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1. AQ: Is the phrasing ‘active faults that were known to be high seismic hazards’ OK?

Changed it slightly.

2. Please check your article carefully, coordinate with any co-authors and enter all final edits clearly in the eproof, remembering to save frequently. Once corrections are submitted, we cannot routinely make further changes to the article.

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5. AQ: Note that at proof stage, in Fig. 1 all magnitude symbols ‘M’ will be made italic and a comma will be added to all numbers >999. (for example, in panel b the label ‘1513 Ms 7.4’ will become ‘1,513 Ms 7.4’)

I'm not entirely sure what you mean here. Not a problem with the M being in itlaic, but 1513 is a year so it shouldn't have a comma.

6. AQ: Please confirm that the headings are appearing correctly (see the PDF)

Yes, the headings are correct

Comment

Preconditioning the 2023 Kahramanmaraş (Türkiye) earthquake disaster

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The 2023 Kahramanmaraş earthquakes occurred on active faults that were known to be a high seismic hazard~~s~~, yet the devastating impacts of these earthquakes show that the risk was not adequately considered. Vulnerabilities arising from exposure, corruption~~,~~ and poverty led to a~~nd~~ lack of seismic ~~awareness~~preparedness which amplified the earthquake risk into a tragic disaster.

In the early ho **AQ1** urs of 6 February 2023, a magnitude 7.8 earthquake struck the Kahramanmaraş region of south-eastern Türkiye. Nine hours later, a magnitude 7.6 earthquake also shook the region. The relatively shallow depth of the earthquakes, at about 10 km, resulted in strong-violent shaking (Modified Mercalli Intensity 6–9) over a large area of Türkiye and Syria. As of 20~~1~~ March 2023, the total death toll of over 57~~1~~,000 (~~4~~50,000 in Türkiye and 7~~6~~,000 in Syria) — with numbers expected to rise — makes this event the deadliest in modern Turkish history, exceeding the tragedy of the 1939 magnitude 7.8 Erzincan earthquake, which killed nearly 33,000 people. As early scientific insights are beginning to emerge, here we discuss the current understanding of the seismic hazard and preconditioning factors that contributed to the devastating events in Türkiye and Syria. **AQ2** **AQ3** **AQ4**

Earthquake hazard

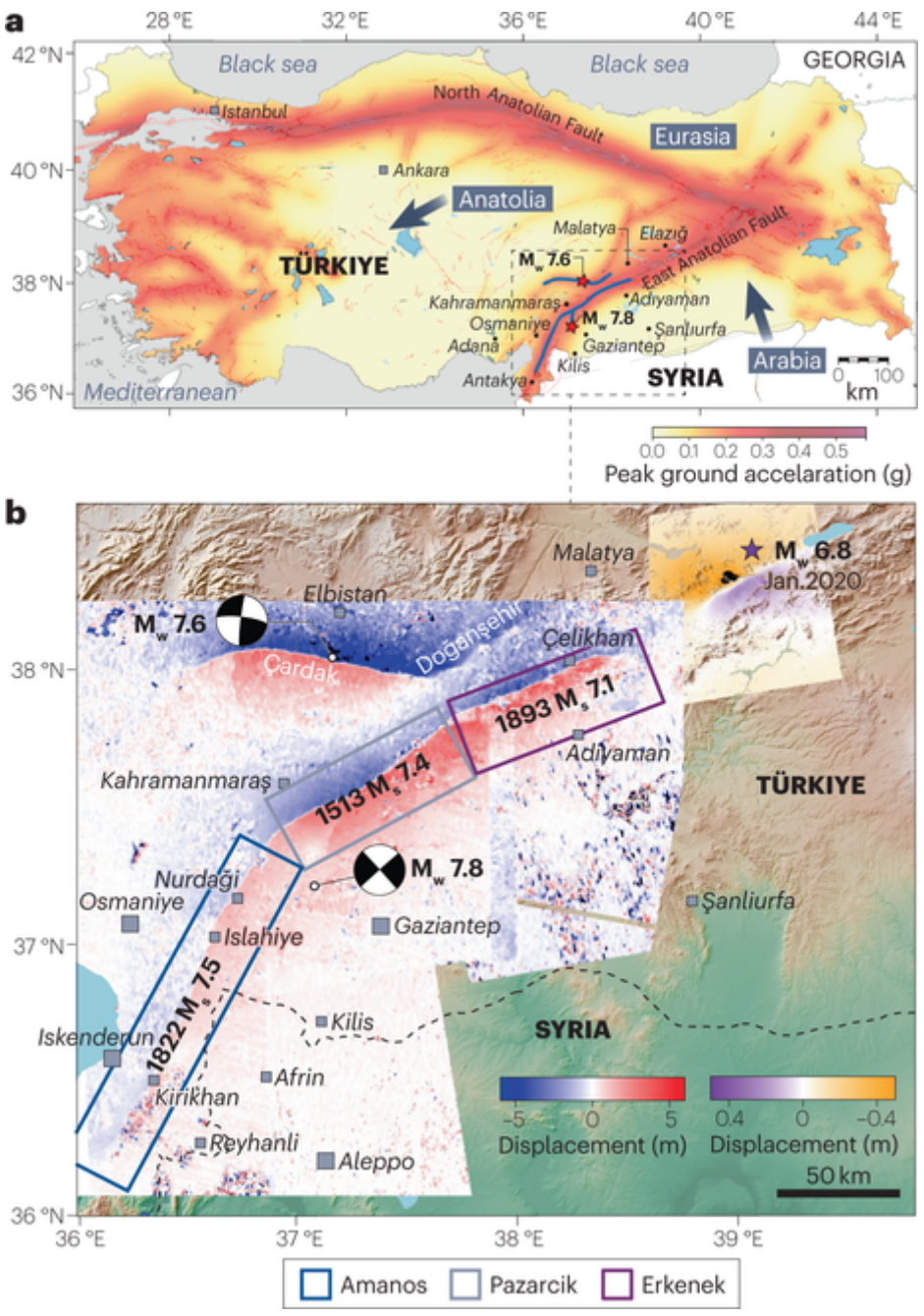
The 2023 earthquakes occurred on the East Anatolian Fault (EAF), which is a major tectonic structure in the eastern Mediterranean, separating the Arabian and Anatolian tectonic plates along a boundary that spans nearly 600 km, ref. [1]. Together with the North Anatolian Fault (NAF), the EAF enables the Anatolian plate (most of mainland Türkiye) to escape westward at about 20 mm yr^{-1} from the collision between the Arabian and Eurasian plates in eastern Türkiye[2] (Fig. 1a). This long-term motion of Anatolia is facilitated by repeated earthquakes along the North and East Anatolian Faults.

Fig. 1

Known seismic hazard and surface rupture maps of the 6 February 2023 earthquakes.

a, Earthquake **AQ5** hazard map of Türkiye from the Turkish disaster and emergency management authority (AFAD) published in 2018. The 6 February 2023 earthquakes (blue lines) occurred on faults known to have high potential hazard. The dashed box is the area shown in panel **b**. **b**, Surface ruptures of the 6 February 2023 magnitude 7.8 and magnitude 7.6 earthquakes and historical events along the East Anatolian Fault. Red-blue colours show surface displacement due to the Kahramanmaraş earthquakes projected into the N79 °E direction (approximately parallel to the EAF), which are estimated from a 3D inversion of pixel offsets of Sentinel-1 radar and Sentinel-2 optical satellite images. Purple-orange colours show fault-parallel surface displacement due to the 2020 magnitude 6.8 earthquake measured using interferometry of Sentinel-1 satellite data. Focal mechanisms and surface rupture (black lines) are from the United States Geological Survey TS: Please, hyper link this to: https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=5229bb842bd64b688d769abbefe43b46

. Earthquake hazard map of Türkiye in p~~P~~anel **a** adapted with permission from AFAD, 2018.



The NAF has experienced eight large earthquakes over a 60-year period between 1939 and 1999. By contrast, the EAF has been quiet since 1971, when the eastern end of the fault was awakened by a magnitude 6.8 earthquake in Bingol. Historical earthquake records in the Bingol and surrounding regions later revealed an extensive history of large and destructive earthquakes along the EAF, dating back over two millennia[3]. Before the 2023 earthquakes, the section of the fault associated with the mainshock (magnitude 7.8) last ruptured in 1513[4]. Therefore, this section of the EAF has been accumulating plate-motion strain at about 10 mm yr^{-1} over the past 500 years, storing around 5 metres of potential fault slip. Indeed, the measured co-seismic displacement of 4–6 metres released by the mainshock agrees remarkably well with the expected amount.

Insight into historical activity along both the EAF and NAF, provided by palaeoseismology, historic earthquake records and measurements of active strain accumulation, ~~was~~have all been used by the Turkish disaster and emergency management authority (AFAD) to develop a seismic hazard model for Türkiye (Fig. 1a). The hazard map clearly shows high seismic hazard potential along both the EAF and NAF.

Shortly after the 6 February magnitude 7.8 earthquake, measurements from satellite images, field surveying and the location of aftershocks confirmed that the earthquake had ruptured a 300 km-long section of the EAF between Antioch and Çelikhan. The second magnitude 7.6 quake occurred on a separate, 150-km long fault zone that included the Çardak and Doğanşehir faults to the north (Fig. 1b). Severe-violent levels of shaking occurred along most of the length of both ruptures, with shaking intensity decreasing away from the faults. However, very strong shaking was felt over 10 km from the rupture zone. Both faults produced up to 8 m of horizontal displacement at the Earth's surface, offsetting infrastructure such as railways, roads and buildings.

Preconditioning the disaster

As the earthquake hazard was known in this region, the focus falls on the preconditioning factors that led to the scale of the disaster. Government authorities and scientists will be increasingly concentrating on these socioeconomic factors in the coming months. However, the general ingredients of a disaster are all too common across regions and countries: exposure, corruption and poverty.

Exposure

Exposure is the spat **AQ6** ial distribution of people and the condition of the buildings in which they live. In Türkiye, over 13 million people experienced moderate to high levels of ground shaking in a region where health services were already dealing with a high number of COVID-19-related illnesses. Additionally, over 2.9 million internally displaced people in northern Syria were exposed to shaking. In ~~Turkey~~Türkiye the cities most affected were on or near the fault ruptures, most damage occurred in Kahramanmaraş, Malatya, Adıyaman and Antakya. The initial mainshock struck at 04:17 am local time, when most people were inside their homes and therefore exposed to building damage. The timing also coincided with a winter storm, meaning the people who managed to escape their homes were subsequently exposed to freezing temperatures of –5 °C to –19 °C outside. Heavy snow also blocked roads and railways, which complicated search and rescue, and prevented aid from reaching affected areas on the same day.

The 11 most-affected Turkish provinces experienced rapid urbanization since the 2000s. At the last count in 2021, 52% of homes in these provinces were built after 2001 when strict new building regulations came into force following the destructive 1999 magnitude-7.4 Izmit earthquake. Despite these regulations, over 85,000 buildings in these regions were either severely damaged or collapsed during the two earthquakes.

Building regulations and enforcement

Images of completely collapsed buildings and the high death toll are a stark reminder that poor building practices are a major contributor to turning earthquakes into major disasters[5]. Reinforced concrete buildings in Türkiye are supposed to conform to detailed standards, which were last updated in 2018. These regulations ensure the maximum likelihood of saving lives by allowing buildings to withstand earthquake shaking or to fail in predictable ways to allow inhabitants to escape through known 'safe' routes. However, enforcement of building regulations has always been a challenge, an issue common in many low- and middle-income countries. The construction industry is also a powerful lobby group in Türkiye with strong political influence[6]. Corruption between contractors, inspection firms and local authorities likely contributed to the 1999 Izmit earthquake tragedy that killed nearly 18,000 people[7].

To manage the legacy of illegally built structures, a construction amnesty (*imar barisi*) was declared in 2018 so that contractors could apply for legal exemption for buildings built before 2018 that did not meet safety regulations in exchange for a fee. According to the Ministry of Environment, Urbanization and Climate Change, as of 2021 over 305,000 buildings across the 11 Turkish provinces benefited from this scheme[8]. Many older buildings and some recently built structures advertised to be "completed in compliance with the latest earthquake regulations" collapsed during the 2023 earthquakes, suggesting the lack of enforcement in building regulations might have been a ~~major~~ factor contributing to the scale of this disaster.

Poverty

The most-affected Turkish provinces hit by the 2023 earthquakes suffer from higher levels of poverty compared to western Türkiye[9]. In 2021, over 1.5 million people lived below the national poverty line in these provinces[9]. The poor generally do not own any property and are more likely to live in houses that are old and/or illegally built. These buildings are generally more fragile and likely to collapse in an earthquake. Additionally, over 6.4 million refugees and displaced people in Türkiye and northern Syria were exposed to earthquake shaking. Refugees and impoverished locals are often more vulnerable to natural hazards as they are likely to live in overcrowded conditions and/or poorer quality housing.

In TS: Please, note that in the PDF this paragraph is adjoined to the one above for poverty. I feel like there should be a space before the concluding remarks otherwise it looks like something to do with the last segment. Please, add a break line here, thanks conclusion, the 2023 Kahramanmaraş earthquakes are a potent reminder that mitigating disaster risk requires not only understanding the hazard conditions people are exposed to, but also managing the social and built environments in which they live. Disasters are not natural; we can mitigate the risk of a future tragedy by addressing the issues of exposure, corruption and poverty through strong governance mechanisms, and by ensuring universal access to good quality homes built to regulations that are tailored to the local seismic hazard.

Related links

BBC News reference to buildings "completed in compliance with the latest earthquake regulations" (Accessed on 20 February 2023): https://www.bbc.co.uk/news/64568826

Earthquake rupture map: https://doi.org/10.5066/P985I7U2

Türkiye 2021 housing census: https://data.tuik.gov.tr/Bulten/Index?p=Population-and-Housing-Census-2021-45866

USGS earthquake list (Accessed 20 February 2023): https://www.usgs.gov/natural-hazards/earthquake-hazards/lists-maps-and-statistics

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Competing interests The authors declare no competing interests.

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