SOURCE MECHANISM OF TURKISH EARTHQUAKES OCCURED ON 06.02.2023 WITH M=7.8, 7.6

G.J Yetirmishli[1]., L.J Nabelek[2]., S.E Kazimova.[1], I.E.Kazimov[1]

Introduction

After strong earthquakes in Turkey, the sea overflowed the region of the large port of Turkey - Iskenderun. Due to rising water levels, the boulevard, streets and avenues were flooded, banks and other offices were evacuated. The water did not recede from the area even 2 days after the earthquake.

In March 2022, scientists from the Middle East Technical University in Ankara published a study suggesting that the center of the Gaziantep region could be severely damaged by a magnitude 6.5 earthquake [16]. This is because most buildings in southern Turkey are extremely vulnerable to earthquakes. These are buildings with fragile brickwork and low-rise concrete frames, built close to each other. People often die in earthquakes precisely because of falling bricks and masonry.

After the tragedy of 1999, the Turkish government introduced new building codes and a compulsory earthquake insurance system. Today, if we look at the seismic hazard map of Turkey, we see that the Anatolian fault zones correspond to the maximum ground accelerations of 0.5 g, which corresponds to 10 points. However, many buildings affected by this earthquake were built before 2000. At the same time, there are even fewer seismically safe buildings in Syria, which led to the collapse of buildings in Aleppo and Idlib.

History of seismicity

Turkey is located in one of the most active seismic zones in the world. Strong earthquakes occur here every two years. The strongest shock in Turkey in the 20th century shook the province of Erzindjan. This happened on December 26, 1939. The earthquake power was 7.9 on the Richter scale, and the source depth was 20 km. As a result of this earthquake, 32,968 people died, more than 100,000 were injured and more than 200,000 houses were destroyed. The people left homeless froze to death. Further, on March 13, 1992, this source was again activated by an earthquake with M=6.8, when almost 500 people died and more than 8000 buildings were destroyed. Being on the same tectonic fault on August 17, 1999, the source was activated in the province of Kodjaeli, with M=7.6. The duration of the earthquake, 37 seconds, caused the death of more than 17,000 people [6] (Fig.1). Then the earthquake in Erzurum occurred on October 30, 1983, which claimed the lives of 1155 people. On October 23, 2011, an earthquake of magnitude 7.1 occurred near the city of Van. Its victims were 604 people; more than 600 thousand were left homeless. More than 30 states provided assistance to Turkey at that time [5].

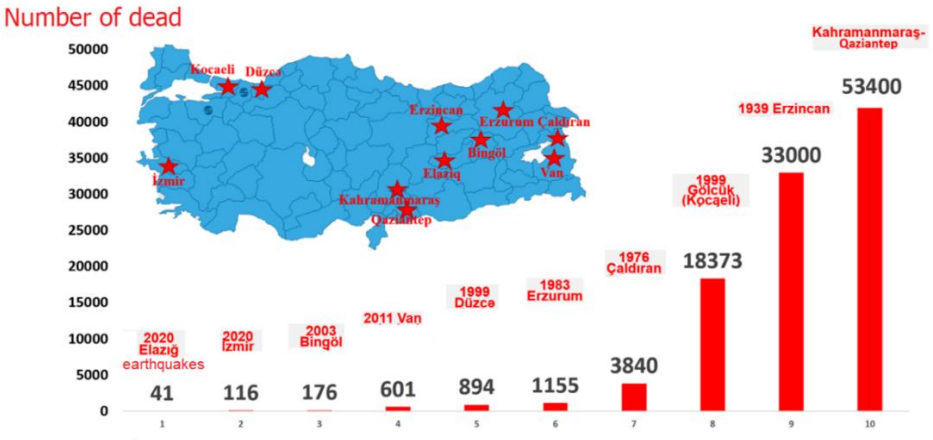

Figure 1. Graph of the sequence of strong earthquakes that occurred in Turkey for the period 1939-2023

[1] *Republican Seismic Survey Center of Azerbaijan National Academy of Sciences*
[2] *Oregon National University (USA)*

On October 30, 2020, an earthquake of 7.0 on the Richter scale occurred in the Aegean Sea, it was felt in Athens and Istanbul. Izmir suffered the most, with about 20 houses collapsed. In total, 119 people died in Turkey as a result of this earthquake, 1,053 were injured.

Of course, the reason for all these events is the tectonic structure of the region where Turkey is located. This region is located at the intersection of three tectonic plates: Anatolian, Arabian and African. According to GPS stations, the Eurasian plate is pressing from the north, the African plate from the south, and the Arabian plate from the east. As a result, the Anatolian Plate (on which most of Turkey is located) is pushed west to the Aegean Sea at a rate of 20 mm/year [2, 3, 6] (Fig. 2).

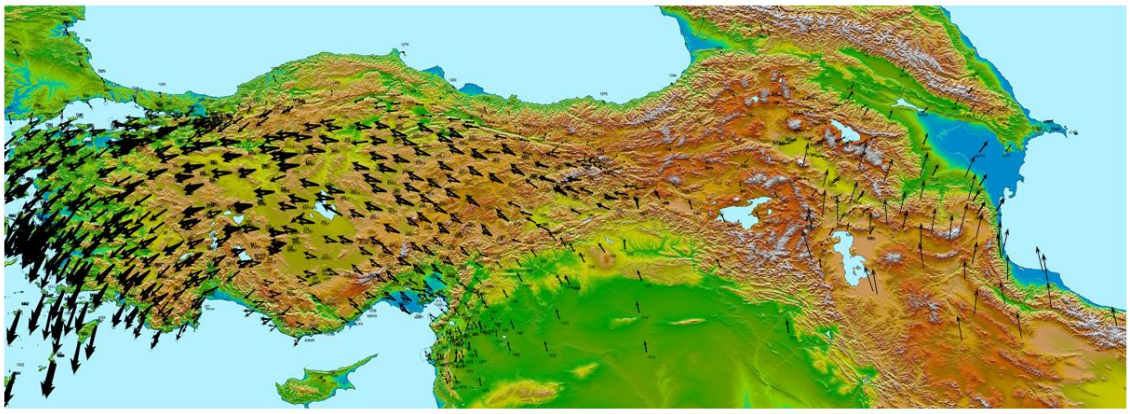

Figure 2. Map of the distribution of horizontal velocity according to the calculated GPS vectors on the territory of the Anatolian Plate and in the Caucasus for 2019-2022

Two large faults pass along the boundaries of the plates - East Anatolian and North Anatolian. Thus, the movement of tectonic plates creates pressure on the fault zones between them [1, 2]. It is the sudden release of the stored energy of this pressure that causes earthquakes.

Tectonics of the region

The source of the earthquake on February 6, 2023 is associated with the dynamics of the East Anatolian Fault. The East Anatolian Fault is one of the main NE-SW main tectonic structures in Turkey, starting from the Karliova Triple Junction in the north and connecting with the Dead Sea Fault in the south [10, 11].

The East Anatolian Fault is characterized by a left-hand shift slip and consists of various segments. Considering the length of the segments, each segment has the potential to cause an earthquake of magnitude 7.0 or greater (Figure 3). Earthquakes of the instrumental period testify to the high activity of the middle and northeastern parts of the East Anatolian fault in terms of destructive earthquakes. This is the Antakya earthquake of 1822 with M=7.5, which caused an almost 200 km rupture along the fault, The Karliova-Bingol earthquake of 1866 with M=7.2, it caused an almost 45 km rupture of the fault. Earthquake on the lake Amik in 1872 with Ms=7.2 caused a fault of almost 20 km, earthquakes on Lake Khazar in 1874 and 1875 with M=7.1 and M=6.7 and the Malatya earthquake of 1893 with M=7.1 [13]. Despite this, the southwestern part of the fault was not characterized by destructive earthquakes. In the Gölbashi-Turkoglu section, located in the south, not a single devastating earthquake has occurred over the past 500 years. This situation is quite remarkable. As you know, the Arabian Plate compresses the Anatolian block in a northeasterly direction. Within this tectonic structure, the East Anatolian Fault connects with the Dead Sea Fault to the SW [12]. The Dead Sea Fault, which is almost 1000 km long, consists of left-hand strike-slip systems, like the East Anatolian Fault. The Dead Sea Fault Zone follows a north-south direction across the eastern side of the Mediterranean Sea, reaching the Gulf of Aqaba and from there joining the Red Sea.

It is the Gulf of Aqaba and the Red Sea that are in expansion mode with the direction NE-SW. Depending on this expansion, the Arabian Plate is believed to be moving in a northeasterly direction. However, this plate movement is limited by the Bitlis-Zagros overlap belt. As a result of all this movement, the southern part of the Arabian Plate is moving counterclockwise and moving at a faster speed compared to the northern part. Depending on this movement, the thesis that the expansion in the Gulf of Aqaba can continue through the Dead Sea fault zone, and from there it can reach the southwest

of the East Anatolian fault, called the Gölbashi-Turkoglu segment, where the source of this earthquake is located, is becoming increasingly important.

On faults, stress accumulates over years and decades. But at some point, the bowels are torn apart, having reached their ultimate strength, as a result of which energy is released. As a result of the current earthquake in Turkey, the tension accumulated along the faults was discharged over a huge area. From preliminary calculations it follows that the "active region" extended 190 kilometers in length and 25 kilometers in width.

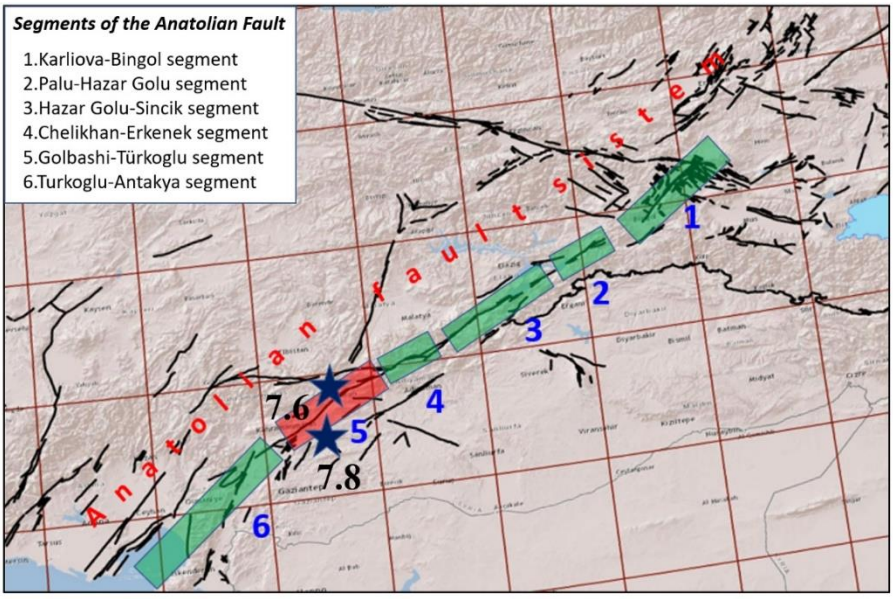

Figure 3. Scheme of the main sources of the Turkish earthquakes that occurred on February 6, 2023 and the main segments of the East Anatolian fault

Source mechanism of the Turkish earthquake

The reasons for the large-scale destruction of buildings are considered to be precisely the underestimation of the level of risks for this area, as well as the lack of regular inspections of the safety of buildings by local authorities. The earthquake caused such destruction, firstly, because of its strength - it is the strongest earthquake in Turkey since 1939 and because it happened right under the settlement. Another sad factor that led to large losses is the timing of the earthquake. The earthquake happened around 4 am. Houses collapsed directly on sleeping or sleepy people who did not have time to prepare for danger.

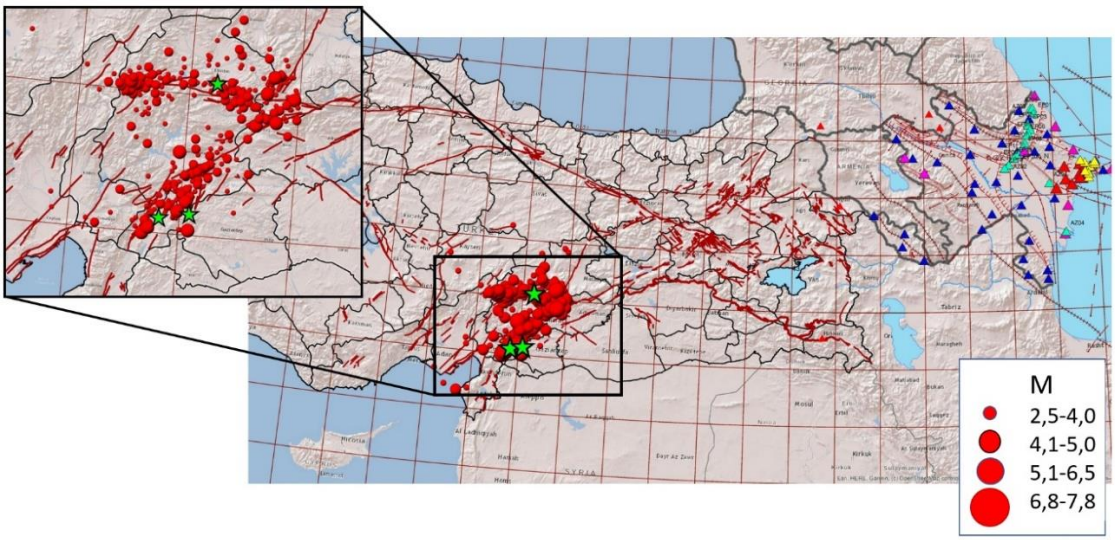

Figure 4. Map of earthquake epicenters after the strong Turkish earthquake on February 6, 2023

An analysis of the distribution of sources in depth showed two source zones located at a depth of 3 to 30 km (Fig. 4). Since the hypocenters of both seismic events were not deep, the intensity of the earthquakes was very high and reached 9 on the 12-point Mercalli scale.

Discharging of stress in a seismic source does not pass without a trace. Stresses are redistributed in the thickness of the rocks of the earth's crust and often occur at a considerable distance, becoming a source of numerous aftershocks. As can be seen on the graph, an average of 450 aftershocks was observed daily during the month (Fig. 5). As a result of this earthquake seismic energy 613*10^13 Joule was released (Fig.6). The magnitude of aftershocks mainly fluctuated within 1.0-4.0. Currently, seismic activity in the region is starting to subside. However, according to some experts, aftershocks after these earthquakes can continue for several more years (science knows such cases). This is due to the processes of stress discharge and restructuring of the medium in the source area.

The earthquake was recorded by all digital seismic stations of the Republican Seismic Survey Center of ANAS (Fig. 7).

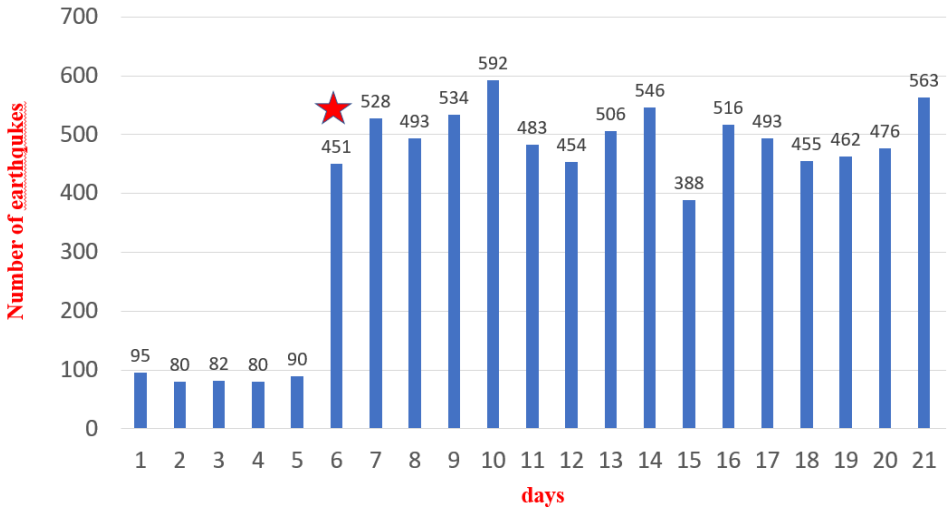

Figure 5. Graph of distribution of aftershock activity for 20 days after strong Turkish earthquakes on February 6, 2023

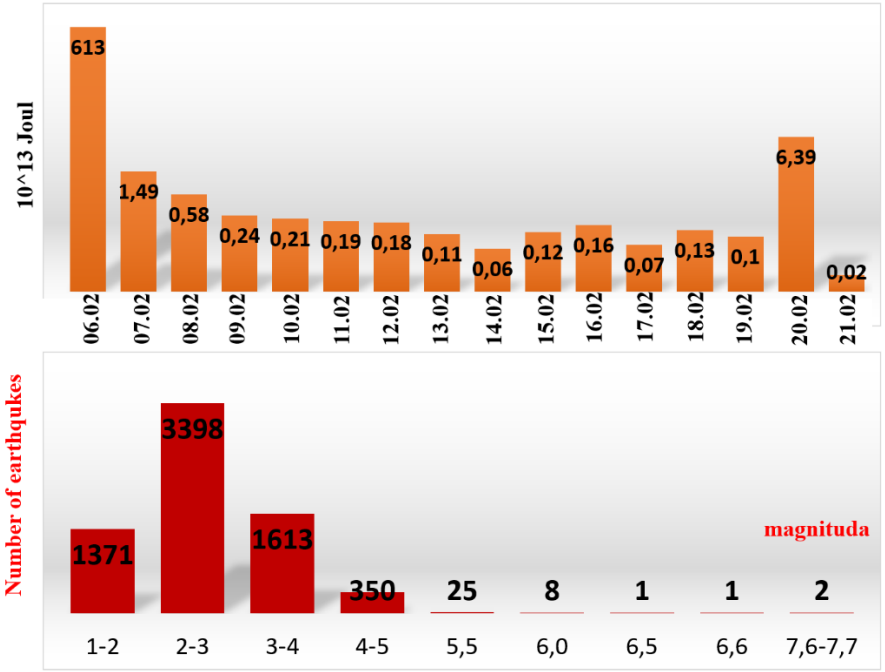

Figure 6. Graph of the distribution of seismic activity and aftershocks by magnitude

Considering the above, the source mechanism of a strong earthquake was constructed and analyzed. In this work, we used the waveform inversion algorithm developed by Professor John Nabelek from University of Oregon [8, 9]. The main source of seismograms is the Republican Seismic Survey Center. Seismograms are downloaded in SEED format for LH channels. The seismic moment tensor describes the equivalent forces acting on a seismic source and is the base value estimated for earthquakes of all scales.

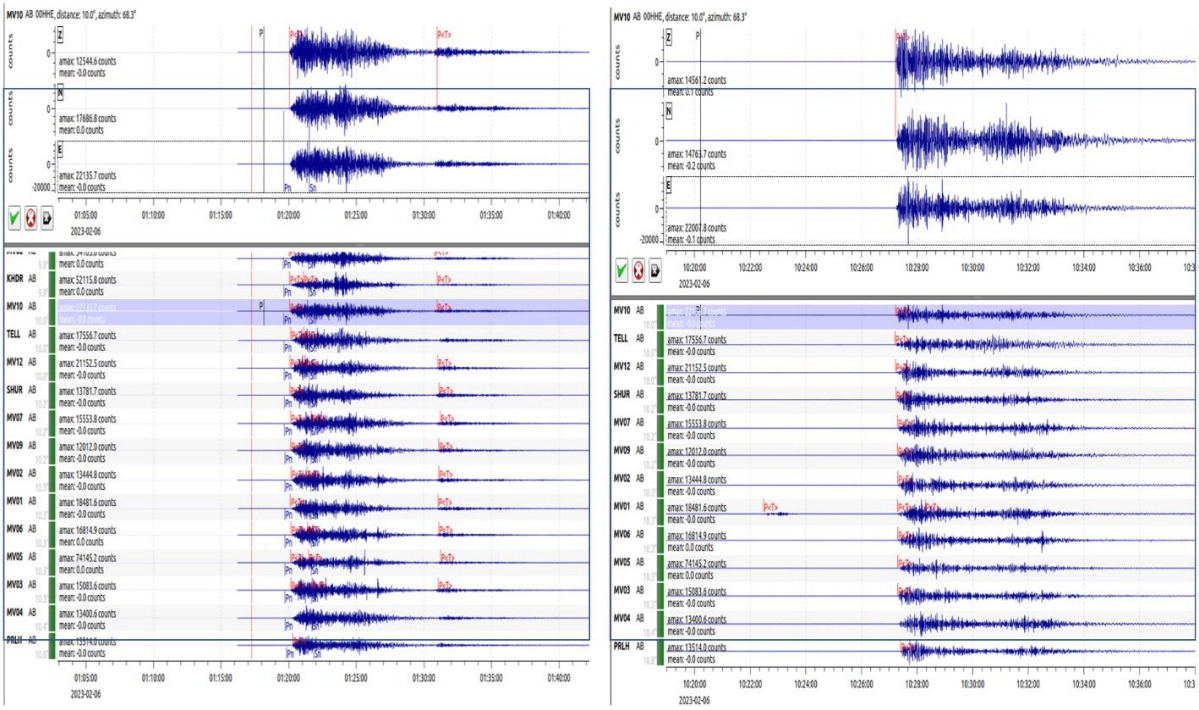

Figure 7. Recording of digital seismic stations of the RSSC ANAS

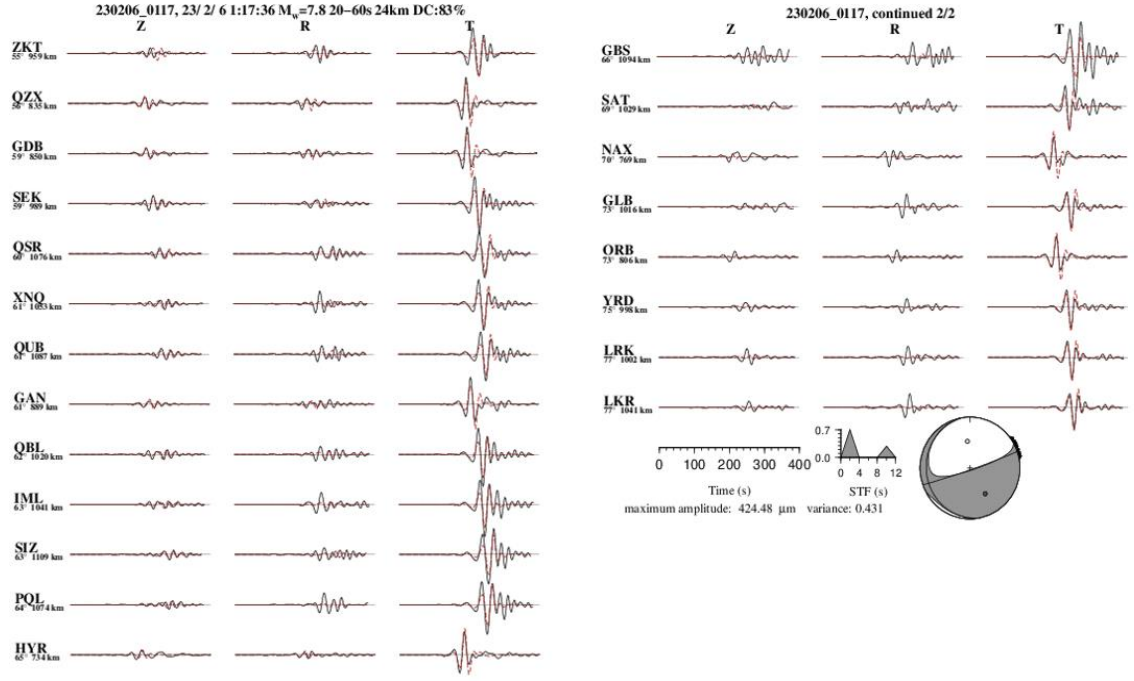

Figure 8. An example of a graphical output file for calculating the seismic moment tensor for the Turkish earthquake with M=7.8. Red lines are synthetic seismograms, black lines are original seismogram.

During the script operation, after reading the parameter files, station coordinates and output files of the location program, the following operations are performed: 1) correction of earthquake waveforms for the amplitude-frequency characteristic of recording devices and the transition from north-south, east-west, vertical to coordinates is radial, tangential, vertical; 2) band-pass filtering with a 4-order Butterworth filter; 3) calculation of the Green's functions used by the inversion of synthetic waveforms for the entire set of depths and source-receiver distances (obtained on the basis of the location program of the real-time subsystem) [14].

The output graphic file contains not only a graphic representation of the source mechanism and wave modeling, but also estimates of the parameters of earthquake sources. These parameters include the angles characterizing the position of the nodal planes (strike, dip, slip), strain tensor components, as well as the scalar seismic moment M0 (determined using the inverse method) and moment magnitude Mw. The main parameters are presented below:

Event: 230206_011736
Depth (km) 18.0 Number of station: 21
Moment Tensor: Scale = 10*27 dyn.sm
Component Value
Mxx -2.038 Myy 1.648
Mxy -1.110 Myz -0.402
Mxz 3.170 Mzz 0.390
Source Composition:
DC/49 CLVD/51 Iso/0
Principal Axes:

Axis	Value	Plunge	Azimuth
T	3.193	41	314
N	1.107	31	75
P	-4.299	33	188

Best Fitting Doble-Couple:
M0 = 3.75E+27 dyn.cm Mw = 7.7

Plane	Strike	Slip	DP
NP1	72	59	85
NP2	335	171	31

Results:

Thus, as a result of data interpretation, it was found that the source mechanism of the main shock is a left-sided strike-slip, consistent with the East Anatolian Fault. Plates move mostly horizontally. But this does not mean that the entire plate is moving. It remains motionless, displacement occurs only in a limited area. The Anatolian plate moves to the southwest at a rate of 20 mm/year, turning counterclockwise relative to Eurasia [4]. At the same time, the plates surrounding it, the Arabian and African, are moving north-northwest at 15 and 5 mm/year, respectively.

However, these velocity values show how the position of the plate changes over millions of years. The average speed of the plates is more or less uniform, and its fluctuations over long periods of time say nothing about the mechanics of earthquakes. Meanwhile, the movement of the plate is a complex process, broken down into local events. The plate deforms non-uniformly: somewhere, a section of the plate creeps a little, in another place it gets stuck, accumulating mechanical stress. And somewhere this stress exceeds the tensile strength and the section slips - a rupture and displacement occurs. And at this moment, the speed of the plate section changes very noticeably [15]. Such events are typical for faults, zones of contact between plates. They are just zones of high seismicity. As happened in this case, for the Turkish earthquake.

The East Anatolian fault runs from the southwest to the northeast along the border of the Anatolian and Arabian plates, only in the west touching the junction of the Anatolian and African. In general, continental blocks are displaced relative to each other mainly horizontally or undergo oblique compression. Accordingly, shear processes play an important role among seismic phenomena.

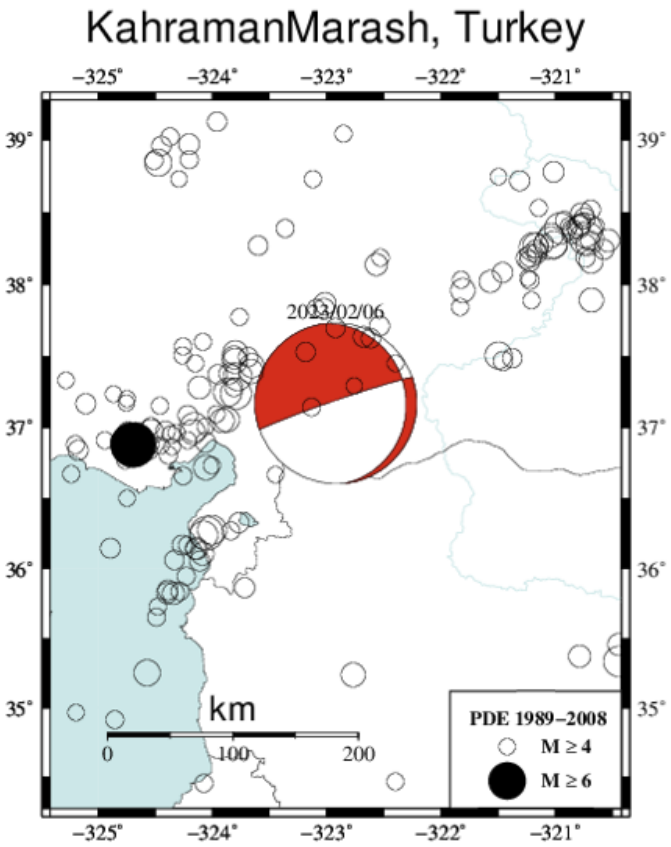

Figure 9. Source mechanism of the Turkish earthquake on February 6, 2023 with M=7.8

And on February 10, the Centre for the Observation and Modelling of Earthquakes, Volcanoes and Tectonics (COMET) reported that the rupture zones along the length of the fault, according to the Sentinel-1 satellite, reach a length of 300 and 125 kilometers [15]. The first gap was formed after an earthquake of magnitude 7.8, the second after a shock of magnitude 7.5. The size of the area affected by the shock shift near Gaziantep is 100×70 kilometers, the magnitude of the shift is about 3.4 meters.

REFERENCES

1. Aktuğ B, Nocquet JM, Cingöz A, Parsons B, Erkan Y, England P, Lenk O, Gürdal MA, Kilicoglu A, Akdeniz H, Tekgül A (2009) Deformation of western Turkey from a combination of permanent and campaign GPS data: limits to block-like behaviour. J Geophys Res 114.
2. Aktuğ B, Parmaksız E, Kurt M, Lenk O, Kılıçoğlu A, Gürdal MA, Özdemir S (2013) Deformation of Central Anatolia: GPS implications. J Geodyn 67:78–96. doi:10.1016/j.jog.2012.05.008
3. Aktug B., Nocquet J.M., A Cingöz, B Parsons, Y Erkan, P England, O Lenk Deformation of western Turkey from a combination of permanent and campaign GPS data: Limits to block-like behavior // Journal of Geophysical Research: Solid Earth 114 (B10), 2009
4. Barka A, Reilinger R (1997) Active tectonics of the Eastern Mediterranean region: deduced from GPS, neotectonic and seismicity data. Analli di Geofisica 40(3):587–610
5. Bilham R., H Ozener, D Mencin, A Dogru, S Ergintav, Z Cakir, A Aytun, ... Surface creep on the North Anatolian fault at Ismetpasa, Turkey, 1944–2016 // Journal of Geophysical Research: Solid Earth 121 (10), 7409-7431
6. Burgmann R., Ayhan M.E., EJ Fielding, TJ Wright, S McClusky, B Aktug, ...Deformation during the 12 November 1999 Duzce, Turkey, earthquake, from GPS and InSAR data // Bulletin of the Seismological Society of America 92 (1), 161-171, 2002
7. Herring, T.A., 1997. GAMIT/GLOBK Kalman Filter VLBI and GPS Analysis Program; Version 4.1. Massachusetts Institute of Technology, Cambridge.

8. Jochen Braunmiller, John L. Nabelek, Abdolreza Ghods Sensor Orientation of Iranian Broadband Seismic Stations from P-Wave Particle Motion // April 2020, Seismological Research Letters 91(3)
9. Karplus M.S., Mohan Pant, Soma Nath Sapkotaç Nabelek J.L. et al. A Rapid Response Network to Record Aftershocks of the 2015 M 7.8 Gorkha Earthquake in Nepal, May 2020, Seismological Research Letters, 91(4)
10. McClusky, S., Balasdsanian, S., Barka, A., Demir, C., Georgiev, I., Hamburger, M., Hurst, K., Kastens, K., Kekelidze, G... 2000. Global positioning system constraints on crustal movements and deformations in the eastern Mediterranean and Caucasus. J. Geophys. Res. 105, 5695–5719.
11. Özener H., Aktuğ B., Doğru A., Sabuncu A., B Turgut, K Halıcıoğlu, O Yılmaz, ... Slip rates and seismic potential on the East Anatolian Fault System using an improved GPS velocity field // Journal of Geodynamics, 2016
12. Parmaksız E., Aktuğ B., M Kurt, O Lenk, A Kılıçoğlu, MA Gürdal, S Özdemir Deformation of central anatolia: GPS implications // Journal of Geodynamics 67, 78-96
13. Straub, C., Kahle, H.G., 1995. Active crustal deformation in the Marmara Sea Region, NW Anatolia, inferred from GPS measurements. Geophys. Res. Lett. 26, 2513–2516. S¸ aroglu, F., Emre, ˘ O., Kus ¨ ¸c¸u, ˙I., 1992. Turkish Active Faults Map. Directoriate of Mineral Research and Exploration, Ankara, Turkey.
14. Воронина Е.В. Особенности механизмов очага сильнейших землетрясений Средиземноморья ВМУ. Серия 3. ФИЗИКА. АСТРОНОМИЯ. 2020. № 1. С. 64–69.
15. https://zemletryaseniya.ru/sejsmicheskie-zony-evropy-i-sejsmichnost-evropejskogo-regiona/
16. ORTA DOĞU TEKNİK ÜNİVERSİTESİ 6 Şubat 2023 Kahramanmaraş-Pazarcık Mw=7.7 ve Elbistan Mw=7.6 Depremleri Ön Değerlendirme Raporu, https://eerc.metu.edu.tr/tr/system/files/documents/DMAM_2023_Kahramanmaras-Pazarcik_ve_Elbistan_Depremleri_Raporu_TR_final.pdf