processes are reflected in the spatial and temporal distribution of strong earthquakes in the territory of the Azerbaijan part of the Greater Caucasus. For this purpose, GPS and seismological data for the period 2012-2022 were considered. The main tasks were to analyze the strong earthquakes that occurred in the territory under consideration, analyze the data on the velocities of horizontal movements obtained from the data of the GPS network of RSSC stations, and also make a correlation between these data. The velocity field clearly illustrates the movement of the earth's surface in a north-northeast direction. This phenomenon reflects the process of successive accumulation of elastic deformations in the zone of subduction interaction of the structures of the northern side of the South Caucasian microplate (Vandam-Gobustan megazone) with the accretionary prism of the Greater Caucasus. Comparing the seismic data with the data of GPS stations, it can be seen that with the gradual immersion of the seismogenic layer, the velocities increase. At SATG and ALIG stations, the data increase to 10-11 mm/g. It can be noted that the change in the values of horizontal movements on the territory of the Zakatalo-Balakan, Oguz-Gabala seismogenic zones is associated with the movement of layers (blocks) of the earth's crust at a depth of 5-20-40 km. In the Sheki seismogenic zone 2-30 km, in the Shamakhi-Ismayilli zone 5-45 km, and in the Hajigabul seismogenic zone 5-55 km.

Key words: *GPS stations, seismogenic layer, seismic geodynamics of the Azerbaijan part of the Greater Caucasus.*

QLOBAL NAVİQASİYA PEYK SİSTEMİNİN MƏLUMATLARINA GÖRƏ BÖYÜK QAFQAZIN SEYSMOGEODİNAMİKASI

Q.C.Yetirmişli, İ.E.Kazımov, A.F.Kazımova

Annotasiya

Məqalədə Böyük Qafqazın Azərbaycan hissəsinin müasir seysmogeodinamikası təhlil edilir. Tədqiqatın məqsədi Böyük Qafqaz ərazisində güclü zəlzələlərin fəza-zaman paylanmasında mürəkkəb geodinamik proseslərin necə əks olunduğunu aşkar etmək idi. Bu məqsədlə 2012-2022-ci illər üçün GPS və seysmoloji məlumatlar nəzərdən keçirilmişdir. Əsas məsələlər nəzərdən keçirilən ərazidə baş vermiş güclü zəlzələlərin təhlili, RSXM-nin stansiyalarının GPS şəbəkəsinin məlumatlarından alınan üfüqi hərəkətlərin sürətləri haqqında məlumatların təhlili, həmçinin bu məlumatlar arasında korrelyasiyanın yaradılması olmuşdur. Sürət sahəsi yer səthinin şimal-şimal-şərq istiqamətində hərəkətini aydın şəkildə göstərir. Bu hadisə Cənubi Qafqaz mikroplitəsinin şimal tərəfi strukturlarının (Vandam-Qobustan meqazonu) Böyük Qafqazın akkresiya prizması ilə üstəgəlmə qarşılıqlı əlaqəsi zonasında elastik deformasiyaların ardıcıl toplanması prosesini əks etdirir. Seysmik məlumatları GPS stansiyalarının məlumatları ilə müqayisə etdikdə görmək olar ki, seysmogen təbəqənin tədricən batırılması ilə sürətlər artır. SATG və ALIG stansiyalarında məlumat 10-11 mm/il qədər artır. Qeyd etmək olar ki, Zaqatala-Balakən, Oğuz-Qəbələ seysmogen zonaları ərazisində üfüqi hərəkətlərin qiymətlərinin dəyişməsi Yer qabığının 5-20 dərinlikdə təbəqələrinin (bloklarının) yerdəyişməsi ilə əlaqədardır,

[1] *Republican Seismic Survey Center of Azerbaijan National Academy of Sciences*

Şəki seysmogen zonasında 2-30 km, Şamaxı-İsmayıllı zonasında 5-45 km, Hacıqabul seysmogen zonasında 5-55 km.

Açar sözlər: *GPS stansiyaları, seysmogen təbəqə, Böyük Qafqazın Azərbaycan hissəsinin seysmik geodinamikası.*

СЕЙСМОГЕОДИНАМИКА БОЛЬШОГО КАВКАЗА ПО ДАННЫМ ГЛОБАЛЬНОЙ НАВИГАЦИОННОЙ СПУТНИКОВОЙ СИСТЕМЫ

Г.Дж.Етирмишли, И.Э.Казымов, А.Ф.Казымова

Аннотация

В статье приводится анализ современной сейсмогеодинамики Азербайджанской части Большого Кавказа. Целью исследований являлось выявить, как отражаются сложные геодинамические процессы в пространственно-временном распределении сильных землетрясений на территории Азербайджанской части Большого Кавказа. Для этой цели рассматривался GPS и сейсмологические данные за период 2012-2022. Основными задачами было провести анализ сильных землетрясений, произошедших на рассматриваемой территории, проанализировать данные скоростей горизонтальных движений, полученных по данным сети GPS станций РЦСС, а также провести корреляцию между этими данными. Поле скоростей чётко иллюстрирует движение земной поверхности в север-северо-восточном направлении. Данное явление отражает процесс последовательного накопления упругих деформаций в зоне надвигового взаимодействия структур северного борта Южно-Кавказской микроплиты (Вандам-Гобустанская мегазона) с аккреционной призмой Большого Кавказа. Сопоставляя сейсмические данные с данными GPS станций видно, что с постепенным погружением сейсмогенерирующего слоя значения скоростей увеличиваются. На станциях SATG и ALIG данные увеличиваются до 10-11 мм/г. Можно отметить, что изменение значений горизонтальных движений на территории Закатало-Балаканской, Огуз-Габалинской сейсмогенных зон связано с подвижкой слоев (блоков) земной коры на глубине 5-20-40 км. В Шекинской сейсмогенной зоне 2-30 км, в Шамахы-Исмаиллинской - 5-45 км, и в Гаджигабульской сейсмогенной зоне 5-55 км.

Ключевые слова: *GPS станции, сейсмогенерирующий слой, сейсмогеодинамика Азербайджанской части Большого Кавказа.*

INTRODUCTION

To address the issues of the contribution of internal processes in the lithosphere to the latest and modern geodynamics of the region, there is also a lack of modern data on the deep structure of the earth's crust and upper mantle. As is known, the Azerbaijan part of the Greater Caucasus is the most geodynamical active region. Previous studies of Alpine folding and orogeny, in particular, quantitative estimates of the horizontal shortening of the surface, were based mainly on abstract ideas about folding and mountain building as a result of the collision of the Eurasian and Arabian lithospheric plates [16].

The question of the deep structure of the zones of large faults in the earth's crust is also relevant. The issue of flattening of tectonic faults with depth, the separation of the sedimentary cover from the surface of the crystalline basement, and, as a result of these processes in the zone of plate collision, the folding and orogeny [11] are often discussed in the literature.

Modern methods of space geodesy: satellite laser distance measurements (SLR), long-baseline interferometry (VLBI), and, above all, satellite-based global positioning system (GPS) have become widely used in geodynamic studies on a global and regional scale. These measurements make it possible to determine the velocities of the horizontal movement of lithospheric plates in general and the displacement velocities of numerous geodesic points in tectonically active zones with errors much smaller than the measured velocities themselves [18].

The active modern convergence of the Eurasian and African-Arabian lithospheric plates is well known. But direct geodetic measurements show that centrifugal displacements of overthrusts and shifts continue to this day. The evidence for this is the strong Turkish earthquake that occurred on February 6, 2023. The areas of modern extension correspond to the areas of Neogene-Quaternary normal faults and grabens in superimposed troughs, while the areas of modern compression correspond to the zones of Jurassic Cretaceous, Neogene Quaternary thrusts and covers. This means that the distribution of types of modern horizontal movements corresponds to the distribution of those in the indicated geological time intervals.

Thus, our conclusion about the modern expansion of the segments of the mobile belt is also valid for previous intervals of geological history. In this work, we set the goal of revealing how complex geodynamic processes are reflected in the spatial and temporal distribution of strong earthquakes in the territory of the Azerbaijan part of the Greater Caucasus. For this purpose, GPS and seismological data for the period 2012-2022 were considered.

Seismological data.

Seismic activity is associated with the ongoing intensive restructuring of the structural plan with significant amplitudes of recent and modern movements: earthquake sources, as a rule, are confined to the boundaries of large geotectonic elements of the earth's crust and the intersection nodes of faults of various directions.

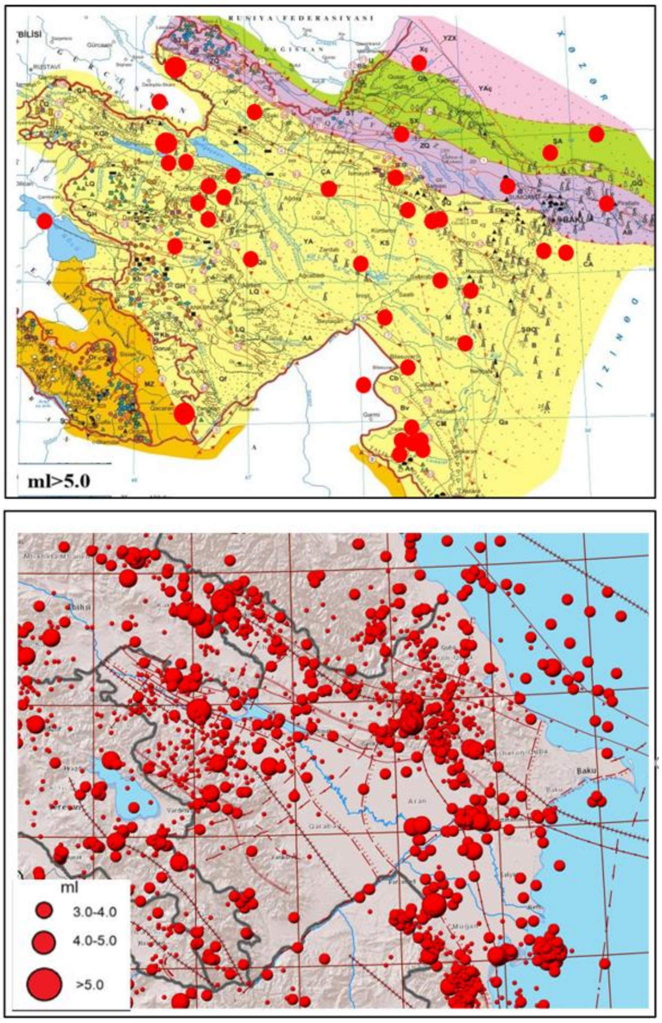

Figure 1. Maps of earthquake epicenters for the period 2003-2022 with ml< 3.0 and ml>5.0 geological map comp. [12]

The geology of the territory of Azerbaijan has been studied since the end of the 19th century, and over the past period a huge amount of actual geological and geophysical material has been accumulated, on the basis of which various geological and tectonic models of the environment, based mainly on the fixist ideology, have been developed in different years. In this context, the changes in views on the structure of the earth's crust of the Caucasus and the Caspian water area that took place in the last quarter of the 20th and early 21st centuries from the atonalistic positions with the adoption of the concept of the underthrust-thrust mechanism of the formation of their alpine structure are of particular importance. In particular, on the territory of Azerbaijan, a significant amount of productive information has been accumulated on ground geological survey, deep geological mapping of land and sea territories by methods of zoning geophysical fields, as well as deep drilling and remote sensing.

In the last decade, significant progress has been made in research related to the interaction of faults and how the occurrence of an earthquake perturbs the stress field in its vicinity, which can cause aftershocks and subsequent earthquakes. These studies are of great importance for assessing the seismic hazard of the region, since voltage changes can either delay or accelerate the occurrence of future earthquakes. In addition, since the seismic hazard assessment depends on the destruction parameters of past earthquakes, it is important to reliably estimate such parameters, rupture location, geometry and extent of past earthquakes [13].

It should be noted that since 2012, a number of strong earthquakes with Ml≥5.0 have been occurring on the territory of the republic. In 2012 and, after some lull, in 2014-2018 a series of strong earthquakes occurred here: Zagatala on May 7, 2012 with Ml=5.6, 5.7, Balakan on October 14, 2012 with Ml=5.8, which were felt in the epicenter with J0=7 b.; Ismailli 07.10.2012 with Ml=5.3; Caspian 10.01.2014 with Ml=5.0, Ajigabul 10.02.2014 with Ml=5.8, Zagatala 29.06.2014 with Ml=5.3, Gabala series 29.09 and 04.10.2014 with Mlmax=5.5; as well as Okhuz on September 4, 2015 with Ml=5.9, Imishli on August 1, 2016 with Ml=5.6, Lerik on August 28, 2018 with Ml=5, etc (fig.1). The intensity of shaking in some of them at the epicenter reached 7 points. An analysis of the spatial distribution of epicenters shows that most of the sources of perceptible earthquakes are located in the zone of the junction of the Kura depression and the southeastern subsidence of the Greater Caucasus or the activation of the southern side of the Kura depression in the zone of transition to the fold system of the Lesser Caucasus [1].

From a tectonic point of view, the modern structure of the Caucasus was formed at the Alpine stage of tectogenesis within the spatial limits covering the southern edge of the Eurasian continent and the northern edge of the South Azerbaijan segment of the Central Iranian microcontinent (microplates, quasi-platforms). In the structure of the eastern, Azerbaijani part of the Caucasus, the decisive role belongs to the following megastructures (from north to south): the North Caucasian microplate, the southern slope trough, the South Caucasian microplate, the South Azerbaijan segment-fragment of the Central Iranian microcontinent, and the Caspian megadepression [4]. As seen in figure strong earthquakes with a magnitude above 5 occurred mainly at the junction of the accretionary prism of the Greater Caucasus with the South Caucasian microplate.

Seismological and paleoseismotectonic studies, seismic and seismotectonic zoning, carried out in various seismic regions of the Caucasus (including the territory of Azerbaijan), confirm the version of the controllability of earthquake source areas by a network of faults of General Caucasian and anti-Caucasian strike with various types of displacement [4]. However, in general, the cause of modern seismic activity is the horizontal movements of different-scale tectonic blocks of the earth's crust, sandwiched in the band of collisional interaction between the Afro-Arabian and Eurasian continental plates.

Analysis of satellite navigation system (GPS) data

Reliable information on the achieved accuracy in determining the annual displacement rates of permanent stations can be obtained from the materials contained in the ITRF data system "International Earth Reference System" for the Earth as a whole and for its European part, that the average error of the ITRF network for the horizontal displacement components is 0.7 and 1.5 mm/year for vertical components [18]. According to the analysis of the European network of permanent stations, which includes 30 sites, the error of the horizontal component for the most stable stations was 0.2 mm/year.

The ITRF system is a catalog that uses as input data time series of station positions and Earth orientation parameters (EOP) provided by the technical centers of four space geodetic methods (VLBI, SLR, GNSS and DORIS) [19]. Comparison of data for ITRF97 and ITRF2014 showed the coordinates of geodetic observation stations, selected in accordance with the accuracy of determining their coordinates and the stability of the position. For these stations, annual values of coordinate changes are given. Station movement velocities are represented in most cases by latitudinal, longitude and vertical velocity components on the reference ellipsoid, best fitted to the geoid figure and used in the processing of geodetic measurements. The velocity vectors defined in the ITRF system are "absolute" vectors in the sense that their direction is set relative to the geodetic coordinate grid fixed on the Earth's body by ITRF stations [18]. The origin of the coordinate system coincides with the center of mass, the position of which is determined using the satellites Lageos1 and Lageos2, which rotate in orbits at an altitude of about 6000 kilometers. According to Kepler's laws, the satellite revolves around the planet in an elliptical orbit, and the center of mass of the planet is located at one of the foci of the orbit. As established using SLR, the position of the center of mass changed during 1993–2003 by ±0.6 mm for the equatorial and ±1.8 mm for the polar component [2].

GPS instruments have been successfully used for a number of years to monitor changes in the earth's surface due to geodynamic processes, as described above. High-precision GPS measurements of almost any line are carried out on the basis of the differential method using the so-called GPS base stations (this method is also called the relative kinematics method). In this case, during measurements, one base station of the satellite receiver is constantly located at a point with known coordinates, and the other moves, fixing the position of the points being taken. The analysis of GPS station data was carried out using the GAMIT/GLOBK program version 10.71. [7]

GPS data were processed and errors estimated using MIT's GAMIT software [7] following the procedure described in [8, 9]. To estimate the speeds of the determined stations, it is necessary to have at least one reference point in the network, and preferably several. GNSS for geodynamics, **YIBL**_OMAN, **SOFI**_BULGARIA, **ANKR**_TURCIYA, **ARTU**_RUSSIAN, **NICO**_CYPRUS, **NOT1**_ITALY, **POL2**_KYRGYZTAN, **POLV**_UKRAINE, **TEHN**_IRAN, **MDVJ**_RUSSIAN, **DRAG**_ISRAEL,**RAMO**_ISRAEL, **SOFI**_BULGARIA, **BUCU**_ROMANIA, **ISTA**_TURKEY, **GLSV**_UKRAINE [3]. The height cutoff angle was taken as 10°.

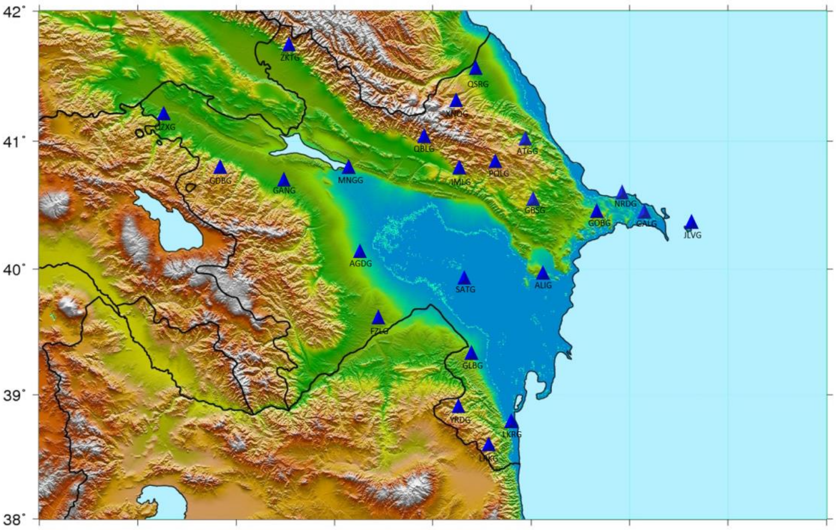

Figure 2. Network of GPS stations of RSSC

Taking into account geomorphology, geotectonics, relief and taking into account the influence of external factors, in 2012 the Republican Center installed a network of 24 stationary GPS stations in Azerbaijan. A set of 24 GPS stations cover the vast territory of Azerbaijan and form the GPS_RCSS geodetic network

(Figure 2). Note that the stations are equipped with Choke Ring model antennas, the number of installed stations of this model is 10, Zephyr Geodetic2-14 and TrimbleNetR9-24 receivers (USA), which record the signal of the corresponding GPS and GLONASS satellites [9]. The formed geodetic network allows solving regional problems of studying the main patterns of modern movements of the earth's crust in the territory of Azerbaijan. It should be noted that for the first time in the world on the territory of the Republic of Azerbaijan in the Saatli region, a GPS station was installed on the Saatli super-deep well (8324 meters) SG-1.

Correlation of seismological activity with satellite navigation data.

As a result of research carried out by the Department of Geodynamics of the RSSC at ANAS, the field of velocities of modern motions throughout the entire territory of the republic was obtained. The velocities of modern movements were estimated based on the results of measurements at 24 stationary GPS stations of the RSSC. The accuracy of determining the coordinates is within 1–3 mm per day. The coordinates of the reference stations of the IGS network used in the analysis are characterized by the same accuracy.

An analysis of the distribution of horizontal displacement rates showed that there is a stable orientation of the velocity vectors (2–15 mm/year) both in the NE direction, typical for the territory of the Arabian Plate, and in the N-E direction, typical for the southeastern part of the Lesser Caucasus. These data confirm the existing ideas about the northern drift of the Arabian lithospheric plate. The shift to the NE is probably due to the thrust structure located in the Jurassic rocks and dipping to the north (Figure 3). The ENE direction of the velocity vectors of horizontal displacements within the Gobustan and Absheron regions (points GBSG, GOBG, GALG, NDRG) most likely indicates that the influence of the northern drift of the Arabian Plate is little felt here.

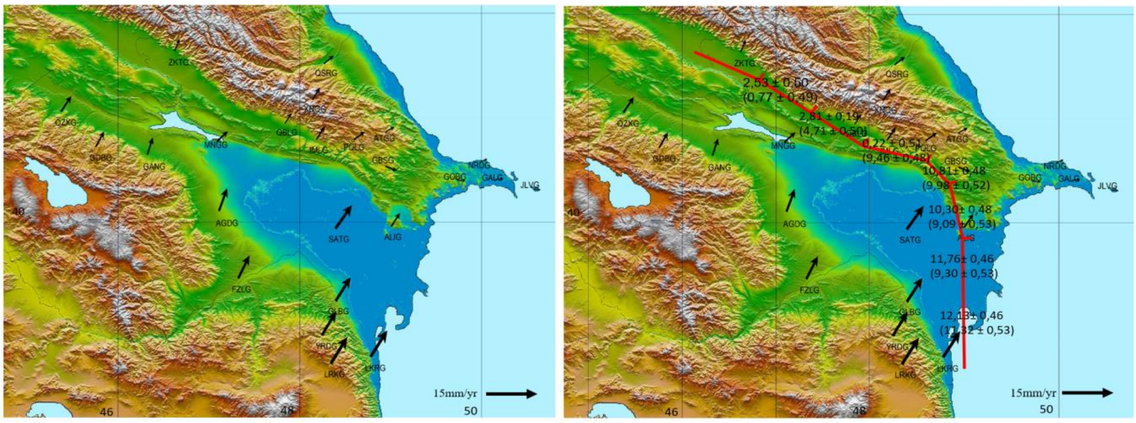

Figure 3. Horizontal velocity vector map for 2014-2022 and fault velocities (mm/yr) obtained from the block model.

The process of formation of the fold-cover tectonic structure of the territory of the Republic of Azerbaijan is explained within the framework of geodynamic models developed for the Mediterranean fold-charge belt and based on the primacy of tangential forces and underthrust mechanism during the formation of modern orogens [10-11]. This is indicated by the scaly-thrust structure of both the Precambrian-Paleozoic basement and the Alpine cover of all the main tectonic zones, which indicates the existence of vast sea basins in the Caucasus region, which were transformed as a result of the Hercynian, Cimmerian and Alpine cycles of tectogenesis into narrow zones of general collapse of rocks or into ophiolite suture belts [12, 15].

It has been established that along the Kura depression in the direction from the Middle Kura depression to the Low Kura depression (i.e. from NW to SE) there is a gradual increase in the rates of horizontal movements from 7.3 to 11.3 mm/year, which is characterized by the compression condition. It should be noted that in the last 3 years the zone of the Low Kura depression is characterized by the manifestation of high seismic activity, expressed in several earthquakes with a magnitude greater than M> 5ml, characterized by a reverse-type movement [5]. At the same time, within the northeastern side of the microplate corresponding to the Vandam-Gobustan megazone of the Greater Caucasus, the velocity vectors experience a decrease to 10–12 mm/yr, and further north, i.e. directly within the accretionary prism, and completely decreases to 3.5-5 mm / yr. In general, the tangential shortening of the earth's crust in the region is estimated at 6.1-11 mm/yr (Figure 4).

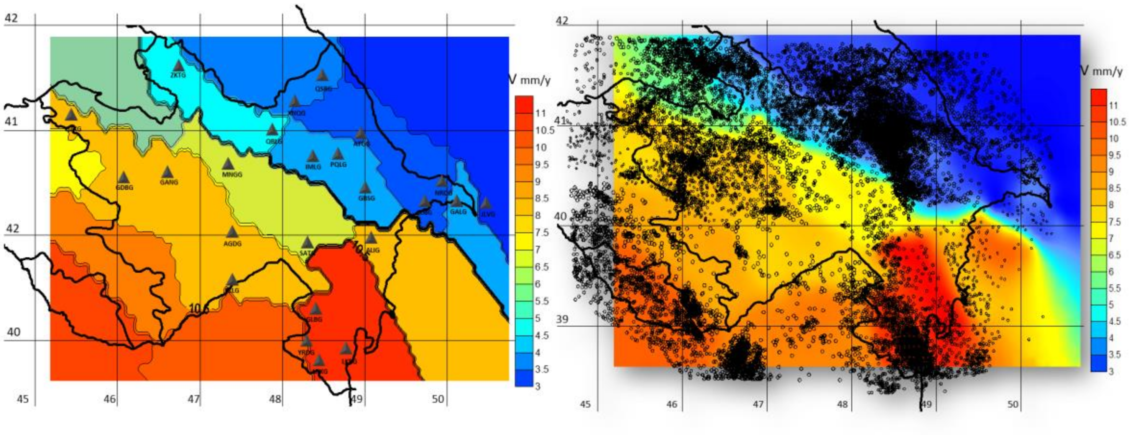

Figure 4. Velocity map of horizontal movements according to GPS stations for 2014-2022 and epicenters of earthquakes for 2003-2022

It should be noted that the regional patterns of neotectonics and modern geodynamic development and landforms of the Caucasus region can be considered as a result of mechanical impacts on it of adjacent geodynamical active areas. It is interesting to note that the rate of modern vertical movements of the QBLG, ZKTG, QSRG, and XNQG GPS points on the southern slope of the Greater Caucasus lags behind the rate of the general uplift. Modern movements along the line stretching from the Lesser to the Greater Caucasus (from south to north) have a wave nature, which is the result of the interference of various tectonic waves, i.e. the result of a complex combination of horizontal and vertical movements of the earth's crust (possibly, the asymmetry of its movements is due to the simultaneous manifestation of waves with different lengths and amplitudes). Consequently, wave-like deformations are not linear, and this determined all the main features of the neotectonics of the region.

The revealed heterogeneous nature of the velocity field of the region allows us to state the block model of the structure of the region, which is closest to the real one. A similar conclusion about the block structure was also obtained for other regions [14]. It was found that in the Guba-Gusar region in the direction NW-SE, a block with velocities of 5.8 mm/g with a length of 55 km is distinguished.

At the GPS stations Nardaran "NRDG", Gobu "QOBG", Gala "GALG" and Zhiloiy Island "JLVG", which are part of the Apsheron zone, almost similar values of horizontal displacement velocities (3.8, 4.9, 4.1 and 3.2 mm/ year respectively). In the direction from the Talysh region to the Apsheron Peninsula (southwest–northeast direction), there is a noticeable decrease in the northern component of displacement velocities compared to high values of points located in the southwestern part of the selected profile (LKRG_GPS=13.8 mm/yr, LRKG_GPS=12.5 mm/year, GLBG_GPS=12.3 mm/yr, YRDG_GPS=12.7 mm/yr). It should be noted a noticeable increase in the azimuthal angles of the Apsheron stations, indicating a clockwise movement in the east–southeast direction up to 88°.

Earthquakes with a magnitude greater than ml>2 were analyzed based on the earthquake catalog data of the RCSS Bureau of Earthquake Research. A deep section of the distribution of magnitudes along the Greater Caucasus was built in order to identify the seismogenic layer of the earth's crust. As seen in fig. This layer in the territory of Georgia and the Belokan region is distributed at a depth of up to 40 km, further in the direction of the Zagatala region, the depth decreases to 20 km, and starting from the Sheki region, a gradual subsidence towards the Caspian Sea is observed. Against the general background of earthquakes, zones of maximum magnitudes are distinguished, corresponding to the Zagatala-Balakan, Oguz-Gabala, Shamakhi-Ismayilli and Hajigabul seismogenic zones (Figure 5).

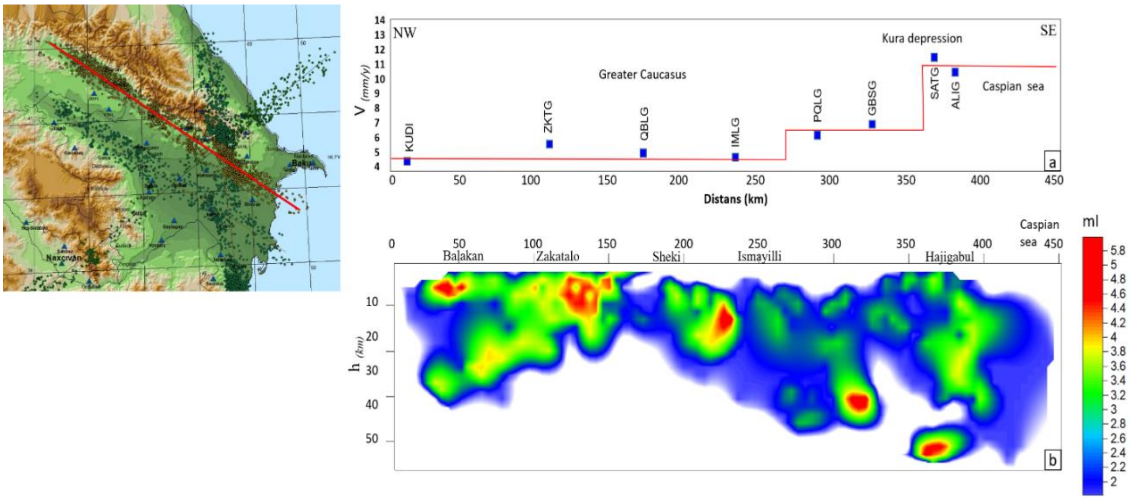

Figure 5. Velocity profile according to GPS data (a) and depth distribution of earthquake magnitudes along profile 1-1 (b)

Comparing the seismic data with the data of GPS stations, it can be seen that with the gradual immersion of the seismogenic layer, the velocities increase. At SATG and ALIG stations, the data increase to 10-11 mm/yr. It can be noted that the change in the values of horizontal movements on the territory of the Zakatalo-Balakan, Oguz-Gabala seismogenic zones is associated with the movement of layers (blocks) of the earth's crust at a depth of 5-20-40 km. In the Sheki seismogenic zone 2-30 km, in the Shamakhi-Ismayilli zone 5-45 km, and in the Hajigabul seismogenic zone 5-55 km [5-6].

In the zone of the West Caspian Fault, at depths from 5 to 35 km, a block boundary is distinguished with velocities of 7.25 mm/yr. On the eastern side of this block, a block is distinguished at depths of 10–25 km with values of 9 mm/yr.

CONCLUSION

Thus, the global positioning system (GPS) has provided a new opportunity for direct observation of modern movements and deformations of the earth's crust.

Comparison of the obtained results of GPS stations shows that the stations located in the Lesser Caucasus and in the zone of the Talysh Mountains move in the northeast direction almost identically. These facts allow us to state that the Lesser Caucasus and Talysh participate in the horizontal movement as a single bloc. On the other hand, the stations located on the territory of the Talysh Mountains are characterized by high horizontal motion rates, which allows us to delineate this region with average horizontal motion rates of 11.6 mm/year.

The velocity field clearly illustrates the movement of the earth's surface in a north-northeast direction. This phenomenon reflects the process of successive accumulation of elastic deformations in the zone of subduction interaction of the structures of the northern side of the South Caucasian microplate (Vandam-Gobustan megazone) with the accretionary prism of the Greater Caucasus.

In addition, within the Middle Kura depression and in the Lesser Caucasus, there is a trend towards horizontal displacement, which is reflected in an increase in the speed of movement from west to east along the continuation of the ridge. It has been established that on the Absheron Peninsula the earth's crust is shortening at a rate of ~ 5 mm/year.

Comparing the seismic data with the data of GPS stations, it can be seen that with the gradual immersion of the seismogenic layer, the velocities increase. At SATG and ALIG stations, the data increase to 10-11 mm/g.

It can be noted that the change in the values of horizontal movements on the territory of the Zakatala-Balakan, Oghuz-Gabala seismogenic zones is associated with the movement of layers (blocks) of the earth's crust at a depth of 5-20-40 km. In the Sheki seismogenic zone 2-30 km, in the Shamakhi-Ismailli zone - 5-45 km, and in the Hajigabul seismogenic zone 5-55 km.

Preliminary data on the comparison of velocity vectors of GPS points with the structure of the Earth's crust of the Greater Caucasus shows that within the projections of these blocks, the directions of velocity vectors are quite consistent. This makes it possible to formulate as an urgent task the search for the relationship between deep sources of tectonic stresses and their possible connection with near-surface geodynamics and seismic regime, which could become the basis of geoecological zoning.

Data on the velocities of vertical and horizontal displacements of individual blocks within various seismogenic zones of the Greater Caucasus, in addition to scientific, are of practical importance, since with their help it will be possible to choose safe places within the BC for the construction of hotels, camp sites, small hydroelectric power stations, cable lifts, roads and railways [17]. In addition, the analysis of available GPS data showed that it is necessary to continue these measurements in the Caucasus, which will increase the accuracy of the results obtained, for which it is necessary to thicken the existing network of points and, as a result, obtain a more detailed picture of the distribution of modern movements.

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ASSESSMENT OF SEISMIC HAZARD AROUND THE FILIZCHAY PYRITE POLYMETAL DEPOSIT

G.J.Yetirmishli[1], G.I.Bekdemirova[1], G.A.Musayeva[1]

Abstract

In Azerbaijan, much attention is paid to the exploitation of mineral deposits in the non-oil sector. The Filizchay deposit, considered one of the largest deposits in Europe in terms of ore reserves and is very rich in base metal reserves throughout the world, is one of the largest projects that the AzerGold organization preparing for operation. The Filizchay deposit is located in the Zagatala-Balakan seismogenic zone. The article analyzes the seismicity of this zone and considers the assessment of seismic hazard around the field. As the analysis showed, the Filizchay pyrite-polymetallic deposit is located in one of the most seismically active regions of Azerbaijan. Such strong earthquakes as the Zagatala earthquake on May 7, 2012, the Balaken earthquake on October 14, 2012, and the Zagatala earthquake on June 5, 2018 have repeatedly occurred here. In addition, it should be noted that this field is affected not only by local earthquakes, but also by strong earthquakes located in neighboring regions. Such as the Oguz earthquake of 2015 and the Gabala earthquakes of 2014. All of the above earthquakes were characterized by an intensity of 7 points at the source and 5-6 points in the territory of the Filizchay field. As can be seen from the seismic activity maps, the Zagatala-Balakan zone is characterized by activity values of 1.6-2.0. Analysis of the depth distribution of hypocenters within the study region showed that the bulk of earthquakes are concentrated at a depth of 2-25 km.

Key words: *Filizchay collichedan polymetal deposit, Zagatala-Balaken seismogenic zone, seismic activity, mechanism of earthquake foci, seismic hazard*

FİLİZÇAY KOLİÇEDAN POLİMETAL YATAĞI ƏTRAFINDA SEYSMİK TƏHLÜKƏNİN QİYMƏTLƏNDİRİLMƏSİ

Q.C.Yetirmişli, G.İ. Bekdəmirova, G.Ə. Musayeva

Xülasə

Azərbaycanda qeyri neft sektorunda faydalı qazıntı yataqlarının istismarına diqqət artmışdır. Filiz ehtiyatlarının həcminə görə Avropanın ən iri yataqlarından biri hesab edilən və dünya miqyasında polimetal ehtiyatına görə çox zəngin olan, Filizçay yatağı “AzerGold” QSC-nin istismarına hazırlıq gördüyü ən böyük layihələrdən biridir. Filizçay yatağının yerləşdiyi Zaqatala-Balakən seysmogen zonası güclü seysmik aktivliklə səciyələnir. Məqalə işində bu zonanın seysmikliyi analiz edilmişdir və yataq ətrafında seysmik təhlükənin qiymətləndirilməsinə baxılmışdır. Təhlil göstərdiyi kimi, Filizçay pirit-polimetal yatağı Azərbaycanın ən seysmik aktiv rayonlarından birində yerləşir. 2012-ci il mayın 7-də Zaqatala zəlzələsi, 14 oktyabr 2012-ci ildə Balakən, 5 iyun 2018-ci ildə Zaqatala zəlzələsi kimi güclü zəlzələlər burada dəfələrlə baş verib. Bundan əlavə, qeyd etmək lazımdır ki, bu yatağa təkcə yerli zəlzələlər deyil, həm də qonşu rayonlarda yerləşən güclü zəlzələlər də təsir edir. Məsələn, 2015-ci ilin Oğuz zəlzələsi və 2014-cü ilin Qəbələ zəlzələləri. Yuxarıda göstərilən bütün zəlzələlər ocağda 7 bal, Filizçay yatağının ərazisində isə 5-6 bal intensivliyi ilə xarakterizə olunub. Seysmik aktivlik xəritəsən göründüyü kimi Zaqatala-Balakın zonası 1.6-2.0 aktivlik geyimləri ilə

[1] *Republican Seismic Survey Center of Azerbaijan National Academy of Sciences*

mümkündür. Tədqiq olunan rayon daxilində hiposentrlərin dərinlik paylanmasının təhlili göstərdi ki, zəlzələlərin əsas hissəsi 2-25 km dərinlikdə cəmləşib.

Açar sözlər : *Filizçay koliçedan polimetal yatağı, Zaqatala- Balakən seysmogen zonası, seysmik aktivlik ,zəlzələ ocaqlarının mexanizmi, seysmik təhlükə.*

ОЦЕНКА СЕЙСМИЧЕСКОЙ ОПАСНОСТИ ВОКРУГ ФИЛИЗЧАЙСКОГО МЕСТОРОЖДЕНИЯ КОЛЧЕДАНОВЫХ ПОЛИМЕТАЛЛОВ

Г.Д. Етирмишли, Г.И. Бекдемирова, Г.А. Мусаева.

Аннотация

В Азербайджане большое внимание уделяется эксплуатации месторождений полезных ископаемых в не нефтяном секторе. Месторождение Филизчай, считающееся одним из крупнейших месторождений в Европе по объему запасов руды и очень богатое запасами полиметаллов во всем мире, является одним из крупнейших проектов, который организация "AzerGold" готовит к эксплуатации. Месторождение Филизчай находится на территории Загатало-Балаканской сейсмогенной зоны. В статье проанализирована сейсмичность этой зоны и рассмотрена оценка сейсмической опасности вокруг месторождения. Как показал анализ, Филизчайское колчеданно-полиметаллическое месторождение располагается в одном из самых сейсмоактивных регионов Азербайджана. Здесь неоднократно происходили такие сильные землетрясения как: Закатальское 7 мая 2012 г., Балакенское 14 октября 2012 г., Закатальское 05 июня 2018 гг. и т.д. Кроме того нужно отметить, что на данное месторождение влияют не только локальные землетрясения, но и сильные землетрясения расположенные в соседних регионах. Такие как Огузское землетрясение 2015 г. и Габалинские землетрясения 2014 г. Все выше указанные землетрясения характеризовались интенсивностью 7 баллов в очаге и 5-6 баллов на территории Филизчайского месторождения. Как видно из карт сейсмической активности, зона Загатала-Балакан характеризуется значениями активности 1,6-2,0. Анализ глубинного распределения гипоцентров в пределах исследуемого региона показал, что основная масса землетрясений сконцентрирована на глубине 2-25 км.

Ключевые слова: *Филизчайское колчеданно-полиметаллическое месторождение, Загатала-Балакенская сейсмогенная зона, сейсмическая активность, механизм очагов землетрясений, сейсмическая опасность.*

INTRODUCTION

Azerbaijan has been and remains the most important mineral resource base of the South Caucasus. On this basis, the mining industry of precious and non-ferrous metals has been created and is successfully developing [5]. By analyzing favorable geological preconditions, direct and indirect prospecting signs, as well as analyzing the patterns of location of identified deposits for the metallogenic zones of the Greater and Lesser Caucasus, the identification of new ore objects is predicted [3]. Ore mineral raw materials, with rare exceptions, are of igneous or metamorphic origin, and therefore are confined to folded tectonic structures, shields and faults of the earth's crust.

The development of deposits in a zone of active seismic influence is correlated with geodynamic processes in the lithosphere. The efficiency of exploitation of mineral deposits, along with other indicators, is characterized by the seismicity of natural and man-made processes, which is taken into account when designing field development technologies. As a result of the combined action of gravitational, seismic and tectonic forces, stresses arise in the massifs, which cause them to deform and collapse if they exceed the tensile strength of the rocks. The seismic hazard of ore-bearing massifs is understood as a risk management system for technology-induced seismic vibrations. The phenomenon of destruction of massifs is explained by the addition of the potential energy of elastic compression of rocks and the energy of elastic deformations during mining [11]. Mining facilities occupy a large area and are characterized by high risk. A local seismic observation network makes it possible to monitor the state of arrays with sufficient sensitivity only in rare cases. The territory of the North Caucasus is the arena of modern intensification of catastrophic processes. Most of the territory is an arena for the formation of folded structures and is characterized by the loss of rock strength properties. Dynamic phenomena are catastrophic in nature, which is expressed by displacement along faults, the appearance of ditches and cracks, and provoke the subsidence of large blocks of rocks, landslide processes, mudflows, landslides and snow avalanches. Linking tectonic, gravimetric and seismometric factors in the exploitation of deposits is an important area of research into the problems of geomechanical safety of mining mineral deposits in seismic zones [11].

The Filizchay deposit ranks second in Europe. The deposit of polymetallic ores was discovered 60 years ago, during the geological survey and prospecting work carried out by the Geology Department of Azerbaijan in the Belokan and Zagatala regions. The deposit is represented by such minerals as pyrite, sphalerite, galena, chalcopyrite, pyrrhotite. The main useful components are copper, zinc, lead, silver, gold, sulfur, etc. Large reserves of the deposit have propelled the region into an independent metallogenic province and as a mineral resource base for the future metallurgical industry of Azerbaijan [5].

Filizchay pyrite-polymetal deposit

Filizchay pyrite-polymetal deposit is located in the territory of Balakan district, 18 km north of the district center, near the state borders of Azerbaijan with Georgia and the Russian Federation. Orographically, the bedrock area consists of a mountainous terrain with steep slopes and rocky deep valleys. Relative heights vary between 800-1600 meters. The area is bounded by the Great Gubakh and Kasdag mountains in the western part, the watershed range of the Great Caucasus and Chugak mountain in the north, Karabchay and Bulanigchay in the east [1].

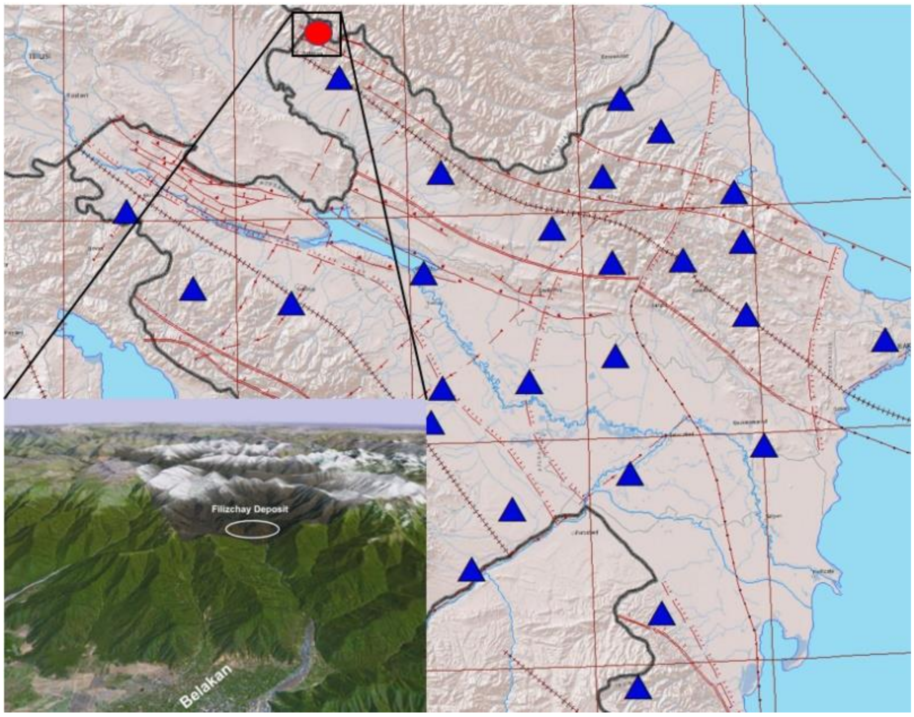

Figure 1. Filizchay field location map

The deposit was discovered in 1959. Filizchay deposit is considered the second deposit in Europe in terms of industrial reserves of pyrite-polymetallic ores. At present, 90% of the reserves of pyrite-polymetallic ores of the Republic of Azerbaijan are concentrated in the Balaken-Zagatala ore region located on the southern slope of the Greater Caucasus (Figure 1). In addition to the Filizchay deposit, there are small deposits of Kasdag, Katekh, Sagator, Garabchay and Mazymchay pyrite-polymetallic deposits, as well as the Gumbulchay-Cheder pyrite-copper-polymetallic ore group, the composition of which is mainly represented by pyrite, sphalerite, galena, chalcopyrite, pyrrhotite, from secondary metals - arsenopyrite, cobalt, various metal sulphosalts, etc. The main useful components are copper, silver, zinc, lead, sulfur, and auxiliary components are represented by gold, bismuth, cobalt, cadmium, selenium, tellurium, indium [2].

It is possible to create a highly profitable mining-metallurgical complex based on the industrial resources of the Filizchay field, which will provide raw materials for more than 50 years. In 2022, the estimated amount of underground resources of "Filizchay" polymetal deposit, which is one of the most complex projects due to its geological structure, was increased. Thus, as part of the process of bringing the field into operation, ore samples were studied in the laboratory of the prestigious "Petrolab" company of Great Britain for mineralogical research. The resources of "Filizchay" were calculated in accordance with the requirements of JORC (Joint Ore Reserves Committee) standards, which is an international classification system for the economic evaluation of mineral deposits. As a result of the calculation, a 20% increase was recorded compared to the results included in the state budget in 1983 during the USSR [1]. As a result, it was confirmed that the estimated amount of underground ore resources of "Filizchay" is 112.71 million tons.

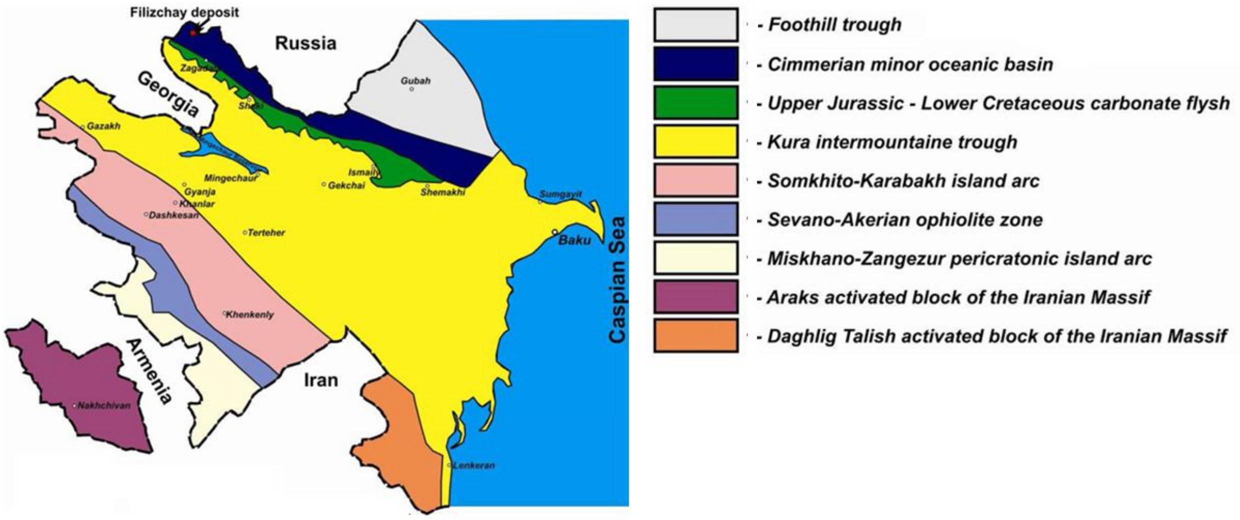

Figure 2. Position of the Filizchay Deposit on the Tectonic & Metallogentic Sketch Map ofAzerbaijan [1]

The structural elements of the central Tfan anticline, the Zagatala-Kovdag syncline, the Vandam anticline and the superimposed Alazan-Agrichay depression take part in the Zakatala zone. The latter within the considered zone, expanding strongly to the north, almost completely overlaps the Vandam anticlinorium [10].

The Tfan anticlinorium extends in a narrow strip along the northern edge of the Zagatala zone. Within the zone, it is characterized by a significant complication of the structure of the southern wing of the western extension of the Bazarduzu anticlinorium and the appearance of new uplifted lower horizons of the aalena, and in some cases, the toar. Here E.Sh.Shikhalibeyli (1956) singled out an independent Sarybash anticlinorium, in the cross-section of which two large anticlinals, Attagay and Suvagil, are distinguished [16]. Further to the west, they are replaced by the Kehnameidan and Karabchai uplifts, and in the south, the third Gyumbulchay uplift appears, which constitutes a new, sufficiently extended single structural zone. In the section under consideration, the Tfan anticlinorium is complicated by the Main Caucasus fault-thrust, which separates the northern, highly uplifted part of the wing from its southern part, which differ significantly in the age of the deposits and the morphology of the folded structure. [10, 16]

The Zagatala-Kovdag synclinorium is located to the south of the Tfan anticlinorium. This large deflection zone extends from the western border of Azerbaijan to the Absheron Peninsula, originating in the river basin. Belakanchay in the form of a narrow depression made by valangine, crumpled into small folds, the synclinorium is gradually opened to the east, its section is filled with younger neocomic deposits. [8]

Seismic activity of Zagatala-Balakan seismic zone

The Zagatala-Balakan seismogenic zone, where the Filizchay deposit is located, is characterized by strong seismic activity.

The Zagatala-Balakan seismically active zone is located in the extreme north-west of the Azerbaijani part of the Greater Caucasus. Conventionally, its border in the east should be considered the Zagatala-Shamkir transverse uplift. In the north, west and south, the zone merges with the highly active seismic zones of Southern Dagestan and Western Georgia. The area of the Zagatala seismically active zone within Azerbaijan is about 3500 km^2. It should be noted that in this zone, during the entire seismostatistical period, only one large earthquake is known, which occurred in 1936 with a magnitude 7 effect in a number of populated areas. More often, tremors with an intensity of 7 points in the Zagatala seismically active zone were felt from strong Dagestan and Georgian earthquakes, which sometimes caused disturbances in local sources.

In the research work, the analysis of the earthquakes that occurred in that area in 2010-2023 was carried out.

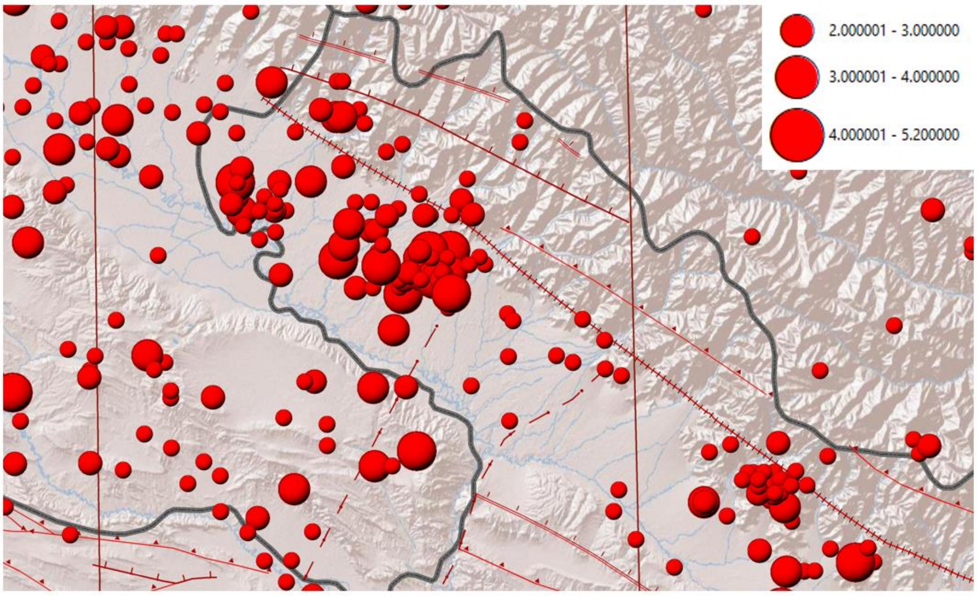

Figure 3. Map of epicenters of earthquakes that occurred in the northwestern part of Azerbaijan during the years 2003-2023

In the research work, the analysis of the earthquakes that occurred in that area in 2010-2023 was carried out. In 2010-2011, seismicity in the Zagatala-Balakan zone was at the background level. In 2012, seismic activation in the north-western part of the Greater Caucasus was observed with a series of strong earthquakes. On 07.05.2012, earthquakes with a magnitude of M=5.6-5.7 occurred in Zagatala region with an interval of about 10 hours (t0=04h40m and t0=14h15m GMT), the earthquake was characterized by numerous aftershocks (magnitude 3.5-5.0) [15, 9].

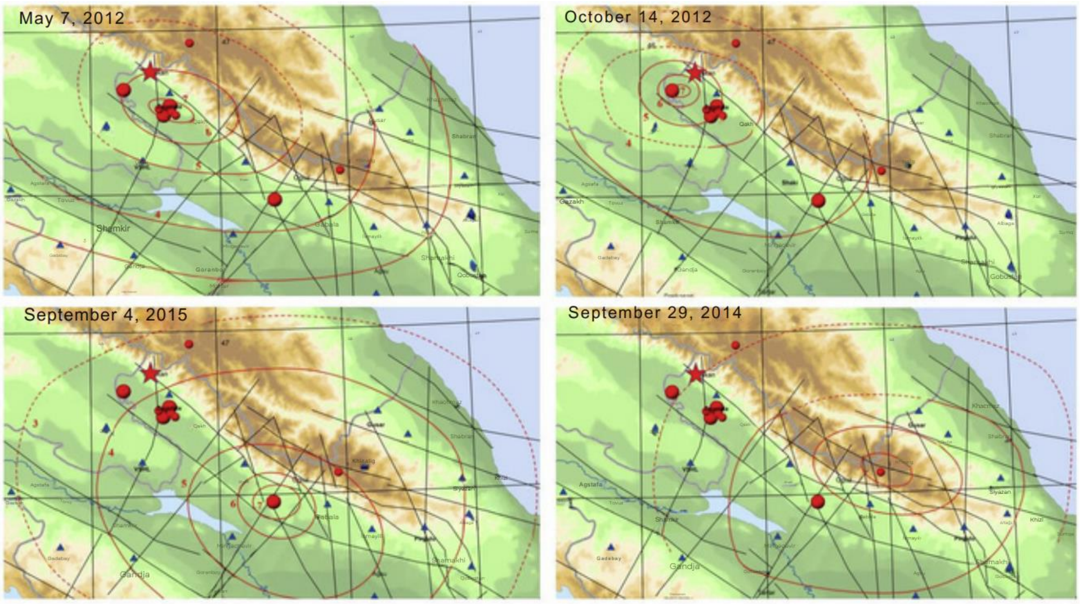

Figure 4. Isoseist maps of strong earthquakes that occurred in the northwestern part of Azerbaijan [9, 15]

The earthquake was felt in the cities of Zagatala, Balaken, Gakh and other surrounding regions with a magnitude of 2-5. In Zagatala district, 274 buildings were completely destroyed, 2052 buildings became unusable. Although there was no damage in Balakan district, 35 houses were damaged. A total of 19 earthquakes with a magnitude higher than 4.7 were recorded in the Zagatala-Balakan seismoactive zone, which were felt in one or more settlements. It should be noted that after the strong Zagatala earthquakes on 14.05.2012 in Sheki region, 2, 14.10. In 2012, 2 earthquakes (5-6 points) occurred in Balakan region, the earthquake was characterized by numerous aftershocks. The intensity values of strong earthquakes were taken from the articles of E.Garaveliyev [6, 13].

In 2014, the seismic activity in the Zagatala-Balakan zone increased compared to 2013, the seismicity was higher than the background level. The strongest earthquake that occurred in this zone on 29.06.2014 was M=5.3, H=9 km. The earthquake was felt up to level V in the epicenter and level III-IV in nearby settlements. After the main shock, there were aftershocks with a weak magnitude of $M \leq 1.5$. In 10 days, 55 aftershocks and 321 weak aftershocks were recorded by Zagatala station alone [7, 13].

On June 5, 2018, another strong earthquake with magnitude M=5.5 occurred in Zagatala. In 2020, compared to 2019, seismicity was weaker in the Zagatala-Balakan area. The highest magnitude earthquake that occurred in the Balakan area was ml=3.2 [8].

In 2021, seismicity was at the background level in the Zagatala-Balakan seismogenic zone. In the area of Zagatala-Balakan, tremors with a magnitude of $ml \leq 1.9$ occurred. In the area of Zagatala-Balakan, the sources were mainly distributed at a depth of 2-25 km. In 2022, the seismicity in the Zagatala-Balaken seismoactive zone was higher than the background level compared to 2021. The highest magnitude earthquake that occurred in the Zagatala area was ml=4.2.

Longitudinal and transverse deep faults pass through the territory of the region: Bash Qafqaz, Gaynar-Zangi, Vandam, Zagatala-Shamkir, etc. In particular, numerous violations and dissections are observed here. The sources of the earthquakes occurring in the Balakan-Zagatala seismoactive zone correspond to the intersection zones of the faults in different directions. As can be seen from the seismic activity maps, the zone of Zagatala-Balakan is characterized by activity values of 1.6-2.0 (Figure 4).

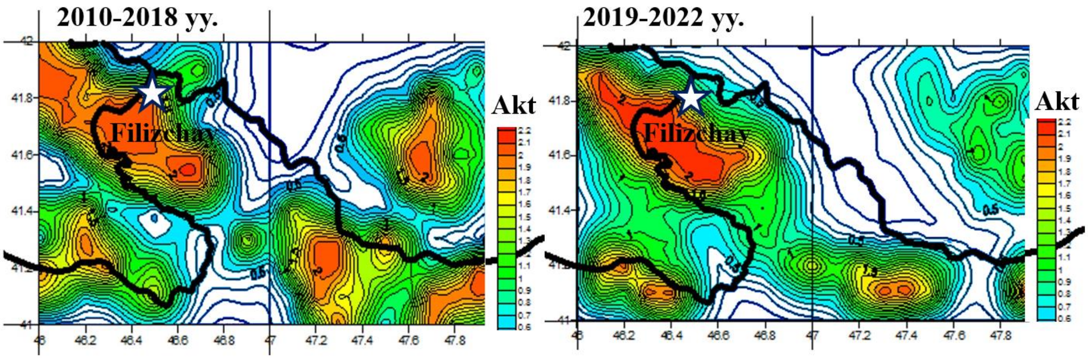

Figure 5. Map of seismic activity in the territory of Azerbaijan in 2010-2022

In order to study the depth distribution of the earthquakes that occurred in the Balakan-Zagatala seismogenic zone, a seismic cross section was constructed on the I-I profile in the southwest-northeast direction (Figure 4). The earthquake catalog was taken from the Bureau of Earthquake Research. The density of earthquake epicenters is observed on the map of epicenters of earthquakes with the established magnitude (Ml≥3.0) for this zone. As can be seen from the picture, strong earthquake epicenters (Ml≥5.0) are observed in the northern, southwestern and southern parts of the region surrounded by the Filizchay field (Figure 4b). The vast majority of earthquakes occurred at a depth of 2-25 km in the seismological section established along the southwest and northeast direction profile.

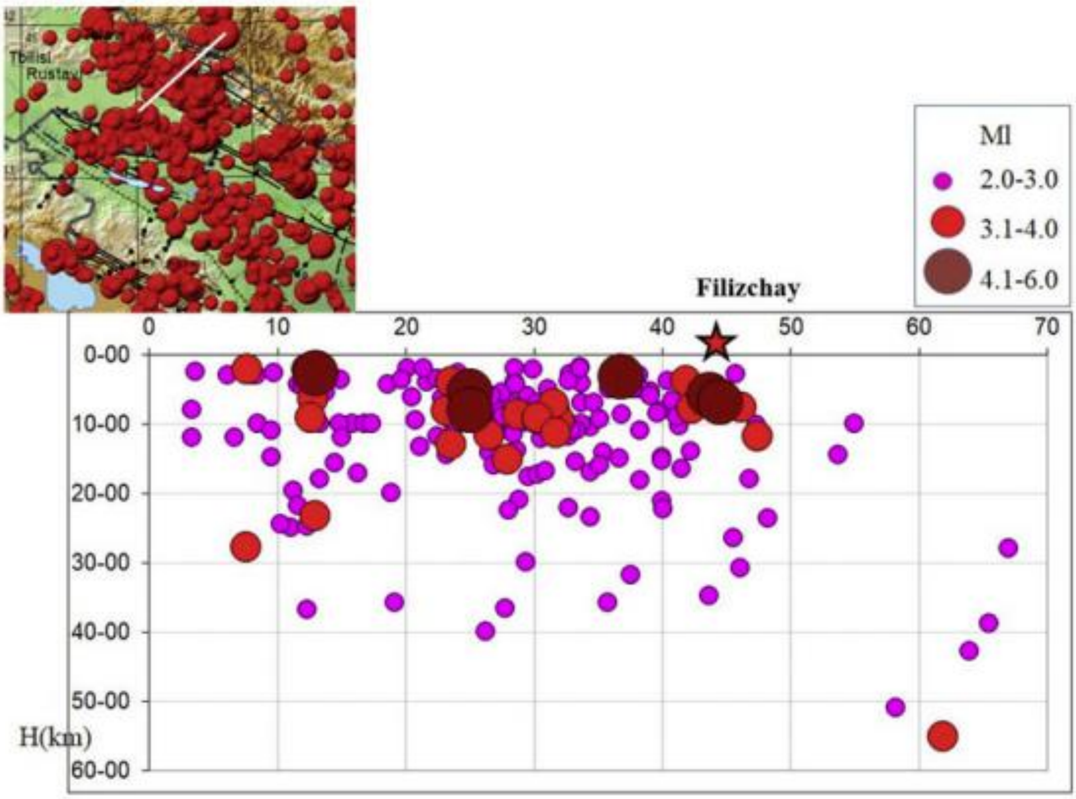

Figure 6a. Seismological cross-section of the I-I profile in the Balakan-Zagatala seismogenic zone

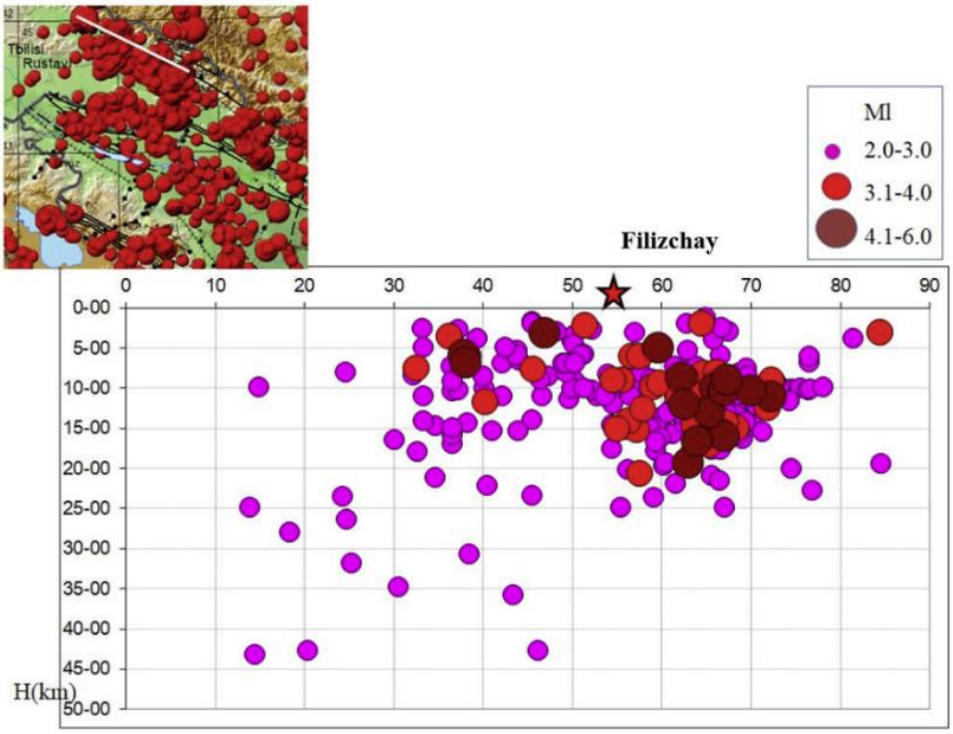

Figure 6b. Seismological section on the II-II profile in the Balaken-Zagatala seismogenic zone

Mechanisms of earthquake sources

Zagatala earthquakes are a consequence of the geodynamic regime of the earth's crust of the Zagatala source zone, the parameters of which are determined by the movements of the earth's crust along the system of longitudinal (over-the-Caucasus) and transverse (anti-Caucasian) faults; among the latter, the main role belongs in all probability to a pair of right-handed shifts - Kazakh-Signakh and Ganjachay-Alazan [5].

Based on the definition of the mechanism of the source of the earthquake, it is established that the mechanism of the source of the first Zakatala earthquake (GMT 4:40, Mw=5.6) is a strike-slip, and the second earthquake (GMT 14:15, Mw=5.7) is a strike-slip. Comparison of the azimuths of the longitudinal axes with the spread of the nodal planes of the mechanism of the aftershock center shows that the first nodal plane is aligned in the NW-SE direction, corresponding to the Balaken-Dzhunut longitudinal fault (thrust-type movement), and the second nodal plane is in the SW-SW direction, corresponding to the Salavat transverse fault (thrust-thrust type of movement). The mechanisms of the majority of aftershocks also point to reset and shear displacements in the focal zone with a subordinate number (5 events) of shock displacements confined to the plane of the Ganyh-Airichai thrust and its rear scales.

Balaken focal zone was active in 2012, 2013 and 2016. Seismic events of October-November 2012. They manifested themselves in a series of aftershocks with a maximum M = 5.60 (14.10.2012). The events of the following years differed in relatively low power with M = 3.14-4.37. As in the first case, the focal zone is confined to the complex intersection of faults of different widths, the majority of hypocenters are located in the upper part of the pre-Jurassic basement, and also confined to the surface of the basement and the base of the Alpine cover, the depth interval is 4-13 km. Seismic events are mainly associated with the activation of the Khimrich-Khalatali (2012) and Balaken (2013 and 2016) faults of the Anti-Caucasian thrust.

The mechanisms of earthquakes in the focal zone indicate the predominance of thrust and shear movements with a subordinate role of shock-type displacements. In particular, the earthquake on October 14, 2012. with M=5.6 and H=8 km was characterized by horizontal (PLP=0°) stretching southwest orientation and bivertical compression (PLT=48°) northwest orientation stresses. Type of motion on both (DP=57°) planes – shift. Plane NP1 has a southeast orientation (STK1=115°), NP2 – north (STK2=2°). Comparison of the extension of nodal planes with fault lines shows the agreement of the first of them (NP1) with the Shambul-Ismailli longitudinal fault.

The Gabala focal zone, activated at the end of September-beginning of October 2014, manifested itself with two perceptible aftershocks with M = 5.0-5.5 and a swarm of weak aftershocks. The focal zone is controlled by the right-striking fault of the northeast strike, which complicates here the subthrust junction of the Kakheti-Vandam-Gobustan zone and the accretionary prism of the Greater Caucasus. The focal zone is characterized mainly by shear displacements along the rupture plane. As an example, it is possible to point to the event of 29.09.2014, when an earthquake occurred with M-5.5 at a depth of 13 km, that is. in the pre-Jurassic base of the Kakheti-Vandam-Gobustan zone.

RESULTS

The problem of monitoring and prevention of dangerous natural processes on the territory of mining landscapes should be solved with a comprehensive consideration of macro phenomena occurring during the development of mineral deposits. This is possible only on the basis of the use of modern methods of seismic hazard assessment by fixing tension, tectonics and seismic arrays.

The development area of the Filizchay deposit crosses seismically active faults, which should be paid close attention to when planning mining operations. The differentiation of the physical properties of the rocks of the section and the presence of active fracture structures cause complex mining and geological conditions for the development of deposits. There is a clear increase over time in man-made seismic activity in active mines. As the analysis showed, the Filizchay pyrite-polymetallic deposit is located in one of the most seismically active regions of Azerbaijan. Such strong earthquakes as: Zagatala on May 7, 2012, Balaken on October 14, 2012, Zagatala on June 05, 2018 have occurred here several times. and etc. In addition, it should be noted that this deposit is affected not only by local earthquakes, but also by strong earthquakes located in neighboring regions. Such as the Oguz earthquake in 2015 and the Gabala earthquake in 2014. All of the above-mentioned earthquakes were characterized by an intensity of 7 points in the center and 5-6 points on the territory of the Filizchay deposit. As can be seen from the seismic activity maps, the zone of Zagatala-Balakan is characterized by activity values of 1.6-2.0.

The analysis of the depth distribution of hypocenters within the studied region showed that the main mass of earthquakes is concentrated at a depth of 2-25 km. The observed picture can be interpreted as follows. In the zone of the transverse Shamkhor-Zagatala structure with a highly raised sub-Alpine base in the region of the meganticlinorium of the Great Caucasus, the thrusts observed on the surface have a shallow foundation and do not determine the seismicity of this area, which is mainly associated with steeply dipping lateral (southern and northern) to the limitations of uplifted blocks of the subalpine base, saturated with magnetically active magmatic rocks, as well as with transverse shears. To the east of the Ganjachay-Alazan fault, where the surface of the pre-Alpine base gradually sinks to the east up to 6 and 8 km, along with the thrusts, the seismogenic character of thrust-thrusts is manifested, the development of which at depth under the general regime of compression of the B. Caucasus was not prevented by the high position of the surface subalpine foundation, as it had a place in the region of the transverse structure.

Thus, seismic waves can act as a trigger and initiate the dynamic destruction of sections of the massif of rocks that are in an extremely stressed state. At the same time, the increase in seismic activity can lead not only to the collapse of rocks from the roof and walls of the underground workings of this deposit, but also to the displacement of blocks under the action of horizontal stresses during an earthquake.

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