

<https://doi.org/10.59849/2219-6641.2025.2.25>

GPS-BASED MONITORING OF HORIZONTAL CRUSTAL MOVEMENTS AND SEISMIC ACTIVITY IN AZERBAIJAN IN 2025

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Annotation

The territory of Azerbaijan is characterized by high seismic activity and complex geodynamic features. In 2025, horizontal movements of the Earth's crust were assessed using data from 22 GPS stations. The analysis revealed that the average velocities were 6.13 mm/yr in the Greater Caucasus, 8.00 mm/yr in the Lesser Caucasus, 11.0 mm/yr in the Kura depression, 13.52 mm/yr in the Talysh region, and 5.34 mm/yr on the Absheron Peninsula. Maximum velocities were observed in Lankaran (13.83 mm/yr), Lerik (13.55 mm/yr), Jalilabad (13.21 mm/yr), and Saatli (13.35 mm/yr).

During the same period, focal mechanisms of 72 earthquakes ($m_l \geq 3.0$) were analyzed, showing the predominance of compressional and right-lateral strike-slip motions. Most earthquakes occurred at depths of 3–74 km, reflecting local geodynamic activity, particularly in the Talysh zone with higher seismic velocities and earthquake intensity. In total, 22 earthquakes occurred in the Caspian Sea sector, 13 in the Kura depression, 22 in the Greater Caucasus, 9 in the Lankaran area, and 3 in the Lesser Caucasus.

Integrated seismic and GPS data indicate that the average horizontal crustal movement across Azerbaijan is approximately 8.04 mm/yr toward the northeast. Results show that increased velocities in the Talysh, Kura depression, and Greater Caucasus zones correspond to enhanced geodynamic stress and seismic activity, while buffer structures in the Absheron Peninsula and southern slopes of the Greater Caucasus reduce horizontal displacement. This provides a detailed characterization of Azerbaijan's geodynamic and seismic environment and forms a scientific basis for assessing potential seismic hazards.

Keywords: Azerbaijan, seismic activity, geodynamic zones, GPS measurements, horizontal velocity, earthquake focal mechanism, Lode-Nadai coefficient

2025-CI İLDƏ AZƏRBAYCAN ƏRAZISINDƏ GPS VASİTƏSİLƏ YER QABIĞININ ÜFÜQİ HƏRƏKƏTLƏRİ VƏ SEYSMIK AKTİVLİYİN MONİTORINQI

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Annotasiya.

Azərbaycan ərazisi yüksək seysmik aktivliyə malik və mürəkkəb geodinamik xüsusiyyətlər göstərən regiondur. 2025-ci ildə aparılmış tədqiqat çərçivəsində 22 GPS stansiyasının məlumatları əsasında Yer qabığının horizontal hərəkətləri qiymətləndirilmişdir. Əldə olunan nəticələr göstərir ki, Böyük Qafqazda orta sürət 6,13 mm/il, Kiçik Qafqazda 8,00 mm/il, Kür çökəkliyində 11,0 mm/il, Talış bölgəsində 13,52 mm/il, Abşeron yarımadasında isə 5,34 mm/il təşkil edir. Maksimal sürətlər Lənkəran (13,83 mm/il), Lerik (13,55 mm/il), Cəlilabad (13,21 mm/il) və Saatlı (13,35 mm/il) stansiyalarında müşahidə olunmuşdur.

Eyni dövrdə 72 zəlzələnin ($m_l \geq 3.0$) ocaq mexanizmləri təhlil edilmiş və sıxılma, sağ tərəfli qırılıb-qalxma tipli hərəkətlərin üstünlük təşkil etdiyi müəyyən edilmişdir. Zəlzələlərin əksəriyyəti 3–74 km dərinlikdə baş vermiş və lokal geodinamik aktivliyi, xüsusilə Talış zonasında yüksək

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seysmik sürət və zəlzələ intensivliyi ilə uzlaşmışdır. Xəzər dənizi sektorunda 22, Kür çökəkliyində 13, Böyük Qafqazda 22, Lənkəran ərazisində 9 və Kiçik Qafqazda 3 zəlzələ qeydə alınmışdır.

İnteqrasiya olunmuş seysmoloji və GPS məlumatlar əsasında Azərbaycan ərazisi üzrə orta üfüqi hərəkət sürəti təxminən 8,04 mm/il və şimal-şərq istiqamətində müəyyən edilmişdir. Nəticələr göstərir ki, Talış, Kür çökəkliyi və Böyük Qafqaz zonalarında sürətlərin artması ilə geodinamik gərginliklər və seysmik aktivlik artır, Abşeron yarımadası və Böyük Qafqazın cənub yamacında isə “buffer” strukturlar hərəkətin ötürülməsini azaldır. Bu nəticələr regionun geodinamik və seysmik mənzərəsini dəqiqliklə ortaya qoyur və potensial seysmik təhlükənin qiymətləndirilməsi üçün elmi əsas yaradır.

Açar sözlər: Azərbaycan, seysmik aktivlik, geodinamik zonalar, GPS müşahidələri, horizontal sürət, zəlzələnin ocaq mexanizmi, Lode-Nadai əmsalı

МОНИТОРИНГ ГОРИЗОНТАЛЬНЫХ ДВИЖЕНИЙ ЗЕМНОЙ КОРЫ И СЕЙСМИЧЕСКОЙ АКТИВНОСТИ НА ТЕРРИТОРИИ АЗЕРБАЙДЖАНА С ИСПОЛЬЗОВАНИЕМ GPS В 2025 ГОДУ

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Аннотация

Территория Азербайджана относится к регионам с высокой сейсмической активностью и сложным геодинамическим строением. В рамках исследований, проведенных в 2025 году, на основе данных 22 GPS-станций была оценена величина горизонтальных движений земной коры. Полученные результаты показывают, что средние скорости составляют: в пределах Большого Кавказа — 6,13 мм/год, Малого Кавказа — 8,00 мм/год, Кураинской впадины — 11,0 мм/год, Талышского региона — 13,52 мм/год, Абшеронского полуострова — 5,34 мм/год. Максимальные значения скоростей зафиксированы на станциях Ленкорань (13,83 мм/год), Лерик (13,55 мм/год), Джалилабад (13,21 мм/год) и Саатлы (13,35 мм/год). В тот же период был выполнен анализ механизмов очагов 72 землетрясений ($m_l \geq 3,0$), по результатам которого установлено преобладание режимов сжатия и правосторонних сдвигово-взбросовых движений. Большинство землетрясений произошло на глубинах 3–74 км и отражает локальную геодинамическую активность, в частности согласованность высоких скоростей деформаций и интенсивной сейсмичности в Талышской зоне. В секторе Каспийского моря зарегистрировано 22 землетрясения, в Кураинской впадине — 13, в Большом Кавказе — 22, в Ленкоранском регионе — 9 и в Малом Кавказе — 3 события. На основе интеграции сейсмологических и GPS-данных средняя скорость горизонтальных движений по территории Азербайджана оценивается примерно в 8,04 мм/год и ориентирована в северо-восточном направлении. Полученные результаты свидетельствуют о том, что в зонах Талыша, Кураинской впадины и Большого Кавказа увеличение скоростей сопровождается ростом геодинамических напряжений и сейсмической активности, тогда как на Абшеронском полуострове и южном склоне Большого Кавказа наличие «буферных» структур приводит к ослаблению передачи деформаций.

Ключевые слова: Территория Азербайджана, сейсмическая активность, геодинамические зоны, GPS-наблюдения, горизонтальные скорости, механизм очага землетрясения, коэффициент Лодэ—Надаи.

Introduction

The territory of Azerbaijan is one of the geodynamically complex regions with high seismic activity. The interaction of the Eurasian, Arabian, and Iranian plates has resulted in the formation of tectonic blocks and fault systems of varying scales. The velocities and directions of movement of these blocks are key indicators that control crustal deformation processes, earthquake intensity, and propagation characteristics. In particular, the Greater Caucasus, Lesser Caucasus, Talysh zone, Kura Depression, and Absheron Peninsula are distinguished by their distinct geodynamic and seismic characteristics [3, 4, 5, 20].

In recent decades, GPS observations have enabled precise monitoring of crustal movements across Azerbaijan. Measurements conducted in 2025 at 22 GPS stations allowed for the assessment of horizontal displacement rates and directions in different parts of the region, taking into account errors related to station topography, ionospheric effects, and signal modulation. The aim of these studies was not only to determine velocities but also to produce accurate geodynamic mapping of the country and identify areas of potential seismic hazard [6, 14, 15].

Analysis for 2025 indicates that horizontal velocities average 6.13 mm/yr in the Greater Caucasus, 8.00 mm/yr in the Lesser Caucasus, 11 mm/yr in the Kura Depression, 13.52 mm/yr in the Talysh zone, and 5.34 mm/yr on the Absheron Peninsula. Maximum velocities were observed in the Talysh region (Lankaran, Lerik, Jalilabad) and at the Saatly station, confirming the high seismogeodynamic activity of these zones. The mean velocity in the northeast direction was 8.04 mm/yr, with increasing trends observed on the Absheron Peninsula, Kura Depression, and Greater Caucasus.

Additionally, the focal mechanisms of 72 earthquakes ($m_l \geq 3.0$) that occurred in Azerbaijan in 2025 were studied, and their geodynamic characteristics were analyzed. The majority of these earthquakes originated in granite and basalt layers of the crust, with dominating compressional and right-lateral reverse faulting. The Caspian Sea, Talysh, and Kura Depression regions exhibited high seismic activity, and GPS observations confirmed correlations between earthquake foci. Based on earthquake distribution and mechanisms, the regional distribution of the Lode-Nadai stress ratio and compression-tension axes was determined, highlighting the complexity of geodynamic and seismic conditions across Azerbaijan and the distinct characteristics of different zones.

Integrated seismological and geodynamic analyses allow for the localization of stress fields resulting from plate collisions, as well as the evaluation of block movement directions and velocity dynamics. These data provide a crucial scientific basis for assessing seismogeodynamic activity, predicting risks, and evaluating earthquake occurrence probabilities in the region.

Thus, this study systematically presents the results of GPS and seismological observations conducted in Azerbaijan in 2025, including horizontal movements of crustal blocks, regional distribution of velocities, and earthquake focal mechanisms. The research contributes both to understanding regional geodynamic processes and to assessing potential seismic risks.

Geodynamics of Azerbaijan in 2025

To determine the velocities and directions of horizontal movements of individual tectonic blocks of the Earth's crust in Azerbaijan, 22 GPS stations were connected to the network, and the positions of globally tracked satellites were refined via the internet. Over the past 13 years, a comprehensive data archive has been accumulated. In 2025, the collected data were analyzed using the GAMIT/GLOBK (v5.76) software package at the University of Massachusetts to evaluate both the quality of the station conditions and the reliability of the measurements (Fig. 1).

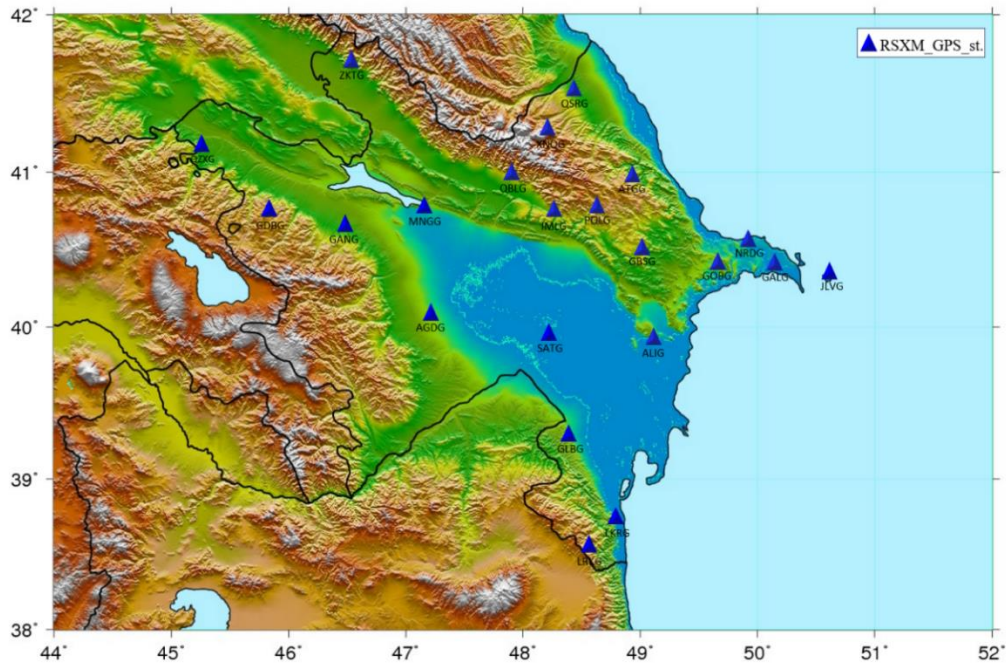


Figure 1. Network map of 22 GPS stations

During the analysis, the modulation errors of GPS signals due to local topography and deviations caused by the ionosphere were calculated on a daily basis for each station. Based on the obtained results, the horizontal displacements and their directions in 2025 were determined (Fig. 1), and velocities were computed individually for each station. In 2025, the average horizontal velocities were found to be 6.13 mm/yr in the Greater Caucasus, 8.00 mm/yr in the Lesser Caucasus, 11 mm/yr in the Kura Depression, 13.52 mm/yr in the Talysh region, and 5.34 mm/yr on the Absheron Peninsula.

The highest velocities were observed at the Lankaran (13.83 mm/yr), Lerik (13.55 mm/yr), and Jalilabad (13.21 mm/yr) stations in the Talysh region, as well as at the Saatly station (13.35 mm/yr). At these stations, the velocities remained consistently high compared to previous years, confirming the intense seismogeodynamic activity in the Talysh zone.

Overall, the 2025 data indicate average northeast-directed horizontal movements of approximately 8.04 mm/yr across Azerbaijan. The table below presents a comparative analysis of average velocities by region, showing an increasing trend, particularly on the Absheron Peninsula, Kura Depression, and Greater Caucasus zones.

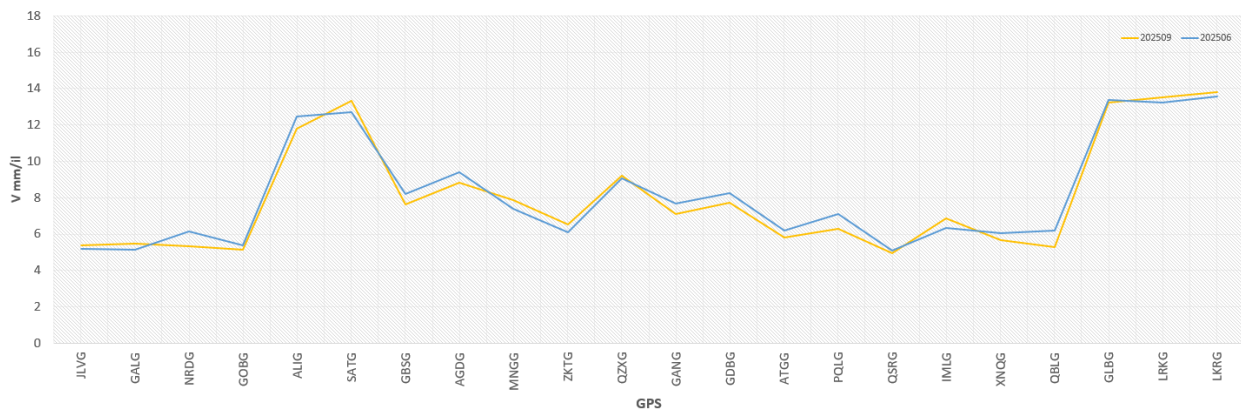


Figure 2. Comparative graph of velocities calculated from GPS stations in 2025

Figure 2 shows the horizontal displacement velocities for the 22 GPS stations. Overall, the lines are closely grouped, indicating the stability of the results. Some variations are observed, but they remain within the range of 0.3–0.8 mm/yr. The minimum velocities (~5 mm/yr) were recorded at the JLVG, NRDG, GOBG, QSRG, and QBLG stations. The maximum velocities (13–14 mm/yr) were observed at the SATG, GLBG, LRKG, and LKRG stations. Thus, over nine months, velocities across the 22 stations ranged from 5 to 14 mm/yr.

The most notable changes were observed at the ALIG and SATG stations. Comparison of six-month data (12.46–12.7 mm/yr) with nine-month data (11.8–13.35 mm/yr) indicates that the velocity at the ALIG station decreased by approximately 0.66 mm/yr, while at the SATG station it increased by approximately 0.65 mm/yr. These trends remained consistent over both periods.

Stations located on the Absheron Peninsula (JLVG, GALG, NRDG, GOBG) showed relatively low velocities, ranging from 5 to 6 mm/yr. In contrast, the southern stations of Azerbaijan (GLBG, LRKG, LKRG) recorded the highest velocities (13–14 mm/yr). The nine-month data indicate that the horizontal movement vectors remained largely stable across almost all stations, with variations within ± 0.1 – 0.2 mm/yr. Only the ALIG station experienced a slight decrease (~ 0.66 mm/yr), while the SATG station showed a slight increase (~ 0.65 mm/yr), likely reflecting local geodynamic processes.

Overall, the horizontal velocities of the Earth's crust in Azerbaijan remained predominantly stable throughout 2025. Distribution maps of horizontal velocities and vectors for GPS stations in 2025 were constructed (Figs. 2 and 3).

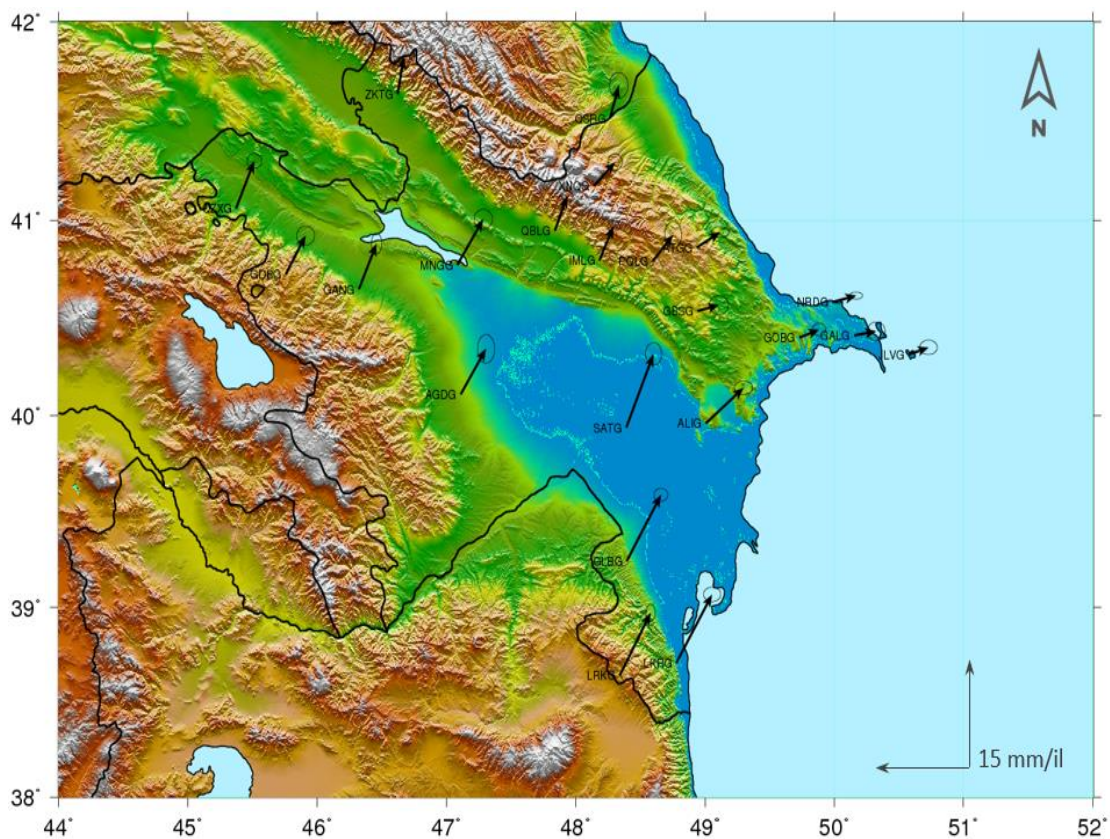


Figure 3. Map of azimuth directions of horizontal velocities obtained from GPS stations in 2025

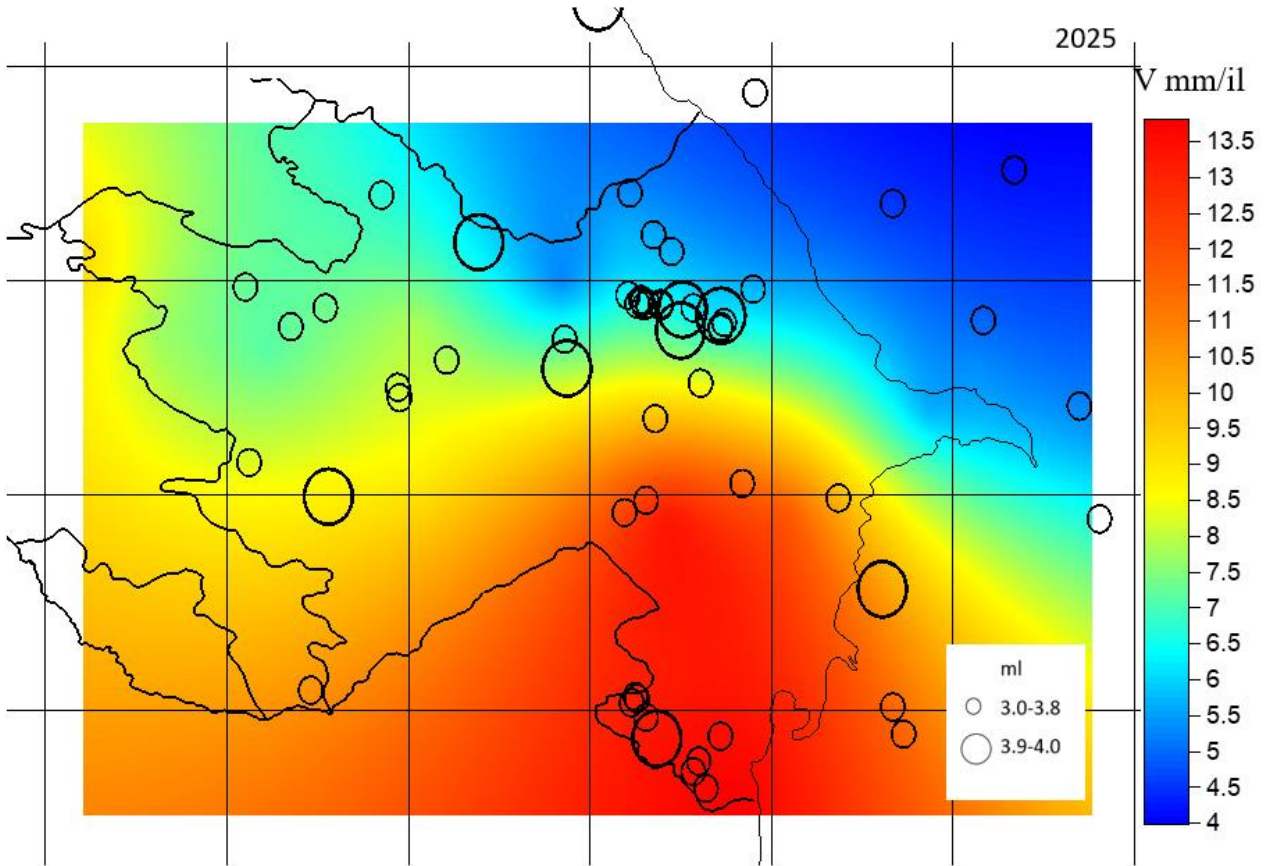


Figure 4. Distribution of horizontal velocities at GPS stations and earthquakes (ml > 3.0) in 2025

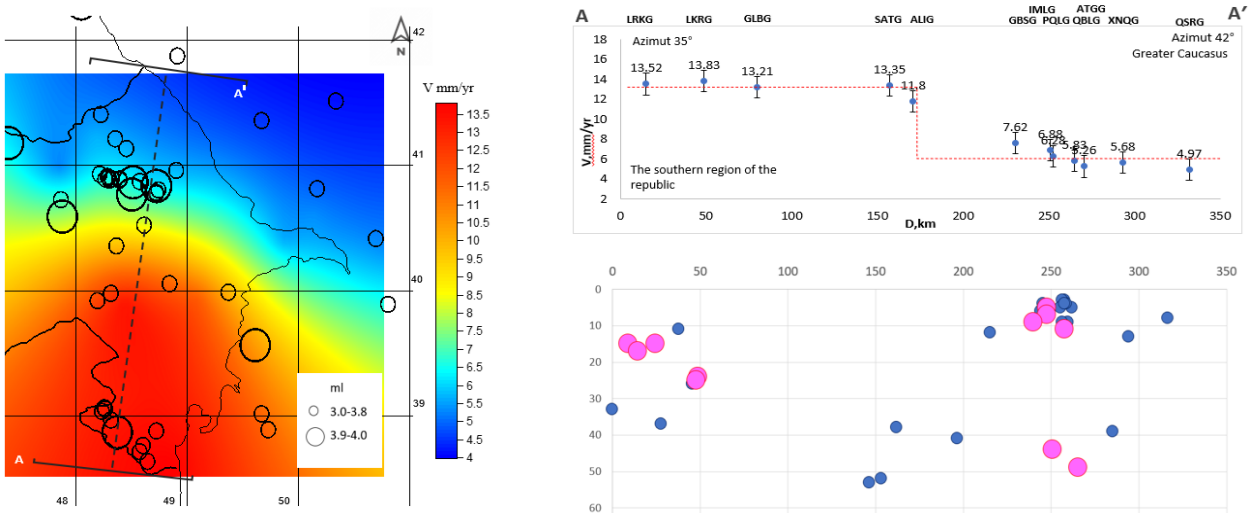


Figure 5. Horizontal velocity directions at GPS stations, histogram of horizontal displacements along the profile, and earthquake depth distribution in 2025

To monitor variations in horizontal velocities across different regions, a profile was constructed along the 1-1 SW–NE direction. The spatial distribution of GPS-derived velocity fields indicates that, overall, the territory of Azerbaijan is moving northeast relative to the Eurasian plate. Notably, a twofold decrease in velocities is observed between GPS stations located west of the Caspian Fault in the Kura depression and Talysh region, and those situated on the Absheron Peninsula

east of the Caspian Fault. This pattern highlights regional differences in crustal motion and confirms the influence of local tectonic structures on horizontal displacement rates.

The observed decrease in velocities between the Talysh region and the Greater Caucasus has several causes. Tectonically, the region between Talysh and the Greater Caucasus consists of small-scale blocks moving in different directions, compensating for deformation through internal slip and rotation. Approaching the Greater Caucasus, resistance to motion increases due to the presence of developed uplifted structures and anticlines that act as buffers, slowing horizontal displacement. In the central Kura depression and the southern slopes of the Greater Caucasus, major tectonic barriers such as the Adjıy-Alyat uplift and the Arpa-Samur fault absorb part of the compressional energy, leading to reduced horizontal velocities. Additionally, the regional plate tectonics must be considered: in the Talysh region, the Iranian block approaches nearly perpendicular to the deformation front, while the influence of the Arabian plate in the Greater Caucasus is more oblique. Consequently, a portion of the motion in the Kura depression and the Greater Caucasus is accommodated by slip or block rotation rather than pure forward displacement, explaining the observed velocity decrease.

Sharp variations in mean horizontal velocities and azimuthal directions along the SW–NE profile indicate stress accumulation between these regions, which is reflected in seismic activity. Results from GPS and seismological studies in 2025 complement each other, providing a comprehensive geodynamic picture of processes in different tectonic zones of Azerbaijan. Out of 70 recorded earthquakes, 68 occurred within Azerbaijan: 21 in the Caspian Sea, 13 in the Kura depression, 22 in the Greater Caucasus, 9 in the Lankaran region, and 3 in the Lesser Caucasus. Seismological data indicate that most events were characterized by thrusting and strike-slip mechanisms, reflecting stress accumulation and release at the intersection of differently oriented tectonic faults. GPS observations corroborate these findings.

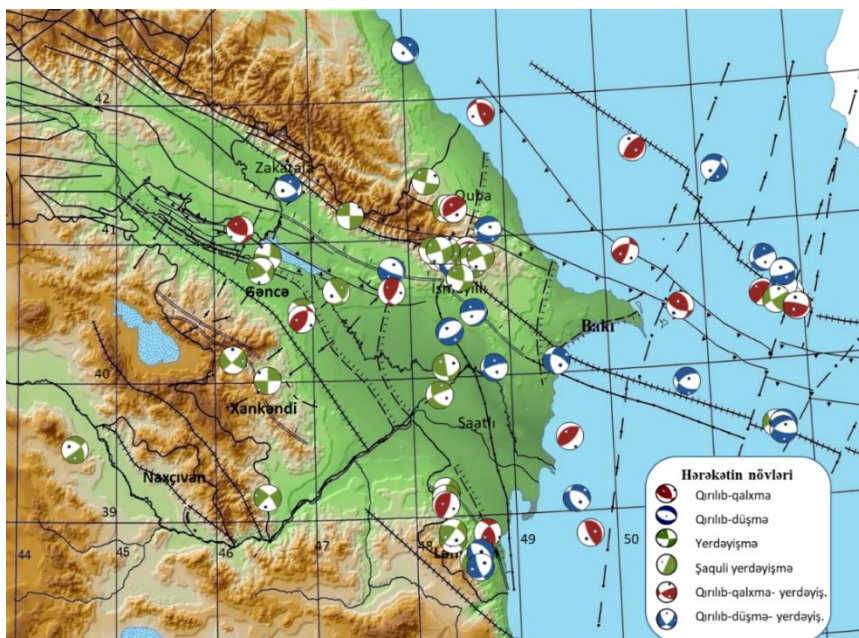


Figure 6. Focal mechanisms of earthquakes with $m_l \geq 3.0$ in 2025

(Fault map compiled by: Kengerli, Shikhalibeyli)[5]

- 1 – Dashgil-Mudrasa, 2 – Vandam, 3 – Gokchay, 4 – Siyazan, 5 – Zangi-Kozluchay, 6 – German, 7 – Adjıchay-Alet, 8 – Western Caspian, 9 – Arpu-Samur, 10 – Gandjachay-Alazan, 11 – Gazakh-Signakh, 12 – Northern Adjinour, 13 – Iori, 14 – Kura, 15 – Mingachevir-Saatly, 16 – Bashlibel, 17 – Palmir-Absheron, 18 – Akhti-Nugedi-Kiliziali, 19 – Talysh, 20 – Yardimli, 21 – Front-Talysh, 22 – Central Caspian, 23 – Absheron-Pribalkan, 24 – Sangachal-Ogurchi, 25 – Chikishler, 26 – Yashma flexure, 26a – Gizilagach, 27 – Shakhov-Azizbeyov, 28 – Qarabogaz-Safidrud

The highest velocities (13–14 mm/yr) were observed at the Lankaran, Lerik, and Jalilabad stations in the Talysh zone, consistent with the region's high seismogeodynamic activity and higher earthquake occurrence. Earthquakes in the Kura depression (e.g., a magnitude $m_l=4.0$ event in the Goychay district) were associated with right-lateral thrusting, consistent with GPS-derived average velocities of ~ 11 mm/yr. In the Greater Caucasus, earthquakes in the Ismayilli–Shamakhi area ($m_l=3.6$ – 3.8) occurred in zones with slower GPS velocities (~ 6.21 mm/yr), but corresponded to areas of locally elevated stress accumulation.

Analysis of Earthquake Focal Mechanisms in the Caspian Sea and Greater Caucasus in 2025

Studying the focal mechanisms of strong earthquakes allows for the identification of characteristic tectonic motion types in different seismically active regions of the crust and enables the estimation of the maximum ground acceleration values associated with these motion types [18, 19]. Accordingly, in 2025, to investigate stress and deformation fields in the crust, the focal mechanisms and dynamic parameters of earthquakes were analyzed, along with their formation conditions, including compressional and extensional stress regions [17]. As a result, the focal mechanisms of 72 earthquakes with magnitudes $m_l \geq 3.0$ were determined and analyzed (Fig. 6).

Of the 72 recorded earthquakes, 70 occurred within the territory of Azerbaijan. Among these 70 earthquakes, 22 were in the Caspian Sea, 13 in the Kura depression, 22 in the Greater Caucasus, 9 in the Lankaran region, and 3 in the Lesser Caucasus (Fig. 7).

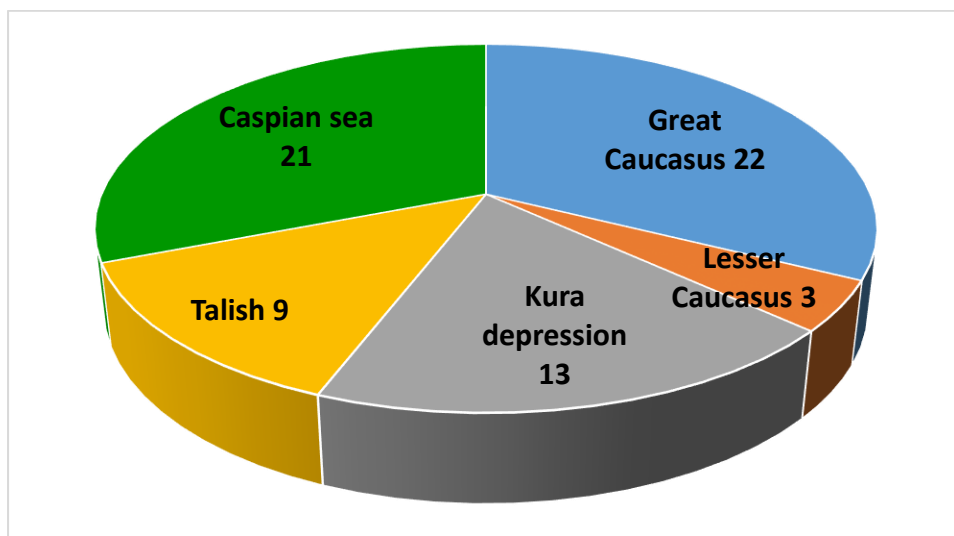


Figure 7. Histogram showing the distribution of focal mechanisms for 68 earthquakes ($m_l \geq 3.0$) recorded over the course of 2025

In 2025, the focal mechanisms of 22 earthquakes in the Caspian Sea were analyzed. The strongest earthquake of the year ($m_l=4.0$) occurred on March 7 at 08:22:58 local time in the Caspian Sea. The earthquake's depth was determined to be $H = 45$ km. The compression axis (P) ($PL = 9$) was oriented vertically, while the tension axis (T) ($PL = 78$) was oriented near-horizontal. For the first nodal plane, a steep dip angle ($DP1 = 54^\circ$) was determined, and for the second nodal plane, a shallow dip angle ($DP2 = 37^\circ$) was obtained. The displacement at the focus indicates that the movement was predominantly of a reverse-fault type.

On April 27, 2025, a magnitude $m_l=3.6$ earthquake occurred near the Absheron Peninsula at 18:13:14 local time. Its depth was $H = 58$ km. The compression axis (P) ($PL = 13$) was vertically oriented, while the tension axis (T) ($PL = 46$) was near-horizontal. Both nodal planes showed steep dip angles ($DP1 = 70^\circ$ and $DP2 = 48^\circ$). The displacement at the focus was primarily reverse-fault, consistent with the Central Caspian fault system.

In 2025, 22 earthquakes occurred in the Greater Caucasus region. In the early months, the strongest earthquakes occurred in the Ismayilli ($m_l = 3.6$) and Shamakhi ($M_L = 3.7$) districts. On February 19, at 15:11:42 local time, an earthquake was recorded in Ismayilli. The epicentral intensity was 4, and nearby settlements—Lahij, Zarat, Julian, Burovdal, and Mudri villages—experienced intensity 3. The earthquake depth was $H = 11$ km. The orientations of the compression (P) and tension (T) axes were both near-vertical ($PL = 4-7$). For the first and second nodal planes, steep dip angles were determined ($DP1 = 88^\circ$ and $DP2 = 82^\circ$). The focal displacement indicates a dominant right-lateral strike-slip movement, consistent with the Vəndam fault.

Another earthquake occurred in the Sheki district on April 21 ($m_l = 4.0$), 5 km east of the Sheki station. The epicentral intensity was 4, with nearby settlements experiencing intensity 3. The earthquake occurred at 08:31:09 local time, with a depth of $H = 17$ km. The compression axis (P) ($PL = 0-0$) was oriented horizontally, and both nodal planes exhibited steep dip angles ($DP1 = 90^\circ$ and $DP2 = 90^\circ$). The focal displacement was primarily strike-slip, consistent with the Dashgil-Mudrese fault.

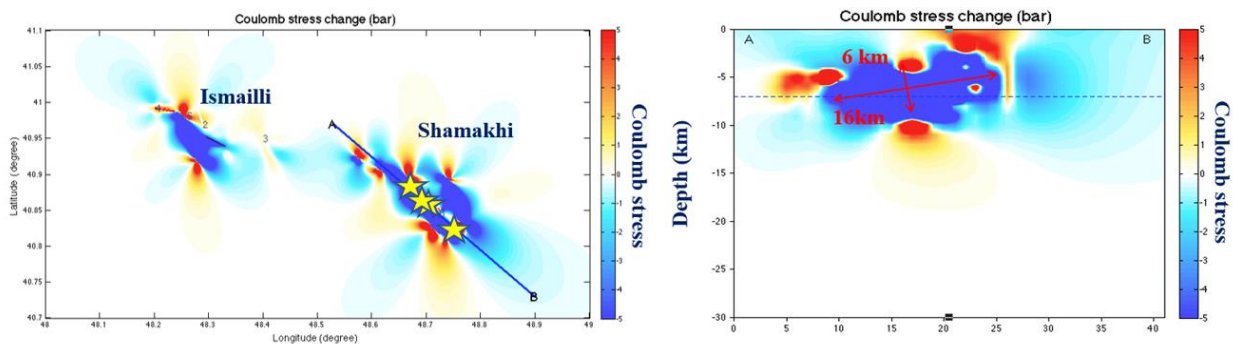


Figure 8. Distribution of Coulomb stresses and depth profiles for the earthquakes that occurred in Shamakhi district on June 5–6, 2025

The Shamakhi district also showed increased activity. The strongest earthquake occurred on June 5, 14 km northeast of the Pirqulu station, with a magnitude of $m_l = 3.7$. The epicentral intensity was 4, with surrounding settlements in Shamakhi and Khizi experiencing 3–4 intensity. The earthquake occurred at 16:02:43 local time, with a depth of $H = 7$ km. The compression axis (P) ($PL = 8-2$) was near-horizontal, and the nodal planes had steep dip angles ($DP1 = 86^\circ$ and $DP2 = 83^\circ$). The displacement at the focus was predominantly right-lateral, consistent with the Dashgil-Mudrese fault.

Additional earthquakes occurred on June 5–6: $M_L = 3.2$ at 12:04:59 (05.06.2025), $m_l = 3.2$ at 02:40:34 (06.06.2025), and $m_l = 3.6$ at 06:18:36 (06.06.2025). The displacements at these foci exhibited the same characteristics as the main events, indicating consistent strike-slip motion. All events, including aftershocks, were shallow, occurring at depths of 2–10 km. Coulomb stress distribution for these earthquakes was mapped, with stress release indicated in blue [8]. Profiles show that four areas within the focal zones maintained residual stress, highlighting continued seismotectonic activity in these regions.

On July 12, 2025, an earthquake of magnitude $M_L = 3.8$ occurred in the Ismayilli district, 10 km west of the Pirqulu station. The epicentral intensity was 4, with nearby settlements in Shamakhi district experiencing intensity 3–4. The earthquake occurred at 07:18:58 local time at a depth of $H = 9$ km. The compression axis (P) ($PL = 4-23$) was oriented near-horizontal, and the dip angles for the first and second nodal planes were steep ($DP1 = 77^\circ$ and $DP2 = 72^\circ$). The focal displacement indicates a dominant left-lateral strike-slip motion, consistent with the Dashgil-Mudrese fault.

On August 21, 2025, an earthquake of $m_l = 3.6$ occurred in Siyazan district, 10 km south of the Siyazan station. The event was not felt in settlements farther from the epicenter; nearby settlements experienced intensity up to 3. The earthquake occurred at 17:17:58 local time at a depth

of $H = 49$ km. The compression axis (P) ($PL = 68$) was oriented vertically, while the tension axis (T) ($PL = 8$) was near-horizontal. The first nodal plane showed a steep dip ($DP1 = 57^\circ$) and the second a shallow dip ($DP2 = 41^\circ$). The focal displacement was dominated by right-lateral reverse-fault motion, consistent with the Siyazan fault.

In the Kura depression, focal mechanisms were determined for 13 earthquakes over the past year. On March 26, 2025, a magnitude $m_l = 3.6$ earthquake occurred in Samukh district, 46 km northwest of the Mingachevir station near the Mingachevir reservoir. The epicentral intensity reached 3 in nearby settlements. The earthquake occurred at 17:09:31 local time at a depth of $H = 11$ km. The compression axis (P) ($PL = 5-7$) was near-horizontal, and both nodal planes exhibited steep dips ($DP1 = 89^\circ$ and $DP2 = 82^\circ$). The focal displacement indicates a dominant left-lateral strike-slip motion, consistent with the Gandja-Chay fault.

The strongest earthquake in the Kura depression occurred on August 9 in Goychay district ($m_l = 4.0$) at 11:03:35 local time. Recorded 35 km southwest of Ismayilli station, the earthquake had an epicentral intensity of 4 in Goychay and 3 in surrounding settlements including Gabala, Ismayilli, and Agdash. The depth was $H = 16$ km. The compression axis (P) ($PL = 16$) was vertical, the tension axis (T) ($PL = 60$) near-horizontal; the first and second nodal planes had dip angles $DP1 = 66^\circ$ and $DP2 = 36^\circ$, respectively. The focal displacement was dominated by right-lateral reverse-fault motion, consistent with the Khachinchay fault.

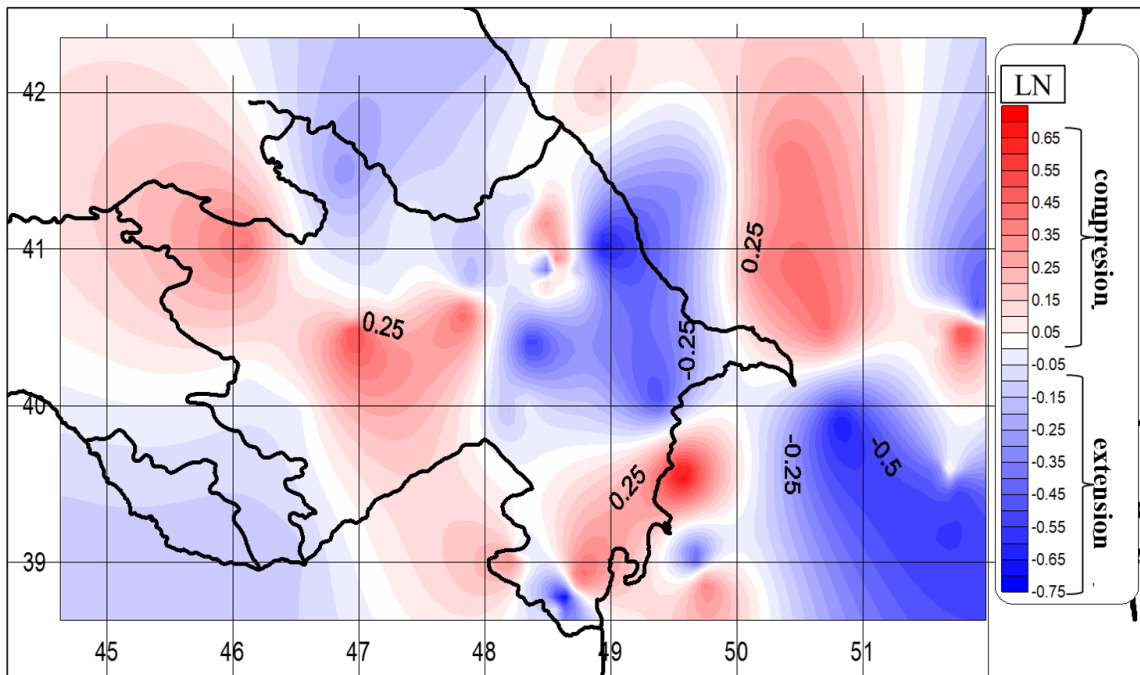


Figure 9. Distribution map of the Lode-Nadai ratio calculated based on the mechanisms of earthquakes that occurred in 2025

In the Lankaran region, focal mechanisms were determined for 9 earthquakes. The strongest event occurred on March 9 in Lerik district ($m_l = 4.0$) at 07:49:54 local time, with a depth of $H = 15$ km. The P and T axes were near-horizontal ($PL = 24-17$), and the nodal planes exhibited steep dips ($DP1 = 86^\circ$ and $DP2 = 61^\circ$). The focal displacement indicates right-lateral strike-slip motion, consistent with the Talish fault. On June 2, a second earthquake occurred at 07:51:15 local time at a depth of $H = 15$ km. The compression axis (P) ($PL = 90$) was horizontal, the tension axis (T) ($PL = 0$) near-vertical, and the nodal planes had dip angles $DP1 = DP2 = 45^\circ$. The focal displacement was dominated by left-lateral strike-slip motion, consistent with the Pre-Talish fault.

In the Lesser Caucasus, 3 earthquakes were recorded, with focal mechanisms determined. The strongest was in Kalbajar district ($m_l = 3.7$) on April 7 at 00:35:55 local time, 50 km southwest of the

Agdam station. The earthquake occurred at $H = 15$ km, with P and T axes oriented horizontally ($PL = 0-0$). Both nodal planes showed steep dips ($DP1 = DP2 = 90^\circ$). The focal displacement indicates dominant strike-slip motion, consistent with the Arpa-Samur fault.

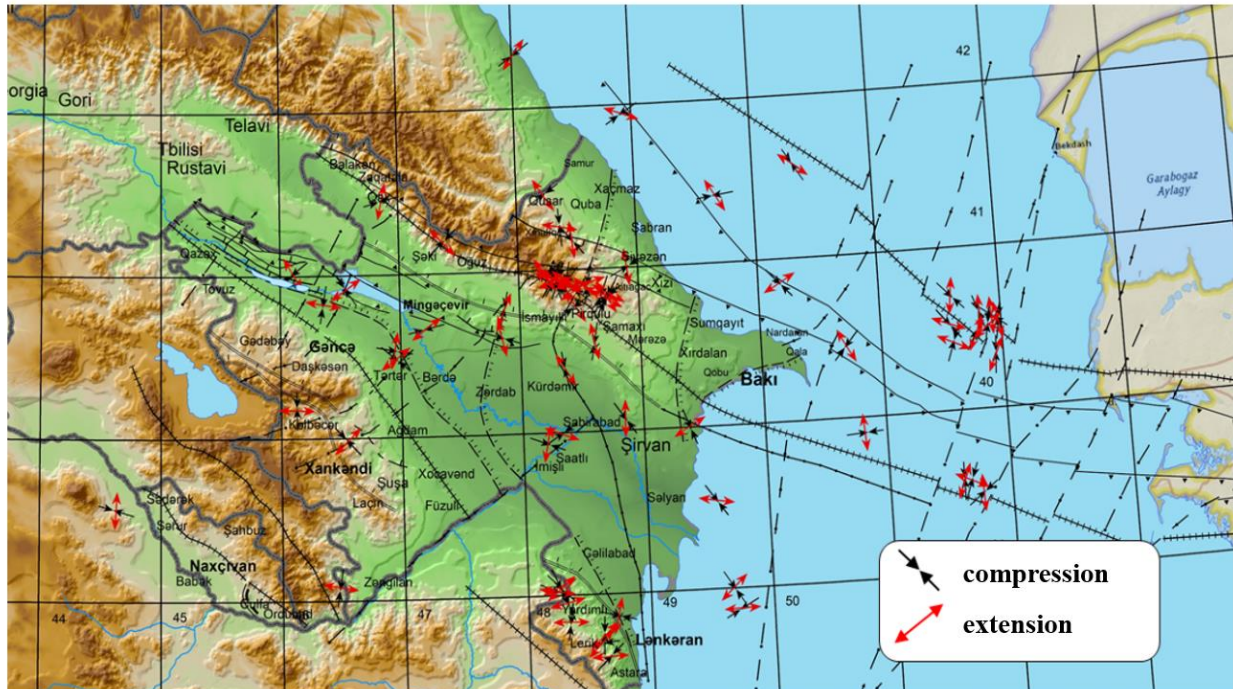


Figure 10. Distribution map of the compression-tension axes calculated based on the mechanisms of earthquakes in 2025

One of the strongest earthquakes of 2025 occurred in Dagestan. According to the Seismological Service Center, the earthquake's hypocenter was near Izberbash, at a depth of 14 km. Seismic waves were recorded at 00:33 Baku time, 28 km east of Izberbash and 51 km north-northwest of Derbent, with a magnitude of $m_l=5.3$. The focal displacement was predominantly reverse-fault.

Based on the calculated focal mechanisms, a map of the Lode-Nadai stress ratio was constructed [1]. The map shows compressional stress dominating in the Lesser Caucasus, northeastern Talish, and the Central Caspian Sea, while extensional stress characterizes the Greater Caucasus, Lower Kura depression, Nakhchivan, Lankaran, and the southern Caspian region (Fig. 9). The geodynamics of crustal blocks in the eastern part of Azerbaijan is primarily influenced by the right-lateral faulting of the Western Caspian, with predominantly right-lateral reverse-fault motion observed in this area.

The orientation of the compression and tension axes shows that in several earthquakes in the Central Caspian and Greater Caucasus regions, they are directed NE–SW, whereas in the Talysh region, the tension axes are oriented NW–SE (Fig. 10).

Almost all earthquakes with magnitudes $m_l > 3.0$ occurred at depths ranging from 3 to 74 km. The majority of seismic activity is observed within the granite and basalt layers of the crust. This suggests that the seismicity of the junction between the Scythian-Turanian platform and the Alpine orogen is associated with the intersection of tectonic faults of various orientations (seismogenic nodes) [9, 11, 12].

Uneven stress distribution over tectonic blocks is observed in areas of thin crust, brittle lithofacies, and specific petro-physical compositions. Such zones facilitate the accumulation of potential stress energy, and as stress increases, fractured structural zones form. For the Central

Caspian basin, the small angles of the tension axes indicate that thrust-faulting dominates in this region.

Results and discussion

Integrated analysis of seismological data (number, magnitude, depth, and distribution of earthquakes), geodynamic observations (GPS-measured velocities of lithospheric blocks, stress fields generated by plate convergence), focal mechanisms, orientation of compression/tension axes, and Lode-Nadai ratios has allowed for the synthesis of generalized results.

In 2025, 5216 local earthquakes were recorded, of which 71 had $m_l \geq 3.0$, and 19 were felt, corresponding to an approximate intensity of 5.4. Overall seismic activity is moderate but increased in zones of higher GPS-measured velocities (Ismayilli, Talysh, and the Caspian Sea). Correlation shows that increased velocities in the northwest of the republic and accumulated stress released in the Caspian Sea correspond to higher seismicity compared to 2024. This aligns with studies from 2023–2024 showing transitions from extension to compression and increased tectonic activity. Approximately 60% of earthquakes at depths ≤ 20 km reflect deformation in the sedimentary layers caused by plate motions. The primary causes of seismicity are collisions between the Arabian, Iranian, and Eurasian plates, resulting in compression, local extension, stress accumulation along faults, and energy release in brittle crustal layers. GPS data indicate that the mean horizontal velocity of continental movement in the northeast is ~ 8.1 mm/year.

Caspian Sea (Azerbaijan sector). A detailed analysis of the Caspian Sea reveals high seismicity in the central and northern parts under compression (28 events with $m_l \geq 3$, depths 20–74 km, focal depths for strong shocks 66–74 km). Strike-slip and thrust mechanisms dominate. Geodynamically, this is associated with the general compression of the Skif-Turan and South Caspian plates, activating faults such as Agrakhan-Krasnovodsk, Sangachal-Ogurchi, Shakhov-Azizbeyov, Mil-Chikishlyar, and Yashma-Byandov. In the central part, compression (axes-oriented NW–SE) and extension in the south promote lithospheric subsidence or rupture at depth. The strongest earthquake (m_l 5.4, depth 74 km) occurred on 26 August 2025 off the Dagestan coast, associated with the Terek fault. Caspian Sea activity increased relative to 2024 due to enhanced compression in the transition from continental collision to oceanic deformation, increasing the risk of strong deep shocks. Low velocities on the Absheron Peninsula explain the weak seismicity—buffer zones absorb deformation without generating strong shocks.

Greater Caucasus (Shamakhi-Ismayilli, Balakan-Gabala, Quba-Qusar, Siyazan zones). The most active part of the Greater Caucasus recorded 22 events with $m_l \geq 3.0$, focal depths mainly 2–49 km (shallow 2–15 km). Seismicity is driven by compression from the Arabian plate (mean GPS velocity ~ 6.1 mm/year from 2024 to 2025) and primarily right-lateral strike-slip mechanisms with steep dip angles (DP 72–90). Block geodynamics enhance meridional migration of epicenters, activating the Western Caspian, Dashgil-Mudrasa, Vandam, and Siyazan faults. In some areas, extension (NW–SE) dominates, promoting brittle deformation in the thin crust and aftershocks (Ismayilli). Analysis of earthquakes from Shamakhi-Ismayilli revealed residual Coulomb stresses caused by uneven energy release due to local obstacles at the collision front, increasing the risk of sequential events in populated areas. Deep foci (up to 45 km) reflect stress accumulation in lower layers consistent with plate collision models. This aligns with the general pattern in the Caucasus, where compressional stresses from the Arabian Plate induce earthquakes along fold and thrust belts [2].

Kura Depression (Central and Lower Kura, Samukh, Goychay). Seismicity is weak (13 events with $m_l \geq 3$, depths 2–30 km). Strike-slip mechanisms dominate, related to compression in sedimentary basins, activating Gandjachay, Khachinchay, and Alazan-Ayrichay faults. Extension moderates activity through creep. Moderate activity results from the balance between plate compression and basin extension, causing moderate shaking at fault intersections; the risk increases with faster movements, affecting hydraulic structures.

Talysh Zone (Lankaran, including the Iranian border). High seismicity is observed, though lower than in 2024 (nine events with $m_l \geq 3$ at 11–19 km depth in the granite layer). Geodynamics is driven by strong compression from the Iranian plate (reverse-slip mechanisms, max velocities ~13–14 mm/year), enhancing deformation in mountainous areas and activating Talysh and Pre-Talysh faults. SW Talysh exhibits extension, NE compression. High velocities are directly related to seismicity: compression from the near-perpendicular approach of the Iranian plate strengthens fault activity, generating earthquakes at 11–19 km depth. Historical data show this zone as an intense deformation area with frequent moderate shocks. The reduction compared to 2024 (m_l 5.3) may indicate partial stress release, but ongoing high ratios maintain risk.

Lesser Caucasus (including Samukh and Kalbajar). Low seismicity is observed (3 events with $m_l \geq 3$, depths 11–14 km), primarily from horizontal strike-slip and moderate-velocity (~8 mm/year) mixed deformation. Geodynamics relate to lateral movements in the plate junction activating Arpa-Samur, Lachin-Bashlibel, and Gandjachay faults. Minimal activity reflects relatively stable tectonics compared to the Greater Caucasus, with strike-slip faults predominating due to regional compression.

Nakhchivan Autonomous Republic. Minimal seismicity (33 shocks with 0.5–2.5 m_l , no significant events) reflects stable geodynamics (~8 mm/year), isolated zones, and infrequent weak surface mechanisms due to the lack of active faults and buffering by surrounding plates.

Conclusions

In 2025, Azerbaijan continued to experience deformation under NE-directed compression due to the collision of the Arabian and Eurasian plates and the active role of the Iranian block. Compared to 2024, horizontal velocities increased in almost all major geotectonic zones. Overall, seismicity reflects the dynamics of plate collisions: compression dominates in the Caspian Sea and southern regions (Talysh), strike-slip faults predominate in the Greater Caucasus, and extension is moderate in the Kura and Nakhchivan regions. Variations in geodynamic conditions arise from uneven stress accumulation along faults and energy release in brittle crustal layers. Moderate-magnitude earthquakes (m_l 3–5) were observed in 2025, with no catastrophic events.

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