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MODERN SEISMOGEODYNAMICS OF TURKEY, NORTHERN IRAN AND CAUCASUS REGION

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ABSTRACT

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

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

TÜRKİYƏ, ŞİMALİ İRAN VƏ QAFQAZ BÖLGƏSİNİN MÜASİR SEYSMİK GEODİNAMİKASI

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XÜLASƏ

Məqalədə tədqiq olunan əraziyə Ərəbistan-İran seqmenti və iki qonşu seqmentin hissələri daxildir: Adrio-Egey və Pamir-Himalay. Seqmentlərin strukturu oxşar xüsusiyyətlərə malikdir. Seysmikliyin təhlili göstərdi ki, 2023-cü ildə Anadolu plitəsi, İran bloku və Qafqaz regionu ərazisində seysmiklik aktivliyin artması müşahidə olunub: 18.04.2021 Cənubi İran M=5.8; 01/11/2022 Kipr regionu M=6,6; 10/05/2022 Şimalı-Qərbi İran M=5,6; 23/11/2022 Qərbi Türkiyə M=6.7; 02/06/2023 Mərkəzi Türkiyə M=7,9, 7,4; 07/03/2023 Xəzər Dənizi, M=5,6; 12/07/2023 Xəzər Dənizi, M=5.6.

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

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

СОВРЕМЕННАЯ СЕЙСМОГЕОДИНАМИКА ТУРЦИИ, СЕВЕРНОГО ИРАНА И КАВКАЗСКОГО РЕГИОНА

Казимов И.Э., Казимова А.Ф.

АННОТАЦИЯ

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

Анатолийской плиты на юго-запад, а скорости перемещения, не превышающие 4-8 мм/год непосредственно вблизи зоны Восточно-Анатолийского разлома, возрастающие к северо-западу до 8-12 мм/год, однако точки, расположенные южнее Восточно-Анатолийской зоны и западнее ее стыка с Левантийской зоной, перемещались в южных направлениях со скоростью 4-5 мм/год.

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

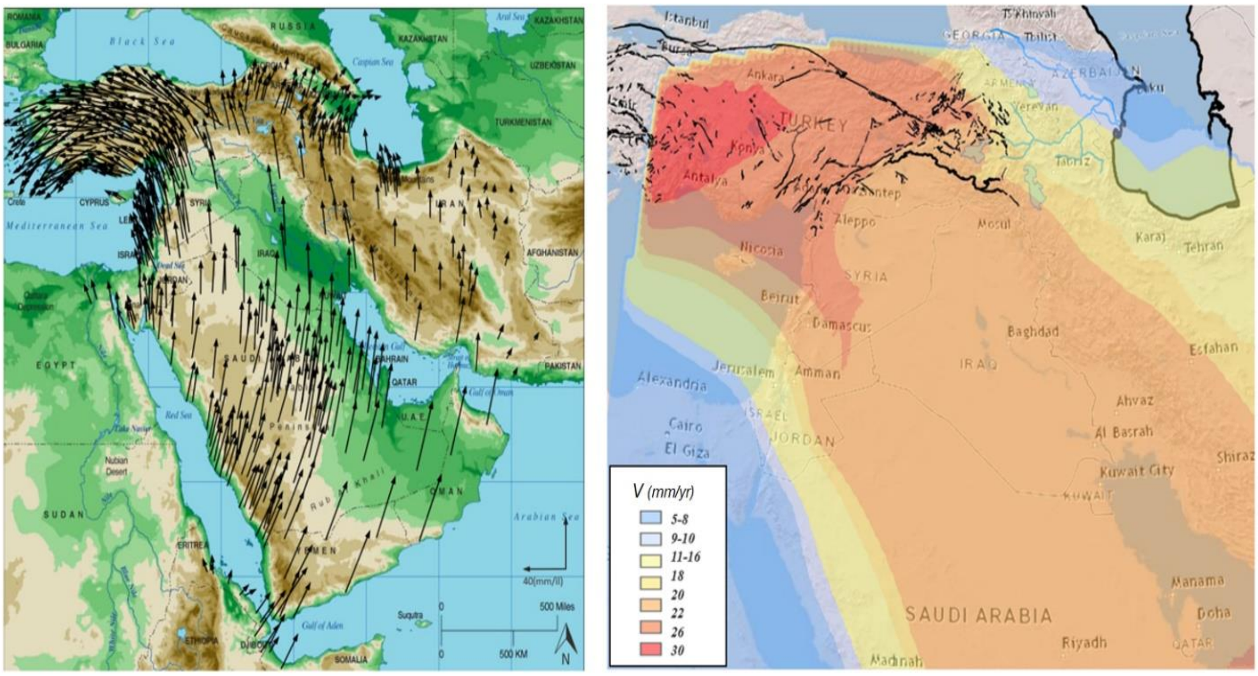
Introduction

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

Active faults of the Anatolian-Iranian segment

The active tectonics of the Arabian-Iranian segment of the Alpine-Himalayan belt shows a number of features common to the Pamir-Himalayan segment. These are, first of all, the above-mentioned directions of displacement on the frames of the Arabian Plate - along the Levant and East Anatolian zones, identical to the Chaman and Darvaz-Alay, and on the eastern segment of the North

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



a) b)

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

Later measurements and calculations [9, 6, 7] showed that the rate of deformation accumulation is approximately 24 mm/year, being dispersed in a strip up to 100 km wide. Of this value, the shear zone itself accounts for about 20 mm/year, and in its central part - no more than 15 mm/year, which coincides with the above geological estimates. The accumulated deformation is sometimes partially realized by creep, and to a greater extent is removed by impulse movements during strong earthquakes. The East

Anatolian zone north of the intersection with the North Anatolian zone is represented by two branches. The western branch, identified by some researchers [14] as the North-Eastern Anatolian zone, is formed by echeloned faults of the south-eastern sides of the Chat and Erzurum depressions, the Dumlu fault and faults near the village Narman and the city of Oltu. Along them, signs of late Quaternary reverse fault movements are noted, and along the Dumlu fault, left-lateral strike-slip displacements of young relief forms are discovered, many times greater than the reverse fault component. The faults can be traced to the city of Akhalkalaki in Southern Georgia, where they are replaced en echelon by the newest Kazbek-Tskhinvali fault, described by E.E.Milanovsky. The main eastern branch of the East Anatolian zone first extends parallel to the western one, and to the northeast it deviates more and more to the east. The fault plane is steeply (50-60°) inclined to the northwest (Fig. 2). Signs of left-lateral strike-slip movements are noted in different parts of the described branch, but are most pronounced at its northeastern end, where their speed is estimated at 4-5 mm/year. It is this branch that articulates in the northeast with the mentioned Pambak-Sevan right reverse fault-slip fault, forming together with it and the Khanarasar and Akerin right fault movements that continue it to the southeast the North Armenian arc of active faults, in which the northern wings are upthrown almost everywhere, and the strike-slip component displacements, close to 5 mm/year, are many times greater than the reverse fault.

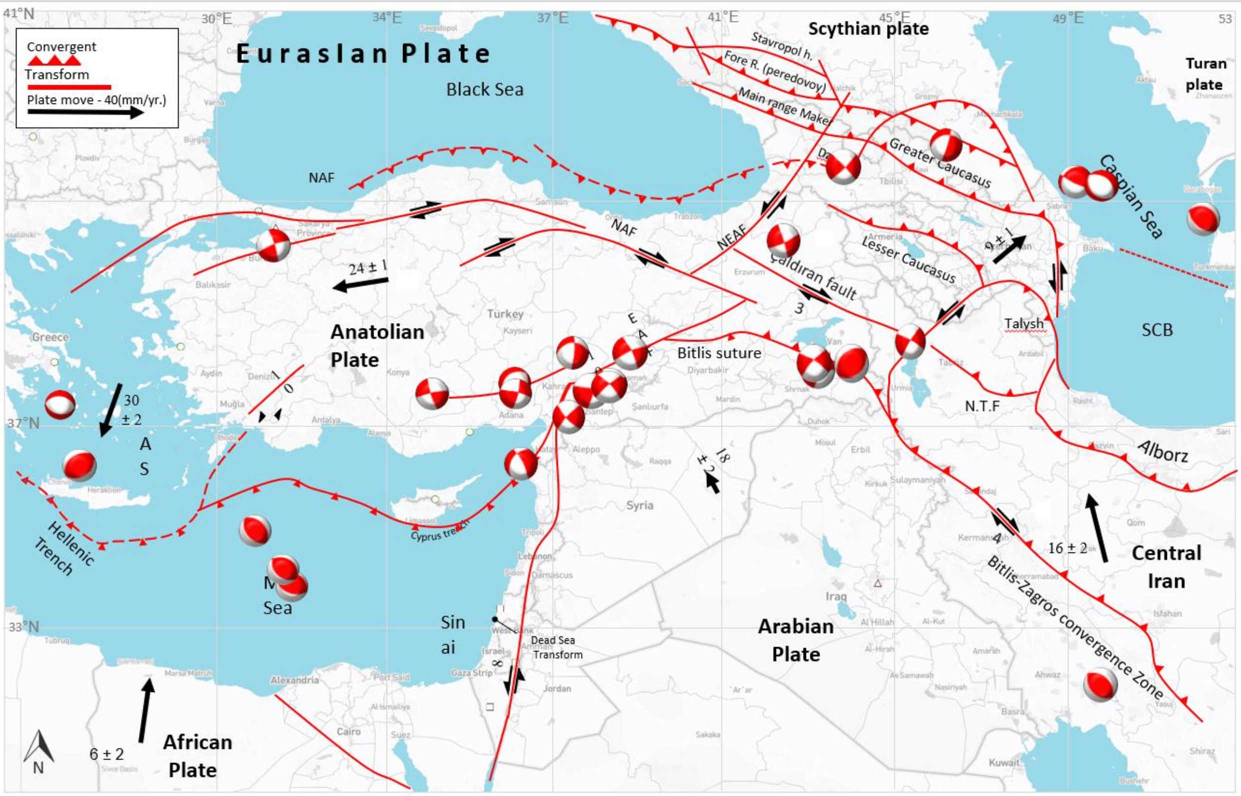


Figure 2. Map of source mechanisms of earthquakes (M>5.0) that occurred in the Eastern Mediterranean Sea and the Caucasus during 2022-2023 [16]

Embedded in the described outer arc is a second, inner, arc of active faults, more steeply curved and touching the outer arc at its apex. The internal arc is represented by the Akhuryan fault of northeastern strike and the Garni fault zone of northwest strike. Interpretation of detailed satellite images of the Turkish part of the Akhuryan fault gives reason to assume left-lateral strike-slip displacements of small river and ravine valleys. Vertical displacements are indicated by the graben-like structure of the fault zone in the area of the Akhuryan reservoir. The Garni zone consists of several segments of northwest and north-northwest strikes, located en echelon relative to each other in such a way that each more southern segment begins east of the previous one [26].

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

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

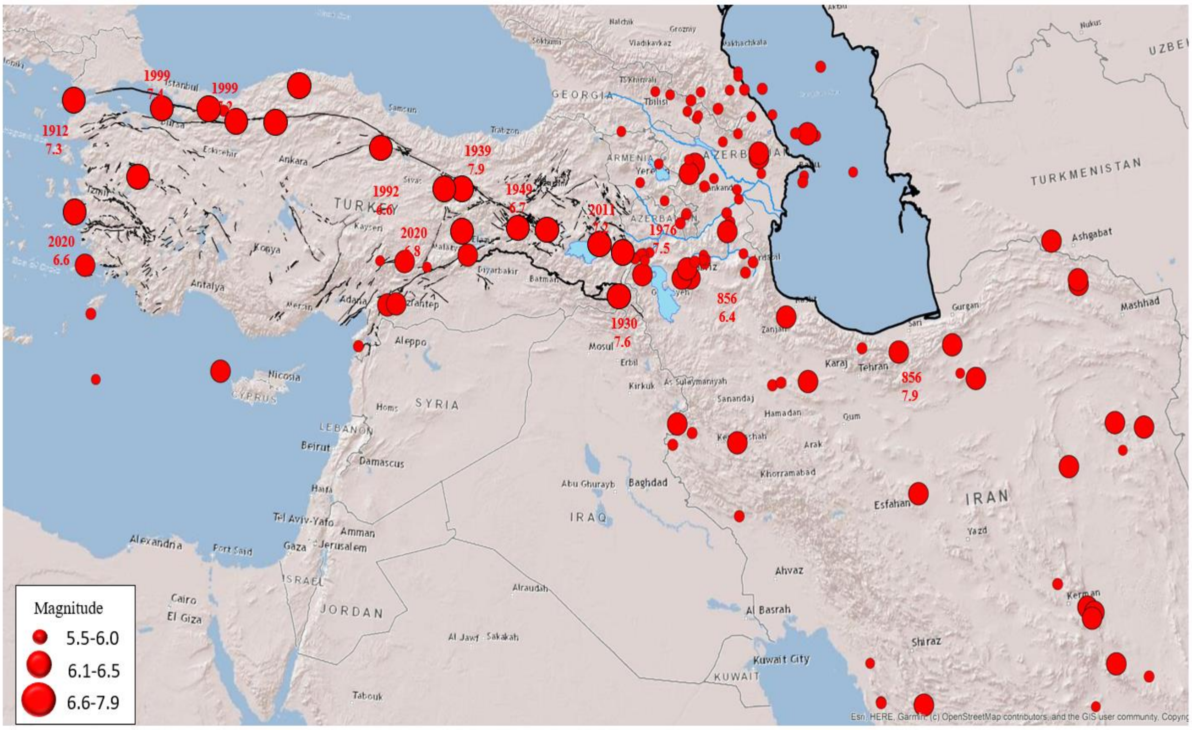


Figure 3. Map of epicenters of catastrophic earthquakes in Turkey, Iran and the Caucasus (years 427-2023 ml>5.5)(The coordinates of earthquakes in Turkey and Iran are taken from the EMSC website)

Active tectonics of Azerbaijan

Most of the active thrusts and reverse faults on the southern slope and southern foothills of the Greater Caucasus extend west-northwest parallel to the axis of the mountain structure. But along some faults deviating to the northwest from this direction, young right-lateral strike-slip displacements were discovered. They are clearly represented in the zone of the Salyan-Lengibiz (Adzhichay) right reverse fault-slip fault on the southern slope of the South-Eastern Caucasus, the average rate of movement along which has reached 1 mm/year since the end of the Pleistocene. The right reverse fault-slip faults of the southern slope continue to the southeast into the waters of the Southern Caspian Sea. The directions of young displacements along the faults of the southern slope and southern foothills of the Greater Caucasus reflect the conditions of submeridional or north-northeast horizontal compression and shortening. This is not contradicted by the appearance of non-extended left-lateral strike-slip faults of northeastern strike along the continuation of the Palmyr-Absheron lineament and normal faults of north-

northeast orientation in Southern Dagestan. An example of the latter is the Kaflan-Kapinsky fault, the rate of Late Pleistocene movements along which reaches 1 mm/year. The main thrust (in the newest structure, a reverse fault) separates the southern slope from the Greater Caucasus proper. On its northern slopes and foothills, the speed of late Quaternary movements is less than in the zone of the southern slope, but active disturbances of the same two main directions predominate: firstly, latitudinal and west-northwest and, secondly, northwestern. The first direction in Dagestan is represented by a series of reverse faults inclined to the south, less often to the north. In Chechnya, this includes the Montenegrin flexure, which apparently corresponds to a consolidated basement fault under a thick sedimentary cover. In the west, the flexure is en echelon substituted by the Vladikavkaz and Baltic faults located to the south, which are associated with asymmetric anticlines with steep southern wings [19, 22, 25]. Changes in terrace heights at the end of the Late Pleistocene indicate movement rates of 1-2 mm/year. Lower rates of movement characterize similar faults and flexures in the Central Caucasus. The northwestern structural direction is often represented by deep zones of active disturbances, expressed on the surface only by indirect signs. These are the tectonic disturbances of the Caspian coast between Makhachkala and Derbent, the Gudermes and Nazran fault zones in Chechnya, the Lysogorsk flexure and the Nalchik (Armavir-Nevinnomysk) fault zone in the Central Caucasus.

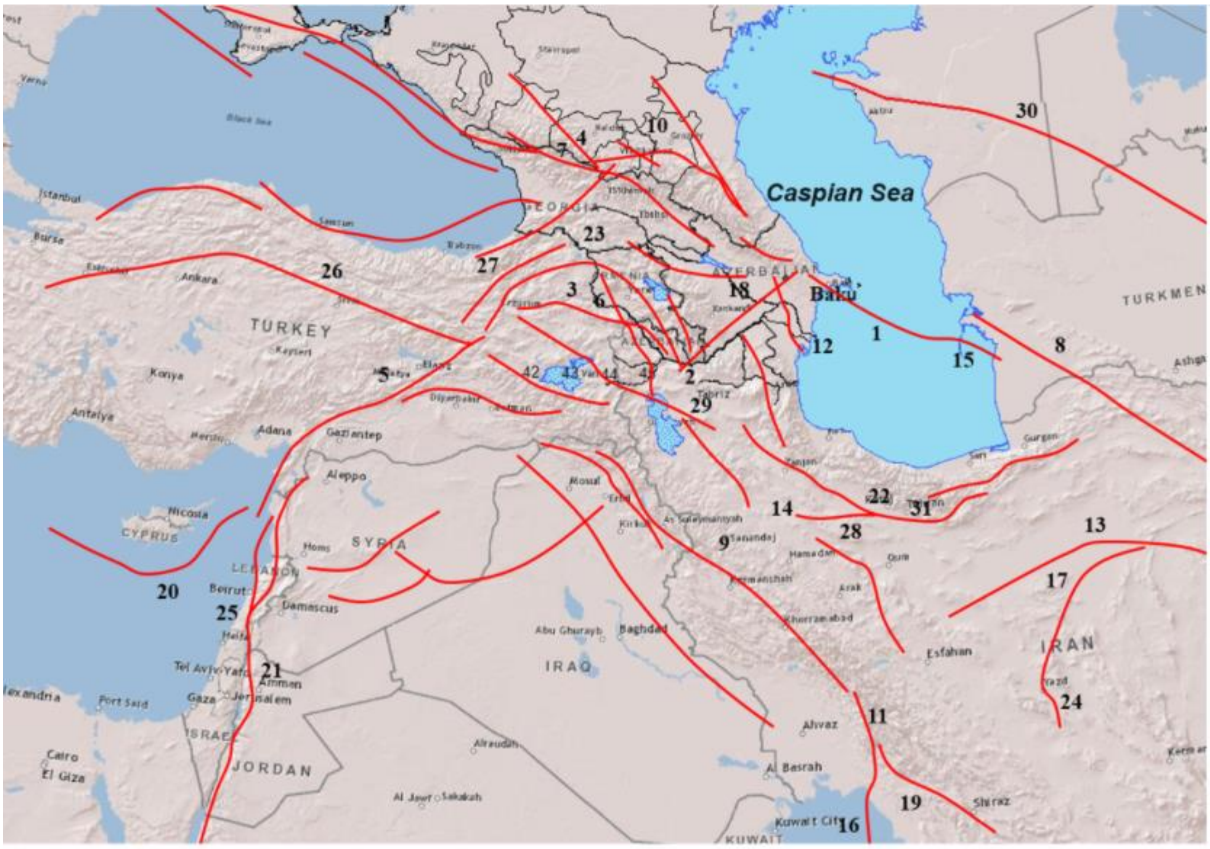


Figure 4. Active faults in the Arabian-Eurasian and Indian-Eurasian collision region. The faults (f.)and fault zones (f.z.), discussed in the text are marked by numerals: 1 - Apsheron Threshald f.z., 2 - Araz f.z., 3 - Akhurian f., 4 - Vladicaucas f., 5 - East Anatolian f.z., 6 - Garni f.z., 7 - Main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

Active tectonics of Central Iran and Alborz

The active tectonics of Central Iran and Alborz is determined by movements along faults extending, firstly, to the east or east-northeast and, secondly, to the north or north-northwest. Catastrophic earthquakes have occurred repeatedly in this region (Fig. 3). In the north of the region, sublatitudinal active disturbances predominate. They are widely represented in Alborz and on both of its slopes, where they are characterized by reverse displacements [20]. However, in the Rudbar earthquake of June 20, 1990, with a magnitude of 7.2, a slip of up to 1 m occurred along the Elbursa longitudinal fault with a predominant left-lateral strike-slip displacement component, and determination of the focal mechanism showed almost pure left-lateral strike-slip. This prompted us to conduct an additional study of sublatitudinal active faults in the southern foothills of Elburz in 1996. As a result, an echeloned series of faults was identified, which, along with the reverse fault, have a significant and in some places predominant left-lateral strike-slip component of displacements [26]. In the west of this row there is a rock-cut Ipak fault zone with a length of about 100 km.

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

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

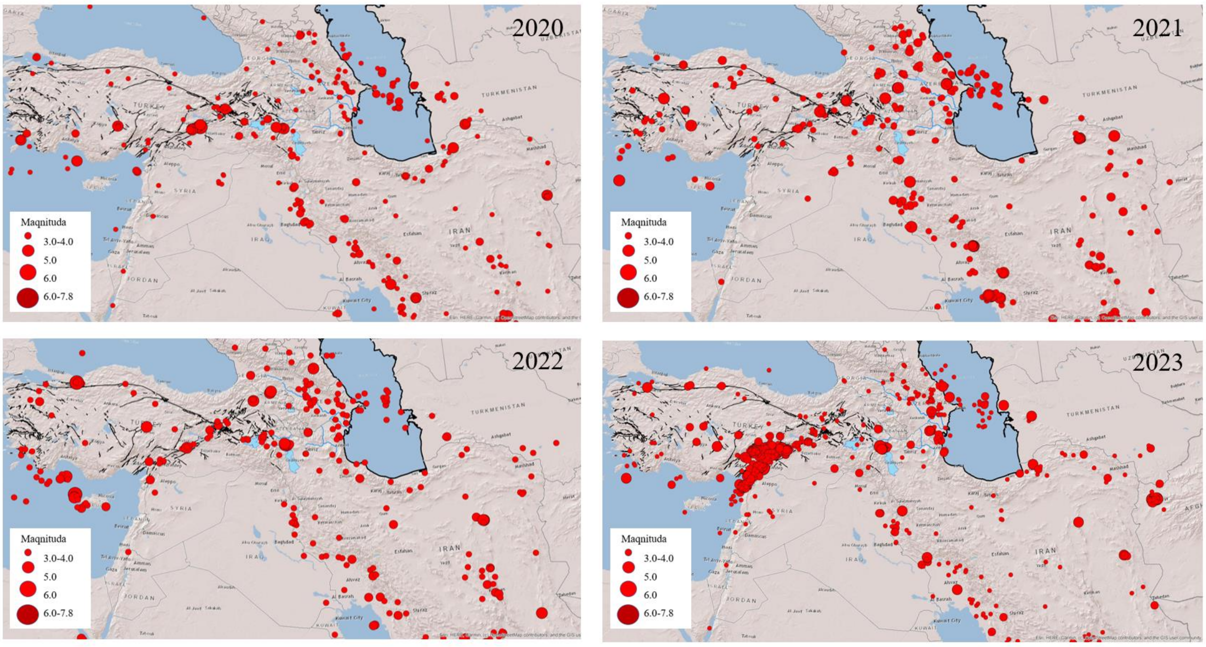


Figure 5. Map of epicenters of earthquakes in Turkey, Iran and the Caucasus during 2020-2023. (M>3.0)

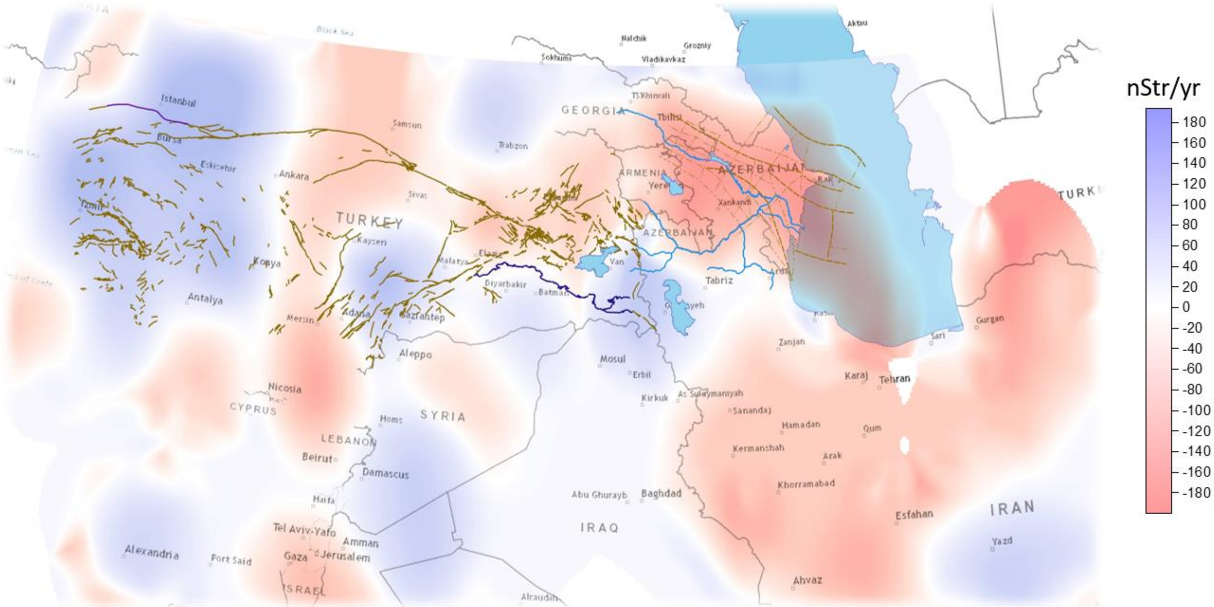


Figure 6. Distribution map of deformation coefficient calculated on the basis of GPS data in 2022-2023

Analysis of modern tectonic deformations.

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

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

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

Conclusions:

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

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

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

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

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