Present to Past Reflection? Notes on the 1114/5 C.E. Earthquake Sequence After the February 2023 Türkiye Doublet

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Abstract

This study examines the seismic sequence of 1114/5 C.E. which occurred in southern Türkiye through the lens of the well-documented February 2023 Türkiye doublet. By drawing parallels between the two, the analysis compares the spatial distribution of damage, temporal clustering, and tectonic context to better constrain the poorly understood twelfth-century scenario. A systematic re-evaluation of the historical sources was conducted with attention to their inherent uncertainties. Using kernel density estimation (KDE) on interpreted intensity data points, we identified two persistent hotspots of destruction near Kahramanmaraş–Elbistan and near Antakya in both the 1114/5 and 2023 sequences, suggesting a recurring pattern of seismic energy release along distinct fault segments. The examination of the spread and severity of the damage indicated that at least one of the 1114/5 earthquakes likely exceeded magnitude 7, comparable to the 2023 doublet. Paleoseismological evidence further supports a dual-fault rupture scenario in 1114/5, analogous to stress-triggered ruptures observed in 2023. This reverse-historic approach using recent seismicity to constrain pre-instrumental earthquakes provides a useful pathway for reconstructing ancient seismic sequences and underscores the capability of the East Anatolian fault zone to generate large earthquakes.

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Supplemental Material

Introduction

Earthquakes may occur as a single abrupt event or a sequence of occurrences, occasionally followed by a noticeable strain (Gomez *et al.*, 2007). When a sequence of successive earthquakes occurs, the strongest event—the mainshock—may be preceded by mild foreshocks and/or followed by weaker aftershocks. A sequence lacking one clearly dominant earthquake is referred to as a swarm, whereas a succession of several mainshock–aftershock sequences is referred to as a seismic storm (Kisslinger, 1996; Utsu, 2002). Doublets are pairs of successive strong earthquakes that occur due to a power-law recurrence mechanism (Kagan and Jackson, 1999). In such cases, one earthquake can trigger a second large event at distances of several kilometers, potentially involving different tectonic segments (Nissen *et al.*, 2016; Ye *et al.*, 2016). It does not mean, however, that two successive earthquakes with similar magnitudes are necessarily a doublet scenario; they can also reflect foreshock–main or main–aftershock scenarios because there is no upper limit for an aftershock size, although generally the size of the largest aftershock is close to one magnitude degree smaller than the mainshock (e.g., Chen and Wang, 2012).

The period during which earthquakes have been quantitatively monitored is less than 150 yr since the deployment of the first seismographs (Dewey and Byerly, 1969). Because seismic cycles may exceed this instrumental timeframe, pre-instrumental earthquakes provide critical insight for examining long-term regional seismicity (e.g., Guidoboni and Ferrari, 1989; Toppozada *et al.*, 2002; Grünthal *et al.*, 2009; Sharman *et al.*, 2013; Rockwell, 2016; Zohar, 2020). However, the characterization of pre-instrumental earthquakes is occasionally constrained by limited source material (Stucchi *et al.*, 2004; Woessner and Wiemer, 2005), requiring scrutiny and critical evaluation (e.g., Karcz, 2004; Ambraseys, 2005). Given the relatively short instrumental period, historical earthquake accounts are frequently used to infer patterns of present and future seismic activity. The rationale behind this is that seismic activity appears to be cyclic. Thus, earthquake patterns tend to repeat themselves in terms of location, size, the spread

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of the damage, and triggered environmental effects (e.g., McGuire, 2008; Uchida and Bürgmann, 2019). The goal of this article, however, is to work the other way around. That is, instead of examining past scenarios to reflect upon future activity, we constrain a historical earthquake(s) scenario using present-day, well-recorded seismic activity. As a test case, two earthquake sequences were selected: the February 2023 Türkiye doublet (Chen *et al.*, 2023; Petersen *et al.*, 2023) and the 1114/5 C.E. sequence, which is believed to have occurred in the same geographic region as the 2023 doublet (Meghraoui *et al.*, 2025) as well as be its predecessor (Stucchi *et al.*, 2024). Like other historical earthquake scenarios, the interpretation of the 1114/5 C.E. sequence includes several unresolved enigmas to be addressed. First are the apparent discrepancies among historical sources, leading to significant interpretation disagreements between modern twenty-first-century catalogs (e.g., Guidoboni and Comastri, 2005; Sbeinati *et al.*, 2005; Ambraseys, 2009). Second is the chronology of the earthquake sequence, specifically, whether it is composed of two or three large events. Third is the uncertainty regarding the extent and severity of the reported damage, making it difficult to attribute individual damage reports to specific events within the sequence. Finally, the source parameters, such as the epicenters and magnitude estimates, remain elusive (Nalbant *et al.*, 2002).

Following the 2023 Türkiye sequence, our research question is whether and to what degree its characteristics resemble those of the twelfth-century C.E. historical sequence. The underlying hypothesis is that, if a meaningful similarity can be established, the 2023 sequence may be used to help constrain and better characterize the 1114/5 sequence, thereby providing new insights into the historical earthquakes.

2023 Türkiye Sequence

On 6 February 2023, at 01:17:32 (UTC), a devastating earthquake (namely the Pazarcık event, M_w 7.8) hit south-central Türkiye. The earthquake with an epicenter at 37.288° N, 37.043° E and a focal depth of 8.6 km (Disaster and Emergency Management Authority [AFAD], see Data and Resources), occurred on the Pazarcık fault along the East Anatolian fault zone (EAFZ, see Arpat and Şaroğlu, 1972), about 32 km west of Gaziantep. Hancilar *et al.* (2023) suggested a strike-slip movement with a length of 290 km, whereas Zabci *et al.* (2023) and Karabulut *et al.* (2023) suggested a northeast–southwest rupture length of 350 km with coseismic slip of up to 8 m on the Pazarcık fault. Over the next eight hours, the main event was followed by several dozen additional earthquakes (M > 4), including a magnitude M_w 6.7 earthquake at 01:28:16, which struck less than 15 km from the epicenter. Then, at 10:24:47 (UTC), another destructive earthquake (namely the Elbistan event, M_w 7.5) with an epicenter at 38.089° N, 37.239° E and focal depth of 7 km (AFAD, see Data and Resources) occurred on the Cardak fault along the Sürgü–Misis fault zone (SMFZ, see Kaymakci *et al.*, 2010), some 20 km south of Elbistan. Cetin *et al.* (2023) suggested a 160 km rupture length with observed surface displacements ranging from 2 to 8 m, whereas Meghraoui *et al.* (2025) suggested east–west trending of 150 km with coseismic slip of 4.1 m on the Kirikhan segment. On 20 February 2023, another strong event occurred (M_w 6.4) with an epicenter along a southern splay of the Amanos fault, close to the Türkiye–Syria border near the city of Antakya (Hatay) (Karabulut *et al.*, 2023) (Fig. 1a). The two largest events (M 7.8 and 7.5) caused widespread alarm in southern Türkiye and northern Syria (see intensities and isoseismal maps in Fig. 1b,c), resulting in massive damage with fatalities and injuries exceeding 50,000 and 100,000, respectively (Dal Zilio and Ampuero, 2023). Nearly 20,000 buildings collapsed, and more than 350,000 were reported to be damaged. The cities that were damaged most are Kahramanmaras, Adiyaman, Hatay, Osmaniye, Gaziantep, Malatya, Adana, Diyarbakir, Elazig, and Kilis (Ozkula *et al.*, 2023).

The two mainshocks were classified as a doublet occurrence for initiating on two separate faults, with the first M 7.8 earthquake triggering the second M 7.5 earthquake (Jia *et al.*, 2023; Melgar *et al.*, 2023; Toda *et al.*, 2023; Toda and Stein, 2024). The depth of the aftershocks varies from a few kilometers up to more than 40 km, but the majority (more than 90%) are less than 15 km. The aftershocks associated with the two strands continued to occur frequently during the following months. Figure 2 presents the temporal distribution of earthquakes (M ≥ 3.5) for more than two years after the mainshocks occurred and during the first three months (between 6 February 2023 and 5 May 2023). It demonstrates continuous activity of aftershocks along the SMFZ (the events elongated horizontally approximately at latitude 38° N) and EAFZ (between latitudes ∼36° to 37° N) rupture zones, reinforcing a bifurcated seismicity on the two different strands. The number of aftershocks decays in time in accordance with the power law of Gutenberg and Richter (1944), suggesting the existence of secondary aftershock activity (Raykova *et al.*, 2024), which supports the suggestion of the two mainshocks forming a doublet.

1114/5 C.E. Sequence

Revisiting the historical sources

In 1114 C.E., or possibly in both 1114 and 1115 C.E., two to three major earthquakes hit southern Türkiye, followed by a few months of aftershocks. The first earthquake occurred on 10 August 1114. Fulcher of Chartres (1058–1127 C.E.), living in Jerusalem at the time and considered a reliable source (Krey, 2012, p. 30), briefly mentioned it: "Later, on the Feast of St. Lawrence, there was an earthquake" (Chartres, 1969, p. 210). A more embellished version appears in the *Estoire de Jerusalem et d'Antioche*, a vernacular Old French chronicle that draws heavily from Fulcher along with other sources. It echoes Fulcher's timeline, stating that "[…] at the Feast of Saint Lawrence, an earthquake affected us," but then dramatically

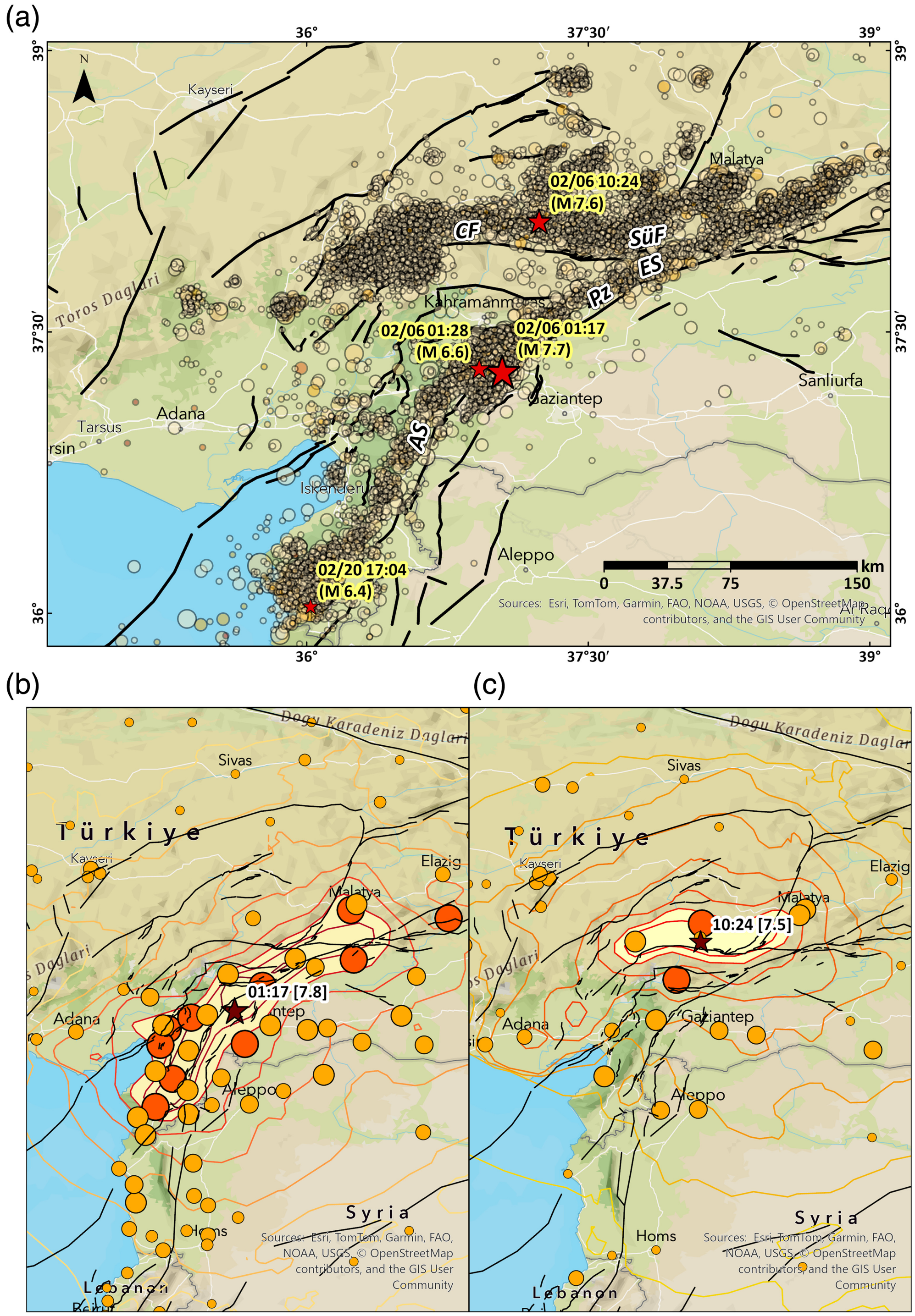

Figure 1. (a) The earthquakes (M ≥ 3) in Türkiye between 6 February 2023 and 10 June 2025. The four large earthquakes (M > 6) are noted in red stars along with the magnitude. Also portrayed are the East Anatolian fault zone (EAFZ, Arpat and Şaroğlu, 1972) segments of Amanos fault (AS); Erkenek (ES); Pazarcık (Pz); Pütürge (PS), and the Sürgü-Misis fault zone (SMFZ, Kaymakci *et al.*, 2010) segments of Çardak (CF); Göksun bend (Gb); Savrun (SaS); and Sürgü (SüF) (Emre *et al.*, 2018). Source of the events: Disaster and Emergency Management Authority (AFAD) (see Data and Resources). (b) Intensity data points (IDPs) and isoseismals for the M 7.8 Pazarcık earthquake (for source website, see Data and Resources). (c) IDPs and isoseismals for the M 7.5 Elbistan earthquake (for source website, see Data and Resources). The area delineated by isoseismals ≥7 is shown in yellow for both (b) and (c). The color version of this figure is available only in the electronic edition.

expands the account: "all the coastal cities and castles collapsed, and the people died" (Estoire-Jerus, 1895, p. 645). The chronicle continues with descriptions of destruction in Maras and Trihalet, although these are details that likely conflate Fulcher's later reference to a "greater quake," which presumably refers to an earthquake that struck on 29 November 1114. Ambraseys (2009, p. 282) accepts this broader narrative cautiously, suggesting that while the extent of coastal destruction is probably exaggerated, the 10 August shock was "probably felt in Antioch," with a possible offshore epicenter in the Bay of Iskenderun. He attributes supporting evidence to Fulcher, Walter the Chancellor, Robert of Torigni (Robert of Torigni, 1889), and the *Estoire*. On closer inspection, the passage that Ambraseys attributes to Fulcher actually originates from the *Secunda pars historiae Iherosolimitane*, an anonymous and loosely structured continuation of Fulcher's chronicle, which is sometimes attributed to Lisiard of Tours. Though it includes material beyond Fulcher's endpoint, Guidoboni and Comastri (2005, p. 70) describe it as "a kind of epitome" of his original work, blending summary, repetition, and additions. Additional description appears in *Secunda pars* stating: "In April or in May and the following [months?], a horrible earthquake struck. Some parts of the city of Mamistria were overturned, and many towns in the region of Antioch were affected—some partially destroyed, others completely—along with loss of life." This version

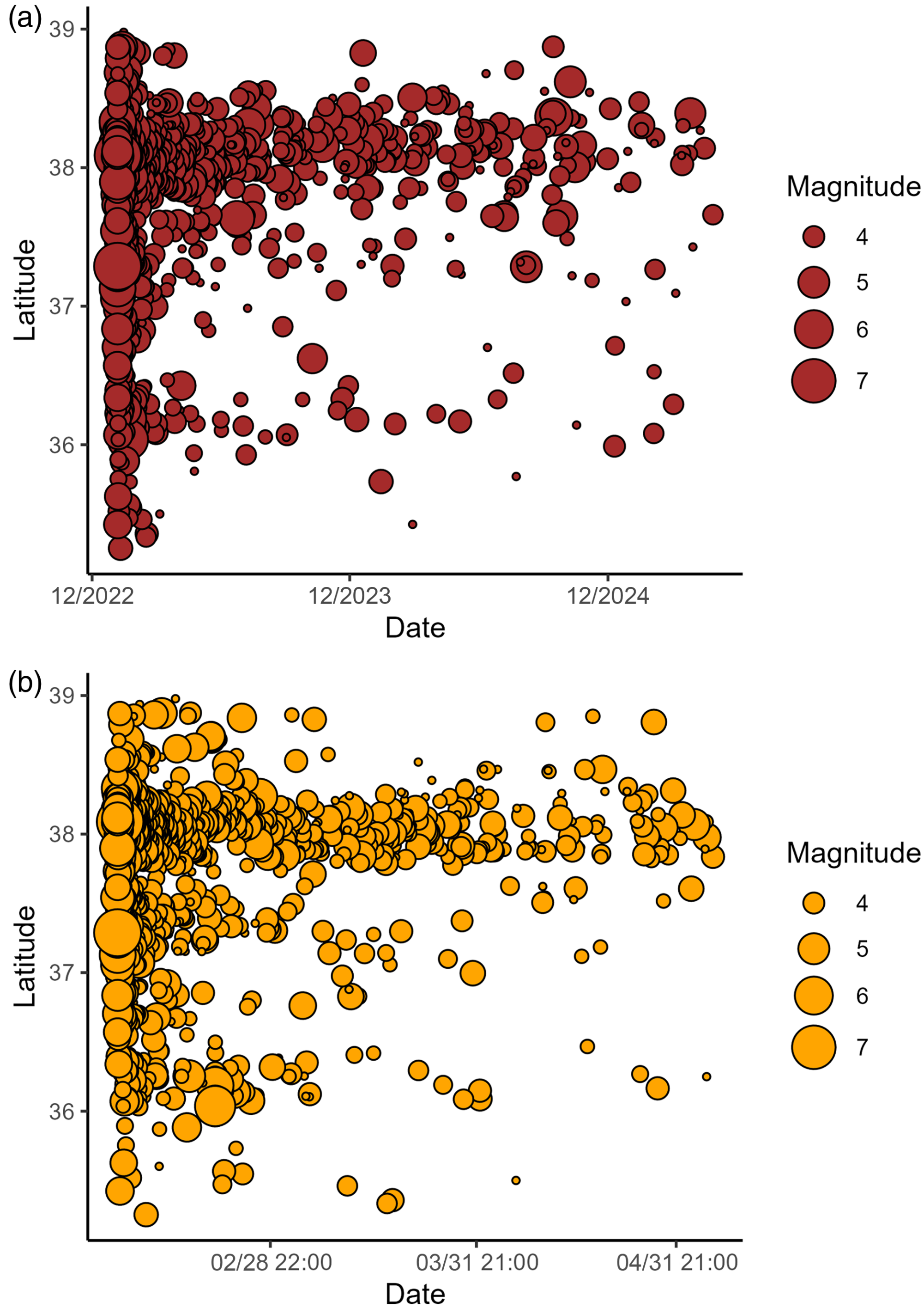

Figure 2. (a) Spatiotemporal distribution of the earthquake occurrences (M ≥ 3.5) between 5 February 2023 and 12 June 2025. (b) The same distribution portrayed in (a) but focused on the first three months (between 6 February 2023 and 5 May 2023). Note the distribution along latitude ~38° N and ~36°–37° N denoting the activity along the northern and southern strands of the Sürgü–Misis fault zone (SMFZ) and East Anatolian fault zone (EAFZ), respectively (source: the Türkiye AFAD catalog, see Data and Resources). The color version of this figure is available only in the electronic edition.

conflates multiple seismic events, including possibly the 13 and 29 November earthquakes, into a vague and imprecise time frame that lacks the chronological clarity of Fulcher's 10 August reference. Importantly, unlike *Secunda pars*, Fulcher himself does not state that the 10 August 1114, C.E. earthquake was felt in Antioch, nor does he mention coastal destruction like *Estoire*. Regarding the other sources cited by Ambraseys, Walter the Chancellor does not refer to an earthquake occurring in the spring, summer, or on 10 August 1114. Robert of Torigni, by contrast, briefly mentions an undated earthquake in 1114 that appears consistent with the 29 November event and may also reflect elements of the 13 November earthquake. Robert subsequently seems to describe the same 29 November earthquake as recurring, or more likely being rereported, in 1115. Thus, although an earthquake near the EAFZ may have occurred and been felt as farther south as Jerusalem (more than 600 km away), the most plausible interpretation is that Fulcher was describing localized shaking in Jerusalem or the broader region of Palestine. Subsequent derivative accounts appear to have embellished the event and introduced chronological confusion.

The second earthquake struck on the night of 13 November, though sources differ on whether it occurred in 1114 or 1115 C.E. Among modern catalogs, the date and region are agreed upon among Guidoboni and Comastri (2005) and Ambraseys (2009), but they disagree about the size of the event. The former argues that this was the biggest event in the sequence, whereas the latter suggests the third earthquake was the largest of the two. Contemporaneous sources Fulcher of Chartres and Walter the Chancellor report that it destroyed part of the city of

Mamistra (Misis) (Walter the Chancellor, 1999, p. 82 and Chartres, 1969, p. 210). During that event, Abbot Anselm of Gembloux (twelfth century C.E.)—a contemporaneous source writing from Belgium possibly echoing reports from returning Crusaders—described how, in the suburbs of Antioch, the ground opened (possibly due to fissures or landslides), houses collapsed, people were killed, and several towers along with nearby structures were destroyed (Anselm in Bethmann, Abbot Anselm, 1844, pp. 375–376, in Latin). However, it seems he misdated the damage in Antioch as local, and a contemporaneous source, Walter the Chancellor, indicates that Antioch was heavily damaged in the earthquake on 29 November rather than in the earthquake on 13 November. Writing more than 200 yr later, Andrea Dandolo added that Cilicia and Mamistra and the surrounding area were especially affected, with aftershocks causing people to fear being swallowed by the earth (Dandolo and Pastorello, 1938–1958, p. 230).

The third reported earthquake occurred a day before the Feast of Saint Andrew on the night of 29 November. This event is documented by over two dozen sources. Some of the most important sources are Walter the Chancellor, Matthew of Edessa, Ibn al-Jawzi, Michael the Syrian, Chronicon Ad Annum 1234, Kemal ad-Din, the Chronicle of Sembat, and Bar Hebraeus (Walter the Chancellor, 1999, pp. 81–87; Matthew of Edessa, 1993, pp. 216–217; Ibn al-Jawzi in Ambraseys, 2009, p. 290; Michael the Syrian, 1899–1910, p. 200; Chronicon ad annum 1234, 1916–1937, v. 2, pp. 58, 60; Kemal ad-Din, Ibn al-ʿAdīm, 1884, p. 607; the Sparapet Sembat, 1869, p. 614; and Bar Hebraeus, 1932, p. 247). This event left a strong historical imprint and appears to have been the largest of the 1114/1115 C.E. earthquake. Contemporaneous sources, Walter the Chancellor and Matthew of Edessa, wrote long, detailed accounts of the earthquake from opposite ends of the fault rupture. Walter was in Antioch when the earthquake struck. He wrote about an "immense and terrible earthquake in Antioch and its region," noting how the townspeople frantically attempted to flee their collapsing structures. By morning, he observed the extensive destruction, stating, "… the vast scale of the wretched disaster was clear beneath the ruin both of men and of other things." (Walter the Chancellor, 1999, p. 81). Reports came in that Marash had been "entirely destroyed with its lord and bishop … the clergy and all the people," and Mamistra also experienced significant damage (Walter the Chancellor, 1999, p. 82). In addition, destruction was feared in al-Atharib and "other Antiochene borders." Walter described aftershocks—"each day, the earthquake threatened for hopeless hours." Walter also noted that many people in Antioch slept outside, which also suggests continuing aftershocks (Walter the Chancellor, 1999, p. 83). In addition, Walter referred to the danger of "threatening" earthquakes persisting for five months, indicating a prolonged period of aftershocks (Walter the Chancellor, 1999, p. 84). Of the sources mentioned earlier, only Walter dated the earthquake to 29 November 1115 C.E. The other sources dated it to 29 November 1114 C.E. For this, and the reasons stated subsequently, Walter likely provided an incorrect year.

According to Walter, after the earthquake, Roger of Salerno, the ruler of the Principality of Antioch, repaired earthquake-damaged fortifications in his realm (Walter the Chancellor, 1999, p. 84). Roger's intelligence agents later returned from their reconnaissance missions, reporting that there was public rejoicing within the Seljuk Empire over the widespread ruin and destruction in Syria. They also relayed that the "Sultan" had assembled an army with the aim of conquering Roger's domain and other parts of Syria, assuming that the earthquake had significantly weakened regional defenses (Walter the Chancellor, 1999, pp. 86–87). Then Walter discusses events leading up to the Battle of Tell Danith (also known as the Battle of Sarmin). Bursuq ibn Bursuq launched an invasion and was met by a broad military alliance: Lulu, the de facto ruler of Aleppo; Tughtegin of Damascus; Il-Ghazi of Mardin; and Crusader forces from the four principal states—Edessa, Antioch, Tripoli, and Jerusalem. Following a period of inconclusive engagements, Roger launched a surprise attack and decisively defeated Bursuq ibn Bursuq's forces at the Battle of Tell Danith on 15 September 1115. This well-dated battle seems to preclude a 1115 C.E. date for the 29 November earthquake, as Roger's post-earthquake repairs took place before this battle and in preparation for expected military activity, not after. Because Walter tells us that the 13 November earthquake struck before the 29 November earthquake, this would suggest that the 13 November earthquake also struck in 1114 C.E. Thus, it appears that the 13 and 29 November earthquakes occurred within 16 days of each other in 1114.

Matthew of Edessa also composed a first-hand account of the 29 November earthquake, likely written from a monastery near Kaysun. He recorded occurrences of landslides, rockfalls, loud noises, seismic concussions, and the cries of those trapped beneath the rubble. (Matthew of Edessa, 1993, p. 216). Matthew also noted ongoing aftershocks (Matthew of Edessa, 1993, pp. 216–217). Reports emerged from other locations, indicating that Samosata, Hisn-Mansur, and Raban were destroyed along with Kaysun (Matthew of Edessa, 1993, p. 217). In a probable exaggeration, Matthew claimed there were no survivors in Marash and reported 40,000 fatalities (Matthew of Edessa, 1993, p. 217). Mamistra was reported to be similarly affected (Matthew of Edessa, 1993, p. 217). Many towns and districts, particularly in the territory of the Crusader States, were said to be destroyed (Matthew of Edessa, 1993, p. 217). Matthew further described damage and loss of life at the Basilian Monastery in the Black Mountains near Marash, and perhaps at the Mashchgavor (Mashkur) Monastery (Matthew of Edessa, 1993, p. 217). Following the earthquake, Matthew wrote that snow covered the land (Matthew of Edessa, 1993, p. 217).

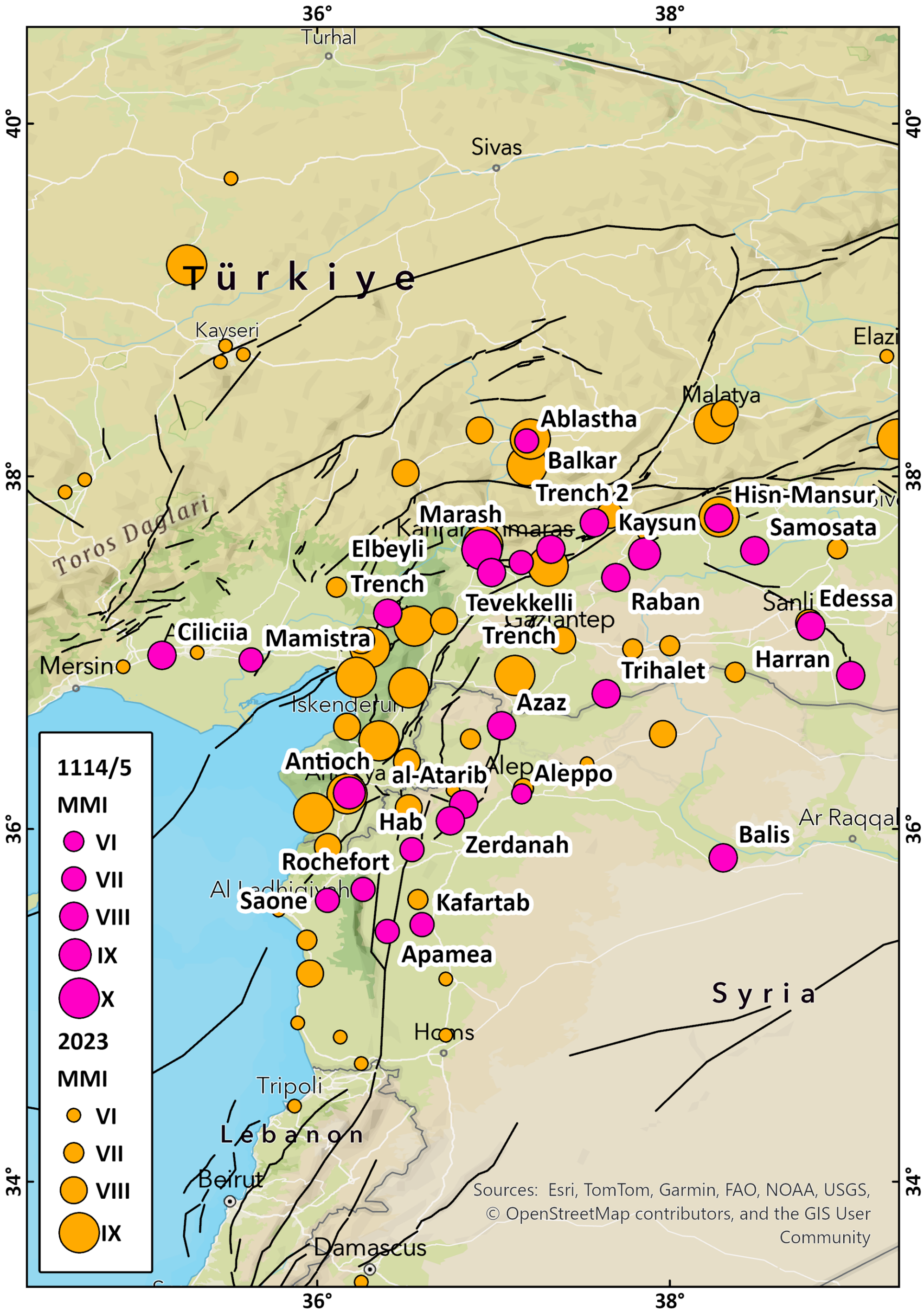

Figure 3. Interpreted IDPs of the historical 1114/5 C.E. sequence (see Tables S2 and S3) superimposed on the U.S. Geological Survey (USGS) IDPs of the 2023 Pazarcık M 7.8 and Elbistan M 7.5 earthquakes. The color version of this figure is available only in the electronic edition.

Magnitude and epicentral region

Modern catalogs and focused investigations offer differing interpretations of these earthquakes. Ambraseys and Jackson (1998) classify the third earthquake (29 November 1114) as a very large event (M ≥ 7.8). Ambraseys (2009, parametric catalog) estimated the magnitudes of the second and third earthquakes to be $M_s = 5$ and $M_s = 6.9$ (±0.3), respectively, with epicenters of 35.6° E, 37° N, and 37.2° E, 37.5° N, respectively (Fig. 3). Guidoboni and Comastri (2005), who appear to have mislocated sites from the third event into the second event and vice versa, refer to the second event (13 November 1114) as the largest event ($M_e = 7.8$, $I_{max} =$ X). In contrast, the magnitude of the third is estimated to be $M_e = 6.3$ ($I_{max} =$ X). They estimated the epicenter of the second and third earthquakes at 37.6° E, 37.4° N and 36.2° E, 37.2° N, respectively (Fig. 3). Sbeinati *et al.* (2005), although not decisive in the number of events, estimate magnitudes for two earthquakes in November 1114 to be M 7.4 and 7.7 with I_0 of VIII–IX and X, respectively, and identical epicenters of 38.5° E, 37.3° N. Ben-Menahem (1979) refers to two events: the first in 10 August 1114, affecting Antioch (with an accompanied tsunami) and felt in Jerusalem, with $M_L = 7.0$ and epicenter at 36.5° N, 36° E, whereas the second on 25 December 1115, in southern Türkiye and also felt in Jerusalem, with $M_L = 7.5$ and epicenter at 38.9° E, 37° N. Duman *et al.* (2020) describe two earthquakes in 1114 and 1115 but suggest they refer to the same one. In addition, they identified paleoseismic evidence that may correspond to an earthquake in 1114/1115 C.E., but the dating is roughly accurate (between ~1035 and 1215 C.E.). Carena *et al.* (2023) follow Ambraseys (2009) and refer to a single earthquake that occurred on 29 November 1114, estimating a magnitude of M_w 7.2 with five aftershocks following the main event and the Pazarcık fault as the triggering tectonic segment. Kondorskaya and Ulomov (1999) mention the 10 August 1114 earthquake with an $I_{max} =$ X and epicenter at 38° E, 37.5° N. The Global Historical Earthquake Archive (GHEA) catalog (Albini *et al.*, 2013) includes two events that occurred in 1114: the first (M 7.4, with epicenter near Şanlurfa, east of the Euphrates valley) has been taken from Sbeinati *et al.* (2005), whereas the second (29 November 1114, M_w 6.9) has been taken from Ambraseys (2009).

Damage distribution

Modern earthquake catalogs list the resulting damage from these three events with a varying degree of discussion. Guidoboni and Comastri (2005) evaluated seismic intensities of 12 damaged and felt sites of the 1114/5 sequence on the Mercalli–Cancani–Sieberg (MCS) macroseismic scale (Sieberg, 1932; Ferrari and Guidoboni, 2000) (see Table S1, available in the supplemental material to this article). They also describe potential environmental effects in Antakya following the second earthquake. Ambraseys (2009) listed these with slightly different classifications between the resulting event sites. Although disagreeing with Guidoboni and Comastri (2005), he made no seismic intensity estimation. Sbeinati *et al.* (2005) evaluated intensities for seven localities in the European macroseismic scale (EMS-92) scale (Grünthal, 1993). However, although stating that their interpreted damage could have been the result of two plausible, separate events in November 1114 C.E., they list the damaged localities in a single list with no distinction of which locality was damaged in which event. Meghraoui *et al.* (2025) (following Sbeinati *et al.*, 2005; APAME, 2007; Ambraseys, 2009) listed 17 damaged localities associated with a single event on 29 November 1114.

Revisiting the historical sources alongside recent paleoseismic evidence yielded three lists: (1) localities damaged or felt by the 13 November earthquake (see Table S2); (2) localities damaged by the 29 November earthquake (see Table S3); and (3) debated localities for the 29 November earthquake (see Table S4). Notably, paleoseismic evidence from the Balkar trench 2, Tevekkelli trench, and the Nacar trench suggests that the Pazarcık segment ruptured during the 29 November earthquake, whereas evidence from the Elbeyli trench indicates that the Düziçi segment ruptured during the 13 November earthquake. It is also important to emphasize that none of the contemporary sources reported damage to fortifications at Apamea, Kafartab, Maarat al-Numan, Shaizar, Hab, Bourzey Castle (potentially Rochefort), or Saone during the 29 November earthquake. However, Walter the Chancellor noted that Prince Roger visited and repaired damaged structures in several castles and surrounding areas after the earthquake (Walter the Chancellor, 1999, p. 84), indicating that additional earthquake-related destruction may have occurred at these and other locations.

Constraining the Twelfth Century C.E. Historical Sequence

When comparing instrumental and pre-instrumental earthquakes, it is important to note that the epicenters and magnitudes of the latter are not calculated but rather are estimated—typically by inference from the spread and severity of the reported damage. However, in the case of a sequence of historical earthquakes, it is often difficult to determine precisely which event caused specific instances of damage. Considering the temporal proximity between the earthquakes of 1114/5, one cannot rule out potential duplication of damage on the one hand and amalgamation of several damages into one on the other hand. Therefore, our inspection of the spread of the damage was not done separately for each of the mainshocks but rather was carried out for the whole historical sequence. The same was done for the damaged localities of the 2023 Pazarcık and Elbistan earthquakes, which were grouped and examined together. If the same locality appeared in connection with two earthquakes, the entries were amalgamated, and the higher intensity value was retained. Because we only have an interpretation of damaged localities associated with the twelfth-century sequence, the examination of the 2023 sequence was carried out only on localities of MMI ≥ 6. Altogether 27 and 69 intensity data points (IDPs) were analyzed for the 1114/5 and 2023 sequences, respectively (Fig. 3).

To detect potential damage patterns with an aim to characterize seismic activity, a kernel density estimation (KDE) process (Silverman, 1986) was carried out on the two IDP datasets. KDE estimates the probability density function of the IDPs by placing a smooth kernel over each data point and adding them to create a continuous surface, allowing for the visualization of damage patterns and identifying hotspots (e.g., Amador Luna *et al.*, 2024). The density of the damage, indicating spatial severity, was evaluated as follows:

1. Kernel density $= \frac{1}{(\text{radius})^2} \sum_{i=n}^{n} \left[\frac{3}{\pi} \left(1 - \left(\frac{\text{dist}_i}{\text{radius}} \right)^2 \right)^2 \right]$.
2. Radius $(h_{\text{opt}}) = (\frac{2}{3n})^{1/4} * \text{SD}$.
3. $\text{SD} = \sqrt{\frac{\sum_{i=1}^{n} Wi(Xi-X)^2}{n} + \frac{\sum_{i=1}^{n} Wi(Yi-Y)^2}{n}}$.

In which the kernel density is the value at a given location; dist_i is the distance between a given point (IDP) and the calculated density location; radius is the optimal search radius (h_{opt}); n is the number of IDPs; SD is the weighted standard distance; Wi is the weighted parameter; Xi, Yi are the coordinates of a given IDP; and X, Y are the mean coordinates of all points (all IDPs) (Zohar *et al.*, 2023). For the 2023 doublet and the 1114/5 sequence, the parameters of n, SD, and search radius (h_{opt}) are 69; 209 km; 65 km and 27; 122 km; 48 km, respectively. Naturally, the number of IDPs of the 2023 scenario is higher than that of the historical 1114/5 sequence, which results in a wider area and a larger standard distance. Yet, the central location of both datasets is relatively close (36.89° E 36.92° N versus 37.13° E 36.82° N), suggesting that the patterns of the damage distribution in both scenarios are similar. In addition, in both scenarios, one can identify two significant hotspots of damage

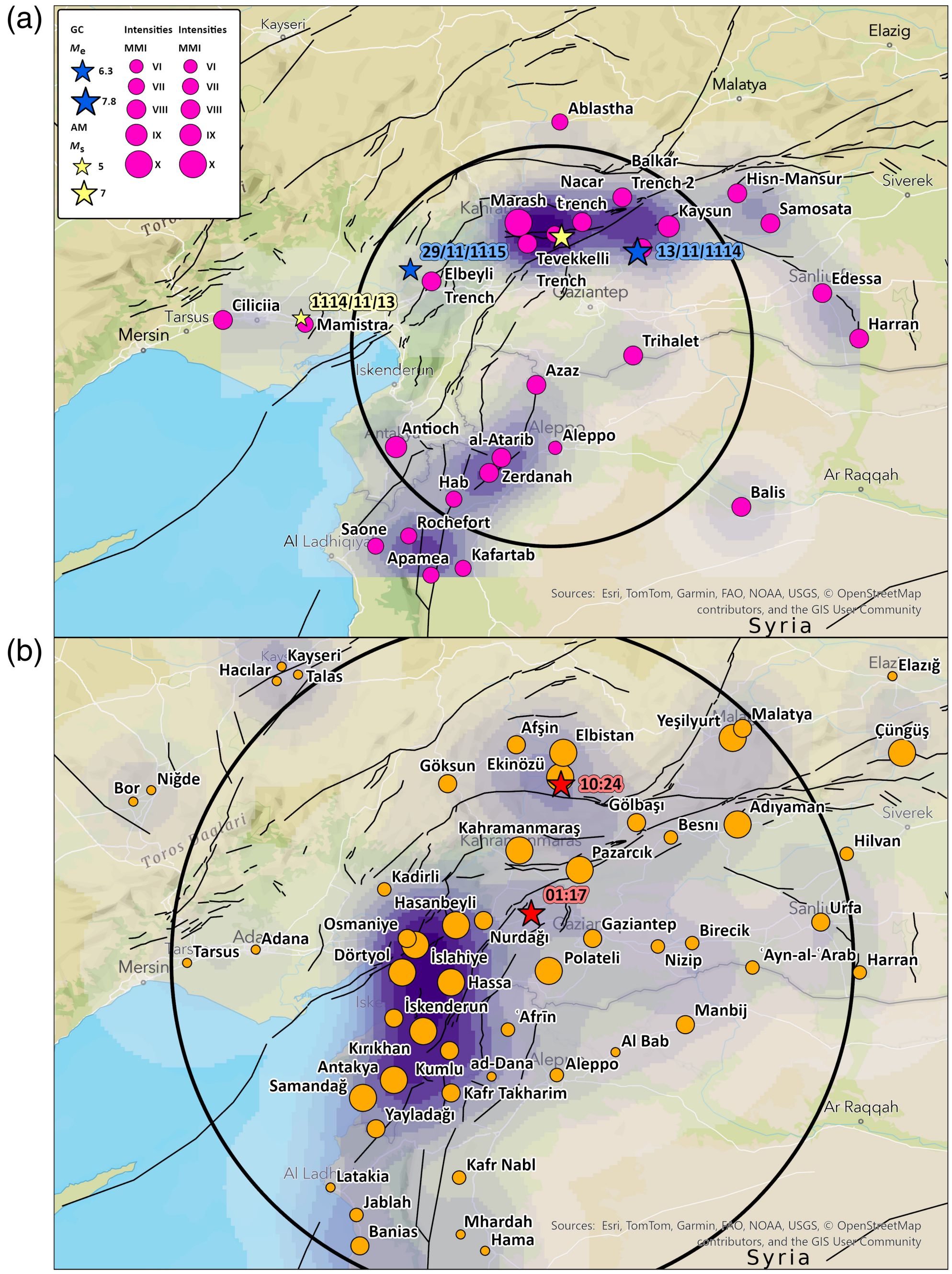

Figure 4. Standard distance and kernel density of the damage distribution of the 1114/5 C.E. and 2023 sequences: (a) IDPs (modified Mercalli intensity [MMI] scale ranging between VI and X) distribution following the 13 and 29 November earthquakes (altogether 27 IDPs without duplicate localities). (b) IDPs (MMI scale ranging between VI and IX) distribution of the M 7.8 Pazarcık (6 February 2023 01:17:35 UTC) and the M 7.5 Elbistan (6 February 2023 10:24:49 UTC) earthquake (altogether 69 IDPs with no duplicate localities). The color version of this figure is available only in the electronic edition.

spread and severity. In the 2023 doublet scenario, the northern hotspot is located close to Elbistan and Ekirozu, about 50 km north of Kahramanmaras, which is also the epicentral region of the M 7.5 Elbistan epicenter (Fig. 4). The southern hotspot, however, extends into the region between the cities Antakya, Islahiye, HasanBeyli, and Hassa. Unlike the northern one, the southern hotspot is relatively far from the epicentral region of the M 7.8 Pazarcık earthquake, some 80 km to the east. The 1114/5 sequence presents a similar dual pattern with some differences. Its northern hotspot is located in the region of Kahramanmaras, close to the epicenters evaluated by Guidoboni and Comastri (referencing 13 November 1114) and Ambraseys (2009) (referring to 29 November 1114). The southern hotspot extends between the cities Apamea and Al-Atarib, about 40 km southeast of Antakya and more than 100 km south of the epicenters evaluated by Guidoboni and Comastri (referring to 29 November 1115) and Ambraseys (2009) (referring to 13 November 1114). In other words, in both scenarios (2023 and 1114/5), the northern hotspot is located close to the epicentral region (whether calculated for the 2023 scenario or estimated for the 1114/5 scenario), whereas the southern hotspot of the 1114/5 sequence is located about 80 km south of the 2023 sequence; both hotspots are not in proximity to the epicentral region.

Comparison of the spread of the damage suggests that the magnitudes of the twelfth-century earthquakes were not substantially lower than those of the 2023 events. One might reasonably consider that poorer construction techniques and materials in the twelfth century could exaggerate the apparent severity of historical damage. However, even when the evaluated intensities are reduced by a full degree (e.g., IX and VIII become VIII and VII, respectively), the affected area remains extensive. Ambraseys (2009) assigns M 5 and 6.9 (±0.3) to the 13 and 29 November historical events, respectively, whereas Guidoboni and Comastri (2005) assign M 7.8 and 6.3 to those events, respectively. When examined and viewed alongside the 2023 damage patterns, it is reasonable to hypothesize that at least one of the 1114/5 events reached M > 7, in agreement with the recent estimates of M 6.4 and 7.7 by Stucchi *et al.* (2024).

The EAFZ is a highly active seismic region driven by the northeastward movement of the Arabian plate relative to the Anatolian plate, resulting in a horizontal slip rate of 10–11 mm/yr in the EAFZ (Cetin *et al.*, 2023). Over the past millennia, this fault system has likely generated multiple large historical earthquakes (e.g., 1269, 1513/1514, and 1544, see Stucchi *et al.*, 2024) reflecting its capacity to produce high-magnitude events (Ozkula *et al.*, 2023). In contrast to the 2023 earthquake doublet, the second event of the twelfth-century sequence appears to have been the larger of the two, as indicated by the broader geographical extent of damage aligned with the EAFZ segments. Notably, in both 2023 and 1114/5 scenarios, aftershocks occurred and persisted for several months, suggesting that the historical scenario might had a decay pattern of seismicity consistent with the modified Omori law as observed in the 2023 sequence (see Rekapalli *et al.*, 2023; Raykova *et al.*, 2024; Polat *et al.*, 2025) might have been similar in the case of the 1114/5 sequence.

The Türkiye 2023 M 7.8 Pazarcık and M 7.5 Elbistan form a doublet of two mainshocks (e.g., Chen *et al.*, 2023; Jia *et al.*, 2023, Petersen *et al.*, 2023; Yan *et al.*, 2024). Toda and Stein (2024) (after Toda *et al.*, 2023) suggest that the Pazarcık earthquake promoted the occurrence of the Elbistan earthquake through stress transfer and unclamping of its epicentral patch. This pattern is also known from other doublet cases worldwide (see examples in Toda and Stein, 2024). This notion is supported in additional studies describing the seismicity of the 2023 sequence (e.g., Okuwaki *et al.*, 2023; Ren *et al.*, 2024; Zhou *et al.*, 2025). Toward the future, Meghraoui *et al.* (2025) observed stress transfer after the 2023 sequence and accordingly suggest that the Pazarcık earthquake rupture increases potential failure along the northern Dead Sea fault.

Recently, Stucchi *et al.* (2024) suggested that the 1114/5 scenario reflects an earthquake sequence that can be considered as a predecessor of the main 2023 earthquake. As far as the 1114/5 sequence is concerned, we are aware that the 1114/5 scenario can vary between multiple patterns, including: one or more strong foreshocks and a stronger mainshock; a strong mainshock followed by one or more strong aftershocks; multiple strong events that might be classed as an earthquake swarm; or multiple earthquakes that are part of an earthquake storm. Although several studies refer to a single event in November 1114 (e.g., Duman *et al.*, 2020; Carena *et al.*, 2023), it seems that the interpretation of the historical sources and paleoseismic evidence (see Tables S2 and S3), as well as the spatial analysis (Fig. 4) suggest that at least two strong earthquakes struck southern Türkiye at the time. According to the Coulomb stress theory (King *et al.*, 1994), it is unlikely that the same fault or adjacent parallel faults with identical kinematics will generate two strong earthquakes within a short period of time. Thus, the two most plausible seismic interpretations of the 1114/5 sequence are either a foreshock–mainshock–aftershock pattern or two distinct major earthquakes rupturing different tectonic segments. Based on the discussion above, we argue that the latter scenario provides a more convincing explanation for the 1114/5 events. Nevertheless, it should be stressed that our opinion relies on an interpretation of incomplete and limited historical records.

Summary

Constraining the 1114/5 C.E. historical sequence through comparison with the February 2023 doublet provides new insights into the nature of past seismic activity in southern Türkiye. Given the limitations of historical data and the temporal proximity between the 1114/5 events, the analysis interrogated the overall damage from each sequence rather than attempting to attribute separate damage to individual events. KDE applied to IDPs reveals two consistent hotspots of severe damage: one in the north near Kahramanmaraş and Elbistan, and one in the south near Antakya, although their exact positions differ slightly between the two periods. Despite these differences, the broader spatial patterns of damage show a notable resemblance. The analysis suggests that at least one of the twelfth-century earthquakes likely exceeded magnitude 7, comparable to the 2023 events. Even when historical intensities are reduced to account for weaker construction practices, the extent of damage remains substantial.

Tectonically, the EAFZ has generated large historical earthquakes and continues to pose significant seismic risk, with a known slip rate of 10–11 mm/yr. The 2023 doublet likely involved stress transfer between the Pazarcık and Elbistan segments. Although some scholars have interpreted the 1114/5 events as a single earthquake, both paleoseismic evidence and historical records suggest a more complex sequence, possibly involving foreshocks, aftershocks, or even an earthquake storm. Coulomb stress principles imply that the twelfth-century sequence did not follow a simple mainshock–aftershock pattern but consisted of two distinct large events. The resemblance between the spatial distribution and character of the 2023 and 1114/5 sequences may imply a recurring seismic pattern, supporting the notion of the twelfth-century sequence as a plausible historical predecessor to the 2023 events. However, whether the early twelfth-century C.E. earthquakes constituted a true doublet remains uncertain because the available historical evidence is insufficient for a definitive conclusion.

Data and Resources

All data used in this article came from published sources listed in the references. Intensity data points (IDPs) and isoseismals for Figure 2 were available at https://earthquake.usgs.gov/earthquakes/eventpage/

us6000jllz/executive and https://earthquake.usgs.gov/earthquakes/eventpage/us6000jlqa/executive. The Türkiye Disaster and Emergency Management Authority (AFAD) catalog is available at https://deprem.afad.gov.tr/event-catalog. All websites were last accessed in June 2025. The supplemental material for this article includes Tables S1–S4 of damage descriptions interpretation, along with intensity evaluation.

Declaration of Competing Interests

The authors acknowledge that there are no conflicts of interest recorded.

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