CONTEMPORARY GEODYNAMICS OF THE EASTERN MEDITERRANEAN

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Introduction

As you know, the Eastern Mediterranean and the Caucasus region are located among the Eurasian, African and Arabian plates, characterized by complex tectonic activity such as volcanic eruptions, orogeny and earthquakes. [15, 16] Eastern Anatolia, the Caucasus and Bitlis-Zagros are zones of active continental collision due to modern tectonic conditions. The Eastern Mediterranean is one of the important regions for understanding fundamental tectonic processes such as continental riftogenesis, subduction and accretion, and post collision. [11] The edges of the colliding continents under conditions of compression break into a large number of micro plates. For this reason, the collision zones, unlike all other types of interplate boundaries, do not represent narrow linear zones (as, for example, zones of spreading, subduction or transform faults), but always have "blurred" outlines in plan, and their width reaches hundreds and thousands kilometers. Note that the movement along the faults coincides with the direction from the movement of Arabia and Eurasia. The result of this geometry is that the continent throughout the active region [17] continues to influence the elevation of the Caucasus.

The Global Positioning System (GPS) has provided a new opportunity for direct observation of modern movements and deformations of the Earth's crust, as well as seismic-ionospheric disturbances [6, 8, 9, 12-14, 23, 24]. Previous GPS studies have helped to quantify regional deformation in the plate interaction zone [1, 18-22]. Regional studies of plate movement use fault orientation, local observations, and constraints on relative plate movement.

The results of GPS measurements obtained in recent years [1, 2, 3, 5, 7], including in the territory of Azerbaijan, once again convincingly indicated the importance of the horizontal component of tectonic movements in the development of the Earth's crust and the entire lithosphere. With the help of global satellite geodesy, it became possible not only to obtain high-quality information about modern geodynamics, but also to quickly monitor all its spatial and temporal changes, which is especially important for the purposes of adequate seismic zoning and long-term prognosis of strong earthquakes.

Intensity of seismicity in the Eastern Mediterranean

The tectonic activity of the Mediterranean was completely determined by the processes of closure of the relict basins of the Tethys Ocean with the residual crust of the oceanic type, taking place against the general background of the convergence of the African and Eurasian plates. Due to the roughness of the contour of the northern edge of the African Plate, subduction did not begin in different arcs simultaneously: in the Middle Miocene in the Calabrian, in the Oligocene in the Hellenic, and at the beginning of the early Miocene in the Cyprus. For the same reason, as well as due to the different width of the band of absorbed residual oceanic crust and different convergence rates along the border of the Eurasian and African plates, the subduction zones of the Eastern Mediterranean closed at different times, but in general, the process of continental collision developed from east to west: from the Middle Miocene to east (Bitlis) to the second half of the Pliocene (Cyprus/Cyrenaica) in the west [5].

The Eastern Mediterranean region has experienced many devastating earthquakes throughout its history. The earthquake observed around the Aegean Sea, covering most of Greece and Western Anatolia, was the most remarkable geodynamic event in the Eastern Mediterranean region (Fig. 1). The tectonic evolution of the Eastern Mediterranean region is dominated by the effects of subduction along the Hellenic (Aegean) arc and continental collision in eastern Turkey (Anatolia) and the Caucasus. The northern subordination of the African plate, Western Turkey and the Aegean region is a continuation of the continental crust [5]. In terms of historical seismicity, strong earthquakes have occurred with a magnitude greater than Mw=6 in the Eastern Mediterranean and the Caucasus. The Anatolian plate is of interest for more than two decades of GPS studies, mainly focusing on the seismically and tectonically active region of the Sea of Marmara, Western Anatolia, Central Anatolia, and the North Anatolian fault system with determination of the rate of deformation and slip [20, 21].

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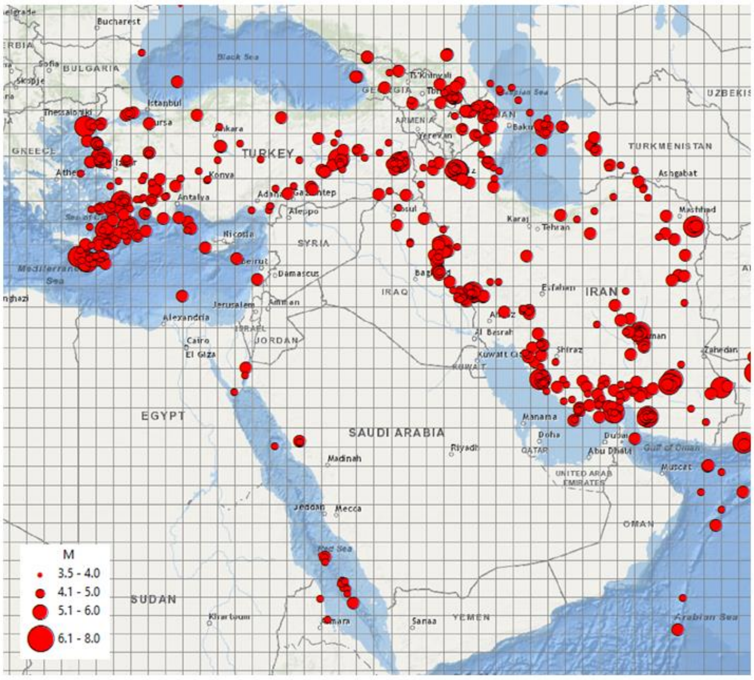

Figure 1. Map of the epicenters of earthquakes with ml>3.5 that occurred within the Mediterranean region for the period from 2005-2020

In seismogenic terms, interblock zones are structures within which, as a result of the gradient of tectonic stresses arising during deformation processes, a significant amount of seismic energy is released. The relatively shallow penetration of these zones into the lithosphere is confirmed by the location of hypocenters in the overwhelming majority of cases at a depth of 20-40 km, much less often up to 80-240 km. In interblock zones, it is easy to see a certain analogue of transit zones established between large plates, which serve as one of the expressions of the fractal structure of the continental lithosphere [5, 10].

Turkey is one of the most earthquake-prone countries in the world. According to scientists, Turkey is located on a small wedge-shaped Anatolian plate. The Anatolian plate is a continental tectonic plate, which is almost entirely located on the territory of Turkey (Fig. 2). The earthquake catalogue was taken from EMSC.

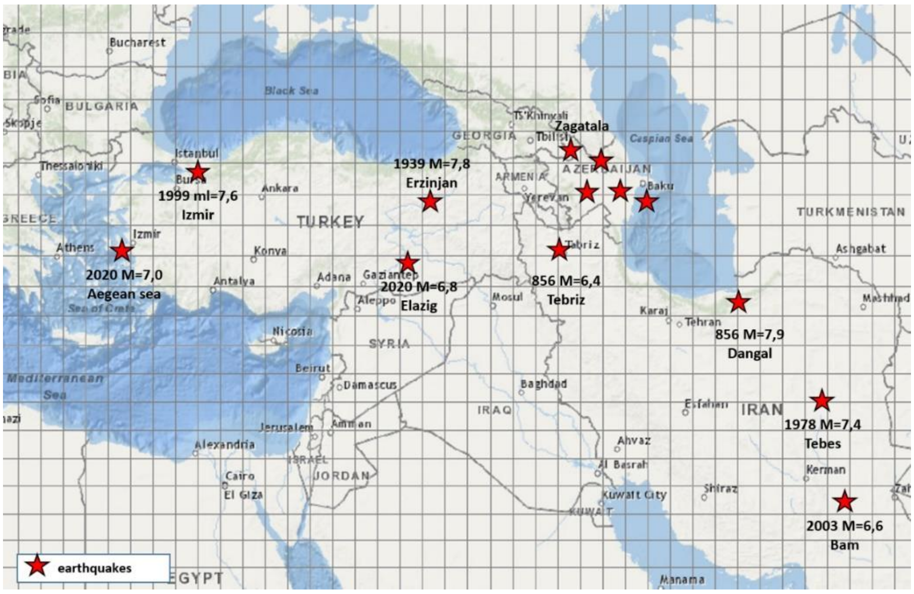

Figure 2. Map of the epicenters of strong historical earthquakes with ml>5.0 that occurred within the Mediterranean region for the period from 856-2020

Has an area of 0.014 18 steradians (0.57 thousand km^2). Usually is considered as a part of the Eurasian Plate. The eastern edge is bordered by the Arabian plate, the left-sided transform East Anatolian fault. In the south and southwest, it has a convergent border with the African Plate, which manifests itself in the features of compression of the oceanic crust under the Mediterranean Sea, as well as within the continental crust of Anatolia and in subduction zones along the Greek and Cypriot arcs. The western edge has a divergent border with the plate of the Aegean Sea [5]. The northern edge along the border with the Eurasian plate forms the North Anatolian fault zone 500 miles long. At its western end is the volcanic underwater North Aegean fault, following through the middle of the Aegean Sea. The fault zone further follows under Greece and further under the Ionian and Adriatic seas. As a result of active interaction and movement along these major faults, hundreds of earthquakes of various strengths occur in this region. The Anatolian plate is moving to the west (2–2.5 cm/year), because it is pressed by the Eurasian plate from the north, the African plate and the Arabian plate from the south (Fig. 3).

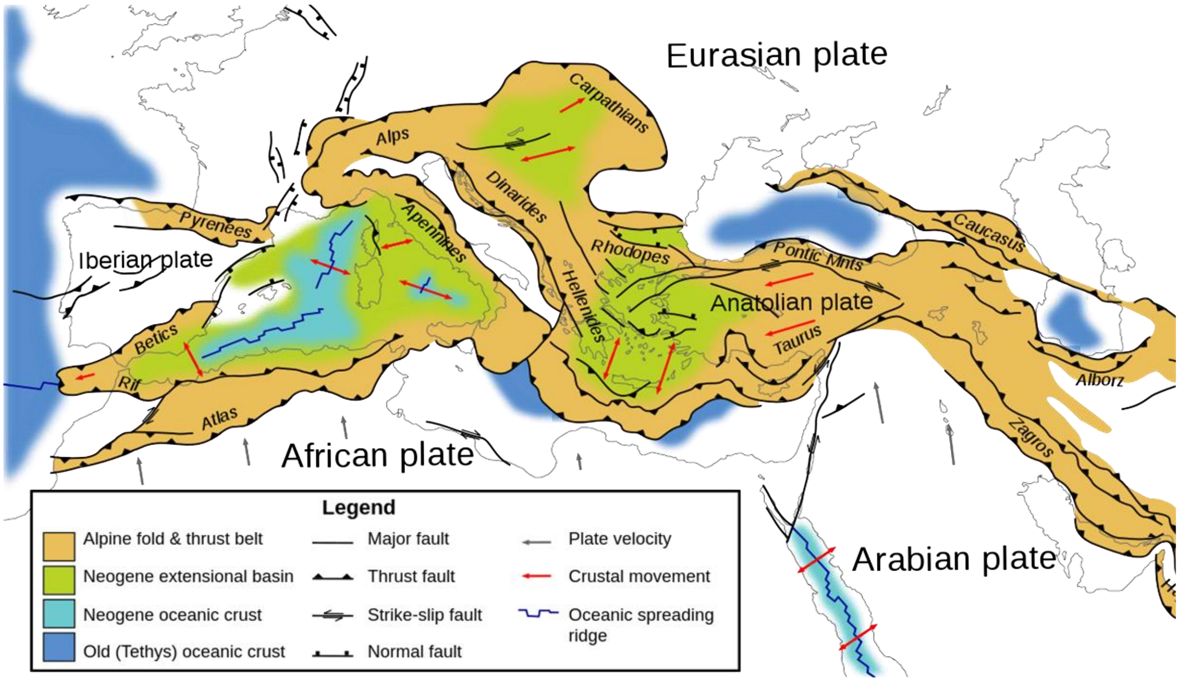

Figure 3. Alpine-Himalayan fold belt

Many major earthquakes in Turkey occur on one of two faults adjacent to the Anatolian plate to the north and east. In 1939-1999 violent tremors went west along the northern rift, causing scientists to fear that Istanbul would eventually be destroyed. In 1999, an earthquake with a magnitude of 7.9 happened in the vicinity of Izmir (only 70 km from Istanbul), killing about 17 thousand people. At the moment, in Turkey, seismically unstable regions are the Black Sea coast and the Eastern part of Turkey, where the border of the junctions of the Arabian and Turan-Scythian lithospheric plates is located. The most earthquake-prone point of this fault is outside the territory of Turkey, namely in the eastern part of the North Caucasus, where the greatest number of earthquakes of great strength occurs. Cities are a mixture of rich and poor infrastructure, putting a huge proportion of the population at risk. In 1999, a 7.4 magnitude earthquake struck the city of Izmit, just 97 km from Istanbul. Around 18,000 people died in the region. In 1997, seismologists predicted that the same earthquake could be repeated in the region until 2026 with a 12 percent chance.

The strongest earthquake that hit Turkey in the 20th century took place in Erzindjan in December 1939. It destroyed most of the city and killed more than 30,000 people. One of the most destructive earthquakes in Turkey occurred near Istanbul on August 17, 1999. The earthquake with epicenter in 11 km from the city of Izmir and 80 km from Istanbul killed 19,000 people and damaged numerous historical monuments and structures. An earthquake with a magnitude of 7.4 almost completely destroyed the industrial center of the country.

Van earthquake On October 23, 2011, a 7.2 magnitude earthquake struck at a distance of 38 km northeast of the city of Van in Turkey. The number of victims of the devastating earthquake in Van exceeded 260 people, about 1300 were injured. The earthquake was also recorded in Armenia, Georgia and Iran. The tremors in Armenia ranged from 3-5 points.

A devastating earthquake in the eastern Turkish province of Elazig with a magnitude of 6.7 occurred on January 24, 2020 at 20 hours 55 minutes local time. The source of oscillations (hypocenter) lay at a depth of 11.9 km near the city of Seavridge. The earthquake was felt in the neighboring provinces of Diyarbakir, Malatya, Adiyaman and Samsun. Its duration was about 40 seconds. The magnitude of the aftershocks ranged from 5.4 to 3.3. The intensity of the earthquake was 8 points.

On October 31, 2020, Izmir shuddered from another earthquake: in the morning at about 08:30 local time, there was a strong aftershock with a magnitude of 5.0. But most residents spent the entire night on the streets, fearing a repetition of a strong shock of almost 7 points on October 30, which could bring down the buildings affected by the first earthquake. According to AFAD, at least 389 aftershocks were recorded, 33 of them having a power of more than 4 points, which lasted until the morning.

Central Iranian block

The Central Iranian block has a Late Precambrian metamorphic basement and a Vendian-Triassic platform cover. The Central Iranian microplate lies in the same zone as the Anatolian-Taurus "platform" of Turkey. In the east, the Lut block of Central Iran is bounded by the zone of development of the Upper Cretaceous-Lower Eocene ophiolites and their accompanying flysch, expanding to the south. Its southwestern framing forms the Urmia-Bazman (Dokhtar) volcano-plutonic belt of Late Cretaceous-Cenozoic age with subalkaline volcanics from basalts to rhyolites [6]. The formation of the belt is associated with the collision of the Arabian and Central Iranian plates. The magma belt itself is confined to the border of Central Iran and the mobile belt of the same northwestern strike, which arose on the site of the southern branch of the Neotethis, stretching here from the Taurus system of Anatolia. In Iran, this belt consists of two zones - the Sanandadj-Sirdjan metamorphic zone and the Zagros fold zone [6].

The Sanandadj-Sirdjan zone is characterized by a complex and not yet fully understood structure. It is composed of the Paleozoic with the participation of volcanics, metamorphosed in the Hercynian or Early Cimmerian epochs, as well as the Mesozoic, and is bounded in the southwest by the Main Zagros thrust, which separates this zone from the Zagros zone. The thrust is directed to the southwest and consists of a number of scales, in which Mesozoic ophiolites protrude in places [6].

Iran is also one of the most seismically active countries in the world, a place where several large faults intersect, which cover at least 90% of the country's territory. As a result, earthquakes in Iran are frequent and quite destructive. Since 1900, there have been at least 126,000 deaths in the Iranian earthquake.

In Iran, earthquakes are concentrated mainly along the fold-thrust belt of the Zagros, extending from northwest to southeast, - the result of the collision of the Arabian and Eurasian plates. This zone is associated with the activity of two main faults - a right lateral strike-slip - the Main Modern Fault (MRF) and its continuation in the southeast - the Main Zagros Thrust (MZT). The mechanisms of earthquake sources in the form of uplift and uplift shifts are mainly observed here. In northern Iran, near the Elburz Mountains, there are numerous strike-slip faults located south of the Caspian Sea. [6]

The 856 Damgan earthquake is the deadliest earthquake in Iranian history, killing more than 200,000 people. On September 16, 1978, there was a strong earthquake in Tebes, which killed 25,000 people. Earthquake in Bam on December 22, 2003, one of the last strong earthquakes occurred on August 11, 2012 in Tabriz (Fig. 2).

Analysis of satellite navigation system (GPS) data

The edges of the colliding continents under conditions of compression and agglomeration break into a large number of microplates. For this reason, the collision zones, unlike all other types of interplate boundaries, do not represent narrow linear zones (as, for example, zones of spreading, subduction or transform faults), but always have "blurred" outlines in plan, and their width reaches hundreds and thousands kilometers. The accretion and collision conditions on the modern Earth are manifested within the Alpine-Himalayan fold belt, which stretches for many thousands of kilometers from the Atlantic to the Pacific Ocean (Fig.3). [5] The Eurasian, Indian, Arabian and African lithospheric plates are currently in contact along this convergent boundary.

Using the data of the GPS stations of the RSSC ANAS, UNAVCO, Turkey and Iran, a map of vectors of azimuthal movements and a diagram of the velocities of horizontal movements of blocks of the studied region were compiled (Fig. 4,5). It should be noted that in the territory of Azerbaijan since 2013, within the framework of the RSSC, a new monitoring system has been installed, consisting of 24 GPS stations from “Trimble” company (USA) [4].

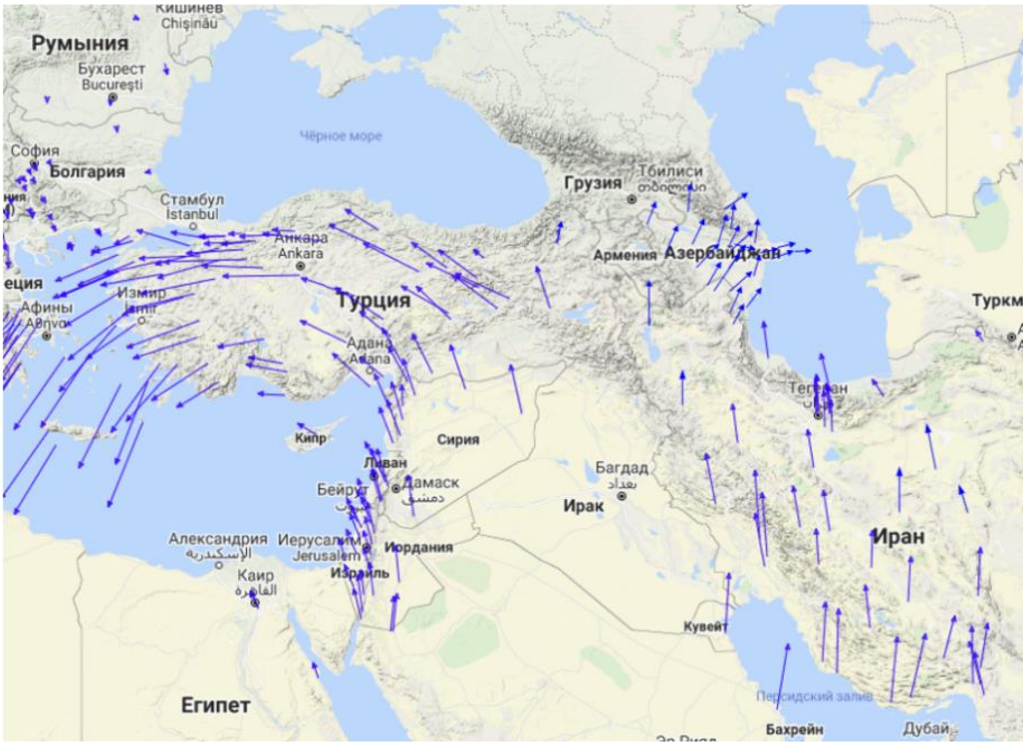

Figure 4. Azimuthal map of vectors of GPS stations of the Mediterranean region according to the RSSC ANAS data, UNAVCO, Turkey and Iran

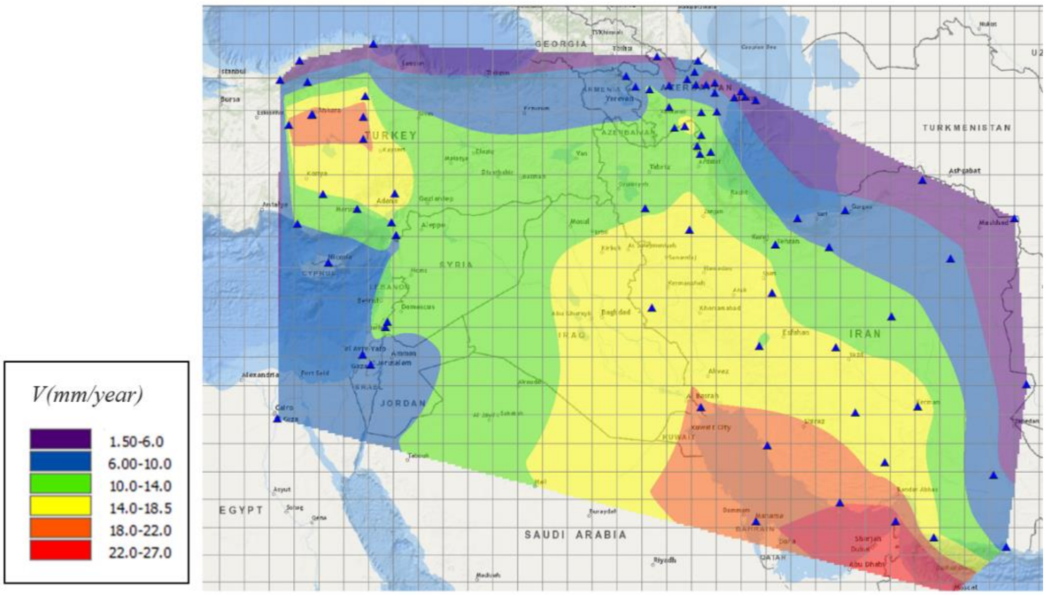

Figure 5. Distribution of the velocities of horizontal movements in the Mediterranean region according to GPS stations for the period 2006-2020

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 one. Considering the velocities of movement of the Anatolian and Eurasian plates, and the Arabian and Anatolian plates, it was found that the shear rate along the North Anatolian fault was 20 mm/year, along the East Anatolian - 14 mm/year. This indicates the convergence of the Anatolian and Eurasian plates through the system of right shift faults in eastern Turkey and the Thrust system in the Caucasus. The total reduction in the distance between the Lesser and Greater Caucasus is 10 mm/year.

According to the results of the study of GPS networks by French and Egyptian researchers (Nocquet et al., 2006), during the opening of rifts, the displacement of blocks in the ITRF (International Terrestrial Reference Frame) system along the eastern and northeastern vectors with speeds of 4-6 mm/year prevails. One of the possible reasons for this may be the higher velocities of movement to the northeast of the Somali and Arabian plates (35-44 mm/year) compared to the eastern part of the African plate (25-32 mm/year). The North African-Apulian transit zone separates the western part of the North Eurasian and African plates (Gatinsky et al., 2007a). [5] The Apulian, Central Mediterranean and Rabat blocks included in it are displaced in absolute coordinates (ITRF system) to the east and northeast at rates of 25-40 mm/year. The first two of them rotate counterclockwise relative to the Eurasian N-plate taken for a stationary one, which is discussed in detail in (Nocquet and Calais, 2003). The movements of the main plates on both sides of the North African-Apulian transit zone are different: the African one is displaced by 40-45° NE, and the North Eurasian by 50-55°. Blocks in the eastern part of the Alpine-Iranian transit zone at the borders of the North Eurasian, African and Arabian plates have even greater kinematic independence. The Aegean block moves along an azimuth of 133-165° SE at velocities of 11-30 mm/year. Their maximum values are observed in the south, which is consistent with the extension in the Aegean Sea within the rear trough of the Hellenic island arc. The Rhodope-Sinop block (6) located to the north is displaced in absolute coordinates to the east at a rate of up to 41 mm/year along the largest North Anatolian right lateral shift fault, which serves as the boundary between it and the Anatolian block located to the south [5]. This shift extends for more than 1400 km from the Karliov point, where the triple junction of the Arabian plate, the Lesser Caucasian and Anatolian blocks occurs, to the Sea of Marmara, in the area of which the fault zone splits into several branches. In general, the kinematics of the Eastern Mediterranean is determined by counterclockwise rotation with respect to the Eurasian N-plate of the Arabian plate and most blocks south of the North Anatolian fault [5, 21]. The increased movement velocities and tension within the Aegean block are associated with the roll-back of the slab in the Hellenic Trench. In some works, it is assumed that such a roll-back occurs under the influence of the more intense velocities of movement of the Arabian plate and subduction in Makran beneath Eurasia in comparison with the velocity of subduction under the Hellenic arc [20]. Thus, the modern relative movements of the blocks of the Eastern Mediterranean are controlled by at least two processes: their "squeezing" to the west from the collision zone of the North Eurasian and Arabian lithospheric plates and the displacement to the south of the southern edge of the Aegean block above the retreating Hellenic trench.

According to modern data from GPS measurements, the Western Zagros with a velocity of ~10±2 mm/year in the direction of 12±8° north-north-west, the central Zagros - 14-18 mm/year, and the Eastern Zagros with approximately twice the velocity (~20±2 mm/year) in the direction of 7±5° north-north-east. The difference in crushing rates is most likely associated with a significant portion of shear deformation along the Main Rift Fault MRF in the Northwest Zagros.

The velocity field of GPS observations within the Caucasus region clearly illustrates the movement of the Earth's crust surface in the N-NE direction in the territory of Azerbaijan and adjacent regions of the Lesser Caucasus relative to Eurasia. The most pronounced feature of the velocity field is a decrease in velocity at observation points located perpendicular to the Main Caucasian Thrust (i.e., at stations PQLG, XNGG, ZKTG, ATGG, IMLG, and GBLG). GPS-observation points located along the GKN show a decrease in velocity in the westerly direction. N-NE movement of the Earth's surface is interpreted as one of the reasons for the accumulation of stresses on this thrust. In addition, there is a tendency for horizontal movement within the Kura depression and the Lesser Caucasus, where the velocity increases from west to east along the strike of the mountain range.

Conclusion

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 one. Considering the velocities of movement of the Anatolian and Eurasian plates, and the Arabian and Anatolian plates, it was found that the shear rate along the North Anatolian fault was 20 mm/year, along the East Anatolian - 14 mm/year. This indicates the convergence of the Anatolian and Eurasian plates through the system of right shift faults in eastern Turkey and the Thrust system in the Caucasus. The total reduction in the distance between the Lesser and Greater Caucasus is 10 mm/year.

In the Central Iranian block and the Caucasian block, movement was noted clockwise with a rotation in azimuth from 350 to 90 degrees. The tectonics of Iran is dominated by the collision of the Arabian and Eurasian plates. The velocity of movement of the plates was estimated at 22 mm/year. During these movements, the Zagros crust is shortened by about 9±2 mm/year in the north-south direction.

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In addition, in the strike cross of the Greater and Lesser Caucasus, a noticeable decrease in the velocities of horizontal movements is observed at an epicentral distance of 65 km, which indicates that the Lesser Caucasus is thrusting into the Kura depression at an average rate of 10-12 mm/year and a gradual underthrust of the Kura depression under the Greater Caucasus.

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