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SEISMOPROGNOSIS OBSERVATIONS IN THE TERRITORY OF AZERBAIJAN

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CHANGES IN COULOMB STRESS DURING CASPIAN EARTHQUAKES IN 2023 WITH M=5.6

Yetirmishli G. J[1]., Kazimova S. E.[1]

ABSTRACT

The article analyzes two significant Caspian earthquakes that occurred on July 4, 2023 local time 00:01 and December 7, 2023 local time 08:15 with a local magnitude of M=5.6. For this purpose, the source mechanisms of these earthquakes were constructed, and two stress state coefficients were analyzed - Lode-Nadai and Coulomb stress. In 2023, as in previous years, the Caspian Sea water area is characterized by high seismicity. The highest density of hypocenters was observed at a depth of 42-68 km. The magnitude of the displacements in the source shows that fault-slip type movements predominate here. A total of 19 earthquakes were plotted and analyzed in the Caspian Sea in 2023. These earthquakes were associated with the zone of influence of the Agrakhan-Krasnovodsk, Turkmenbashi, Sangachal-Ogurchi, Shakhov-Azizbekov, Siyazan and Garabogaz-Safidrud faults. Based on these mechanisms, the Lode-Nadai coefficient was constructed and it was established that the sources of Caspian earthquakes are located in the extension zone. The solution of the moment tensor showed that the movement at the source of the July 4 earthquake arose under tension conditions. Movement in the source along both planes is shear. The length of the outbreak was 6.1 km, width – 4.53 km. The movement along the fault was 24 cm. In the source of the earthquake that occurred on December 7, 2023, according to the solution of the mechanism, movement in the source also occurred under tension conditions. The type of movement, along the first plane NP1 of a northwest strike and along the second plane NP2 of an east-southeast strike, is a strike-slip fault with fault elements. The moment magnitude was determined to be Mw=5.4. Seismic moment $1.56*10^{24}$ dyn*sm. The depth of the source is 48 km. The length of the outbreak was 6.58 km, width – 5.49 km. The movement along the fault was 24 cm.

Key words: Source mechanism of the earthquake, moment tensor, Columb stress coefficient, seismotomography, Caspian Sea.

2023-CÜ İLDƏ MAQNİTUDASI M=5,6 OLAN XƏZƏR DƏNİZİNDƏ BAŞ VERMİŞ ZƏLZƏLƏLƏR ZAMANI KULON GƏRGİNLİYİNİN DƏYİŞMƏSİ

Yetirmişli Q.C., Kazımova S.E.

XÜLASƏ

Məqalədə 4 iyul 2023-cü il yerli vaxtla saat 00:01 və 7 dekabr 2023-cü il yerli vaxtla saat 08:15-də lokal maqnitudası M=5,6 olan baş vermiş iki güclü Xəzər zəlzələsi təhlil edilir. Bu məqsədlə zəlzələlərin ocaq mexanizmləri qurulmuş, iki gərginlik əmsalı - Lode-Nadai və Kulon gərginliyi təhlil edilmişdir. 2023-cü ildə, əvvəlki illərdə olduğu kimi, Xəzər dənizinin akvatoriyası yüksək seysmiklik ilə səciyyələnir. Hiposentrlərin ən yüksək sıxlığı 42-68 km dərinlikdə müşahidə olunur. Ocağda yerdəyişmələrin ölçüləri göstərir ki, burada qırılma-düşmə tipli hərəkətlər üstünlük təşkil edir. 2023-cü ildə Xəzər dənizində ümumilikdə 19 zəlzələnin ocaq mexanizmləri qurulmuş və təhlil edilmişdir. Bu zəlzələlər Aqraxan-Krasnovodsk, Türkmənbaşı, Səngəçal-Oğurçu, Şaxovo-Əzizbəyov, Siyəzən və Qaraboğaz-Səfidrud qırılmalarının təsir zonası ilə əlaqə-dardır. Bu mexanizmlər əsasında Lode-Nadai əmsalı qurulmuş və müəyyən edilmişdir ki, Xəzər zəlzələlərinin

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

ocaqları gərilmə zonasında yerləşir. Moment tenzorunun həlli 4 iyul zəlzələsinin ocağında hərəkətin gərilmə gərginliyi şəraitində yarandığını göstərir. Mənbədə hər iki müstəvi boyunca hərəkət horizontal yerdəyişmədir. Ocağın uzunluğu 6,1 km, eni 4,53 km-dir. Qırılma boyunca hərəkət 24 sm təşkil edir. 2023-cü il dekabrın 7-də baş vermiş zəlzələ gərilmə gərginlik şəraitində baş vermişdir. Şimal-qərb istiqamətində yönəlmiş birinci müstəvi NP1 və şərq-cənub-şərq istiqamətində yönəlmiş ikinci nodal müstəvisi NP2 boyunca qırılıb düşmə elementli horizantal hərəkətlər müəyyən olunub. Moment maqnitudası Mw=5,4 müəyyən edilmişdir. Seysmik moment 1.56*1024 dn*sm-dir. Ocağın dərinliyi 48 km-dir. Ocağın uzunluğu 6,58 km, eni 5,49 km təşkil edir.

Açar sözləri: Zəlzələnin ocaq mexanizmi, Moment tenzor, Kulon gərginlik əmsalı, seysmotomoqrafiya, Xəzər dənizi.

ИЗМЕНЕНИЯ НАПРЯЖЕНИЯ КУЛОНА ВО ВРЕМЯ КАСПИЙСКИХ ЗЕМЛЕТРЯСЕНИЙ M=5.6 В 2023 ГОДУ

Етирмишли Г.Дж., Казимова С.Э.

АННОТАЦИЯ

В статье анализируются два значительных прикаспийских землетрясения, произошедшие 4 июля 2023 года по местному времени в 00:01 и 7 декабря 2023 года по местному времени в 08:15 с локальной магнитудой M=5,6. Для этого были построены механизмы очагов этих землетрясений и проанализированы два коэффициента напряженного состояния - Лоде-Надаи и кулоновское напряжение. В 2023 году, как и в предыдущие годы, акватория Каспийского моря характеризуется высокой сейсмичностью. Наибольшая плотность гипоцентров наблюдалась на глубине 42-68 км. Величина смещений в очаге показывает, что здесь преобладают движения сбросо-сдвигового типа. Всего в 2023 году на Каспии было построено и проанализировано 19 землетрясений. Эти землетрясения были связаны с зоной влияния Аграханско-Красноводского, Туркменбашинского, Сангачал-Огурчинского, Шахово-Азизбековского, Сиязанского и Гарабогаз-Сафидрудского разломов. На основе этих механизмов был построен коэффициент Лоде-Надаи и установлено, что очаги прикаспийских землетрясений расположены в зоне растяжения. Решение тензора момента показало, что движение в очаге землетрясения 4 июля возникло в условиях напряжения растяжения. Движение в источнике по обеим плоскостям является сдвиговым. Длина очага составила 6,1 км, ширина – 4,53 км. Смещение по разлому составило 24 см. В очаге землетрясения, произошедшего 7 декабря 2023 г., согласно решению механизма, движение очага также происходило в условиях напряжения растяжения. Тип движения - по первой плоскости NP1 северо-западного простирания и по второй плоскости NP2 восточно-юго-восточного простирания - сдвиг-с элементами сброса. Моментная магнитуда была определена как Mw=5,4. Сейсмический момент $1,56*10^{24}$ дин*см. Глубина очага - 48 км. Длина очага составила 6,58 км, ширина – 5,49 км. Смещение по разлому составило 24 см.

Ключевые слова: Механизм очага землетрясения, тензор момента, коэффициент кулоновского напряжения, сейсмическая томография, Каспийское море.

Introduction

The submeridionally oriented megadepression of the Caspian Sea covers a vast space from Elburz in the south to the Caspian Lowland in the north and has a length of about 1200 km with an average width of 320 km and an area of 422 thousand sq km. In the modern structure of the earth's crust, the Caspian Sea is an intracontinental depression with a heterogeneous base structure, which is confined to the meridional zone of subsidence, superimposed on a number of structural elements belonging to the southeastern margin of the

Precambrian East European Platform, the Scythian-Turanian Epihercynian Plate and the Mediterranean (Alpine-Himalayan) fold belt [12].

The Caspian Sea is an important seismically active zone of Azerbaijan. The spatial distribution of source zones is irregular. The source zones of the Caspian Sea region reach a depth of 60–80 km. The depth of strong earthquakes with $M \geq 5.0$ reaches 30–50 km. According to the catalog of the RSSC ANAS, over the past century, a number of strong earthquakes have been recorded in the Caspian waters, with an intensity of 6 points or more at the epicenter. Most of the known most powerful earthquakes in this zone occurred in the North Absheron waters of the Caspian Sea. Their intensity at the epicenter (earthquakes of 1842, 1963, 1986 and 1989) reached VIII points [16]. The source of the earthquake on November 25, 2000 is located in the southern part of the Absheron zone and is confined to the Absheron-Cheleken threshold.

The outbreaks that occurred in 2023 in July and December with a magnitude of M=5.6 were no exception. In this article, we analyzed the parameters of the source of these earthquakes and identified the geodynamic situation. For this purpose, two stress state coefficients were analyzed - Lode-Nadai and Coulomb stress. The Coulomb initiation theory has become widespread, being one of the popular explanations for the fact that earthquake aftershocks manifest themselves not only within the fault zone, but also in neighboring areas [1, 3]. Typically, the best agreement between the Coulomb stress change and the aftershock distribution is observed at distances greater than a few kilometers from the earthquake fault, since unknown details of the displacement distribution and geometry play a significant role closer to the earthquake fault.

Note that changes in stress leading to the initiation of deformation processes are very small. A comparison of the results of calculations of changes in the static stress field with the prevalence of aftershocks shows that changes in stress of the order of 1–3 bar are sufficient to initiate seismicity, while a decrease by the same amount restrains it. However, this picture is not always observed [2]. Such small values, being an insignificant part of the total stress release during an earthquake, indicate that quasi-static stress changes are not the cause of the earthquake, but only bring the moment of the event closer or further away. In order to assess the change in the variation of the Coulomb function on the plane of a future rupture of a tectonic earthquake as a result of rock excavation, it is necessary to know the geometric parameters of the fault zone. In this article we will use fault tectonics compiled based on materials: Agabekov M.G. et al. 1971; Alikhanov E.N. 1978; Gasanov I.S.1990; Babaev D.Kh. et al. 2005; Mamedov A.V.1984; Kangerli T.N. 2005; Shikhalibeyli E.Sh.1996; Khain V.E. et al. 2003 [5-7, 13, 18, 19].

Tectonic structure of the Middle Caspian megazone

The Middle Caspian megazone covers a tectonically complex section of the earth's crust in the area of conjugation of the Alpine and Cimmerian folded structures of the Greater Caucasus, Mangyshlak and platform structures of the Scythian-Turanian plate. Within the Azerbaijani water area, the megazone is represented in the north by the Samur-Peschanomys uplift, limiting the Terek-Caspian trough from the south, in the central part - by the North Absheron trough, which continues the Guba zone of the Gusar-Devechi superimposed trough in the sea, and in the south - by the Absheron-Pribalkhan uplift zone. The latter is bounded from the south by the Krasno Polyansko-Zangin deep fault, separating the Middle Caspian block with a relatively high position of the pre-Jurassic basement from the deeply submerged South Caspian block of the megadepression [17]. The west-southwest border of the megazone can be conditionally drawn along the Derbent fault and the Mugtadyr fault, which continues it within Azerbaijan, with contrastingly lowered northeastern wings. Until recently, tectonic zoning of the Middle Caspian was based on data from gravimetric and magnetic surveys and single regional seismic profiles. In recent years, in the Caspian Sea, the geophysical exploration trust has carried out comprehensive geophysical research on a large scale, including geophysical exploration work. The Jurassic-Quaternary sedimentary cover of the megazone, reaching its maximum thickness in the Dagestan coastal zone (8-10 km) and the central part of the North Absheron depression (14-15 km or more), is underlain by a partially dislocated Permian-Triassic complex and metamorphic Paleozoic, formed together with the trough of the Kazakh Gulf on the reworked and submerged northern part of the vast Paleozoic Middle Caspian

massif of the Scythian-Turanian plate, the thickness of the sedimentary cover is 3-4 km. Moreover, in many areas, various rock complexes, including Upper Jurassic ones, fall out of the section, which is explained by breaks in sedimentation at various stages of development, the most significant of which is the Pre-Pliocene regression. The Triassic–Jurassic boundary is characterized by a regional unconformity associated with Early Cimmerian tectonic activity and a hiatus in sedimentation. According to new data from gravimagnetometric studies, to the north of the indicated shelf zone in the pre-Jurassic basement there are magmatic bodies (depths from 5-6 to 7-9 km), which may be eastern fragments of the ophiolite belt of the Front Range of the Greater Caucasus (North Caspian ophiolite belt), traced to the periphery of the Karabogaz massif. The thickness of the crust of the Middle Caspian megazone is about 40 km, and the thickness of the lithosphere is 150 km. In the direction to the Absheron threshold, there is a significant increase in the depth of the Moho boundary and a relative increase in the depth of the surfaces of the granite and basalt layers. Several structural and material complexes are distinguished within the sedimentary cover [9-11, 14]. The Upper Pliocene-Quaternary complex is represented by shallow marine clays, sands and shell rocks, which lie very calmly, weakly repeating the local dislocations of the underlying sediments. At the base of this complex lie alluvial-deltaic sandy-clayey sediments of the Paleo-Volga valley and delta, the valley incision of which is clearly visible on seismic profiles. Further in the descending section lie Paleocene-Eocene carbonate-terrigenous, Upper Cretaceous marl-limestone, Lower Cretaceous terrigenous, Upper Jurassic carbonate and Lower-Middle Jurassic sandy-clayey formations [17].

Based on seismic tomography data, a deep velocity model was built along profile 1-1 in the south-north direction. As can be seen on the profile, the thickness of the sedimentary cover in the center of the profile plunges to a depth of 20 km. Next is a granite layer to a depth of 35 km. At a depth of 45-50 km, the Moho boundary is observed, however, at an epicentral distance of 100-160 km, a subsidence of the Moho boundary to a depth of 70-75 km is observed, probably corresponding to the boundaries of deep faults. As can be seen in the profile (Fig. 1), the sources of strong Caspian earthquakes correspond to this subsidence zone.

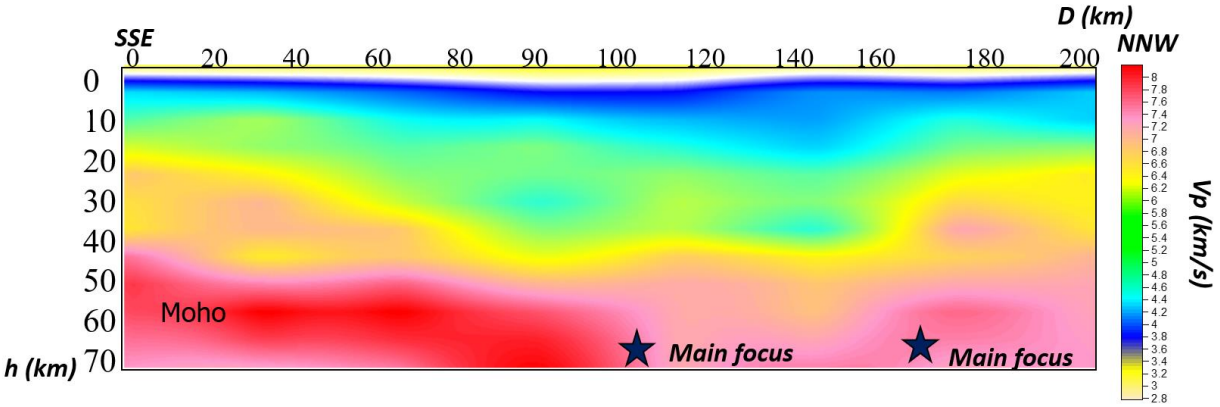


Figure 1. Seismic tomographic profile along the source zone of the Caspian earthquakes in 2023.

The North Absheron zone is a deep trough extending in the pan-Caucasian direction for a distance of more than 110 km, located on the southeastern continuation of the Guba depressed zone of the Gusar-Devechi superimposed trough and having a similar asymmetric structure with a relatively flat northeastern and steep southwestern sides. The latter adjoins from the north the Absheron-Pribalkhan zone of uplifts, grouped along the Miocene-Pleistocene complex into two (northern and southern) fold lines - the Gilyazi-Prigubadag and the Absheron-Pribalkhan proper, separated by the Pirallakhi trough [17]. According to the chalk complex, the zone is presented in the form of five synclines, the depth of which along the chalk surface is 7900-8300 m. The structural plan of the Paleocene-Miocene and Pliocene complexes in general remains similar to that of the Upper Cretaceous deposits, and a chain of isometric depressions separated by saddles can be traced throughout the Pliocene-Quaternary complex. Along the south-southwestern side of the North Absheron trough, Mesozoic

sediments are uplifted and folded into anticlinal folds, which, in particular, include the Zarat-Deniz and Gyzylburun-Deniz structures, possibly the Shimali Absheron. Longitudinal faults identified on the more southern structures of Sumgayit-Deniz, Gosha-Dash, Shuraabad-Deniz, Absheron-Kyupasi, Ashrafi and others are interpreted as the eastern continuation of the Siyazan thrust, separating the trough from the Absheron-Balkhan uplift zone [17].

Various-scale tectonic stress fields

The nature of the distribution of stresses acting in fault zones is determined by regional tectonics or local anomalies in the temperature field of the earth's crust, and the stress values depend on the structural and material state of the rocks and the fluid regime of these zones. Since, unlike materials used for structures, the geological environment is significantly heterogeneous, this predetermines the presence of significant heterogeneity - mosaicism in the stress field, manifested at different scale levels of averaging, and, consequently, in the strong dependence of the values of the components of the natural stress tensor on the averaging scale. It should be noted that at different scales the causes and manifestation of this heterogeneity in the effective properties of the geoenvironment (average for a certain scale) are also different. Thus, inhomogeneities at the microscopic level, caused by the presence of crystals, grains and aggregates, dislocations and microcracks, micropores, can be smoothed out by averaging physical parameters with a linear size of less than 1 cm (uniform deformation of small samples), which will characterize the macroscopic level of averaging of the properties of the geomedium and components stress and strain tensors.

The waters of the Caspian Sea in 2023, as in previous years, are characterized by high seismicity. The highest density of hypocenters is observed at a depth of 22-68 km. Type of movements in 2023 in percentage: 45% - shift, 55% - reset. The magnitude of the displacements in the source shows that fault-slip type movements predominate here. A total of 19 earthquakes were plotted and analyzed in the Caspian Sea in 2023. These earthquakes are associated with the zone of influence of the Agrakhan-Krasnovodsk, Sangachal-Ogurchi, Shakhov-Azizbekov and Garabogaz-Safidrud faults. Based on these mechanisms, the Lode-Nadai coefficient was constructed. As can be seen in Fig. 2, the sources of Caspian earthquakes are located in the extension zone.

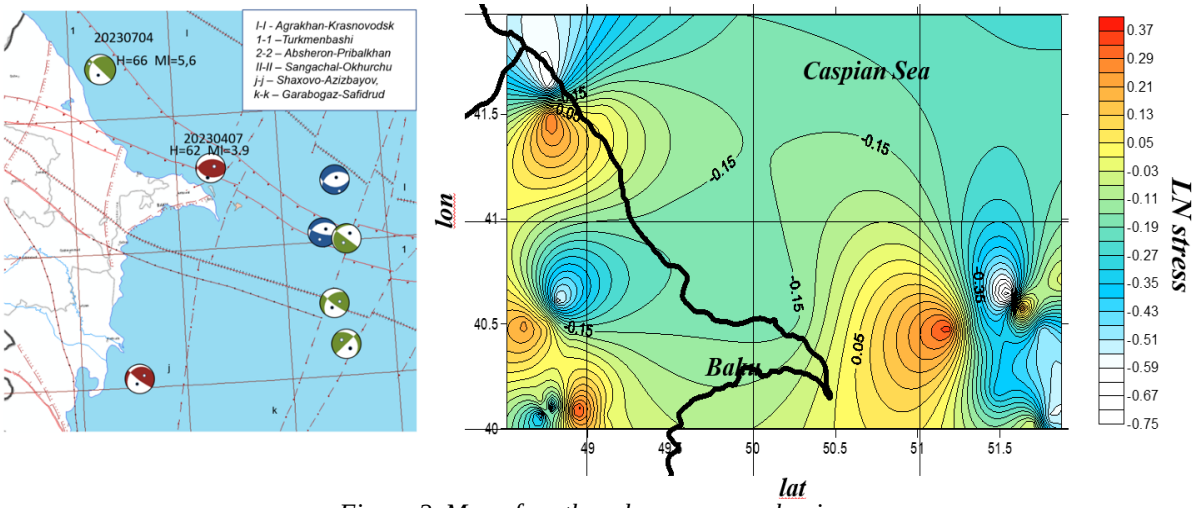


Figure 2. Map of earthquake source mechanisms

Let us dwell separately on two strong tangible centers of the Caspian Sea. On July 4, 2023, local time 00:01, an earthquake occurred in the Middle Caspian Sea, which was felt in Guba, Khachmaz, Shabran, Siyazan up to 6 points, in Sumgait, Absheron up to 5-4 points. The depth of the source was 66 km, magnitude M=5.6, coordinates lat = 41.52; long = 49.10. Then, on December 7, local time 08:15, 70 km southeast of the first source, another earthquake with a magnitude of M=5.6 occurred. This earthquake, like the first one in Altyagach, Siyazan, Guba, Gusar, Khachmakh, Shabran, Gobustan and Absheron, was felt up to 5-3 points. The depth of this earthquake is 68 km, coordinates lat = 40.96; long = 49.53.

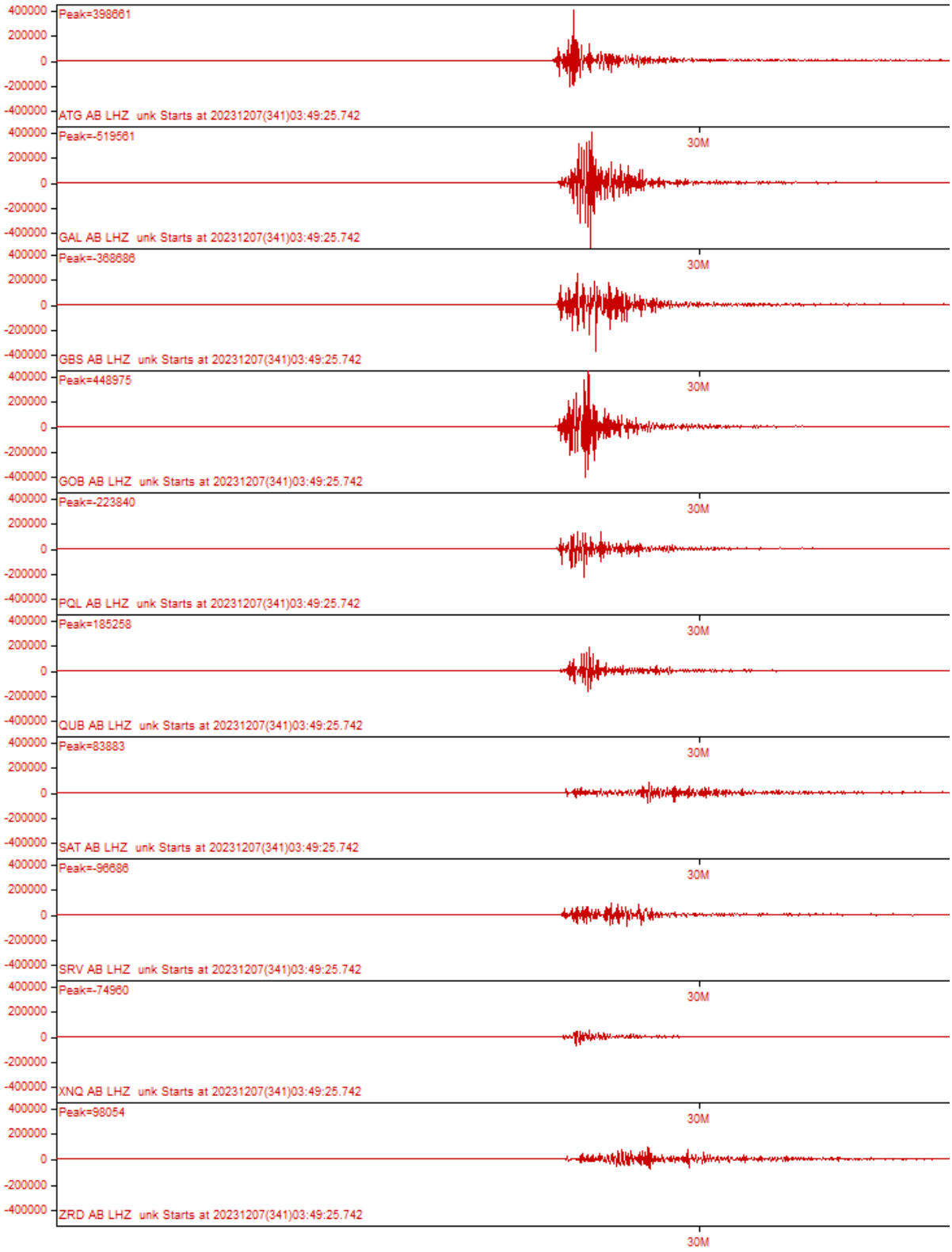


Figure 3. Wave recording the Caspian earthquake of 12/07/2023 via LH channels

Based on a program developed at the University of Oregon by Professor John Nabelek we have constructed a moment tensor for Caspian earthquakes. The rate of seismotectonic deformation directly characterizes the stage of discontinuity of the medium. It is determined by the total seismic moment of a fixed number of earthquakes that have occurred (1) [8]:

$$\acute{\varepsilon}_{i,j} = \frac{1}{2\mu VT} \cdot \sum_{k=1}^{N} M_{ij}^{k}, \quad (1)$$

where $\acute{\varepsilon}_{i,j}$ - seismotectonic deformation rate tensor, μ - shear modulus in the region of the earthquake hypocenter. This value is determined in accordance with the parameters of the generalized Earth model PREM in the range of values (2,66÷9,76)· 10^{10} (Н/м^2). Seismogenic volume $V = SH$. where S - rupture area, H - depth of the earthquake hypocenter. Other options: T- observation period, N - number of earthquakes и M_{ij}^{k} - seismic moment tensor of an individual earthquake; provided that inelastic movements in earthquake sources are small compared to the size of the seismogenic volume [8]. The last condition is always met. The small strain rate tensor differs from the strain tensor only by a time factor.

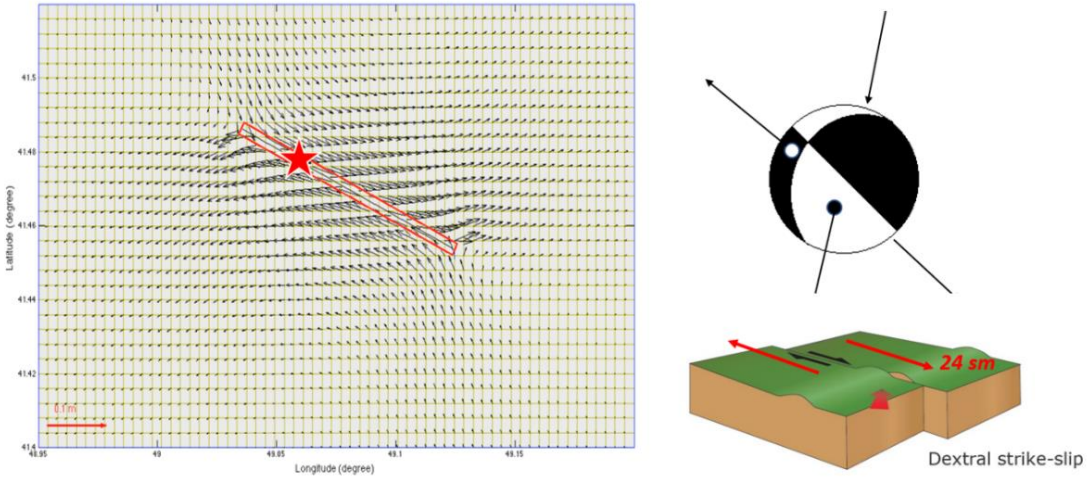


Figure 4. Source mechanism of the Caspian earthquake of 07.04.2023

Assuming that during the process of rupture, the direction of shear relative to the rupture plane does not change in the source. the average displacement along the rupture Ū will be determined from the static seismic moment M_0:

$$M_0 = \mu \cdot \bar{U} \cdot S,$$

where μ is the shear modulus, and S is the area of the rupture surface. The surface area of the rupture is estimated based on the empirical relation:

$$M_W = 0.98 lgS + 4.07 \quad (2)$$

where M_W – moment magnitude of earthquake [8].

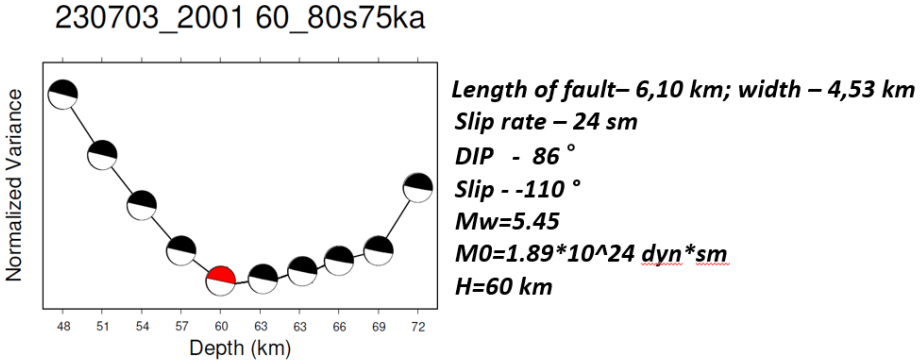


Figure 5. Source parameters of the Caspian earthquake of 07/04/2023

The parameters of the source mechanism also include data on the magnitude and orientation of the main axes of the stress tensor released at the rupture. Since the stresses released at the rupture form the inelastic residual displacement in the source zone of the earthquake, they can be called residual. To determine the time of a possible future earthquake, the differences in the absolute values of the principal tension and compression stresses of the residual stress tensor were used: $\sigma_1 - \sigma_2$ [8] In this article, LH channels recorded by digital seismic stations of the RSSC at ANAS were used (fig. 3).

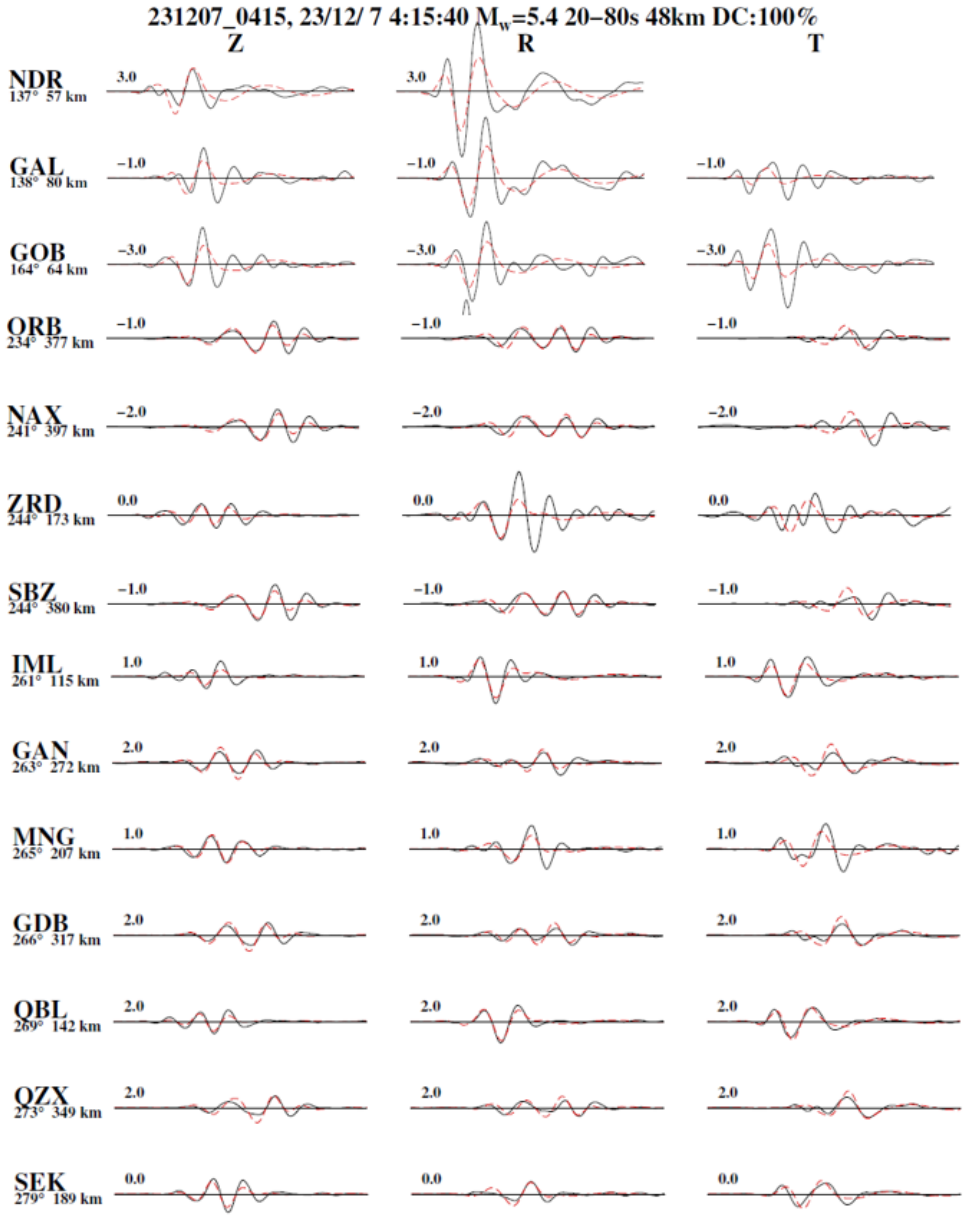


Figure 6. Waveform fitting between observed (black traces) and synthetic (red traces) seismogram of earthquakes of 07.12.2023

The movement in the source of the July 4 earthquake arose under tensile conditions: the axis of tensile stresses is horizontal (PL_P=46°) and oriented in the NE direction (AZM=22°), the axis of compression stresses is also near horizontal (PL_T=43°) and oriented towards SSW (AZM=194°). The movement in the focus along both planes is shear (SLIP=21°, SLIP=94°) (Fig. 4, 5). The angle of incidence is 88°. The orientation of the nodal planes of the NW-SE strike coincides with the strike of the Turkmenbashi longitudinal fault. The moment

magnitude was determined to be Mw=5.4. Seismic moment $1.89 \cdot 10^{24}$ dyn·sm. The depth of the source is 60 km. The length of the outbreak was 6.1 km, width – 4.53 km. The movement along the fault was 24 cm.

In the source of the earthquake that occurred on December 7, 2023, according to the solution of the mechanism, movement in the source occurred under conditions of tension. The main tectonic stresses that acted in the source correspond to the near-vertical orientation of the compression axes (PL_P = 59°) and the near-horizontal orientation of the extension axes (PL_T = 5°). The inclination of the first nodal plane is DP1=57°, the second – DP_2=48°. Type of movement, along the first plane NP_1 with a northwest strike (STK_1=333) and along the second NP_2 with an east-southeast strike (STK_1=99°) shear with fault elements (Fig. 6).

The moment magnitude was determined to be Mw=5.4. Seismic moment $1.56 \cdot 10^{24}$ dyn·sm. The depth of the source is 48 km. The length of the outbreak was 6.58 km, width – 5.49 km. The movement along the fault was 24 cm (Fig. 7).

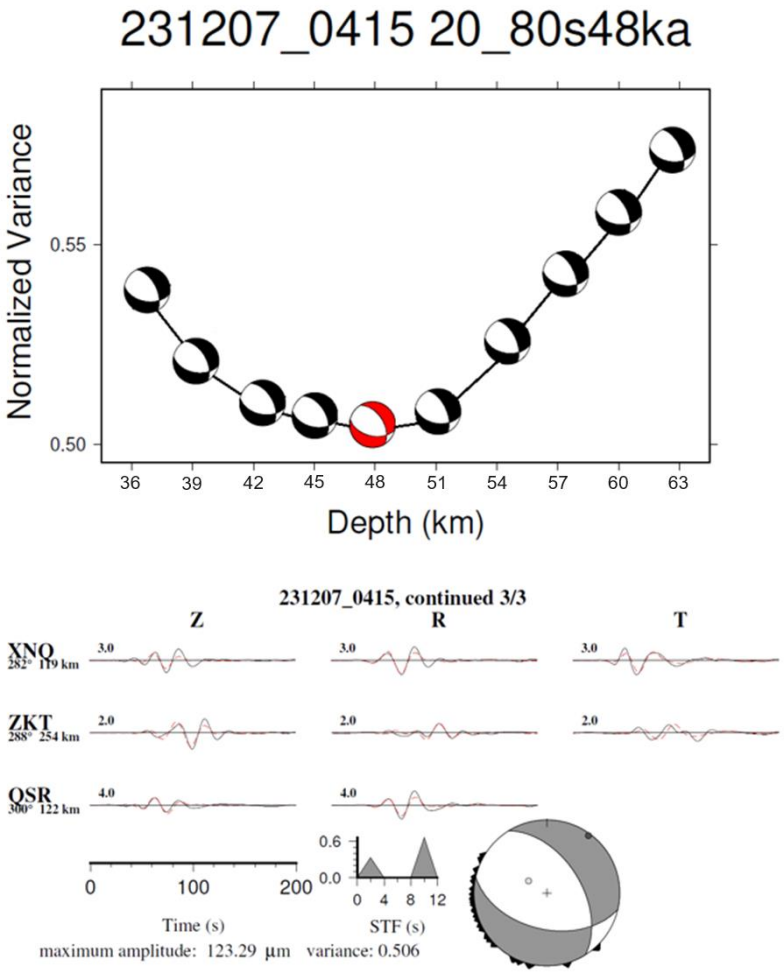


Figure 7. Best solution for DC and depth fitting for best solution DC

Coulomb stress environment of Caspian earthquakes

One of the main provisions of existing earthquake source models is the hypothesis of a high level of tangential stresses in most of the future earthquake source. It is believed that at the last stage of earthquake preparation, these stresses increase to a certain limiting value, and in the process of aftershock activity, stress relaxes in those areas of the source where they remained high after the earthquake. It is also assumed that the higher the intensity of stresses acting in the earth's crust, the higher the value of the released stresses and, therefore, the more destructive an earthquake can occur. However, studies based on the analysis of natural stresses and the results of laboratory experiments force us to significantly correct, and in some aspects, revise

such ideas [15]. Based on the results obtained, geological models of the foci of the two Caspian earthquakes were constructed (Fig. 8).

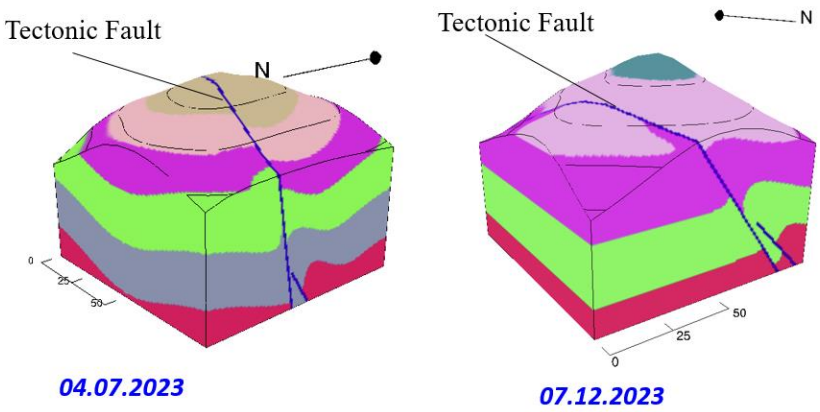


Figure 8. Geological model of the Caspian earthquakes in 2023

In the class of models associated with frictional destruction, direct initiation by dynamic loads is considered, providing the stress increment necessary to exceed the frictional strength of faults, thus leading to the occurrence of unstable slip. Since the use of the classical Coulomb model does not allow us to describe the observed effects, modified models are used to describe the frictional interaction, taking into account second-order effects - the dependence of the shear resistance force on time, speed, loading history, etc. [4]. According to this approach, when seismic waves pass through appropriately oriented faults, instability occurs due to the sum of static and dynamic stresses exceeding the frictional strength limit. As a result, despite the fact that exceeding the strength limit is short-lived, it is often sufficient to produce effects on the dependence of shear strength on speed and time. Such models describe a number of effects that do not follow from the simple Coulomb model. For example, the possibility of a decline in initiated seismicity similar to Omori's law is allowed. One interesting consequence of friction in the conditionally stable regime is that dynamic stresses can temporarily convert stable slip into stick-slip slip. As discussed, [15], this represents "new seismicity" in the sense that earthquakes generated during the shear process might not have occurred in the absence of dynamic initiation. Subcritical crack growth or stress corrosion is a well-known crack instability process in materials science. The growth rate of small cracks within the fault zone gradually increases due to chemical reactions at the spout between the silicate rock and water. With a sharp dynamic change in the stress-strain state in the vicinity of a crack, especially in the presence of high temperatures and fluids, the growth rate of the defect can increase sharply, which can lead after some time to catastrophic failure. These processes are capable of changing the effective normal stresses enough to initiate failure or aseismic creep. The latter, in turn, after some time can lead to instability. Such models are supported by the fact that geothermal and volcanic areas are the most sensitive to dynamic initiation [15]. A number of proposed models are based on changes in the permeability of individual sections of the crust by dynamic deformations from a distant earthquake through, for example, decolmatation of cracks, thus leading to a redistribution of pore pressure. The fact that changes in permeability can be quite significant is indicated by recently published results, where the permeability value of a granodiorite layer increased several times as a result of the influence of vibrations from distant earthquakes [4].

Figure 9 presents the results of tectonophysical reconstruction of natural stresses for the crust of a section of the Caspian zone, according to data on the mechanisms of earthquake source, with Mw = 5.4. at a depth of 48-60 km. The reconstruction results show that the source of the earthquake of 07.03.2023, with a length of about 50 km, was located in an area of a reduced level of effective pressure (reduced Coulomb friction forces), and the beginning of the "explosion" (epicenter) of the earthquake was located near the place of local increase in effective pressure, which can be considered as a section of delayed shear flow (asperity). The area of

increased effective pressure located to the north of the realized source can be considered as a section of the crust with increased Coulomb friction forces, which stopped the movement of the source in this direction. To the south of this source there is also an area of increased effective pressure, but the development of the source stopped 10 km before this section of the crust in a zone where there is no data on the stress state. The latter is due to the absence of a sufficient number of earthquakes, which indirectly indicates a subcritical stress state.

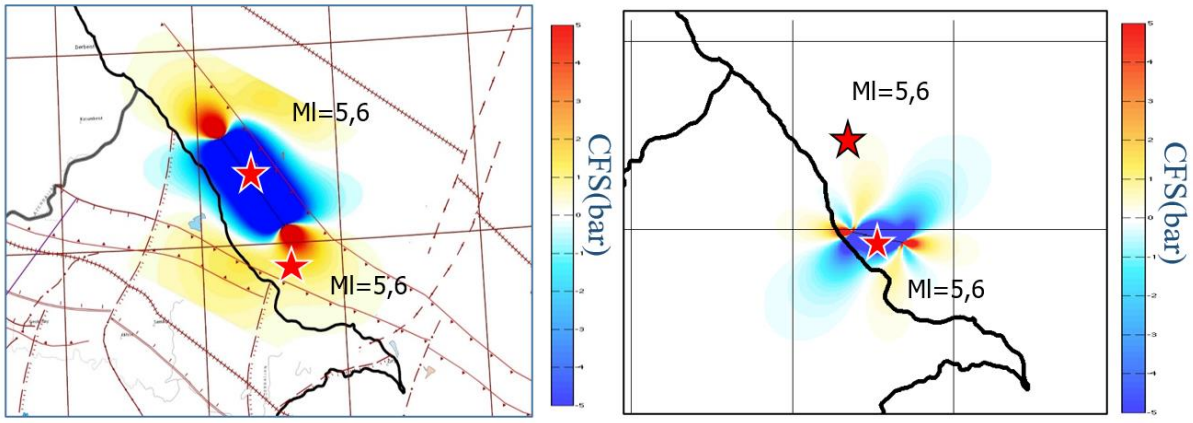


Figure 9. Coulomb stress distribution diagram for the Caspian earthquakes of 07.04.2023 and 12.07.2023.

Let us consider the influence of a rigid block on the initiation of rupture in a fault zone. It is assumed that the study area is under conditions of unequal tension, causing displacement along the fault. Near the fault there is a block that has higher elastic and strength characteristics. In what follows we will call this block rigid. A fault zone, on the other hand, is a strip of weakened material. Shear deformation along the fault due to differences in mechanical characteristics leads to a slight clockwise rotation of the rigid block. As a result of this rotation, zones of decreasing and increasing compression appear, which, in combination with the intensity of shear stresses, determine the distribution of Coulomb stresses that determine the shear strength of the material. Orthogonal to the fault, “tension” occurs as a result of clockwise rotation of the block, while along the fault, “tension” is associated with the action of shear. Obviously, under such conditions, destruction will be initiated in the “tension” region (and primarily orthogonal to the direction of the tension axis, or least compression), that is, the start of fault propagation will occur in the area of intersection of the zone, reducing compressive stresses with the Siyazan fault. In this section of the Siyazan fault, it is possible to stop the propagation of the rupture.

Conclusions

The waters of the Caspian Sea in 2023, as in previous years, are characterized by high seismicity. The highest density of hypocenters is observed at a depth of 42-68 km. Type of movements in 2023 in percentage: 45% – shift, 55% – reset. The magnitude of the displacements in the source shows that fault-slip type movements predominate here. A total of 19 earthquakes were plotted and analyzed in the Caspian Sea in 2023. These earthquakes were associated with the zone of influence of the Agrakhan-Krasnovodsk, Turkmenbashi, Sangachal-Ogurchi, Shakhov-Azizbekov, Siyazan and Garabogaz-Safidrud faults. Based on these mechanisms, the Lode-Nadai coefficient was constructed and it was established that the sources of Caspian earthquakes are located in the extension zone. The solution of the moment tensor showed that the movement at the source of the July 4 earthquake arose under tension conditions. Movement in the source along both planes is shear. The orientation of the nodal planes of the NW-SE strike coincides with the strike of the Turkmenbashi longitudinal fault. The moment magnitude was determined to be Mw=5.4. Seismic moment $1.89 \cdot 10^{24}$ dyn·sm. The depth of the source is 60 km. The length of the outbreak was 6.1 km, width – 4.53 km. The movement along the fault was 24 cm. In the source of the earthquake that occurred on December 7, 2023, according to the solution of the mechanism, movement in the source also occurred under tension conditions. The type of

movement, along the first plane NP_1 of a northwest strike and along the second plane NP_2 of an east-southeast strike, is a strike-slip fault with fault elements. The moment magnitude was determined to be Mw=5.4. Seismic moment $1.56 \cdot 10^{24}$ dyn·sm. The depth of the source is 48 km. The length of the outbreak was 6.58 km, width – 5.49 km. The movement along the fault was 24 cm.

Based on data on the mechanisms of earthquake foci, reconstructions of natural stresses were constructed for the crust of a section of the Caspian zone. The reconstruction results showed that the source of the earthquake of 07.03.2023, with a length of about 50 km, was located in an area of a reduced level of effective pressure (reduced Coulomb friction forces), and the beginning of the "explosion" (epicenter) of the earthquake was located near the place of local increase in effective pressure, which can be considered as a section of delayed shear flow. The area of increased effective pressure located to the north of the realized source can be considered as a section of the crust with increased Coulomb friction forces, which stopped the movement of the source in this direction. To the south of this source there is also an area of increased effective pressure, but the development of the source stopped 10 km before this section of the crust in a zone where there is no data on the stress state. The latter is due to the absence of a sufficient number of earthquakes, which indirectly indicates a subcritical stress state.

Shear deformation along the fault due to differences in mechanical characteristics leads to a slight clockwise rotation of the rigid block. As a result of this rotation, zones of decreasing and increasing compression appear, which, in combination with the intensity of shear stresses, determine the distribution of Coulomb stresses that determine the shear strength of the material. Orthogonal to the fault, "tension" occurs as a result of clockwise rotation of the block, while along the fault, "tension" is associated with the action of shear. Obviously, under such conditions, destruction will be initiated in the "tension" region (and primarily orthogonal to the direction of the tension axis, or least compression), that is, the start of fault propagation will occur in the area of intersection of the zone, reducing compressive stresses with the Siyazan fault. In this section of the Siyazan fault, it is possible to stop the propagation of the rupture.

References

1. Das S. and Scholz C. H. Off-fault aftershock clusters caused by shear stress increase, Bull. Seismol. Soc. Amer., 1983, Vol. 71, No. 5. — P. 1669 – 1675.
2. Felzer K. R. and Brodsky E. E. The absence of stress shadows, Seismol. Res. Lett, 2003. — Vol. 75. — P. 285.
3. King G. C. P., Stein R. S., and Lin J. Static stress changes and the triggering of earthquakes, Bull. Seismol. Soc. Amer., 1994, Vol. 84, No. 1. — P. 935 – 953.
4. Ulomov V.I. A three-dimensional model of the lithosphere dynamics seismicity structure, and variations in the Caspian sea level // Izvestiya, Physics of the Solid Earth. 2003. T. 39. № 5. C.353-364.
5. Агабеков М.Г., Керимов К.М., Мошашвили А.Б., Хаин В.Е. Новые данные о строении центральной части Куринской впадины. – Геотектоника, 1976, №5, с.75-81.
6. Алиханов Э.Н. Геология Каспийского моря. – Баку: Элм, 1978.
7. Ахмедбейли, Ф.С., Бабазаде, О.Б., Гасанов, А.Г., Кулиев, Ф.Т., Панахи, Б.М, Шихалибейли, Э.Ш. 1991. Новые схемы областей возникновения очагов сильнейших землетрясений и сейсморайонирования территории Азербайджана. Элм. Баку.
8. Воронина Е.В. Возможность прогноза сильного землетрясения по данным механизма очагов землетрясений // *Физические проблемы экологии № 16, с. 66-75*
9. Гаджиев А.Н., Попков В.И. Строение осадочного чехла Среднего Каспия. – Геотектоника, 1988, №6, с.101-112.
10. Гаджиев А.Н., Рагимханов Ф.Г. Тектоника Апшеронского архипелага и прилегающей части Бакинского архипелага в свете новых геофизических исследований. – АНХ, 1982, №12.

11. Гаджиев Р.М. Глубинное геологическое строение Азербайджана. - Б.: Азернешр, 1965.
12. Казымова С.Э., Казымов И.Э. СОВРЕМЕННАЯ ГЕОДИНАМИКА СРЕДНЕГО И ЮЖНОГО КАСПИЯ // Геология и геофизика Юга России, № 2, 2016, с 140-152
13. Мамедов А.В. Тектоника четвертичных отложений Азербайджана. – В сб.: Очерки по геологии Азербайджана. Баку: Азернешр, 1984, с.256-269.
14. Петрофизическая характеристика осадочного покрова нефтегазоносных провинций СССР. Справочник. М.: Недра, 1985.
15. Ребецкий Ю.Л. Тектонические напряжения и области триггерного механизма возникновения землетрясений / Физическая мезомеханика, 10, 1, 2007, с. 25-37
16. Султанова, З.З., Раджабов, М.М. 1983. Сейсмичность Каспийского моря и ее связь с глубинным строением. В кн.: Геолого-геоморфологические исследования Каспийского моря. Наука. Москва. 10-15.
17. Хаин В.Е., Ак.А.Ализаде, Геология Азербайджана, Том IV Тектоника, ред. 2005. Баку, Из-во Nafta-Press, С. 369-399.
18. Хаин В.Е., Чехович П.А. Основные этапы тектонического развития Каспийского региона. – В кн.: Объяснительная записка к Международной тектонической карте Каспийского моря и его обрамления. Масштаб 1:2500000 (гл. ред.: В.Е.Хаин и Н.А.Богданов). М.: Научный мир, 2003, с.66-74.
19. Шихалибейли Э.Ш. Некоторые проблемные вопросы геологического строения итектоники Азербайджана. - Баку: Элм, 1996.

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GRAVIMETRIC RESEARCH PLANNING WORKS CARRIED OUT WITHIN THE FRAMEWORK OF THE CREATION OF A WATER RESERVOIR ON THE HAKARI RIVER OF LACHIN DISTRICT

Bagırov E.M.[1], İsmayılova A.T.[1]

ABSTRACT

Although there are more than 140 reservoirs in the territory of the Republic, the demand for irrigation and drinking water in the Republic is not fully met. Therefore, the creation of new water reservoirs is one of the most urgent problems in the state program.

After the victory of the Patriotic War in Karabakh, as in other regions, the creation of the necessary infrastructure and the restoration of basic communications are successfully carried out in the Lachine region. In addition to these works, the "Hakarichay" water reservoir in Lachine region is also one of the successful projects.

To ensure the normal operation of the water reservoir with a capacity of approximately 90 million cub meters, which will be built on the Hakari River in Lachine region, to assess the ecological-seismic risks of the area, to determine the areas where environmental risks may occur and to take preventive measures is the main goal.

Key words: seismic risks, environmental risks, Khakarichay reservoir

LAÇIN RAYONU HƏKƏRİ ÇAYI ÜZƏRİNDƏ SU ANBARININ YARADILMASI ÇƏRÇİVƏSİNDƏ APARILMIŞ QRAVİMETRİK TƏDQİQAT PLANALMA İŞLƏRİ

Bağırov E.M., İsmayılova A.T.

XÜLASƏ

Respublika ərazisində 140-dan çox su anbarı olsa da, Respublikada suvarma və içməli suya olan tələbat tam ödənilmir. Ona görə də dövlət proqramında yeni su anbarlarının yaradılması ən aktual problemlərdən biridir.

Qarabağda Vətən müharibəsi qələbə ilə başa çatdıqdan sonra, digər rayonlarda olduğu kimi Laçın rayonunda da zəruri infrastrukturun yaradılması, əsas kommunikasiyaların bərpası tədbirləri uğurla həyata keçirilir. Bu işlərlə yanaşı Laçın rayonu ərazisində "Həkəriçay" su anbarı da uğurlu layihələrdən biridir.

Laçın rayonunda Həkəri çayı üzərində tikiləcək, tutumu təxminən 90 milyon kubmetr olan su anbarının gələcəkdə normal fəaliyyətini təmin etmək, ərazinin ekoloji-seysmik risklərininn qiymətləndirilməsi, sürüşmə, uçqun və s., ekoloji risklərin baş verə biləcəyi sahələrin müəyyən edilməsi və qabaqlayıcı tədbirlərin görülməsi qarşıya qoyulmuş əsas məqsəddir.

Açar sözlər: seysmik risklər, ekoloji risklər, Həkəriçay su anbarı

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

В РАМКАХ СОЗДАНИЯ ВОДОХРАНИЛИЩА НА РЕКЕ ХАКАРИ ЛАЧИНСКОГО РАЙОНА ВЫПОЛНЯЮТСЯ ГРАВИМЕТРИЧЕСКИЕ ИССЛЕДОВАТЕЛЬСКИЕ ПЛАНИРОВОЧНЫЕ РАБОТЫ

Багиров Э.М., Исмайылова А.Т.

АННОТАЦИЯ

Хотя на территории республики имеется более 140 водоемов, потребность в оросительной и питьевой воде в республике удовлетворяется не полностью. Поэтому создание новых водохранилищ является одной из самых актуальных задач государственной программы.

После победы в Отечественной войне в Карабахе, как и в других регионах, в Лачинском районе успешно осуществляется создание необходимой инфраструктуры и восстановление основных коммуникаций. Помимо этих работ, одним из успешных проектов является водохранилище «Хакаричай» в Лачинском районе.

Обеспечить нормальную работу водохранилища емкостью около 90 миллионов кубометров, которое будет построено на реке Хакари в Лачинском районе, оценить эколого-сейсмические риски территории, определить зоны, где возможны экологические риски, и принятие профилактических мер является основной целью.

Ключевые слова: сейсмические риски, экологические риски, водохранилище «Хакаричай»

Introduction

For this purpose, within the framework of the "Creation of Reservoir on the Hakari River" project, gravimetric research and planning works were carried out together with complex engineering-geological works in the territory of Lachine region. From the orohydrographic point of view, the area is a harsh nature, complex relief, steep slopes with ravines, and a complex geological-tectonic structure. The geomorphological features of the area to be worked on, forest, thicket, heather, ravine, etc. a network of profiles consisting of measuring points was established taking into account impassable places (Fig. 1.).

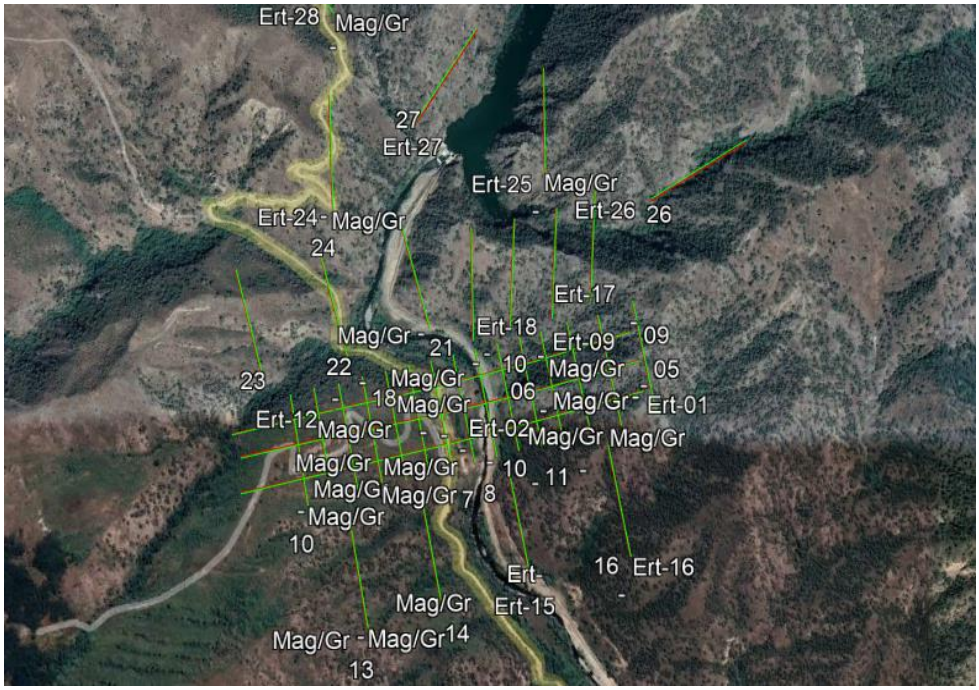


Figure 1. Profile network of gravimetric research works to be carried out in the area where the Hakari reservoir will be built in Lachine region.

Research work was carried out in order to determine the relative gravity of the gravity field and probable stress dynamics by determining the exact coordinates and height above sea level in the profiles. Isoanomalous two-dimensional (2D) maps, cross-sections and three-dimensional (3D) models were prepared, reflecting the gravity field stress and depth dynamics in the areas, characterizing the change of this geodynamic stress, using the gravimetric prospecting method.



Figure 2. View of the Canadian-made CG-5 AutoGrav gravimeter under investigation.

The obtained data allowed monitoring of tectonic disturbances at different depth intervals in the area and assessment of the geodynamic regime of the area. Gravimetric observations in the area where the Hakari water reservoir will be built in Lachine district were carried out by operators on foot at selected points on a special network, using a high-precision gravimeter device of the Canadian CG-5 AutoGrav brand (Fig 2.).

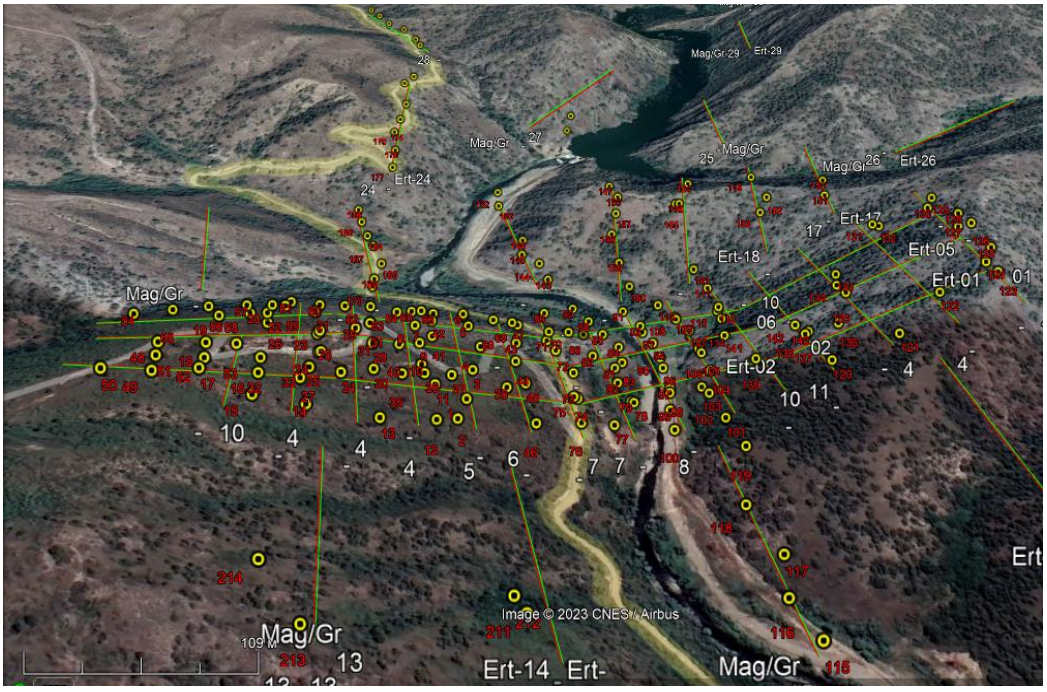


Figure 3. Location scheme of the gravimetric observation points performed in the area where the Hakari reservoir will be built in Lachine region.

In the area where the Hakari water reservoir will be built in Lachin district, it was carried out by the method of repeated measurement at the observation and reference points indicated in the scheme of research works (Fig 3). The data of the measurement works are processed with modern methods and programs.

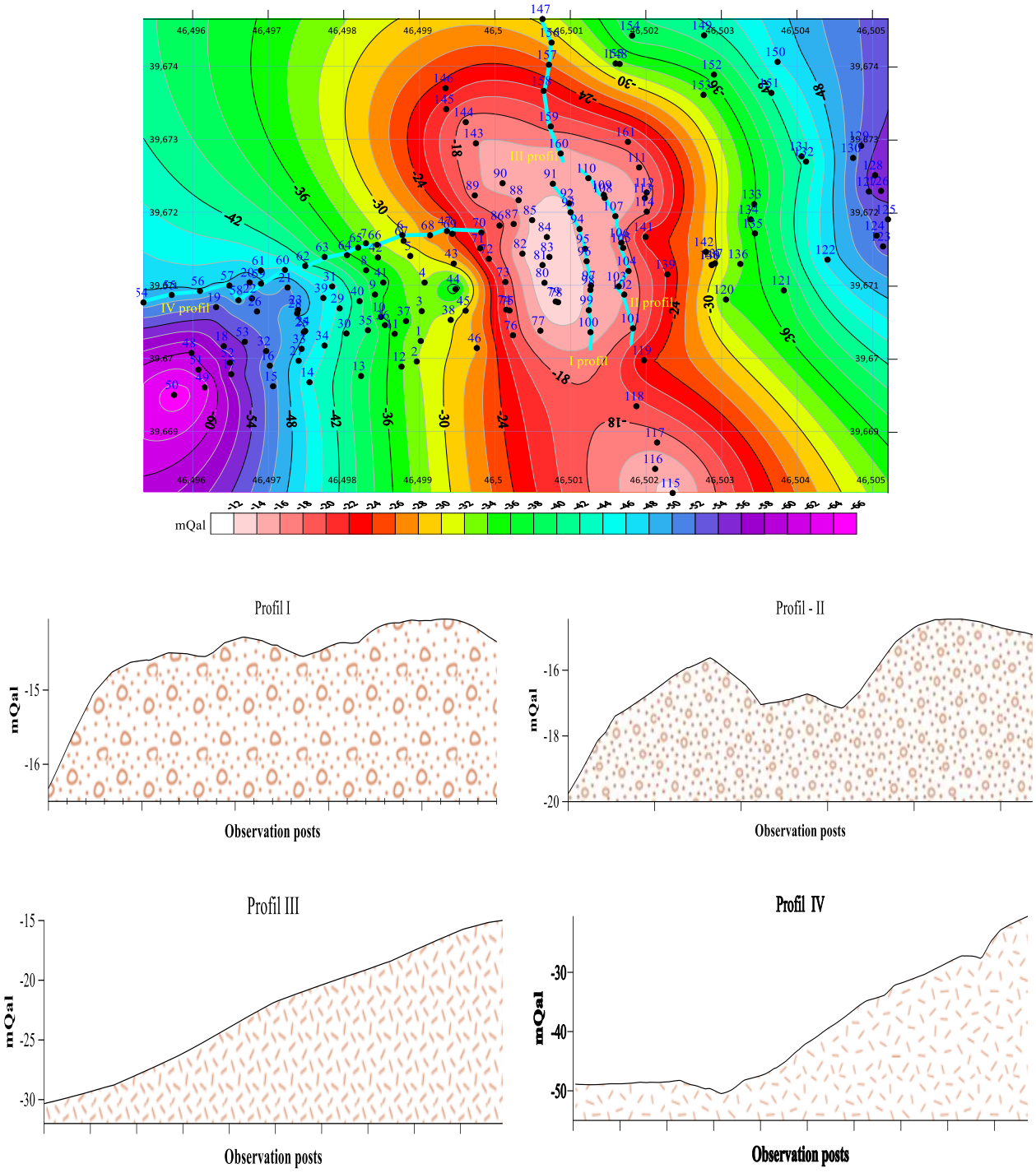


Figure 4. Sections on the profiles according to the isoanomaly map of the gravity field reflecting the stress-strain state in the reservoir area on the Hakari River.

Gravimetric measurements were carried out on 50 profiles, the distance between measurement points was 30 meters, and the total volume of observations was 235.

Changes in the gravity field on each profile in the area of the water reservoir to be built on the Hakari River in Lachin region and the cross-sections of the gravity field according to the relief according to the calculation results (pictures 4-8), 2-dimensional (2D) isoanomaly map (picture 9) and 3-dimensional (3D) models (Fig. 10.) were constructed.

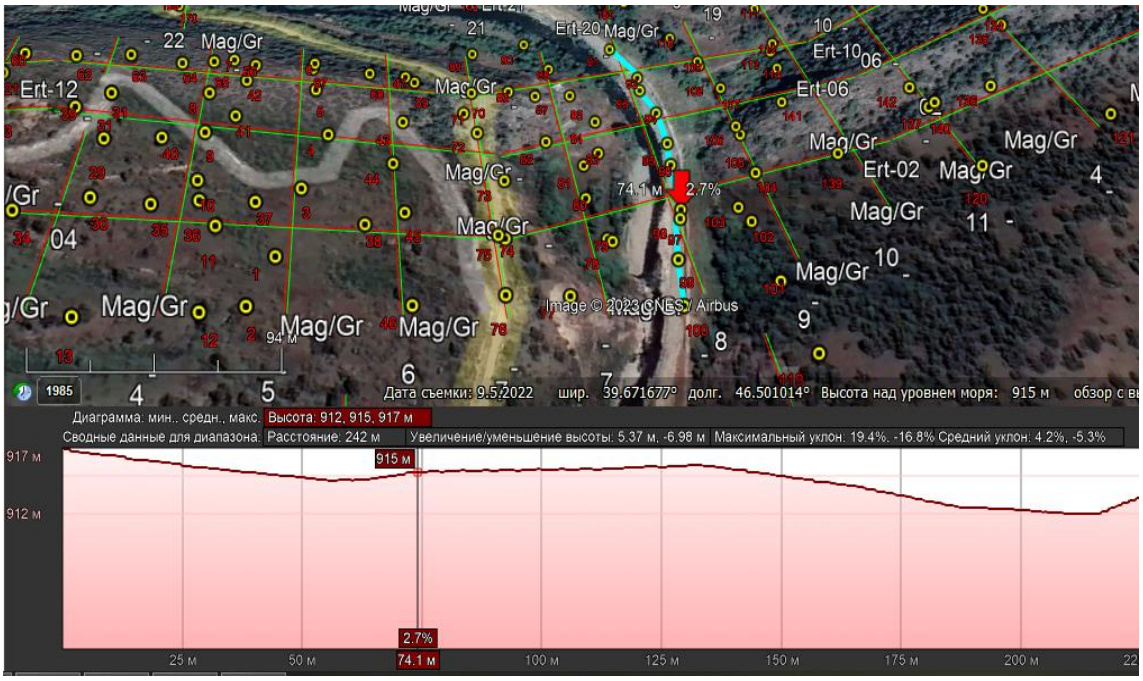


Figure 5. Cross-sectional diagram of profile I, where gravimetric observation points are located.

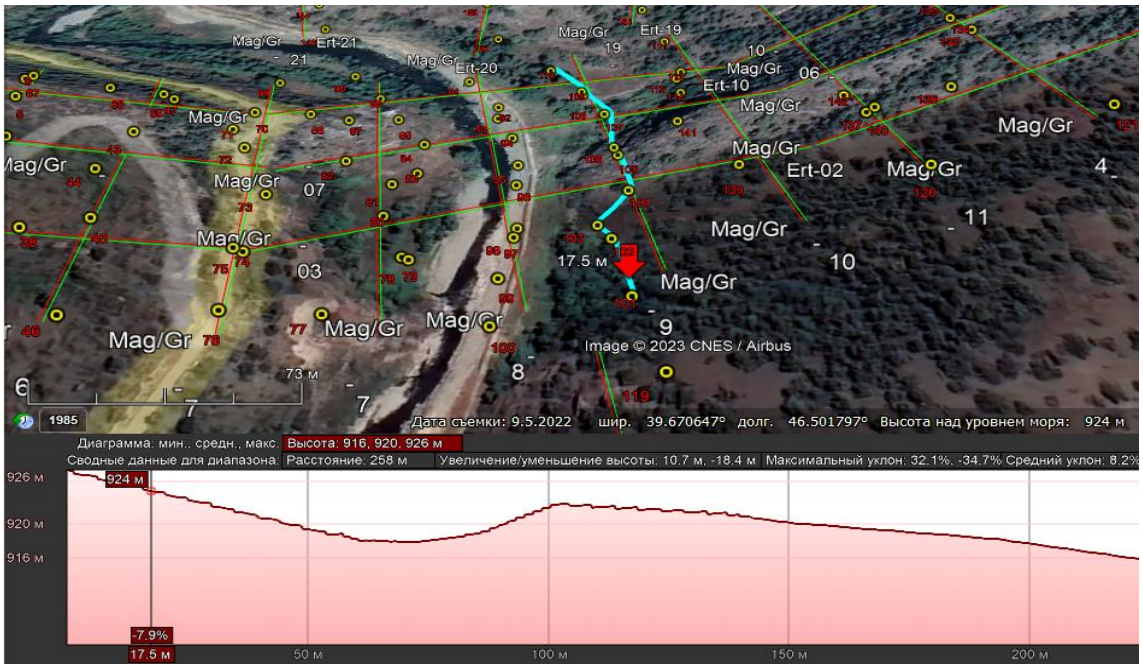


Figure 6. Relief section scheme of profile II, where gravimetric observation points are located.

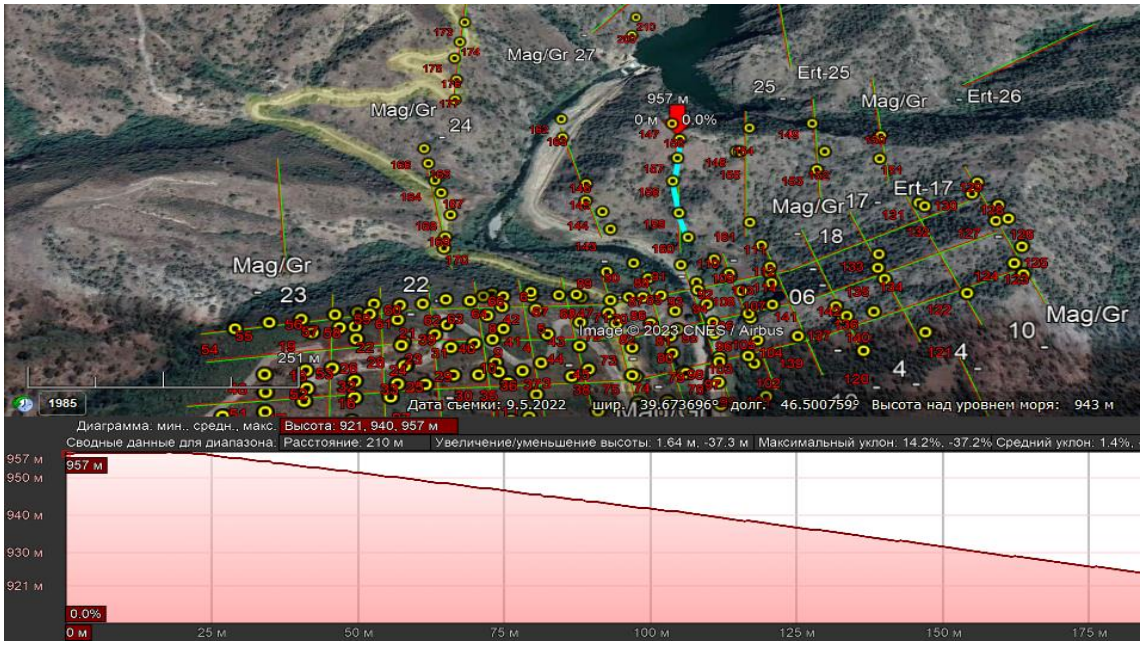


Figure 7. Cross-sectional diagram of profile III, where gravimetric observation points are located.

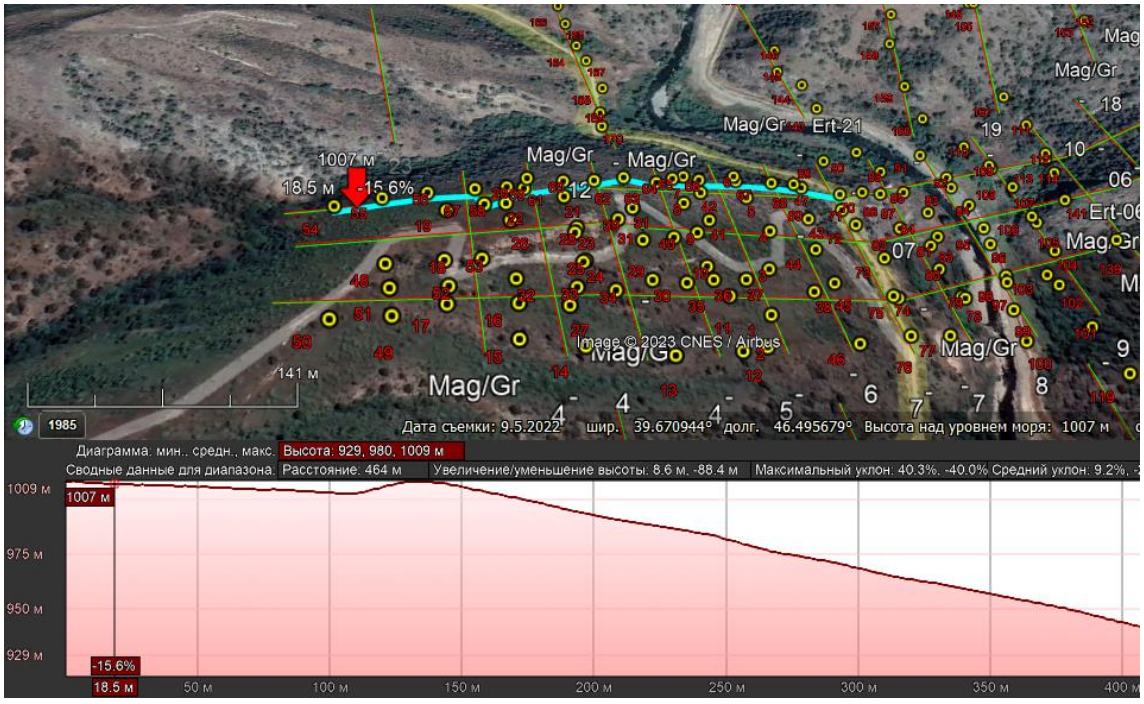


Figure 8. Relief cross-section scheme of profile III, where gravimetric observation points are located.

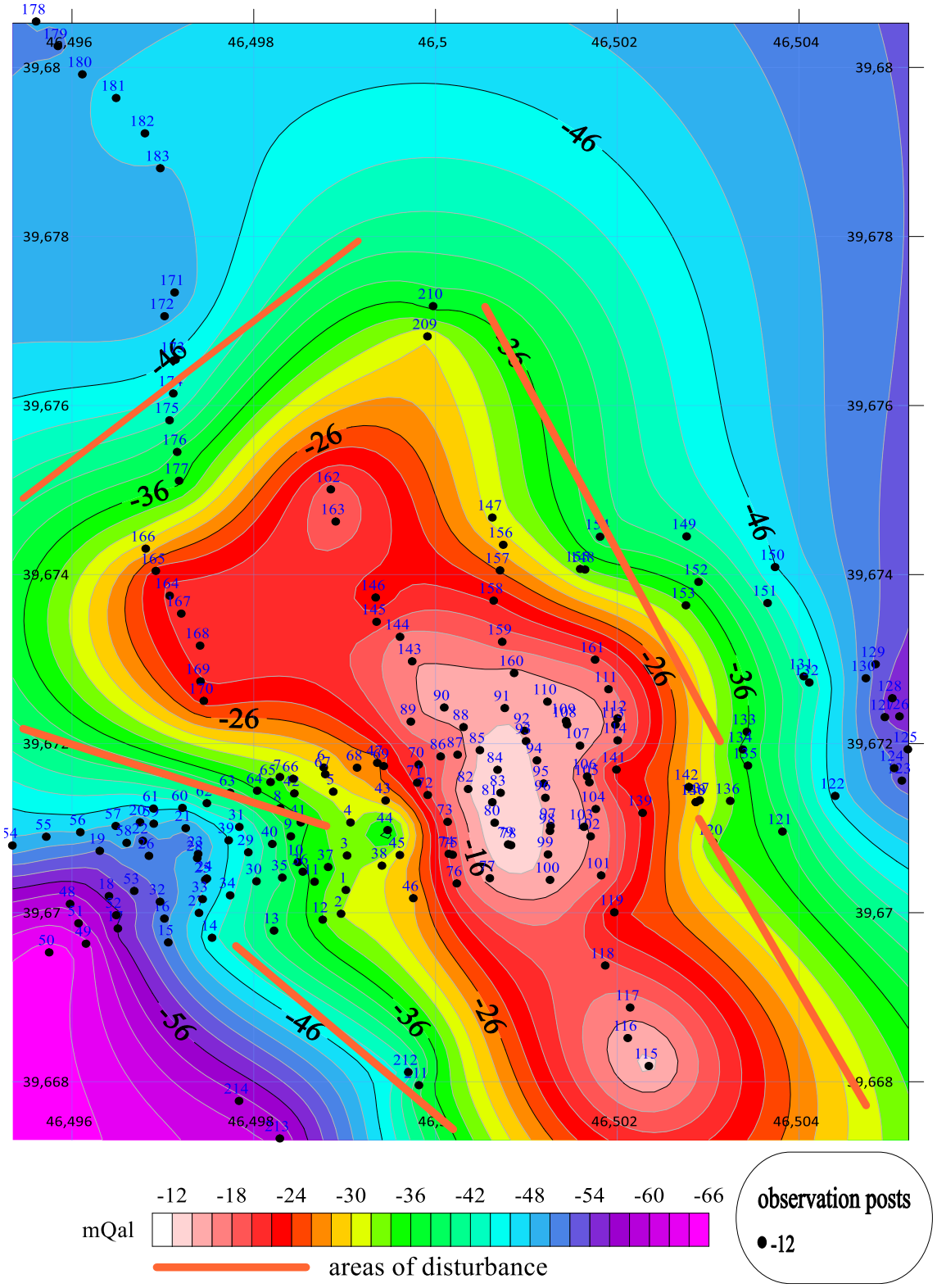


Figure 9. General iso-anomalies map of the gravity field reflecting the stress-strain state in the reservoir area on the Hakari River.

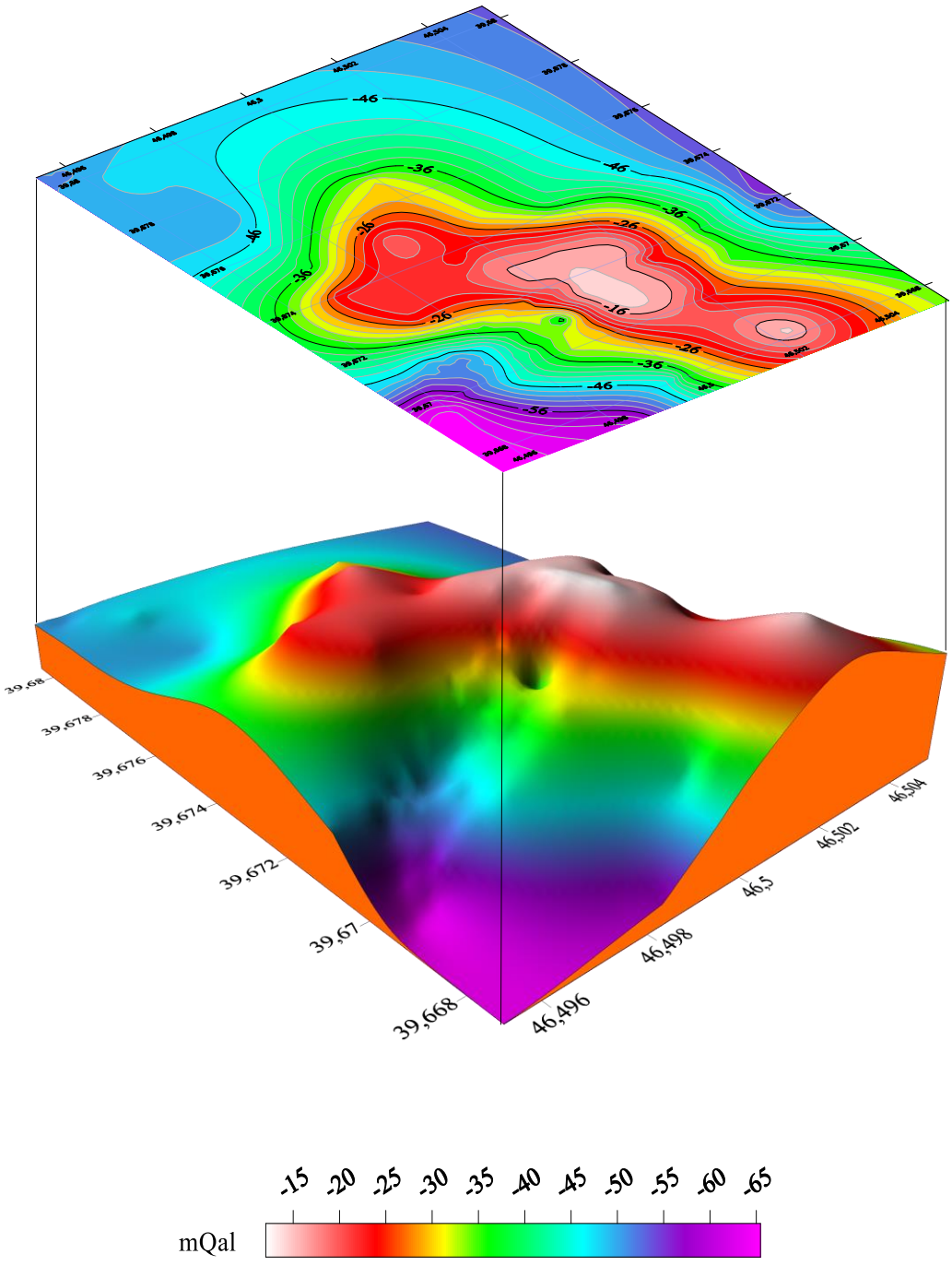


Figure 10. A 3D model showing the stress-strain state of the reservoir area on the Hakari River.

As can be seen from the isoanomalies maps of the gravity field, the anomalous areas accompanied by the variable value of the relative gravity force and the disturbance zones at their transition points have been determined. Thus, the relative gravity force in the center of the study area is completely closed from the north, partially closed from the south, and spreads from the sides to the center with an increasing value, varying from -26,066 mgal to -11,866 mgal, and there is a local anomaly in a stretched state. The surroundings of this anomaly are open in all three directions, varying from -32,031 mgal to -65,164 mgal, accompanied by decreasing values spreading towards the northwest, northeast, and southwest. Such anomalies of the area's gravity field provide information that the research area has a complex geological structure and that there are rock masses of different densities. If we pay attention to the 3D model of the stress-deformation state of the

geological environment based on the data of the gravity field corresponding to the reservoir area on the Hakari River, the results of the above-mentioned interpretation can be seen more accurately (Fig. 10.).

Conclusion

1. Using the gravimetric method, the geodynamic regime of the area where construction works will be carried out in the area where a water reservoir will be created on the Hekari River was evaluated, the tension dynamics of the gravity field was studied, and the fault zones were determined at the gradient crossing points of the detected anomalous gravity fields.

2. Based on the observations made in the research area, the possibility of the risk of anomalous areas and failure zones accompanied by the gradient increase and decrease of stress in local areas in 2D isoanomalous maps of Δg and 3D models reflecting the stress-deformation state of the geological environment is not assumed.

3. In the area, geological disturbances were monitored at different depth intervals, and the geodynamic regime was evaluated. It has been shown that there are no anomalous gradient dynamics in the area where the Hekari water reservoir will be built in Lachin region, and there are currently no areas prone to subsidence, landslides, or landslides in the areas where the water reservoir will be created.

References

1. Boulanger Yu.D. Study of non-tidal changes in gravity acceleration. Sat. scientific works. Repeated gravimetric observations Moscow, ed. “Petrogeophysics”, 1978, pp., 10-17
2. Nemtsov L. D. Methods and technology of high-precision gravimetric work. High-precision gravity survey, M., ed. “Nedra”, 1967, pp. 46-57
3. Sagaitov M.U. Lunar gravimetry, M., ed. “The Subsoil”, 1979, 180 pp.
4. Sorokin L.V. Gravimetry and gravimetric exploration, M., L. “Gostoptekhizdat”, 1953, 483 pp.
5. Uspensky D.G. Gravity exploration, M., ed. “Nedra”., 1968, 331s
6. Fedynsky V.V. Exploration geophysics. M., ed. “Nedra”, 1967, 662s.

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MODERN SEISMOGEODYNAMICS OF TURKEY, NORTHERN IRAN AND CAUCASUS REGION

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ABSTRACT

Large transverse fault zones divide the Alpine-Himalayan belt into several segments. The entire Arabian-Iranian segment and parts of two neighboring segments fall within the region under consideration: the Adria-Aegean and the Pamir-Himalayan. The structure of the segments has similar features. In 2023, an increase in seismic activity was observed on the territory of the Anatolian plate, the Iranian block and the Caucasus region: 04/18/2021 southern İran M=5.8; 01/11/2022 Cyprus region M=6.6; 10/05/2022 north-western İran M=5.6; 11/23/2022 western Turkey M=6.7; 02/06/2023 central Turkey M=7.9, 7.4; 07/03/2023 Caspian Sea, offshore azerbaijan M=5.6; 12/07/2023 Caspian Sea, offshore Azerbaijan M=5.6. This article analyzes seismic activity for the period 2020-2023, mechanisms of earthquake foci, tectonics, as well as data obtained at GPS stations. The features of the geodynamic regime of each region under study, the types of tectonic movements, fault tectonics and the values of the velocities of horizontal movements of tectonic blocks have been established. Analysis of the velocity field of GPS stations showed the heterogeneity of deformation processes in the region of the Eastern Mediterranean and the Caucasus. The considered results show the movement of the Arabian plate relative to the Eurasian plate. Considering the speed of movement of the Anatolian and Eurasian plates, and the Arabian and Anatolian plates, it was established that for the East Anatolian - 14 mm/year. This indicates the convergence of the Anatolian and Eurasian plates through a system of dextral strike-slip faults in eastern Turkey and a thrust system in the Caucasus. The total reduction in distance between the Lesser and Greater Caucasus is 10 mm/year. A study of the North Anatolian essentially right-lateral strike-slip active zone showed that seismogenic movements during modern and historical earthquakes, as a rule, retain the predominance of right-slip displacements, but at the same time have a larger vertical component than the total Quaternary displacement in this zone. For the region of the Arabian-Caucasian junction, a recalculation of movement vectors relative to the fixed northern part of the Arabian Plate was performed. It showed small movements of points of the adjacent part of the Anatolian plate to the southwest, and the speeds of movement, not exceeding 4-8 mm/year immediately near the East Anatolian fault zone, increase to the northwest to 8-12 mm/year, while points located south of the East Anatolian zone and west of its junction with the Levantine zone, they moved in southern directions at speeds of 4-5 mm/year.

Key words: GPS stations, Anatolian plate, Alpine-Mediterranean belt, East Anatolian fault.

TÜRKİYƏ, ŞİMALİ İRAN VƏ QAFQAZ BÖLGƏSİNİN MÜASİR SEYSMİK GEODİNAMİKASI

Kazımov İ.E., Kazımova A.F.

XÜLASƏ

Məqalədə tədqiq olunan əraziyə Ərəbistan-İran seqmenti və iki qonşu seqmentin hissələri daxildir: Adrio-Egey və Pamir-Himalay. Seqmentlərin strukturu oxşar xüsusiyyətlərə malikdir. Seysmikliyin təhlili göstərdi ki, 2023-cü ildə Anadolu plitəsi, İran bloku və Qafqaz regionu ərazisində seysmiklik aktivliyin artması müşahidə olunub: 18.04.2021 Cənubi İran M=5.8; 01/11/2022 Kipr regionu M=6,6; 10/05/2022 Şimalı-Qərbi

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

İran M=5,6; 23/11/2022 Qərbi Türkiyə M=6.7; 02/06/2023 Mərkəzi Türkiyə M=7,9, 7,4; 07/03/2023 Xəzər Dənizi, M=5,6; 12/07/2023 Xəzər Dənizi, M=5.6. Məqalədə 2020-2023-cü illər üçün zəlzələ ocaqlarının mexanizmləri, tektonikası, həmçinin GPS stansiyalarında əldə edilmiş məlumatlar təhlil edilir. Tədqiq olunan hər bir bölgənin geodinamik rejiminin xüsusiyyətləri, tektonik hərəkətlərin növləri, qırılma tektonikası və tektonik blokların üfüqi hərəkətlərinin sürətlərinin qiymətləri müəyyən edilmişdir. GPS stansiyalarının sürətlərin paylanma təhlili Şərqi Aralıq dənizi və Qafqaz regionunda deformasiya proseslərinin qeyribircinsliyi göstərdi. Nəzərdən keçirilən nəticələr. Anadolu və Avrasiya plitələrinin, eləcə də Ərəbistan və Anadolu plitələrinin hərəkət sürətini nəzərə alsaq, Ərəb plitəsi Avrasiya plitəsinə nisbətən hərəkətini göstərir. Şərqi Anadolu Plitəsi üçün hərəkətlərin sürətləri - 14 mm/il olaraq təyin edilmişdir. Bu, Anadolu və Avrasiya plitələrinin Türkiyənin şərqində yerdəyişmə qırılmalar sistemi və Qafqazda ustəgəlmə qırılmalar sistemi vasitəsilə yaxınlaşmasını göstərir. Kiçik və Böyük Qafqaz arasında məsafənin ümumi azalmasının sürəti 10 mm/il təşkil edir. Şimali Anadolu sağ tərəfli yerdəyişmə aktiv zonasının tədqiqi göstərdi ki, müasir və tarixi zəlzələlər zamanı seysmogen hərəkətlər, bir qayda olaraq, sağa doğru sürüşmələrinin üstünlüyünü saxlayır, lakin eyni zamanda böyük şaquli komponentə malikdir. Ərəb-Qafqaz qovşağının regionu üçün Ərəb plitəsinin sabit şimal hissəsinə nisbətən horizontal hərəkətlərin vektorları yenidən hesablanmışdır. Anadolu plitəsinin cənub-qərbə bitişik hissəsinin, birbaşa Şərqi Anadolu qırılma zonasının yaxınlığında yerdəyişmə giymətləri 4-8 mm/il-dən çox olmayan kiçik hərəkətlərini göstərdi. Şimal-qərbə 8-12 mm/il-ə qədər artım müşahidə olunur və Şərqi Anadolu qurşağından cənubda və onun Levantin zonası ilə birləşməsindən qərbdə yerləşən GPS stansiyaların məlumatlar əsasın 4-5 mm/il sürətlə cənub istiqamətlərində hərəkət edir.

Açar sözlər: GPS stansiyaları, Anadolu plitəsi, Alp-Aralıq dənizi qurşağı, Şərqi Anadolu qırılması.

СОВРЕМЕННАЯ СЕЙСМОГЕОДИНАМИКА ТУРЦИИ, СЕВЕРНОГО ИРАНА И КАВКАЗСКОГО РЕГИОНА

Казимов И.Э., Казимова А.Ф.

АННОТАЦИЯ

В состав рассматриваемого региона входят Иранский блок и части двух соседних сегментов: Адрио-Эгейского и Памиро-Гималайского. Строение сегментов имеет схожие особенности. В 2023 г. повышение сейсмической активности наблюдалось на территории Анатолийской плиты, Иранского блока и Кавказского региона где произошли такие землетрясения как: 18.04.2021 южный Иран с магнитудой M=5,8; 11.01.2022 Кипр M=6,6; 05.10.2022 северо-западный Иран M=5,6; 23.11.2022 западная Турция M=6,7; 06.02.2023 центральная Турция M=7,9, 7,4; 03.07.2023 Каспийское море, Азербайджана M=5,6; 07.12.2023 Каспийское море, M=5,6 и т.д.. В данной статье анализируется сейсмическая активность за период 2020-2023 гг., механизмы очагов землетрясений, тектоника, а также данные, полученные на GPS-станциях РЦСС. Установлены особенности геодинамического режима каждого исследуемого региона, типы тектонических движений, разломная тектоника и значения скоростей горизонтальных движений тектонических блоков. Анализ поля скоростей GPS-станций показал неоднородность деформационных процессов в районе Восточного Средиземноморья и Кавказа. Рассмотренные результаты показывают движение Аравийской плиты относительно Евразийской плиты. Учитывая скорость движения Анатолийской и Евразийской плит, а также Аравийской и Анатолийской плит, установлено, что для Восточно-Анатолийского разлома установлено движение 14 мм/год. Это указывает на сближение Анатолийской и Евразийской плит посредством системы право-сдвигов на востоке Турции и системы надвигов на Кавказе. Суммарное сокращение расстояния между Малым и Большим Кавказом составляет 10 мм/год. Исследование Северо-Анатолийской существенно право-сдвиговой активной зоны показало, что механизм землетрясений, как правило, сохраняет

преобладание сдвиговых смещений, но при этом имеют большую вертикальную составляющую. Для района Аравийско-Кавказского сочленения произведен перерасчет векторов горизонтальных движения. Он показал небольшие перемещения точек прилегающей части Анатолийской плиты на юго-запад, а скорости перемещения, не превышающие 4-8 мм/год непосредственно вблизи зоны Восточно-Анатолийского разлома, возрастающие к северо-западу до 8-12 мм/год, однако точки, расположенные южнее Восточно-Анатолийской зоны и западнее ее стыка с Левантийской зоной, перемещались в южных направлениях со скоростью 4-5 мм/год.

Ключевые слова: GPS станции, Анатолийская плита, Альпийско-Средиземноморский пояс, Восточно-Анатолийский разлом.

Introduction

The Alpine-Himalayan fold belt is divided into several segments: the Arabian-Iranian segment and parts of two neighboring segments, the Adria-Aegean and Pamir-Himalayan. Each segment is bounded from the west by a north-northeast-trending system of weakly curved active faults, which continues into the plates of the southern row and articulates with elements of the Indian Ocean rift system [26]. Such a boundary of the Adria-Aegean and Arabian-Iranian segments is the Levantine left-lateral strike-slip zone, which is built up to the northeast by the East Anatolian zone. In the south, the Levan zone meets the Red Sea rift. The modern boundary of the Arabian-Iranian and Pamir-Himalayan segments is formed by a system of left-lateral strike-slip faults, the largest of which are the Chaman fault and the Darvaz segment of the Darvaz-Alai zone. On the northeastern flank of the Lesser Caucasus Syntax and the northern protrusion of the Arabian Plate there are two active fault systems. The first system is formed by the Pambak and the Khanarasar right-lateral strike-slip zones, which branch off from it to the southeast, on the northeastern flank of the syntax, where the rate of late Quaternary shear is 4.5-5 mm/year. The vertical component is variable, inferior to the strike-slip component by 7-12 times, with the northeastern wing being uplifted more often [18, 24]. In the southeast, the Khanarasar fault is arched by the northwestern branches of the Tabriz fault. Merging, they bend to the east, and the reverse-thrust component increases. To the southeast of the Tabriz fault, in the rear of the Zagros, new faults are known, the Late Quaternary activity of which has been established only in individual segments. They are characterized by dextral strike-slip displacements, but in sections of the segments that bend to the east, the reverse-thrust component increases. The second fault system of the northeastern flank of the syntax corresponds to the modern boundary of the Arabian Plate. It is formed by the southeastern segment of the North Anatolian dextral shear zone with a Quaternary shear rate of about 9 mm/year [14]. Adjacent to it from the south is the Main Modern Zagros Fault, which is also predominantly right-shear. Its speed was determined on the Dorud segment of the fault to be 5-10 mm/year [17, 11]. The East Anatolian zone of northeast strike connects with the Pambak zone at an angle of only 17°. At the same time, up to the junction point, the first zone retains left-shear, and the second, right-slip types of movements with speeds of about 5 mm/year. On the northeastern flanks of the Arabian and Indian plates, convex to the southwest, in the foothills of the Zagros and Himalayas, these plates are gently subducted under the crustal structures of the belt, and in front of the thrust front, the thick sedimentary cover of the foredeep is torn off, where folds and thrusts develop, directly reflected in relief. [21]. Along with the boundaries of the syntaxes and the southern flanks of the Alpine-Himalayan belt, active faults are numerous both within the syntaxes and between them and to the north of them. On the northeastern flank of the belt, the boundaries of the segments are somewhat blurred, not being expressed by specific zones of transverse faults. However, even in such a blurred form they are quite obvious. Thus, the continuation of the border of the Adria-Aegean and Arabian-Iranian segments can be traced along the western edge of the Lesser Caucasus and to the north it separates the mountainous part of the Greater Caucasus from its northwestern pericline and the Black Sea depression. The continuation of the border of the Arabian-Iranian and Pamir-Himalayan segments corresponds to the western edge of the Tien Shan mountains.

Active faults of the Anatolian-Iranian segment

The active tectonics of the Arabian-Iranian segment of the Alpine-Himalayan belt shows a number of features common to the Pamir-Himalayan segment. These are, first of all, the above-mentioned directions of displacement on the frames of the Arabian Plate - along the Levant and East Anatolian zones, identical to the Chaman and Darvaz-Alay, and on the eastern segment of the North Anatolian zone, along the Main modern Zagros fault and its southern continuation, similar to Pamir-Karakoram fault. There are also many similarities in the active tectonics of the Zagros and the southern slopes and foothills of the Himalayas. At the same time, differences are also observed [10, 26]. One of them is that the East Anatolian and North Anatolian zones framing the Arabian Plate intersect near the village Karlova and continue to the northeast and northwest, respectively. At the intersection, they experience characteristic branches and bends, indicating long-term mutual displacements of the zones during repeated strike-slip movements. From the intersection, the North Anatolian zone runs northwest and then west for more than 1000 km along the entire Anatolia and consists of a number of faults, often located in echelon relative to each other. Feathering faults with signs of dextral strike-slip displacements extend from the zone to the southwest [2, 12, 13, 15]. Along the zone itself, numerous examples of Late Quaternary right-hand displacements of river and ravine valleys and other young landforms of tens and hundreds of meters are described; in this case, the vertical component of the displacements is variable and significantly inferior to the shear component, and in some places, it is absent [16, 26]. The average shear rate since the end of the Pliocene is estimated from displacements of large river valleys at 18-20 mm/year in the east of the zone and 13 mm/year in its central part. The data of A.Kiratsi, who calculated the speed of movement using the tensors of seismic moments of modern earthquakes, are close to this: it decreases from east to west from 27 to 16 mm/year. The rate of accumulation of modern shear deformation in the fault zone, determined in the 90s using GPS technology, is 26 mm/year [27]. Based on data from 24 GPS stations of the RSSC ANAS, data from the Iranian and Turkish centers, a map of vectors and velocities of horizontal movements within the study region was constructed (Fig. 1).

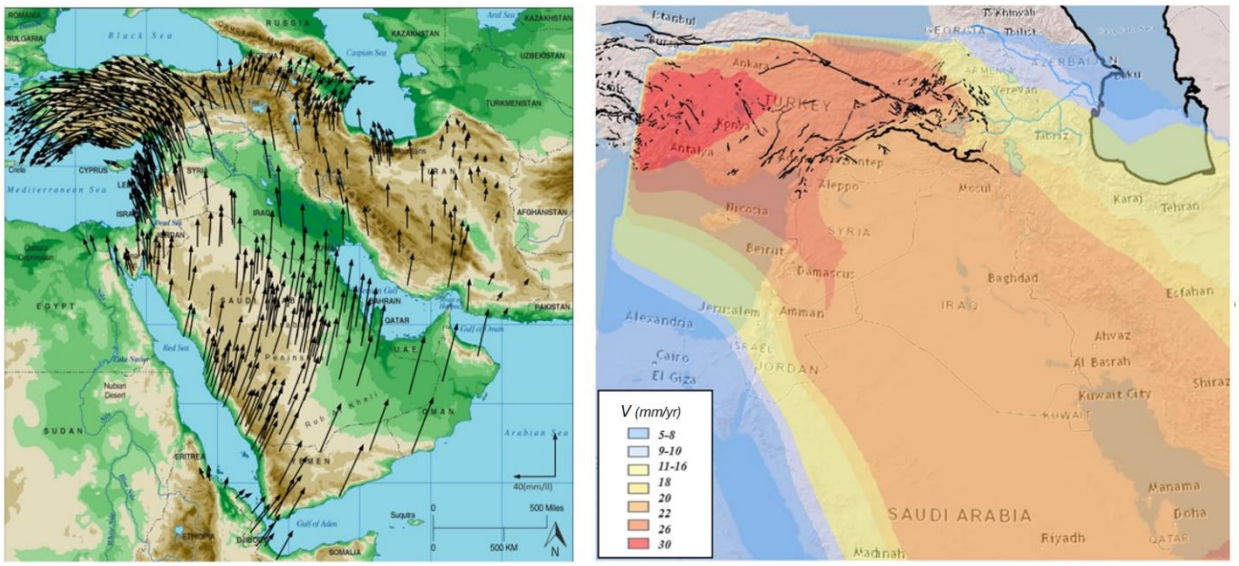


Figure 1. The directions of horizontal movements among the data of GPS stations installed in the territories of Turkey, Arabia, Iran and Azerbaijan (2014-2023)(a); velocities of horizontal movements of GPS stations calculated on the basis of data (2019-2023 years)[16,17]

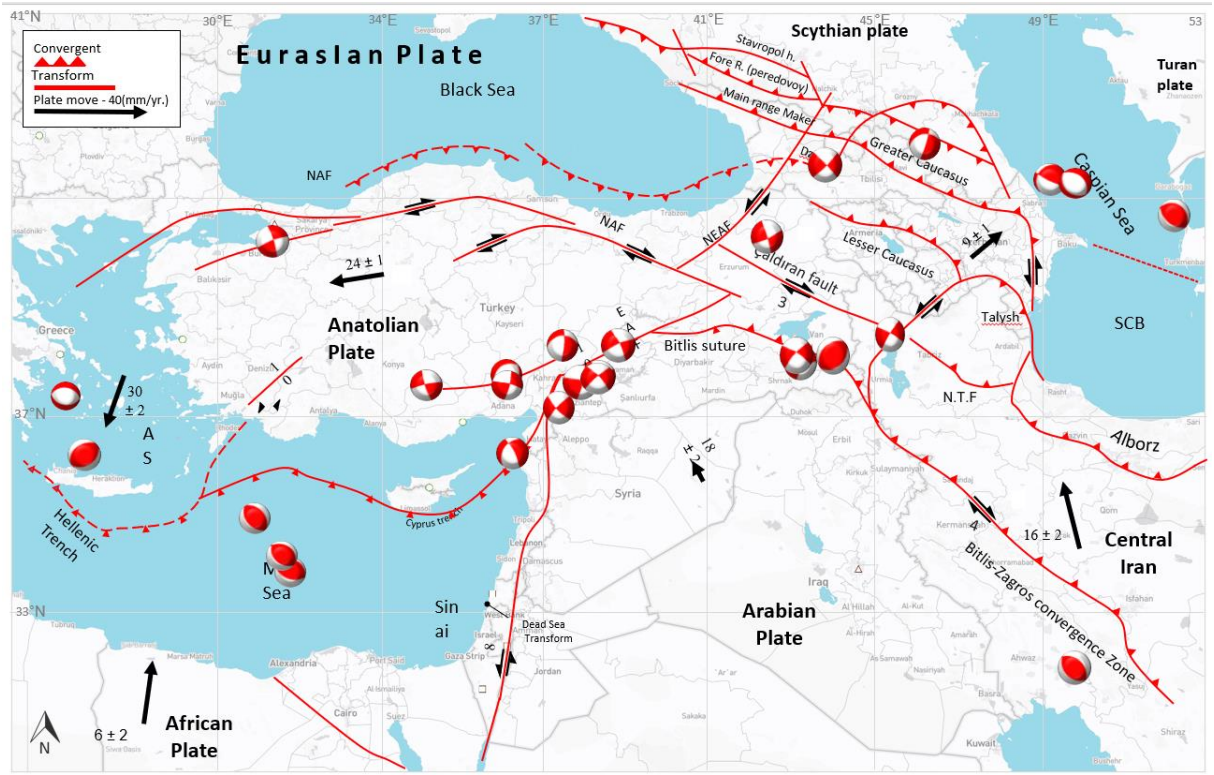


Figure 2. Map of source mechanisms of earthquakes (M>5.0) that occurred in the Eastern Mediterranean Sea and the Caucasus during 2022-2023 [16]

Later measurements and calculations [9, 6, 7] showed that the rate of deformation accumulation is approximately 24 mm/year, being dispersed in a strip up to 100 km wide. Of this value, the shear zone itself accounts for about 20 mm/year, and in its central part - no more than 15 mm/year, which coincides with the above geological estimates. The accumulated deformation is sometimes partially realized by creep, and to a greater extent is removed by impulse movements during strong earthquakes. The East Anatolian zone north of the intersection with the North Anatolian zone is represented by two branches. The western branch, identified by some researchers [14] as the North-Eastern Anatolian zone, is formed by echeloned faults of the south-eastern sides of the Chat and Erzurum depressions, the Dumlu fault and faults near the village Narman and the city of Oltu. Along them, signs of late Quaternary reverse fault movements are noted, and along the Dumlu fault, left-lateral strike-slip displacements of young relief forms are discovered, many times greater than the reverse fault component. The faults can be traced to the city of Akhalkalaki in Southern Georgia, where they are replaced en echelon by the newest Kazbek-Tskhinvali fault, described by E.E.Milanovsky. The main eastern branch of the East Anatolian zone first extends parallel to the western one, and to the northeast it deviates more and more to the east. The fault plane is steeply (50-60°) inclined to the northwest (Fig. 2). Signs of left-lateral strike-slip movements are noted in different parts of the described branch, but are most pronounced at its northeastern end, where their speed is estimated at 4-5 mm/year. It is this branch that articulates in the northeast with the mentioned Pambak-Sevan right reverse fault-slip fault, forming together with it and the Khanarasar and Akerin right fault movements that continue it to the southeast the North Armenian arc of active faults, in which the northern wings are upthrown almost everywhere, and the strike-slip component displacements, close to 5 mm/year, are many times greater than the reverse fault.

Embedded in the described outer arc is a second, inner, arc of active faults, more steeply curved and touching the outer arc at its apex. The internal arc is represented by the Akhuryan fault of northeastern strike and the Garni fault zone of northwest strike. Interpretation of detailed satellite images of the Turkish part of the Akhuryan fault gives reason to assume left-lateral strike-slip displacements of small river and ravine

valleys. Vertical displacements are indicated by the graben-like structure of the fault zone in the area of the Akhuryan reservoir. The Garni zone consists of several segments of northwest and north-northwest strikes, located en echelon relative to each other in such a way that each more southern segment begins east of the previous one [26].

The faults of the Talysh Mountains have the shape of a Z-shaped bundle in plan, in the center of which the faults are close together and extend almost meridionally along the Caspian coast, and in the north and south they deviate to the northwest and southeast, gradually moving away from one another. In the north, the faults of the bundle form the front of the arc and are conjugate with the Araz zone, and in the south, they are connected with the active faults of Western Elburz. Young reverse fault displacements, possibly with a dextral strike-slip component, have been identified along the Talysh faults. As a rule, the western wings are raised. The Araz zone of young disturbances is part of the Palmyr-Absheron lineament, individual segments of which experienced late Quaternary activation. One of them is the Central Palmir fault, adjacent in the southwest to the active compressed folds and reverse faults of the Damascus region, feathering the Levant fault zone.

Signs of mid- and late-Quaternary movements were also noted along some folded reverse faults and thrusts of the Palmyrids, as well as along grabens and normal faults that flank the Central-Palmyr fault [26]. The Araz segment of the Palmyr-Absheron lineament, which forms the northwestern flank of the Talysh arc, is expressed on the earth's surface by relatively short ledges of terraces and slopes of the Araz River valley.

Active tectonics of Azerbaijan

Most of the active thrusts and reverse faults on the southern slope and southern foothills of the Greater Caucasus extend west-northwest parallel to the axis of the mountain structure. But along some faults deviating to the northwest from this direction, young right-lateral strike-slip displacements were discovered. They are clearly represented in the zone of the Salyan-Lengibiz (Adzhichay) right reverse fault-slip fault on the southern slope of the South-Eastern Caucasus, the average rate of movement along which has reached 1 mm/year since the end of the Pleistocene. The right reverse fault-slip faults of the southern slope continue to the southeast into the waters of the Southern Caspian Sea. The directions of young displacements along the faults of the southern slope and southern foothills of the Greater Caucasus reflect the conditions of submeridional or north-northeast horizontal compression and shortening. This is not contradicted by the appearance of non-extended left-lateral strike-slip faults of northeastern strike along the continuation of the Palmyr-Absheron lineament and normal faults of north-northeast orientation in Southern Dagestan. An example of the latter is the Kaflan-Kapinsky fault, the rate of Late Pleistocene movements along which reaches 1 mm/year. The main thrust (in the newest structure, a reverse fault) separates the southern slope from the Greater Caucasus proper. On its northern slopes and foothills, the speed of late Quaternary movements is less than in the zone of the southern slope, but active disturbances of the same two main directions predominate: firstly, latitudinal and west-northwest and, secondly, northwestern. The first direction in Dagestan is represented by a series of reverse faults inclined to the south, less often to the north. In Chechnya, this includes the Montenegrin flexure, which apparently corresponds to a consolidated basement fault under a thick sedimentary cover. In the west, the flexure is en echelon substituted by the Vladikavkaz and Baltic faults located to the south, which are associated with asymmetric anticlines with steep southern wings [19, 22, 25]. Changes in terrace heights at the end of the Late Pleistocene indicate movement rates of 1-2 mm/year. Lower rates of movement characterize similar faults and flexures in the Central Caucasus. The northwestern structural direction is often represented by deep zones of active disturbances, expressed on the surface only by indirect signs. These are the tectonic disturbances of the Caspian coast between Makhachkala and Derbent, the Gudermes and Nazran fault zones in Chechnya, the Lysogorsk flexure and the Nalchik (Armavir-Nevinnomysk) fault zone in the Central Caucasus.

Active tectonics of Central Iran and Alborz

The active tectonics of Central Iran and Alborz is determined by movements along faults extending, firstly, to the east or east-northeast and, secondly, to the north or north-northwest. Catastrophic earthquakes have occurred repeatedly in this region (Fig. 3). In the north of the region, sublatitudinal active disturbances

predominate. They are widely represented in Alborz and on both of its slopes, where they are characterized by reverse displacements [20]. However, in the Rudbar earthquake of June 20, 1990, with a magnitude of 7.2, a slip of up to 1 m occurred along the Elbursa longitudinal fault with a predominant left-lateral strike-slip displacement component, and determination of the focal mechanism showed almost pure left-lateral strike-slip. This prompted us to conduct an additional study of sublatitudinal active faults in the southern foothills of Elburz in 1996. As a result, an echeloned series of faults was identified, which, along with the reverse fault, have a significant and in some places predominant left-lateral strike-slip component of displacements [26]. In the west of this row there is a rock-cut Ipak fault zone with a length of about 100 km.

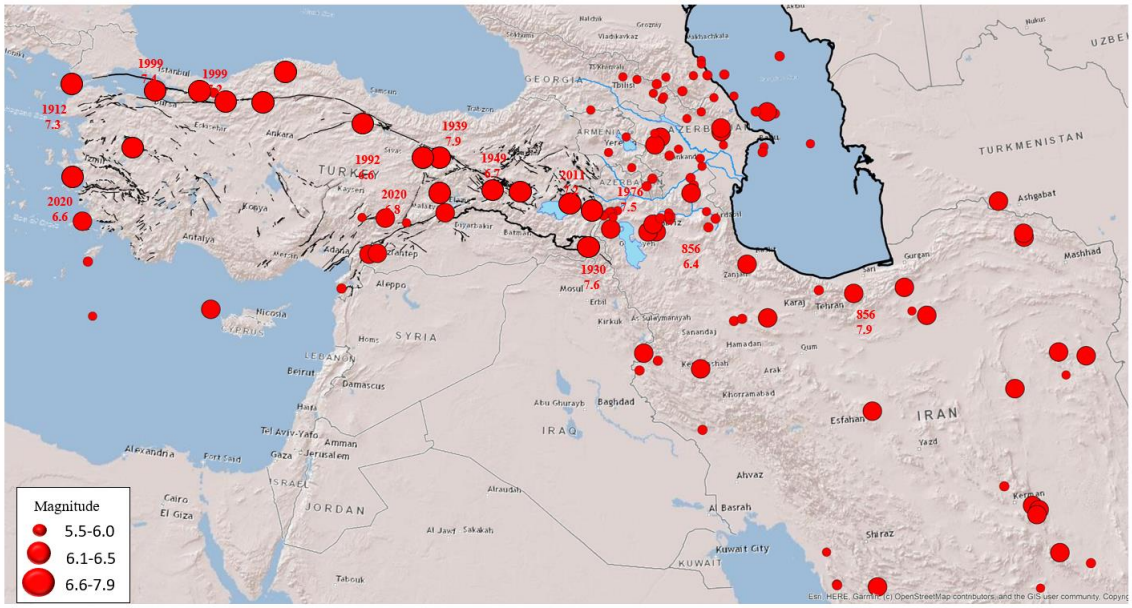


Figure 3. Map of epicenters of catastrophic earthquakes in Turkey, Iran and the Caucasus (years 427-2023 ml>5.5) (The coordinates of earthquakes in Turkey and Iran are taken from the EMSC website)

Left-lateral strike-slip displacements have been identified that significantly exceed the reverse component. The displacement of the fan at the beginning of the Late Pleistocene allows us to estimate the rate of displacement at 0.5–1.5 mm/year. Quaternary and locally late Quaternary reverse and thrust displacements are evident along the North Tehran fault. However, on the northern edge of Tehran near Shahid Beheshti University, along the rejuvenated segment of the fault, it can be assumed that there is a left displacement of 100-200 m in the valley of the Darakeh River. The North Tehran fault adjoins the Mosha fault in the east, which extends for 175 km in the east-southeast direction. Usually its northern wing is raised (thrown up and occasionally pushed down). At the same time, there are numerous signs of left-lateral shift movements. The speed of the Holocene shift is at least 2-2.5 mm/year, and the total average speed of reverse-slip movements is more than 3 mm/year. A possible eastern continuation of the described system of left reverse faults and strike-slip faults is an active fault of east-northeast strike, along which N.Wellman, who called it Shahrudsky, deciphered the left displacements of watercourses on aerial photographs. The same type of displacements has been established along the Dasht-Bayaz fault in eastern Iran [12]. A more complex nature of young displacements was revealed along the 700-kilometer Bolynekevir (Doruneh) fault located between the Shahrud and Dasht-Bayaz faults. It forms a gentle arc convex to the north, which in the more extended western part extends to the east-northeast, and in the eastern part - to the east-southeast. Essentially, the relationship between segments with different shear directions is the same as between the East Anatolian and Pambak-Sevan faults, and also reflects submeridional shortening, which may be associated in this case with the northern drift of the Lut massif, caused by the influence of the Oman small syntax (Fig. 4). The faults of the second, submeridional,

system frame the Lut depression from the west and east. On the western frame these are the Kuh-Benan, Ravar, Naibend and Kalmard faults.

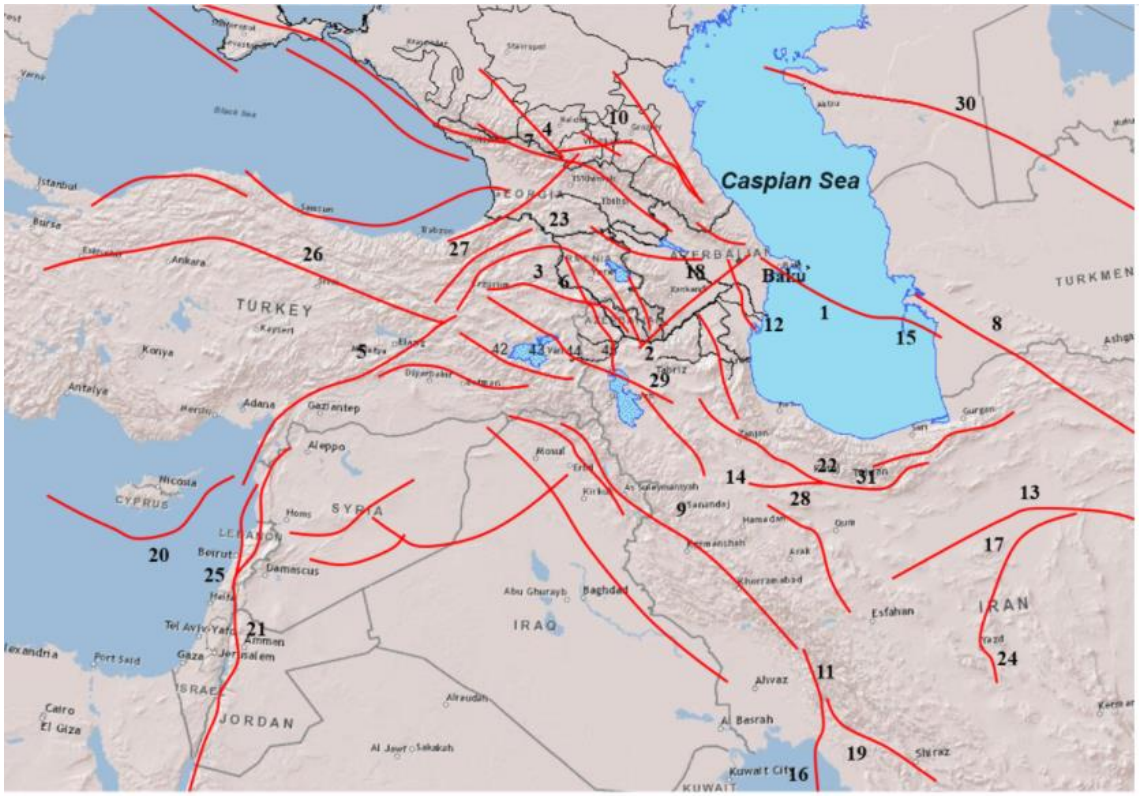


Figure 4. Active faults in the Arabian-Eurasian and Indian-Eurasian collision region. The faults (f.) and fault zones (f.z.), discussed in the text are marked by numerals: 1 - Apsheron Threshald f.z., 2 - Araz f.z., 3 - Akhurian f., 4 - Vladicaucas f., 5 - East Anatolian f.z., 6 - Garni f.z., 7 - Main Caucasus f., 8 - Main Copet Dagh f., 9 - Main Recent f. of Zagros, 10 - Gudermes f.z., 11 - Dena f.z., 12 - Main Dzhungarian f., 13 - Doruneh (Great Kavir) f., 14 - Ipak f.z., 15 - Isak-Cheleken f.z., 16 - Kazemn-Borazjan f.z., 17 - Kalmard f., 18 - Karamarian f., 19 - Kareh Bas f.z., 20 - Cyprus trench f.z., 21 - Levant f.z., 22 - Lepsy f., 23 - Pambak-Sevan f., 24 - Ravar f., 25 - Roum f., 26 - North Anatolian f.z., 27 - Northwestern Anatolian f.z., 28 - North Tehran f., 29 - Tabriz f., 30 - Central Ustiurt f., 31 - Shahrud f.[13,16,18]

The strikes vary from north-northwest and meridional in the south to north-northeast in the north. Regardless of the change in strikes along the faults, dextral displacements of young relief forms occur everywhere, which are accompanied by a fault or, more often, a reverse fault component. Right-lateral strike-slip displacements were also revealed in the zone of the meridional Jabbar fault, which intersects the eastern part of the Dasht-Bayaz fault. Young vertical displacements were noted on the eastern frame of the Lut depression. The nature of the Late Quaternary displacements along the faults of Central Iran indicates the northeastern direction of maximum shortening of the earth's crust, which coincides with the direction of compression at the sources of most strong earthquakes in the region [10]. Active faults are distributed unevenly, limiting more or less large blocks. However, the presence of such blocks does not significantly distort the uniformity of the dynamic picture, similar to that one. which is reconstructed above for the territory of Central Asia north of Tibet. In Northern Iran, the dynamic situation of rupture formation is different: the northern drift of the Lut massif led to the formation of the newest structural arc of Aladag-Binalud and the Turkmen-Khorasan Mountains in general. Young reverse and thrust displacements have been recorded along the longitudinal faults of the arc. In general, the width of the belt of intense active tectogenesis in the Caucasian-Arabian segment of the Alpine-Himalayan belt is significantly less than in the Pamir-Himalayan belt [5].

Analysis of modern tectonic deformations.

Calculations of deformation fields in the earth's crust based on data on active faults are based on the assumption that displacements along faults are not only the result of tectonic deformation, but also themselves contribute to the magnitude of this deformation, to some extent determining its nature. The magnitude of displacements along active faults varies widely: from micromovements (creep, creep) during continuous tectonic deformation to large discrete movements during strong and catastrophic earthquakes. In large spatiotemporal volumes, these displacements can be formally considered as a process of quasi-plastic deformation (tectonic flow). If these volumes contain a large number of fragments of active faults, they can be considered as macroparticles of a continuous medium. In order to analyze the dynamics of seismicity for 2020-2023. Maps of earthquake epicenters in the studied region were constructed (Fig. 5). As can be seen in the figures, throughout all the years, the most active areas were the areas of the East Anatolian Fault, the Zagros zone, the boundary of the Arabian Plate and the Iranian block, as well as the central part of the Caspian Sea. The map of earthquake epicenters for 2022 shows that the epicenters along the East Anatolian Fault continue in Armenia, Georgia and Dagestan. Maximum activity was noted in 2023, as a result of aftershock activity after the catastrophic Turkish earthquake that occurred on February 6, 2023 with a magnitude of 7.4-7.8.

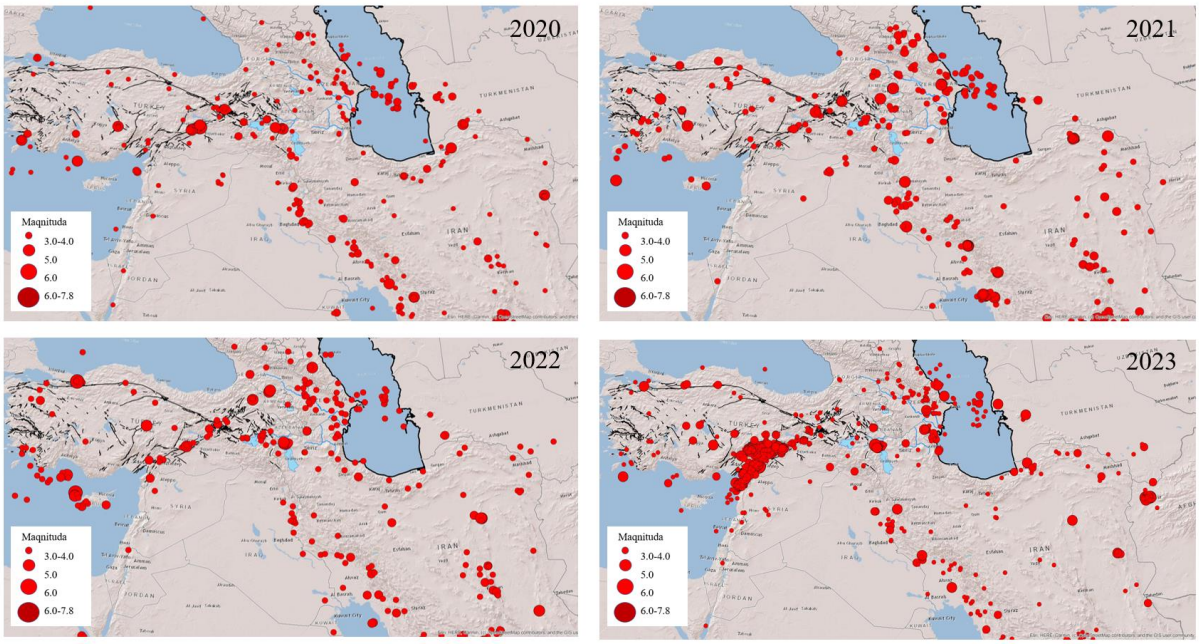


Figure 5. Map of epicenters of earthquakes in Turkey, Iran and the Caucasus during 2020-2023. (M>3.0)

Using data from GPS stations using the GAMIT/GLOBK program [3, 4, 8], the directions and magnitudes of the main modern tectonic deformations were calculated, calculated from data on active faults at the minimum, most probable and maximum values of their parameters. The features of their distribution are as follows. Based on these data, a map of crustal deformations was constructed (Fig. 6). The axes of maximum shortening are subhorizontal throughout almost the entire region and are oriented mainly in the north-south direction. This supports the idea that the main source of modern deformation in the region is the movement and pressure of the Arabian and Indian plates. Deviations from this pattern are observed to the east and west of the Arabian and Punjab syntaxes and near the northeastern flank of the Indian plate, and they are most significant in the eastern part of Tibet and its eastern frame, in Yunnan, the Eastern Sayan Mountains, Quetta, Northern Anatolia and near the northern parts of the Aral Sea. These deviations are associated with the reorientation of deformations on the flanks of the southern plates and the peculiarities of their transformation in local zones. In rare cases, local shortening is almost vertical. This is found in some parts of Tibet, near lake.

Khubsugol in Northern Mongolia, in the east of the Aral Sea, in the Lut region and on the northern slope of the Ciscaucasia foredeep.

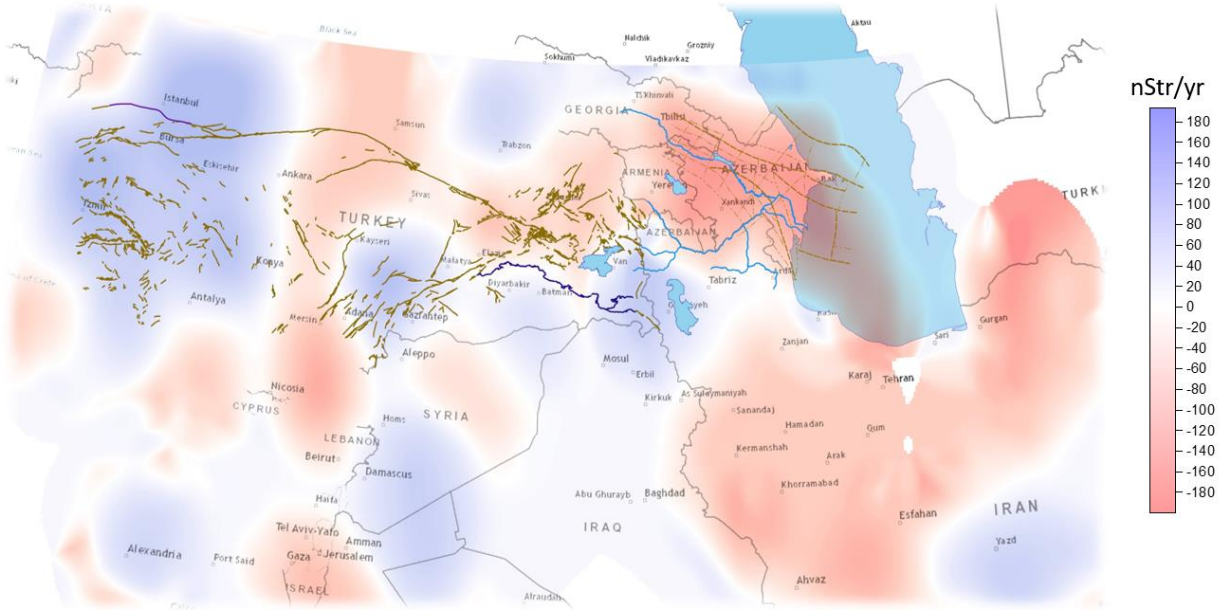


Figure 6. Distribution map of deformation coefficient calculated on the basis of GPS data in 2022-2023

The axes of maximum elongation often extend in the west-east direction and deviate from this general direction in areas of orientation deviations. The axes are subhorizontal on 60-70% of the territory. The subhorizontal orientation of both axes, indicating strike-slip tectonics, prevails throughout the area. And this confirms our earlier conclusion about the leading role of strike-slip faults as the most energy-efficient (compared to normal faults and, especially, reverse faults and thrusts) method of tectonic movement of continental crustal masses [1]. At the same time, subvertical orientation of the axis is more common than the axle. This is typical for areas of intense young thrusting and folding: the Himalayas, Western and Eastern Tien Shan, a significant part of the Sayans, Baluchistan, Makran, Elborz, the Cyprus Arc and partly the Greater Caucasus. For example, under conditions when, in the field of elastic deformation, the greatest shortening is subhorizontal (for example, submeridional), and the elongation is vertical, a sublatitudinal thrust should arise in a homogeneous medium. But, if the environment is disturbed by a fault zone with a northwestern strike, the resulting elastic deformation will be removed precisely along this weakened zone by right-lateral strike-slip movement. Formally, this will mean that the greatest shortening will remain submeridional, and the greatest elongation will become sublatitudinal, exchanging places with the intermediate deformation axis. This deformation is observed within the Main Caucasus thrust.

Conclusion

Analysis of the velocity field of GPS stations showed the heterogeneity of deformation processes in the region of the Eastern Mediterranean and the Caucasus. The considered results show the movement of the Arabian plate relative to the Eurasian plate. Considering the speed of movement of the Anatolian and Eurasian plates, and the Arabian and Anatolian plates, it was established that for the East Anatolian - 20 mm/year. This indicates the convergence of the Anatolian and Eurasian plates through a system of dextral strike-slip faults in eastern Turkey and a thrust system in the Caucasus. The total reduction in distance between the Lesser and Greater Caucasus is 10 mm/year. A study of the North Anatolian essentially right-lateral strike-slip active zone showed that seismogenic movements during modern and historical earthquakes, as a rule, retain the predominance of right-slip displacements, but at the same time have a larger vertical component than the total Quaternary displacement in this zone. In the Erzincan segment of the North Anatolian zone, the total

seismogenic movement during the last seismic cycle turned out to be even greater than that which follows from the average rate of Quaternary movements, and this increase is due to the vertical component of movements, probably due to the action of the mentioned local processes.

For the region of the Arabian-Caucasian junction, a recalculation of movement vectors relative to the fixed northern part of the Arabian Plate was performed. It showed small movements of points of the adjacent part of the Anatolian plate to the southwest, and the speeds of movement, not exceeding 4-8 mm/year immediately near the East Anatolian fault zone, increase to the northwest to 8-12 mm/year, while points located south of the East Anatolian zone and west of its junction with the Levantine zone, they moved in southern directions at speeds of 4-5 mm/year.

In the Central Iranian block and the Caucasian block, clockwise movement was noted with an azimuth rotation from 350 to 90 degrees. The tectonics of Iran is dominated by the collision of the Arabian and Eurasian plates. The speed of plate movement was estimated at 22 mm/g. During these movements, the Zagros crust is shortened by about 9±2 mm/year in the north-south direction. According to modern GPS measurements, the Western Zagros with a speed of ~10±2 mm/year in the direction of 12±8° north-northwest, the central Zagros - 14-18 mm/year, and the Eastern Zagros with approximately twice the speed (~20 ±2 mm/year) in the direction 7±5° north–northeast. The difference in crush rates is most likely due to a significant proportion of strike-slip deformation along the Modern Main Fault MRF in the Northwestern Zagros. The overall transverse shortening of the upper part of the earth's crust in the Alpine-Himalayan belt is 3±1 cm/year within the Tien Shan-Pamir-Himalayan segment and 2±1 cm/year within the Caucasian-Arabian segment (taking into account the minimum and maximum values speeds).

An analysis of the mechanisms of earthquake foci showed that normal faults mainly predominate in the western part of Turkey, normal faults prevail in the central part, and a small part in the northeast of the country is characterized by reverse faults. Along the Zagros fold-and-thrust belt, earthquake focal mechanisms are observed in the form of thrusts (reverse faults) and reverse faults. In northern Iran, near the Elborz Mountains, there are numerous strike-slip and left-lateral strike-slip faults located south of the Caspian Sea. The territory of the Caucasus region is characterized by reverse faults and thrusts.

References

1. Babayev G., Yetirmishli G., Kazimova S., Kadirov F., Telesca L. Stress field pattern in the Northeastern part of Azerbaijan // Pure and Applied Geophysics, on-line, 201
2. Bingol E. Geological map of Turkey. Scale 1:2000000. Ankara: MTA, 1989.
3. Chavet X., Valette J., Feissel) Vernier M. Analysis of Geo" center Time Series derived from SLR, GPS, DORIS. Am. Geophys. Union. Fall Meeting, 8–12 Dec, San Fran" cisco. 2003. P. 1–4.
4. Herring T.A. GLOBK: Global Kalman filter VLBI and GPS analysis program version 4.1. Cambridge, MA: Massachu setts Institute of Technology. 2004
5. Kangarli T.N., Kadirov F.A., Yetirmishli G.J., Aliyev F.A., Kazimova S.E., Aliyev A.M., et al. Recent geodynamics, active faults and earthquake focal mechanisms of the zone of pseudosubduction interaction between the Northern and Southern Caucasus microplates in the southern slope of the Greater Caucasus (Azerbaijan) // Geodynamics & Tectonophysics. – 2018. – T. 9, № 4. – P. 1099–1126.
6. Kazimov I.E. Geodynamics of the territory of Azerbaijan on the basıs of GPS data in 2017–2019 yy // Геология и Геофизика Юга России. – 2021. – Т. 11, № 2. – С. 51–61. doi:10.46698/VNC.2021.47.92.004. EDN: WTROIW
7. Kazimov I.E., Kazimova A.F. Modern geodynamics of Azerbaijan on GPS station data for 2017-2018 years // Seismoprognosis observations in the territory of Azerbaijan. – 2019. – V. 16, N 1. – P. 35–42.
8. King R.W., Herring T.A., Floyd M.A., McClusky S.C. GAMIT/GLOBK Overview [Электронный ресурс]. – URL: http://geoweb.mit.edu/~floyd/courses/gg/201807, Bishkek, 2018.
9. McClusky S., Balassanian S., Barka A. et al Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus // J. Geophys. Res. 2000. Vol. 105, N B3. P. 5695-5719.

10. McKenzie D. Active tectonics of the Alpine-Himalayan belt, the Aegean Sea and surrounding regions // Geophys. J. Roy. Astron. Soc. 1978. Vol. 55. P. 217-254.
11. Özkan A., Solak H.İ., Tiryakioğlu İ., Şentürk M.D., Aktuğ B., Gezgin C., Poyraz F. Characterization of the co-seismic pattern and slip distribution of the February 06, 2023, Kahramanmaraş (Turkey) earthquakes (Mw 7.7 and Mw 7.6) with a dense GNSS network, Tectonophysics 866, 230041, 2023
12. Reilinger R., Barka A. GPS constraints on fault slip rates in the Arabia-Africa-Eurasia plate collision zone: implications for earthquake recurrence times // Historical and prehistorical earthquakes in the Caucasus. Dordrecht: Kluwer Acad. Publ., 1997. P. 91-108.
13. Saroglu F., Emre O., Kuscu /. Active fault map of Turkey. Scale 1:1 000 000. Ankara: Dir. of Mineral Resources and Explor., 1992.
14. Saroglu F., Yilmaz Y. Geology of the Karliova region. Intersection of the North Anatolian and East Anatolian transform faults // Bui. Tech. Univ., Istanbul. 1991. Vol. 44. P. 475-493.
15. Sengor A.M.C., Yilmaz Y. Tethyan evolution of Turkey: a plate tectonic approach // Tectonophysics. 1981. Vol. 75, N 1 P. 181-241
16. Seyitoğlu G., Esat K., Tün M., Oruç B., Pekşen E., Aktuğ B., Kaypak B., Koca B. Newly discovered, the Kayapa-Yenişehir cross-basin fault: As revealed by geological and geophysical studies along the southern branch of the North Anatolian Fault Zone, Journal of Structural Geology 179, 105028, 2024
17. Solak H.İ., Tiryakioğlu İ., Özkaymak Ç., Sözbilir H., Aktuğ B., Yavaşoğlu H.H., Özkan A. Recent tectonic features of Western Anatolia based on half-space modeling of GNSS Data, Tectonophysics, 872, 2024
18. Trifonov V.G., Hessami Kh.T., Jamali F.H. West-trending oblique sinistral-reverse fault system in Northern Iran. Final Rep. Tehran: IIEES, 1996. 42 p.
19. Ulomov V.I., Danilova T.I., Medvedeva N.S., Polyakova T.P. Seismogeodynamics of lineament structures in the mountainous regions bordering the Scythian-Turan plate. Izvestiya, Physics of the Solid Earth, 42(7), 2006, P. 551-566. doi:10.1134/S1069351306070032. EDN: LJRSKJ
20. Yetirmishli G.J., Kazimov I.E., Kazimova A.F. Contemporary geodynamics of the Eastern Mediterranean // Seismoprognosis observations in the territory of Azerbaijan. – 2021. – V. 20, N 2. – P. 3–10.
21. Бачманов Д.М., Иванова Т.П., Кожурин А.И, Трифонов В.Г. Проблемы континентальной коллизии: Современный коллизионный пояс Загроса // Общие вопросы тектоники. Тектоника России. М.: ГЕОС, 2000. С. 36-39.
22. Костюк А.Д., Сычева Н.А., Юнга С.Л., Богомолов Л.М., Яги Ю. Деформация земной коры Северного ТяньШаня по данным очагов землетрясений и космической геодезии // Физика Земли. 2010. No 3. С. 52–65
23. Рзаев А.Г., Етирмишли Г.Дж, Казымова С.Э. Отражение геодинамического режима в вариациях напряженности геомагнитного поля (на примере южного склона Большого Кавказа) Известия, Науки о Земле. Баку 2013, № 4., с. 3-15
24. Рогожин Е.А., Горбатиков А.В., Степанова М.Ю., Овсюченко А.Н. и др. Структура и современная геодинамика мегантиклинория Большого Кавказа в свете новых данных о глубинном строении, геотектоника, 2015, № 2, с. 36–49
25. Стогний В.В., Заалишвили В.Б., Пономарева Н.Л. Современная геодинамика и сейсмичность Северного Кавказа: проблемы мониторинга, Geology and Geophysics of Russian South 12 (2) 2022, С. 34-52
26. Трифонов В.Г., Соболева О.В., Трифонов Р.В., Востриков Г.А. Т Современная геодинамика Альпийско-Гималайского коллизионного пояса. – Труды, вып. 541, М.: ГЕОС, 2002. – 106 С.
27. Шевченко В.И., Лукк А.А., Прилепин М.Т., Рейлинджер Р.Е. Современная геодинамика Средиземноморской–Малокавказской части Альпийско-Индонезийского подвижного пояса, 2014 г., Физика земли, 2014, № 1, С. 40–58.

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SEISMIC MONITORING SYSTEM, METHODS AND TECHNOLOGIES

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ANNOTATION

The article describes the seismic monitoring system in Azerbaijan and surrounding regions, using BRTT Antelope software. In the period from 2003 to 2023, the main attention of the Republican Seismic Survey Center (RSSC), along with monitoring geodynamic processes on the territory of the republic and adjacent regions, was aimed at expanding the network, as well as developing and modernizing methods and means for organizing observations, collecting, data processing and analysis.

As a result, a wide network of telemetry stations was created, equipped with the most modern instruments for recording earth vibrations in real time. A storage system for seismological and geodetic (GPS) data was organized, high-speed access to the data archive was provided, high-performance computing clusters were deployed, and all seismic stations were connected into a single network. Work is being carried out and continues to introduce innovative technologies and master world experience in monitoring the parameters of the seismic regime on the territory of the republic.

In 2003–2023 the seismic monitoring system in Azerbaijan allowed to process and analyze all recorded local, regional, remote tectonic earthquakes, industrial explosions, volcanic eruptions, as well as conduct comprehensive studies for seismic records.

Key words: seismic monitoring, software, magnitude, trigger.

SEYSMİK MONİTORİNQ SİSTEMİ, ÜSULLARI VƏ TEXNOLOGİYALARI

Kərimova R.D., İsmayılova S.S.

ANNOTASİYA

Məqalədə Azərbaycanda və ətraf bölgələrdə BRTT Antelope proqram təminatından istifadə edərək seysmik monitorinq sistemi təsvir edilmişdir.

2003-cü ildən 2023-cü ilə qədər Respublika Seysmik Xidmət Mərkəzinin (RSXM) əsas diqqəti respublika ərazisində və qonşu bölgələrdə geodinamik proseslərin monitorinqi ilə yanaşı, şəbəkənin genişləndirilməsinə, məlumatların toplanması, emalı və təhlili, müşahidələrin təşkili üsul və vasitələrinin hazırlanması və modernləşdirilməsinə diqqət yönəldilmişdir.

Nəticədə real vaxtda yer titrəmələri qeydə alınması üçün ən müasir cihazlarla təchiz olunmuş geniş telemetrik stansiyalar şəbəkəsi yaradılmışdır. Seysmoloji və geodeziya (GPS) məlumatlarının saxlanması sistemi təşkil olunub, məlumatlar arxivinə yüksək sürətli giriş təmin edilib, yüksək məhsuldar hesablama klasterləri yerləşdirilib, bütün seysmik stansiyalar vahid şəbəkəyə birləşdirilib. Innovativ texnologiyaların tətbiqi və dünya təcrübəsinin mənimsənilməsi istiqamətində işlər aparılır və davam etdirilir.

2003-2023-cü illərdə Azərbaycanda yaranmış seysmik monitorinq sistemi qeydə alınmış bütün yerli, regional, uzaq tektonik zəlzələləri, sənaye partlayışlarını, vulkan püskürmələrini emal və təhlil etməyə, habelə seysmik qeydlər üzrə kompleks tədqiqatlar aparmağa imkan vermişdir.

Açar sözlər: seysmik monitorinq, proqram təminatı, miqyas, triqqer.

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СИСТЕМА СЕЙСМИЧЕСКОГО МОНИТОРИНГА, МЕТОДЫ И ТЕХНОЛОГИИ

Керимова Р.Д., Исмайлова С.С.

АННОТАЦИЯ

В статье описана система сейсмического мониторинга в Азербайджане и прилегающих регионах с использованием программного обеспечения BRTT Antelope. В период с 2003 по 2023 год основное внимание Республиканского Центра Сейсмической Службы (РЦСС), наряду с мониторингом геодинамических процессов на территории республики и сопредельных регионов, было направлено на расширение сети, а также разработку и модернизацию методов и средств организации наблюдений, сбора, обработки и анализа данных.

В результате была создана широкая сеть телеметрических станций, оснащенных самыми современными приборами для регистрации колебаний земли в реальном времени. Была организована система хранения сейсмолого-геодезических (GPS) данных, обеспечен высокоскоростной доступ к архиву данных, развернуты высокопроизводительные вычислительные кластеры, все сейсмические станции объединены в единую сеть. Ведутся и продолжаются работы по внедрению инновационных технологий и освоению мирового опыта мониторинга параметров сейсмического режима на территории республики.

В 2003–2023 годах система сейсмического мониторинга в Азербайджане позволила обработать и проанализировать все зафиксированные локальные, региональные, отдаленные тектонические землетрясения, промышленные взрывы, извержения вулканов, а также провести комплексные исследования сейсмических записей.

Ключевые слова: сейсмический мониторинг, программное обеспечение, магнитуда, триггер.

Introduction

The ability to reduce the impact of earthquakes on society depends on the availability of large quantities of high-quality observational data. The development of the seismic network and advanced data acquisition system over the past few years is essential to achieving this goal. Modernization of the system for collecting, processing and storing seismological information in Azerbaijan began in 2003 and was carried out simultaneously with the expansion of the network of seismic stations. In this case, the main attention was paid to telecommunications and storage of data at the stations themselves in case of accidental loss of communication with the Earthquake Research Center located in Baku, with the possibility of subsequent reading of information upon request from the information processing center. Work was carried out to clarify the velocity characteristics of the earth's crust and upper mantle on the territory of Azerbaijan and adjacent regions with the assistance of specialists from the relevant services. Since 2003, digital recording of seismic information has been introduced and since that time, processing of seismological data has become possible in real time. Digital recording of seismological data has made it possible to put into practice the processing and interpretation of this data, using the capabilities of the latest computer systems. This in turn led to the development and implementation of methodological and software tools for processing information in an automated manner. As a result, a system for monitoring seismicity on the territory of the republic was created on-line, meeting all the necessary requirements for uninterrupted and efficient operation.

Seismic network expansion, data transmission

In 2003, the Republican Seismic Survey Center (RSSC) of the Azerbaijan National Academy of Sciences (ANAS) began reconstruction of the seismic monitoring system in the republic. The first 14 seismic telemetry stations were purchased from Kinemetrics (USA), which were installed in seismically active zones. To expand complex seismological and geophysical research, from 2008 to 2013, under the leadership of the General Director of the RSSC, corresponding member of ANAS, Honoured Scientist, Doctor of Geological

and Mineralogical Sciences, Professor Gurban Jalal oglu Yetirmishli, the seismic network of the republic was expanded, the total number of digital seismic stations reached 35. Then work continued to expand the seismic network. To study the deep processes of the Absheron Peninsula, a network of ten Kinemetrics Basalt accelerographs was installed, recording strong ground vibrations. In 2017, as part of the international project "Caucasian Transect", together with the University of Missouri (USA) and the Science and Technology Center in Ukraine, 17 new seismic stations were installed in the transition zone of the Kura Basin and the Greater Caucasus. In 2021, as part of another international project "Expansion of the seismic network in the Caucasus and Central Asia", another 22 new seismic stations produced by Nanometrics (Canada) were installed on the territory of Azerbaijan. Of these, 12 stations are located near volcanoes, which allows continuous monitoring of volcanic activity in real time.

Currently, the seismic network of Azerbaijan consists of 84 seismic stations (Fig.1).

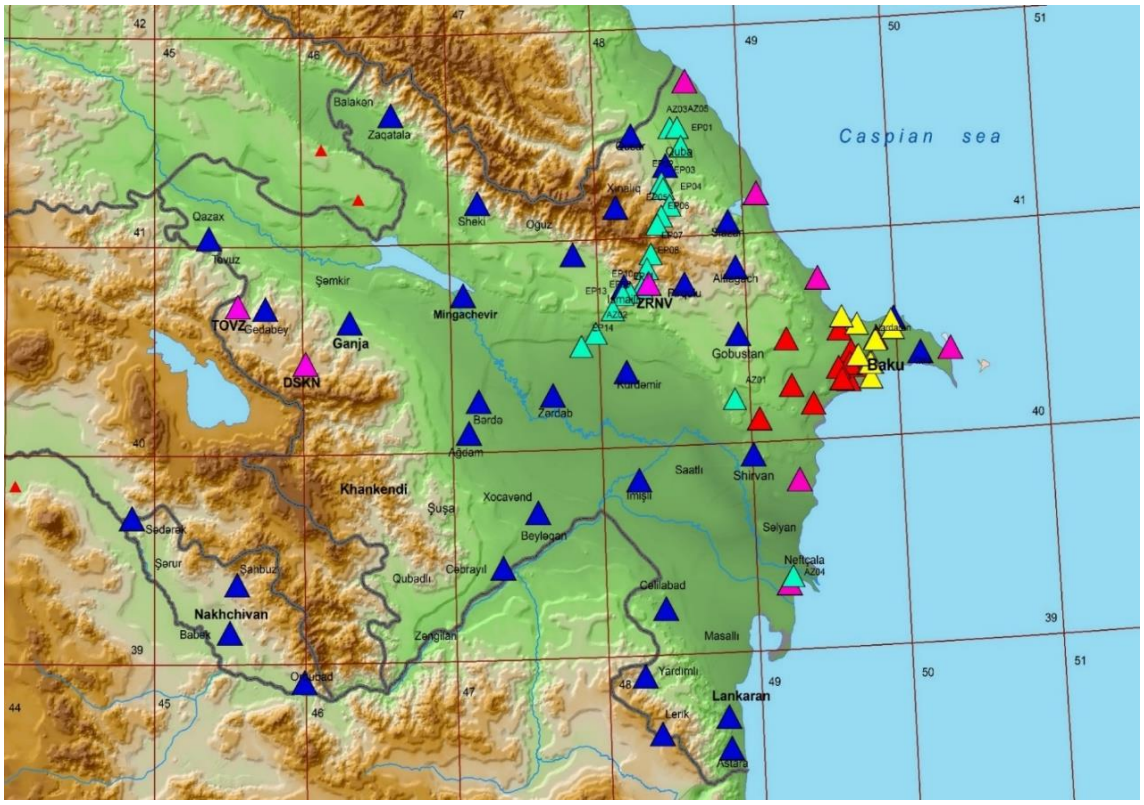


Figure 1. Seismic station location map.

▲ - *the Kinemetric's stations* ;

▲ - *"Caucasian Transect" project stations*;

▲ - *accelerometer "Basalt"*;

▲ ▲ - *"Expansion of the seismic network in the Caucasus and Central Asia" project stations.*

All data from seismic stations is transmitted via satellite in real time and integrated into a system using BRTT Antelope software from Boulder Real-Time Technologies (BRTT), which provides data acquisition, automatic location determination, data archiving and a warning system through a short-wave service. messages (SMS), e-mail, fax and Internet. The main purpose of the real-time seismic network is to provide earthquake parameters from broadband stations with a large dynamic range for faster and more accurate determination of earthquake location and magnitude. And also, in case of strong earthquakes, quickly report the parameters of the event to the necessary decision-making bodies. Research conducted on the basis of earthquake catalogues and bulletins makes it possible to identify seismic active zones.

Using Antelope's Seedlink connection, data is exchanged with neighbouring countries; Türkiye (2 stations) and Georgia (3 stations). Real-time data exchange increases the number of stations, and now real-time data from all these stations is used to more accurately determine the location of regional seismic events. Seismic monitoring is carried out uninterruptedly with information transmitted via satellite communication channels (Fig. 2).

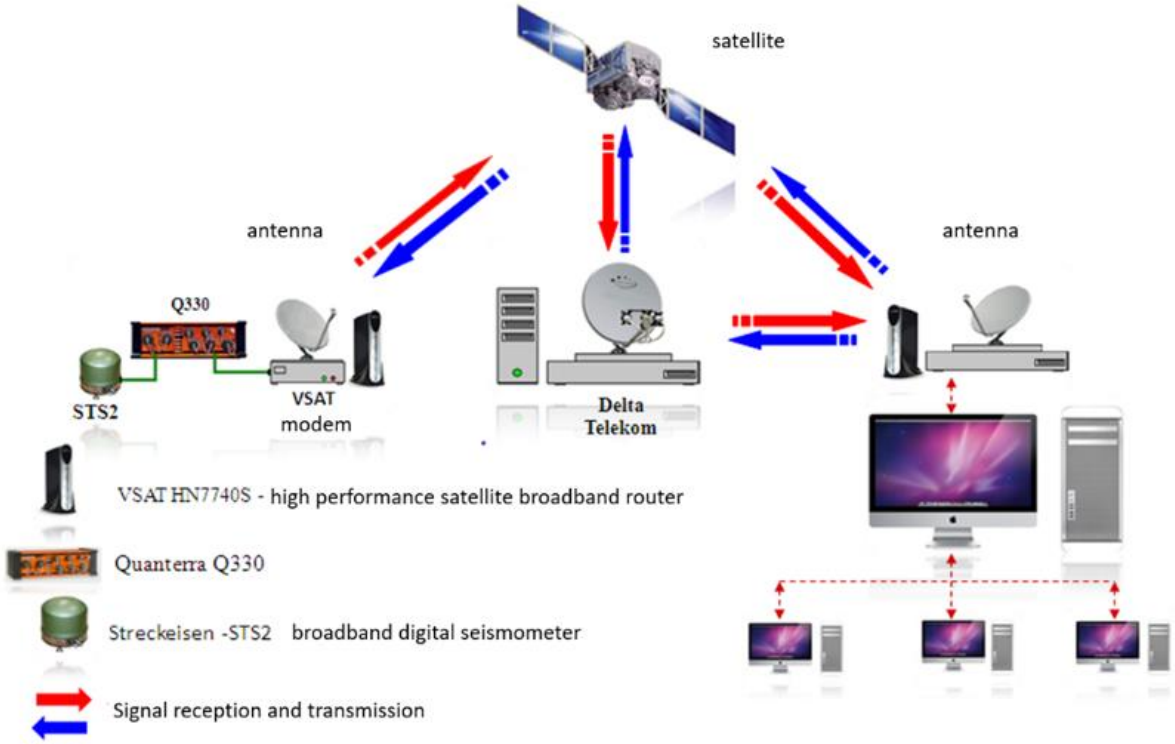


Figure 2. Scheme of data transmission via satellite channels from seismic stations in real time to the Earthquake Research Bureau of the RSSC

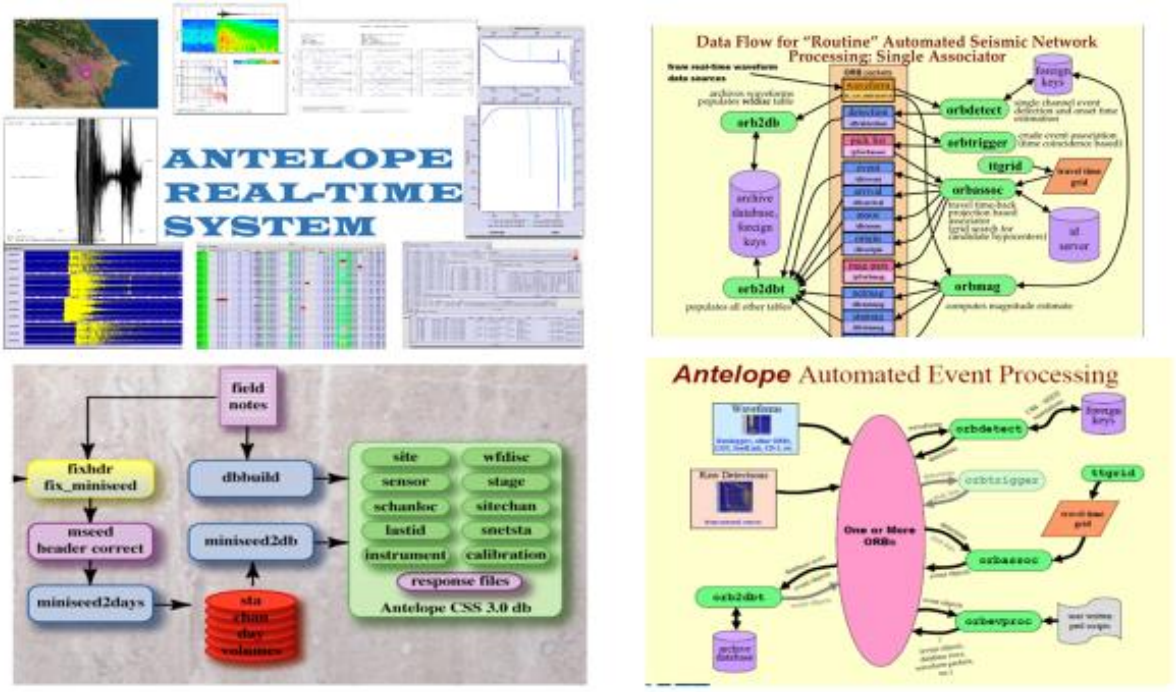


Figure 3. Functional diagram of Antelope Real-Time System

Information about earthquakes with a magnitude of 3.0 and higher is promptly posted on the website www.seismology.az and also sent to all decision-making bodies, as well as to the Ministry of Emergency Situations.

Technological capabilities of the ARTS collection and processing system

Antelope Real Time System (ARTS) is a software package running on the UNIX operating system (MacOSX, Linux). ARTS provides multi-dimensional array management, including real-time data acquisition from field digitizers (s/stations), interactive control of field equipment, system health monitoring, automatic real-time data processing (detection, data processing, seismic event correlation, seismic event location, archiving) (Fig.3).

ARTS is constantly updated and we are currently using one of the newest versions, Antelope 5.6. This system supports all types of telemetry using either standard full-duplex serial interfaces or standard TCP/IP protocol over multiple physical interfaces. In addition to data acquisition, seismic network functionality includes automatic real-time event detection, phase extraction, seismic event correlation and location, archiving, system health monitoring, interactive control of remote stations, automatic distribution of raw data and processed data, processing seismic data arrays in batch mode and powerful development tools for system configuration. It can process continuous data based on event files and uses a form of relational database management and CSS v3.0 scheme for the resulting information.

Data collection and processing

All seismic material received from seismic stations via satellite communication to the Earthquake Research Bureau of the Seismological Center located in Baku is processed on the basis of an individual program included in ARTS. This is the *dbloc2* program which is used to handle all earthquakes such as local, regional and remote earthquakes. The high sensitivity of seismometers installed at seismic stations makes it possible to record all vibrations of the earth's surface, including the weakest. These include weak earthquakes, industrial and nuclear explosions, volcanic eruptions, and landslides. Satellite communications make it possible to receive information about seismic events in real time, process them and, in a very short time (several minutes), determine all the parameters of earthquakes (coordinate, source depth, moment of wave entry, mechanism, etc.). Interactive online communication allows seismic stations located in various regions of the republic to monitor their technical condition, temperature conditions and other characteristics of the equipment, as well as, if necessary, carry out calibration and alignment of records.

In ARTS, data is buffered and transferred using a mechanism known as an Object Ring Buffer (ORB), which acts as the core of ARTS. Each ORB is controlled by one *orbserver* program, the interface of which is described in the configuration parameter library (PF). Interface modules record all data from field stations into one or more ORBs, which can also be used to send commands to field interface modules and on to remote digitizers.

Automatic processing of seismic networks is performed using ORB programs: *orbdetect, orb2db, orbtrigger, orbassoc, orbmag*. Multi-frequency *STA/LTA (Short Time Average over Long Time Average)* detection and recording start time estimation are performed using *orbdetect*, which reads real-time waveform data from the data processing ORB and writes detection status information for each channel and frequency band.

The *orb2db* program reads data from a ring buffer and creates a continuous database, *orbtrigger* implements the system's trigger algorithm, *orbassoc* is an associator/locator that determines the location of a seismic event and searches for its registration in other sources, *orbmag* calculates the magnitude of the event in real time.

All ARTS modules are started, stopped, controlled and executed by the *rtexec* script. This is the main ARTS configuration parameter file and is used to describe the entire processing network and all module

parameter files and command line arguments. When started, *rtexec* reads the main configuration parameter file and runs all ARTS modules defined in the configuration.

Determining the hypocentre of an earthquake depends on the correct determination of the P and S phases. It can sometimes be difficult to recognize the correct start of the phase because the signal may be blurred for various reasons, such as the complexity of the fault mechanism and the presence of natural or artificial noise. For this reason, we study, analyse and compare different phase selection and location methods. The more phases (P- and S-waves) are involved in determining the hypocentre, and the more accurate the velocity model of the lithosphere used in the calculations, the more accurately the parameters of the earthquake hypocentre are determined. In interactive mode, the clarification of the parameters of the hypocentres includes two stages: the first - the time of arrival of the P-wave is specified and the time of arrival of the S-wave at the station is determined; the second is recalculation of the hypocentre parameters based on the data obtained. The first stage uses the *dbpick* program, the second uses *dbloc2*, included in the Antelope package. The *dbpick* program uses waveforms (*MINISEED* format) and database tables *(wfdisc*, *arrival*, etc.) generated by the automatic processing mode as input data. When exiting, the program edits existing and adds new records about S-wave arrival times to the arrival table of the database. The *dbloc2* program uses the edited arrival table as input, calculates new values for the event hypocentre parameters, and also edits entries in the origin table. Antelope's procedure for locating an earthquake is called *orbassoc*. This methodology reads picks determined using the STA/LTA method and associates the location of the event along three possible grids: teleseismic, regional and local. The solution that produces a set of minimum travel time residuals (the difference between the synthetic travel time and the observed travel time) is considered to be the best.

Data interpretation

After the final processing of the earthquake, all data is recorded in the corresponding database tables, using which earthquake catalogues and bulletins are compiled. By examining and analysing the data obtained, maps of earthquake epicentres are constructed for each quarter and for the entire year, graphs, an activity map, the mechanism of earthquake source is determined, spectral analysis is determined, the current seismicity of seismically active zones is analysed, and calm zones are identified, the migration of foci is traced, and the seismic situation is assessed in the republic, the deep distribution of earthquake sources and their connections with faults is studied, distributed seismic energy is analysed by year, and research work is carried out to study statistical and dynamic parameters.

Data obtained as a result of processing earthquakes with a magnitude of 3.0 and above are promptly transmitted to policymakers and other relevant authorities.

Archiving of received data and processing results

Creating the necessary conditions for the security of the archive is one of the main tasks of the Seismological Center. We have collected an electronic archive of data on strong and weak earthquakes, explosions, and volcanic eruptions for 20 years, from 2003 to 2023. Data is stored on disks in several copies. One copy is located on a server allocated for the RSSC by the Institute of Information and Technology. The server also stores copies of data from all divisions of the RSSC, as well as an archive of annual records of GPS stations.

The data is stored in a closed box at a certain temperature.

The entire archive is periodically checked for integrity and, if necessary, updated. The compiled catalogues are reviewed again, additional research and updates are carried out.

Discussions

The study of modern geodynamics in regions with high seismic activity makes it possible to identify the connection between seismicity and physical processes in the earth's crust and mantle, as well as to quantify the natural hazard of these phenomena. These problems can be solved using a digital recording system for seismic

signals based on modern broadband seismic stations. This requires stable, continuous operation of equipment to compile a standard data archive and automate the process of their collection, transmission and storage.

At RSSC we maintain and continuously improve a seismological system that covers basic requirements such as data acquisition, automatic processing and real-time analysis. The system is based on Antelope software, which is also used to exchange real-time data with neighbouring countries.

In the process of processing and analysing seismic data from the network, it was found that the system used makes it possible to well record not only local seismicity, but also remote large seismic events, as well as explosions, landslides, and volcanic eruptions. A comparison of the results of processing seismic events recorded by our system with data from the global seismic network showed their good compatibility. The results obtained led to the conclusion that this network is a unique tool for conducting various seismological studies.

References

1. L. Geldart and R. Sheriff. Problems in exploration Seismology and their solutions. Society of Exploration Geophysicists, 14(-):–, 2004.
2. M. Leonard. Comparison of manual and automatic onset time picking.
3. Bulletin of Seismological Society of America, 90(6):1384–1390, 2000.
4. Юнга С.Л. Методы и результаты определения сейсмотектонической деформации. М.: Наука, 1990. 191 с.
5. Pavlis, G. L., F. Vernon, D. Harvey, and D. Quinlan, 2004. “The generalized earthquake location (GENLOC) package: an earthquake-location library”, Computers & Geosciences, 30:1079-1091.
6. Г.Д. Етирмишли, С.Э. Казымова, С.С. Исмаилова, Р.Д. Керимова. Модернизация системы сейсмологических наблюдений на территории Азербайджана. Российский сейсмологический журнал 2022. Т. 4, № 3. С. 25–35. DOI: https://doi.org/10.35540/2686-7907.2022.3.02

https://doi.org/10.59849/2219-6641.2024.1.44

CHARACTERISTICS OF RESEARCH IN GAS WELLS

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ABSTRACT

Investigation characteristics of underground gas storages, gas wells

In the article it has been mentioned that research methods of underground gas storages (UGS) gas wells in the decided regimes have more distinguishing features than analogous research methods of pure gas and gas condensate fields wells. Besides the parameters defined on the research results of gas fields wells it is necessary to determine a and b coefficients of UGS wells accepting ability during gas injecting.

It has been shown the accuracy of determination of layer pressure average value in UGS is very significant, because this index is used as reliability (surface layers) value of UGS cap of gas injection. Otherwise UGS will put out of order and all gas reserve in the storage mixing with atmosphere will lose.

Herein distinguishing features between UGS and pure gas and gas condensate fields have been shown and well № 415 of UGS has been analyzed, indicator diagram has been set up and values of a and b coefficients (during gas injection) have been determined.

Key words: underground gas storage, pure gas fold, gas-condensate field, research features, gas injection, gas production.

QAZ QUYULARINDA TƏDQİQATIN APARILMASI XASSƏLƏRİ

Qədirov Z.S., Comərdov A.Y.

XÜLASƏ

Məqalədə, yeraltı qaz anbarları qaz quyularının qərarlaşmış rejimlərdə tədqiqat üsullarının təmiz qaz və qaz-kondensat yataqları quyularının analoji tədqiqat üsullarına nisbətən müəyyən fərqli xüsusiyyətlərinin olduğu qeyd olunmuşdur. Qaz yataqları quyularının tədqiqat nəticələri üzrə təyin edilən parametrlərindən başqa YQA quyularının qəbul etmə qabiliyyətini və qaz vurma zamanı, a və b əmsallarını təyin etmək lazımdır. Bu əmsallar qazın hasil olunması prosesində tədqiqatın nəticələrinə əsasən alınmış a və b əmsallarından xeyli fərqlənirlər. Göstərilmişdir ki, YQA-da lay təzyiqinin orta qiymətinin təyin edilməsinin dəqiqliyi daha çox əhəmiyyət kəsb edir, çünki bu göstərici qaza vurulmasının sonuna YQA örtüyünün (pokrışkasının), (yer səthindəki yerləşmiş layların) etibarlılıq meyarı kimi istifadə edilir. Əks təqdirdə YQA sıradan çıxar və anbardakı qaz ehtiyatının hamısı atmosferə qarışaraq itər.

Burada, YQA-ları ilə təmiz qaz və qaz-kondensat yataqları arasındakı fərqli xüsusiyyətlər şərh edilmişdir və buna misal olaraq YQA-nın 415 saylı quyusu tədqiq edilmiş, indikator diaqramı qurulmuş və a və b əmsallarının (qazvurma zamanı) qiymətləri təyin edilmişdir.

Açar sözlər: yeraltı qaz anbarı, qazkondensat yatağı, qazın vurulması, yeraltı qaz anbarı, təmiz qaz yatağı, tədqiqat xüsusiyyətləri, qazın hasil edilməsi.

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ИССЛЕДОВАТЕЛЬСКИЕ ОСОБЕННОСТИ ГАЗОВЫХ СКВАЖИН ПОДЗЕМНЫЕ ХРАНИЛИЩА ГАЗА

Гадиров З.С, Джомардов А.Я

АННОТАЦИЯ

В статье отмечено наличие определенных отличительных особенностей способов исследования газовых скважин ПХГ на установившихся режимах по сравнению с аналогичными исследовательскими способами исследования скважин чисто газовых и газоконденсатных месторождений. Кроме определяемых параметров по результатам исследования скважин газового месторождения, необходимо также определить приемистость газовых скважин ПХГ и значений коэффициентов a и b, при закачке газа в ПХГ. Эти коэффициенты резко отличаются от значений коэффициентов a и b, полученных на основе результатов исследования при проведении процесса добычи газа из подземные хранилища газа.

Показано, что точность определения среднего значения пластового давления имеет большое значение, потому что, этот показатель в конце закачки газа в подземный амбар используется как критерий надежности покрытия ПХГ (покрышки), (пластов, залегаемых на поверхности земли). В противном случае ПХГ может выйти из строя и запасы газа в амбаре могут уйти в атмосферу.

Здесь изложены отличительные особенности ПХГ и чисто газовых и газоконденсатных месторождений и в качестве примера исследована скважина 415, построена индикаторная диаграмма и определены значения коэффициентов a и b, при закачке газа в амбар.

Ключевые слова: подземные хранилища газа, чисто газовое месторождение, газоконденсатное месторождение, исследовательские особенности, закачка газа, добыча газа.

Introduction

It is necessary to determine the capacity of receiving gas injected into the gas wells of the Underground Gas Reservoirs created in depleted gas condensate deposits and the coefficients a and b during gas injection. These coefficients are significantly different from the a and b coefficients obtained based on the results of research in the process of gas production. It has become clear that the accuracy of determining the average value of formation pressure of Underground Gas Reservoirs wells is more important. Because this indicator is used as a criterion of reliability of the cover of the Underground Gas Storage at the end of the gas injection. For this, studying the research characteristics of gas wells of Underground Gas Storages is of great importance.

In underground gas reservoirs, the accuracy of determining the average value of the reservoir pressure is more important. If the upper layer of the underground gas reservoir does not sustain the indefinite pressure, the underground gas reservoirs will collapse and fail, and all the gas reserves there will be mixed into the atmosphere and lost.

The existing properties of the studies were determined by the UGR and various functional purposes of the gas fields. Research of UGR gas wells should be done without releasing the gas to the atmosphere. This condition requires that research work is carried out during the period of gas injection of most of the total volume of the reservoir and the wellbore zone. However, research work on determining the parameters of the technological operation mode of the wells should be carried out during the period of gas injection into the well and extraction from the well.

Research methods of wells in underground gas reservoirs (UGR) essentially do not differ from research methods of gas field wells. The research issues of the gas wells of UGR created in depleted gas condensate, oil fields and water structures are identical to the research issues of gas field wells with the application of the fixed purchases method in the period of gas purchase and in the neutral period [1,4].

The existing properties of the studies were determined by the UGR and various functional purposes of the gas fields. Research of UGR gas wells should be done without releasing the gas to the atmosphere. This

condition requires that research work is carried out during the period of gas injection of most of the total volume of the reservoir and the wellbore zone. However, research work on determining the parameters of the technological operation mode of the wells should be carried out during the period of gas injection into the well and extraction from the well.

During the testing of the gas wells of the underground gas reservoirs, it is necessary to determine the receiving capacity of the wells of UGR, in addition to the parameters determined by the method of the research results of the wells of gas fields, and the coefficients a and b of the seepage resistance during gas injection should be determined. These coefficients can be significantly different from the similar a and b coefficients obtained based on the results of testing in the gas production process [2,3].

The formation pressure of underground gas reservoirs changes from maximum to minimum in a relatively small (compared to gas fields) time interval. Therefore, during the relatively long-term stabilization of the pressure and discharge of UGR wells, it is necessary to take into account the possible changes of the formation pressure.

If the UGR is divided into hydrodynamically screened inhomogeneous blocks, then accurate values of reservoir pressure sufficient for practice should be determined separately for each block averaged.

Depending on the location of the establishment of the UGR (spent gas condensate, oil fields and water structures), the necessary scope and issues of the research of its gas wells arise.

If Underground Gas Storages are created in Depleted Gas Condensate Fields, then:

1. It is necessary to carry out studies according to gas-condensation;

2. It is necessary to conduct stationary and non-stationary researches in wells.

3. It is necessary to take into account the results of the studies conducted during the development of the beds;

4. In most cases, the volume of research works on determining formation pressure in wells is 1.5 to 2 times greater than that of UGR created in water structures, which is related to their inhomogeneity.

The difference between underground gas storages and pure gas and gas condensate deposits is as follows:

– in some cases, due to the need, gas is produced from one or more wells of the storage and sent to the customers, in which case the storage is used as a gas deposit. , i.e. the reservoir is exploited, such wells become production wells, and the remaining wells are hermetically sealed;

– in underground gas reservoirs, gas is never pumped into the reservoir from some wells, and gas is not produced from the reservoir from other wells at the same time, i.e. at the same time both gas injection and gas production wells do not work in the reservoir, because there is no need to do such work in the reservoirs;

– underground gas reservoirs, in most cases, dry hydrocarbon gas is injected from their wells, not for the purpose of maintaining formation pressure, but to accumulate gas reserves in the reservoir they do, in this case those wells become gas injection wells. The process of injecting gas into the reservoir is carried out in one or more wells, the rest of the wells are hermetically sealed;

– gas and condensate producing wells are operated until the end of development in gas condensate fields, but when the reservoir pressure drops, the condensate falls, and in order to prevent it, the productive layer is drained from some well's hydrocarbon gas is injected, this process is called the cycling process. In gas condensate deposits, the phenomenon of counter condensation occurs due to the drop in formation pressure, which is called retrograde condensation;

– in clean gas fields, gas-producing wells are always operated until the end of development.

If underground gas reservoirs are created in water structures (as a rule, in relatively homogeneous and high-permeability layers), then take into account the results of hydro exploration and the limited possibility of using non-stationary research methods of wells necessary.

The procedure for testing gas wells of Underground Gas Storages and processing the results is identical to those for gas field wells. Conducting research is similar to the research of gas wells, in which the extracted gas is delivered to the gas measurement distribution point of the mine.

Different technological modes of operation of the wells are created with adjustable plugs. Gas consumption is determined based on the data of the differential manometer at the measuring point. The range of gas consumption changes depends on the reservoir's absorption capacity and the pressure in the reservoir, etc. is limited. Below is an example of research data processing in the gas injection process [5].

$$P_q^2 - P_{lqy}^2 = aQ + bQ^2 \quad (2)$$

Here P_q, P_{lay} –are the wellbore and formation pressures, kQ/cm2, respectively; Q-is gas consumption, min m3/day; a,b- are the coefficients of seepage resistance.

The research results of well No. 415 of the Underground Gas Storage are given. Here, it should be $P_q > P_{lay}$ so that the injected gas can enter the UGR.

Primary $P_{st} = 54{,}7kQ/sm^2; \overline{Q} = 0{,}745$; the depth of the well is L=247m.

According to the test data, the injection mode was determined with a flow rate of Q = 218min.m3/day.

According to table 1, the values of $\alpha = 0{,}84$ and $b = 0{,}016$ values of seepage resistance coefficients were found graphically.

Regime	$P_{b.a}$, kQ/sm^2	$t_{q.a}$, ^{0}C	Q, min m^{3}day	P_q, kQ/sm^2	P_q^2, kQ/sm^2	$\Delta P^2 = P_q^2 - P_{lqy}^2$ (Mpa)^2	$\frac{P_q^2 - P_{lqy}^2}{Q}$
–	54,7	24	–	57,6	3323	–	–
1	59,3	27	80	58,3	3399	76	0,95
2	59,5	29	100	58,5	3422	99	0,99
3	59,7	30	128	58,8	3454	131	1,02
4	56,1	33	157	59,1	3499	172	1,09
5	56,3	34	178	59,3	3521	198	1,11
6	56,4	36	196	59,5	3949	222	1,13
7	56,8	39	218	59,8	3582	299	1,18
8	68,4	41	226	61,6	3889	465	2,08

If we substitute the values of these coefficients in formula (1), we will get the binomial flow equation for specific well No. 415:

$$P_q^2 - P_{lay}^2 = \Delta P^2 = 0{,}84Q + 0{,}0016Q^2 \quad (2)$$

If we write P_{q_1} – the pressure of the well bottom, that is, the pressure that can be released instead of Pq, then we solve equation $P_{q_1}^2 - P_{lqy}^2 = \Delta P_1^2 = 0{,}84 \cdot Q_{nor} + 0{,}0016Q_{nor}^2$ according to Q_{nor} to find the rate of consumption of the gas injected from the well into the URG.

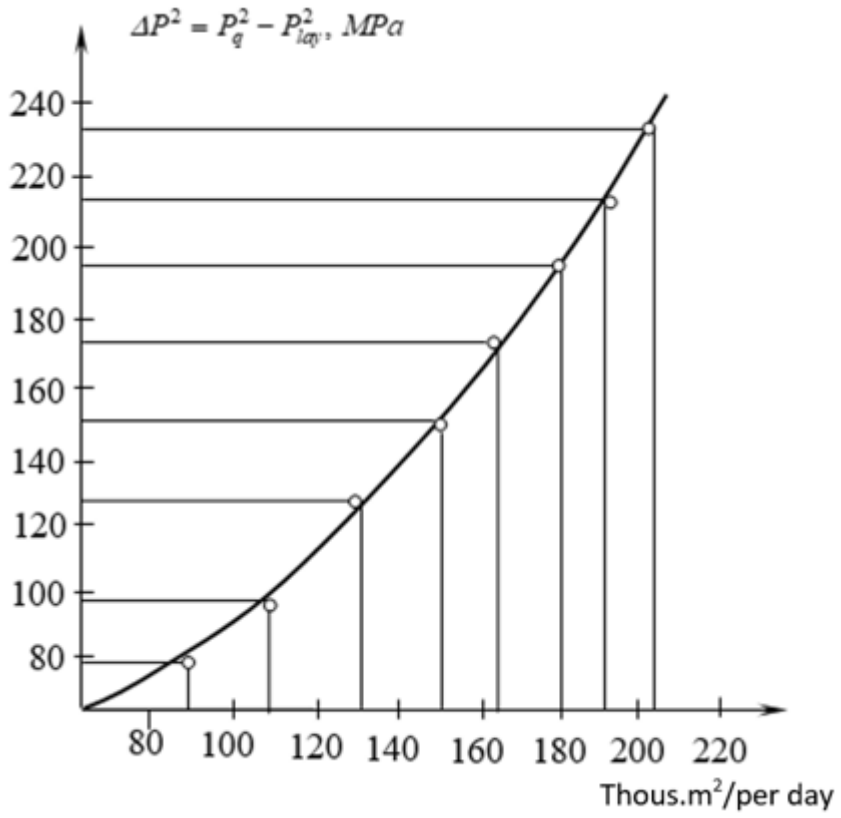


Figure 1. Underground gas storage gas well No. 415 indicator diagram

If $P_{q_q} = 100at = 10MPa;\ P_{lay} = 70at = 7MPa$

$$100 - \gamma q = 0{,}84Q_{nor} + 0{,}0016Q_{nor}^2$$

$$0{,}0016Q_{nor}^2 + 0{,}84Q_{nor} - 51 = 0$$

$$Q_{nor_{1,2}} = \frac{-0{,}84 \pm \sqrt{0{,}84^2 + 4 \cdot 0{,}0016 \cdot 51}}{2 \cdot 0{,}0016} = 5{,}5 \min .m^3/day$$

$$Q_{nor} = 5{,}5 \text{ min.m}^3\text{/day}$$

So, if the research results are processed using a binomial equation, then the coefficients a and b of the equation are determined by the least squares method with the following formulas:

$$a = \frac{\sum \frac{\Delta P^2}{q} \sum q^2 - \sum q \sum \Delta p^2}{N \sum q^2 - \left(\sum q\right)^2} \tag{3}$$

$$b = \frac{n \sum \Delta p^2 - \sum q \sum \frac{\Delta P^2}{q}}{N \sum q^2 - \left(\sum q\right)^2} \tag{4}$$

Here N is the number of different working modes.

The values of coefficients a and b calculated by formulas (3) and (4) will be equal to 0.84 and 0.0016 in equation (2).

If the gas reservoir is created in a depleted gas condensate field, then there is a certain amount of residual condensate in its pores, and in this case, the condensate of the gas reservoir, i.e., the condensate saturation coefficient, is determined.

Conclusion

It has been noted that the research methods of underground gas storage gas wells in fixed regimes have certain different characteristics compared to the similar research methods of pure gas and gas-condensate wells. In addition to the parameters determined by the research results of gas field wells, it is necessary to determine the absorption capacity of UGR wells and the coefficients a and b during gas injection. These coefficients are significantly different from the coefficients a and b obtained based on the results of research in the gas production process. It has been shown that the accuracy of determining the average value of the formation pressure in the UGR is more important, because this indicator is used as a criterion of reliability of the UGR cover (cover), (layers located on the surface of the earth) at the end of gas injection. Otherwise, the UGR will fail and all the gas reserves in the reservoir will be mixed into the atmosphere. diagram was constructed and the values of coefficients a and b (during gas injection) were determined.

References

1. Korotayev Yu.P. “Comprehensive exploration and development of gas fields”, Edition 1968, 428 pp.
2. Chernov B.S., Bazlov M.N., Zhukov A.I. “Hydrodynamic methods for studying wells and formations”, Gostoptekhizdat, Moscow, 1960, 319 pp.
3. Instructions for the comprehensive study of gas and gas condensate formations and wells. Edited by G.A.Zotov, Z.S.Aliev. Moscow, Nedra", 1980, 301 pp.
4. Briskman AA and others "Extraction and transportation of gas", Azerbaijan State Oil and scientific and technical literature publishing house. Baku, 1956, 594 pages.
5. Mustafayev SD, Aliyeva O.A., Gadirov Z.S. and others. "Research characteristics of underground gas storage gas wells", Azerbaijan Oil Industry Journal, 07-08.2017, p. 31-35.

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ASSESSMENT OF ECOLOGICAL RISK CAUSED BY LEAKS TO THE EARTH SURFACE WHEN INCREASING THE VOLUME OF GAS INJECTED INTO THE GARADAGH GAS RESERVOIR

Khanbabayev N.B.[1]

ANNOTATİON

The article notes that maintaining seismicity and the geological-tectonic structure of underground gas storage facilities, which are of exceptional importance in the national economy, is one of the important problems and is always the focus of attention of the state of Azerbaijan.

Before environmental risks arise when changing the volumes of gas injected and withdrawn from the reservoir, it is proposed to compile maps reflecting the state of stress and deformation for different levels, taking into account the increase and decrease in the effect of density in the reservoir.

Key words: seismomagnetic effect, geodynamic regime, geomagnetic field strength, gravity force, gravimetric field strength, local anomaly, engineering-seismic exploration.

QARADAĞ QAZ ANBARINADA QAZIN HƏCİMİNİN ARTIRILMASI ZAMANI YER SƏTHİNƏ SIZMALARIN ETDİYİ EKOLOJİ RİSKİN QİYMƏTLƏNDİRİLMƏSİ

N.B.Xanbabayev

XÜLASƏ

Məqalədə xalq təsərrüfatında müstəsna əhəmiyyəti olan yeraltı qaz anbarların (YQA) seysmikliyi və geoloji-tektonik quruluşunu mütəmadi nəzarətdə saxlamaq vacib problemlərdən biri olmaqla daim Azərbaycan dövlətinin diqqət mərkəzində olduğu qeyd edilir.

Anbara vurulan və götürülən qazın həcmi dəyişdikcə yaranacaq ekoloji risklərdən öncə, anbarda sıxlıq effektinin artıb- azalmasını nəzərə alaraq müxtəlif səviyyələr üçün gəginlik – deformasiya vəziyyətini əks etdirən xəritələrin qurulması təklif olunur.

Açar sözlər: seysmomaqnit effekt, geodinamik rejim, geomaqnit sahəsinin gücü, cazibə qüvvəsi, qravimetrik sahənin gücü, yerli anomaliya, mühəndis-seysmik kəşfiyyat.

ОЦЕНКА ЭКОЛОГИЧЕСКОГО РИСКА, ВЫЗВАННОГО УТЕЧКАМИ НА ПОВЕРХНОСТЬ ЗЕМЛИ, ПРИ УВЕЛИЧЕНИИ ОБЪЕМА ЗАКАЧИВАЕМОГО ГАЗА В ГАРАДАГСКИЙ ГАЗОВЫЙ РЕЗЕРВУАР

Н.Б.Ханбабаев

АННОТАЦИЯ

В статье отмечается, что поддержание сейсмичности и геолого-тектонического строения подземных газовых хранилищ, имеющих исключительное значение в национальной экономике, является одной из важных проблем и всегда находится в центре внимания Азербайджанского государства.

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До того, как возникнут экологические риски, возникающие при изменении объемов закачиваемого и отбираемого из пласта газа, предлагается строить карты, отражающие состояние напряженности и деформаций для разных уровней с учетом увеличения и уменьшения эффекта плотности в пласте.

Ключевые слова: сейсмомагнитное воздействие, геодинамический режим, напряженность геомагнитного поля, сила тяжести, напряженность гравиметрического поля, локальная аномалия, инженерно-сейсморазведка

Introduction

Clarification of the geological and tectonic structure of underground gas deposits, which is of exceptional importance in the development of the oil and gas industry of the republic, is one of the important problems and is constantly in the focus of attention of geologists and geophysicists. The volume of gas pumped into the Garadagh gas storage facility does not always remain stable depending on the season.

In summer, the volume of gas injection into the reservoir increases. Seismic risk, seismic zoning work and the activation of tectonic faults in this territory must be constantly monitored in order to avoid environmental hazards during the further exploitation of gas fields, which will expand and increase in capacity.

One of the most current problems of our time is the study of factors for preventing danger that may arise as a result of an increase in the anomalous energy of geodynamic stresses in gas-injected layers and the assessment of environmental risk. The Garadagh gas field is located 30 km southwest of the city of Baku. There are mud volcanoes Akhtarma (96 m) and Osman-Bozdagh (384 m) in these areas. In these volcanoes, activation is observed from time to time (Fig. 1).

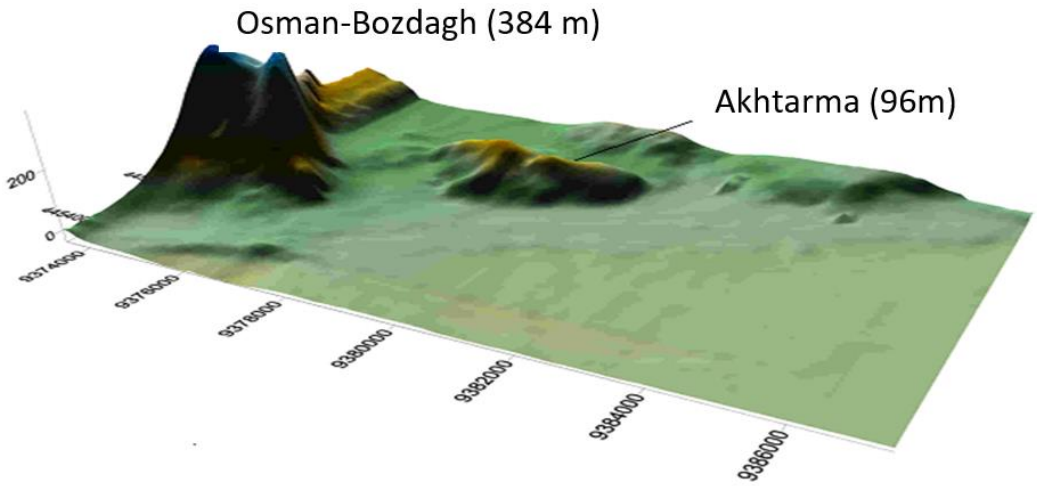


Figure 1. Three-dimensional relief map of the study area.

Due to the high seismic activity of the area where the Garadagh gas field is located, a number of deep faults pass through it. On maps of seismic activity in recent years, an increase in the dynamics of the internal structure of the earth in these areas is observed (Fig. 2). Strong earthquakes occurring in fault zones running through the territory pose a high seismic hazard for the Garadagh and Galmaz gas fields. The Caspian earthquake that occurred on November 25, 2000, consisted of two seismic shocks (M=5.8 and M=6.2) and was accompanied by thousands of aftershocks.

On the territory of the Garadagh gas field, the earthquake was felt with a force of 6-7 points on the MSK-64 scale. Taking into account the above, the increase in reservoir capacity should be adjusted in such a way that changes in geodynamic-tectonic conditions at depth do not cause anomalous activation of the surrounding mud volcanoes, and also do not activate tectonic faults passing through the territory. From the study of strong earthquakes and analysis of the results, it is known that the magnitude of earthquakes is large and the depth is relatively small, which leads to the formation of cracks on the earth's surface in the pleistoseist zones. At this

time, gas leakage from such cracks onto the earth's surface is very likely. The large ridge of the Garadagh mud volcano, located in the area of the Garadagh gas field, forms a general uplift.

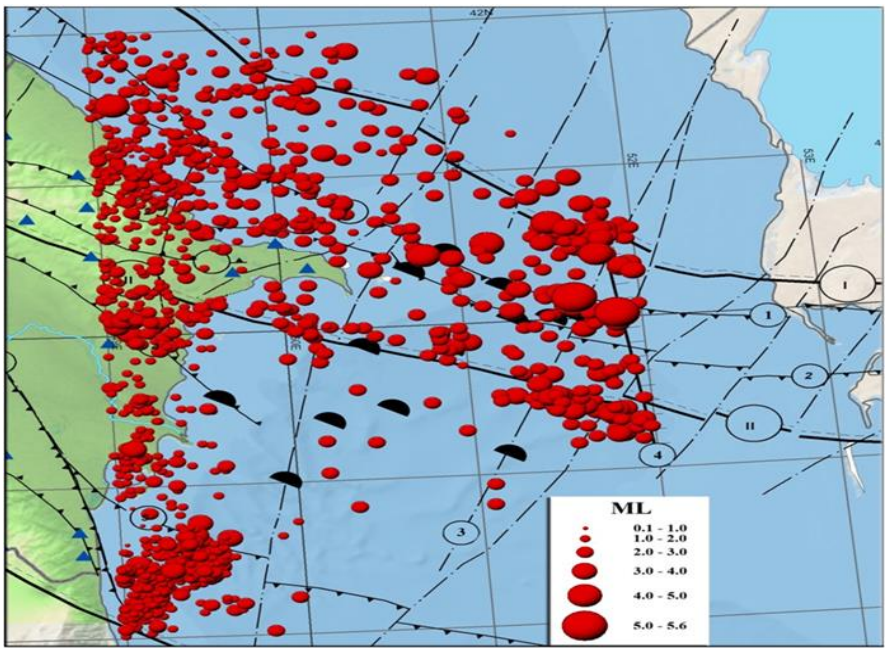


Figure 2. Map of epicenters and deep faults of earthquakes that occurred in the Caspian Sea and nearby territories in 2014-2022 [4]

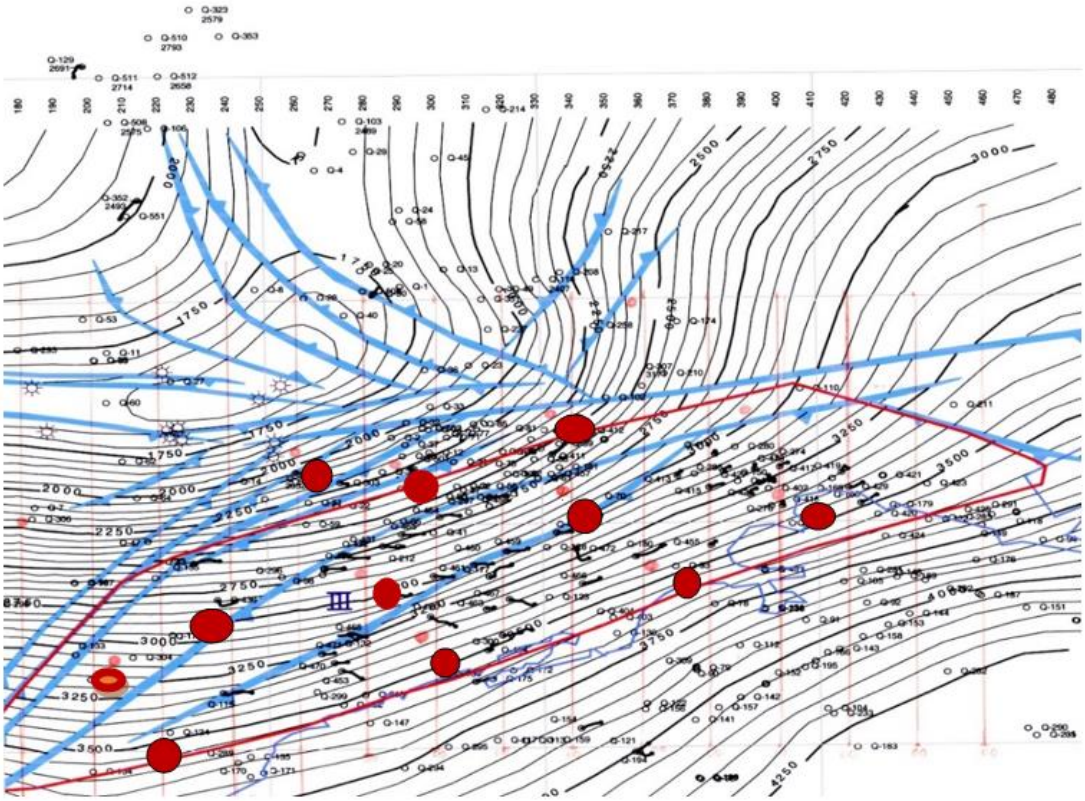


Figure 3. Layout of geophysical (gravimagnetometric) monitoring points planned for creation on the territory of the Garadagh gas field [5].

Territory of the Garadagh gas field

Geophysical monitoring stations

The Akhtarma mud volcano is located in the eastern part of the fold and consists of 6 gryphons, inside of which gas, water and mud are released. Gas was first pumped into the Garadagh field in 1986 and put into operation as a reservoir (VII horizon). This horizon covers the southern flank of the field and has historically contained large gas reserves. Therefore, it is very important to conduct regular geophysical monitoring in the area, depending on the volume of gas injected into the reservoir.

Seismic risk must be regularly monitored to ensure that it does not pose imminent threats to the future environmental performance of increasing and expanding gas fields. One of the current issues is the prevention of danger that may arise as a result of an increase in the energy of anomalous geodynamic stresses in gas-injected layers.

In order to avoid an environmental disaster, it is necessary to study in detail the possible consequences of earthquakes on gas reservoirs that may occur in the study area and nearby areas. Taking into account the geological and tectonic structure of the gas reservoir, geophysical monitoring work should be carried out on the research territory and adjacent territories. Based on seismic and gravimagnetometric data, it is necessary to create 10-11 gravimagnetometric reference observation points, taking into account the blocks and faults identified to date in the research area (Figure 3). As the volumes of gas injected and withdrawn from the reservoir increase and decrease, it is proposed to construct maps of local anomalies (deformations) for different levels (depths) and preliminary assess the environmental risk taking into account changes in the density effect in the layers.

References

1. A.H.Qocayev. Qaradağ strukturunun dəqiqləşdirilməsi və yeraltı qaz anbarının genişləndirilməsi haqqında. 2015. Azərbaycanda Geofizika Yenilikləri elmi texniki jurnalı, №1-2, səh. 43-45.
2. Ə.Ə.Feyzullayev, Y.A.Şixəliyev, A.H.Qocayev. Səthə yaxın qaz planalması üsulu ilə yeraltı qaz anbarlarından qaz itkisinin aşkarlanmasının effektivliyi barədə. 2016. Azərbaycanda Geofizika Yenilikləri elmi texniki jurnalı, №1-2, səh. 52-57.
3. G.J.Yetirmishli,T.Y.Mammadli, L.A.Ibrahimova. Seismotectonics of oil and gas areas in Lower Kura depression of Azerbaijan. 2016. Seismoprogn. Observ. Territ. Azerb. V.13, №1, pp.3-11.
4. R.R.Abdullayeva, S.E.Kazimova, S.S.Ismayilova, E.R.Akbarov. Geodynamics of Azerbaijan part of the Caspian Sea. 2016. Seismoprogn. Observ. Territ. Azerb. V.13, №1, pp.16-22.
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