2023 Turkey Earthquake Virtual Report on Geotechnical Impacts

Report Date: 2/9/2023

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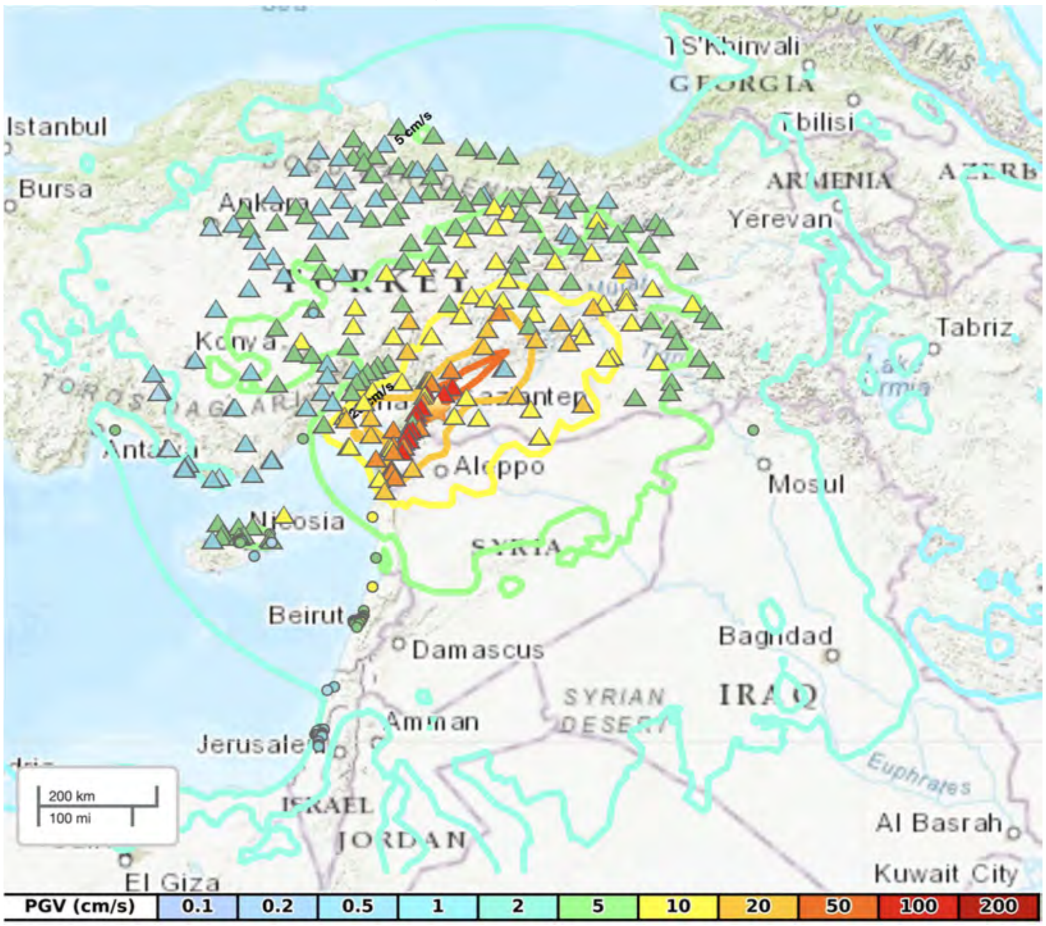

Geotechnical Extreme Events Reconnaissance (GEER) Association

Turning Disaster into Knowledge

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1. Background

1.1. Event Overview

On February 6, 2023, a Mw 7.8 earthquake occurred near Nurdagi, Turkey at a focal depth of 17.9 km. The event occurred around 4am local time. This mainshock was followed by aftershocks of Mw 6.7 and Mw 7.5, approximately 11 minutes and 9 hours after the mainshock respectively. This series of events adds to the long history of seismic activity in this region, which is primarily characterized as the North Anatolian Fault. The most recent significant event occurring on this fault occurred in 1999 near Duzce, Turkey, where a Mw 7.2 mainshock resulted in 894 reported deaths.

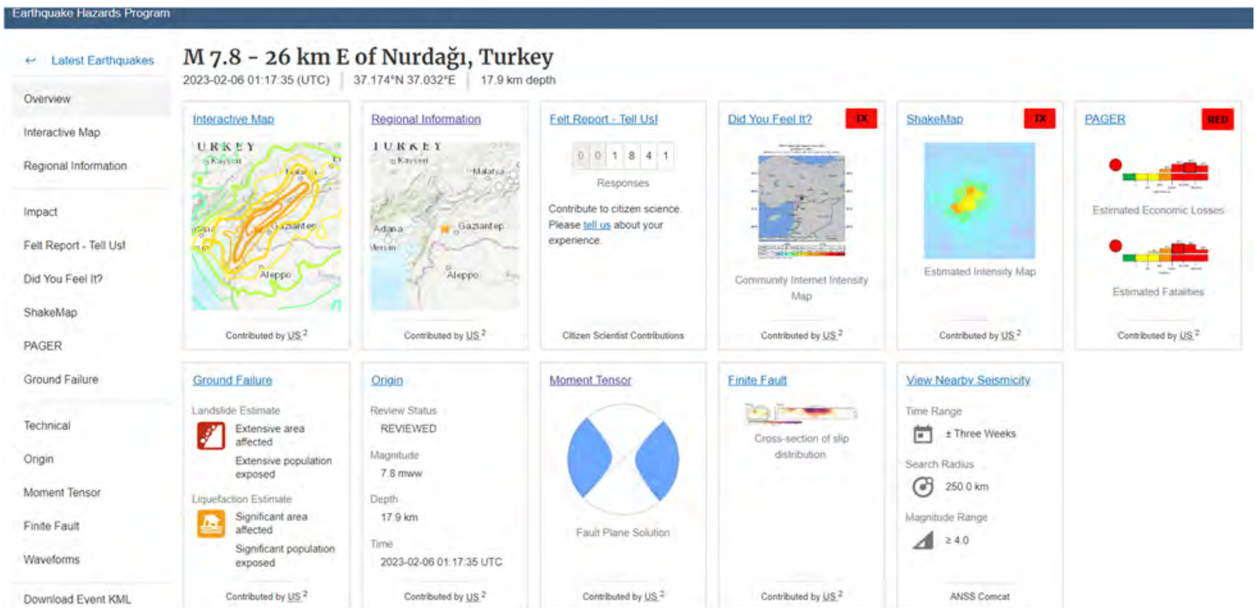

Figure 1: USGS event page for the M7.8 mainshock

The goal of this preliminary report is primarily to summarize the geotechnical impacts that have been observed thus far (Report Date: 2/9/2023) in the virtual reconnaissance phase. As well as geotechnical observations, an overview of satellite-based products will be presented as well as an event summary and technical details of the mainshock.

1.2. Social Impacts

A M7.8 earthquake occurred in Pazarcik, Kahramanmaras, Turkey, on February 6, 2023, at 04.17 am local time. Later the same day (01.24 pm local time), another major earthquake with a M7.6 occurred in Elbistan, Kahramanmaras (Disaster and Emergency Management Presidency, 2023). The earthquake took place in the southeastern part of Turkey and affected the cities of Kahramanmaras, Gaziantep, Sanliurfa, Diyarbakir, Adana, Adiyaman, Osmaniye, Hatay, Kilis, Malatya, and Elazig. The total population of these cities is approximately 13.4 million. By February 9, 14,351 people had lost their lives, and 63,794 people had been injured. The distribution of the casualties and the number of injured people are shown in Table 1 (this statistic was announced on February 7).

6444 buildings have been reported as collapsed by February 7. The construction date for the buildings was reported by Turkish Statistical Institute and reported in Table 1.

City	**Casualties**	**Injured**
Hatay	1647	6200
Kahramanmaras	1243	5000
Gaziantep	504	4809
Sanliurfa	127	2551
Diyarbakir	120	854
Adana	167	3993
Adiyaman	896	400
Malatya	201	4900
Osmaniye	502	2173
Kilis	22	518
Elazig	5	379

Table 1: Distribution of the number of injured people and casualties

City	**Number of buildings**	**Pre-1980 (%)**	**1981 – 2000 (%)**	**2001 and after (%)**	**Unknown (%)**
Hatay	449151	13.5	32.6	50.0	3.9
Kahramanmaras	311458	11.7	26.9	58.1	3.3
Gaziantep	522947	6.6	25.9	51.6	15.9

Sanliurfa	411421	5.5	18.5	61.0	14.9
Diyarbakir	394867	6.5	26.6	58.1	8.8
Adana	632875	13.0	34.8	38.7	13.5
Adiyaman	155300	8.7	23.6	52.3	15.4
Malatya	230499	14.0	28.1	48.4	9.5
Osmaniye	156199	10.5	25.7	46.5	17.3
Kilis	40020	11.2	21.7	52.3	14.9
Elazig	173836	10.0	23.6	52.8	13.6

Table 2: Construction years of existing buildings in each city and their distributions (Turkish Statistical Institute, 2021)

Critical infrastructures such as roads, viaducts, airports, railways, and hospitals were reported as collapsed or heavily damaged.

Figure 2: Damage to Hatay Airport runway (https://www.ozgurkocaeli.com.tr/haber/13964829/hatayda-deprem-sonrasi-havaalani-pisti-yikildi)

Figure 3: Collapsed state hospital in Iskenderun, Hatay (https://www.diken.com.tr/hastane-nasil-yikilir/)

Figure 4: An image taken by UAV from Kahramanmaras (https://www.milliyet.com.tr/galeri/buyuk-afette-ucuncu-gun-deprem-bolgesinde-zamana-karsi-yaris-6900343/1)

One reporter showed the lack of lighting during the search and rescue on the second day of the earthquake in Hatay. The only lighting rescuers had in the field was the lighting of the camera crew.

Figure 5: A live Turkish news broadcast showing no lighting in the field (February 7)

1.3. Technical Background

1.3.1. Geology/Tectonics

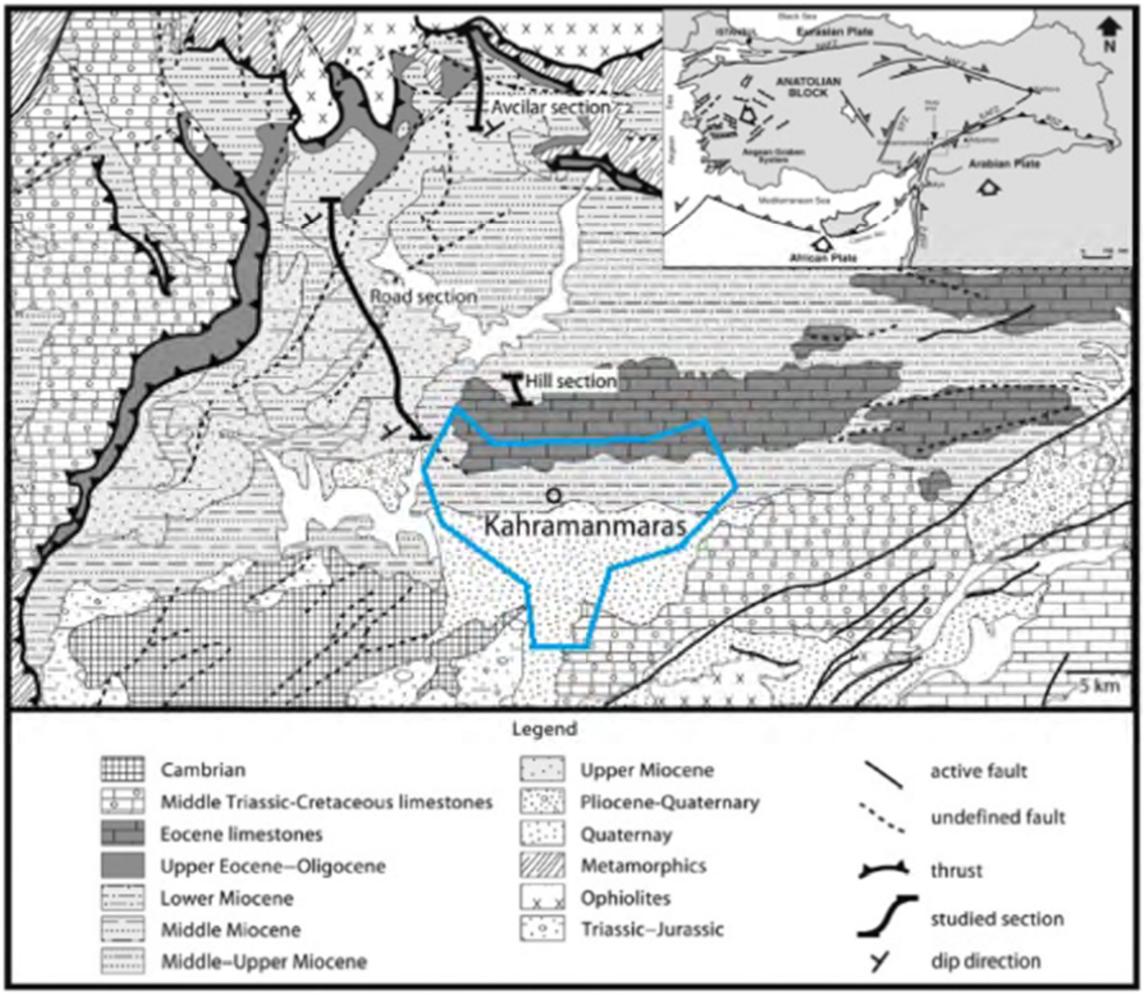

Figure 6: Geological Map of Impacted area (modified from Yilmaz, 2006; Husing et al., 2009)

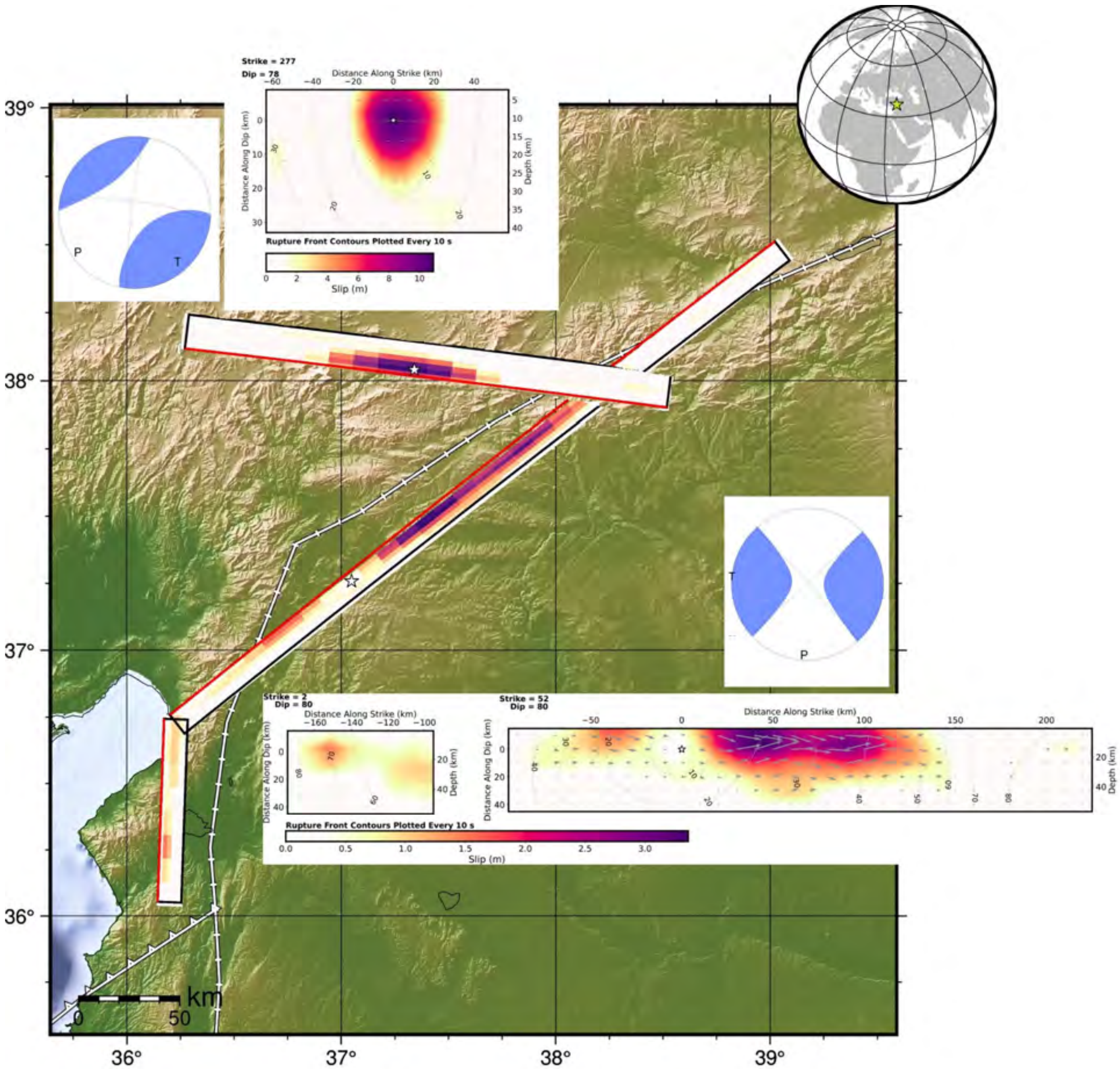

Figure 7: Finite rupture model for the Mw7.8 and Mw7.5 earthquakes (Source: USGS).

The M7.8 mainshock occurred from steeply dipping strike-slip faulting between the triple junction fault zone of the Anatolia, Africa, and Arabian plates. The USGS resolves the focal mechanism as either left-lateral strike towards northeast/southwest or a right-lateral strike towards southeast/northwest. This ambiguity comes from the presence of two active seismic zones in the vicinity, the East Anatolia and Dead Sea fault zones. Westward movement from Turkey is accommodated by the East Anatolia fault zone, whereas the northward motion of the Arabia plate is accommodated by the Dead Sea Transform fault. Bulut et al. (2012) show that slip rates along these faults have been occurring between 6 to 10 mm/yr since the Miocene.

1.3.2. *Earthquake intensities*

Earthquake intensities and magnitude are rapidly published by USGS in the form of a ShakeMap product. Throughout the response of the Turkey Earthquake, modifications to the fault model and inclusion of more seismometer data generated multiple versions of this product. The following figure shows the earthquake intensity for version 5, which was released four hours after the event, and version 7, released two days after the event.

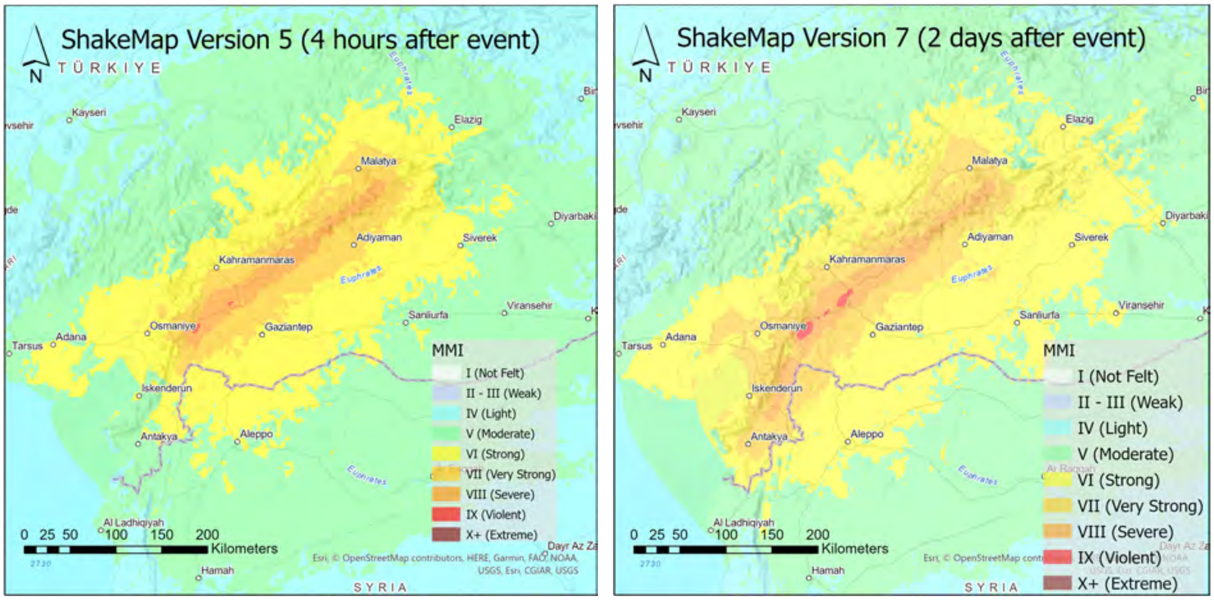

Figure 8: Earthquake intensity for two ShakeMap versions (Source: USGS)

Version 5 was the one used by most news reports because it was not updated during the first day of the event. This is why most information from February 6th references this data. Then, two days after, the finite rupture model was modified to account for the rupture of the southern border between Turkey and Syria (See ShakeMap version 7). Note that the earthquake intensity increases for the city of Antakya (located to the East of Aleppo) from V (Moderate) to VII (very strong).

1.3.3. *Ground Motion Recordings*

Information from the ShakeMap is primarily generated from recording of seismometers. The following figure depicts the distribution of Peak Ground Acceleration (PGA) for the network of seismometers after the 7.8 earthquake.

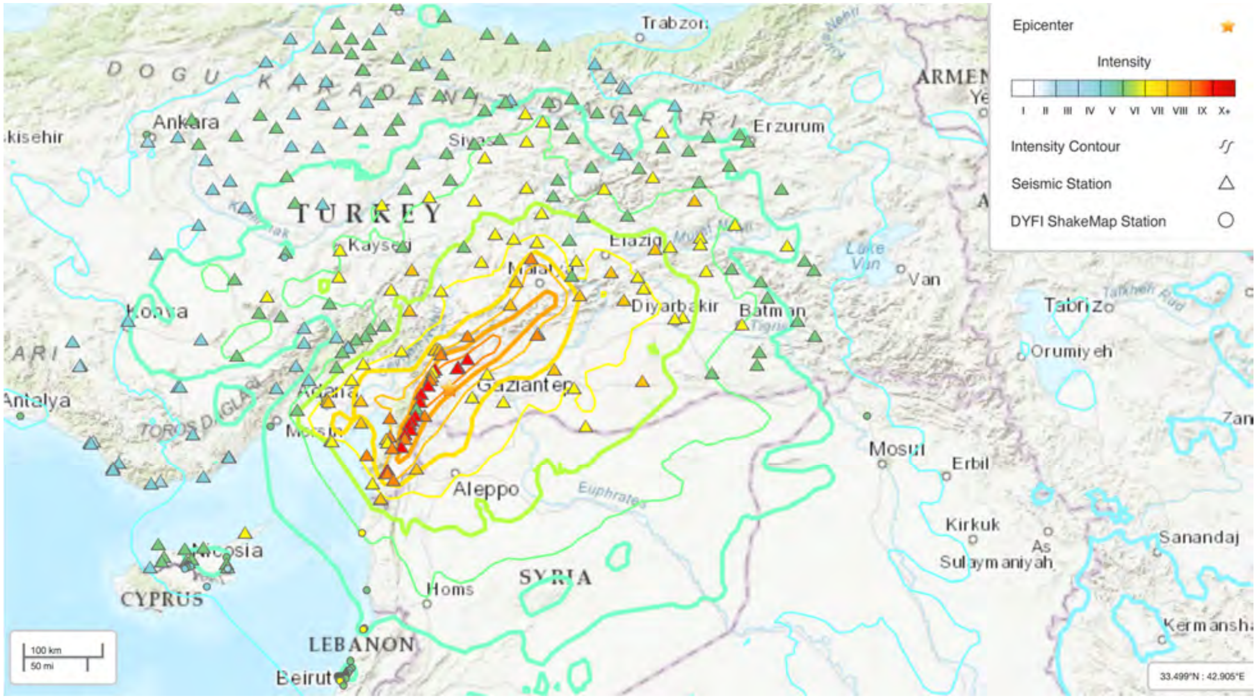

Figure 9: Earthquake intensities at seismometer locations of the ShakeMap (Source: USGS)

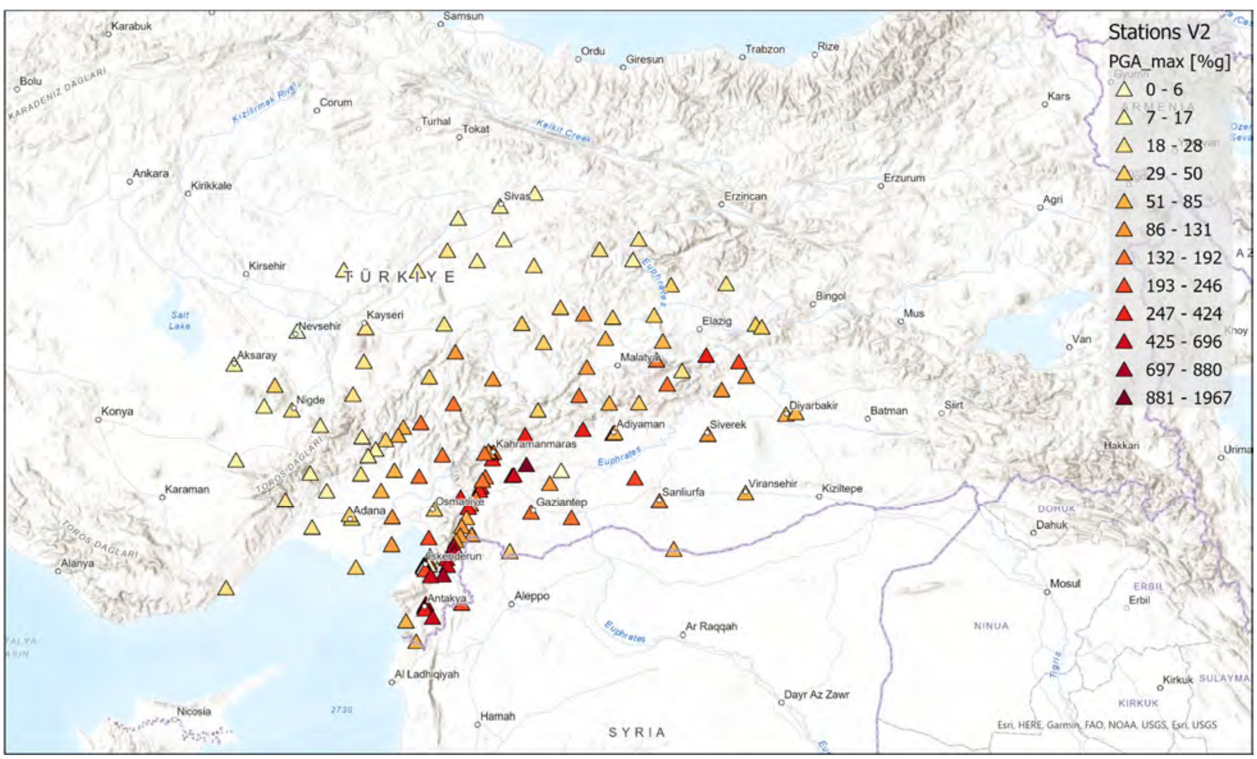

Figure 10: Peak Ground Acceleration recorded by seismometers near the fault rupture (Source: Cetin, 2023).

2. Virtual Observations

2.1. Satellite-Based Damage Estimations

Two days after the event, Maxar Technologies provided pre- and post-earthquake imagery for free by registering to the following link:
https://www.maxar.com/open-data/turkey-earthquake-2023 . These images have been used by multiple entities to quantify damage by comparing pre- and post-earthquake images using computer vision.

2.1.1. Damage Proxy Map

One of these products is the Damage Proxy Map (DPM), which highlights the areas that likely suffered damage after the earthquake. This dataset was computed using synthetic aperture radar (SAR) images captured by the ALOS-2 satellite before the event (from April 2021 to April 2022), and after the event (February 8 2023).

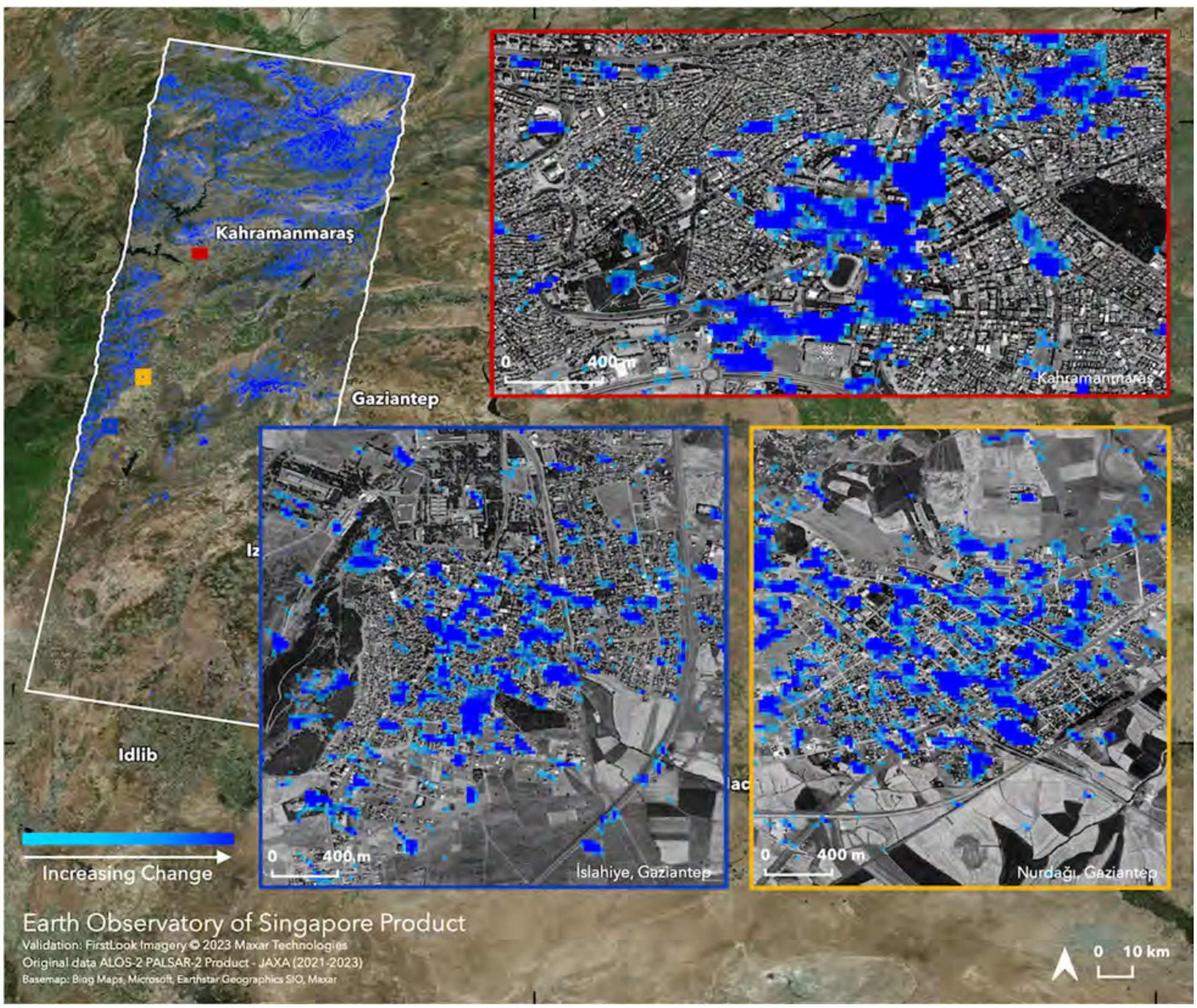

Figure 11: Damage Proxy Map (Source: Earth observatory of Singapore)

2.1.2. Surface displacement

NASA JPL Laboratoyry has generated Stripmap displacement maps by computing the interferometric difference (interferogram or interferometric SAR) and pixel offset tracking between the post-event image acquired on February 8, 2023 with a pre-event image acquired on April 6, 2022, on the ALOS-2 descending (satellite moving south) track 78.

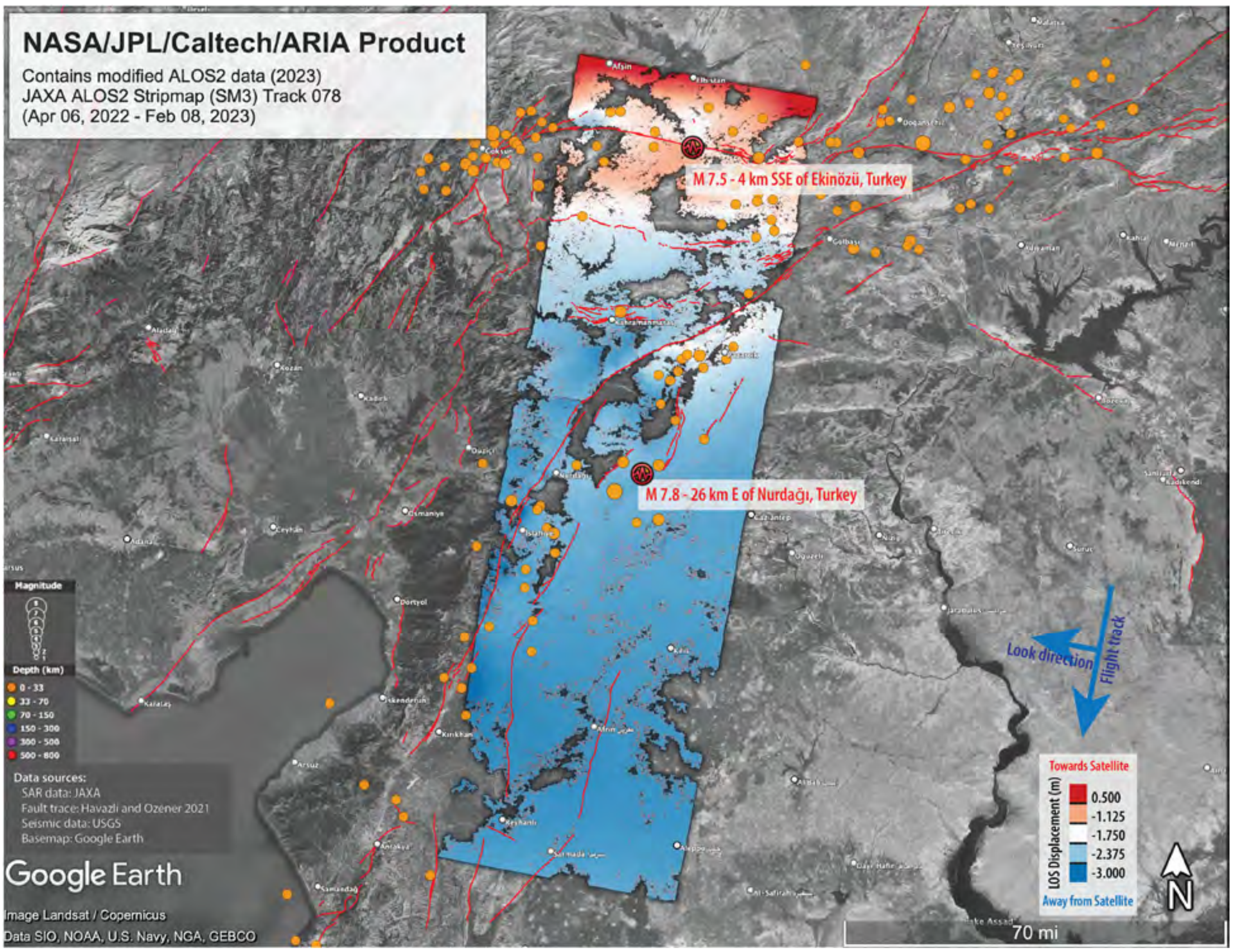

Figure 12: Preliminary dataset on surface displacement (Source: NASA JPL)

From their website: “This displacement map should be used as guidance to identify areas of significant ground displacement, and may be less reliable over snow-covered and vegetated areas.”

2.1.3. Copernicus damage grading

Copernicus Emergency Management Service (EMS) activated a mapping service for the earthquake in the East Anatolian Fault Zone. 20 areas of interest (AOI) are currently being analyzed, as shown by the following figure.

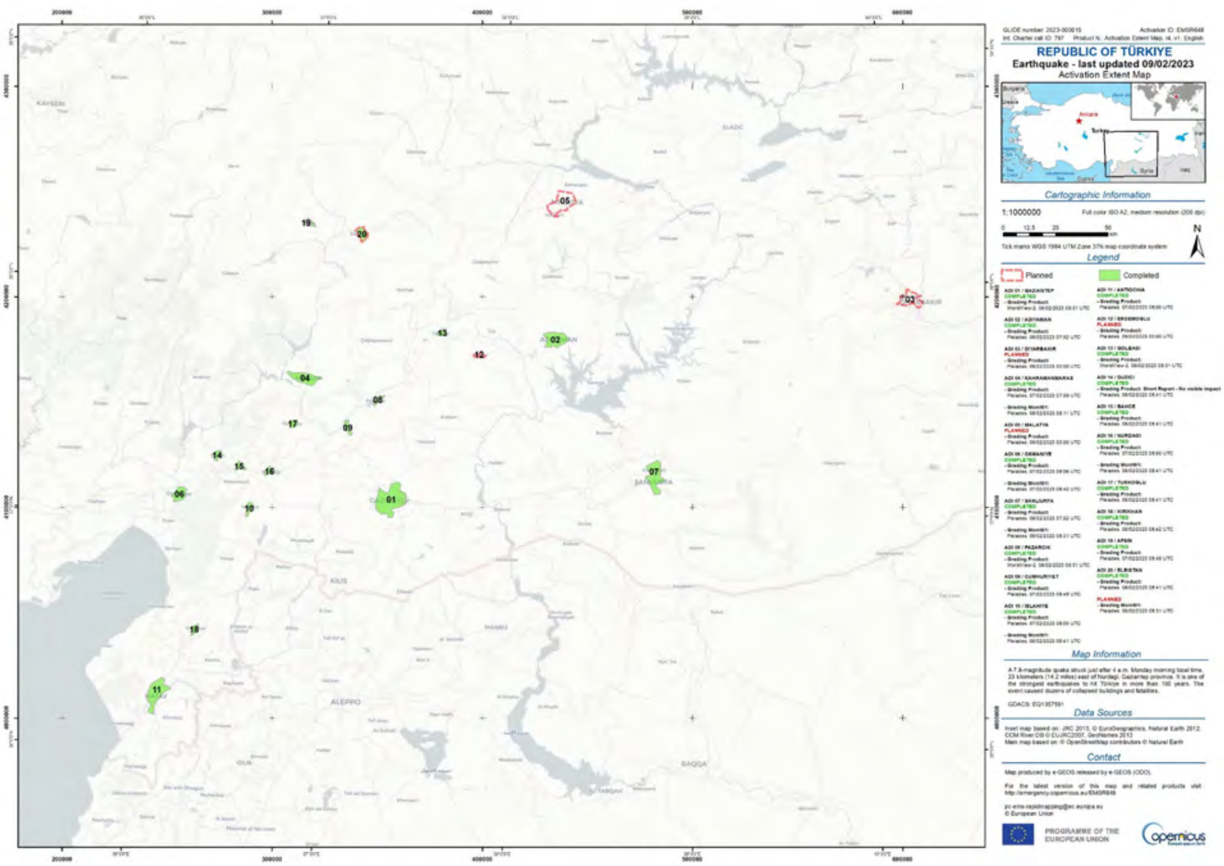

Figure 13: Areas of interest used by Copernicus EMS.

For each of these areas, satellite imagery is used to manually identify damage to infrastructure. The next forge shows the damage grading product for Osmaniye (Turkey) where red areas represent Destroyed, orange Damaged, and yellow Possibly Damaged. A larger grading product was released for the city of Kahramanmaras.

Figure 14: Damage grading in Osmaniye (Source: Copernicus EMS)
https://emergency.copernicus.eu/mapping/ems-product-component/EMSR648_AOI06_GRA_MONIT01_r1_RTP02/1

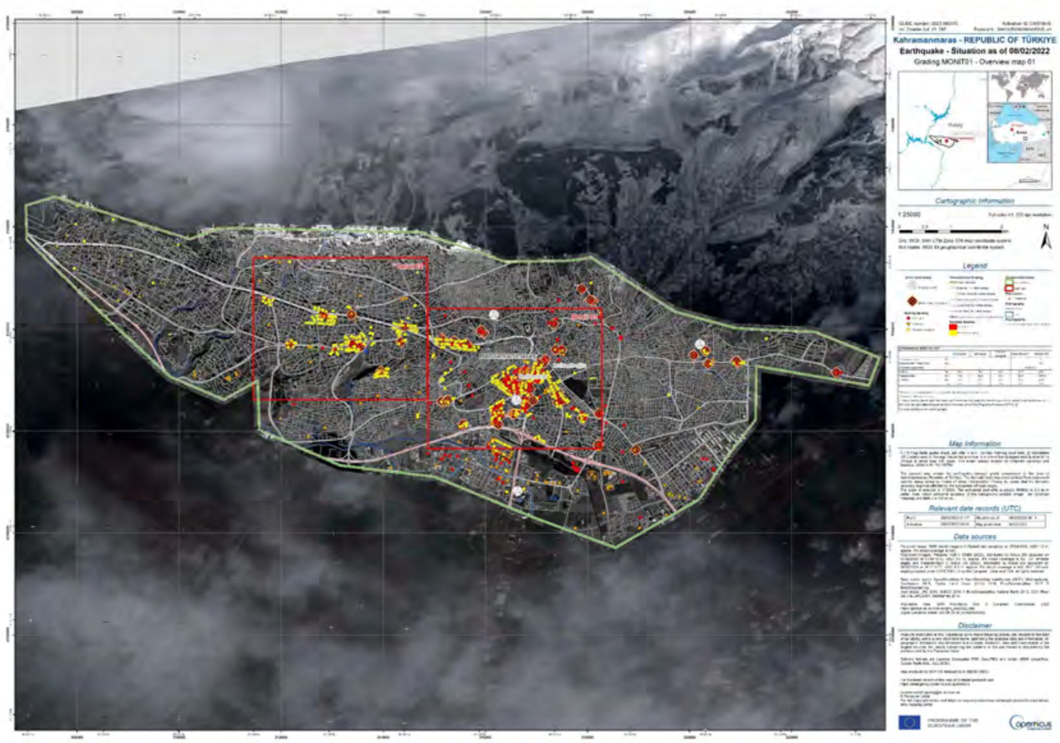

Figure 15: Damage grading in Kahramanmaras (Source: Copernicus EMS)
https://emergency.copernicus.eu/mapping/ems-product-component/EMSR648_AOI04_GRA_MONIT01_r1_RTP01/1

2.2. *Surface Rupture*

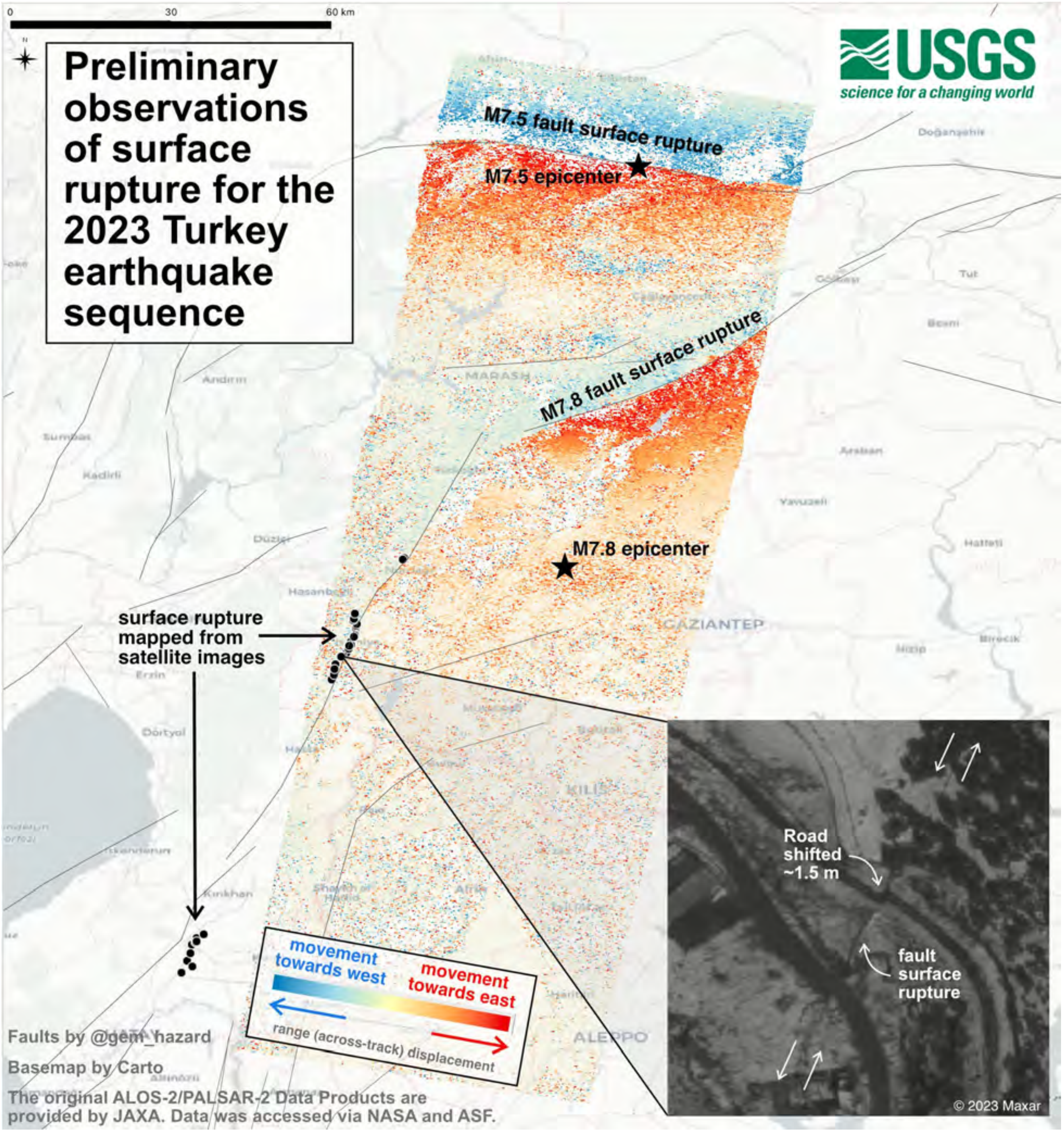

Figure 16: Surface Rupture estimation from satellite imagery (Source: @USGS_Quakes on Twitter)

Figure 17: Surface rupture observed in residential neighborhood near Hessa (Source: https://twitter.com/ziyadin/status/1623288689894871046/photo/1)

Professor Cengiz Zabcı from Istanbul Technical University (ITU) generated some of the first UAV-based digital Surface Models (DSMs) of the surface rupture.

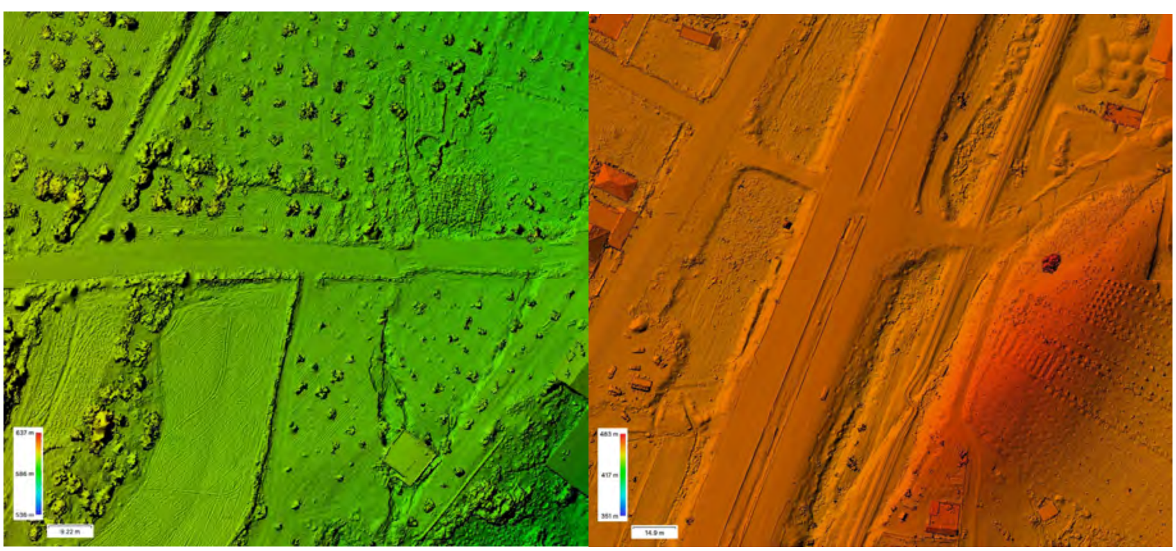

Figure 18: UAV-based Digital Surface Model in Şekeroba, Turkey (Source: Twitter Cengiz Zabcı https://twitter.com/CengizZabci/status/1623569420554493953)

Figure 19: Ground displacement in Kahramanmaras measured by fence offset of 6.7m (Source:Twitter Taylan SANÇAR; https://twitter.com/tsancar/status/1623698495730339840/photo/1)

2.3. Road & Railway Damage

The severity of the fault rupture generated multiple road damage throughout Turkey. These are some examples of road damage due to the earthquake.

Figure 20: Road damage in Kahramanmaraş/Türkoğlu. 3.3m of displacement (Source: Twitter Cengiz Zabcı). https://twitter.com/CengizZabci/status/1623236487687929857/photo/1

Figure 21: Road damage in Tevekkelli, Tevekkelli Village Road, 46090. (Source: Twitter Zeliş; https://twitter.com/Panthalassa_Z/status/1623237597752352769)

Figure 22: Lateral flow landslide on the road between Adana and Gaziantep (Source: Twitter video Sokagin Sesi Gazetesi; https://twitter.com/sokaginsesigaz1/status/1622689001332215853)

Figure 23: Road in Hatay, Turkey completely split open. (Source Video: Video https://twitter.com/porcumali/status/1622594257176469506)

Figure 24: Surface displacement in Şekeroba highlighted by rail displacement (Source: Twitter Cengiz Zabcı https://twitter.com/CengizZabci/status/1623236454926229504/photo/1)

Figure 25: Surface displacement in Şekeroba highlighted by rail displacement (Source: @akyuz24 on Twitter)

2.4. Liquefaction

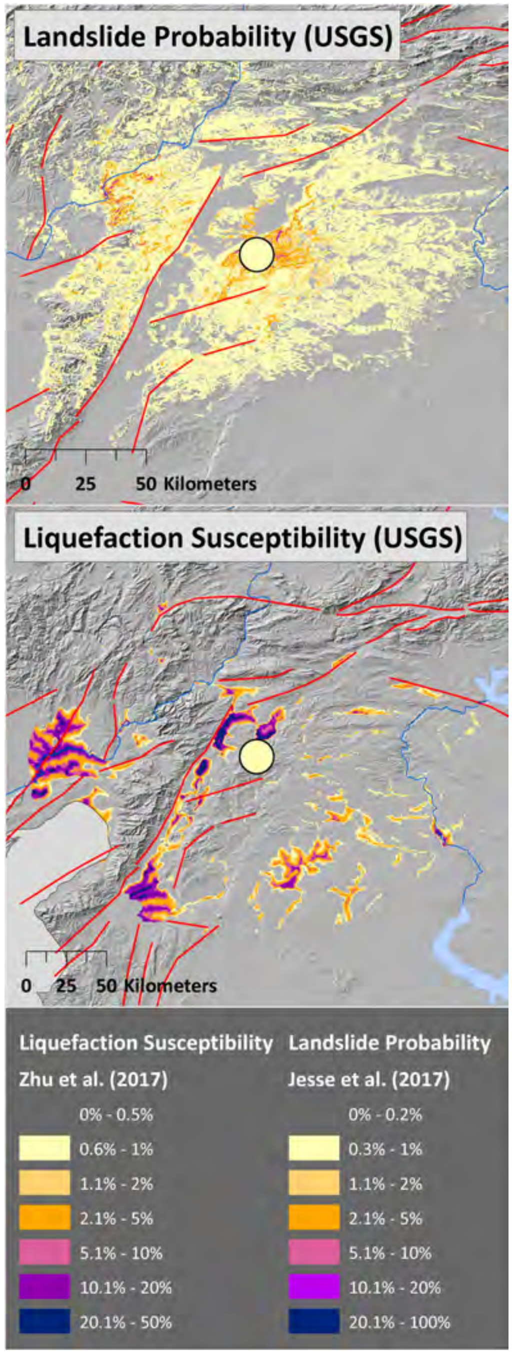

Figure 26: Landslide and Liquefaction Susceptibility Maps (USGS; Zhu et al., 2017; Jesse et al., 2017)

There have been no reports of liquefaction to date, although more thorough investigation will be needed to determine failure mode of many structure. Field investigations will be needed to determine the severity of liquefaction induced building settlements and failures.

2.5. Dams

The Afrin Dam, also called the Maydanki Dam is an earth-filled hydroelectric dam. Located on the Afrin River in northwest Syria, this dam provides drinking water for about 200,000 people.

Figure 27: Cracking in the Afrin Dam (Source: https://twitter.com/Hibakarm/status/1623723294686838784)

Figure 28: Aerial view of the al-Tlul village, where damage to the Afrin dam led to flooding (Photo Credit: AP Photo/Ghaith Alsayed).

The earthquake sequence resulted in the cracking of the Afrin Dam and the subsequent flooding of a downstream Syrian enclave, al-Tlul. There have been no further reports of flooding or damage, and no evacuation notices have been sent. Additionally, the Ataturk dam, the third largest dam in the world, has been cleared of any damage or impacts resulting from the earthquakes.

Figure 29: Cracking damage observed in the Sultansuyu Dam (Source: https://www.ntv.com.tr/galeri/turkiye/govde-aksinda-catlaklar-olusan-malatyadaki-sultansuyu-baraji-tahliye-ediliyor,xxRN92Huy0iiG0tyCNu4fA/aimTJcX5X0egL7OUo5ez0Q)

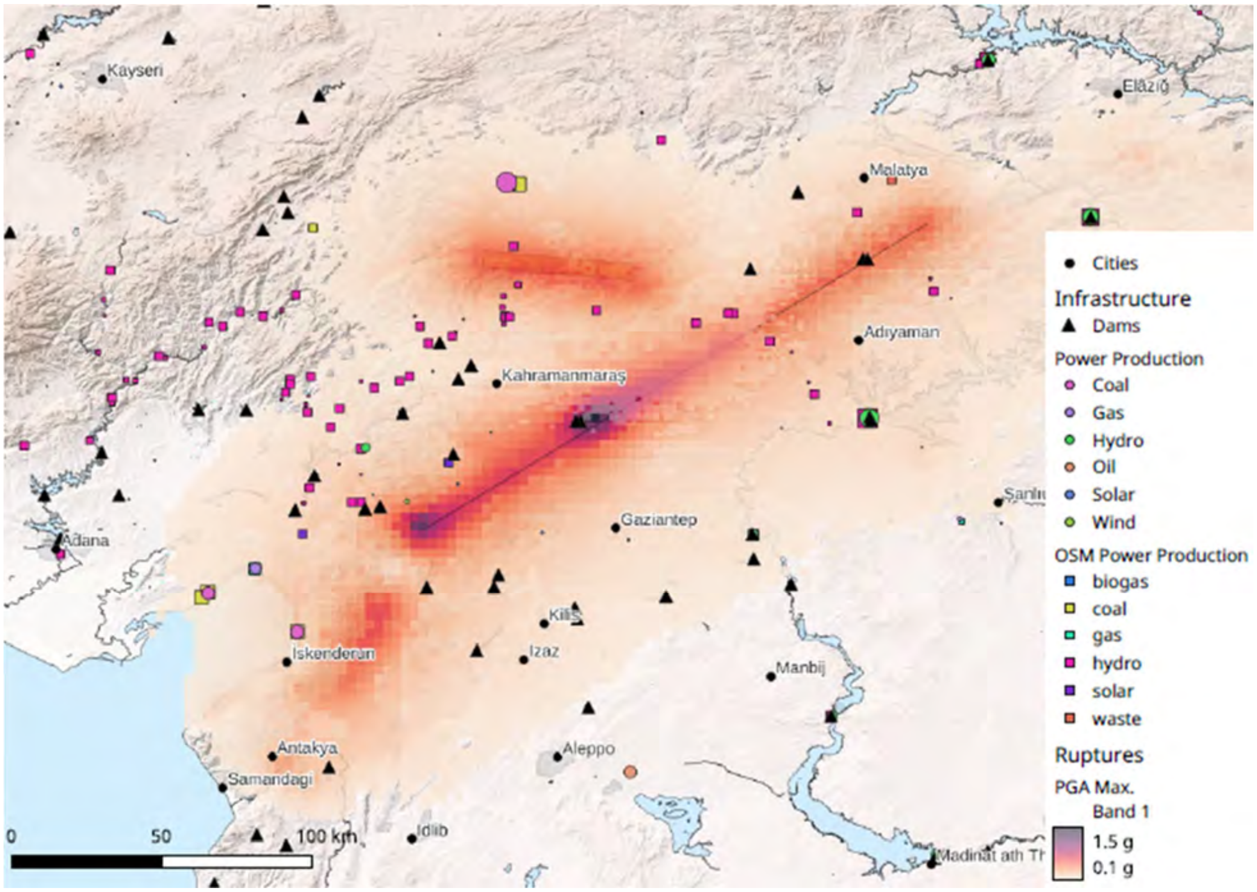

Figure 30: Locations of dams and critical power infrastructure assets in the affected region (Source: Albert Kottke & Ozgur Kozaci)

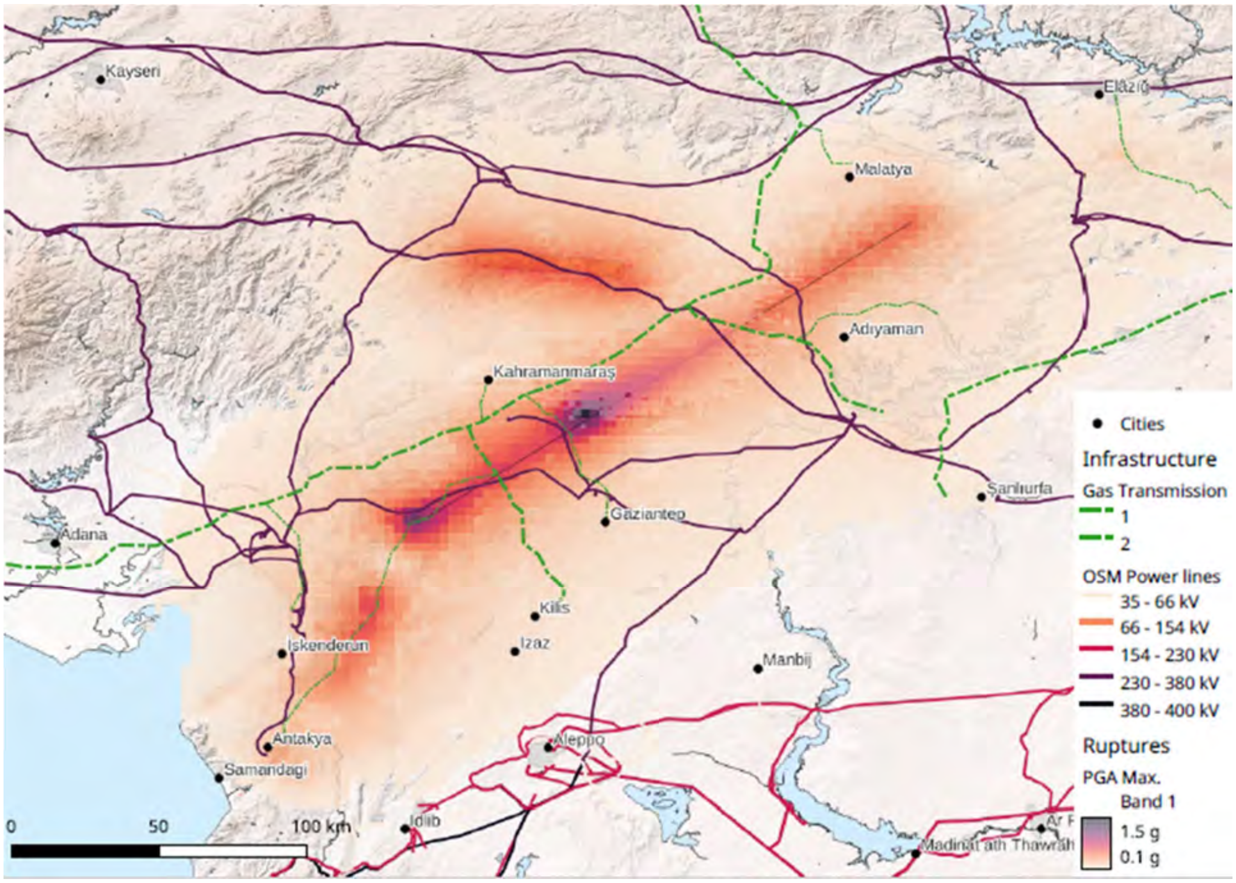

Figure 31: Locations of critical gas transmission and power lines (Source: Albert Kottke & Ozgur Kozaci)

References

Birgun (2023). “Habertürk ekibi kameralarının ışığını kapattı, arama-kurtarma çalışmalarındaki durum dehşete düşürdü” https://www.birgun.net/haber/haberturk-ekibi-kameralarinin-isigini-kapatti-arama-kurtarma-calismalarindaki-durum-dehsete-dusurdu-420565

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. *Journal of Geophysical Research: Solid Earth*, *117*(B7).

Cetin, Onder (2023). Distribution of peak ground accelerations recorded by seismometers after 7.8 Turkey Earthquake.

CNNTurk (2023): *The current latest situation, how many dead, how many injured in the earthquake? How many buildings were destroyed in which province, how many people died?;* February 9, 2023. https://www.cnn.com/2023/02/05/europe/earthquake-hits-turkey-intl-hnk/index.html

CNN (2023) https://www.cnnturk.com/turkiye/9-subat-deprem-haberleri-depremde-olu-ve-yarali-sayisi-kac-oldu-hangi-ilde-kac-bina-yikildi-kac-kisi-oldu

Diken (2023). “Hastane nasıl yıkılır!” https://www.diken.com.tr/hastane-nasil-yikilir/

Disaster and Emergency Management Presidency (2023). “PRESS BULLETIN-19 about the Earthquake in Kahramanmaraş.”

Earth Obserbatory of Singapore (EOS). Damage Proxy Map: Turkey and Syria, Earthquake, 8 Feb 2023, v0.5 https://eos-rs-products.earthobservatory.sg/EOS-RS_202302_Turkiye_Syria_Earthquake/

European Commission, Coperninucs Emergency Management service (2023). Activation EMSR648: Earthquake in East Anatolian Fault Zone, https://emergency.copernicus.eu/mapping/list-of-components/EMSR648

Hüsing, S. K., Zachariasse, W. J., Van Hinsbergen, D. J., Krijgsman, W., Inceöz, M., Harzhauser, M., ... & Kroh, A. (2009). Oligocene–Miocene basin evolution in SE Anatolia, Turkey: constraints on the closure of the eastern Tethys gateway. *Geological Society, London, Special Publications*, *311*(1), 107-132.

KTU-DU (2022). Altunisik A. C., Arslan M. E., and Aykanat B. *November 23, 2022 Golyaka* (*Duzce*) *Earthquake* (*Mw 5.9*) *Field Observations and Investigation Report.* Karadeniz Technical University and Duzce University. https://www.ktu.edu.tr/dosyalar/insaat_b5481.pdf

NASA JPL (2023).ALOS-2 Stripmap displacement maps (interferograms) for Turkey earthquake 2023. https://aria-share.jpl.nasa.gov/20230206_Turkey_EQ/Displacements/

NewsNation/Associated Press (2023). Chehayeb, K., Abuelgasim. F., and Albam, O. February 9, 2023. Days after quake, aid trucks reach northwest Syrian enclave. https://www.newsnationnow.com/world/international-headlines/ap-days-after-quake-aid-trucks-reach-northwest-syrian-enclave/

NTV (2023). “Gövde aksında çatlaklar oluşan Malatya'daki Sultansuyu Barajı tahliye ediliyor” https://www.ntv.com.tr/galeri/turkiye/govde-aksinda-catlaklar-olusan-malatyadaki-sultansuyu-baraji-tahliye-ediliyor,xxRN92Huy0iiG0tyCNu4fA

Ozgur Kocaeli News (2023). Airport Runway Destroyed After Earthquake in Hatay. February 6, 2023.https://www.ozgurkocaeli.com.tr/haber/13964829/hatayda-deprem-sonrasi-havaalani-pisti-yikildi#

Turkish Statistical Institute (2021) “Bina ve Konut Nitelikleri Araştırması” https://data.tuik.gov.tr/Bulten/Index?p=Bina-ve-Konut-Nitelikleri-Arastirmasi-2021-45870

US Geological Survey (USGS) (2023a). “M 7.8 - Central Turkey” & “M 7.5 - 4 km SSE of Ekinözü, Turkey”. Feb. 6th, 2023. https://earthquake.usgs.gov/earthquakes/eventpage/us6000jllz/executive & https://earthquake.usgs.gov/earthquakes/eventpage/us6000jlqa/executive

US Geological Survey (USGS) (2023b). “M 7.8 - Central Turkey - PAGER”. Feb.. 6th, 2023. https://earthquake.usgs.gov/earthquakes/eventpage/us6000jllz/pager

Yılmaz, C. (2006). Platform–slope transition during rifting: The mid-Cretaceous succession of the Amasya Region (Northern Anatolia), Turkey. *Journal of Asian Earth Sciences*, *27*(2), 194-206.