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# A NEW APPROACH TO DETERMINE THE IMPACT OF GEODYNAMIC STRESS ON OIL PRODUCTION IN THE SOUTH CASPIAN BASIN

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A B S T R A C T

The scientific justification of the geodynamic impact of small and strong earthquakes that occurred in Azerbaijan between 2003 and 2024 on the structural layers within the South Caspian Basin (exemplified by the Bulla-Deniz oil and gas field) has been provided. Based on the epicentral distance distribution of the earthquakes, earthquakes with a magnitude of $M \geq 3$, that occurred in this structure between 2018 and 2024, were selected. The effect of these earthquakes on the field and the changes in production were analyzed comparatively. In this analysis, only the epicentral distance of the earthquakes was considered, and the potential geodynamic effect of the earthquakes on the field was studied using a different methodological approach. The effect radius corresponding to the earthquake energy distribution and the accumulation time of the potential elastic strain energy were calculated. Based on these calculations, earthquakes that could potentially impact the field were selected, and a table was constructed showing the changes in energy accumulation period and impact distance. Thus, using a new methodological approach, the impact of earthquakes with a magnitude of $M \geq 3$ that occurred in Azerbaijan between 2003 and 2024 in the Bulla-Deniz field was determined. In this context, an analysis was conducted to identify the parameters of earthquakes that could cause anomalous variations in the field, taking into account the impact distances of the earthquakes. In the study area, the geodynamic impact and the energy store period of the earthquakes were considered in evaluating their effect on oil production in exploitation wells.

**Keywords:** South Caspian Basin; Bulla-Deniz oil and gas field; earthquake; hydrocarbon-bearing formations; oil production.

**Date submitted:** 25.10.2024 **Date accepted:** 03.03.2025

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## Introduction

The epicenters of earthquakes occurring in the South Caspian Basin are unevenly distributed across different regions, and similarly, the hypocenters of the earthquakes are unevenly distributed at various depth intervals. This distribution causes various geodynamic changes in the region. The formation of earthquake sources resulting from accumulated stress directly affects oil and gas reservoirs, leading to certain changes. The accumulated stress directly impacts hydrocarbon production, causing various changes in production rates. This is considered to be associated with geodynamic processes occurring in oil and gas reservoirs. The accurate identification of these effects requires a comprehensive approach to the ongoing research in the area. Therefore, geological, geophysical, and deep seismic exploration work should be conducted in the region. A key focus of the research is identifying the regularities of the geodynamic impact of earthquakes that occurring in the research area and nearby regions, as well as determining the geodynamic factors that caused changes in production rates at wells in the Bulla-Deniz oil and gas field.

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http://dx.doi.org/10.5510/OGP20250101037

It has been observed by us that the epicenters of earthquakes occurring around the Bulla-Deniz structure extend from the Earth's surface to a depth interval of $H=70$ km across the region (based on the earthquake catalog data of the Republican Seismic Survey Center of the Azerbaijan National Academy of Sciences). To ensure the normal operation of oil and gas production in the Bulla-Deniz oil and gas field and to monitor the field's exploitation regime, it is crucial to study the technical condition of the wells, the geological environment surrounding the wells, as well as production-related changes and the effects of possible geodynamic stress, which could potentially impact the exploitation regime. For this purpose, seismic earthquake catalogs have been used to identify natural and technogenic risks that could threaten sharp changes in production, assess potential risks, and take appropriate measures, while considering the temporal and spatial variations in geophysical fields. Certain analytical work has been carried out for this purpose [1]. In the research work, the mechanism of earthquake sources has been analyzed, oil and gas reservoirs have been studied in greater depth, and the impact of the stress generated in these reservoirs on oil and gas production has been determined, presenting a new methodological approach. During the development of the

new methodological approach, a comprehensive analysis of seismic, geophysical, and geodynamic data was conducted, and a comparative analysis was carried out. The method of studying the impact of stress on oil production, explored in the research, will be significant for the future optimization of hydrocarbon production.

### The method of assessing the impact of earthquakes on oil and gas production in the wells of oil fields up to the present

To clarify the change in production due to the impact of earthquakes on operating fields, scientists at the University of Texas have studied the relationship between seismic activity and changes in oil production caused by earthquakes for many years [2]. As it is obvious from studies, that after earthquakes, oil production in oil fields fluctuated significantly [2, 3].

A group of researchers notes that oil production in wells of oil fields changes due to the impact of earthquakes, while another group of scientists suggests that seismic events in oil fields are associated with dynamic changes in the oil-bearing reservoirs being exploited, the formation of anomalous reservoir pressures, and other related processes. According to their point of view, dynamic changes in the exploited layers lead to earthquakes occurring within the field and its surrounding area. Another group of scientists links changes in oil production in wells of oil fields due to earthquakes with geodynamic stress [4, 5].

Numerous sources report an increase in oil production in oil fields as a result of earthquake impacts. In depth cross-sections, the mechanical properties of rocks in the geological environment are affected by geodynamic impacts, and the created mechanical processes lead to favorable conditions for the migration of hydrocarbons, which has been confirmed through experimental studies [6-8].

To clarify the features of processes occurring in the hydrocarbon-bearing geological environment under the influence of geodynamic stress, experimental laboratory studies were conducted, and vibroseismic effects were applied to rock samples with hydrocarbon capacity in specialized devices. The experiments revealed the separation of hydrocarbons from the rocks and the acceleration of the migration process due to cycling effects [9, 10].

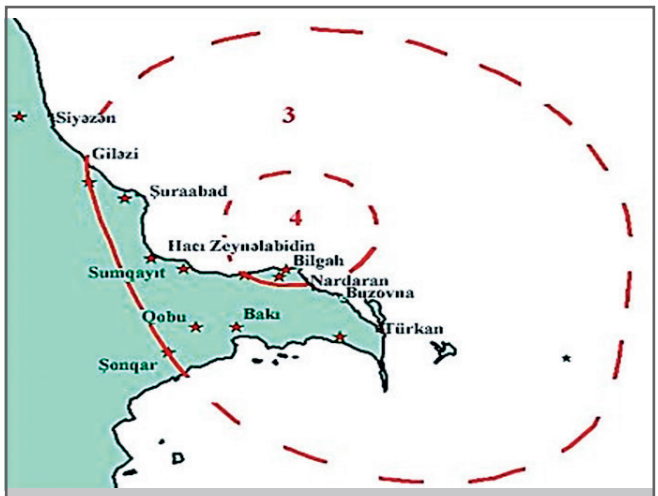


**Fig. 1. Map diagram of the earthquake that occurred on June 3, 2005, in the Caspian Sea**

In our research, it was noted that oil production in wells increased with the epicentral distance from earthquakes in the field area. However, the dynamic characteristics of the changes in the geological environment between the epicenter and the well have not been thoroughly studied. The impact of earthquakes in the studied area on the field and changes in production were noted, considering only the epicentral distance, showing production changes.

During such comparative analysis, each researcher used seismic zoning scales applied in the regions where the fields are located to perform a statistical analysis of production changes. In fact, the seismic zoning of each region is assessed using different scales.

### Evaluation of earthquake intensity in different regions

After an earthquake occurs, the intensity of the shockwave in the rocks (ground), the scale of the destruction, the signs of building collapse on the surface, the collapse of buildings and residential areas, the perception of the tremor by people, and etc, are taken into account when assessing the earthquake on a scale. This is done using different seismic scales based on various earthquake scales developed in different countries to evaluate the strength and extent of the earthquake.

With macroseismic observations, the determination of earthquake intensity was previously evaluated with a high degree of subjectivity. For example, people would consider an earthquake that caused serious damage to their homes to be stronger than one that was scarcely perceptible. However, a stronger earthquake may have been less perceptible simply because it occurred at a greater distance and deeper in the earth.

The determination of key earthquake parameters was previously based on the propagation of waves in the environment, and was mainly determined by people's perceptions and the destruction caused in the research area. Previously, such evaluations were made by assessing the earthquake's strength based on human sensations, the damage to buildings, and visual inspections of the surrounding geological environment. Changes in production in the oil wells of oil fields were also analyzed according to such evaluations.

In the research conducted by scientists, considering the importance of the results obtained for ensuring safe operation of exploitation processes and completing new wells without accidents, seismic epicentral maps were used to assess the potential impact of earthquakes on oil fields.

Although this data is important for the future monitoring of the exploitation dynamics of the field, regulating water influx in the exploited layers, and reducing certain risks in the field, its degree of accuracy was very low. For example, during the earthquake that occurred on June 3, 2005, in the Caspian Sea with a magnitude of 4 according to the MSK-64 scale, the potential impact in the Bulla-Deniz oil and gas field was estimated to be observed with an intensity of 2.5-3 on the epicenter map scheme [11]. The impact of the earthquake was observed with a magnitude of 2-3 in the Bulla-Deniz oil and gas field (fig. 1).

The comparative assessment of the potential impact of earthquakes on oil fields is of a qualitative nature. Since it is based on logical reasoning, quantitatively substantiating the dynamic changes caused by the earthquake in the geological environment does not always yield accurate scientific

results. For example, the distribution map of the effects of the earthquake that occurred on February 4, 2006, in the Altyaghach and Khizi areas has been prepared (fig. 2). The impact of this earthquake was also determined to be in the 3-magnitude impact zone in the Bulla-Deniz oil and gas field. Another earthquake occurred on October 7, 2012, in the Ismayilli area, and a map diagram of the earthquake was prepared (fig. 3).The impact of this earthquake on the Bulla-Deniz oil and gas field was assessed to be of magnitude 3. The earthquake that occurred near the city of Hajigabul on February 10, 2014 (fig. 4) had an impact of 3 magnitude in the Bulla-Deniz oil and gas field. On August 1, 2016, an earthquake occurred near Imishli, and the map diagram of the earthquake (fig. 5) shows that the impact in the Bulla-Deniz oil and gas field was magnitude 3 [11].

As it is obvious from the epicenter maps of the earthquakes that occurred, their impact on the Bulla-Deniz oil field region, with an intensity of approximately 3 on the MSK-64 scale, could potentially alter oil production. To date, the impact of earthquakes that occurred both in Azerbaijan and other countries on oil fields has been studied in this way. The geodynamic characteristics of the environment between the epicenter of the earthquake and the well – where oil extraction is being carried out – have not been considered. In the diagrams provided above (fig. 1, 2), the earthquakes occurred in different geological zones, tectonic blocks, and various lithological rock complexes. Until now, earthquakes were selected without considering the geological environment. In contrast, in the Lower Kur depression, changes in oil production in wells due to the impact of earthquakes were analyzed using a slightly different methodology. In these analyses, based on the research of S. I. Zubkov and V. A. Morqunov, earthquakes were selected based on their energy class [9, 12].

When we began our research, we initially chose earthquakes based on the methods outlined earlier. In accordance with the outlined methodological approach, we identified parameters for earthquakes with a magnitude of $M \geq 3$ that occurred between 2018 and 2024, the effects of which were likely to be observed in the structure of the Bulla-Deniz oil field, based on their epicentral distance (table 1).

The research conducted so far has shown that the previously applied approach was not very effective. The results revealed that this approach does not take into account the propagation of seismic waves in different environments; rather, the impact of earthquakes is evaluated based on macroseismic indicators. In classifying earthquakes based on their epicentral distance and energy, the propagation characteristics of seismic waves in the environment and the geodynamic-tectonic features of the region are not thoroughly assessed.

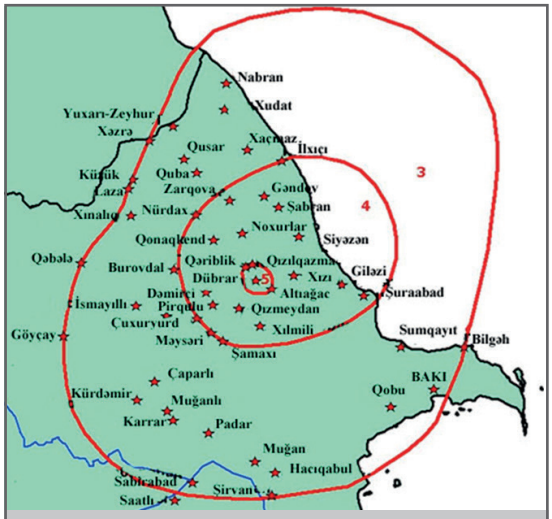


**Fig. 2. Map diagram of the earthquake that occurred in the Khizi area on February 4, 2006**

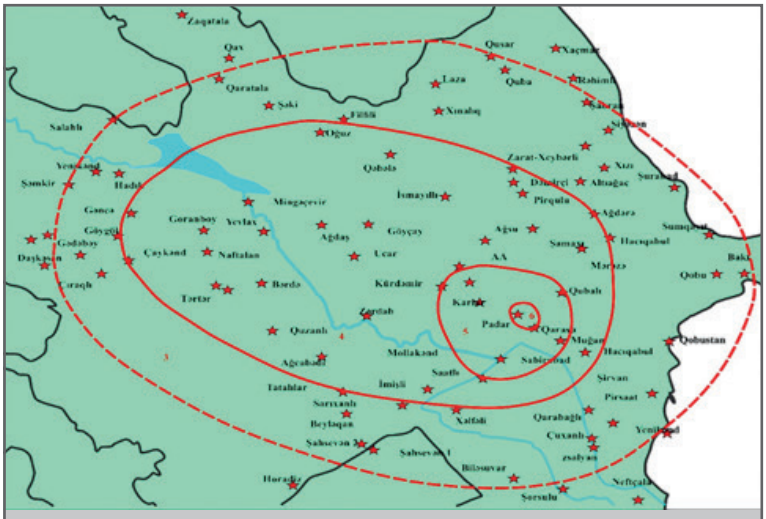


**Fig. 3. Map diagram of the earthquake that occurred in the Ismayilli area on October 7, 2012**

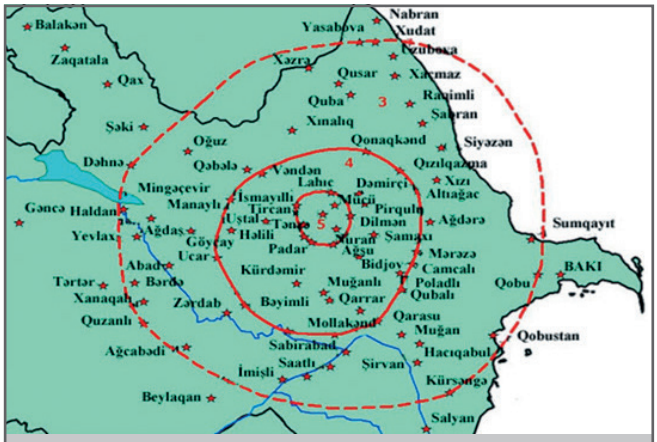


**Fig. 4. Map diagram of the earthquake that occurred in the Hajigabul area on February 10, 2014**

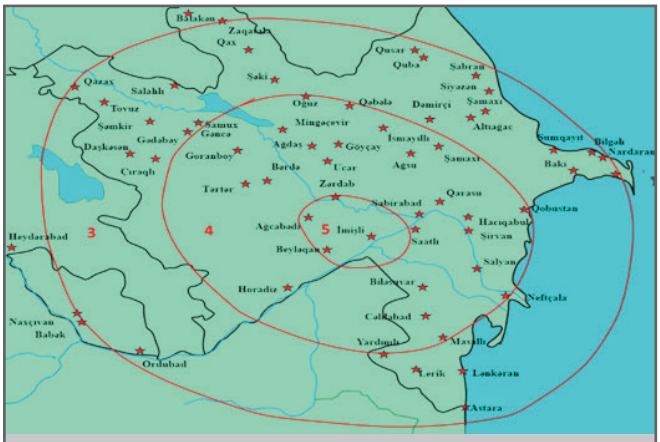


**Fig. 5. Map diagram of the earthquake that occurred in the Imishli area on August 1, 2016**

Taking these factors into account, we decided to evaluate the geodynamic impact of the earthquakes on oil fields using a different approach method.

In order to investigate the potential geodynamic impact of an earthquake on the Bulla-Deniz oil field, we developed a new approach that considers the magnitude ($M$) of the earthquake, the geodynamic energy accumulated at the earthquake source equivalent to the earthquake's magnitude ($E$, Coul), the impact radius ($\Delta R$) of the earthquake based on its epicentral distance, and the time period ($\Delta t$) for the accumulation of geodynamic energy at the earthquake source.

In investigating the impact of earthquakes on oil production in oil fields, we found that using the magnitude unit to select earthquakes, considering the changes occurring in the environment, would yield more accurate results. Based on this, we developed a new methodology.

The magnitude is named according to the type of wave: surface wave magnitude ($M_s$); local magnitude ($M_l$); body

**Table 1**
**Earthquakes ($M \geq 3$) impacting Bulla-Deniz oil and gas field (2018-2024)**

| year | time | lat | lon | h | ml |
|---|---|---|---|---|---|
| 01.01.2018 | 9:11:23 | 40.86 | 48.38 | 7.84 | 3.93 |
| 28.08.2018 | 12:57:14 | 38.72 | 48.63 | 15.39 | 5.02 |
| 26.09.2018 | 1:03:14 | 40.54 | 51.71 | 44.53 | 3.25 |
| 02.03.2019 | 16:52:14 | 40.38 | 51.81 | 5 | 3.01 |
| 06.04.2019 | 8:33:49 | 40.73 | 50.67 | 62 | 3.79 |
| 06.04.2019 | 19:09:28 | 40.66 | 50.47 | 58 | 3.16 |
| 07.04.2019 | 8:27:24 | 41.28 | 46.60 | 4 | 4.54 |
| 07.06.2019 | 14:25:45 | 40.41 | 51.98 | 39 | 3.3 |
| 29.06.2019 | 6:56:03 | 40.58 | 51.91 | 58 | 3.44 |
| 10.09.2019 | 16:22:47 | 41.06 | 44.06 | 10 | 5.08 |
| 27.09.2019 | 19:17:23 | 41.23 | 48.24 | 38 | 3.34 |
| 29.09.2019 | 10:29:01 | 40.42 | 51.81 | 8 | 3.19 |
| 09.10.2019 | 3:06:33 | 40.42 | 51.79 | 28 | 4.44 |
| 09.10.2019 | 5:33:08 | 41.62 | 49.20 | 9 | 3.44 |
| 21.10.2019 | 6:58:28 | 40.71 | 51.69 | 62 | 4.33 |
| 21.10.2019 | 20:57:40 | 40.45 | 51.87 | 25 | 3.78 |
| 22.10.2019 | 7:14:09 | 39.30 | 51.82 | 56 | 3.05 |
| 19.12.2019 | 23:57:31 | 40.97 | 49.17 | 43 | 3.37 |
| 20.01.2020 | 16:53:04 | 40.96 | 49.00 | 42 | 3.08 |
| 25.01.2020 | 23:43:15 | 39.52 | 51.47 | 59 | 3.34 |
| 15.02.2020 | 21:45:40 | 38.17 | 48.25 | 2 | 4.71 |
| 22.02.2020 | 3:05:24 | 40.24 | 48.81 | 8 | 3.84 |
| 23.02.2020 | 0:43:45 | 40.24 | 48.75 | 3 | 3.45 |
| 27.02.2020 | 10:17:34 | 39.65 | 51.48 | 45 | 4.45 |
| 27.02.2020 | 10:25:16 | 39.70 | 51.38 | 45 | 3.32 |
| 05.03.2020 | 12:19:01 | 40.58 | 51.64 | 62 | 3.80 |
| 20.03.2020 | 13:32:52 | 39.98 | 50.99 | 59 | 3.13 |
| 21.03.2020 | 15:43:47 | 39.92 | 51.54 | 35 | 3.26 |
| 20.04.2020 | 23:31:48 | 40.05 | 52.91 | 40 | 4.50 |
| 30.08.2020 | 20:35:55 | 40.40 | 51.73 | 33 | 4.21 |
| 26.09.2020 | 7:00:26 | 39.36 | 53.75 | 10 | 5.03 |
| 22.10.2020 | 12:52:55 | 40.98 | 48.07 | 11 | 3.62 |
| 07.02.2021 | 17:03:56 | 40.03 | 52.68 | 40 | 3.33 |
| 08.02.2021 | 4:12:23 | 40.30 | 48.74 | 3 | 3.73 |
| 08.02.2021 | 4:10:27 | 40.21 | 48.88 | 2 | 3.98 |
| 08.02.2021 | 4:11:11 | 40.27 | 48.81 | 2 | 3.86 |
| 21.03.2021 | 1:45:30 | 40.53 | 52.07 | 59 | 3.51 |
| 10.08.2021 | 17:57:34 | 40.38 | 52.02 | 62 | 3.96 |
| 30.09.2021 | 0:53:52 | 40.16 | 52.29 | 62 | 3.25 |

**Table 1 continued**

| year | time | lat | lon | h | ml |
|---|---|---|---|---|---|
| 26.11.2021 | 23:44:43 | 40.13 | 51.60 | 62 | 3.43 |
| 30.11.2021 | 9:22:15 | 39.28 | 49.49 | 6 | 3.29 |
| 30.11.2021 | 9:21:27 | 40.23 | 50.83 | 62 | 3.78 |
| 15.12.2021 | 1:17:50 | 39.36 | 48.67 | 24 | 3.52 |
| 29.12.2021 | 9:15:45 | 41.92 | 48.39 | 51 | 3.87 |
| 14.01.2022 | 13:45:36 | 39.53 | 49.10 | 45 | 3.05 |
| 15.01.2022 | 2:13:16 | 39.15 | 52.11 | 52 | 3.09 |
| 16.01.2022 | 3:25:06 | 39.12 | 46.55 | 8 | 4.86 |
| 10.02.2022 | 14:58:28 | 38.13 | 48.11 | 9 | 4.02 |
| 01.04.2022 | 19:24:32 | 40.33 | 51.78 | 23 | 3.79 |
| 20.04.2022 | 7:13:27 | 39.52 | 53.34 | 10 | 3.99 |
| 23.04.2022 | 7:37:34 | 41.04 | 50.40 | 24 | 3.5 |
| 03.06.2022 | 17:00:54 | 40.53 | 51.74 | 62 | 3.33 |
| 23.07.2022 | 16:12:04 | 38.06 | 48.54 | 0 | 3.68 |
| 28.07.2022 | 2:17:54 | 39.92 | 52.77 | 15 | 4.11 |
| 31.07.2022 | 14:35:12 | 39.24 | 48.18 | 12 | 3.3 |
| 12.08.2022 | 11:26:45 | 40.48 | 50.46 | 62 | 3.48 |
| 28.08.2022 | 23:52:16 | 39.55 | 52.15 | 60 | 4.09 |
| 05.10.2022 | 0:21:26 | 38.56 | 45.01 | 3 | 5.87 |
| 12.10.2022 | 23:52:49 | 40.14 | 50.07 | 62 | 3.02 |
| 24.10.2022 | 3:38:24 | 40.68 | 51.86 | 62 | 4.25 |
| 29.10.2022 | 13:50:45 | 40.45 | 48.83 | 4 | 3.58 |
| 30.10.2022 | 4:08:12 | 40.43 | 48.88 | 4 | 3.09 |
| 24.12.2022 | 8:04:25 | 40.53 | 51.72 | 45 | 3.12 |
| 07.01.2023 | 2:31:29 | 38.99 | 49.43 | 14.45 | 3.21 |
| 16.01.2023 | 12:09:33 | 40.61 | 48.82 | 8.01 | 3.14 |
| 18.01.2023 | 10:08:09 | 38.54 | 44.82 | 2.01 | 5.95 |
| 28.01.2023 | 18:16:55 | 38.55 | 44.89 | 10.18 | 4.89 |
| 31.01.2023 | 2:54:07 | 40.97 | 48.23 | 12.14 | 3.75 |
| 22.02.2023 | 7:25:10 | 38.83 | 48.47 | 26.92 | 3.08 |
| 08.03.2023 | 6:14:35 | 39.45 | 48.36 | 39.26 | 4.2 |
| 24.03.2023 | 3:16:54. | 38.40 | 44.87 | 9.89 | 5.73 |
| 26.03.2023 | 15:32:34 | 40.17 | 51.47 | 62.04 | 3.06 |
| 12.06.2023 | 1:09:56 | 40.63 | 51.57 | 55.76 | 3.42 |
| 03.07.2023 | 20:01:52 | 41.52 | 49.10 | 66.42 | 5.55 |
| 13.07.2023 | 5:51:06 | 40.07 | 49.08 | 34.40 | 3.47 |
| 26.07.2023 | 7:03:10 | 38.85 | 48.59 | 5.56 | 4.77 |
| 08.08.2023 | 15:48:34 | 40.59 | 51.63 | 62.00 | 3.28 |
| 16.09.2023 | 22:51:27 | 40.46 | 51.88 | 62.00 | 4.6 |

wave magnitude ($M_b$); seismic moment magnitude ($M_w$), which refers to the seismic moment or tectonic rupture moment. In international earthquake catalogs, the magnitude is provided using the $M_w$ unit. The magnitude of the occurring earthquake is calculated using the following formula:

$$M = \log A_1 / A_2$$

A new methodology has been developed to classify earthquakes based on magnitude and determine the geodynamic impact of seismic events on oil production wells in oil fields. This methodology considers the propagation of seismic waves in the environment. Magnitude is a quantitative indicator that reflects the geological and mechanical variability of the environment.

For the first time in Azerbaijan, a methodology for selecting and determining earthquakes with observable effects on a specific field – using the example of the Bulla-Deniz oil and gas field – has been developed. While previous literature has mentioned the influence of geodynamic processes on the increase or decrease in oil production, no field has been examined in detail with a special methodological approach to analyze the impact of earthquakes on production changes, using actual data, statistical calculations, and graphs.

In our research, considering these factors, we have conducted seismological-geophysical investigations in the Bulla-Deniz oil and gas field with a slightly different approach, aiming to evaluate the potential impact of seismic risks on changes in oil production in the wells, based on factual data and using a new methodological approach.

## The modern method for evaluating the impact of earthquakes on oil production in exploitation wells of oil reservoirs in the area

In the Bulla-Deniz oil and gas field, the geodynamic stress and exploitation risks created in the reservoir complexes during periods of geodynamic activation observed due to the impact of earthquakes on the exploitation wells have been determined. To assess this, the parameters of potentially observable earthquakes in the Bulla-Deniz oil and gas field have been considered, and the seismic-geodynamic activity conditions were evaluated.

The anomalous activation periods of earthquakes, which may cause changes in oil production in the wells of the Bulla-Deniz oil and gas field and have a risk impact, have been identified using the newly developed method.

In the Bulla-Deniz oil and gas field, pressure differences caused by geological-geodynamic changes are directly related to the reservoir characteristics of the rocks in the layers and the diffusion processes. Several other geodynamic processes also anomalously alter the pressure variations in the layers and the reservoir characteristics of the rocks. These factors include tectonic shifts, earthquakes, active mud volcanoes, and other active processes [13]. Although it is difficult to constantly study the effects of such endogenous forces and pressure variations in the exploitation layers of the reservoir, an attempt has been made to assess the potential impact of recent earthquakes in the Bulla-Deniz oil and gas field and their possible effect on production changes in the field.

The study area of the Bulla-Deniz oil and gas field is limited by the following coordinates in the WGS-84 geographic coordinate system:

1. 40°03' 29.64" N, 49°44' 34.53" E
2. 39°58' 08.60" N, 49°54' 10.21" E
3. 39°54' 52.80" N, 49°53' 21.80" E
4. 39°49' 16.42" N, 49°48' 14.22" E
5. 39°47' 45.44" N, 49°45' 18.75" E
6. 39°49' 03.12" N, 49°41' 53.74" E
7. 39°52' 11.06" N, 49°36' 51.06" E
8. 39°52' 59.55" N, 49°35' 56.44" E
9. 39°58' 26.96" N, 49°38' 04.10" E
10. 40°01' 54.97" N, 49°41' 47.63" E

To clarify the patterns of production changes that may arise from the impact of earthquakes on the exploitation wells in the reservoir area, a common point has been selected within the boundaries of the Bulla-Deniz oil and gas field structure (fig. 6).

The coordinates of the central point of the Bulla-Deniz oil and gas field structure in the WGS-84 coordinate system are 39°52'19.480" N, 49°46'06.707" E. From this point, the energy accumulation time ($\Delta t$) corresponding to the amount of geodynamic energy ($E$, Coul) at the epicenter of the earthquakes included in the study, as well as the impact radii ($\Delta R$) of the earthquakes, have been determined based on the hypocentral distance. These impact radii have been used to select earthquakes that may affect oil production in the Bulla field, and a map has been created (fig. 6).

To uncover the patterns of production changes in the reservoir complexes due to geodynamic processes, earthquakes, mud volcanoes, and other factors in the Bulla-Deniz oil and gas field, a new methodological approach was developed. This was based on parameters of earthquakes observed in the field (such as the time of occurrence, geographical coordinates of the earthquake epicenter, depth of the hypocenter, geometric and volumetric measurements of the epicenter, energy accumulation time of geodynamic stress at the epicenter, etc.). The catalogs prepared by the Republic Seismological Service Center under the Azerbaijan National Academy of Sciences (ANAS) were utilized.

In the reservoir layers of the field, changes in the physical-mechanical properties of rocks that could be anomalous due to earthquakes were analyzed. The amount of geodynamic stress energy accumulated at the epicenter of the

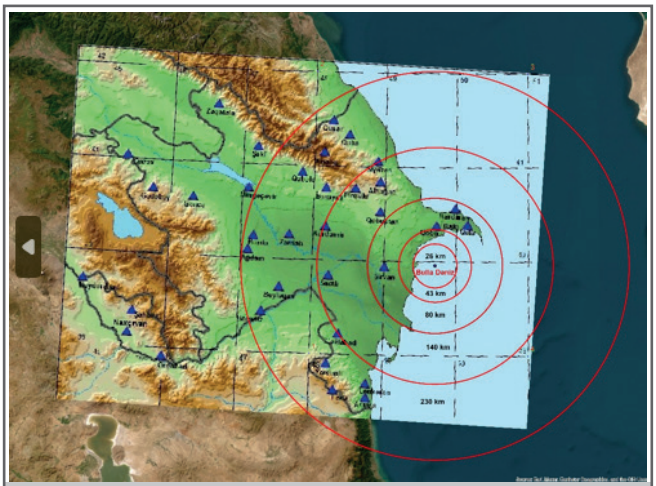


**Fig. 6. Schematic representation of the location of the selected central point with coordinates of the Bulla-Deniz oil and gas field structure in the WGS-84 coordinate system: 39°52'19.480" N, 49°46'06.707" E**

earthquake (*E*, Coul), the earthquake magnitude (*M*), and the distance from the epicenter to the oil reservoir were taken into account to calculate the changes in geophysical fields. Relevant formulas were used for these calculations. The parameters that may be caused by the impact of earthquakes and lead to changes in oil production in the wells were calculated.

A diagram was constructed to determine the impact radius of the energy generated by the earthquake in the geological environment according to the magnitude of the earthquake (fig. 7). The potential elastic strain energy radiating from the epicenter and the effect distance that could cause changes in the oil and gas layers in the Bulla-Deniz oil and gas field was calculated using the following formula: ($R=10^{0.43M-1.29}$ and $R=10^{0.40M-1.45}$, km).

The impact radius corresponding to the earthquake's magnitude is calculated as follows:

$$\Delta R=10^{0.43M},\ \text{km}$$

The period during which potential stress energy accumulates in the earthquake source:

$$\Delta t=10^{0.74M-4.60},\ \text{year}$$

A table has been constructed for selecting earthquakes that could impact the Bulla-Deniz oil and gas field using these formulas (table 2).

The table of energy accumulation time ($\Delta t$, days) and impact distance ($\Delta R$, km) changes depending on the magnitude ($M$) of the earthquakes to be observed in the Bulla-Deniz oil and gas field.

In the preparation of the table, the impact radius ($\Delta R$) corresponding to the magnitude ($M$) of the earthquakes was determined using a diagram. Within the impact area of the earthquake, the anomalous increase in geodynamic stress leads to changes in various characteristics, such as the elasticity modulus of the layer, specific resistance in the layer-collectors, porosity in the rocks, the permeability coefficient of hydrocarbons, the water saturation coefficient, the resistance ratio, and other properties. These changes are considered to determine the impact distance ($\Delta R$) based on the earthquake magnitude ($M$) (fig. 7).

Based on the data provided in table 1, the earthquakes impacting the Bulla-Deniz oil and gas field have been selected, and anomalous activation periods in the oil field area have been determined. For example, considering the impact radius ($\Delta R$) of the earthquake of the Baku-Caspian Sea on November 25, 2000, with an influence up to $\Delta R=500$ km, the energy accumulation period of this earthquake at the epicenter was $\Delta t=260$ days, and it was determined that the Bulla-Deniz oil and gas field fell within its impact zone.

The earthquakes observed in the Bulla-Deniz oil and gas field and its surroundings from 2003 to 2024 were selected based on the new methodological approach (table 2).

Based on the new methodological approach, the impact of earthquakes with a magnitude greater than 3, occurring in Azerbaijan between 2003 and 2024, on the Bulla-Deniz oil and gas field has been identified. Taking into account the impact distances of the occurring earthquakes, an analysis was conducted to determine the parameters of earthquakes that could induce anomalous variations in the Bulla-Deniz oil and gas field.

The epicenter map of the earthquakes that could potentially affect the production in the exploitation wells of the Bulla-Deniz oil and gas field during the period from 2020 to 2024 was created at a scale of 1:1,000,000. Additionally, a graph showing the magnitude of the earthquakes over the years was developed (fig. 8).

In the Bulla-Deniz oil and gas field, when studying the change in production in well No. 123 throughout the year and the impact of earthquakes in the region and the field area, it was determined that, unlike single earthquakes, a series of earthquakes (9 earthquakes with magnitudes ranging from 3.3 to 4.5, consecutive) caused a more significant and characteristic change in production (fig. 8). The first series of earthquakes occurred in the Lower Kur Depression, 20-25 km away from well No. 123, between February 22-23, 2020. Subsequent seismic events continued as aftershocks in the South Caspian Depression, located 45-50 km in the opposite

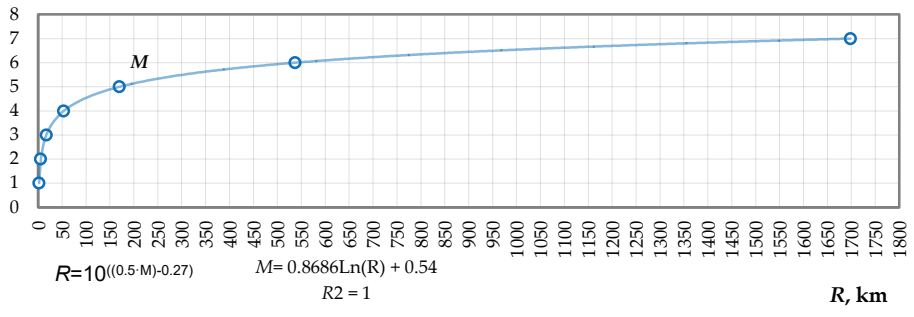


**Fig. 7. A diagram constructed for determining the impact distance ($\Delta R$) based on the magnitude ($M$) of earthquakes**

**Table 2**

**Earthquake selection in Bulla-Deniz oil and gas field (2003-2024) based on New Approach**

| Magnitude (M) | 1.5 | 2.1 | 2.7 | 3.3 | 3.8 | 4.4 | 5.0 | 5.5 |
|---|---|---|---|---|---|---|---|---|
| Earthquake impact distance ($\Delta R$), km | 4.5 | 8.0 | 15.0 | 26.0 | 43.0 | 80.0 | 140.0 | 230.0 |
| According to the amount of energy (*E*, Coul) Collection period ($\Delta t$), day | 3 hour | 8 hour | 1 day | 2.5 day | 6 day | 17 day | 50 day | 180 day |

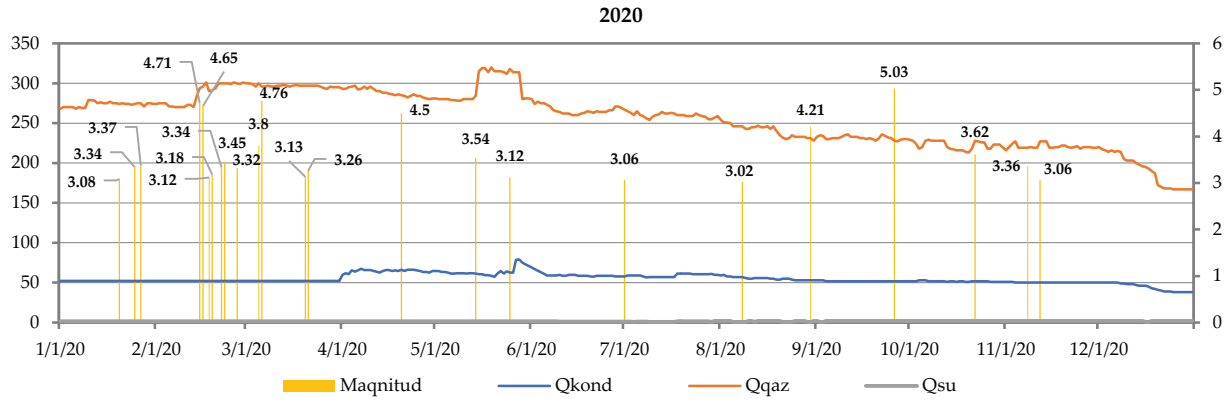


**Fig. 8. Graphs of the statistical monitoring of oil and gas production in the exploitation wells of the Bulla-Deniz oil and gas field, showing the earthquakes with magnitudes $M \geq 3$ that occurred in 2020 in well No. 123**

direction, between February 27 and March 21, 2020, originating from the same epicenters. During this period, increased activity was also observed in nearby epicenters.

In well No. 123 of the Bulla-Deniz oil and gas field, during the period from March 30, 2020, to September 6, 2020 (5 months), a significant change in oil production was observed, with an increase from 52.4 to 79 tons/day, reaching up to 27-28 tons/day. The change in gas production occurred slightly earlier than the oil production change in the same well: on February 14, 2020, gas production was observed at -294 thousand m³/day, and before oil production returned to its previous levels, by June 10, 2020, gas production had normalized at 262 thousand m³/day. Thus, the patterns of production change before and after the earthquakes were studied, and it was determined that oil production increased by 5-25 % in the wells' production dynamics.

## Conclusions

1. The distribution of the number of earthquakes ($N$, count) and depth ($H$, km) in the territory of Azerbaijan and its surroundings from 2003 to 2024 has been determined by a graph, revealing that the most active interval is within the 0-20 km range (earthquake count - 38.688).
2. In the case of the Bulla-Deniz oil and gas field, to investigate the geodynamic impact of earthquakes on oil production in exploitation wells, the magnitude ($M$) of the earthquake, the duration ($\Delta t$) of the accumulation of geodynamic energy ($E$) at the earthquake focus, and the hypocentral distance from the earthquake focus were considered. Based on this, the impact distance ($\Delta R$) of the earthquakes were calculated, and a new methodological approach was developed to select earthquakes that could affect oil production in the exploitation wells.
3. Using the new methodological approach, earthquakes that could impact the exploitation wells of the Bulla-Deniz field were selected. The fields of earthquake occurrence were determined based on the magnitude of the earthquakes, hypocentral distance, and energy accumulation duration.
4. A nomogram diagram was constructed to determine the affected area of the selected earthquake according to its magnitude. Based on this diagram, the impact radius of the earthquake was calculated, and earthquakes were selected. Anomalous activation periods in the oil field were identified.
5. During the analysis, a new effect was discovered: within the calculated impact radii, the oil production in the exploitation wells changed more significantly under the influence of sequential series of earthquakes occurring simultaneously. For the first time, in the case of the Bulla-Deniz field, the production change patterns before and after the earthquake were studied in wells located in different tectonic blocks. It was determined that production in these wells increased by 5-25 %.

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