Dedicated to the people who lost their lives and injured by the 2023 Pazarcık and Ekinözü Earthquakes of Türkiye

A QUICK REPORT ON PAZARCIK AND EKİNÖZÜ EARTHQUAKES (TÜRKİYE) OF FEBRUARY 6, 2023

Ömer AYDAN* and Reşat ULUSAY**

** University of the Ryukyus, Okinawa, Japan*
*** Hacettepe University, Ankara, Türkiye*

15 February 2023

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ATTENTION

Please note that this document is prepared with a sole purpose to provide an overview of various aspects of the earthquake for researchers, who would be involved with this earthquake.

The pictures and some figures are obtained from various sources with due references available in various web-sites. The figures drawn by the authors of this report are cited as (DbA) next to them.

The major source of the pictures relevant to the aspects of this document are obtained from the web-sites of the mass media of Türkiye and relevant institutes and they are gratefully acknowledged for the information through images and data of the earthquake:

https://www.aa.com.tr/tr
https://www.dha.com.tr/
https://www.trt.net.tr/
https://www.emsc-csem.org/#2
https://www.usgs.gov/
https://www.mta.gov.tr
https://www.koeri.boun.edu.tr
https://www.afad.gov.tr
https://www.maxar.com/open-data/turkey-earthquake-2023

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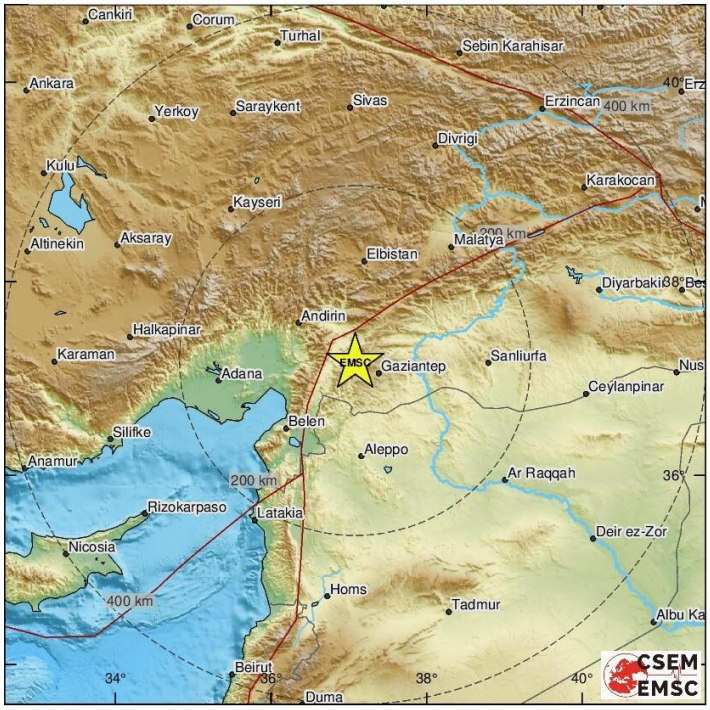
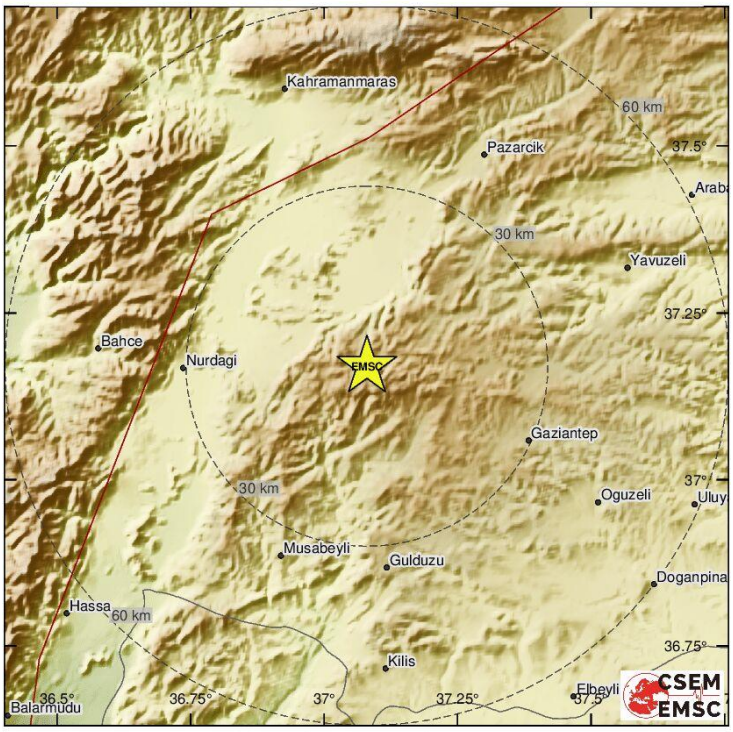
LOCATIONS

PAZARCIK EARTHQUAKE

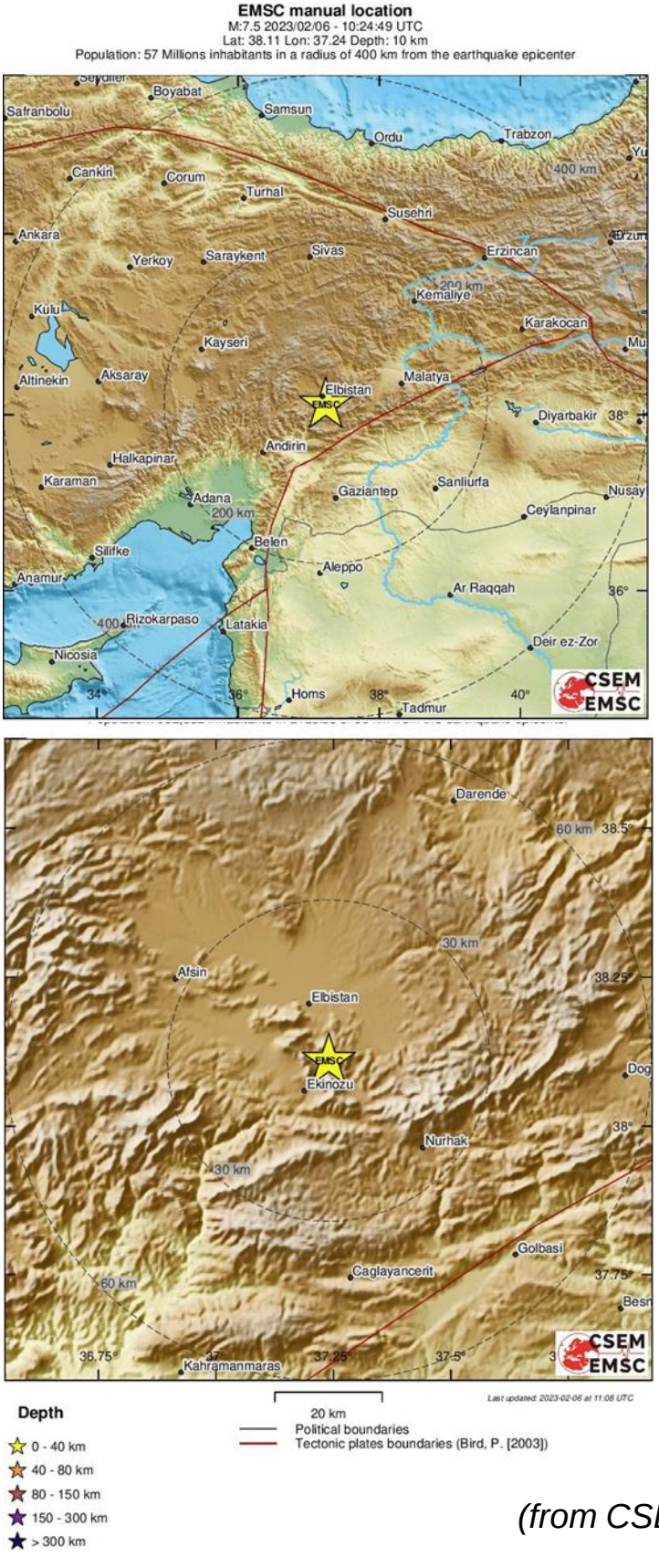
EMSC manual location
M:7.8 2023/02/06 - 01:17:36 UTC
Lat: 37.17 Lon: 37.08 Depth: 20 km
Population: 59 Millions inhabitants in a radius of 400 km from the earthquake epicenter





(from CSEM-EMSC)

EKİNÖZÜ EARTHQUAKE



(from CSEM-EMSC)

MAIN CHARACTERISTICS OF THE EARTHQUAKES

The Pazarcık earthquake occurred at 4:17 (TST) on February 6, 2023 and the Ekinözü earthquake occurred at 13:24 on the same day after about 9 hours. The earthquake involve rupturing on the segments of East Anadolu Fault (EAF) and Dead-Sea Fault. The initial total length of Pazarcık earthquake was about 210-230 km and reach to a total length of 400-450 km. Ekinözü earthquake E-W trending Çardak and Sürgü faults with a total length of 120-130 km. As of 15 February 2023,
Number of casualties is 35.418.
Number of injured people is more than 105.505.
Number of after shocks is more than 1.900.
10 provinces with a total population of 15 million people were affected.

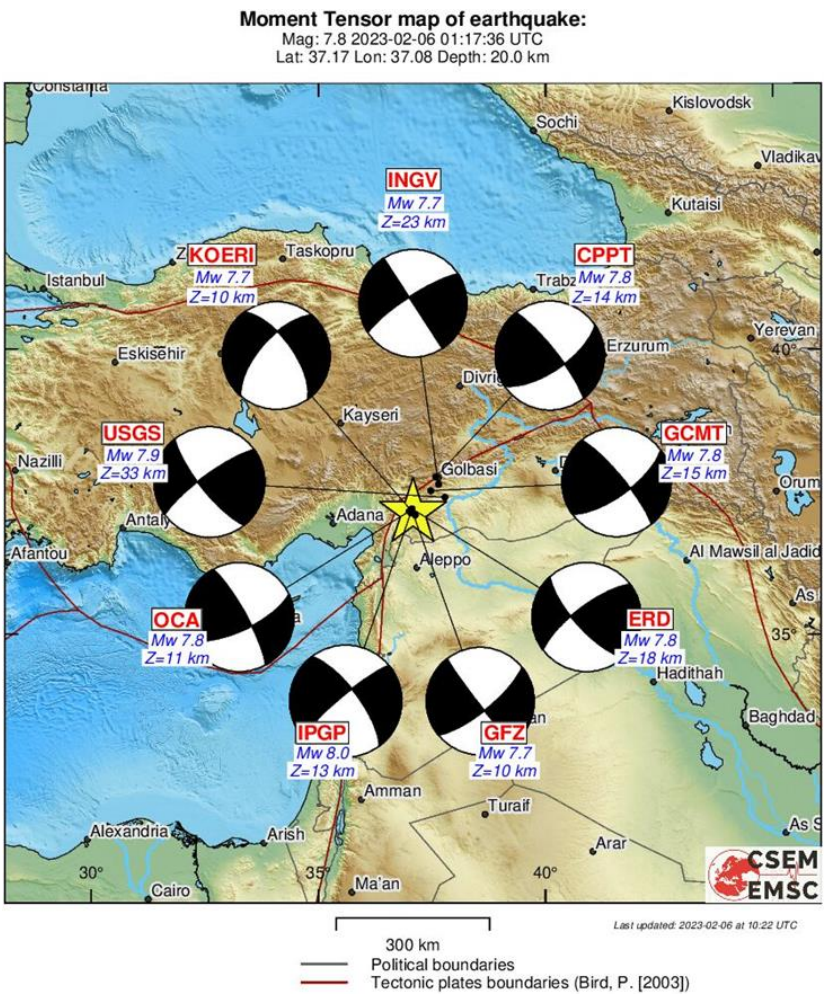
Affected provinces

MAIN CHARACTERISTICS OF THE EARTHQUAKES

PAZARCIK EARTHQUAKE

The earthquake occurred at 4:17:35 (TST) (1:17:35 GMT) on NE-SW trending fault with sinistral slip. This fault might be a combined slip of East Anatolian Fault and Dead-Sea Fault. Moment magnitude of this earthquake has been estimated by different institutes and they range between 7.7 and 8.0.

Institute	Mw	LAT	LON	Depth (km)	Fault Plane			Auxiliary Plane		
					Strike	Dip	Rake	Strike	Dip	Rake
QCMT	7.8	37.6	37.5	15	54	70	11	320	80	160
USGS	7.9	37.4	37.8	33	234	79	14	142	76	169
KOERI	7.7	37.1	37.1	10	222	64	-27	324	65	-152
ERD	7.8	37.2	37.1	18	233	74	18	140	77	168
IPGP	8.0	37.2	37.0	13	230	81	-18	323	72	-171



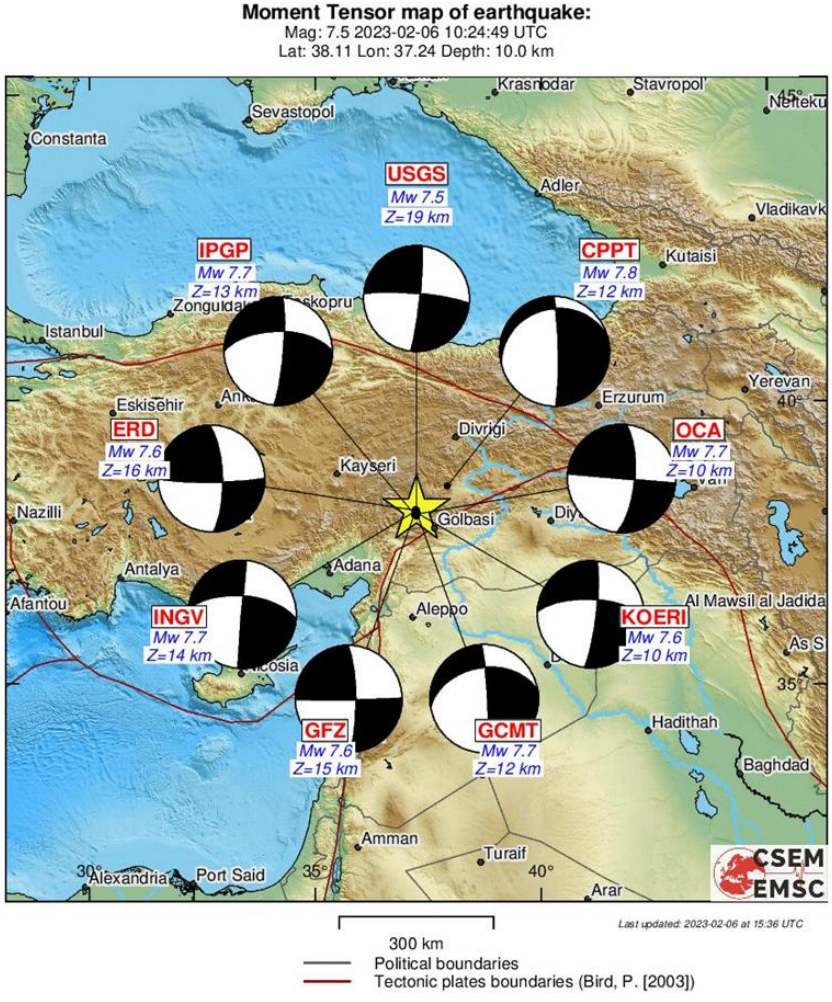
Among all focal plane solutions, focal plane by KOERI is close to the actual situations.

(from CSEM-EMSC)

EKİNÖZÜ EARTHQUAKE

The earthquake occurred at 13:24:49 (TST) (10:24:49 GMT) on almost E-W trending fault with sinistral slip. This fault might be a combined slip of Çardak and Sürgü Faults. Moment magnitude of this earthquake has been estimated by different institutes and they range between 7.6 and 7.7.

Institute	Mw	LAT	LON	Depth (km)	Fault Plane			Auxiliary Plane		
					Strike	Dip	Rake	Strike	Dip	Rake
QCMT	7.7	38.1	37.2	12	261	42	-8	358	84	-132
USGS	7.6	38.0	37.2	19	276	82	-6	6	85	-172
KOERI	7.6	38.0	37.3	10	273	67	-9	6	81	-157
ERD	7.6	38.0	37.2	16	174	90	13	358	73	174
IPGP	7.7	38.0	37.2	13	270	60	-9	5	82	-150



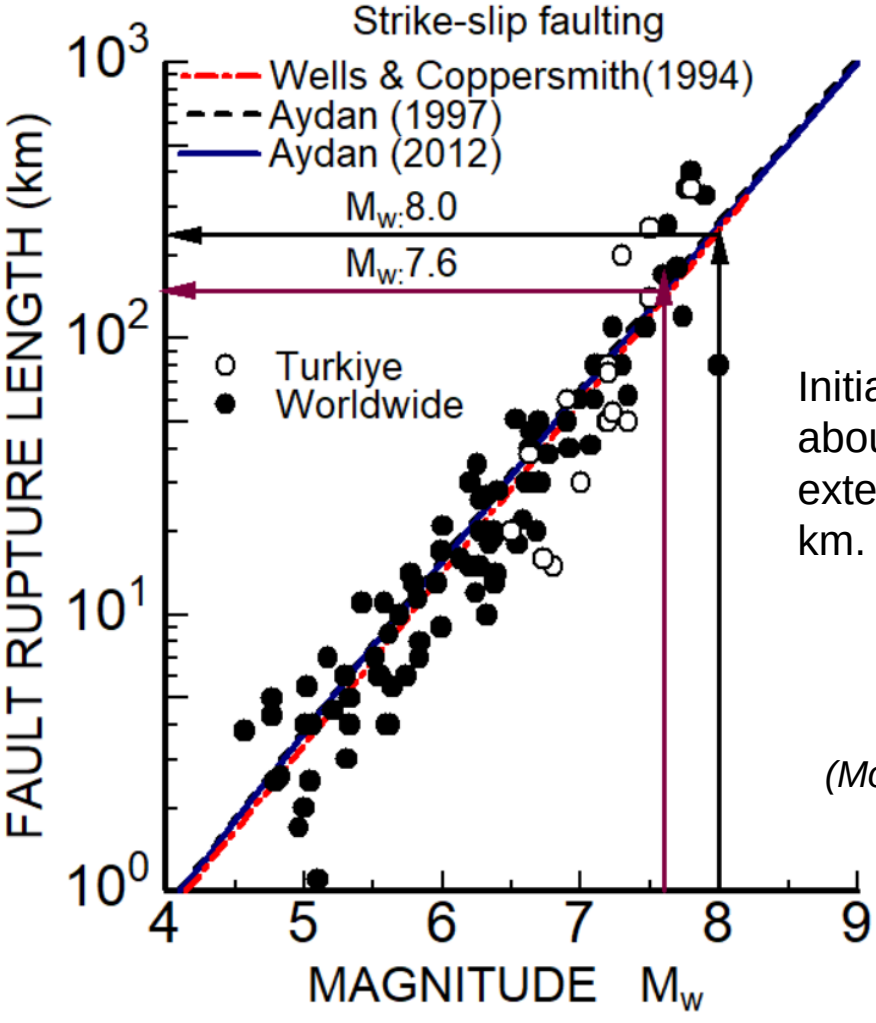
Earthquake occurred in north dipping fault and large ground susidence occurred on the northern part.

(from CSEM-EMSC)

Estimation of the Earthquake Parameters

Estimation of the earthquake parameters from fault length (based on relations of Aydan, 2012, 2023). AMAX and VMAX are computed for a hypocenter distance of 14 km and surface shear wave velocity of 300 m/s.

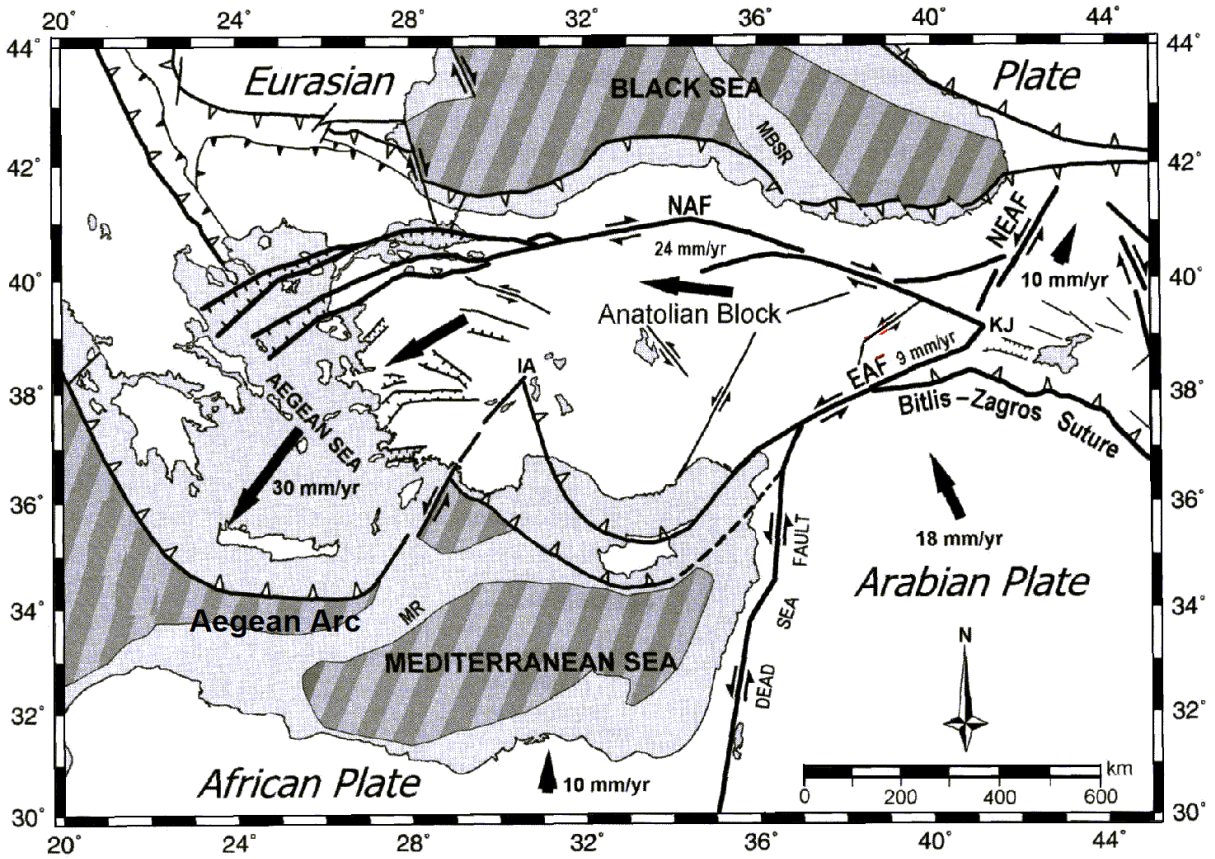
Length	Mw	AMAX (gals)	VMAX (kines)	DMAX (cm)	Tr (s)
147	7.6	1020,3	72.9	506	35.6
195	7.8	1217.6	87.0	721	45.8
222	7.9	1320.7	94.3	848.4	51.4
255	8.0	1440.6	102.3	1009.5	58.2



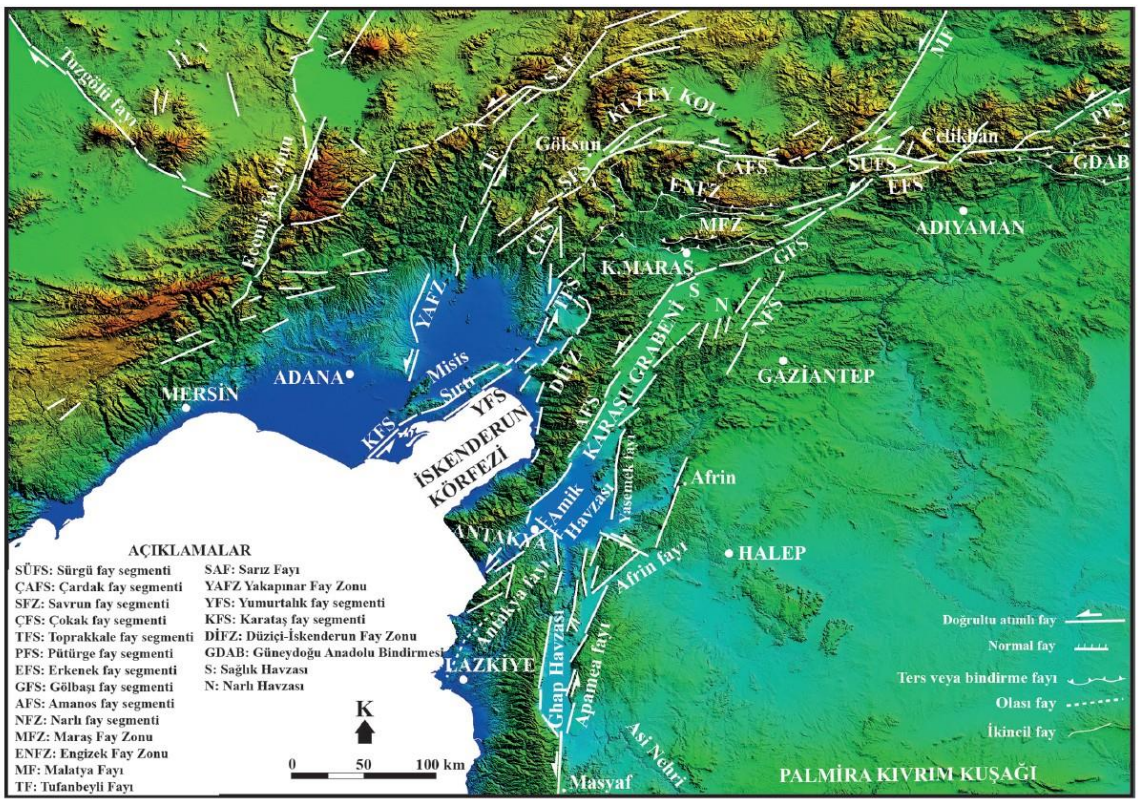
Initial fault length was about 200-220 km and it extended to about 400 km.

(Modified from Aydan, 2012)

TECTONICS



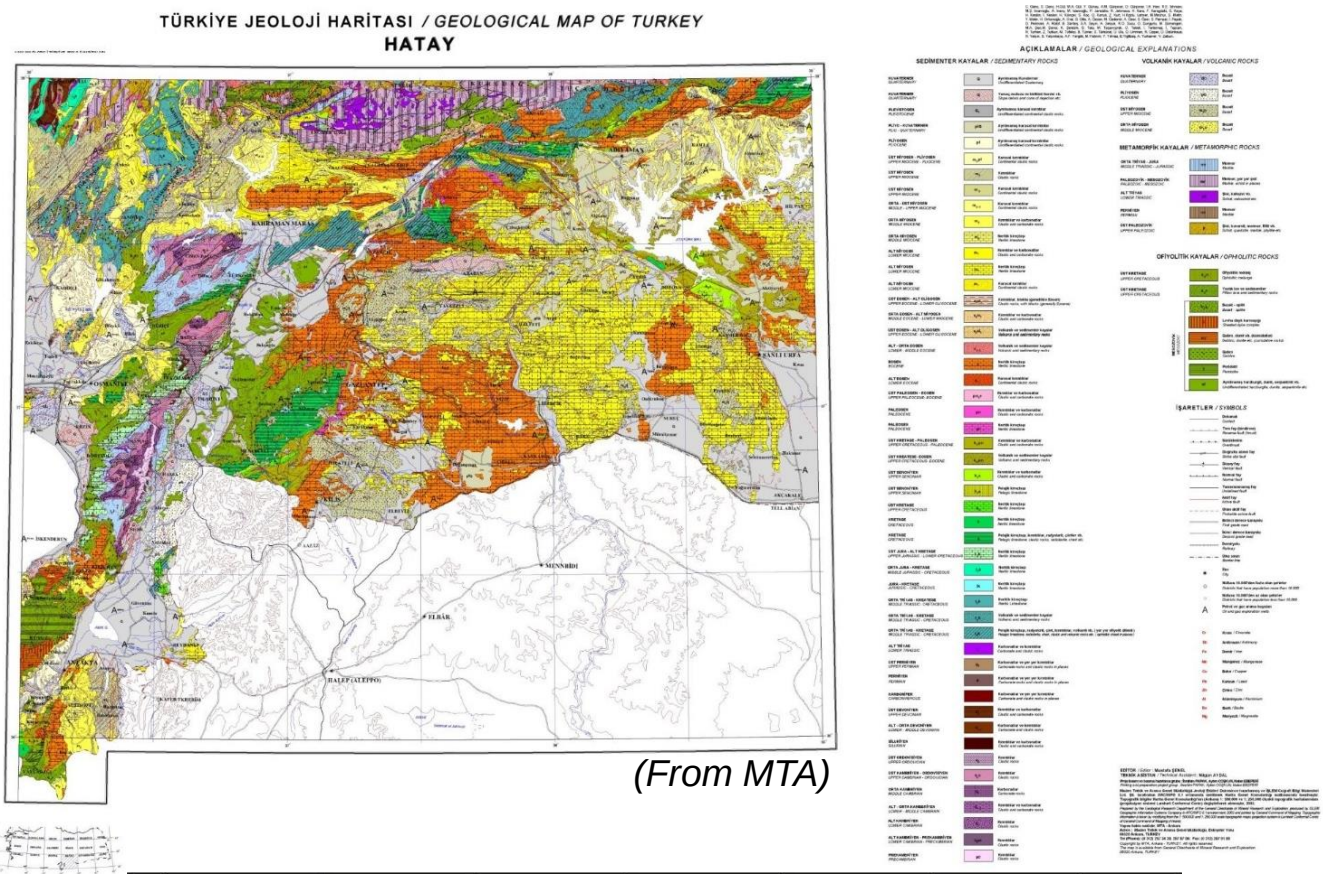
(From Ulusay and Aydan (2005) based on the original drawing by Gülen et al.(2002))



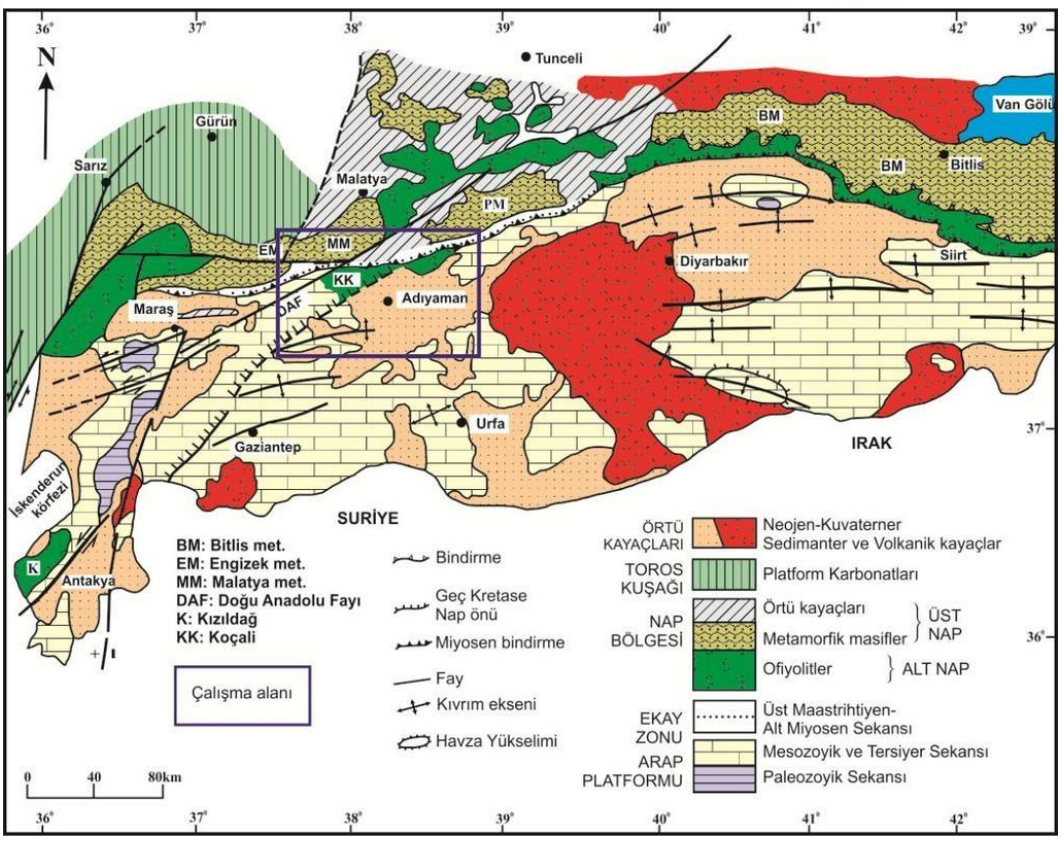
(From Palutoğlu and Şaşmaz, 2017)

GEOLOGY

Regional Geology of the Affected Region

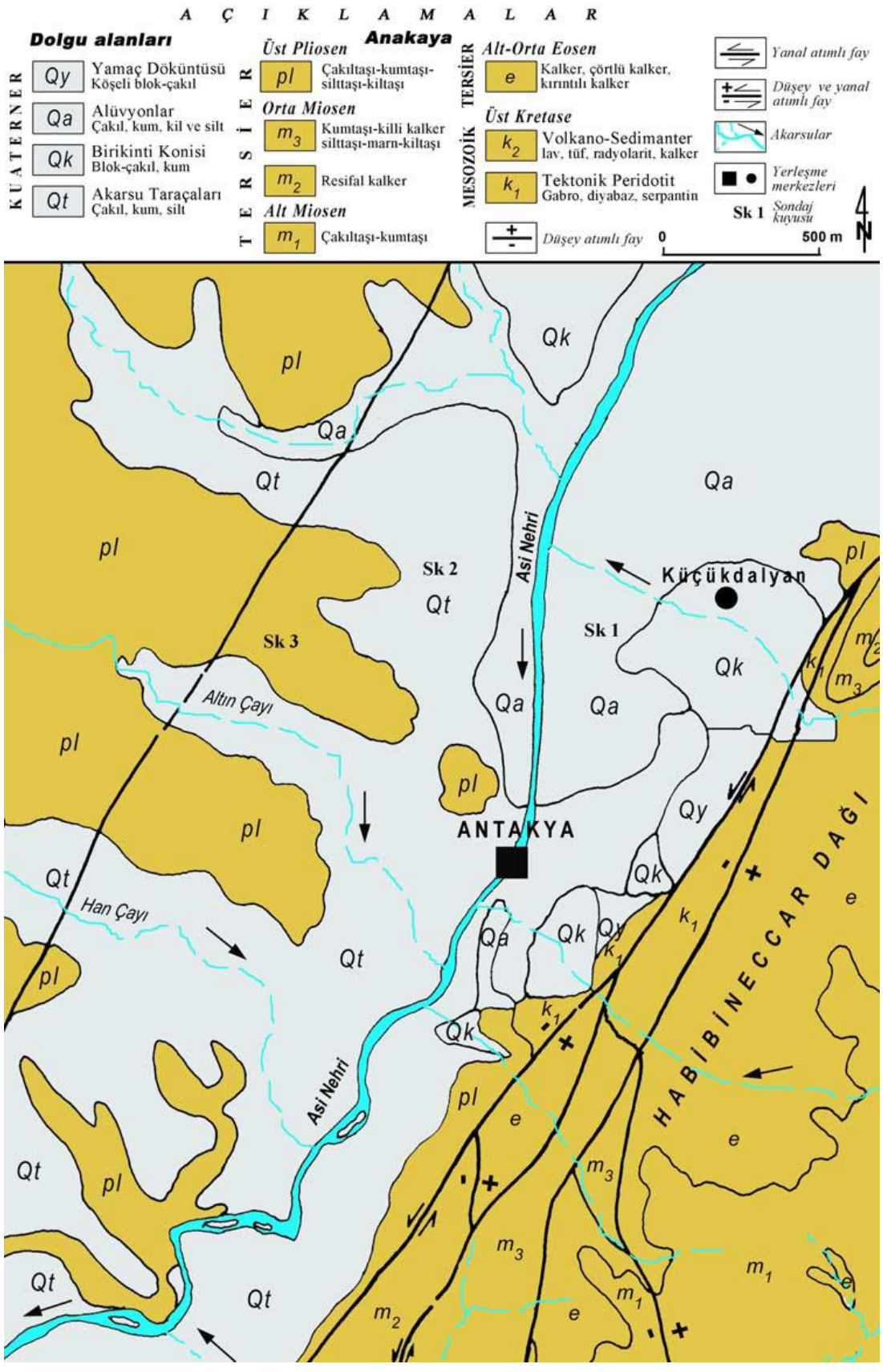


(From MTA)



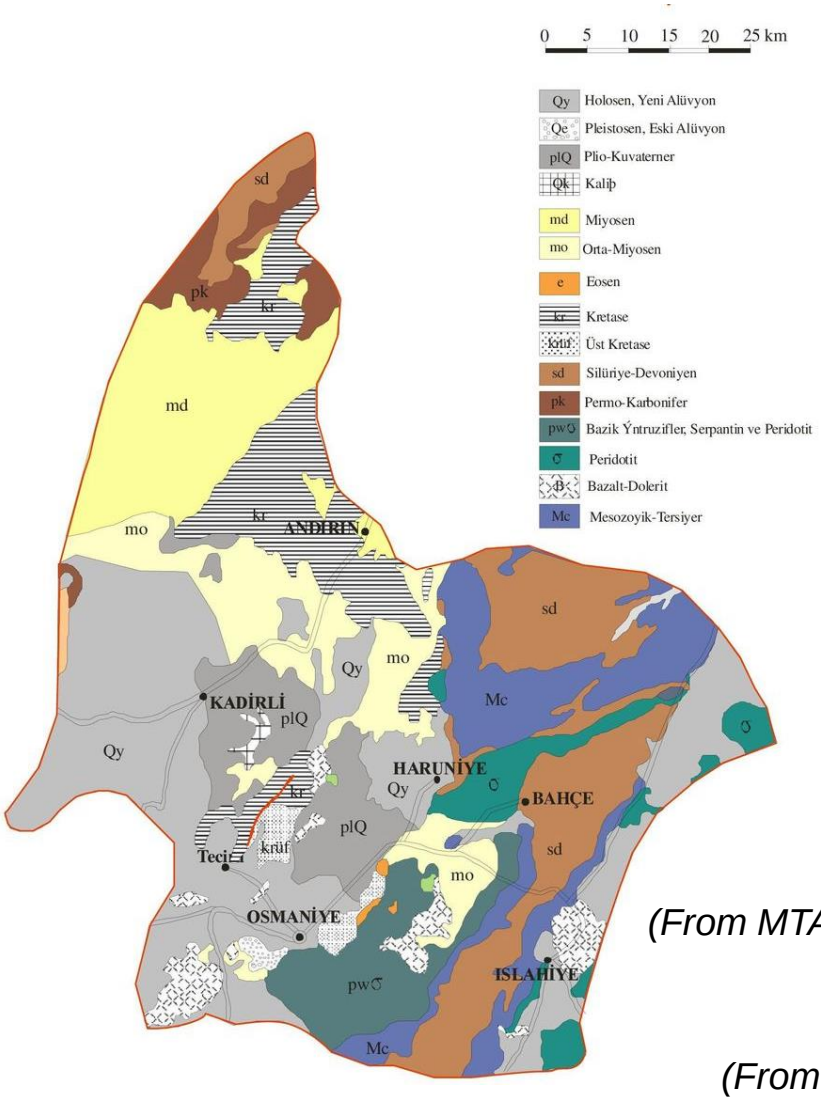
(Yılmaz et al.,1993)

Geology and Faults of Hatay (Antakya)



(From Korkmaz, 2006)

Geology and Faults of Osmaniye

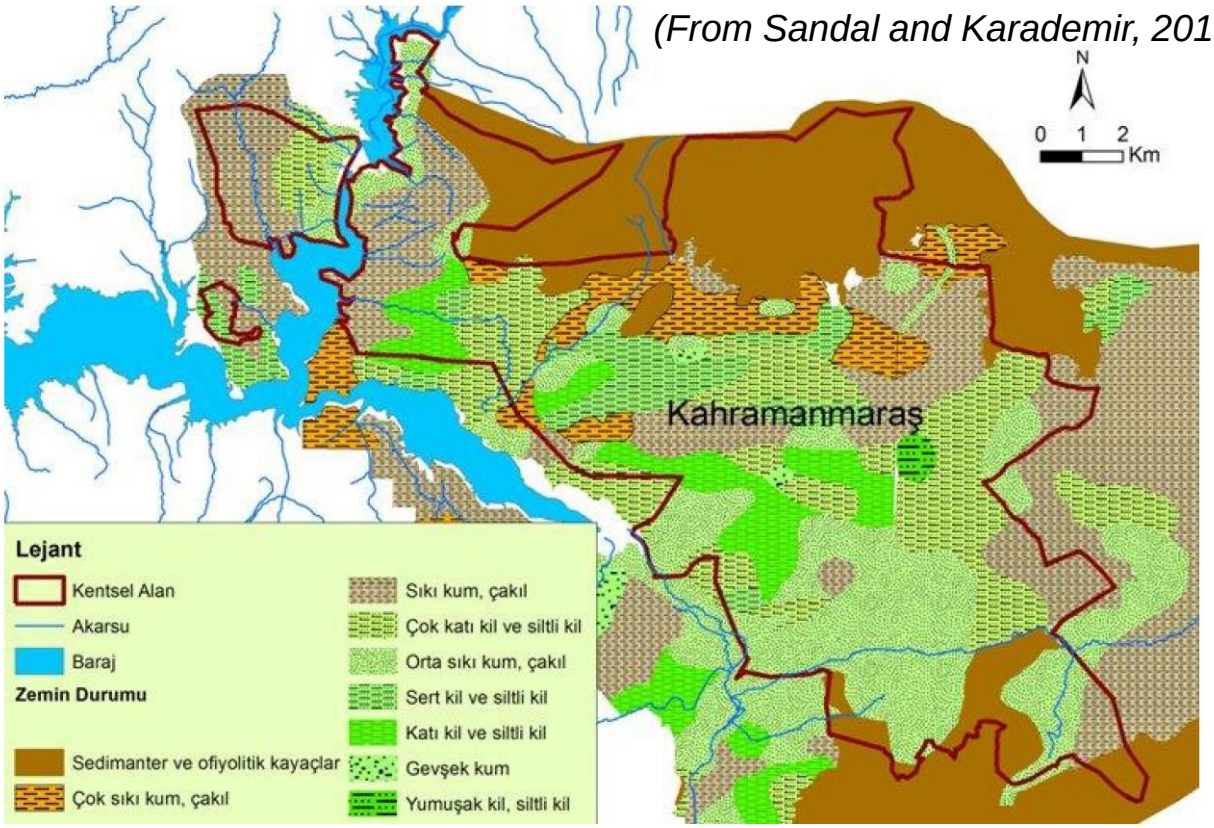


(From MTA)

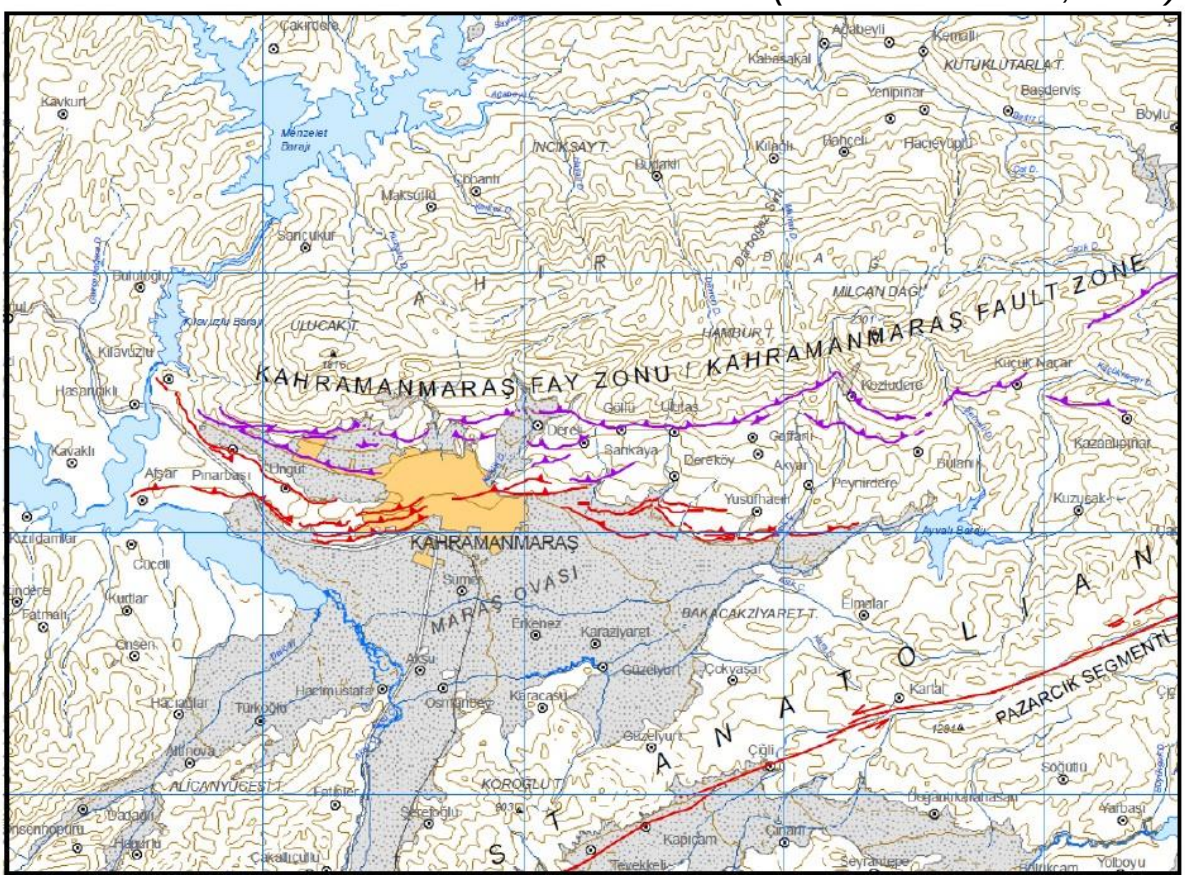
(From Emre et al., 2013)

Geology and Faults of Kahramanmaraş

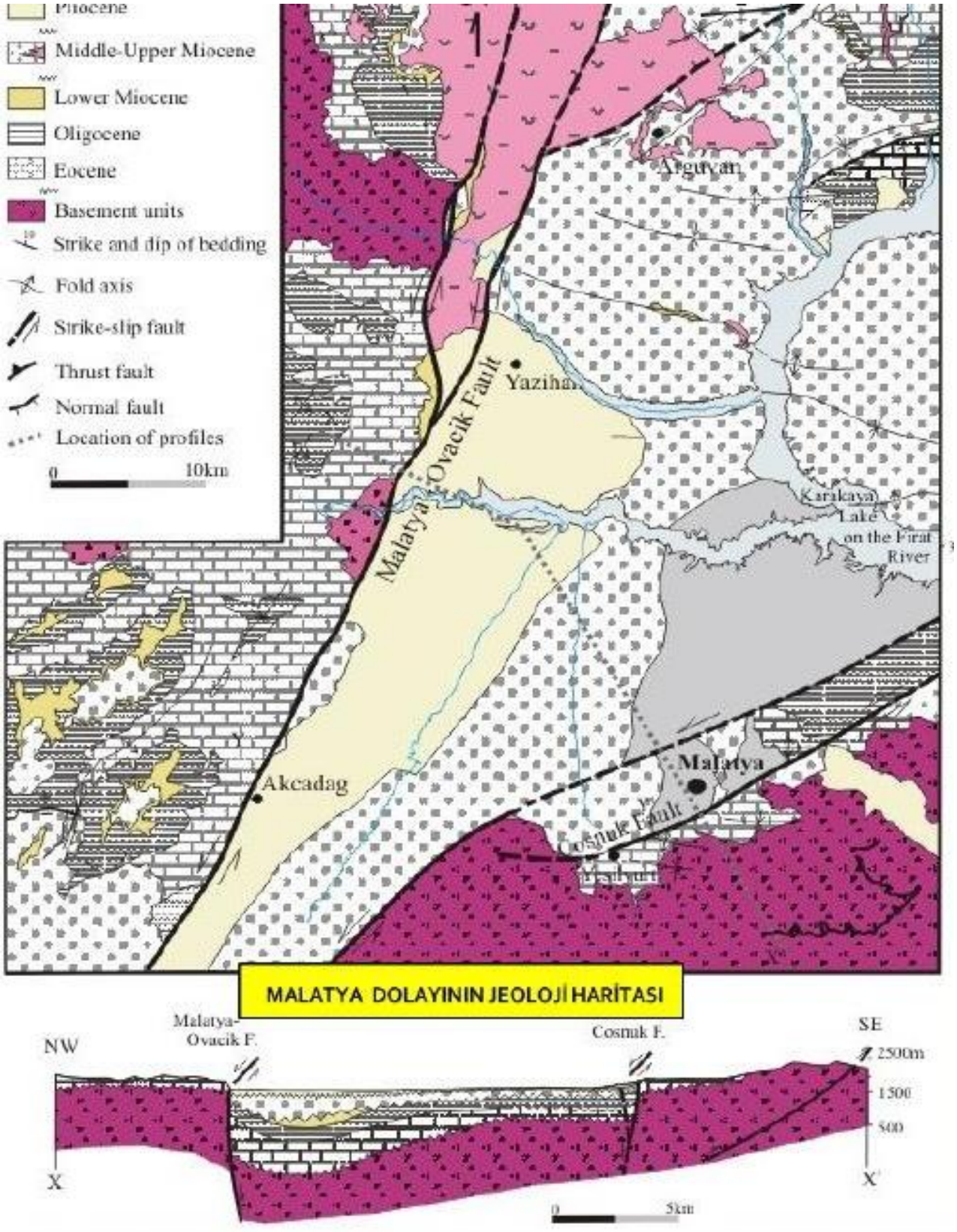
(From Sandal and Karademir, 2013)



(From Emre et al., 2013)

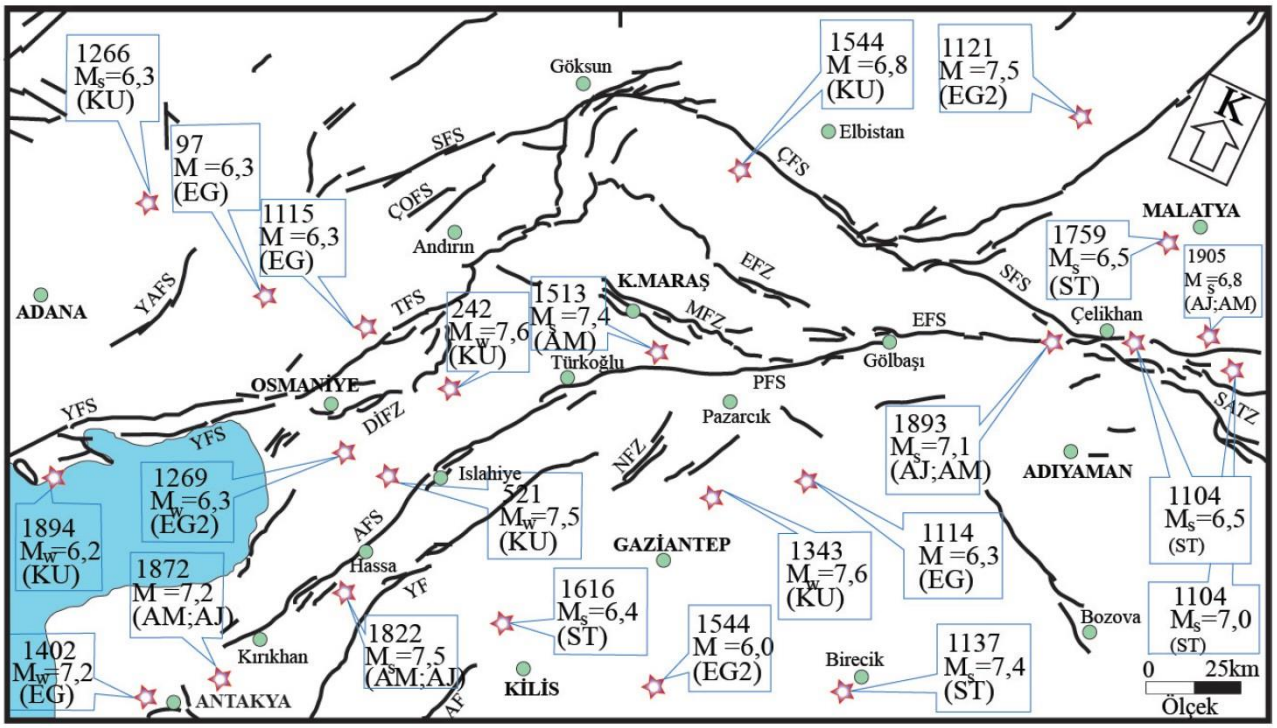


Geology and Faults of Malatya

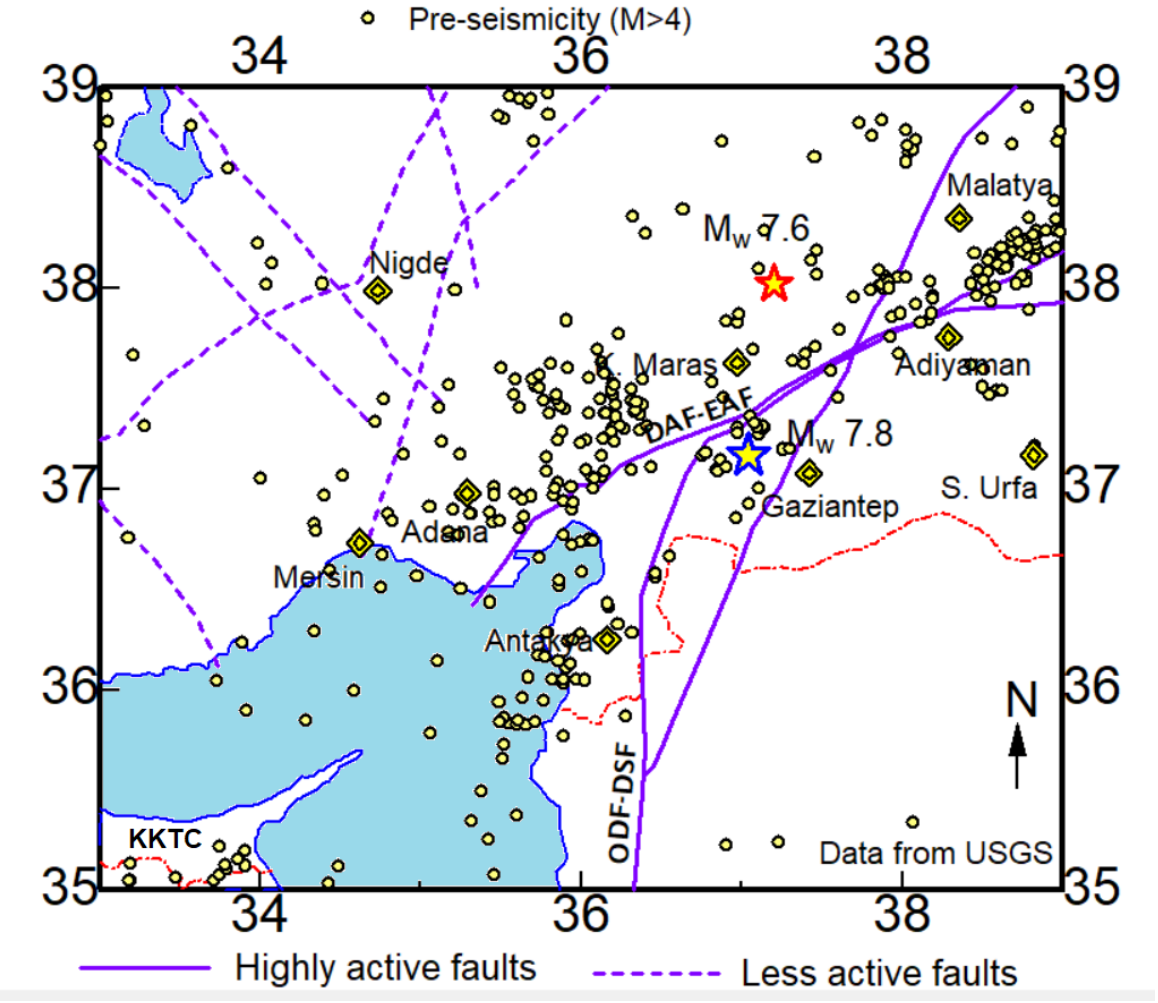


(From Önal, 2007)

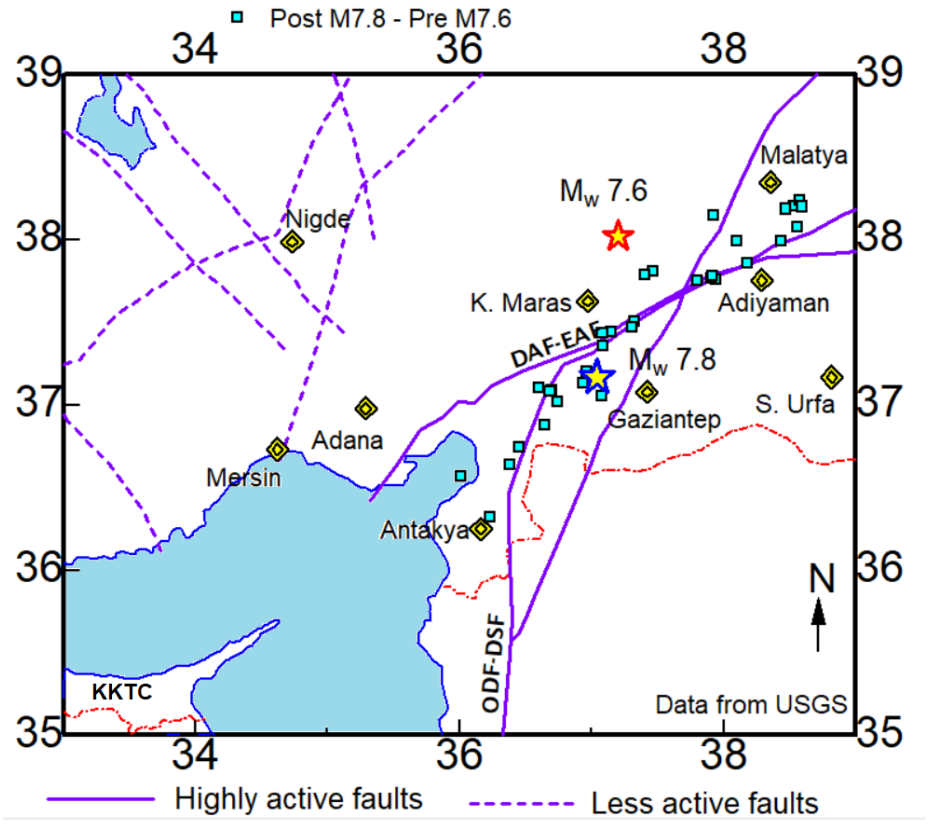
PRE- AND POST-SEISMICITY



(From Palutoğlu and Şaşmaz, 2015)

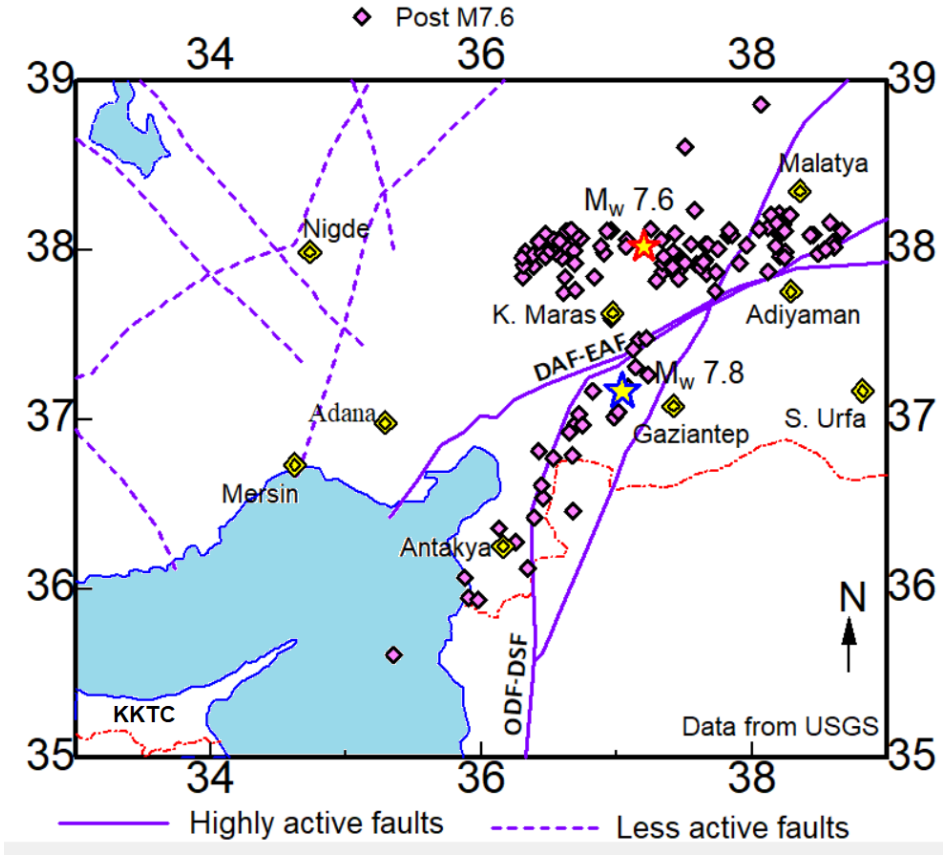


(DbA, base map by Aydan, unpublished)



(DbA, base map by Aydan, unpublished)

The Pazarcık earthquake involved EAFZ (2 segments) and DSF-Death Sea Fault (1 segment). The total length of the surface rupture could be in the order of 210-230 kms.

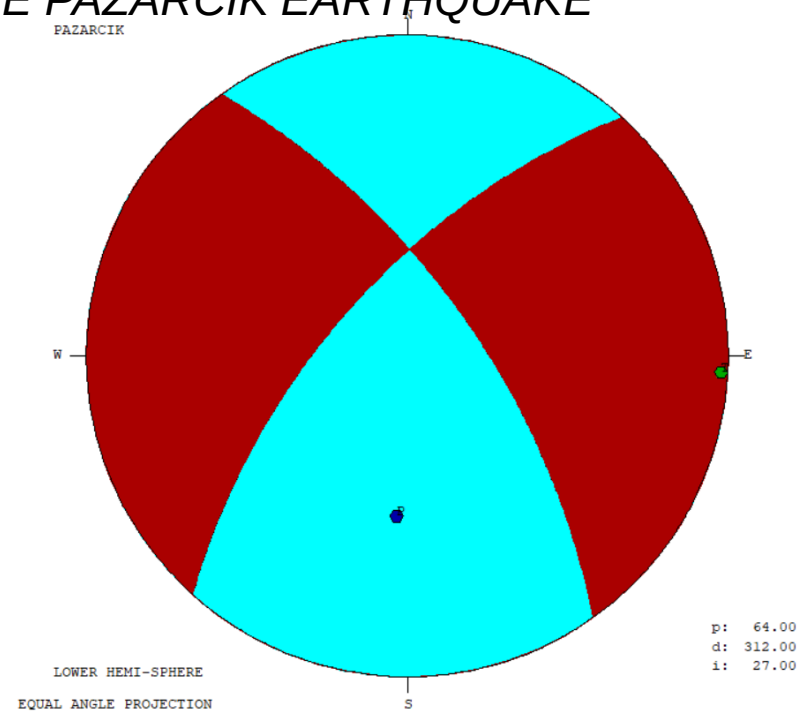


(DbA, base map by Aydan, unpublished)

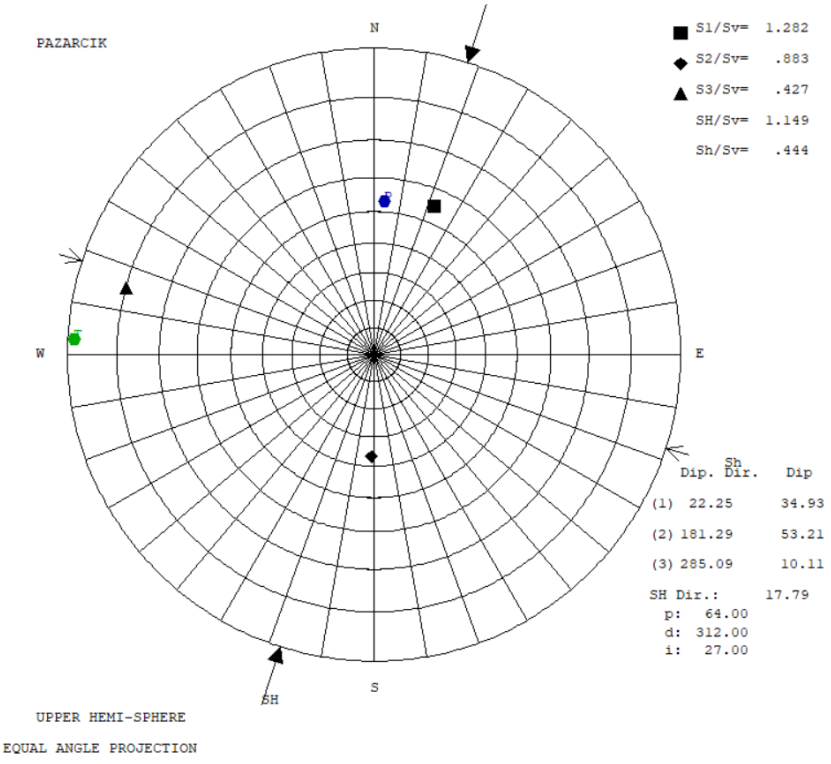
FOCAL MECHANISM AND ASSOCIATED STRESS FIELD

THE PAZARCIK EARTHQUAKE

FOCAL MECHANISM



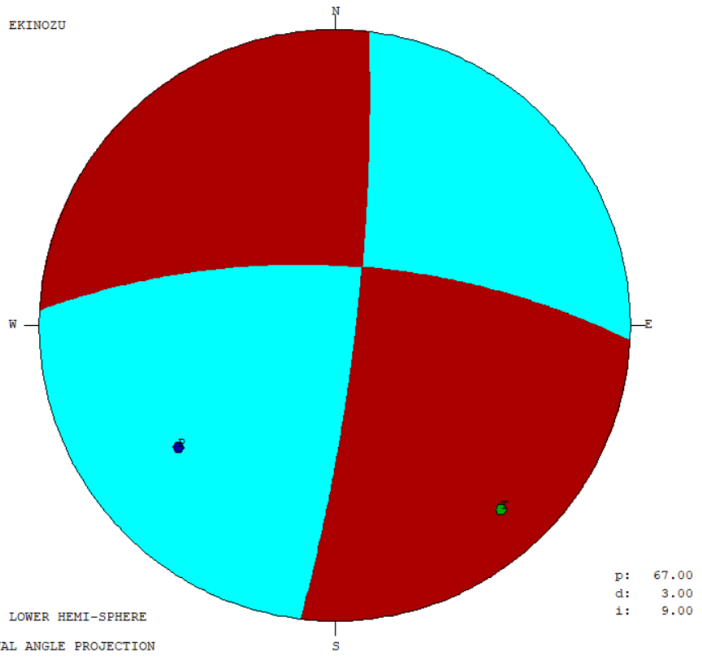
ASSOCIATED STRESS FIELD



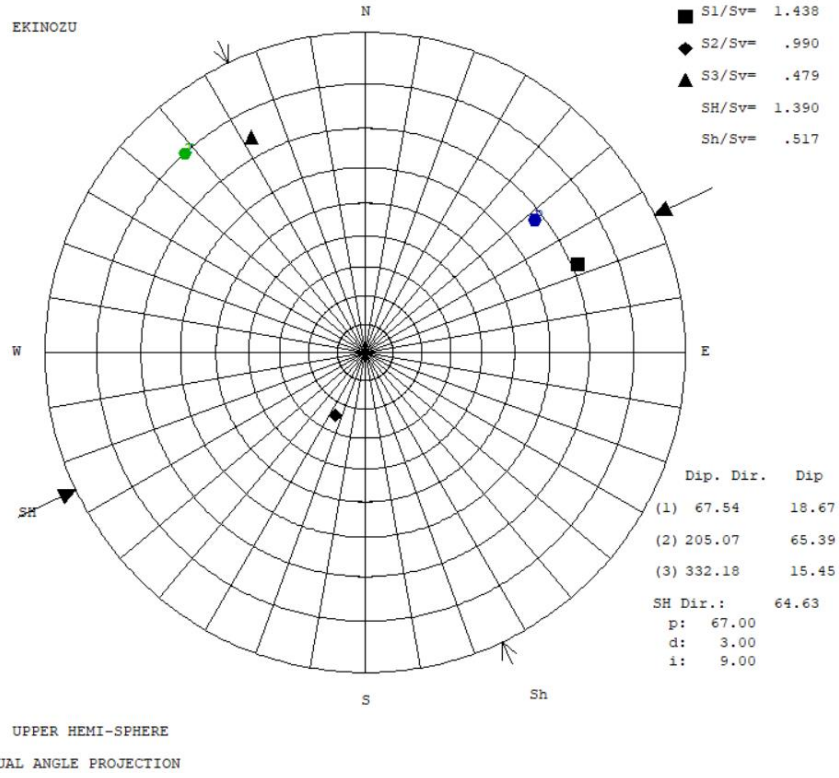
Inferred crustal stresses of the epicentral area for focal plane solution by KOERI using Aydan's Method (Aydan 2000a, 2016, 2020). KOERI focal mechanism involves normal component as observed in-situ (DbA).

THE EKİNÖZÜ EARTHQUAKE

FOCAL MECHANISM

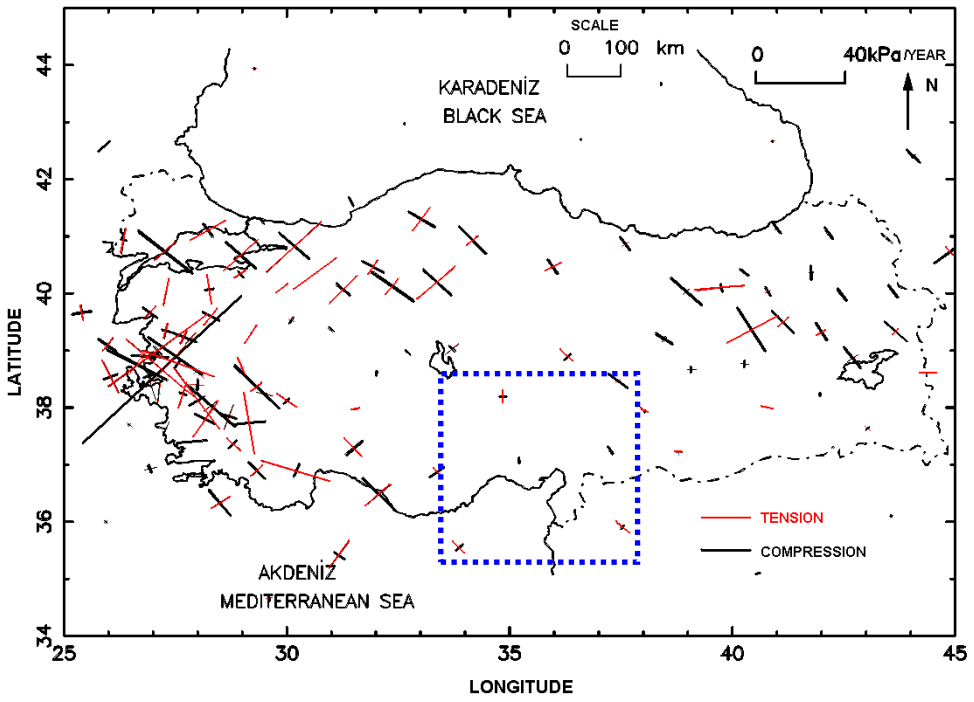


ASSOCIATED STRESS FIELD

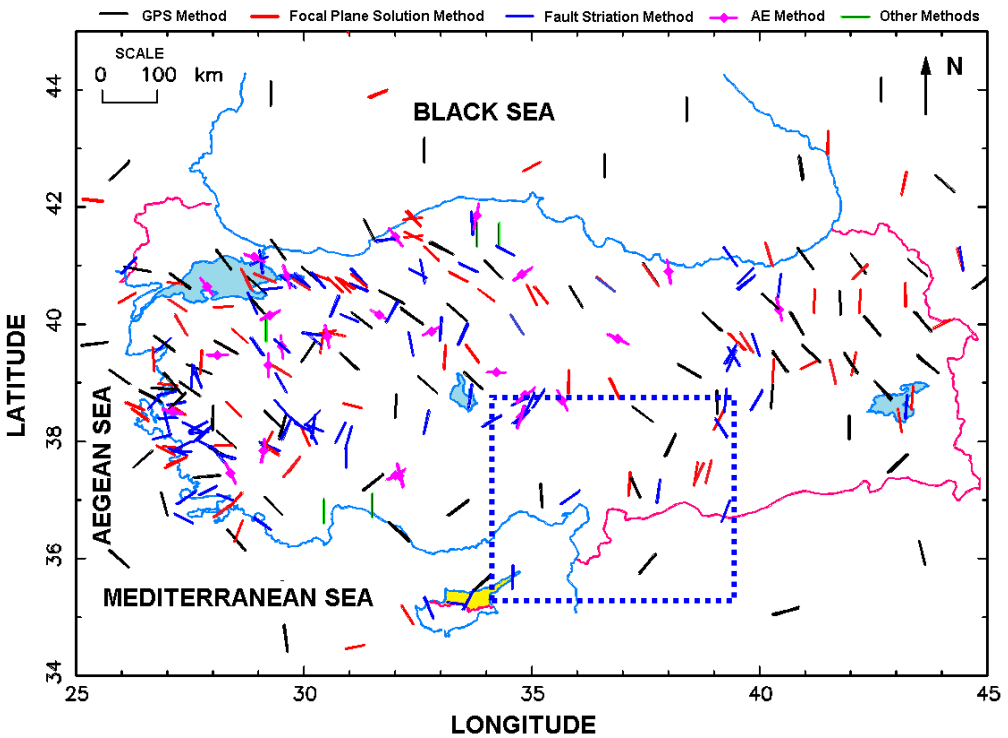


Inferred crustal stresses of the epicentral area for focal plane solution by KOERI using Aydan's Method (Aydan 2000a, 2016, 2020). Pazarcık earthquake greately altered the stress state. On the northern side, some downward motions are reported (DbA)

CRUSTAL STRESSES



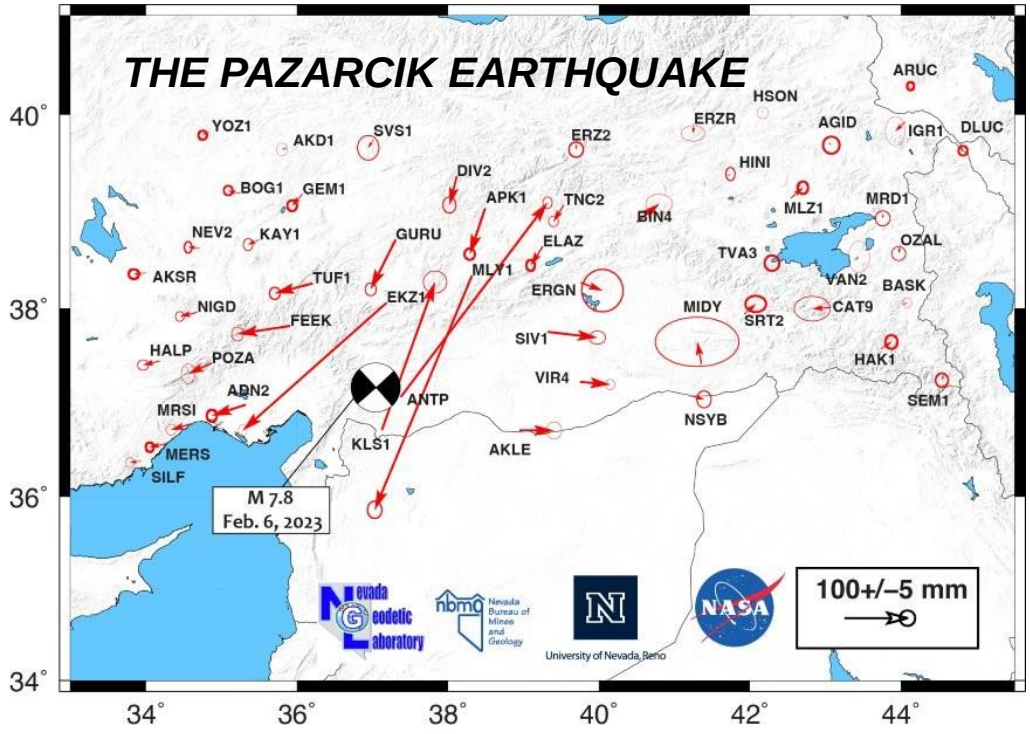
Annual pricipal stress rates of Türkiye (Aydan, 2000b) inferred from GPS measurements

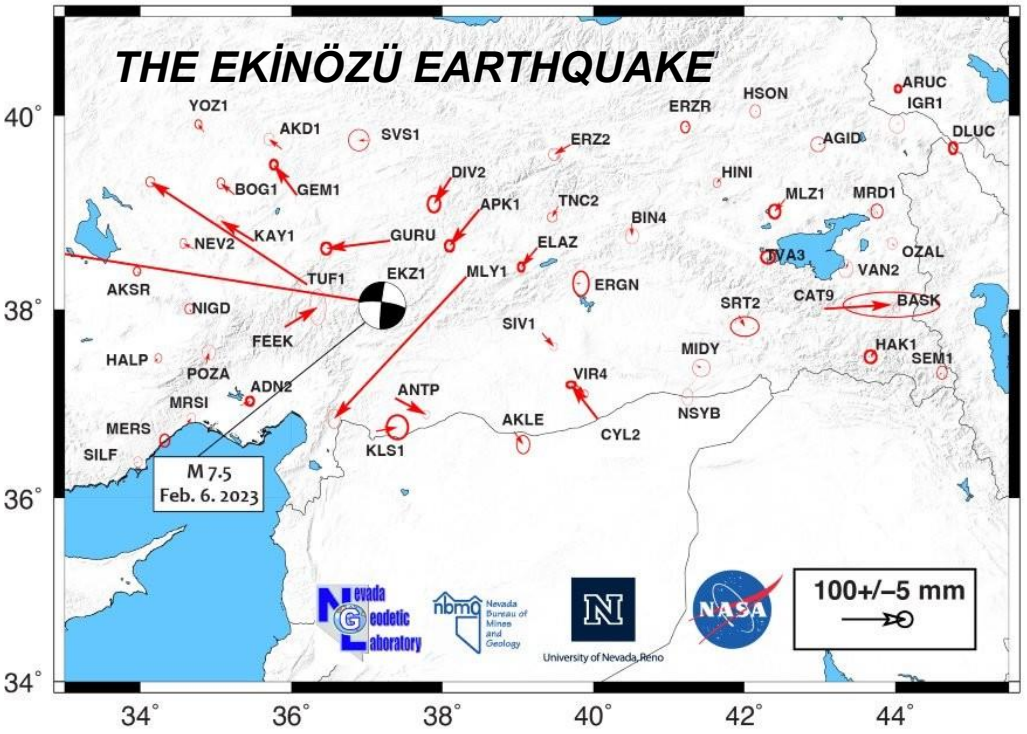


Maximum horizontal stress directions (Aydan, 2020)

SURFACE DEFORMATION FROM GPS & DINSAR

GPS

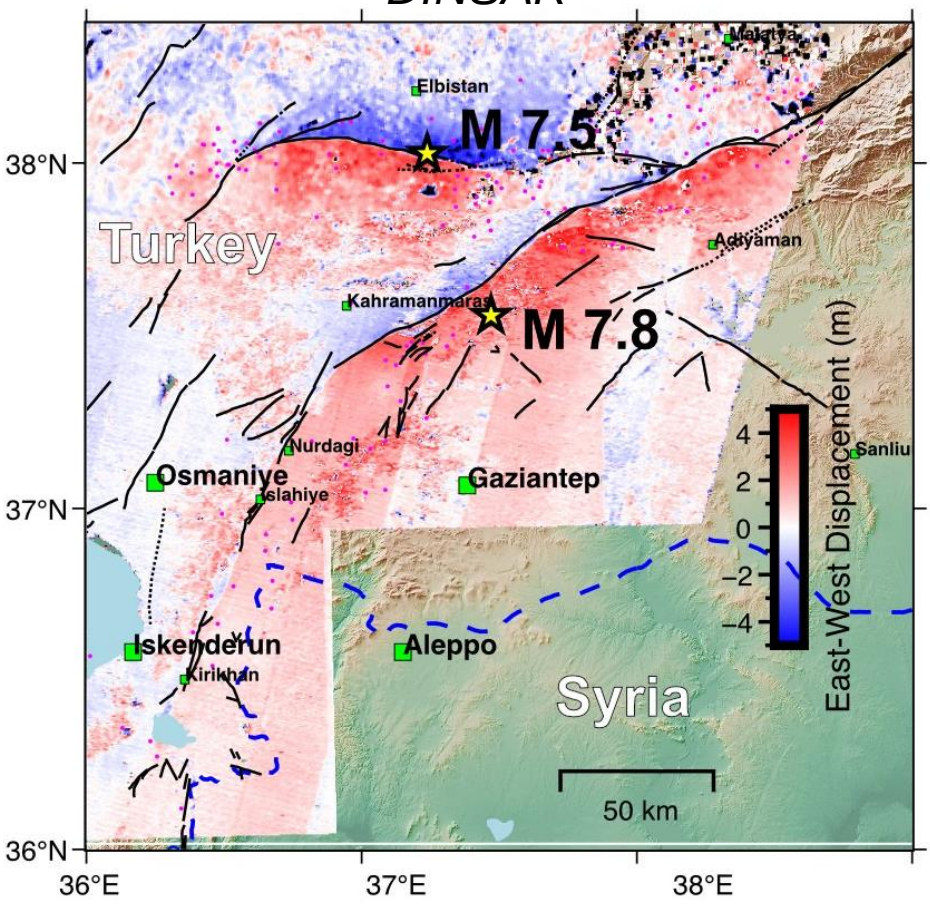


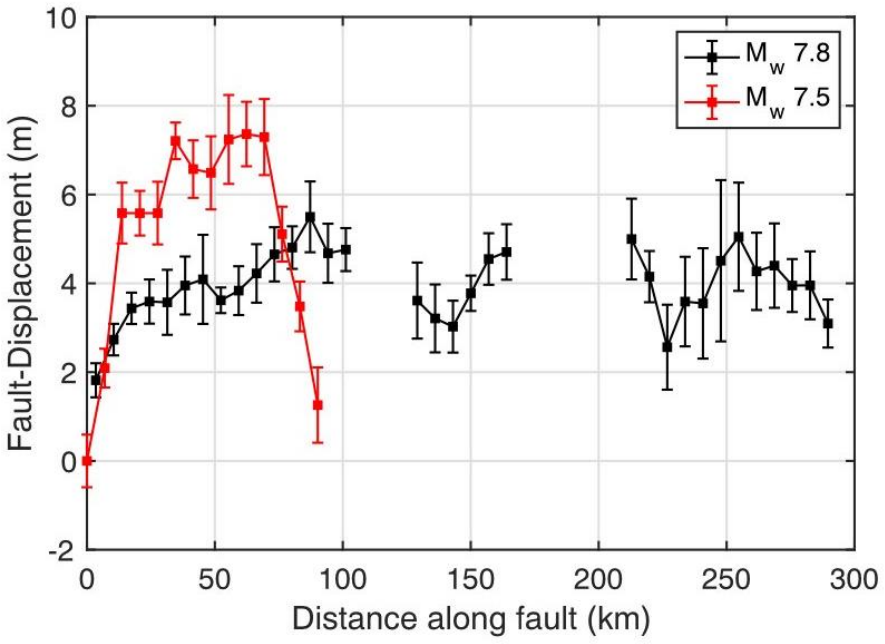


Displacement reflects the expected faulting movements

(From Nevada Geodetic Laboratory /NVGeodeticLab/status/1625241970460491777/photo/1)

DINSAR

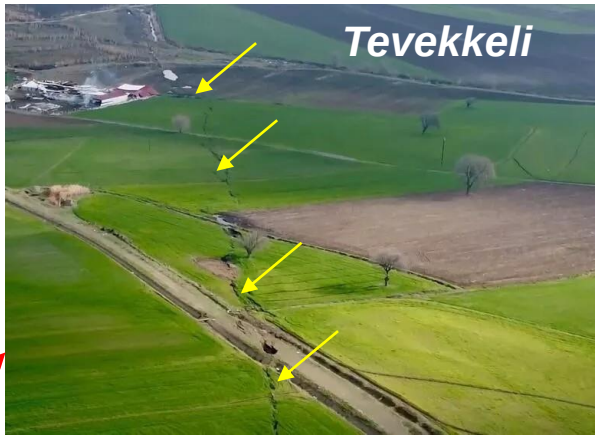




(From Dr. C. Milliner, 2023, JPL, USA)

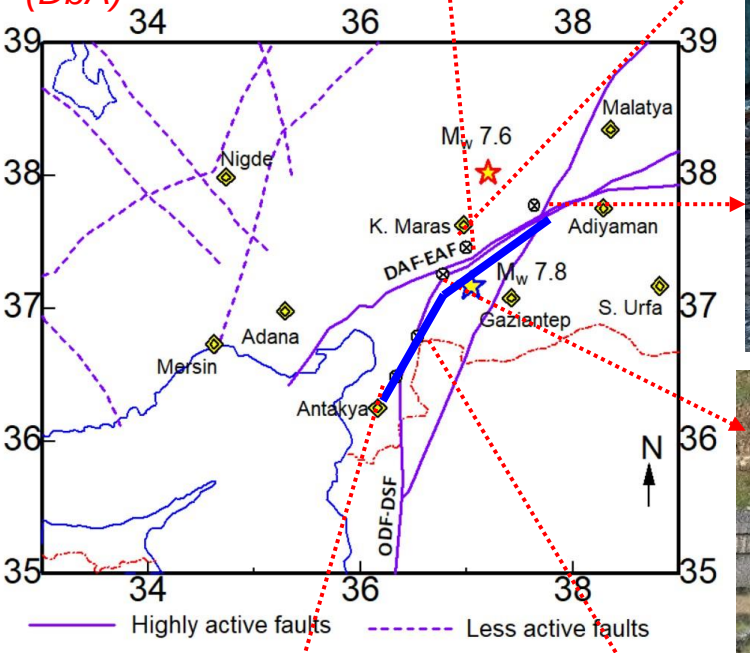
The Pazarcık earthquake caused about 5-6 m sinistral slip and the distribution has a parabolic shape. While the Ekinözü earthquake has the same sense of relative slip, the shape is triangular

Surface Ruptures

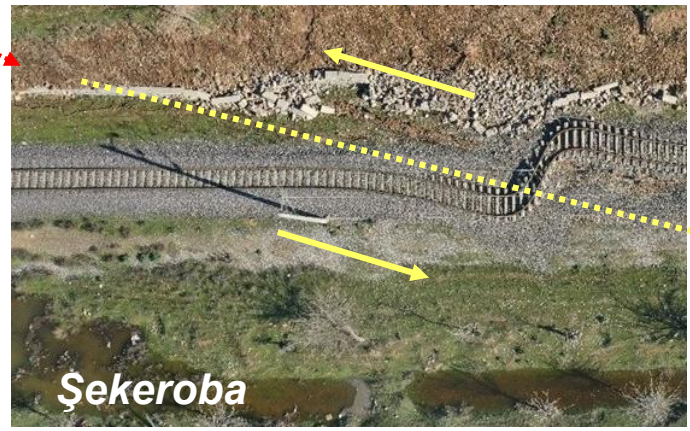


(Photos: Internet)

(DbA)

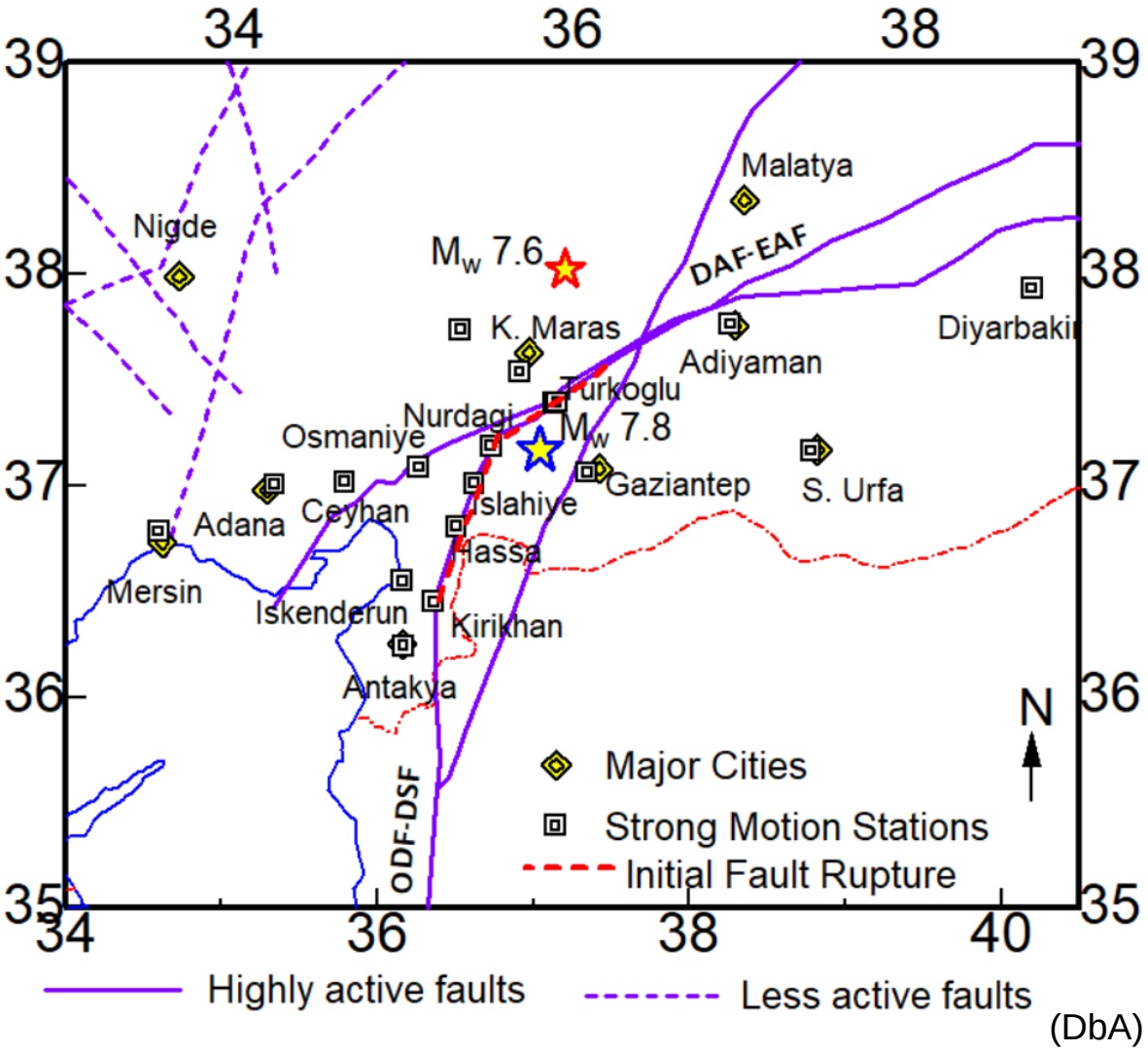


Surface rupture trace

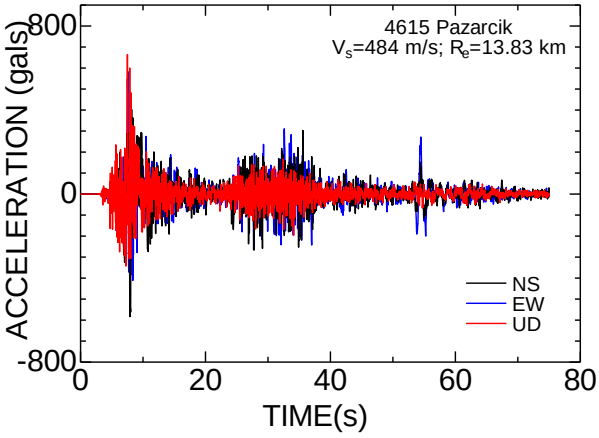


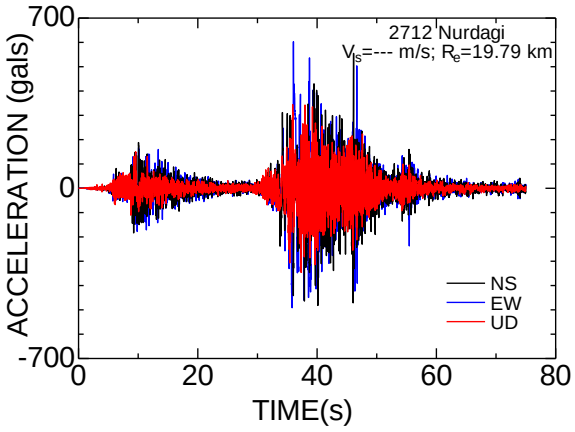
Relative slip is generally more than 300 cm in many rupture observations and the southern rupture has also normal component. This may also explain why some part of İskenderun city subsided and immersed by sea-water. Şekeroba – Kırıkhan segment is on Dead Sea fault.

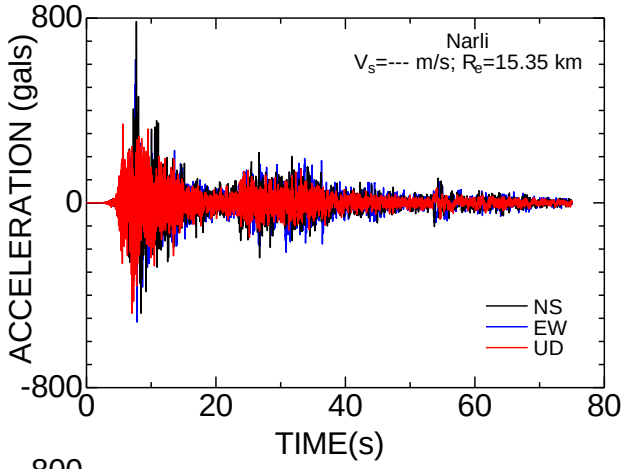
STRONG MOTION RECORDS

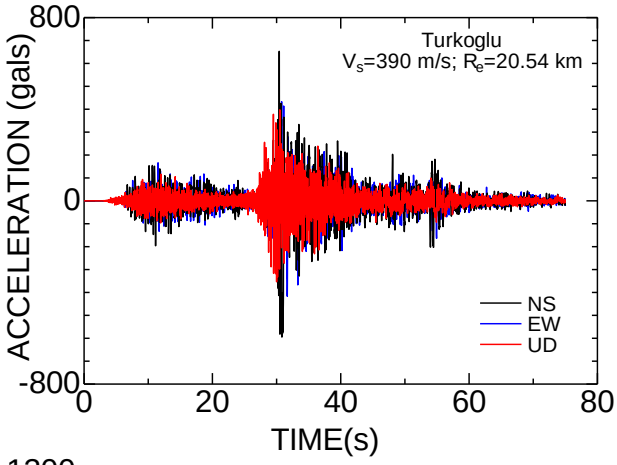


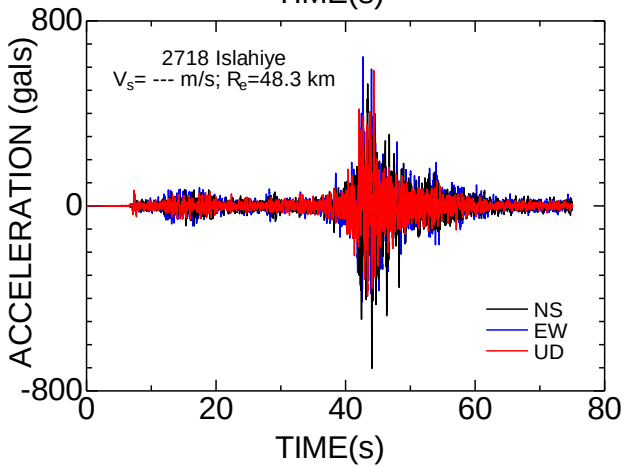
Turkish Strong Motion Network (TADAS) has recorded the motions induced by Pazarcık and Ekinözü earthquakes. In this report, the strong motion caused by the Pazarcık earthquakes are reported and discussed. The stations along the faut rupture and Arabian Plate recorded much higher ground motions and duration of shaking was more than 70 seconds and it was about more than 220 seconds at Şanlı Urfa. Next figures show strong motion records for selected 16 cities. Response spectra of 12 cities are plotted. The response spectra generally exceed the seismic design spectra of Türkiye. Furthermore, maximum ground accelerations in affected cities exceed the maximum ground acceleration assumed in the seismic code particularly at locations near earthquake rupture. This simply implies that the design code should be revised.

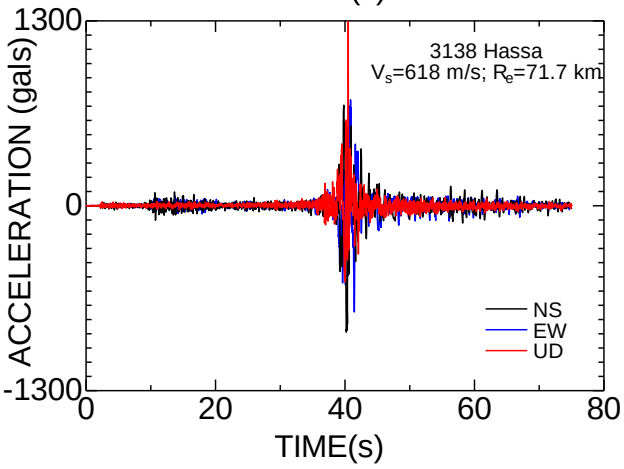

4615 Pazarcik
Vs=484 m/s; Re=13.83 km
ACCELERATION (gals)
800
0
-800
0
20
40
60
80
TIME(s)
NS
EW
UD

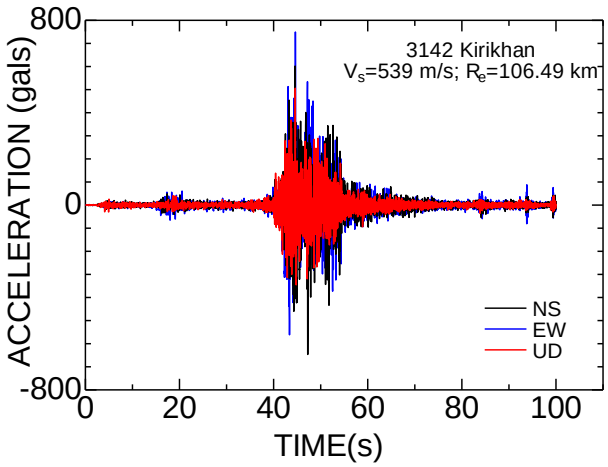

2712 Nurdagi
Vs=--- m/s; Re=19.79 km
ACCELERATION (gals)
700
0
-700
0
20
40
60
80
TIME(s)
NS
EW
UD

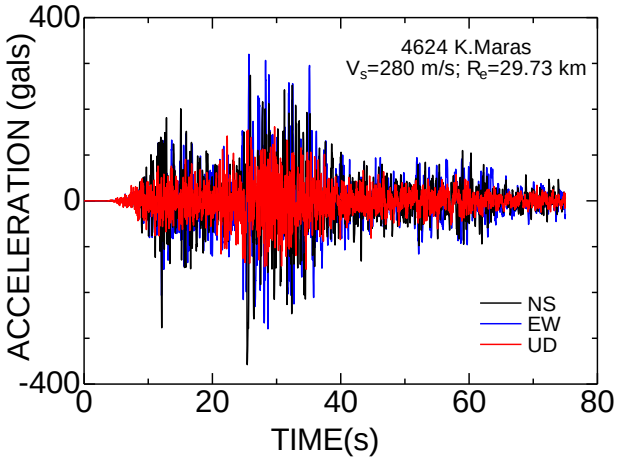

Narli
Vs=--- m/s; Re=15.35 km
ACCELERATION (gals)
800
0
-800
0
20
40
60
80
TIME(s)
NS
EW
UD

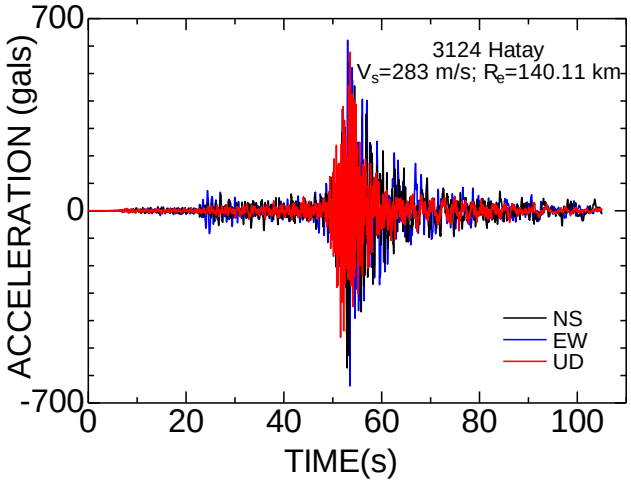

Turkoglu
Vs=390 m/s; Re=20.54 km
ACCELERATION (gals)
800
0
-800
0
20
40
60
80
TIME(s)
NS
EW
UD

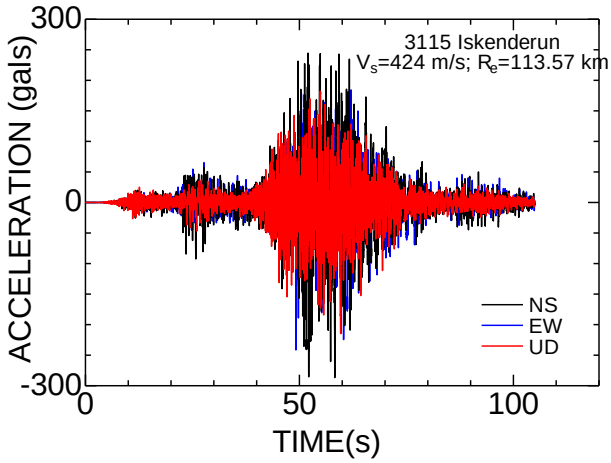

2718 Islahiye
Vs= --- m/s; Re=48.3 km
ACCELERATION (gals)
800
0
-800
0
20
40
60
80
TIME(s)
NS
EW
UD

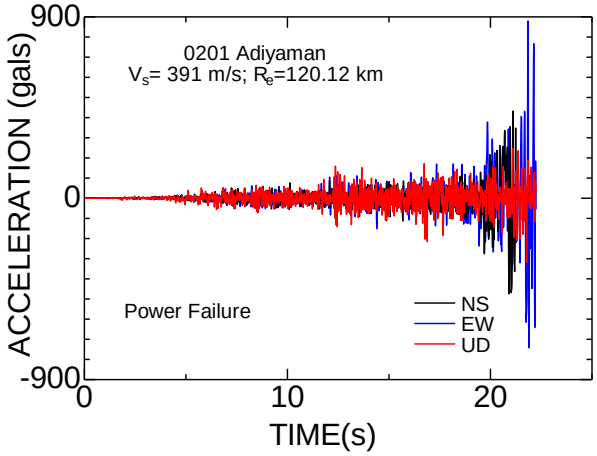

3138 Hassa
Vs=618 m/s; Re=71.7 km
ACCELERATION (gals)
1300
0
-1300
0
20
40
60
80
TIME(s)
NS
EW
UD

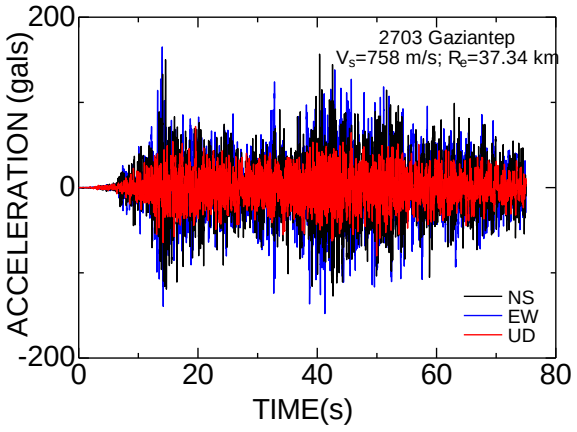

3142 Kirikhan
Vs=539 m/s; Re=106.49 km
ACCELERATION (gals)
800
0
-800
0
20
40
60
80
100
TIME(s)
NS
EW
UD

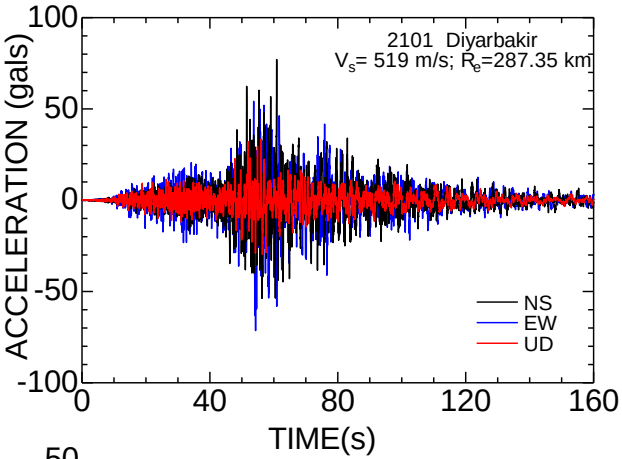

4624 K.Maras
Vs=280 m/s; Re=29.73 km
ACCELERATION (gals)
400
0
-400
0
20
40
60
80
TIME(s)
NS
EW
UD

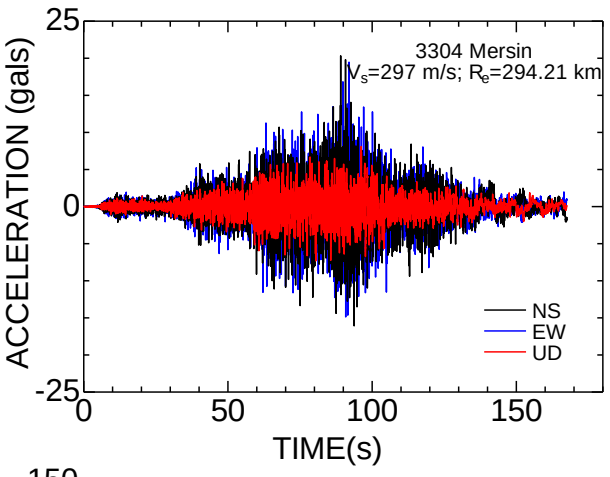

3124 Hatay
Vs=283 m/s; Re=140.11 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

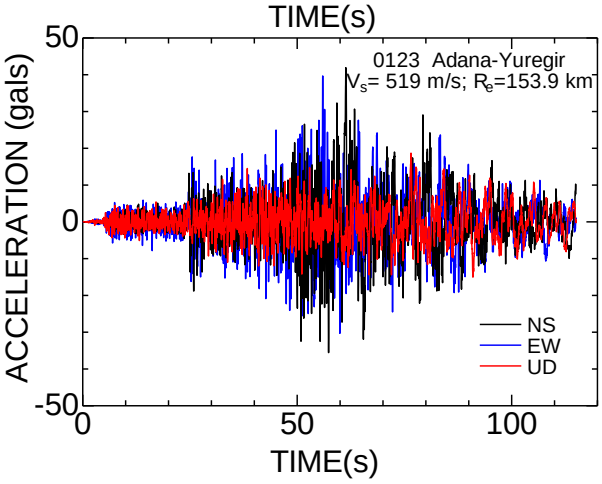

3115 Iskenderun
Vs=424 m/s; Re=113.57 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

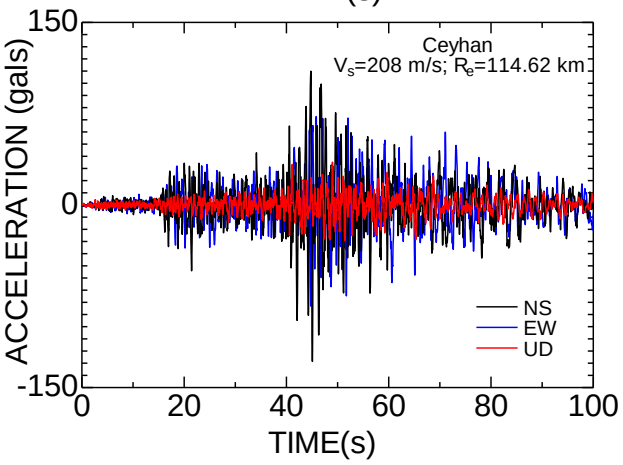

0201 Adiyaman
Vs= 391 m/s; Re=120.12 km
Power Failure
NS
EW
UD
ACCELERATION (gals)
TIME(s)


2703 Gaziantep
Vs=758 m/s; Re=37.34 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

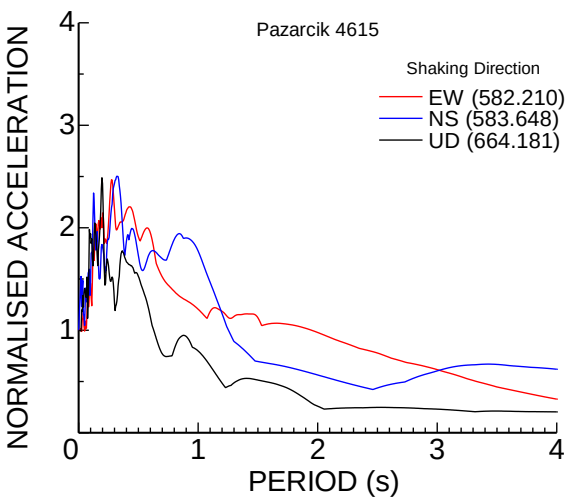

2101 Diyarbakir
Vs= 519 m/s; Re=287.35 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

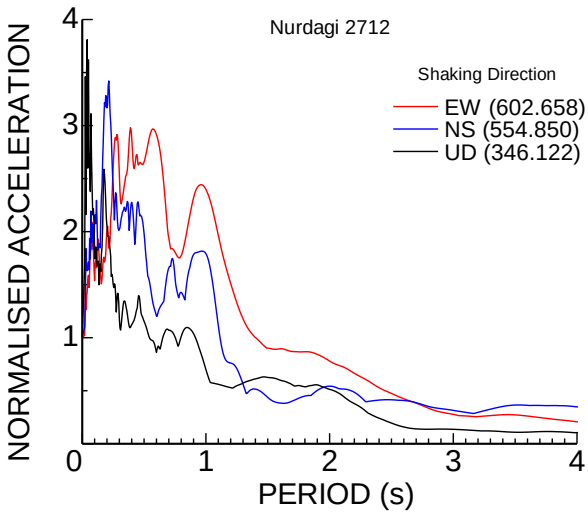

3304 Mersin
Vs=297 m/s; Re=294.21 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

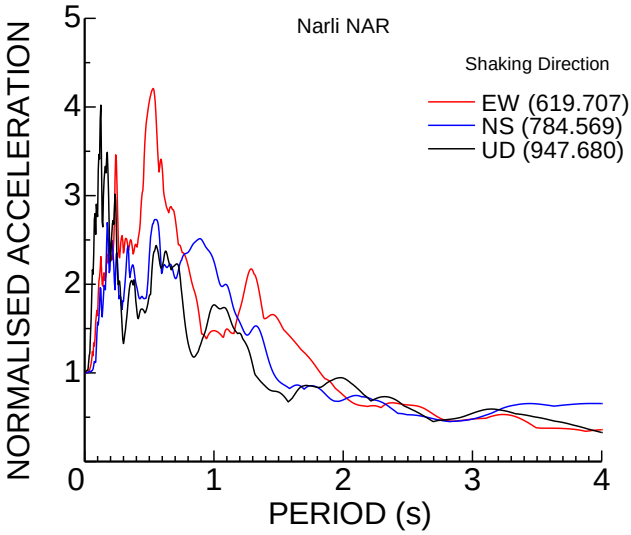

0123 Adana-Yuregir
Vs= 519 m/s; Re=153.9 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

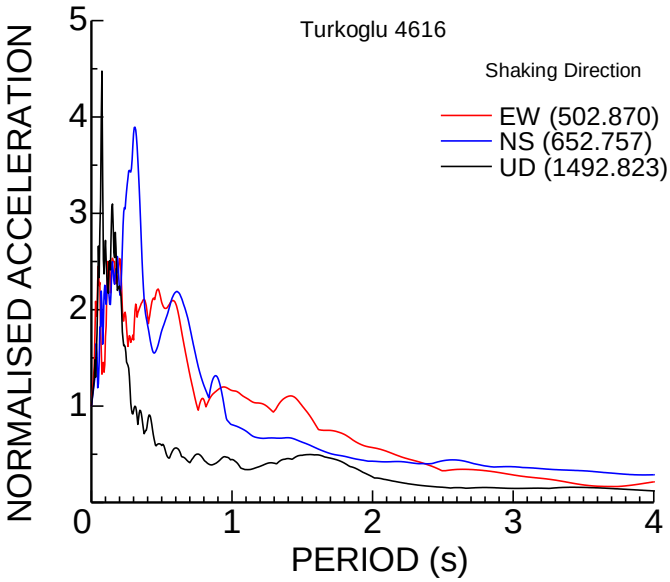

Ceyhan
Vs=208 m/s; Re=114.62 km
NS
EW
UD
ACCELERATION (gals)
TIME(s)

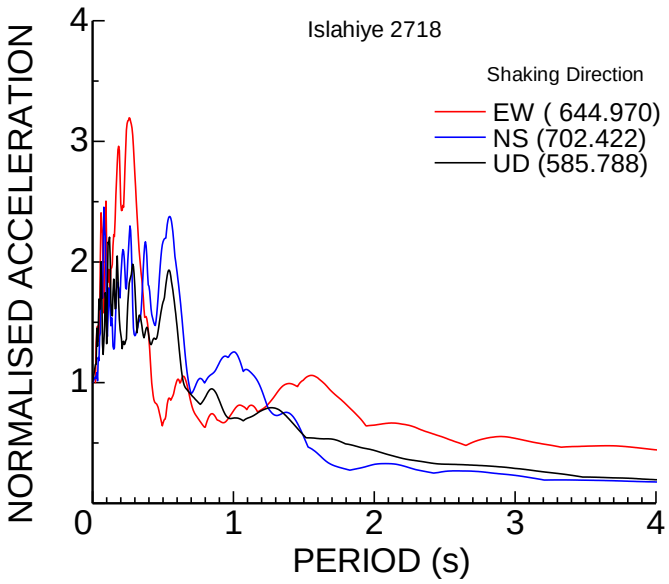
Response Spectra of the selected stations

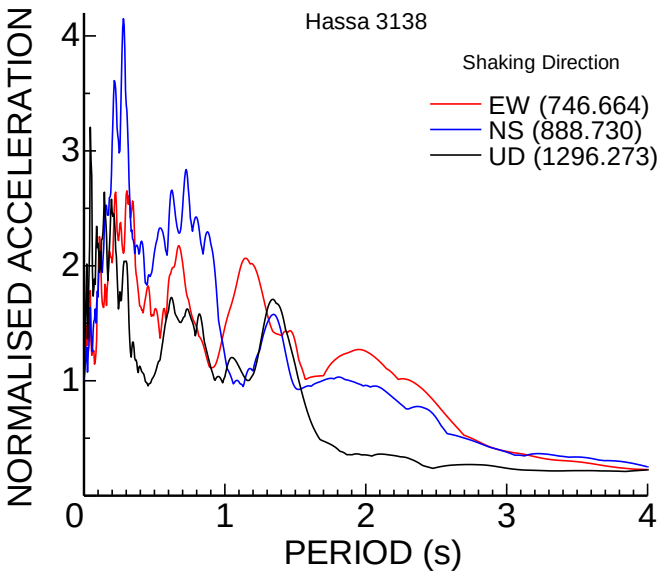


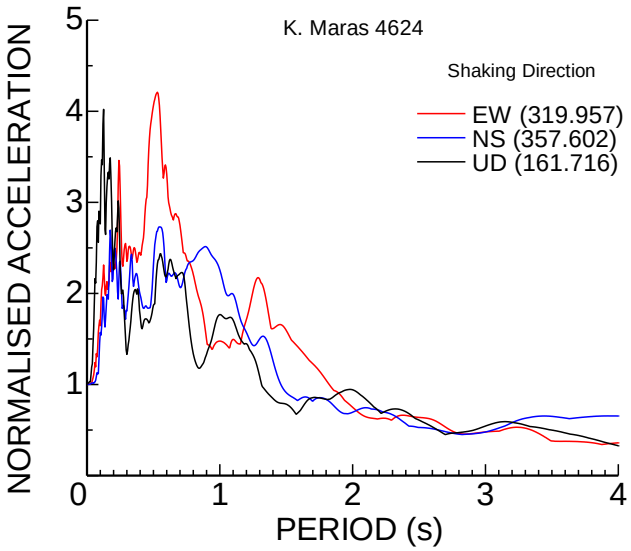


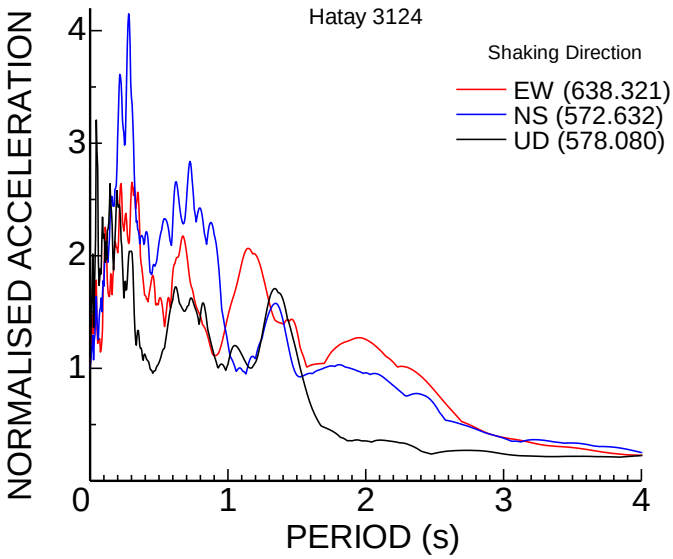


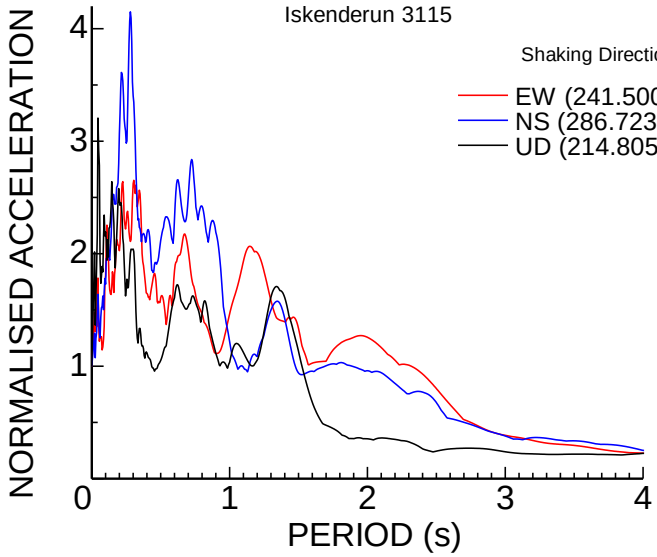


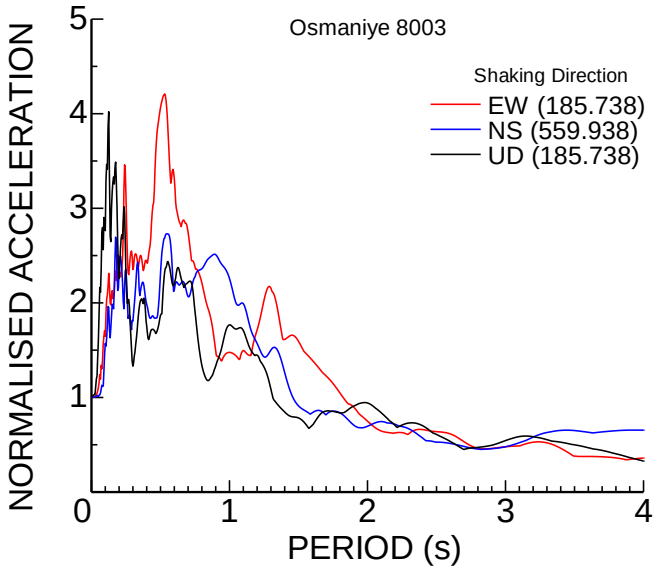


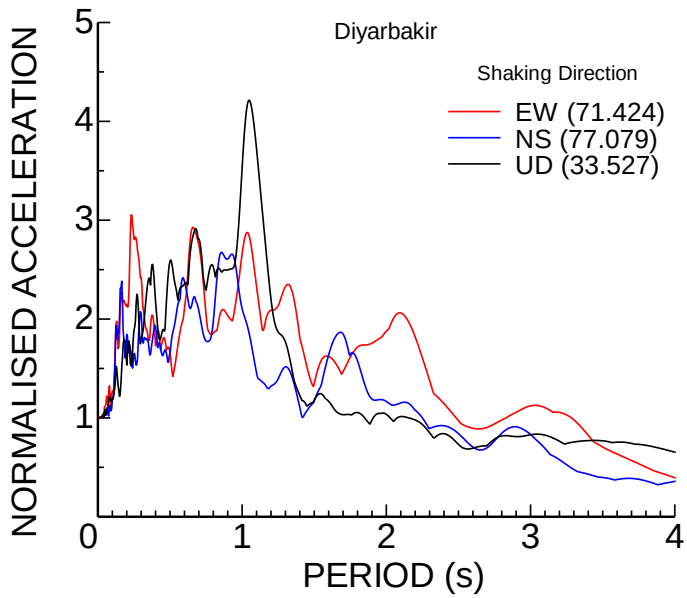


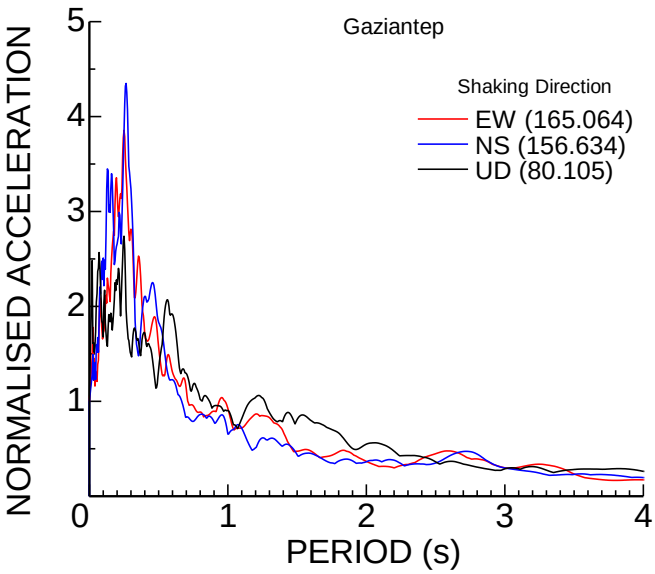

K. Maras 4624
Shaking Direction
EW (319.957)
NS (357.602)
UD (161.716)
NORMALISED ACCELERATION
PERIOD (s)


Hatay 3124
Shaking Direction
EW (638.321)
NS (572.632)
UD (578.080)
NORMALISED ACCELERATION
PERIOD (s)

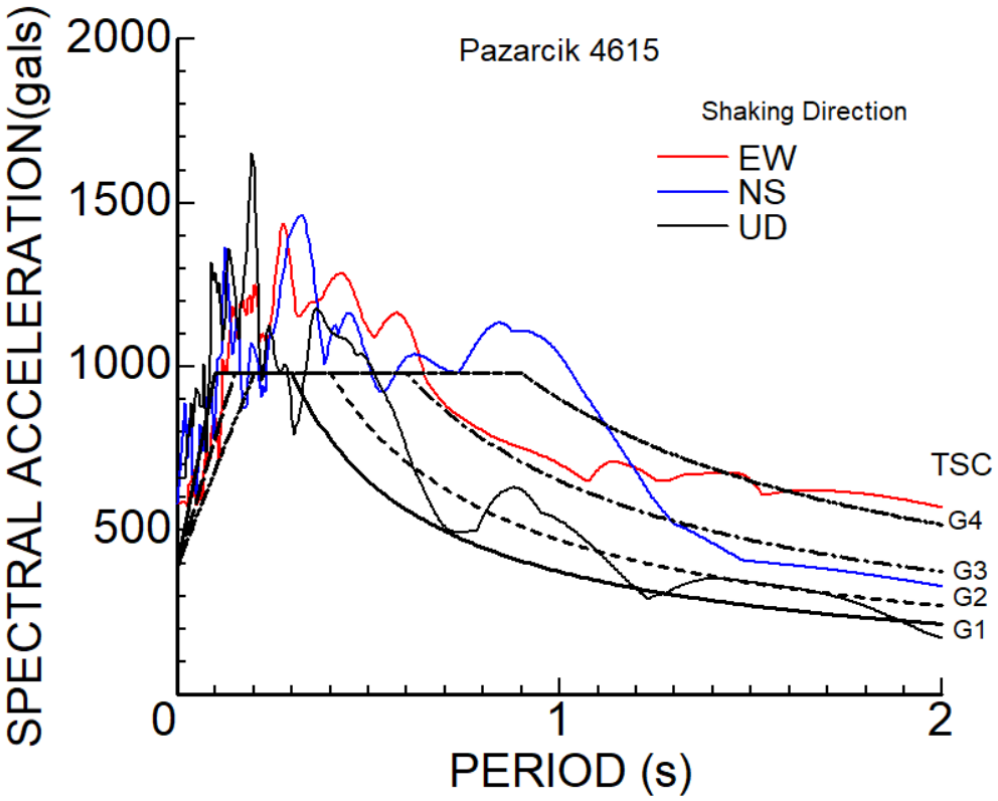

Iskenderun 3115
Shaking Direction
EW (241.500)
NS (286.723)
UD (214.805)
NORMALISED ACCELERATION
PERIOD (s)

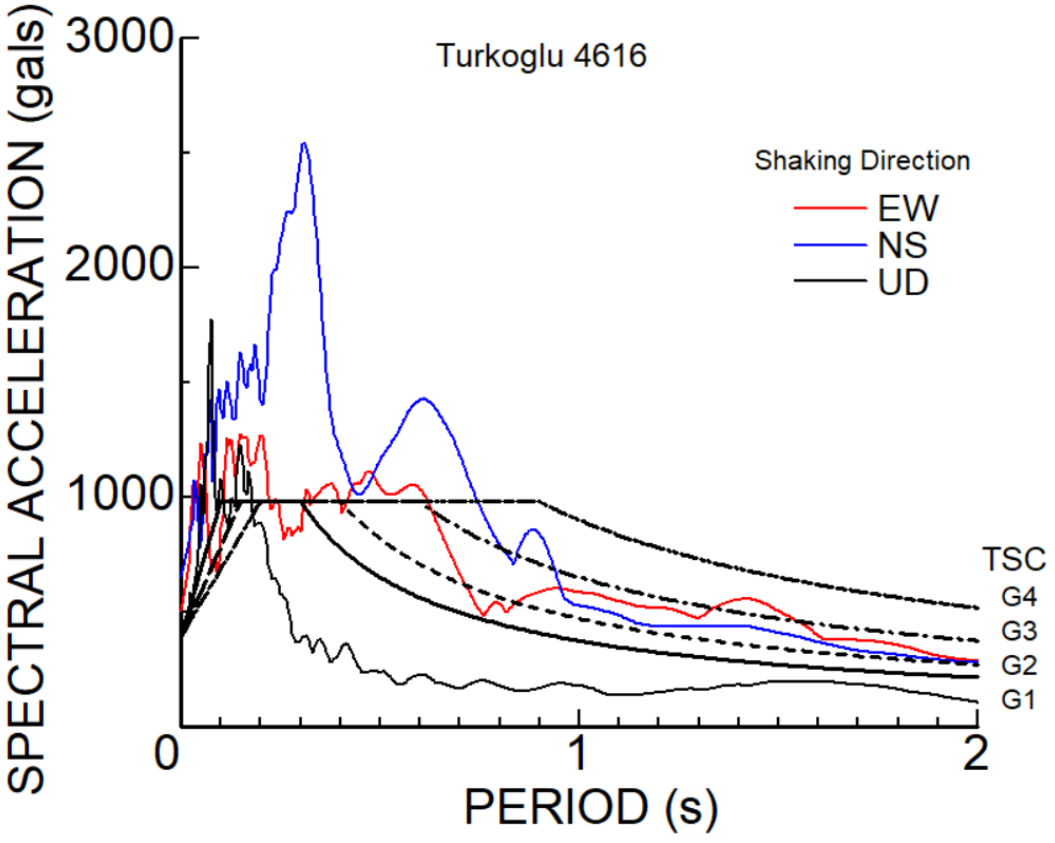

Osmaniye 8003
Shaking Direction
EW (185.738)
NS (559.938)
UD (185.738)
NORMALISED ACCELERATION
PERIOD (s)


Diyarbakir
Shaking Direction
EW (71.424)
NS (77.079)
UD (33.527)
NORMALISED ACCELERATION
PERIOD (s)


Gaziantep
Shaking Direction
EW (165.064)
NS (156.634)
UD (80.105)
NORMALISED ACCELERATION
PERIOD (s)

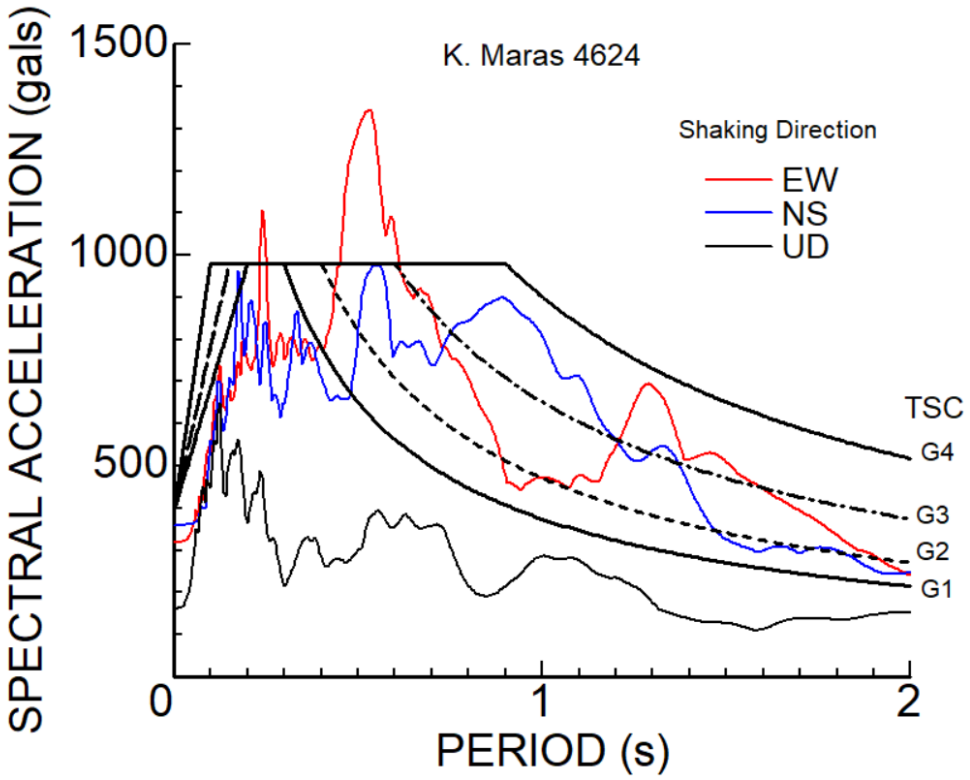
Response spectra of selected acceleration records near the fault

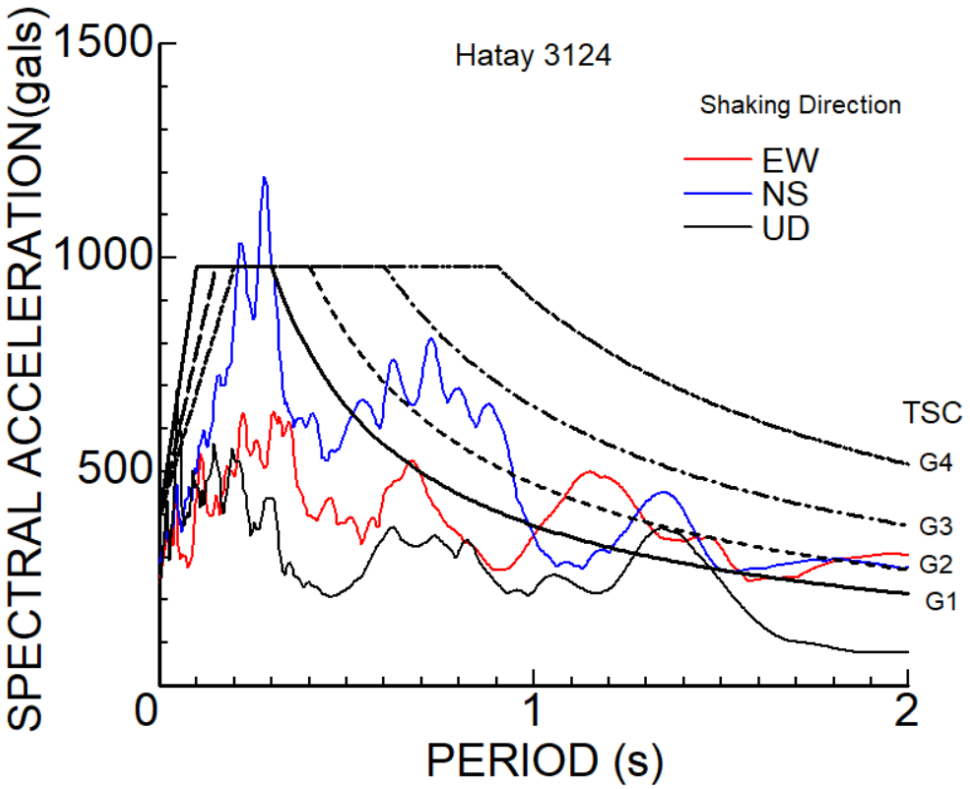




TSC: Turkish Seismic Code

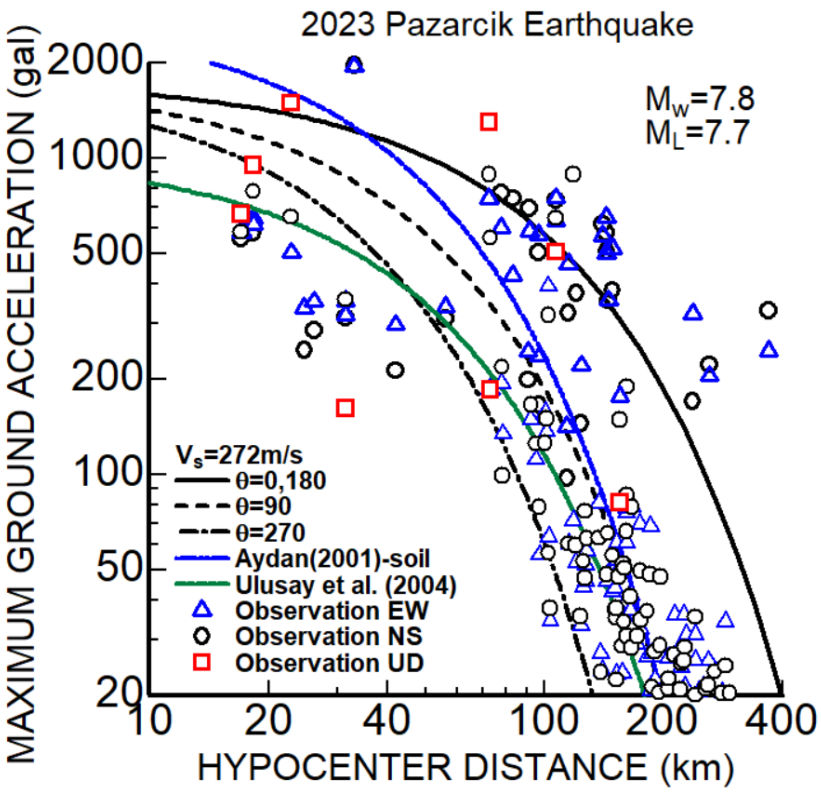
Response spectra of acceleration records at the selected heavily damaged cities



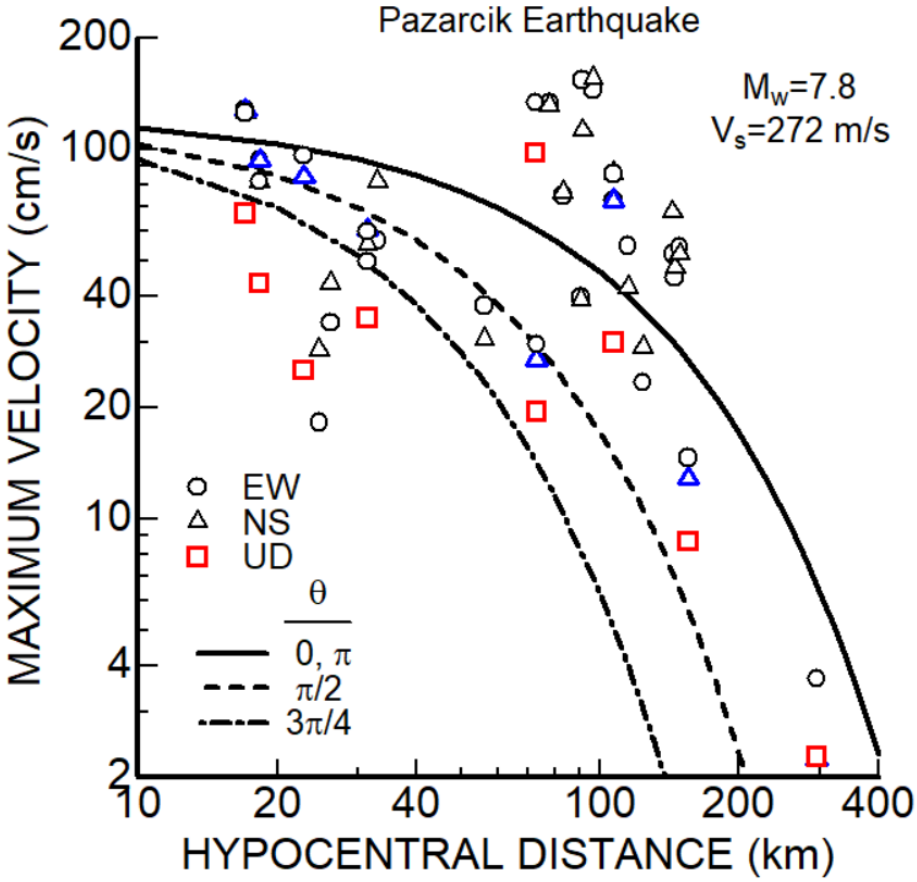


TSC: Turkish Seismic Code

Attenuation of Strong Motions with Distance

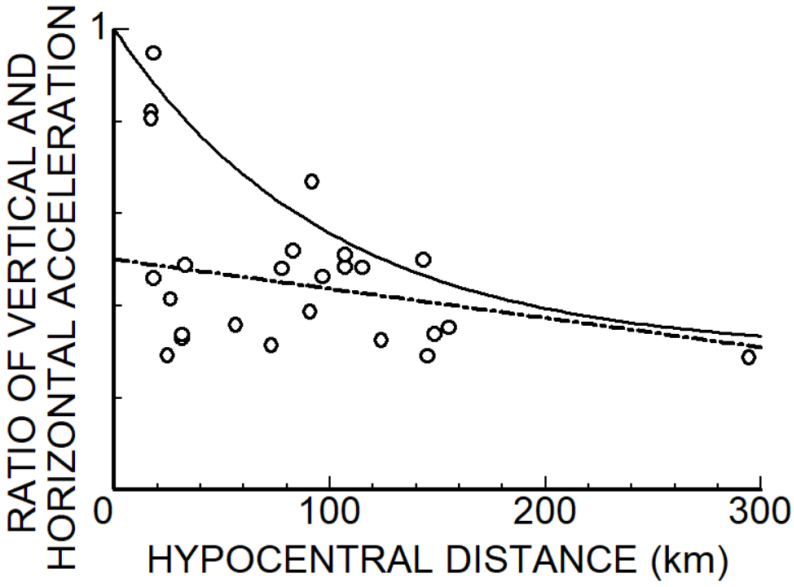


Orginal drawings from Aydan 2012, DbA)



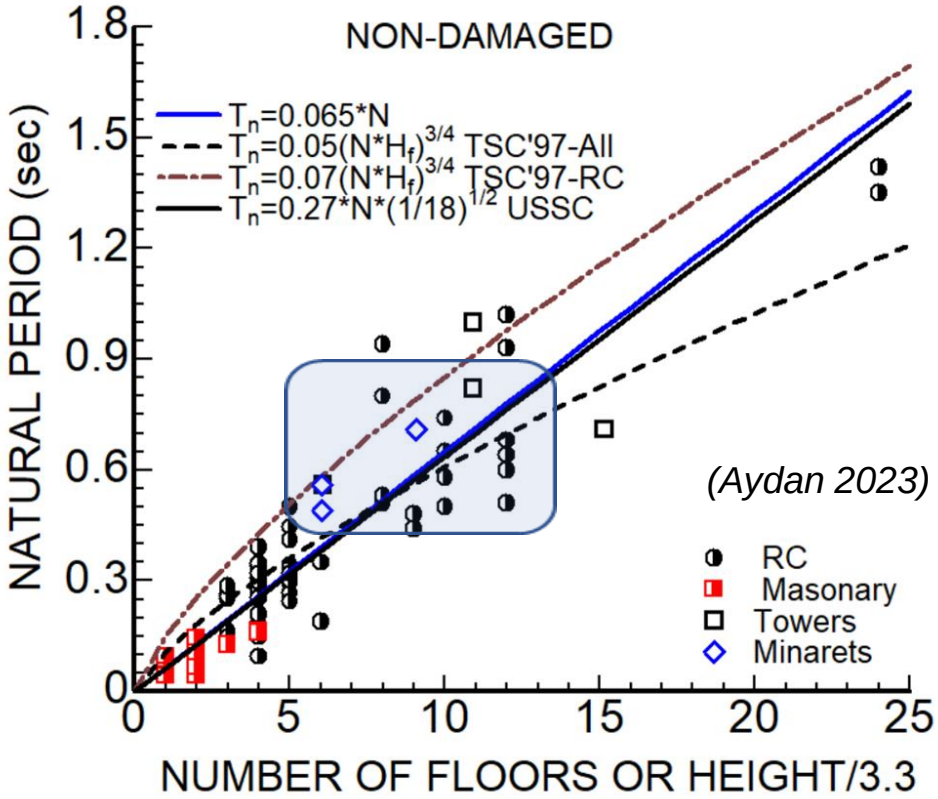
(DbA)

Orginal drawings from Aydan 2012, DbA)



(DbA)

The vertical component of strong motions near the fault rupture is quite high and it decades with distance



Most of RC buildings has 5 to 14 stories. The estimated natural frequency for the first mode ranges between 0.3 to 0.9 seconds, this might have an influence on their collapses. If the design and construction were properly done according to the Turkish Seismic Code, this scale damage would not occur

TRANSPORTATION FACILITIES

Roadways

The map of Damaged Roadways from KGM (General Directorate of Highways of Turkey) (yellow lines indicates roadways closed to traffic due to damage)

Damage occurred due to

1) Separation or collision of bridge deck with abutments
2) Faulting induced deformations
3) Retaining wall failures
4) Deformation of pavement (separation or buckling=)
5) Fall of bridge decks
6) Tunnel damage
7) Embankment failures

The above damages occurred along Tarsus-Adana-Gaziantep Highway, Malatya Adıyaman Highway, Kahramanmaraş-Malatya highways.

Separation or collision of bridge deck with abutments

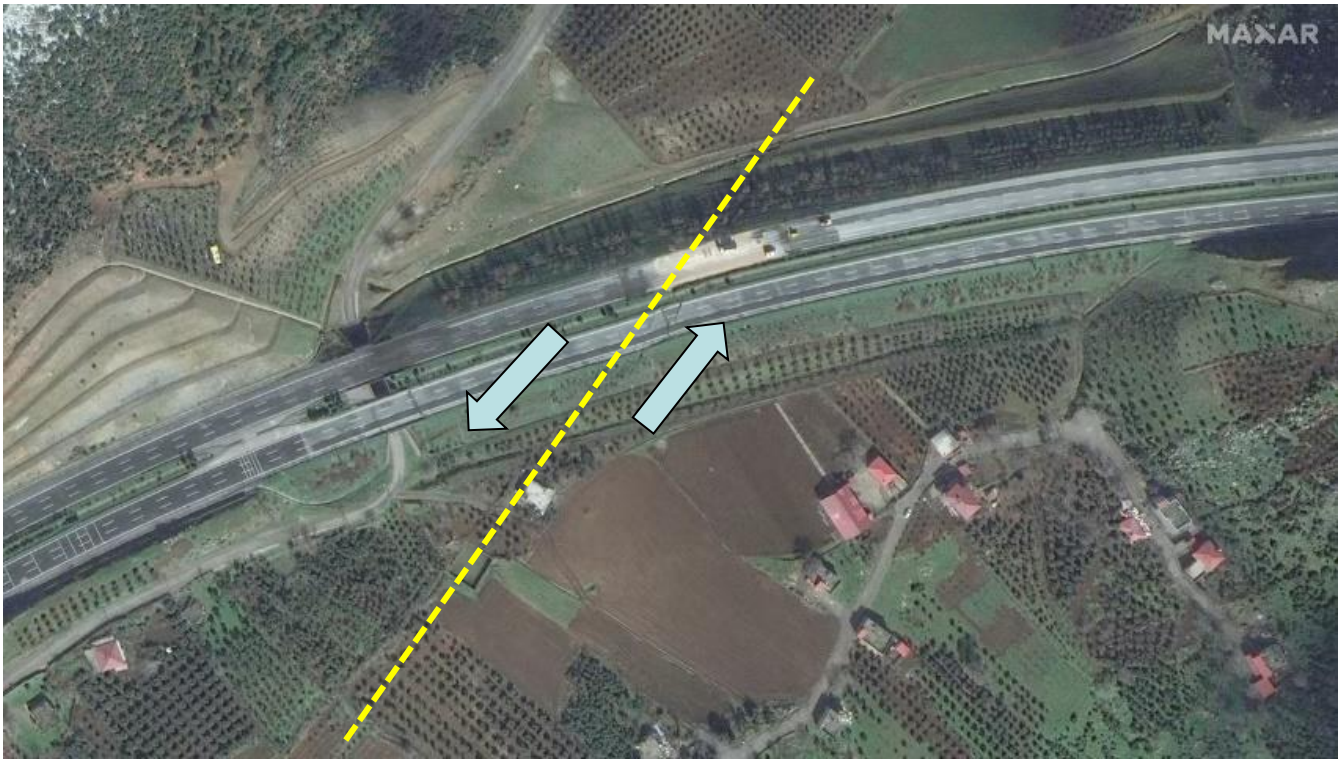
Bridge deck fall

(Photos: Internet)

Hatay Airport road

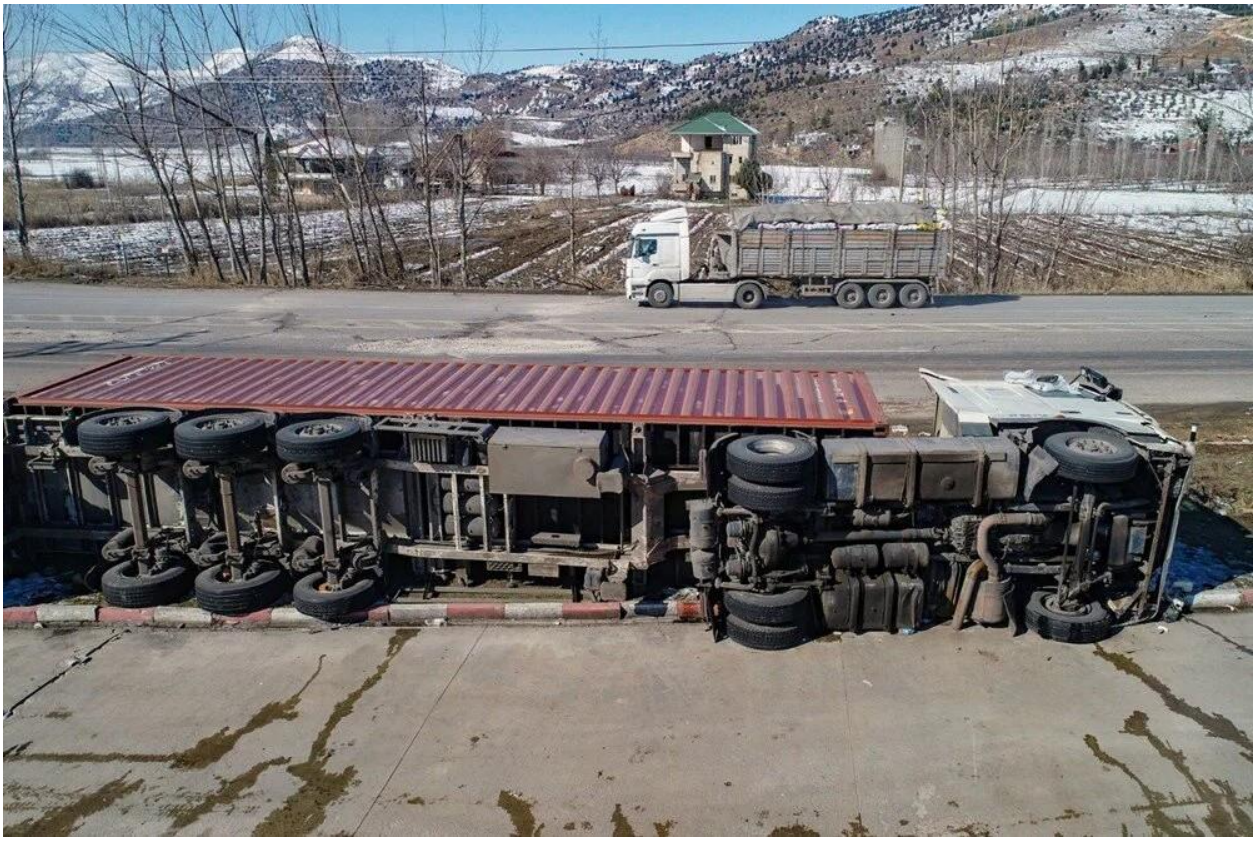
(Photos: Internet)

Damage of Tarsus Adana Gaziantep (TAG) near Islahiye by the fault rupture



(Photos: Internet)

Toppled stationary vehicles



(Photos: Internet)

Adıyaman-Malatya highway

Tunnel Damages

Rockfalls at the portal and spalling of concrete lining of the Erkenek Tunnel occurred as reported by KGM. One of Erkenek Tunel tubes is closed to traffic while the other is utilised for traffic despite some spalling location of the lining were reported at some locations. The tunnel was almost on the activated Erkenek fault.

Location of Erkenek tunnel

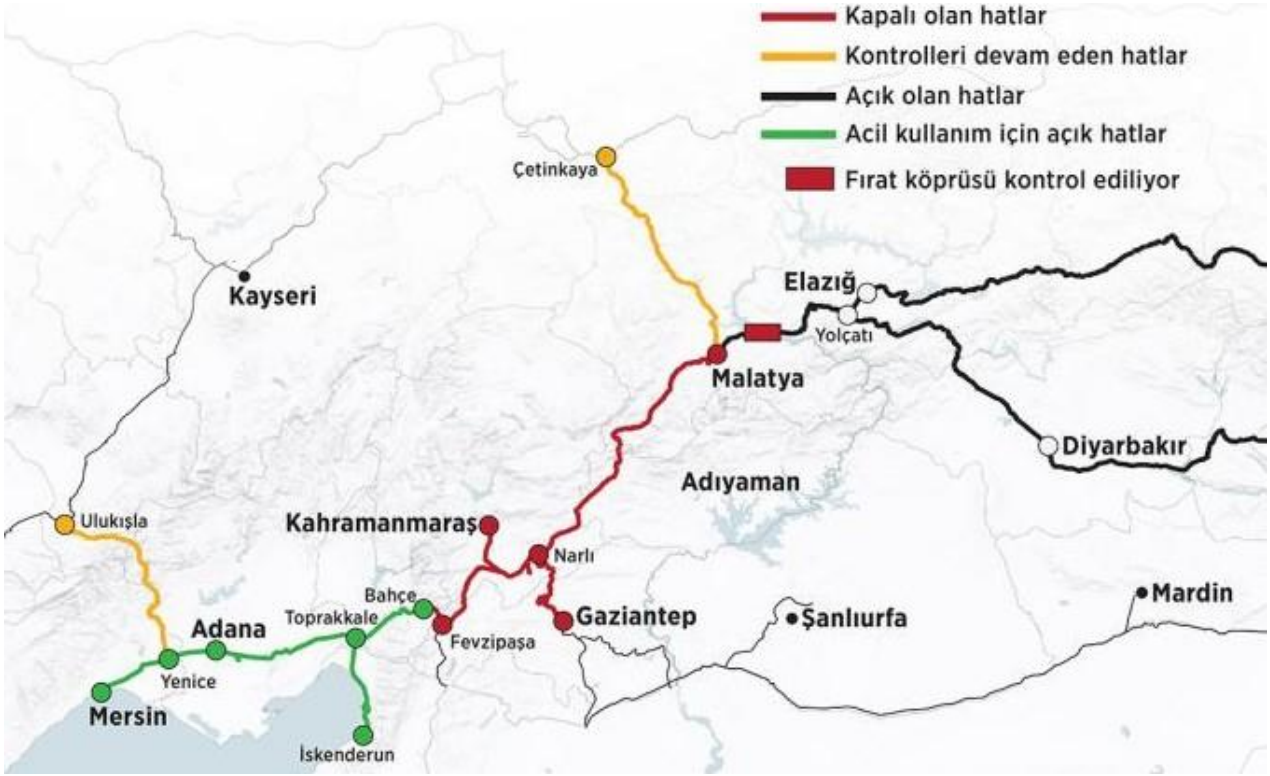
Traces and Rockfalls above the portals of Erkenek tunnel

(Photo: Internet)

Spalling of concrete linings in Erkenek Tunnel

(Photos: Internet)

Railways



Locations of the damaged railway lines (from TCDD)

Damage was mainly caused by deformation of rails whereever earthquake faults crossed. In addition, trains and wagons were derailed or toppled. Rockfalls and slope failures also caused obstructions.

(Photos: Internet)

Derailed and toppled wagons at Gölbaşı Train Station

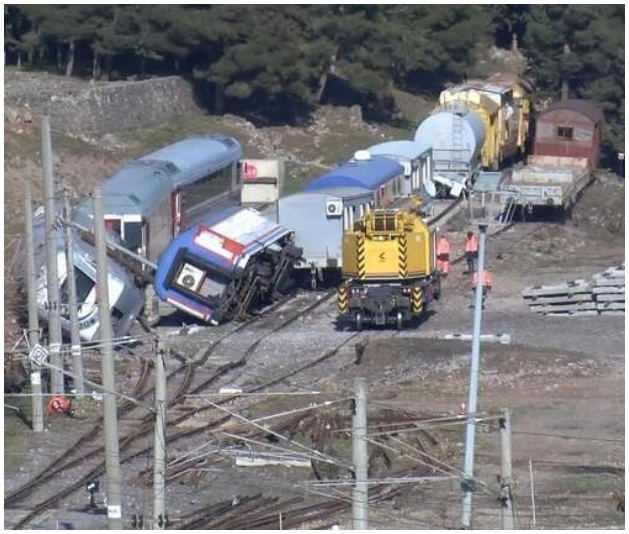
(Photos: Internet)

Deformed rails in Gölbaşı

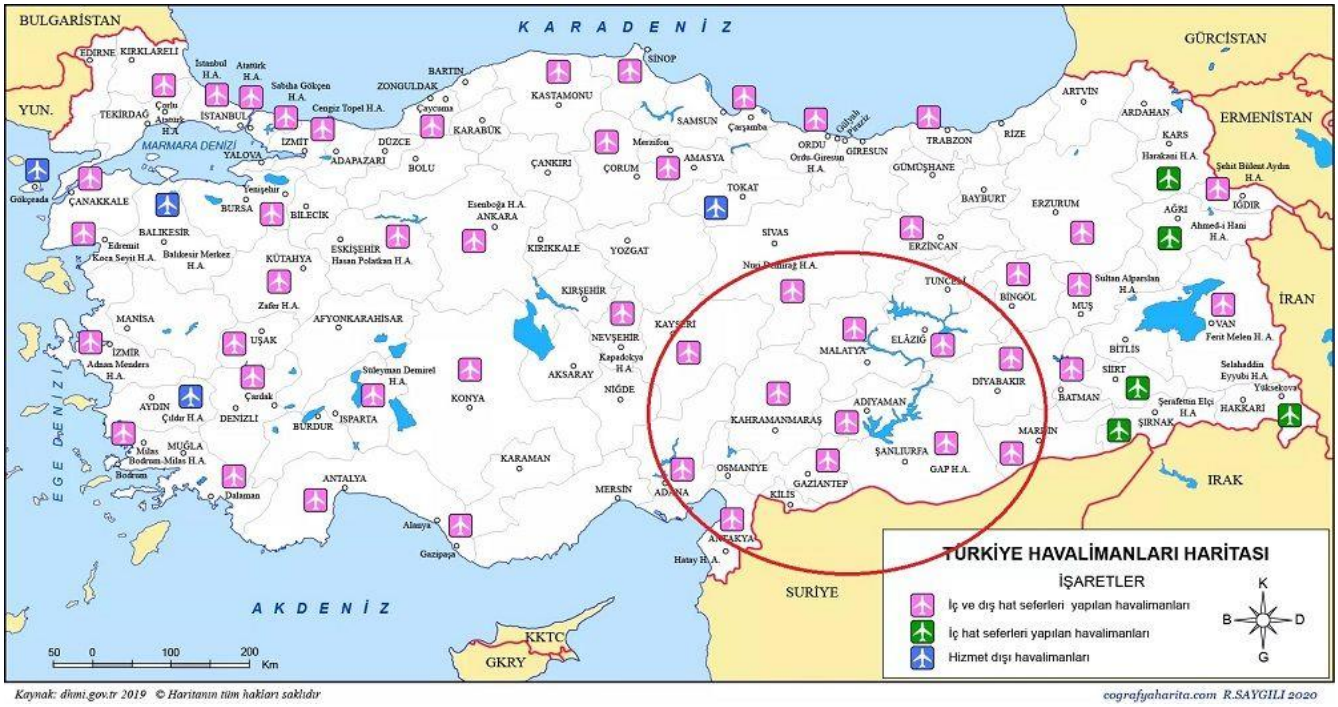
(Photos: Internet)

Islahiye-Fevzipaşa Train Station

(Photos: Internet)



Airports



Airports of Türkiye. The circle indicates the airports in the epicentral area

(Photos: Internet)

Gaziantep Airport at the time of Pazarcık earthquake occurred. Note the small pieces of debris falling from the suspended ceilings. Similar situation occurred at Malatya Airport.

Hatay Airport

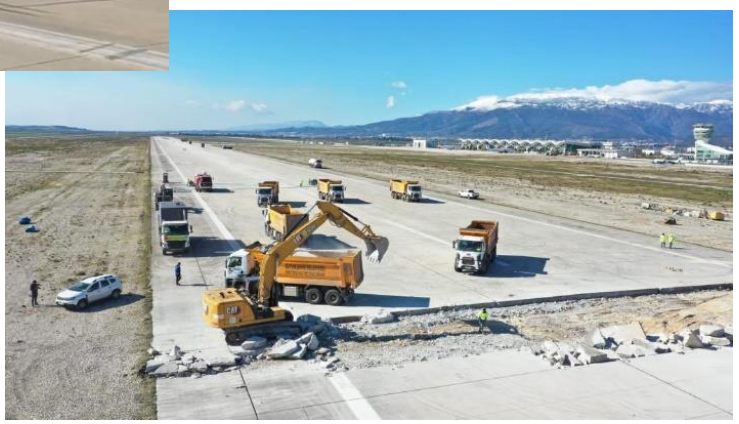
(Photos: Internet)

Ground settled around the terminal building at Hatay Airport

Runway buckled at Hatay Airport

Under reparation

Runway was repaired on February 11, 2023

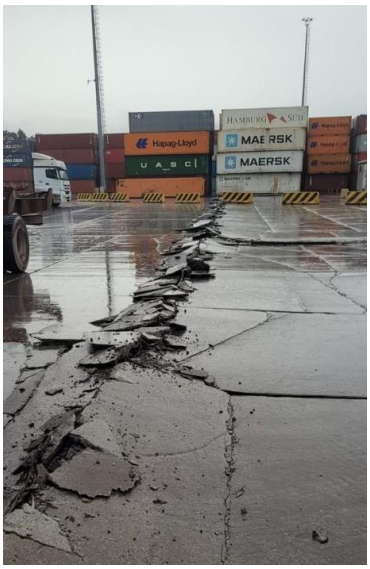


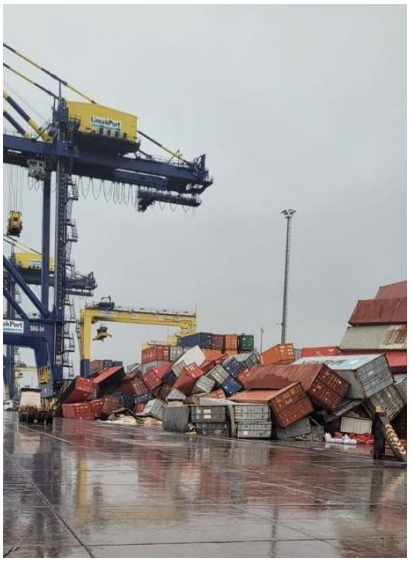
First flight was done on February 12, 2023

Ports

Iskenderun Port

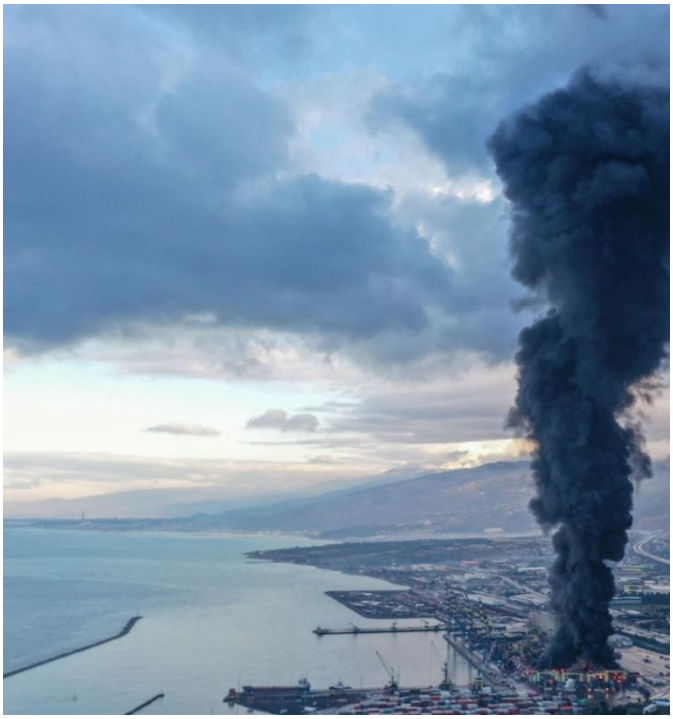
(Photos: Internet)

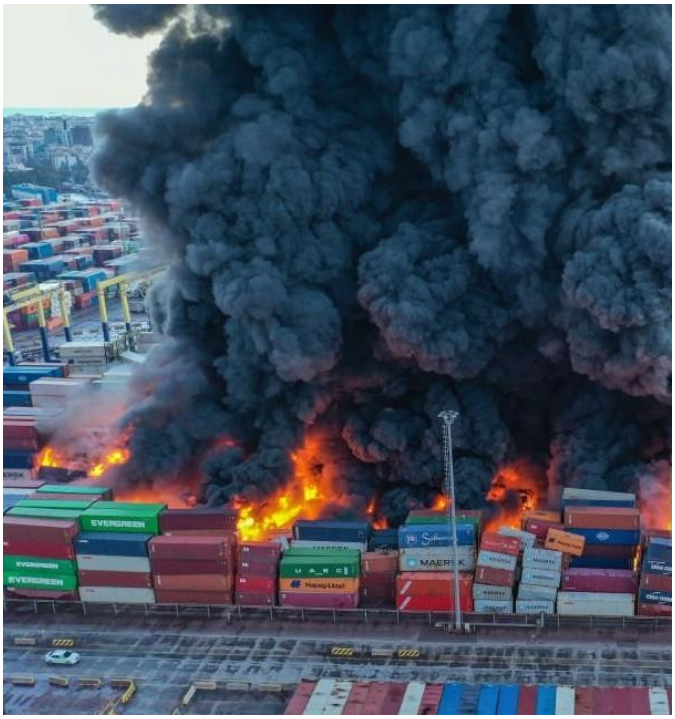




Fire at Iskenderun Port

(Photos: Internet)



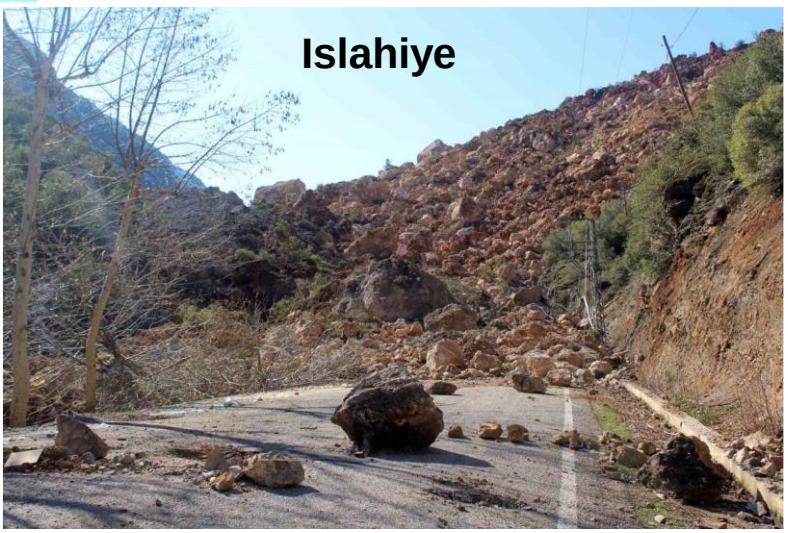


GEOTECHNICAL DAMAGES

Rockfalls

(Photos: Internet)

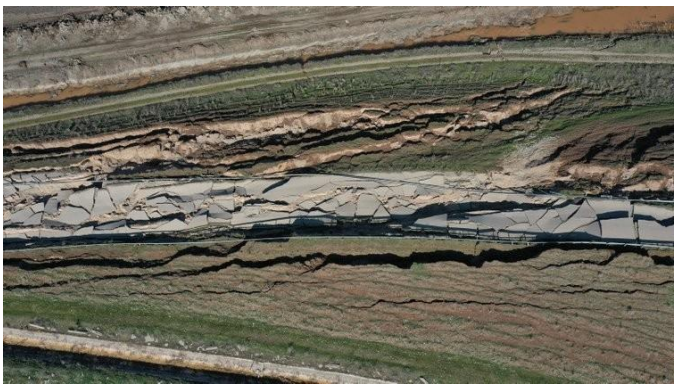
Slope Failures (Landslides)



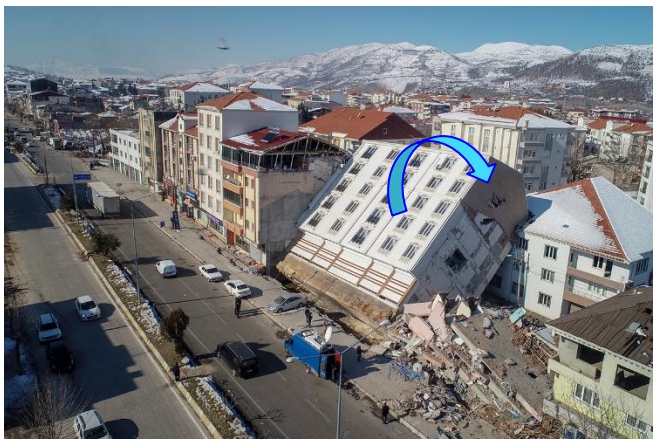
(Photos: Internet)

Liquefaction and Lateral Spreading

Antakya-Reyhanlı Highway



Near Çöçelli village



Gölbaşı

(Photos: Internet)

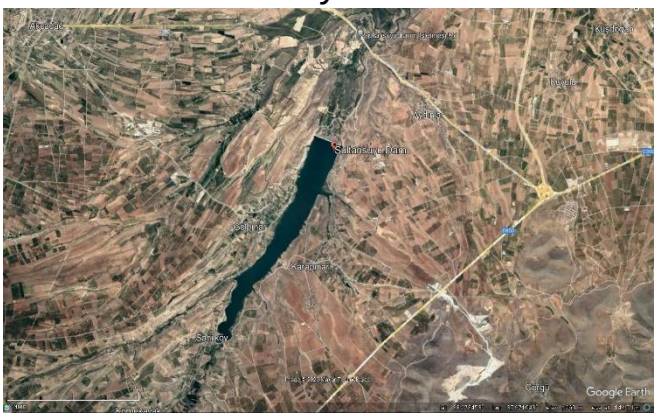
Sinkholes

Gaziantep Yavuzlar District

(Photos: Internet)

DAMS

Kartalkaya Dam



Sultansuyu Dam

(Photos: Internet)

Atatürk Dam

The third largest rockfill dam in the world. 169 m high and epicentral distance is about 90 km. No damage was reported.

Areal view after the earthquakes

Aerial inspection by the minister

(Photos: Internet)

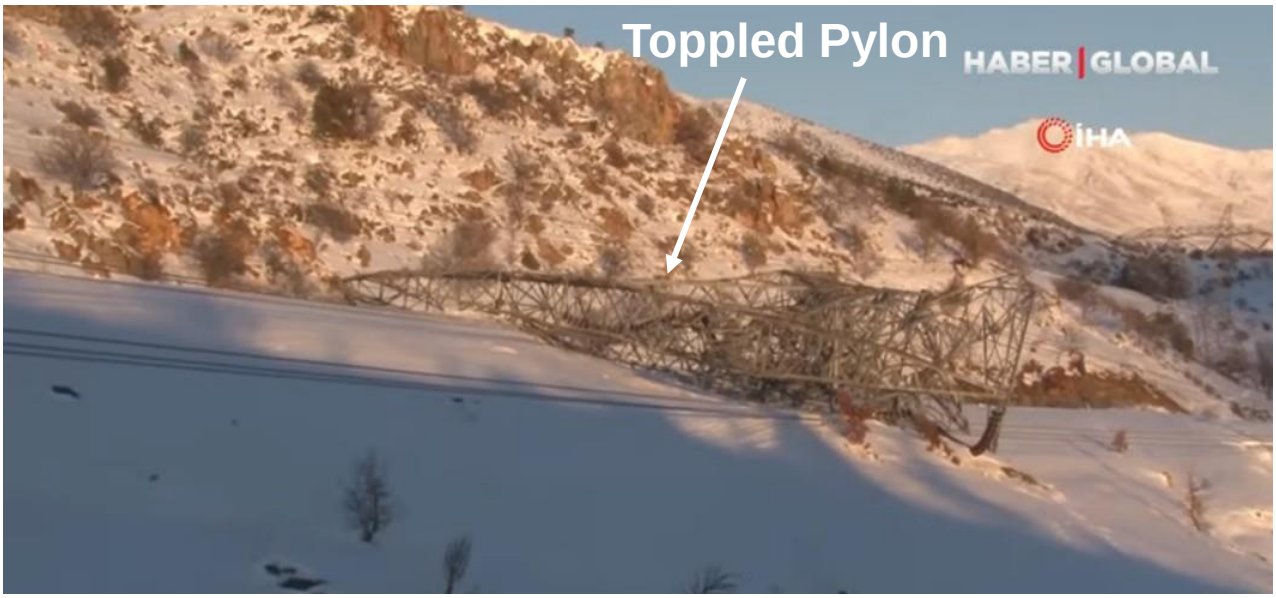
Landslide Dams

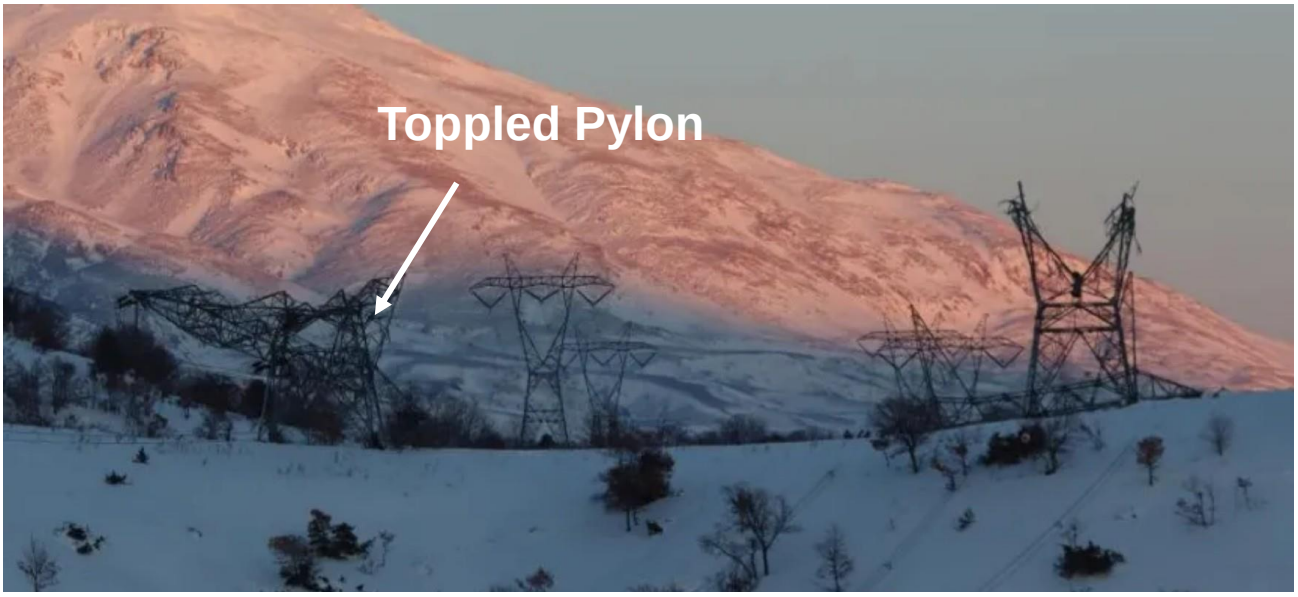
Islahiye

Tepehan

(Photos: Internet)

LIFELINES





(Photos: Internet)

DAMAGED AND COLLAPSED STRUCTURES

Reinforced Concrete (RC) Building Damages

The totally collapsed or heavily damaged school, residential and office buildings had mainly 3-14 stories. These structures are designed as moment-resistant frame structures with in-fill walls made of hollow bricks. The failure of RC structures was due to soft-story (weak-floor) situation as it is a common problem resulting in high casualties in earthquakes since 1960. The ground floors of collapsed buildings were mostly used as either shops, depots or garages. As a result, this type of usage constitutes a weak(soft)-floor situation. Furthermore, many buildings had heavy balconies of cantilever type.

The causes of the damage were almost the same as those seen in the previous earthquakes of Turkey. The causes listed below are taken from the reports by the first author on March 13, 1992 Erzincan Earthquake with few amendments and additions from the reports of the Turkish earthquakes occurred after 1992 (Aydan et al., 1998: Aydan et al., 2000a, b; Ulusay et al., 2002; Aydan et al., 2003; Aydan et al., 2012):

Poor workmanship: There are two kinds of poor workmanship. One of them is that the connections of columns and beams were very weak since the connections of steel bars were not properly done. The second one is that the granulometry of the sand and gravel of concrete was very poor and the range was wide. In addition, big chunks of gravel blocked the concrete during casting at locations where steel connections were dense and this resulted in very porous and weak connections. During shaking, it seems that concrete at the connections first failed and this subsequently caused the buckling of steel bars at such locations and rupturing in-fill hollow brick walls in a brittle sense. As a result, the collapse of buildings ended up in a pancake mode.

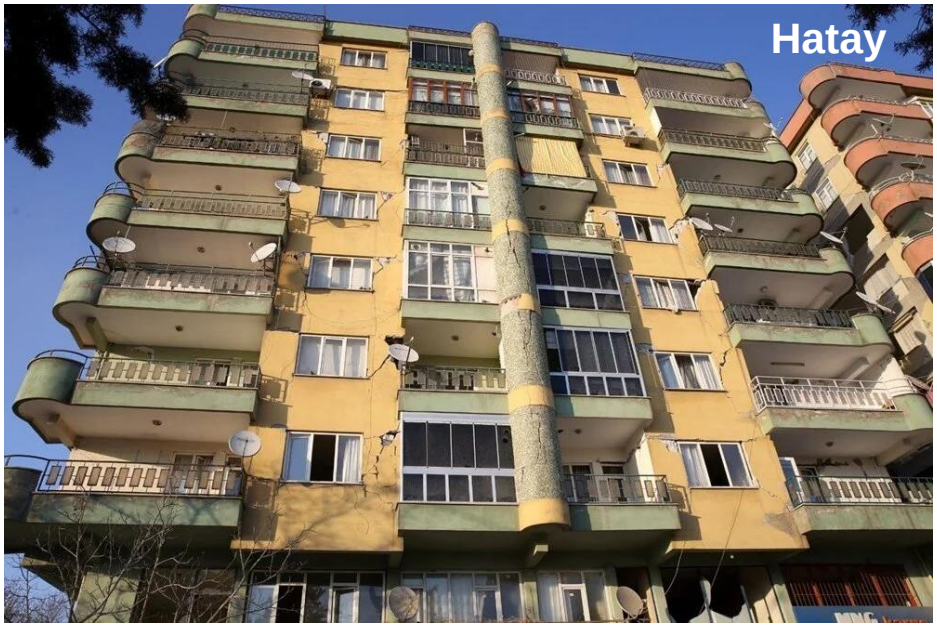
Construction negligence and lack of moral: One of the most striking construction negligence was the confinement of concrete at the beam-column connections in-spite of the Turkish design code for seismic regions. As stir-ups were very few at such locations, the failure of concrete was very brittle and it could not absorb the work done by the earthquake forces.

Resonance: Natural periods of collapsed buildings mostly coincided with those of the input waves and this resulted in the resonance-like shaking of structures and their subsequent collapses.

Soft Story: Many buildings had shops at their ground floor. As there are generally no shear-walls to take up the load during earthquakes, the total load is transferred onto the columns. The super structure acts as a top-heavy structure on the columns and in-fill walls, which are in poor contact with columns and beams, has no effect against the earthquake loading and they fail subsequently.

Pounding of adjacent structures: Buildings at the corners of streets were mostly collapsed as a result of pounding with the adjacent building.

Adıyaman

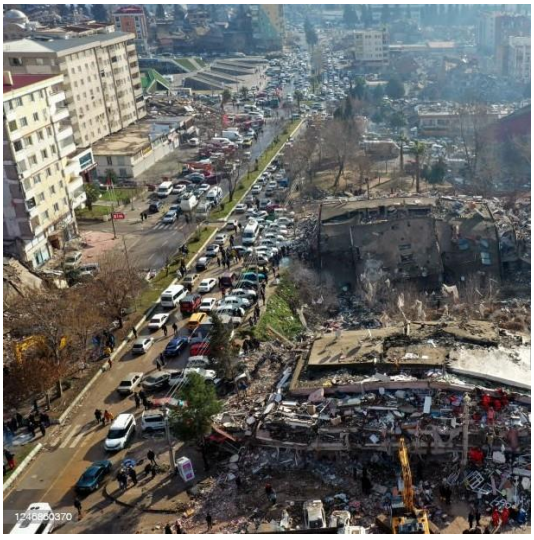


Buildings with problematic issues mentioned above

(Photos: Internet)

Views of Building Damages

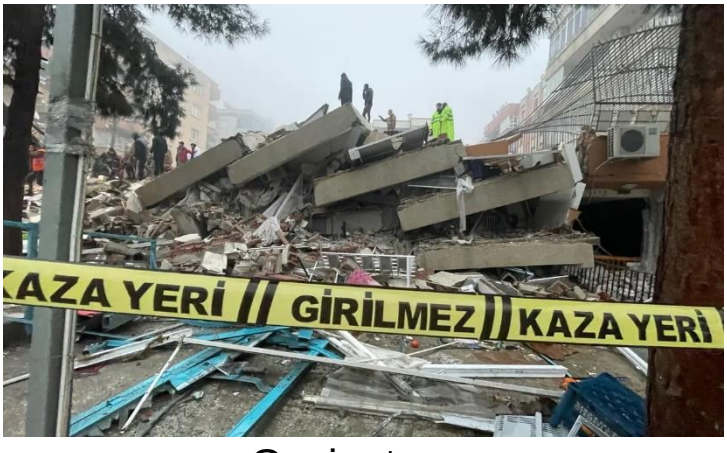
(Photos: Internet)



Kahramanmaraş

Antakya (Hatay)

Diyarbakır



Gaziantep

Gaziantep

(Photos: Internet)

Kahramanmaraş

Diyarbakır

Antakya

Adıyaman

(Photos: Internet)

Malatya

Adıyaman

Antakya

Antakya

Antakya

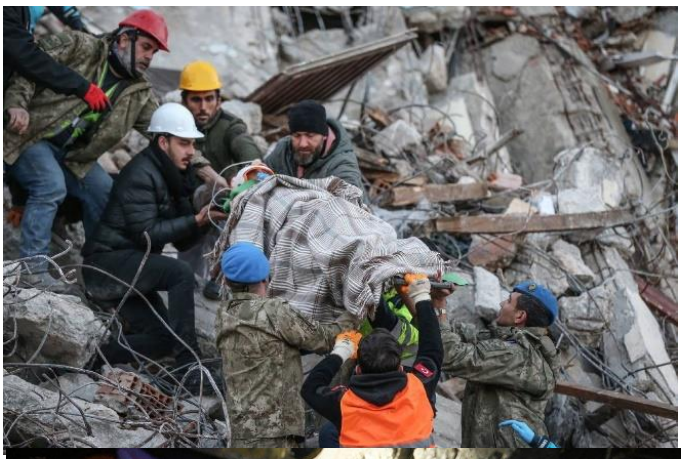
SEARCH AND RESCUE

(Photos: Internet)

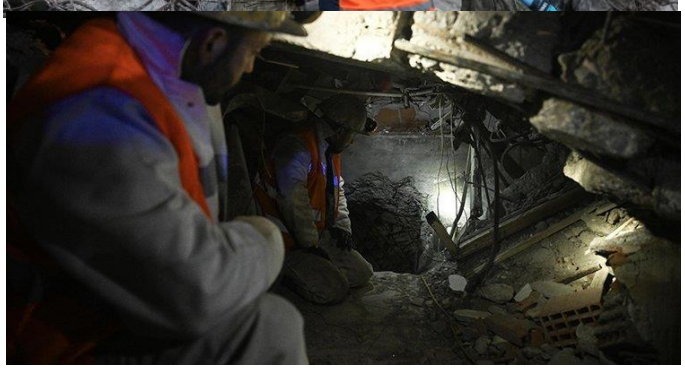
(Photos: Internet)

Turkish Ambassador thanking to Japanese Rescue Team

Korean Rescue Team

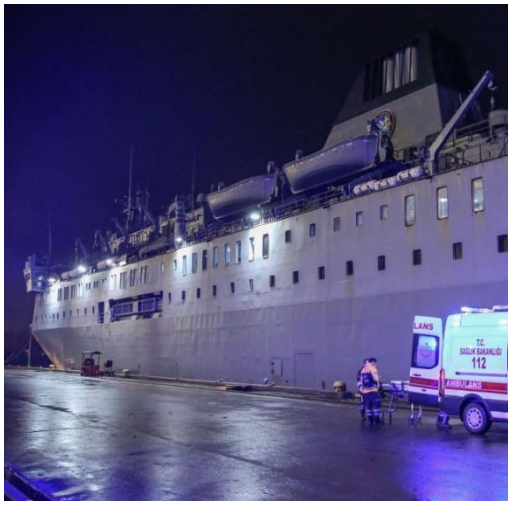


Turkish governmental airplanes played great role in transferring injured people to the hospitals in non-affected cities

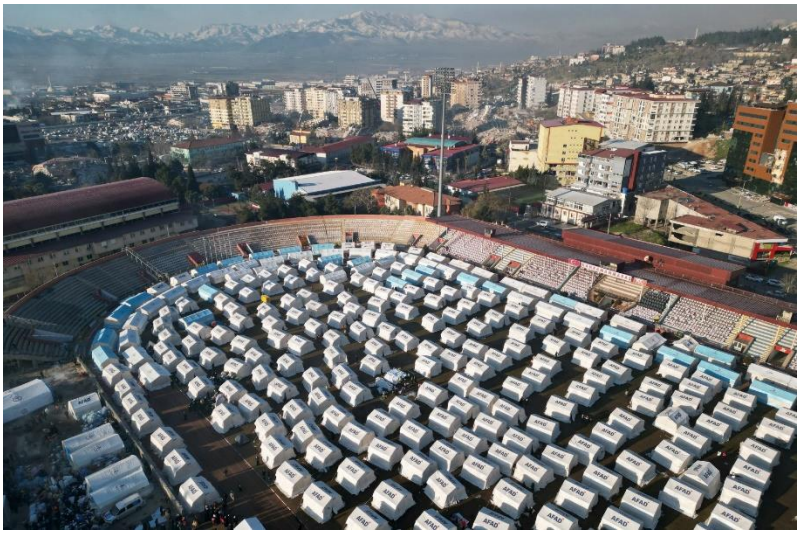


Turkish Army, Miners and AFAD played great role in rescue operations

EVACUATION AND IMMEDIATE HOUSING



TCG for evacuation peoples



Tent village at Gaziantep

Traditional Turkish Tents ‘Yurts’ by Kırgızistan

Kızılay (Red Crescent) offers hot meal.

Field hospital

(Photos: Internet)

UNUSUAL OBSERVATIONS

Earthquake lights occurred during the fault rupture process. The authors also observed the same phenomenon during 1999 Kocaeli Earthquake (Aydan et al., 2000a) and in laboratory experiment on rocks.

Barking dogs just before the erathquake

Blue lightning in Hatay

Blue lightning in Adıyaman

(Photos: Internet)

Earthquake lights in Kahramanmaraş

(Photos: Internet)

(Photos: Internet)

Before the earthquake transparent Balıklıgöl, Şanlı Urfa

After the earthquake muddy Balıklıgöl, Şanlı Urfa

Before the earthquake transparent Gökpınar Lake, Gürün, Sivas (124 km from M7.8 epicenter

After the earthquake muddy Gökpınar Lake, Gürün, Sivas

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