

DOI: 10.46698/VNC.2025.64.62.001

Original paper

On the seismicity of the Karabakh and East Zangezur territories of Azerbaijan

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Received: 02.07.2025, revised: 01.09.2025, accepted: 03.09.2025

Abstract: Relevance. This paper examines the seismic and tectonic characteristics of Azerbaijan, with emphasis on the Karabakh and Eastern Zangezur regions. The study is relevant because the absence of seismic stations in these areas has led to a prolonged lack of systematic observations. **Aim.** The main objective is to analyze the seismicity of the Karabakh and Eastern Zangezur zones in greater detail and to identify their specific features. **Methods.** The research considers the spatial and temporal distribution of earthquakes and their relationship with regional tectonics. Azerbaijan is a seismically active territory where both strong and moderate earthquakes have occurred. The epicenters of major events are concentrated mainly along the southern slope of the Greater Caucasus. In the Lesser Caucasus, large earthquakes are less frequent but have been recorded in Ganja, Kalbajar, and Agdam, as well as in the Lerik and Masalli districts. In the Kura depression, earthquake foci are observed but less densely distributed. A significant clustering of strong earthquake epicenters is also noted in the Caspian Sea – 60–70 km north, 100–120 km east, and about 50 km south of the Absheron Peninsula. Weak tremors are unevenly distributed, mainly in the eastern Greater Caucasus, often coinciding with strong earthquake zones. **Results.** Unlike many seismically active regions of Azerbaijan, the Karabakh and Eastern Zangezur zones (except the Kalbajar district and its eastern part) are considered aseismic, owing to the absence of active faults. However, seismic hazard may still arise from neighboring, more active regions.

Keywords: earthquakes, seismicity, epicenter map, tectonics, aseismicity, earthquake source, faults.

Acknowledgment: *This work was supported by the Azerbaijan Science Foundation-Grant No. AEF-MGC-2024-2(50)-16/05/2-M-05.*

For citation: Mammadli T.Ya. On the seismicity of the Karabakh and East Zangezur territories of Azerbaijan. *Geologiya i Geofizika Yuga Rossii = Geology and Geophysics of Russian South*. (in Russ.). 2025. 15(3): 128-135. DOI: 10.46698/VNC.2025.64.62.001

УДК 550.34

DOI: 10.46698/VNC.2025.64.62.001

Оригинальная статья

О сейсмичности Карабахской и Восточно-Зенгезурской областей территории Азербайджана

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Статья поступила: 02.07.2025, доработана: 01.09.2025, принята к публикации: 03.09.2025

Резюме: Актуальность работы. В данной работе рассматриваются сейсмические и тектонические особенности Азербайджана, с акцентом на Карабахский и Восточно-Зангезурский регионы. Актуальность определяется отсутствием сейсмических станций в этих районах, что привело к длительному отсутствию систематических наблюдений. **Цель исследования.** Основная цель заключается в более детальном анализе сейсмичности Карабахской и Восточно-Зангезурской зон и выявлении их специфических особенностей. **Методы.** В работе рассматриваются пространственно-временные особенности распределения землетрясений и их связь с региональной тектоникой. Азербайджан является сейсмически активной территорией, где происходили как сильные, так и умеренные землетрясения. Эпицентры крупных событий сосредоточены главным образом на южном склоне Большого Кавказа. В пределах Малого Кавказа сильные землетрясения наблюдаются реже, однако они зафиксированы в районах Гянджа, Кельбаджар и Агдам, а также в Лерикском и Масаллинском районах. В Кюрской впадине очаги землетрясений встречаются, но распределены менее плотно. Значительное скопление эпицентров сильных землетрясений отмечается и в Каспийском море – в 60–70 км к северу, 100–120 км к востоку и около 50 км к югу от Апшеронского полуострова. Слабые толчки распределены крайне неравномерно, преимущественно в восточной части Большого Кавказа, и чаще всего совпадают с зонами сильных землетрясений. **Результаты.** В отличие от многих других сейсмоактивных регионов Азербайджана, Карабахская и Восточно-Зангезурская зоны (за исключением Кельбаджарского района и его восточной части) считаются асейсмичными, что объясняется отсутствием активных разломов. Тем не менее, сейсмическая угроза для этих регионов может исходить от соседних, более активных зон.

Ключевые слова: землетрясения, сейсмичность, карта эпицентров, тектоника, асейсмичность, очаг землетрясения, разломы.

Благодарности: Работа выполнена при финансовой поддержке Азербайджанского научного фонда в рамках проекта № AEF-MGC-2024-2(50)-16/05/2-M-05.

Для цитирования: Маммадли Т.Я. О сейсмичности Карабахской и Восточно-Зангезурской областей территории Азербайджана. *Геология и геофизика Юга России*. 2025. 15(3):128-135. DOI: 10.46698/VNC.2025.64.62.001

Introduction

In the Karabakh and East Zangezur regions of Azerbaijan, seismic research has not been conducted for about 30 years. It is worth noting that these studies were not widely developed even during the Soviet era. Seismic stations in this region were opened in the mid-1980s in the Jebail, Kalbacar, and Aghdam districts. Thus, the seismicity of this area

has not been investigated. Currently, the region is undergoing reconstruction. Large cities, roads, bridges, tunnels, airports and other civil and industrial facilities are being built. All this makes the study of the seismicity of this territory relevant, which is necessary for assessing the seismic hazard and risk.

Seismicity manifestations in the territory of Azerbaijan

The territory of Azerbaijan is characterized by fairly high seismic activity. Strong earthquakes have repeatedly occurred here, examples of which are the earthquakes of Gandja ($M \gg 6.7$, $I_0 \gg 9$ points) in 427, ($M \gg 6.8$, $I_0 \gg 9$ points) in 1139 and Shamakhi ($M \gg 7.0$, $I_0 \gg 9-10$ points) in 1667, ($M \gg 6.9$, $I_0 \gg 9-10$ points) in 1902. During the Gandja earthquake of 1139, the largest lake in Azerbaijan, Goygol, was formed. The earthquake that occurred in Shamakhi in 1667 ($M \gg 7.0$, $I_0 \gg 9-10$ points) is considered the strongest earthquake in the Caucasus. Data from that time indicate that rock avalanches during this earthquake claimed the lives of more than 80,000 people [New Catalogue, 1977]. This earthquake was followed by strong aftershocks over the next few years, with an Intensity of 8 on the MSK-64 scale at the epicenter.

In addition to strong ones, numerous weak ($M < 4.0$) and moderate ($M = 4.0-5.5$) earthquakes occur annually in Azerbaijan. Moderate earthquakes usually caused cracks in houses and rarely resulted in destruction. Such earthquakes include Ismayilli ($M = 5.1$) of 1981, Aghdash ($M = 4.9$) of 1999, Caspian (Baku) ($M = 6.2$) of 2000, Zagatala ($M = 5.6$) of 2012, Shamakhi-Ismayilli-Akhsu ($M = 5.1$) of 2019. Maps of the earthquake epicenters of different magnitudes allow us to judge the features of seismicity in the territory of Azerbaijan.

The map of strong earthquake epicenters (with $M \geq 5.0$) in Azerbaijan for the period 427-2024, constructed using the earthquake catalogue (fund of the Seismic Survey Center of ANAS), shows that strong earthquakes occurred rarely and not everywhere (fig. 1). The epicenters of strong earthquakes are mainly concentrated in certain areas of the southern slope of the Greater Caucasus, which are separated by less active or aseismic zones. Moreover, the densest cluster is characteristic for the Shamakhi-Ismayilli region. High seismic activity is also observed in the northeast of the Republic (in Guba, Gusar and Khachmaz regions).

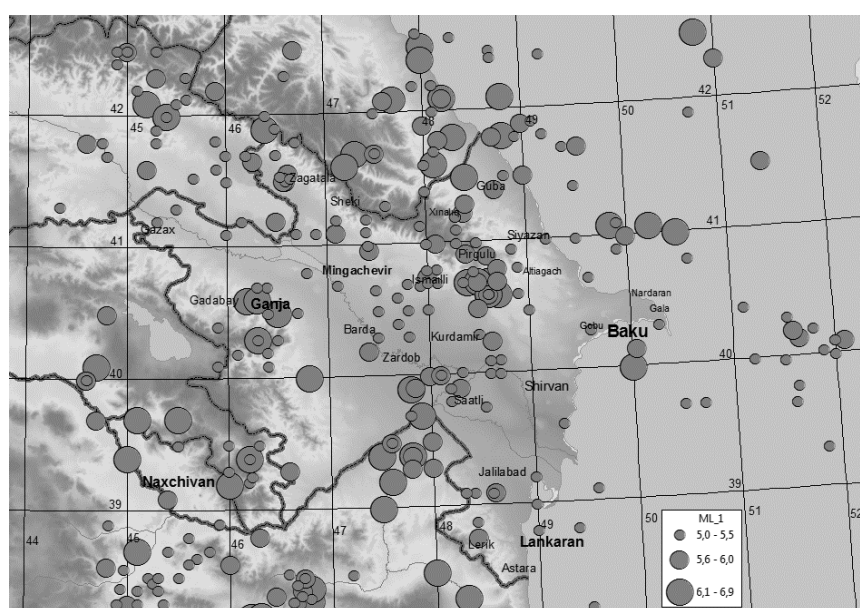


Fig. 1. Map of earthquake epicenters with $M \geq 5.0$ in the territory of Azerbaijan for the period 427-2024

To the south of the eastern part of the Greater Caucasus – within the Kura Depression, there are sources of strong earthquakes, although they are not distributed so densely.

In the Azerbaijani part of the Lesser Caucasus, rare strong earthquakes are observed in Gandja, Kalbajar and Aghdam, as well as in Lerik and Masalli regions.

The epicenters of strong earthquakes are concentrated in the Caspian Sea – approximately 60-70 km north, 100-120 km east and 50 km south of the Absheron Peninsula.

The analysis shows that within Azerbaijan, weak seismic tremors are also distributed extremely unevenly (fig. 2). The overwhelming majority of earthquakes occur in the eastern part of the Greater Caucasus. It should be noted that this region is characterized by such an uneven distribution. There is a concentration of earthquake epicenters in some places and a small number of them or their absence in others.

Here, an increased concentration of epicenters is noted in the zones of occurrence of strong earthquakes – in the area between the cities of Balakan and Zagatala, in the Oghuz region, to the east of the Gabala meridian, as well as in the Ismailly and Shamakhi regions. These zones of accumulation of seismic tremors are separated by areas characterized by a small number of earthquakes, or their complete absence.

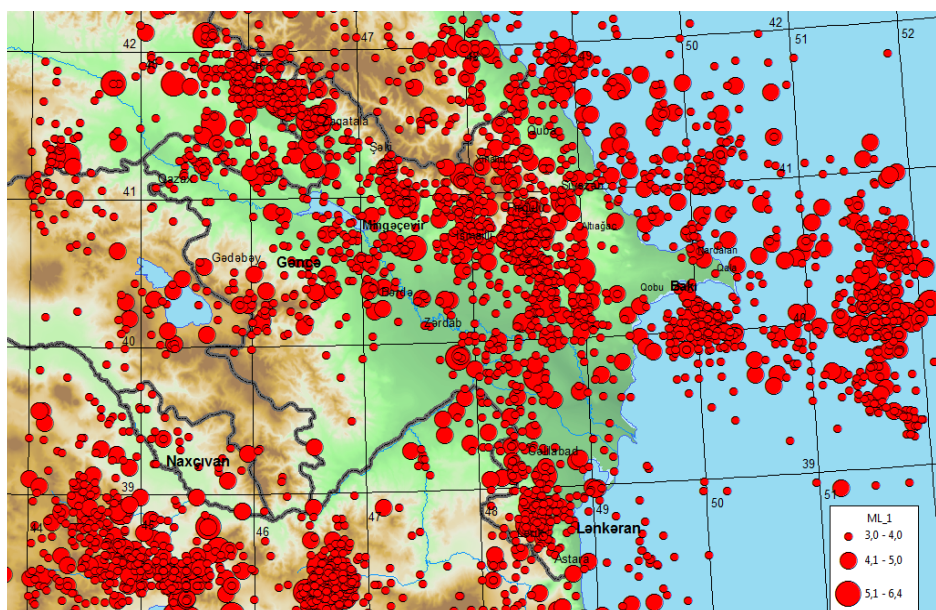


Fig. 2. Map of earthquake epicenters with $M \geq 3.0$ in the territory of Azerbaijan for the period 1980-2024

An increased level of weak seismicity is also characteristic of all source zones in the Kura Depression (Aghdash, Kurdamir, Zardab, Imishli districts), the Azerbaijani part of the Lesser Caucasus (Gandja and Kalbajar districts). A high concentration of weak earthquake sources is characteristic of the Lerik and Masalli districts.

In addition to the above seismically active areas, there are also separate aseismic zones in Azerbaijan.

These zones include the Absheron Peninsula with its western part (up to the meridian of 49° E), a small zone north of the Gadabay region (the zone between $40,5^\circ$ and 41° N and from the border with Armenia to 46° E), and a fairly large territory covering the areas of the Karabakh and East Zangezur regions. Within these zones, isolated epicenters of seismic tremors are observed or they are absent altogether. Thus, the territory of Azerbaijan can be considered a unique seismological laboratory, where nature conducts various

experiments: in one case, the depression zone (east of the meridian of 49° E, including the Absheron Peninsula, as well as the flat part of Karabakh) is aseismic, i.e. isolated epicenters of seismic tremors are observed, in another case the same zone (Kura Depression) is characterized by high seismicity. On the other hand, one mountain-fold system (the eastern part of the Greater Caucasus) is characterized by increased seismicity, and at the same time another mountain-fold system – in East Zangezur – does not have seismic tremors. All this shows that the zones of occurrence of earthquakes are not connected in any way by the geomorphological conditions of the area.

Tectonic substantiation of seismicity of the territory of Azerbaijan

Scientists have long established that strong and destructive earthquakes are confined to fault zones [Caputo et al., 1980; Gamburtsev, 1955; Gelfand et al., 1972]. It should be noted that weak and medium-strength earthquakes also occur in fault zones. The fact is that an indispensable condition for the occurrence of strong earthquakes is contrasting tectonic movements, which are characteristic of fault zones dividing areas with different, and sometimes sharply changing, directions of tectonic movements. And areas within geological structures are characterized by a common tectonic regime (without contrasting movements) and, therefore, there are no conditions for the occurrence of strong earthquakes.

As noted, researchers believe that strong and destructive earthquakes are associated with fault zones observed at the surface or inferred at depth [Gamburtsev, 1955; Gubin, 1978; Gubin, 1950; Rantsman, 1979; Riznichenko, 1976].

However, there are alternative views regarding seismogenic zones. Some scholars argue that the foci of major earthquakes are localized at morphostructural nodes, i.e., at the intersections of active faults [Caputo et al., 1980; Gelfand et al., 1972]. The locations of such nodes are determined using the method of morphostructural zoning [Alekseevskaya et al., 1977; Gelfand et al., 1972; Gorshkov, 2010; Polyakova, 1985; Shikhalibeyli, 1996]. It has been demonstrated in that the assumption concerning the localization of strong earthquake foci at the intersections of active faults is supported by statistical analysis.

On the territory of the Greater Caucasus, a number of structural elements are distinguished, with a general Caucasian direction, which plunge in the eastern direction.

The Kura Trough has a complex structure. Within its boundaries, marginal and internal zones with geosynclinal and platform foundations of the Meso-Paleogene, respectively, are distinguished. Karabakh and East Zangezur regions of Azerbaijan are located within the Lesser Caucasus, which is a folded-block mountain belt. The main tectonic structures are the Zangezur folded-block massif, which includes raised blocks of crystalline rocks, the Karabakh Highland – a volcano-plutonic structure composed of Jurassic and Cretaceous volcanogenic-sedimentary formations, and the Megan synclinorium – a large geological structure containing a thick layer of sedimentary rocks of the Jurassic and Cretaceous age.

Large structures in the territory of Azerbaijan during the entire Alpine cycle or its individual stages were limited by deep faults and experienced intensive differential movements, predetermining the modern structure of the region.

Deep faults in the territory of Azerbaijan were studied by E.Sh. Shikhalibeyli, F.S.Akhmedbeyli and other researchers [Akhmedbeyli, 2004; Shikhalibeyli, 1996]. Along with faults with a general Caucasian direction, they also distinguish transverse (anti-Caucasian) faults.

However, it was established [Mammadli, 2011, 2012, 2014, 2022; Mammadli, Muradov, 2023; Mammadli, Rogozhin, 2019; Ovsyuchenko et al., 2011; Yetirmishli, Kazimov, 2022] that tectonic faults are not active along their entire length and, accordingly, strong earthquakes may not occur at all their points. A method was developed for determining active segments of deep faults based on weak seismicity, which allows more accurately establishing the spatial positions of real source zones of strong earthquakes [Gubin, 1978]. Using this method, many active segments of deep faults (source zones) with different lengths and directions were established in the territory of Azerbaijan (fig. 3).

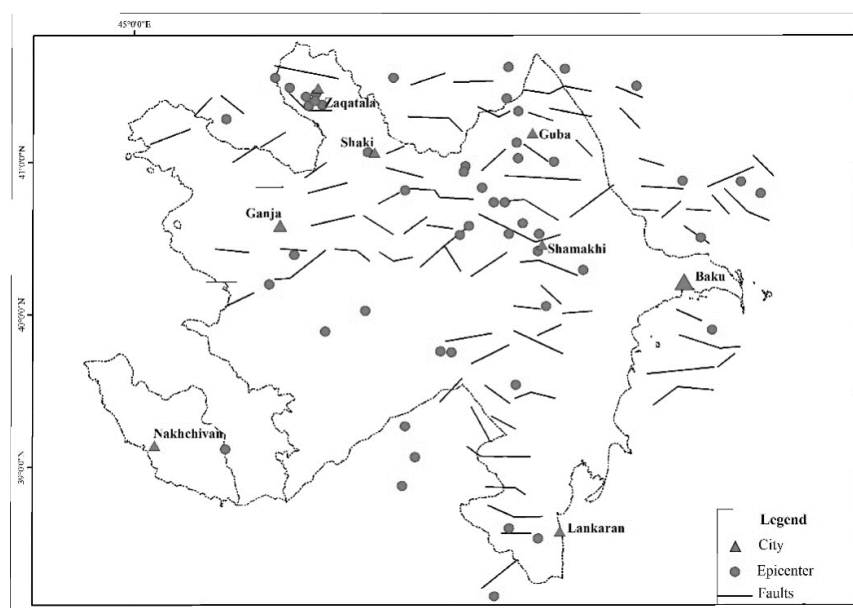


Fig. 3. Schematic map of active segments of deep faults (source zones) of strong earthquake zones in Azerbaijan

This schematic map shows that these sources of strong earthquakes correspond to individual segments of faults. In other words, active segments of deep faults are the generators of earthquakes. In zones where there are no active deep faults, there are isolated epicenters of seismic tremors.

Discussion of Results

The results of our research allow us to conclude that some areas of the territory of Azerbaijan, including Karabakh and East Zangezur regions, are characterized by aseismicity, i.e. in these areas there are no tectonic conditions for the occurrence of earthquakes. The seismic threat to these zones comes from the sources of strong earthquakes in neighbouring regions and, given their potential strength, the seismic hazard of the territory of the Karabakh and East Zangezur regions (except for the Kalbajar region and its eastern part) is estimated at 7 points on the MSK-64 scale [Mammadli, 2022] (fig. 4). The same seismic hazard is characteristic of small zones to the north of the Gadabay region (the zone between 40,5° and 41° N and from the border with Armenia to 46° E), to the south of the city of Gakh, to the north of the city of Sumgait, between the cities of Shirvan and Neftchala.

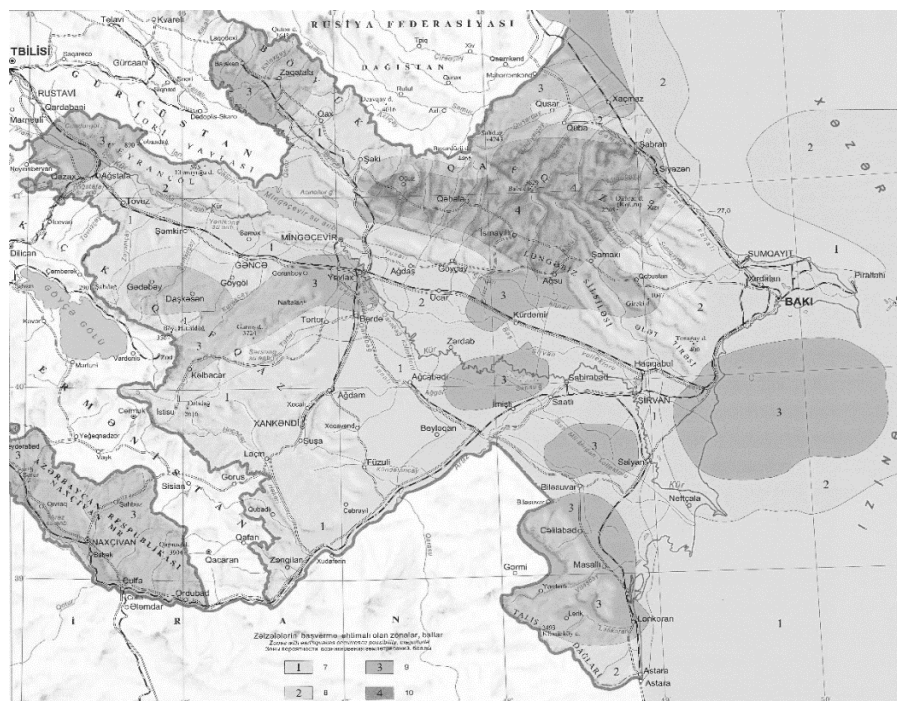


Fig. 4. Map of the probability of the strong earthquake's occurrence within the territory of the Republic of Azerbaijan (Mammadli, Yetirmishli, 2013)

It should be noted that, unlike other zones with a low level of seismic hazard, the Karabakh and East Zangezur regions occupy a fairly large territory. Currently, large-scale construction works are being carried out in these territories. Cities, roads, bridges, tunnels, airports and many other civil and industrial facilities are being built. Territories with a low level of seismic hazard are the most favourable for such major construction work. Detailed seismotectonic studies and anti-seismic calculations are not required.

Conclusion

The conducted studies allow us to conclude the following:

1. The seismicity of the territory of Azerbaijan is characterized by extreme heterogeneity.
2. Along with areas of increased seismicity, there are aseismic zones where isolated epicenters of seismic tremors are observed.
3. The aseismicity of some areas of the territory of Azerbaijan, including the Karabakh and East Zangezur zones (with the exception of Kalbajar region and its eastern part) is due to the fact that there are no tectonic conditions for the occurrence of earthquakes within them.
4. The territory of Karabakh and East Zangezur (with the exception of Kalbajar region and its eastern part) with a low level of seismic hazard are the most favourable for many civil and industrial construction works.

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