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INTERCONNECTION OF GEODYNAMIC PROCESSES IN THE CAUCASUS AND ADJACENT REGIONS (TURKEY, IRAN)

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ABSTRACT

This article is dedicated to the study of the tectonic evolution of the Caucasus within the context of the central segment of the Alpine-Himalayan orogenic belt, including the adjacent territories of Turkey and Iran. Based on paleotectonic and geophysical data, including the research of A.A.Belov (1986), R.Kolman (1974), N.Kelder (1975), N.Falcon (1977), V.E.Khain (1990), F.Ahmedbeyli (2010), Cowgil (2016), Forte (2015), T.Kengerli (2018) and others, the stages of regional formation from the Mesozoic to the present are analyzed. It is established that the Caucasus, Turkey, and Iran initially constituted a single tectonic block associated with Gondwana, the collapse of which during the Jurassic period and the subsequent formation of the Red Sea Rift led to their tectonic differentiation. Special attention is given to the role of Arabian Plate movement, the influence of compression, and autonomous geodynamic processes in the development of structures such as the Greater and Lesser Caucasus, Pontides, Taurides, Elburz, and Zagros, as well as differences in geological structure, volcanic activity, and rock distribution. An analysis of GPS data (2018–2024) and Lode-Nadai coefficient maps (2019–2024) reveals a shift in dominant stresses in the region—from extension in 2019–2022 to compression in 2023–2024 linked to tectonic activity and earthquakes. Linear seismic zones reflecting the region's high seismicity are identified, including events such as the Shamakhi (1902), Spitak (1988), and Racha (1991) earthquakes. In conclusion, it is emphasized that the tectonic evolution of the region is driven by both horizontal and vertical movements, and the Caucasus, Turkey, and Iran remain interconnected without breaking into separate plates. This study is significant for assessing seismic hazards and predicting geodynamic processes.

Keywords: Caucasus, Turkey, Iran, Alpine-Himalayan belt, tectonics, geodynamics, Gondwana, Red Sea Rift, seismicity, GPS, Lode-Nadai coefficient.

ВЗАИМОСВЯЗЬ ГЕОДИНАМИЧЕСКИХ ПРОЦЕССОВ КАВКАЗА И СОСЕДНИХ РЕГИОНОВ (ТУРЦИЯ, ИРАН)

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АННОТАЦИЯ

Статья посвящена исследованию тектонической эволюции Кавказа в контексте центрального сегмента Альпийско-Гималайского горно-складчатого пояса, включая прилегающие территории Турции и Ирана. На основе палеотектонических и геофизических данных, включая исследования А.А.Белова (1986), Р.Колмана (1974), Н.Кельдера (1975), Н.Фолкона (1977), В.Е.Хаина (1990), Ф.Ахмедбейли (2010), Ковгила (2016) [3], Форте (2015), Т.Кенгерли (2018) и др., анализируются этапы формирования региона с мезозоя до настоящего времени. Устанавливается, что Кавказ, Турция и Иран

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изначально составляли единый тектонический блок, связанный с Гондваной, распад которой в юрском периоде и последующее формирование Красноморского рифта обусловили их тектоническую дифференциацию. Особое внимание уделено роли движения Аравийской плиты, влиянию сжатия и автономных геодинамических процессов на развитие структур (Большой и Малый Кавказ, Понтиды, Тавриды, Эльбурс, Загрос), а также различиям в геологическом строении, вулканической активности и распределении пород. Анализ данных GPS (2018–2024) и карт коэффициента Лодэ-Надаи (2019–2024) демонстрирует смену доминирующих напряжений в регионе — от растяжения в 2019–2022 годах к сжатию в 2023–2024 годах, что связано с тектонической активностью и землетрясениями. Выделяются линейные сейсмические зоны, отражающие высокую сейсмичность региона, включая такие события, как Шемахинское (1902), Спитакское (1988) и Рачинское (1991) землетрясения. В заключение подчеркивается, что тектоническая эволюция региона определяется как горизонтальными, так и вертикальными движениями, а Кавказ, Турция и Иран сохраняют взаимосвязь, не разделяясь на отдельные плиты. Работа имеет значение для оценки сейсмических рисков и прогноза геодинамических процессов.

Ключевые слова: Кавказ, Турция, Иран, Альпийско-Гималайский пояс, тектоника, геодинамика, Гондвана, Красноморский рифт, сейсмичность, GPS, коэффициент Лодэ-Надаи.

QAFQAZ VƏ QONŞU REGIONLARIN (TÜRKİYƏ, İRAN) GEODINAMİK PROSESLƏRİNİN QARŞILIQLI ƏLAQƏSİ

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XÜLASƏ

Məqalə Türkiyə və İranın qonşu əraziləri də daxil olmaqla, Alp-Himalay dağ qırışığı qurşağının mərkəzi seqmenti kontekstində Qafqazın tektonik təkamülünün öyrənilməsinə həsr edilmişdir. Paleotektonik və geofiziki məlumatlara, o cümlədən A.A. Belov (1986), R. Koulman (1974), N. Kelder (1975), N. Falkon (1977), V.E. Xain (1990), F. Əhmədbəyli (2010), Kovgil (2016), Forte (2015), T. Kəngərli (2018) və başqaları bölgənin mezozoydan bu günə qədər formalaşma mərhələləri təhlil edilmişdir. Müəyyən olunmuşdur ki, Qafqaz, Türkiyə və İran ilkin olaraq Qondvana ilə əlaqəli vahid tektonik bloku təşkil edirdi. Yura dövründə Qondvananın parçalanması və sonrasında Qırmızı dəniz riftinin formalaşması bu regionların tektonik diferensiasiyasına səbəb olmuşdur. Xüsusi diqqət, Ərəbistan plitəsinin hərəkətinə, sıxılma proseslərinin təsirinə və avtonom geodinamik proseslərin Böyük və Kiçik Qafqaz, Pontidlər, Tavridlər, Elburs, Zaqros və digər struktur vahidlərinin inkişafına təsirinə yönəldilmişdir. Eyni zamanda, geoloji quruluş, vulkanik aktivlik və süxur paylanmasındakı fərqlər də araşdırılmışdır. 2018–2024-cü illər üzrə GPS məlumatlarının və 2019–2024-cü illər üzrə Lode-Nadai əmsal xəritələrinin təhlili göstərir ki, regionda 2019–2022-ci illərdə dominant gərginlik rejimi dartılma (ekstensiya) olub, 2023–2024-cü illərdə isə sıxılma (kompresiya) üstünlük təşkil edib. Bu dəyişikliklər tektonik aktivlik və zəlzələlərlə bağlıdır. Yüksək seysmikliyə malik xətlər boyunca yerləşən seysmik zonalər müəyyən edilmişdir, o cümlədən 1902-ci il Şamaxı, 1988-ci il Spitak və 1991-ci il Raça zəlzələləri kimi hadisələrə diqqət yetirilmişdir. Nəticə etibarilə vurğulanır ki, regionun tektonik təkamülü həm üfüqi, həm də şaquli hərəkətlərlə müəyyən olunur və Qafqaz, Türkiyə və İran vahid tektonik əlaqəsini qoruyaraq ayrı-ayrı plitələrə parçalanmışdır. Bu araşdırma seysmik risklərin qiymətləndirilməsi və geodinamik proseslərin proqnozlaşdırılması baxımından əhəmiyyətlidir.

Açar sözlər: Qafqaz, Türkiyə, İran, Alp-Himalay qurşağı, tektonika, geodinamika, Qondvana, Qırmızı dəniz rift sistemi, seysmiklik, GPS, Lode-Nadaı əmsalı.

Introduction

The Caucasus, along with key tectonic elements of Turkey, Iran, Russia, as well as the Black Sea and Caspian basins, forms part of the central segment of the Alpine-Himalayan orogenic belt. This belt has undergone a long and multi-stage process of geotectonic and geodynamic development. According to paleotectonic studies conducted by A.A.Belov in 1986, during the early stages of Alpine orogenesis, the present-day outlines of the belt were not yet clearly defined. At that time, vast territories were occupied by the Meso-Tethys Ocean, as well as large fragments of Gondwana and young epigeric platforms [6, 15].

An analysis of available data indicates that by the mid-Mesozoic period, around the beginning of the Early Cretaceous, the contours of the Alpine belt started to become more distinct, although major sections, such as the Arabian and Punjab segments, were not yet fully formed. Different regions of the Alpine fold belt exhibit variations in the intensity and frequency of tectonic movements, levels of volcanic activity, differences in the structure of Mesozoic-Cenozoic deposits at various depths, the development of deep fault networks, as well as lateral propagation of folding deformations and other processes [4, 15].

In the geophysical fields of the fold-block structure of the Greater Caucasus, a negative gravity field is observed, with an intensity of up to -50 mGal on the outer periphery of the structure and up to -130 mGal in areas associated with Neogene-Quaternary volcanic activity. The magnetic field varies from -0.5 to +1.0 nT, while in certain areas it can reach -15.6 nT to +3–5 nT, reflecting the geological characteristics of the pre-Jurassic basement [26].

The primary first-order Alpine structure within the fold-block system of the Greater Caucasus is the fold-block uplift of the Main Ridge and the North Caucasian marginal massif. The structural framework of the Main Ridge uplift is inherited from the Hercynian basement structure, and its precise delineation is complicated by modern erosion of the sedimentary cover.

The Caucasus within the Alpine-Himalayan Belt

The Caucasus, in combination with adjacent countries such as Turkey and Iran, represents a significant geological entity with a highly complex tectonic organization. Following the collapse of the Gondwana supercontinent, this territory fragmented into separate large blocks (microplates or microcontinents), each possessing unique characteristics in terms of internal structure, geotectonic evolution, fold structures, magmatism, and other features. By the beginning of the neotectonic stage (approximately in the Oligocene), the main structural elements of the region—the Caucasus, Pontides, Taurides, Elburz, Zagros, as well as the Black Sea and Caspian basins—had acquired outlines close to their present-day configuration (Fig.1). These structures are bounded to the north by the Scythian Plate, to the south by the Arabian Plate, to the east by the Lut Block (Central Iran), and to the west by the Rhodope Massif (eastern part) [4, 10].

After the collapse of Gondwana in the Jurassic period, this vast area separated from the Afro-Arabian block, maintaining its integrity until the mid-neotectonic stage. During this period, the formation of the Red Sea Rift began, leading to the north-eastward movement of the Arabian Plate. As noted by R.Coleman [21] in 1974, the rift formed in post-Miocene time, at the late stage of neotectonic development, and, according to GPS data, its expansion process continues to this day.

Before their division into separate microplates, the Caucasus, Turkey and Iran developed within a single geodynamic regime, experiencing horizontal compression between the Arabian

Plate and the East European Platform. According to N.Kelder (1975) [20], the Iranian segment also took an active part in this process from the beginning of the Miocene (about 17 million years ago). However, each of these regions continued to evolve autonomously, especially at the stage of neotectonic development, when the final tectonic differentiation of such structures as the Greater and Lesser Caucasus, the Kura-Rion Depression, the Anatolides, the Taurides, the Elburz and the Zagross occurred. Each of these large structures is distinguished by the types of folding, their morphology (linear, arc, etc.), the time of formation, the relationship with volcanic complexes and magmatic formations, as well as the degree of complexity of rupture deformations and the location of faults [16].

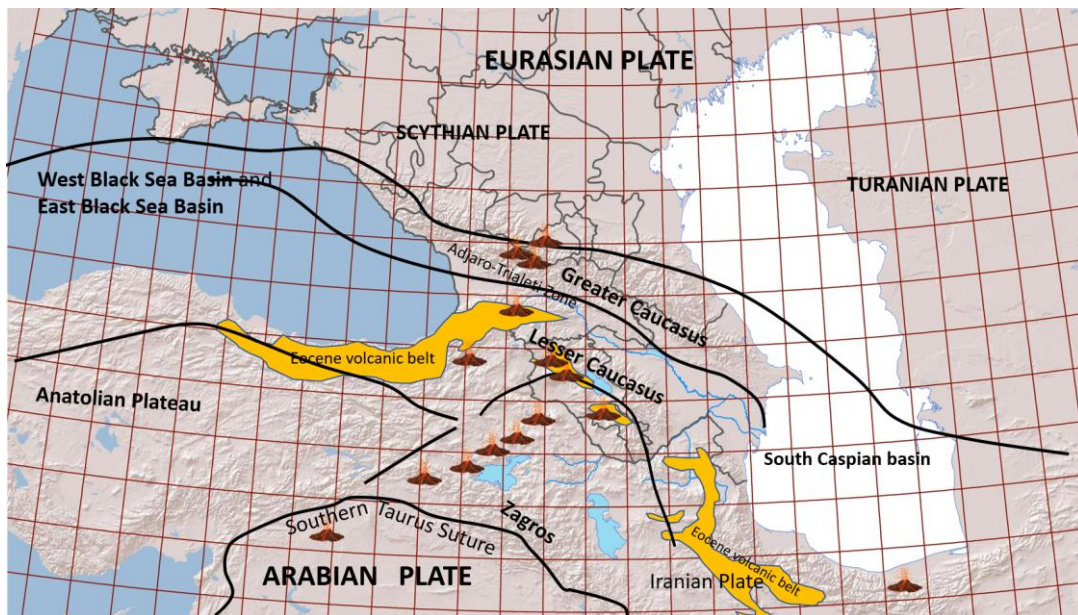


Figure 1. Mesozoic-Cenozoic tectonic zones of the Black Sea-Crimean-Caucasian-Caspian region in their modern boundaries [15, 23,24]

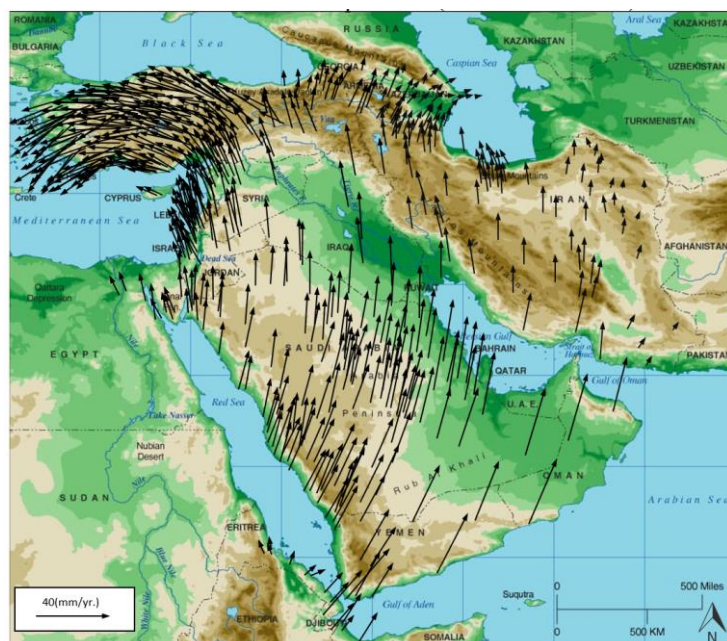


Figure 2. Horizontal movement directions among GPS stations installed in Turkey, Arabia, Iran, and Azerbaijan (2018-2023) [1, 2, 8, 9]

Geodynamic features of the region.

Within each region, zones with different characteristics, mentioned above, are distinguished. In the South Caucasus, such zones include the southern slope of the Greater Caucasus, its southeastern plunge, the northeastern, central, and southwestern parts of the Lesser Caucasus, and the Talysh folded zone. In Iran, according to the classification of N. Falcon (1977) [25], three main zones are distinguished: a region of complex structure with metamorphic rocks, a zone of imbricated thrusts, and a zone of simple folds of the foothills. These zones are parts of the large megastructure of Zagross and adjacent territories. For Turkey, E. Ilkhan (1977) [19] described zones such as the Pontides, Taurides, areas of marginal folds and depressions, including regions of Neogene and modern volcanism, distributed over these four zones. The structural zone of the Pontides is elongated in the latitudinal direction, while in the Taurides, arcuate folding forms are sometimes found. In this aspect, some similarities are observed between the Caucasus and Turkey. The orientation of the structures of the Greater Caucasus and the Pontides is very similar, while in the Lesser Caucasus and southwestern Turkey, arcuate structures predominate. The general sizes of these regions are also similar: the length of the Caucasus is about 1125 km, Turkey - 1300 km, and their transverse sizes vary from 300-500 km for the Caucasus to 380-700 km for Turkey. Something in common can be noted in geological characteristics, such as the distribution of sedimentary, volcanic and metamorphic rocks and fault deformations. As can be seen, the fragments of Gondwana - the Caucasus, Turkey, and Iran - developed under the influence of both regional compression and partially autonomous geodynamic processes. This was reflected in differences in the deep structure and surface structure, heterogeneity of the thickness of the sedimentary layer and the earth's crust, and variations in the distribution of rocks on the surface. For example, in Turkey, sedimentary rocks make up about 40%, volcanic rocks - 25%, metamorphic rocks - 10%, and ultramafic rocks - 25%, intrusions are rare. In Iran, according to J. Stecklin (1979) [28], sedimentary rocks occupy 50%, metamorphic rocks - 45%, and intrusive rocks - 5%. In the South Caucasus, approximately: sedimentary rocks - 50%, volcanic rocks - up to 30%, metamorphic rocks - 15%, intrusions - 5%.

GPS studies of the Caucasus, Turkey, and Iran

These differences indicate that deep processes in the lithosphere of these geostructures developed under partially independent geodynamic regimes that varied in time and space. The direction of compression associated with the movement of the Arabian Plate plays an important role here (Fig. 2).

According to GPS measurements, the vectors of horizontal compression movements in Iran and the Caucasus are predominantly oriented to the north, with minor deviations to the northeast.

In the east of Turkey, the direction of modern movements gradually changes to the northwest, then in the central part, to the latitudinal, and in the west of regions, to the southwest. The boundary of these changes coincides with a significant tectonic element - the Transcaucasian submerged uplift (north-south), which crosses the entire Caucasus and extends to the border zones of Turkey and Iran.

The general picture of horizontal movements indicates a translational-rotational movement of the Arabian Plate, probably caused by the uneven expansion of the Red Sea rift. Its modern transverse dimensions are 175 km in the northern part, 265 km in the central part and 375 km in the south. Thus, the speed of movement of the Arabian Plate is significantly higher on its southern edge, and the direction of movement is northeast. The northern part of the plate acts as a kind of support, where the speed of horizontal movements is lower.

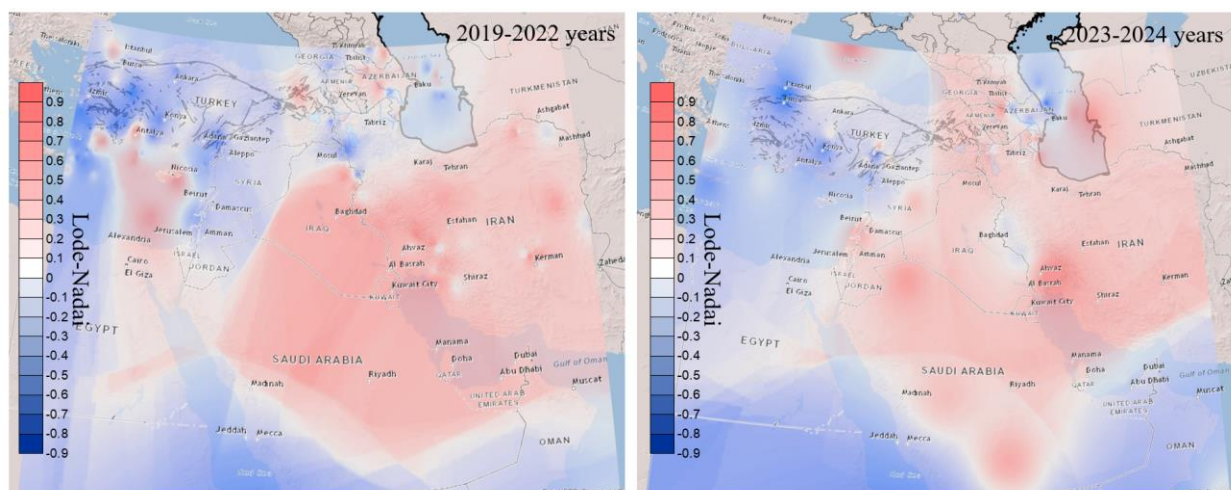


Figure 3. Distribution map of the Lode-Nadai stress coefficient for earthquakes that occurred in 2019-2022 and 2023-2024

As already mentioned, the separation of the Arabian Plate from Africa began in the Miocene, at the late neotectonic stage. The researchers suggest that GPS data on modern velocities and directions of horizontal movements can be extrapolated to the entire late orogenic stage, although taking into account periodic changes in these parameters. The presented maps (Fig.3) show the distribution of the Lode-Nadai coefficient in the Middle East, Caucasus, and Turkey region for two time periods: the left map is data for 2019–2022; the right map is data for 2023–2024 yy. The maps demonstrate how the tectonic state of the region changes over time, which is important for assessing seismic risks and forecasting geodynamic processes. The color scale to the right of the maps reflects the values of the Lode-Nadai coefficient, which characterizes the type of stress state in the earth's crust: red shades (positive values, up to 0.9, $\sigma_1 > \sigma_2 > \sigma_3$) indicate dominant extension (rock separation), which is typical for areas where normal faults occur; blue shades (negative values, up to -0.9, $\sigma_1 < \sigma_2 < \sigma_3$) – indicate the predominance of compression, which is typical for areas where reverse faults or thrusts are formed; neutral (white) areas are zones where the stress state is balanced [8, 12, 13]. During the period 2019–2022yy, extensional stresses (red areas) prevailed, especially in: Iran – a wide extension zone in the central and southern parts of the country (Tehran, Isfahan, Kerman); Saudi Arabia – a significant area of positive values, indicating tectonic extension; Northwestern Turkey – areas of positive values are also noticeable, which may be associated with the activity of the North Anatolian Fault. Compressional areas (blue shades) were comparatively less pronounced, but small areas of negative values were present in eastern Turkey and western Iran. There are also signs of compressive stresses in the eastern Mediterranean and the Caucasus regions. In 2023–2024, compared to the previous period, there was a noticeable redistribution of stresses: an increase in compression (blue areas).

In the Caucasus region, especially in Azerbaijan and Georgia, a significant increase in negative values of the Lode-Nadai coefficient is observed. This may be due to regional tectonic activity and stress redistribution. In northern Turkey, compression areas have also increased, consistent with the North Anatolian Fault activity. Pronounced compressive stresses have also appeared in Egypt and the eastern Mediterranean. A decrease in extension is observed in several regions. In Iran and Saudi Arabia, a weakening of extension is observed compared to the previous period. In Turkey, the areas of positive values have decreased, which may indicate a redistribution of stresses after earthquakes. In general, during the period under review, there was a change in the dominant stress mechanism. If 2019–2022yy, extension stresses prevailed

(especially in Iran and Saudi Arabia in 2023–2024yy, an increase in compression is observed, especially in the Caucasus, northern Turkey, and the eastern Mediterranean. Such changes may be associated with regional geodynamic processes, including: displacement and activation of fault zones, consequences of recent earthquakes, deep processes in the lithosphere, reflecting the redistribution of stresses.

Tectonic-geomorphological structure of the region

In the areas of the Greater and Lesser Caucasus, Pontides, Taurides, Elbrus, and Zagros, sedimentary strata of varying thickness accumulated, represented by terrigenous, carbonate, and, in places, flysch deposits. In the orogenic zones, Mesozoic-Paleogene deposits formed regional thrusts large layers to the south, sometimes creating overturned folds [16]. In these tectonic zones, volcanic activity manifested with varying intensity, sometimes covering significant areas. An extensive strip of ophiolitic tectonomagmatic complex is associated with the orogenic structures of Elbrus, Lesser Caucasus, and Pontides. In the Paleocene-Eocene period, differentiated uplifts created a pronounced relief contrast (Fig. 4).

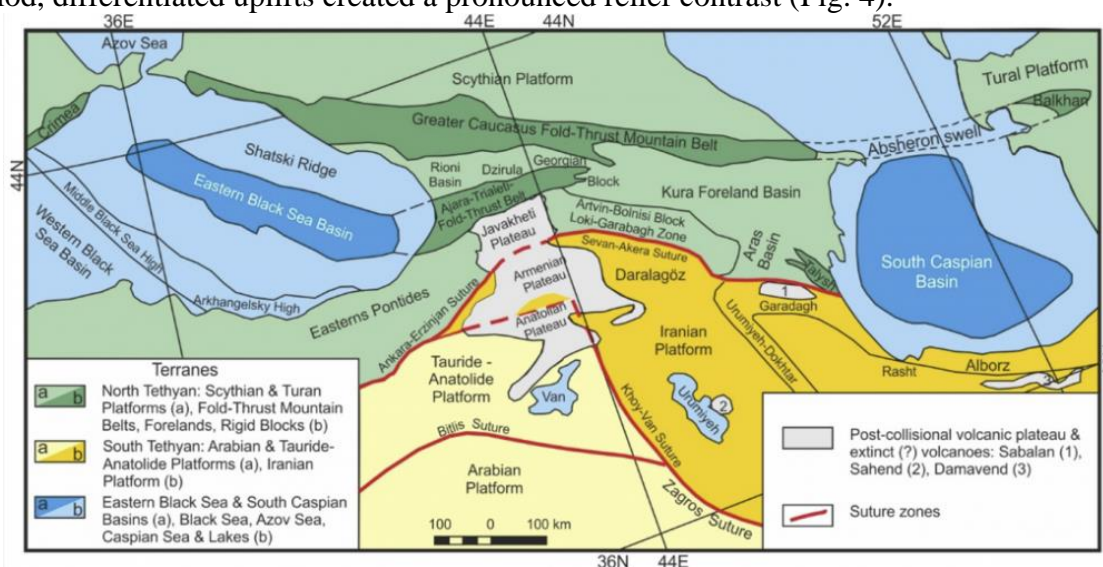


Figure 4. Correlation map of the central tectonic units of the Caucasus and adjacent areas [6]

Analysis of available data shows that at the beginning of the Mesozoic, the Caucasus and adjacent regions of Turkey and Iran represented a single tectonic block associated with Gondwana, whose disintegration, according to scientists, occurred in the Late Cretaceous. The African continent, including the Arabian platform, remained intact until the formation of the Red Sea rift.

After tectonics, and the development of the Caucasus, Turkey, and Iran was analyzed from the standpoint of this theory. Such elements as the Rio-Shirvan, Middle Kura, Transcaucasian, Turkish, and Lut plates, the Jeyranbatan-South Kura microplate, and the Iranian microcontinent were identified. Their boundaries were determined by the linear concentrations of earthquake epicenters, similar to the boundaries of global lithospheric plates. As noted by B.Isaacs, J.Oliver and L.Sykes in 1974 [14], "many of the key data obtained by seismology are so obvious that they are often accepted without in-depth analysis of their nature; they are in good agreement with the concept of a new global tectonics, including a system of seismically active zones dividing the earth's surface into stable blocks."

Seismostatistical data show the presence of linear seismically active zones in the Caucasus, Turkey, and Iran. Examples include the strip of the southern slope of the Greater Caucasus, Pontides, Zagros (all sublatitudinal), as well as the East Azerbaijan (meridional) and

Central Caucasian zones (along the Transcaucasian uplift). Clusters of epicenters often form narrow but relatively short strips. Many authors who distinguished these plates, microplates, and microcontinents sometimes did not take into account the depth and types of seismic sources, the frequency of strong earthquakes, their intensity, the connection with different depth levels, or lateral displacements of the plates. Also, insufficient attention was paid to the transregional geodynamic regime. Today, it is known that the seismic activity of the lithosphere has changed over time, which leads to more frequent strong earthquakes in Turkey and Iran to those in the Caucasus (according to statistics). The features of the geomorphology of the orogenic structures that form the extended mountain ranges in the region are also important. The ranges of Elbrus, Talysh, Lesser Caucasus, and Pontides stretch for almost 2300 km, in places forming arcs with bulges to the south (Elbrus, Eastern Pontides) or the north (Lesser Caucasus, Western Pontides). The Greater Caucasus is a linear megastructure 1250–1300 km long. The Tauride Mountains and the Zagros Range form a single strip about 3,000 km long, starting in southwestern Turkey and extending to the Persian Gulf coast in a gently curved arc to the north.

There is no convincing evidence for stable plate or microplate boundaries in the modern tectonic structure of the South Caucasus, Turkey, and Iran. Some scientists' attempts to interpret suture zones such as the Anatolian-Middle Kura as plate boundaries are not supported by specific data. Modern geophysical studies show that the Middle Kura zone is only a deep regional fault that does not penetrate below the lower crustal boundary.

According to the authors presented in [16], the folded mountain systems of the region cannot be explained solely by the collision of plates or microplates, although this process is important. An essential role in the formation of orogens was played by vertical tectonic movements, which, in combination with horizontal movements, determined the main features of modern geology. Another feature of the tectonic-geomorphological structure of the region is the relationship of the main tectonic elements of the Caucasus, Turkey, and Iran. Geological and tectonic maps show that key folded and orogenic structures smoothly pass from one region to another without abrupt changes. An example is the Elborz-Talysh-Lesser Caucasus-Pontides and Zagross-Taurides chains.

According to the results of the study [16], it was established that after the separation of the Arabian Plate from Africa in the Miocene, associated with the expansion of the Red Sea rift, a vast territory including the Caucasus, Turkey and Iran was not divided into separate plates, microplates or microcontinents, as some researchers assumed without sufficient grounds. Proponents of the "plate" interpretation have often revised their conclusions based on plate tectonics, but the area remained unified even after the breakup of Gondwana, when large plates such as Africa, Australia, India, and Antarctica separated.

Seismicity

The Caucasus region, being part of the ongoing continental collision between the Arabian and Eurasian plates, is characterized by moderate to high seismicity. Destructive earthquakes in this area have repeatedly caused significant loss of life and property, including the Shamakhi earthquake (Azerbaijan, 1902), the Spitak earthquake (Armenia, 1988), and the Racha earthquake (Georgia, 1991). The eastern part of the North Caucasus (Dagestan, Chechnya, Ingushetia, North Ossetia) is also subject to powerful seismic events, including earthquakes in Dagestan (1830, 1970), Chechnya (1976), and Karachay-Cherkessia (Teberda, 1905).

Figure 5 presents a map of earthquake epicenters in the Caucasus and neighboring regions with a magnitude of 4.5 and above. Earthquake data were taken from the catalogues of the Republican Seismological Service Centre, as well as from the EMSC website. Below is a brief overview of seismic activity within the Earth's crust in this area. Earthquake focal points

are typically associated with tectonic faults of various orientations. However, of the East Anatolian and North Anatolian Faults, as well as the Greater Caucasus Thrust Zone, there are no clearly defined linear chains of seismic events on the map. Overall, earthquake epicenters are unevenly distributed. The western part of the Caucasus Mountain belt is characterized by relatively low seismic activity. However, significant historical earthquakes have occurred near Novorossiysk, including the Lower Kuban events in 150 BCE ($M_s=6.1$) and 1879 ($M_s=6.0$). East of this region, there is a noticeable decrease in the number of significant earthquakes. However, further east, seismic activity increases again, with events of magnitude 6–7 concentrated along the southern slope and foothills of the Greater Caucasus Thrust.

The number of large earthquakes rises in the central part of the Greater Caucasus Thrust, near the active Kazbek volcano. These events are distributed along the range's southern and northern slopes. In the northeastern foothills, the epicenters of the strongest earthquakes are located closer to the foreland zone. The eastern part of the Caucasus range exhibits the highest seismic activity. This region has recorded the strongest earthquakes in the Caucasus, from 742 CE to 2012, with magnitudes ranging from 5.7 to 7.8. The Shamakhi region stands out in particular, having experienced dozens of powerful earthquakes. This area's most recent strong event occurred in February 2019, with $M_w=5.5$.

High seismic activity is also observed along the southern boundary of the Scythian Plate, in the

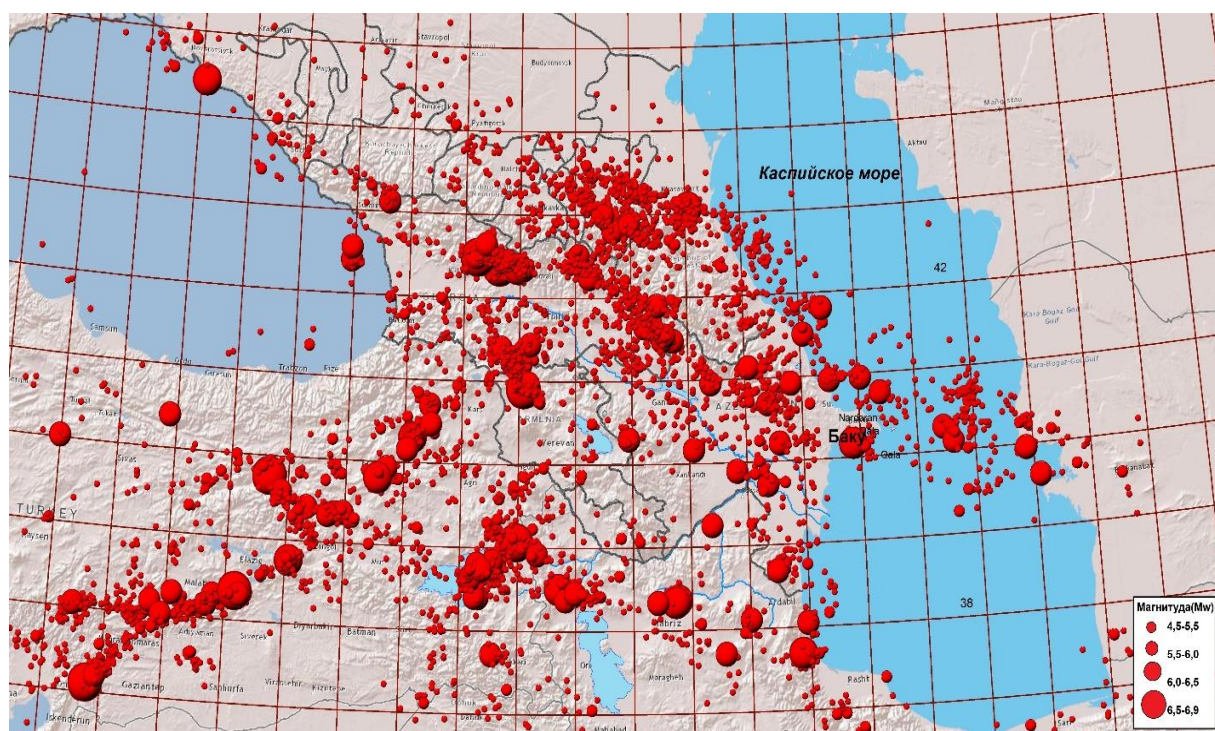


Figure 5. Map of earthquake epicenters in the Caucasus and adjacent territories with a magnitude of 4.5 or more for 1990–2024

Terek-Caspian Depression and Dagestan. In these areas, earthquakes with magnitudes of 5.7–6.8 have been recorded between 650 and 1976 CE. Approximately 95% of all earthquakes in the Greater Caucasus Thrust Zone and 85% within the Scythian Plate occur within the upper 20 km of the Earth's crust. Most events are concentrated at depths of 5 and 10 km, while in the Scythian Plate, earthquakes also occur at depths of 15–25 km. In the Greater Caucasus Thrust, about 4% of earthquakes occur at depths of 21–40 km, while 1% occur within

the 41–80 km range. In the Scythian Plate, 12% of events have been recorded at depths of 21–45 km, and 3% at depths exceeding 46 km, reaching as deep as 150 km.

Data analysis indicates that earthquakes with magnitudes below five predominantly occur in sedimentary deposits, whereas events with $M \geq 5$ are associated with granitic rocks.

According to Akhmedbeyli [16], in the pre-neotectonic period, the Caucasus, Turkey, and Iran constituted a single large tectonic block or terrane, which is confirmed by the following facts. The central segment of the Alpine-Himalayan belt is characterized by high seismic activity. According to B. Isaacs et al. (1974) [14], most earthquake epicenters are concentrated along linear zones that form a trapezoidal configuration. The diagrams of V.E.Khain and L.I.Lobkovsky (1990) [26] demonstrate not only crust-mantle, but also mantle earthquakes, with linear seismic zones 1,750 km (southwestern boundary), 800 km (northwestern), 1,300 km (northeastern), and 1,400 km (eastern) long. The territory's total area is 1,677,500 km², and the width of the linear seismic zones does not exceed 80–110 km, indicating a high concentration of epicenters.

These linear zones are reflected on the Earth's surface and in the deep layers of the lithosphere as transregional deep faults penetrating the crust and upper mantle. Seismic activity of linear seismic zones is associated with foci at different depths, but is manifested unevenly: earthquakes occur fragmentarily, and the velocities and directions of horizontal movements measured by GPS differ significantly. The modern tectonic structure and seismicity of linear seismic zones are heterogeneous. For example, the zone passing near the eastern part of the Black Sea Basin coincides with the convergence of Alpine and Cimmerian structures, where many epicenters are concentrated. Here, the distances between the latitudinal Phanerozoic faults coming from the Black Sea Basin also decrease, and the contours of the granite-free crust narrow, as shown by N.A.Belyaevsky and A.E.Mikhailov (1980) [17]. Another linear seismic zone runs through Iran from northeast to southwest to the Persian Gulf, crossing the eastern part of the Elburz belt, the area of its junction with the Kopetdag, the southeastern part of the Zagros, and intermediate structures. According to J.Stecklin [28, 29] and N. Falcon (1977) [25], these structures are complex, with high tectonic activity in the Cenozoic. Orogenic processes in the Elburz were accompanied by increased compression, which reduced the transverse dimensions of the belt by about half. Most of the foci of crust-mantle earthquakes are concentrated along this seismic zone, while mantle earthquakes are rare, except the area near the coast of the Persian Gulf. Another linear seismic zone is characterized by seismically active structures such as the "Dagestan wedge" and the Makhachkala-Krasnovodsk fault, associated with earthquakes of 7-8 points, as well as the boundary between the Middle and South Caspian basins. Of particular interest are seismic zones with of mantle foci, which coincide with the folded structure of Zagros (e.g., Eppelbaum and Katz, 2017), then passes through the eastern part of the Tauride Mountains and stretches along the Pontides. These linear seismic zones are explained as the boundaries of the Caucasus-Turkey megablock, which underwent significant changes in the neotectonic period. Their destruction did not begin immediately: at the end of the Mesozoic, after the breakup of Gondwana, the African-Arabian continent, as a single plate, began to move to the north-northeast. According to the paleotectonic reconstructions of M.I.Rustamova (2001) [22], the Caucasus-Turkey-Iranian single microplate was located between the northern and southern branches of the Mesotethys, which closed before the beginning of the neotectonic stage. The geodynamic regime in this microplate was repeatedly activated or weakened unevenly in time and space, which is confirmed by changes in the intensity of tectonic movements, volcanism, metamorphism, geomorphological relief, large, folded structures, depressions, ophiolite belts, and other features.

Conclusions

The Caucasus occupies an important place in the Alpine-Himalayan belt; its tectonic evolution is associated with the breakup of Gondwana, the movement of the Arabian Plate, and complex geodynamic processes that formed the modern structure of the region under conditions of compression and autonomous development. By the middle of the Mesozoic period (Early Cretaceous), the outlines of the Alpine belt began to appear, although large segments such as the Arabian and Punjab had not yet fully formed. Different parts of the belt differ in the intensity of tectonic movements, volcanic activity, sediment structure, fault development and the nature of folded deformations.

The Caucasus, Turkey, and Iran form a complex geological object. After the breakup of Gondwana in the Jurassic period, the region was divided into large blocks (microplates), each with unique structure, folding, and magmatism characteristics. By the beginning of the neotectonic stage (Oligocene), the main structures had formed: the Caucasus, Pontides, Taurides, Elborz, Zagross and adjacent basins, bounded by the Scythian Plate in the north and the Arabian Plate in the south. The formation of the Red Sea rift in the post-Miocene period caused the Arabian Plate to move to the northeast, affecting the region's geodynamics.

In the orogenic zones (Caucasus, Pontides, Elborz, Zagros), sedimentary strata accumulated, thrusts and overturned folds formed. Volcanic activity was significant, with ophiolite complexes in the Elborz, Lesser Caucasus, and Pontides. At the beginning of the Mesozoic, the Caucasus, Türkiye, and Iran formed a single block associated with Gondwana, the breakup of which occurred in the Late Cretaceous. Before the division into microplates, the Caucasus, Turkey, and Iran developed in a single compression regime between the Arabian Plate and the East European Platform. At the stage of neotectonic development, differentiation of structures (Greater and Lesser Caucasus, Anatolides, Elborz, Zagros) occurred, differing in folding types, volcanism, and faults. Zones with different characteristics are distinguished in the region: in the Caucasus - the southern slope of the Greater Caucasus, Lesser Caucasus, Talysh zone; in Iran - zones of metamorphic rocks, thrusts and folds; in Turkey - the Pontides, Taurides and volcanic areas. The Greater Caucasus and Pontides (Turkey) have a latitudinal orientation, while the Lesser Caucasus and southwest Turkey are arc structures. The length of the Caucasus is about 1,125 km, Turkey – 1,300 km; transverse dimensions: 300-500 km (Caucasus) and 380-700 km (Türkiye). The distribution of rocks varies: Turkey has more volcanic (25%) and ultramafic (25%) rocks, Iran has more metamorphic (45%) rocks, and the Caucasus has more sedimentary (50%) and volcanic (30%) rocks. Deep processes in the region developed partially autonomously, which is reflected in the differences in structure and rocks. GPS data show compression to the north in Iran and the Caucasus, and from the northwest to the southwest in Turkey, associated with the Transcaucasian uplift. The movement of the Arabian Plate is due to the expansion of the Red Sea rift (175–375 km in diameter), which is confirmed by GPS data.

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