SAKARYA UNIVERSITY
DISASTER MANAGEMENT APPLICATION AND RESEARCH CENTER
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THE 2023 PAZARCIK (Mw=7.8) and ELBİSTAN (Mw=7.6), KAHRAMANMARAŞ EARTHQUAKES IN THE SOUTHEAST TÜRKİYE

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Searching for the surface ruptures of the February 6, 2023 Pazarcık earthquake (M_W7.8) near the northern end of the Erkenek Fault Segment of the East Anatolian Fault Zone in Çelikhan (Adıyaman).

Introduction

Two destructive earthquakes struck SE Türkiye on the February 6, 2023. (Figure 1) (AFAD 2023; KOERI 2023; USGS NEIC). The earthquakes occurred along the East Anatolian Fault Zone (EAFZ), within or in close vicinity of a prominent seismic gap known as the Maraş Seismic Gap (Figure 2) (Nalbant et al. 2002; Duman and Emre 2013; Aktuğ et al. 2016; Utkucu et al. 2023). Thousands of buildings collapsed, killing or trapping thousands of people under the debris. Both earthquakes proved again that Türkiye is one of the most earthquake prone country on the Earth.

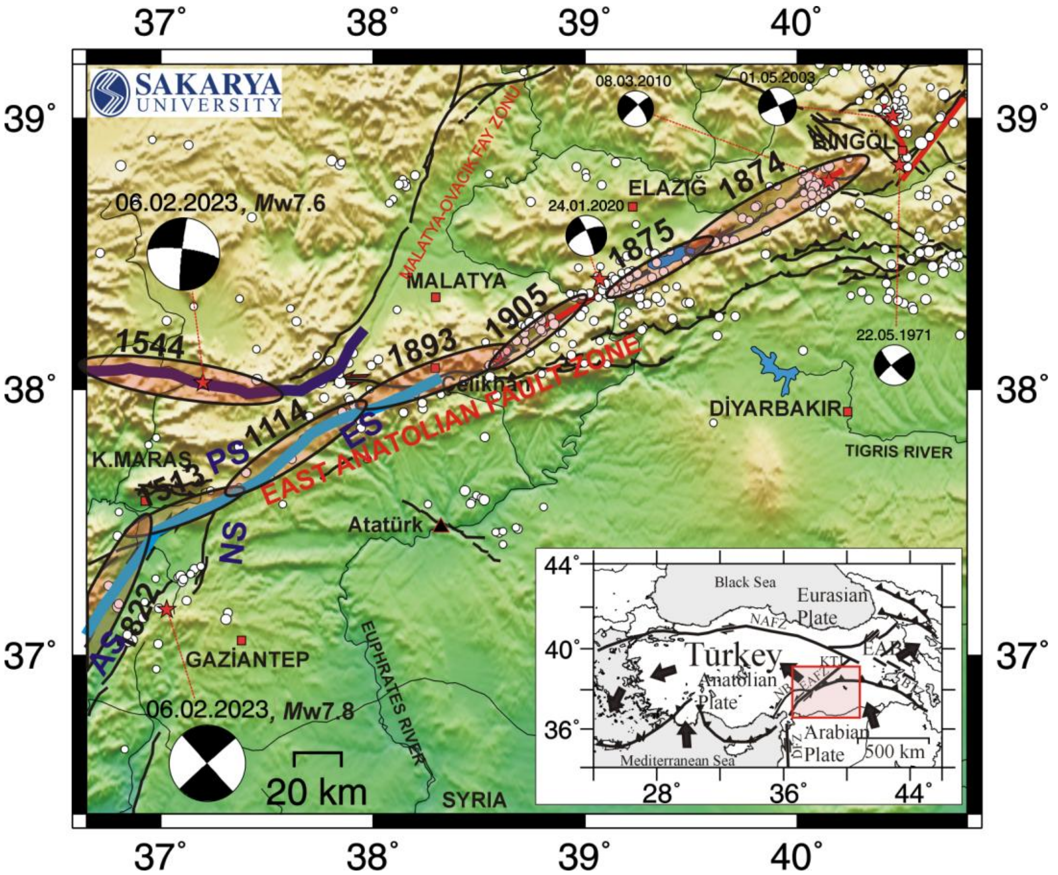

Figure 1. Major tectonic elements of Türkiye (inset map) along with seismicity along the East Anatolian Fault Zone. Seismicty include $M_W \geq 4.0$ earthquakes (white circles) after 1970 and destructive historical (red shaded ellipses) and M≥6.0 instrumental (red stars) earthquakes. The seismicity data is taken from the catalogue of Kandilli Observatory and Earthquake Research Institute of Türkiye. The triangle denotes the largest dam of Türkiye. The thick blue and purple lines represent surface rupture extents of the 2023 Pazarcık and Elbistan earthquakes, respectively. Information on the map is compiled from Barka and Kadinsky-Cade (1988), Ambraseys (1989), Taymaz et al. (1991), McClusky et al. (2000), Emre et al. (2013), Tan et al. (2011), Utkucu et al. (2018, 2023). NAFZ: North Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone, DFZ: Dead Sea Fault Zone, NB: Northern Branch of the EAFZ, AS: Amanos Segment, PS: Pazarcık Segment, ES: Erkenek Segment, NS: narlı Segment

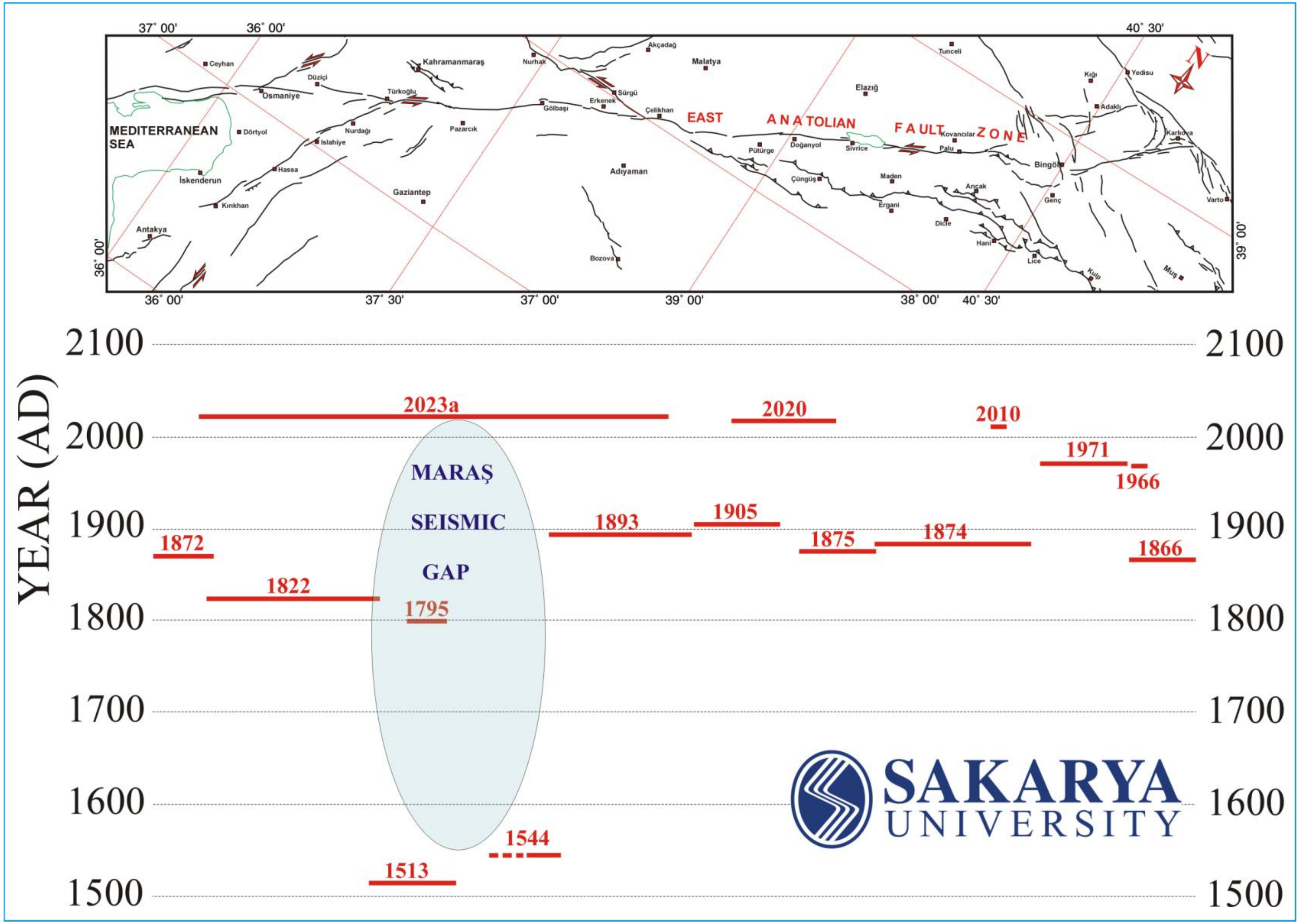

Figure 2. Earthquake occurrence model of the East Anatolian Fault Zone after the 1513 Kahramanmaraş earthquake.

The EAFZ and the North Anatolian Fault Zone (NAFZ) are continental strike-slip faults that undertake westward movement of the Anatolian Plate with frequent generation of large destructive earthquakes (Figures 1 and 2) (Barka and Kadinsky-Cade 1988; Ambraseys 1989; Taymaz et al. 1991; Hubert-Ferrari et al. 2003; Şengör et al. 2005; Ambraseys 2009; Bulut et al. 2012; Duman and Emre 2013). The EAFZ constitutes the southern boundary of the Anatolian plate and is a sinistral fault extending between Karlıova in the north, where it connects with the NAFZ, and Antakya, where it meets with the Dead Sea Fault (Figure 1) (Barka and Kadinsky-Cade 1988; Duman and Emre 2013). Additionally, it has a branch, called the Northern Branch, separates from the main fault in the immediate west of the Çelikhan and extends through Adana Basin to the Mediterranean Sea (Figures 1 and 2) (Westaway 2004; Duman and Emre 2013; Seyrek et al. 2014). GPS studies indicate 9-10 mm/year slip rate for the EAFZ (McClusky et al. 2000; Reilinger et al. 2006; Aktuğ et al. 2016), about one third of which is shared by the Northern Strand after the bifurcation (Westaway 2004; Altunel et al. 2009; Mahmoud et al. 2012; Emre et al. 2013). The geologic slip rate of about 8 mm/year has also been proposed from the data coming from the field studies (Herece 2008; Duman and Emre, 2013).

The EAFZ was relatively quiescent in the 20th century comparing with its activity in the 19th century as indicated by the historical seismicity studies (Ambraseys 1989; Nalbant et al. 2002). Only the 1905 Malatya and 1971 Bingöl earthquakes occurred along the EAFZ in the 20th century. Recent occurrence of the 2003 Bingöl, 2010 Başyurt and 2020 Sivrice-Doğanyol earthquakes and current occurrence of the 2023 Pazarcık and Elbistan earthquakes suggest that the fault is much more active in the 21st century.

Occurrence of the M_W7.8 shock was not surprise because it filled a section of the EAFZ called as Maraş Seismic Gap and known for its large earthquake quiescence for at least 500 years (Figure 2). The data coming from the trenches excavated along the fault indicated that the 1114 and 1513 earthquakes were the last earthquakes to rupture the gap (Yönlü 2012). The stress load and anomalous changes in the background seismicity around the gap have been previously indicated (Nalbant vd. 2002; Utkucu et al. 2023a). Utkucu et al. (2023a) estimated a size of M_W7.45 for the expected earthquake along the gap. The preliminary results of the project carried out by the authors also indicated increased stresses along the gap.

However, it is complete surprise that M_W7.6 occurred along the Northern Strand of the EAFZ approximately 9 hours later. As an earthquake prone country such earthquake doublets with shocks close in space and time are not uncommon in Türkiye. The doublets were 16 days apart in 1114, a month apart in 1866, 2 months apart in 1943-1944 and 3 months apart in 1766 and 1999. Notice that none of these previous earthquakes occurred within hours of each other. It is known that the Northern Strand active. Nevertheless, it produced much rarer destructive earthquakes compared the NAFZ and the southern strand of the EAFZ. Limited earthquake science efforts in Türkiye focused on the source of frequent large earthquakes, mainly on the NAFZ and EAFZ. Thus, an earthquake along the Maraş Seismic Gap was successfully foreseen by the earth sciences.

The 2023 Pazarcık and Elbistan earthquakes

The 2023 Pazarcık and Elbistan earthquakes occurred along the EAFZ. The hypocentral and source parameters of the 2023 Pazarcık and Elbistan earthquakes obtained by different seismological institutes (Table 1, Figure 1) confirm that sense of faulting is sinistral. The source mechanisms suggest NE-SW and E-W trending fault ruptures for the first and latter mainshocks, respectively.

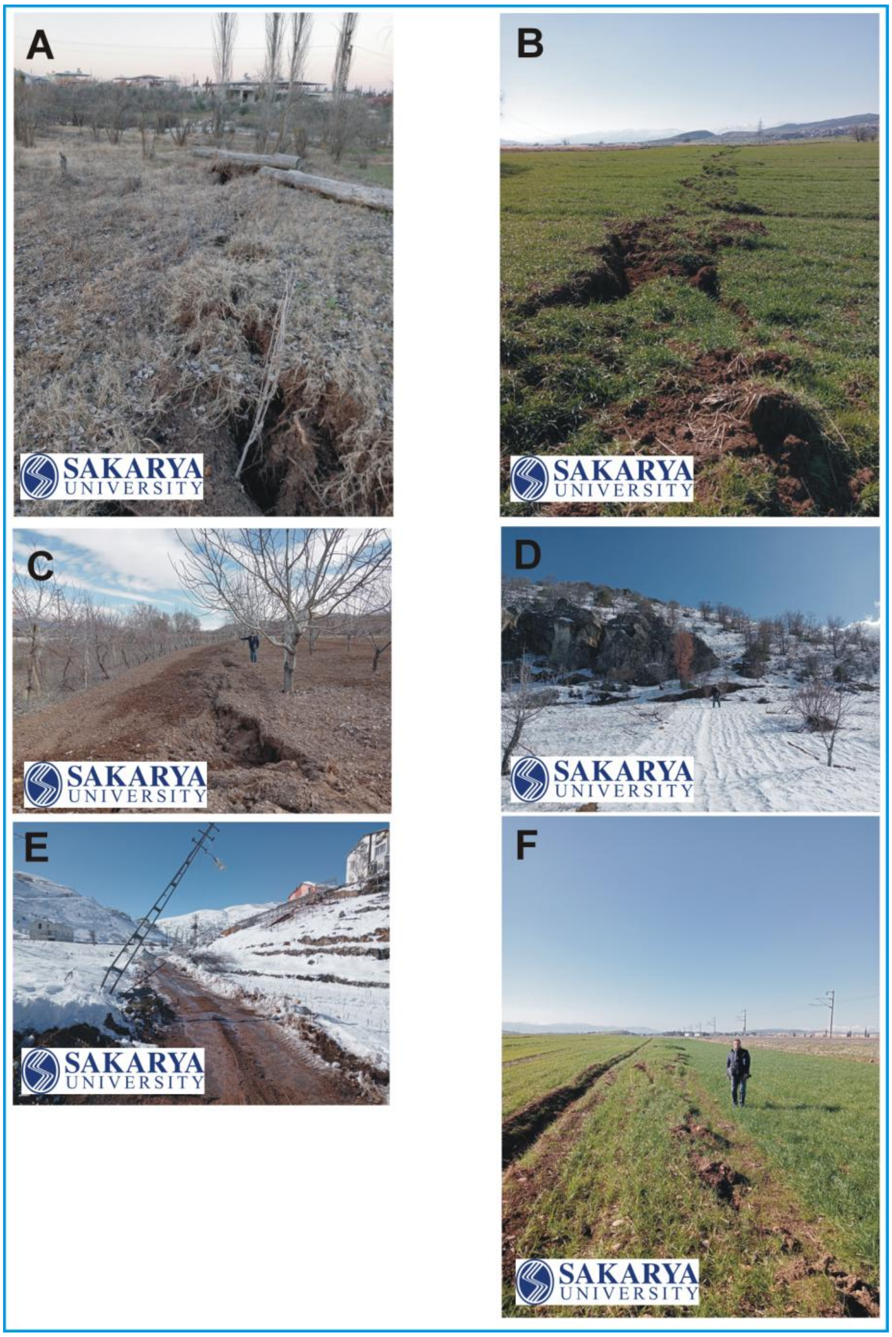

Figure 3. Surface ruptures of the 2023 Pazarcık earthquake at different part of the fault rupture. Photos are from (a) Hassa (Amanos Segment), (b) east of Kahramanmaraş (Pazarcık Segment), (c) Balkar, (d) Ozan and (e) Balıkburnu (Erkenek Segment) and north of Narlı (Narlı Segment).

Table 1. The hypocentral and source parameters of the 2023 Pazarcık and Elbistan earthquakes obtained by different seismological institutes.

Date	Origin Time	Lat	Long	Depth	Mw (GCMT)	Mo x10^{20}Nm	NP1 Strike	NP1 Dip	NP1 Rake	NP2 Strike	NP2 Dip	NP2 Rake	CMT Depth	Institute
FEBRUARY, 6 2023, MAINSHOCK_1, 01:17 Mw7.7														
06.02.2023	01:17:35	37,1736	37,032	17,9	7,8 7.9	5.383* 7.92**	228	89	-1	318	89	-179	17,5	USGS NEIC
06.02.2023	01:17:31	37,1123	37,1195	5	7,7		222	64	-27	324	65	-152		KOERI
06.02.2023	01:17:32	37,288	37.043	8,6	7,7									AFAD
06.02.2013	01:18:10	37,56	37,47	14,9	7,8		54	70	11	320	80	160		GCMT
FEBRUARY, 6 2023, THE LARGEST AFTERSHOCK, 01:28 Mw6.7														
06.02.2023	01:28:15	37,127	36,943	14,5	6,7		2							USGS
06.02.2023	01:28:16	37,304	36,920	6,2	6,6									AFAD
06.02.2023	01:28:21	37,18	36,85	25	6,8									GCMT
FEBRUARY, 6 2023, MAINSHOCK_2 10:24 Mw7.5														
06.02.2023	10:24:49	38,024	37,203	10,0	7,6 7.74	2.637* 5.05**	277	78	4	186	87	168	13,5	USGS NEIC
06.03.2023	10:24:46	38,0717	37,2063	5	7,5									KOERI
06.02.2023	10:24:47	38,089	37,239	7	7,6									AFAD
06.02.2023	10:24:59	38,11	37,22	12	7,7		261	42	-8	358	84	-137		GCMT

USGS: United States Geological Survey; NEIC: National Earthquake Information Center; KOERI: Kandilli Observatory and Earthquake Research Institute; AFAD: Republic of Turkey Ministry of Interior Disaster and Emergency Management Authoity; GCMT: Global Centroid Moment Tensor Project;
* Point Source; ** Finite Fault

The first mainshock struck just before the sunrise, mostly catching the people while they slept. The most powerful in the sequence the first mainshock ruptured a fault length of about 300 km. A field study implemented by two of the authors confirmed that the fault rupture extends from Kırıkhan (Hatay) in the south to Çelikhan (Adıyaman) in the North (Figures 1, 3). As documented from the field study the first earthquake produced clear surface ruptures along three segments of main strand of the EAFZ, called Amanos, Pazarcık and Erkenek fault segments from the south to the north (Emre et al. 2013; Duman and Emre 2013) (Figure 1). Nevertheless the rupture did not initiate along these segments that constituting the main strand but rather along a secondary fault segment called the Narlı Segment (Gülen et al. 1987; Emre et al. 2013), bifurcating from the main strand in the North of Pazarcık town (Figure 1). We measured sinistral and vertical displacements of as much as 4.5 m and 1-2 m along the fault rupture, respectively. The aftershocks recorded and located by AFAD agency and Kandilli Observatory and Earthquake Research Institute of Türkiye and seismogram analysis by the institutes across the globe in accordance with our field study, regarding the ruptured faults. It is interpreted that the fault sections ruptured during the 1114-1513, 1822 and 1893 earthquakes ruptured together to produce 2023 Pazarcık earhquake.

Table 2. The hypocentral and source parameters of the 17 August 1999 İzmit earthquake.

	KOERI[1]	ÖZ[2]	TI[3]	Harvard CMT	USGS	RE[4]	Gülen et al. 2002[5]	Delouis et al. 2002[6]	Li et al. 2002[7]	Utkucu et al. 2009[7]
Lat. (^{o})	40.770	40.729		41.010	40.748					
Long. (^{o})	29.960	29.967		29.970	29.864					
Depth (km)	10	13		17	13					
M_o x10^{20}Nm			1.47	2.88	1.4	1.7	2.42	2.4	1.3	2.6
Strike (^{o})			270	182	185				90	
Dip (^{o})			83	74	90				90	
Rake (^{o})			181	3	9				-180	

[1] Kandilli Observatory and Earthquake Research Institute. [2]Özalaybey et al. (2002). [3]Tibi et al. (2001). [4] Reilinger et al. (2000).[3,5,7] From the inversion of the teleseismic P and SH waveforms.[4] From the modelling of the GPS data. [6] From the inversion of the strong-motion, teleseismic, GPS and InSAR data.

Table 3. Source prameters of the November 12, 1999, Düzce earthquake.

	ERD	**USGS**	**HRV**	**Tibi *et al.*, 2000 [1]**	**Ayhan *et al.*, 2001[3]**	**Wright *et al.*, 2001[4]**	**Utkucu et al. 2003**
Latitude (^{o})	40.818	40.77	40.93				
Longitude (^{o})	31.198	31.15	31.25				
Depth (km)	12.5	14	18				
M_o(x10^{19}Nm)		4.5	6.7	4.6	5.1-5.8	4.2±0.4	5.5
M_W		7.1	7.2				
Strike (^{o})			264	264			
Dip (^{o})			54	64		57±4	
Rake (^{o})			-167	184		-134±17	

[1] From the inversion of the P and SH waveforms. [2] From the inversion of the P and SH waveforms. [3] From the inversion of the GPS data. [4] From the inversion of the InSAR data

In order to better understand size of the 2023 Pazarcık earthquake, its rupture length and seismic moment compared with the devastating earthquakes of the 1999 İzmit and Düzce earthquakes. The 1999 İzmit and Düzce earthquakes ruptured fault lengths of 150 and 45 kilometres along the NAFZ, respectively. The focal and source parameters of the 1999 earthquakes are compiled in Tables 2 and 3. The M_W7.8 earthquake released a seismic moment that about two-fold larger than the seismic moment of the 1999 İzmit (M_W7.6) and Düzce (M_W7.2) earthquakes summed (compare point- and finite-source estimations of between 5.38 and 7.9 x 10^{20} Nt.m in Table 1, respectively, with the sum of 3.46 x 10^{20} Nt.m for the 1999 earthquakes in Tables 2 and 3). Strong aftershocks as large as M_W 6.7 followed. The first mainshock rupture triggered the second mainshock, the 2023 Elbistan earthquake (M_W7.6-7.7) as it was proven from Coulomb stress modeling (Figure 4) (Utkucu et al. 2023b). The second mainshock occured along a fault branch of the EAFZ, called the Northern Strand, mainly rupturing a fault perpendicular to the first one. The first mainshock, depending on faulting type of the EAFZ caused a damage area elongated in NE-SW direction along the fault rupture. However, the second mainshock mainly ruptured a E-W trending fault, causing further broadening of the damaged area in the east-west direction. Adding the magnitudes of both shocks, this is why a wide damaging area comprising 11 provinces that complicates the disaster relief efforts took place.

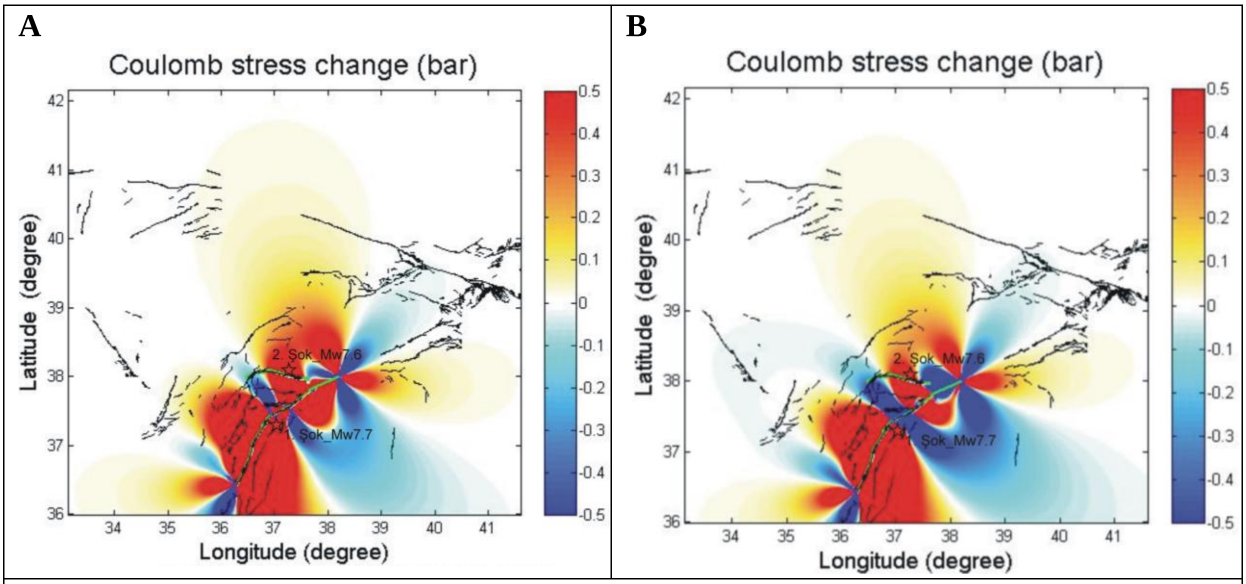

Figure 4. The stress changes caused by the 2023 Pazarcık earthquake (the first mainshock) calculated **(a)** along a fault with parameters 285°, dip 90° and rake 0°, representing the fault segment that host the 2023 Elbistan earthquake's (the second mainshock) epicenter, and **(b)** along a fault with parameters 274°, dip 90° and rake 0°. After Utkucu et al. (2023b).

The magnitude of the first mainshock is also stunning for earthquake science community because the historical seismology studies have suggested the maximum magnitude of large earthquakes along the EAFZ were M_W7.5-7.6. Considering the nature of earthquake magnitude scale and the magnitude of the first mainshock, this means considerable difference in size. It was known that faster slipping NAFZ produced Mw7.9-8.0 Erzincan earthquake in 1939 but it was not expected such a large earthquake to take place along the EAFZ.

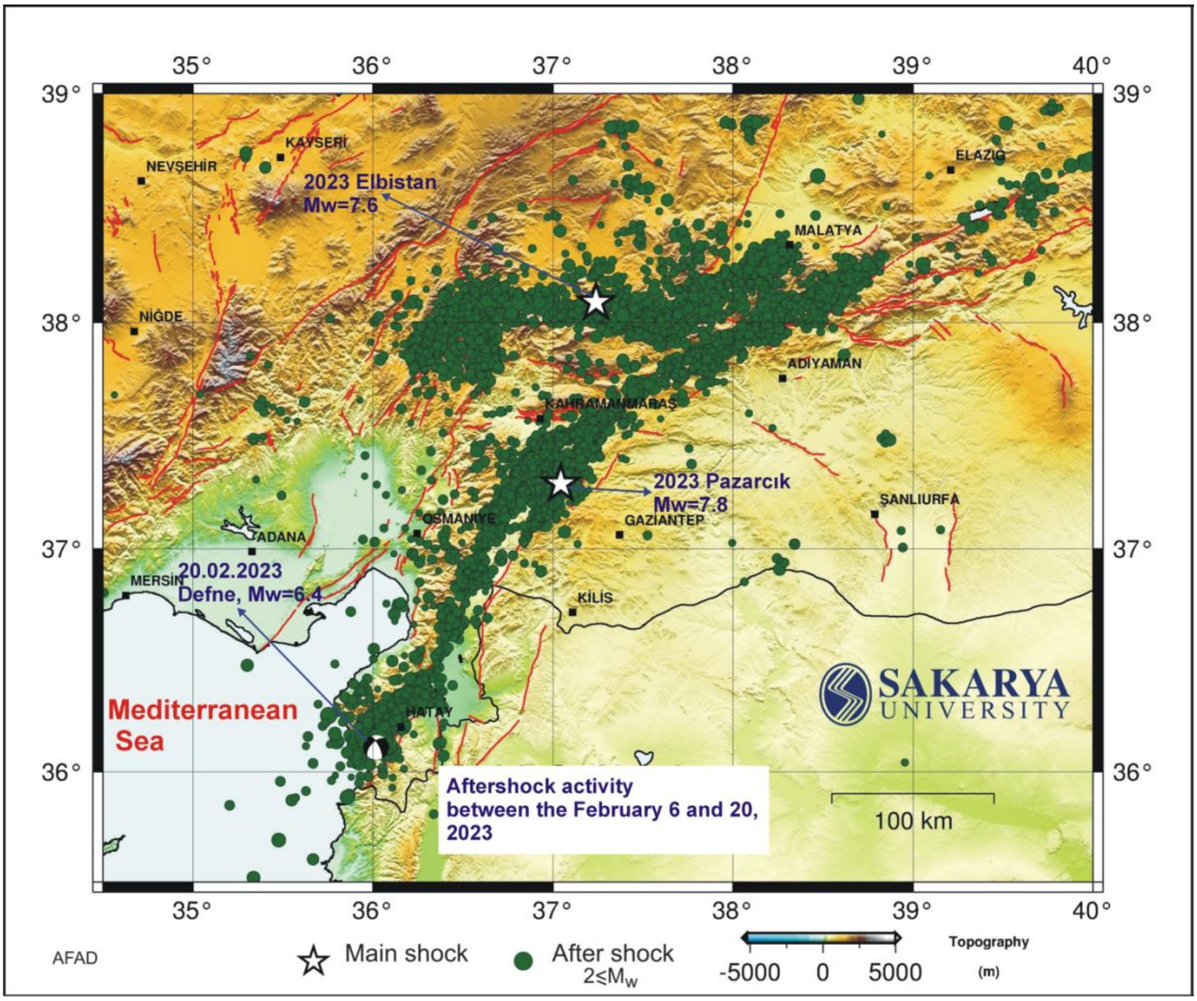

Figure 5. The aftershock activity of the 2023 Pazarcık and Elbistan earthquakes. Aftershocks are taken from AFAD catalogue.

The aftershock activity

Numerous aftershocks, including several $M_W \geq$ 6.0 aftershocks, occurred in the earthquake struck area (Figure 5). A large aftershock of M_W6.4 occurred along the Antakya Fault Zone on the February 20, 2023 causing collapse of many damaged buildings and several casualties. The M_W6.4 sparked great fear among the people. Focal and source parameters of this aftershock are given in Table 4. The source mechanism suggests a dominant sinistral faulting with significant normal component. Coulomb stress modeling clearly indicates that the M_W=6.4 shock is an aftershock triggered by the 2023 Pazarcık earthquake (Figure 6). Coulomb 3.2 software is used to estimate Coulomb failure stress changes (Lin and Stein 2004; Toda et al. 2005). An animation of the aftershock activity hour by hour from origin time of the first mainshock to the February 12 and day by day after that day to the February 20 is provided as a supplementary to this report. Note that the animation also includes month by month background seismicity activity from the February 2022 to the occurrence of the first mainshock. The aftershocks are still continuing to shake the earthquake struck area.

Table 4. The hypocentral and source parameters of the 20 February 2023 aftershock.

	Time	Lat. (°)	Lon. (°)	Depth (km)	Mw	NP1 Strike (°)	NP1 Dip (°)	NP1 Rake (°)	NP2 Strike (°)	NP2 Dip (°)	NP2 Rake (°)
KOERI	17:04:28	36.10	36.13	16	6.3	330	68	-143	225	56	-25
AFAD	17:04:28	36.121	36.074	16.7	6.4	332	55	-138	214	57	-44
Harvard CMT	17:04:31	36.04	36.04	12	63	329	79	-134	227	45	-16
USGS	17:04:29	36.109	36.017	11.5	6.3	333	69	-139	225	53	-27

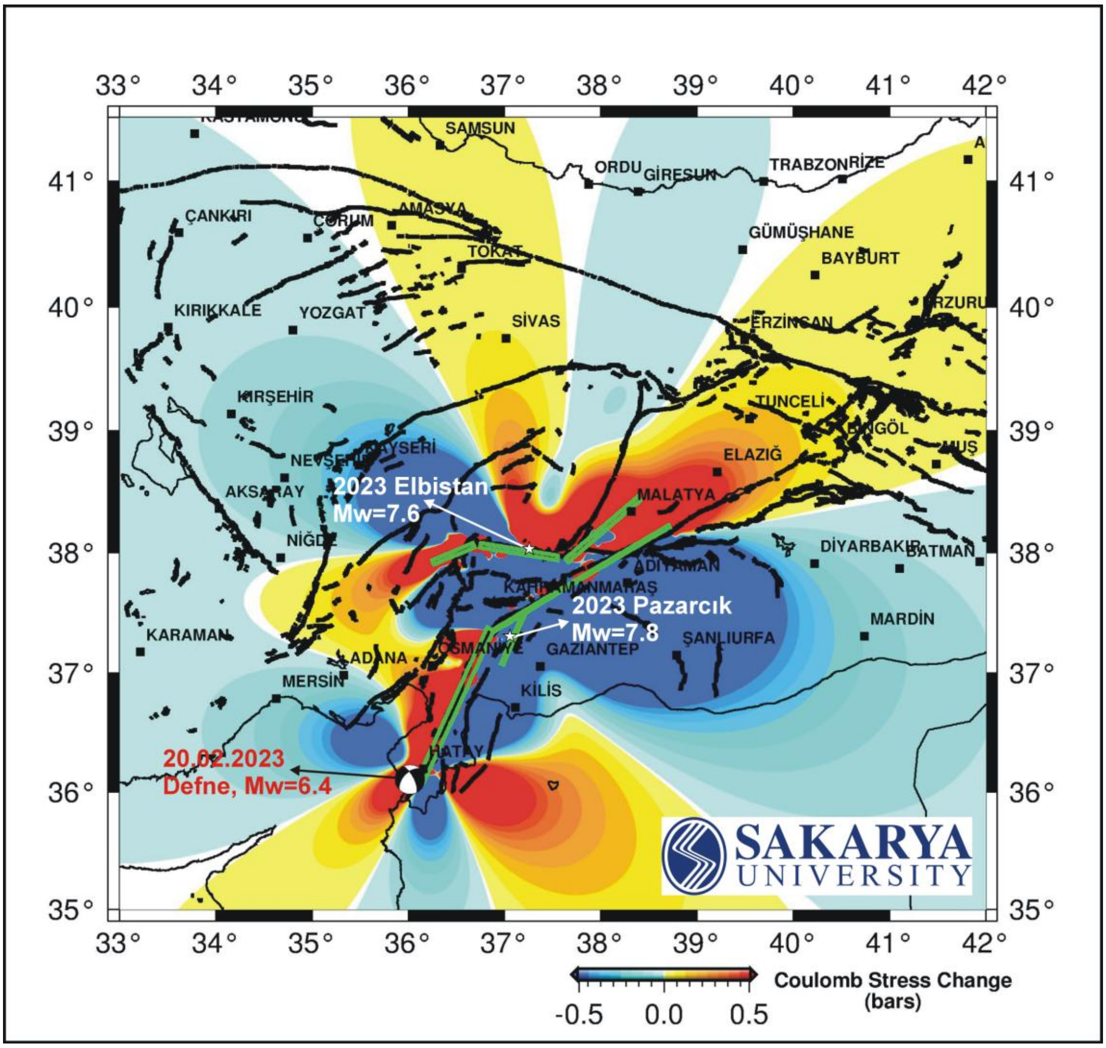

Figure 6. Coulomb stress changes due to the 2023 Pazarcık and Elbistan eartquakes calculated along the fault plane of the February 20, 2023 Defne aftershock.

Some remarks about future earthquake hazard in Türkiye

There are still two well defined seismic gaps in Türkiye, both are along the NAFZ. These are Yedisu Seismic Gap in the east of Erzincan and East Marmara Sea Seismic gap, lying offshore İstanbul, between Kartal district of İstanbul and Marmara Ereğlisi town of Tekirdağ.

The first was lastly ruptured by the 1784 earthquake while the latter produced no major earthquake since May 1766. As the both gaps generated no large earthquake that enough for deformation relaxation along the respective fault segments, the passing 250 years are sufficient for them to produce M_W7.0 or larger earthquake, meaning high earthquake hazard.

All these show how high earthquake hazard and how vital earthquake science studies in Türkiye. Türkiye has experienced dozens of the major earthquakes in the last millennia. The 1668 North Anatolian earthquake might be a M_W8.0-8.1 shock (Ambraseys 2009). Even earthquake that could be classified as "great" in seismology perspective occurs in Türkiye. Earthquake science studies and education, earthquake safety and disaster management should be among the first priority things in Türkiye. Despite all structural design procedures, the buildings are still collapsing. Considering the high standards of civil engineering in Türkiye and the past experiences, the collapses are mostly due to application process and lack or neglecting of proper inspection during the construction process. Since, these problems could not be overcome in short term, in order to mitigate earthquake risk necessity of short building designs or giving priority to the risk rather than hazard should be discussed by the civil engineering community.

Conclusions

- The first mainshock ruptured a fault length of about 300 km. A field study implemented by the authors confirmed clear surface ruptures along three segments of main strand of the EAFZ, called Amanos, Pazarcık and Erkenek fault segments from south to North. The fault rupture extends from Kırıkhan (Hatay) in the south to Çelikhan (Adıyaman) in the North. It is interpreted that the fault sections had ruptured during the 1114-1513, 1822 and 1893 earthquakes ruptured together to produce 2023 Pazarcık earthquake.

- The sinistral and vertical displacement of as much as 4.5 m and 1-2 m were measured along the fault rupture of the 2023 Pazarcık earthquake in the field studies, respectively.

- The rupture did not initiate along the main strand but rather along a secondary fault segment called the Narlı Segment, bifurcating from the main strand in the North of Pazarcık.

- The size of the 2023 Pazarcık earthquake about two-fold larger than the sum of the 1999 İzmit (M_W7.6) and Düzce (M_W7.2) earthquakes and caused a damage area elongated in NE-SWdirection along the fault rupture, depending on the faulting type. However, the second mainshock ruptured a E-W trending fault, causing further broadening of the damaged area in the east-west direction. Adding the size of both shocks, this is why a wide damaging area comprising 11 provinces that complicates the disaster relief efforts took place.

- The February 20, 2023, M_W6.4 shock occurred along the Antakya Fault Zone is an aftershock of the 2023 Pazarcık earthquake. Coulomb stress modeling in the present study clearly indicates that the M_W6.4 shock was triggered by the 2023 Pazarcık earthquake.

- There is a high earthquake hazard in Türkiye. Not only the current mainshocks but dozens of the major earthquakes in the past support this fact. Even earthquake that could be classified as “great” in seismology perspective occurs in Türkiye. This shows how vital earthquake science studies in Türkiye. Earthquake science studies and education, earthquake safety and disaster management should be among the first priority things in Türkiye.

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References

AFAD (2023) www.afad.gov.tr

Aktuğ B, Özener H, Dogru A, Sabuncu A, Turgut B, Halicioglu K,Yilmaz O, Havazli E (2016) Slip rates and seismic potentialon the East Anatolian Fault System using an improved GPSvelocity field. J Geodynamics 94-95: 1-12

Altunel E, Meghraoui M, Karabacak V, Akyüz S H, Ferry M, Yalçıner Ç, Munschy M (2009) Archaeological sites (tell and road) offset by the dead sea fault in the Amik Basin, southern Turkey. Geophys J Int 179(3), 1313-1329

Ambraseys N N (1989) Temporary seismic quiescence: SE Turkey. Geophys J Int 96(2), 311-331

Ambraseys N N (2009) Earthquakes in the Mediterranean and Middle East: a multidisciplinary study of seismicity up to 1900. Cambridge University Press, https://doi.org/10.1017/CBO9781139195430

Ayhan, M.E., Burgmann, R., McClusky, S., Lenk, O., Aktug, B., Herece, E. & Reilinger, R.E., (2001) Kinematics of the Mw = 7.2, 12 November 1999, Düzce, Turkey earthquake, Geophys. Res. Lett., 28, 367–370.

Barka A A, Kadinsky-Cade K (1988) Strik- slip fault geometry in Turkey and its influence on earthquake activity. Tectonics 7(3) 663-684

Bulut F, Bohnhoff M, Eken T, Janssen C, Kılıç T, Dresen G (2012) The East Anatolian Fault Zone: Seismotectonic setting and spatiotemporal characteristics of seismicity based on precise earthquake locations. J Geophys Res-Sol Ea doi:10.1029/2011JB008966

Delouis, B., D. Giardini, P. Lundgren, J. Salichon (2002). Joint inversion of InSAR, GPS, teleseismic, and strong-motion data for the spatial and temporal distribution of earthquake slip: application to the 1999 İzmit mainshock. Bull. Seism. Soc. Am. 92, 278-299.

Duman TY, Emre Ö (2013) The East Anatolian Fault: geometrysegmentation and jog characteristics. Geol Soc London SpecPubl 372: 495-529

Emre Ö, DumanTY, Özalp S, Elmacı H, Olgun Ş, Şaroğlu F (2013) Active Fault Map of Turkey. General Directorate of Mineral Research and Exploration, Special Publication Series-30. Ankara Turkey

Gülen, L., Barka, A., Toksöz, M.N. (1987) Kıtaların Çarpışması ile ilgili Kompleks Deformasyon, Maraş Üçlü Eklemi ve Çevre Yapıları. Yerbilimleri 14, 319-336.

Gülen, L., A. Pınar, D. Kalafat, N. Özel, G. Horasan, M. Yılmazer, A.M. Işıkara (2002). Surface fault breaks, aftershock distribution, and rupture process of the 17 August 1999 İzmit, Turkey, earthquake. Bull. Seism. Soc. Am. 92, 230-245.

Herece, E. (2008) Atlas of the East Anatolian Fault. Ankara, Turkey: General Directorate of Mineral Research and Exploration (MTA), Special Publication Series.

Hubert-Ferrari A, King G, Manighetti I, Armijo R, Meyer B, Tapponnier P (2003) Long-term elasticity in the continental lithosphere; modelling the Aden Ridge propagation and the Anatolian extrusion process. Geophys J Int 153(1), 111-132

KOERI (2023) 06 Şubat 2023 Sofalaca Şehitkamil Gaziantep Depremi Basın Bülteni. B.Ü. Kandilli Rasathanesi ve Deprem Araştırma Enstitüsü Bölgesel Deprem-Tsunami İzleme ve Değerlendirme Merkezi, İstanbul Şubat 2023, 4 sayfa

Li, X., V.F. Cormier, M.N. Toksöz (2002). Complex source process of the 17 August 1999 İzmit, Turkey, earthquake, Bull. Seism. Soc. Am. 92, 267–277.

Lin J, Stein R S (2004) Stress triggering in thrust and subduction earthquakes and stress interaction between the southern San Andreas and nearby thrust and strike-slip faults. J Geophys Res 109:B02303, https://doi.org/10.1029/2003JB002607

Mahmoud Y, Masson F, Meghraoui M, Cakir Z, Alchalbi A, Yavasoglu H et al (2013) Kinematic study at the junction of the East Anatolian fault and the Dead Sea fault from GPS measurements. J Geodyn 67, 30-39

McClusky S, Balassanian S, Barka A, Demir C, Ergintav S, Georgiev I et al (2000) Global Positioning System constraints on plate kinematics and dynamics in the eastern Mediterranean and Caucasus. J Geophys Res-Sol Ea 105(B3), 5695-5719

Nalbant S S, McCloskey J, Steacy S, Barka A A (2002) Stress accumulation and increased seismic risk in eastern Turkey. Earth Planet Sc Lett 195(3), 291-298

Özalaybey, S., M. Ergin, M. Aktar, C. Tapırdamaz, F. Biçmen and A. Yörük (2002) The 1999 İzmit earthquake sequence in Turkey: seismological and tectonic aspects, B. Seismol. Soc. Am., 92, 376-386.

Reilinger, R., S. Ergintav, R. Bürgman, S. McClusky, O. Lenk, A. Barka, O. Gürkan, L. Hearn, K.L. Feigl, R. Çakmak, B. Aktu , H. Özener and M.N. Toksöz (2000) Coseismic and postseismic fault slip for the 17 August 1999, M = 7.5, İzmit, Turkey earthquake, Science, 289, 1519-1524.

Reilinger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., Çakmak, R., Özener, H., Kadirov, F., Guliev, I., Stepanyan, R., Nadariya, M., Hahubia, G., Mahmoud, S., Sakr, K., ArRajehi, A., Paradissis, D., Al-Aydrus, A., Prilepin, M., Guseva, T., Evren, E., Dmitrotsa,A., Filikov, S.V., Gomez, F., Al-Gha R. and Karam, G., (2006) GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for thedynamics of plate interactions. Journal of Geophysical Research, 111, B05411, doi:10.1029/2005JB004051.

Seyrek A, Demir T, Westaway R, Guillou H, Scaillet S, White T S, Bridgland D R (2014) The kinematics of central-southern Turkey and northwest Syria revisited. Tectonophysics 618, 35-66

Şengör A M C, Tüysüz O, İmren C, Sakınç M, Eyidoğan H, Görür N et al (2005) The North Anatolian fault: A new look Annu Rev Earth Planet Sci 33, 37-112

Tan O, Pabucçu Z, Tapırdamaz C, İnan S, Ergintav S, Eyidoğan H, Aksoy E, Kuluöztürk F (2011) Aftershock study and seismotectonic implications of the 8 March 2010 Kovancılar (Elazığ, Turkey) earthquake (Mw=6.1), Geophys. Res. Lett., 38, L11304, doi:10.1029/2011GL047702.

Taymaz T, Eyidoğan H, Jackson J (1991) Source parameters of large earthquakes in the East Anatolian Fault Zone (Turkey). Geophys J Int 106(3), 537-550

Tibi, R., G. Bock, Y. Xia, M. Baumbach, H. Grosser, C. Milkerit, S. Karakisa, S. Zünbül, R. Kind and J. Zschau (2001). Rupture process of the August 17 Izmit and November 12, 1999 Düzce (Turkey) earthquakes, Geophys. J. Int., 144, F1-F7.

Toda, S., R. S. Stein, K. Richards-Dinger, and S. B. Bozkurt (2005) Forecasting the evolution of seismicity in southern California: Animations built on earthquake stress transfer, J. Geophys. Res., 110, B05S16, doi:10.1029/2004JB00341

USGS NEIC (2023) https://earthquake.usgs.gov/earthquakes/eventpage/us6000jllz/executive

Utkucu M and Durmuş, H. 2012. A teleseismic finite-fault rupture model for the August 17, 1999, İzmit earthquake (Mw = 7.6): implications for the seismic nucleation phase Annals of Geophysics, 55, 2, 235-252; doi: 10.4401/ag-4954.

Utkucu, M., S. Nalbant, J. McClusky, S. Steacy and Ö. Alptekin (2003) Slip distribution and stress changes associated with the 1999 November 12, Düzce (Turkey) earthquake (Mw =7.1). Geophys. J. Int., 153, 229-241

Utkucu M, Budakoğlu E, Çabuk M (2018) Teleseismic finite-fault inversion of two Mw=6.4 earthquakes along the East Anatolian Fault Zone in Turkey: the 1998 Adana and 2003 Bingöl earthquakes. Arab J Geosci 11, 721. https://doi.org/10.1007/s12517-018-4089-y

Utkucu, M., Kurnaz T.F. and İnce Y., (2023a) The seismicity assessment and probabilistic seismic hazard analysis of the plateau containing large dams around the East Anatolian Fault Zone, Eastern Türkiye. Submitted to Environmental Earth Sciences.

Utkucu, M., Durmuş, H., Uzunca, F., Nalbant S. S (2023b) 6 Şubat 2023 Gaziantep (Mw=7.7) ve Elbistan (Mw7.5) Depremleri Üzerine Bir Değerlendirme, Sakarya Üniversitesi Afet Yönetim ve Araştırma Merkezi, Sakarya Şubat 2023, 11 Sayfa

Yönlü, Ö. (2012) Doğu Anadolu Fay Zonu'nun Gölbaşı (Adıyaman) ile Karataş (Adana) arasındaki kesiminin geç kuvaterner aktivitesi, (Doctoral dissertation, Eskisehir Osmangazi University).

Westaway R (2004) Kinematic consistency between the Dead Sea Fault Zone and the Neogene and Quaternary left-lateral faulting in SE Turkey. Tectonophysics 391(1), 203-237

Wright, T., Fielding, E. & Parsons, B., (2001) Triggered slip: observations of the 17 August 1999 Izmit (Turkey) earthquake using radar interferometry, Geophys. Res. Lett., 28, 1079–1082.


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