CHAPTER 6

Historical Seismology

Lee Mordechai

Earthquakes feature regularly in 21st-century news. The immense casualties and damage associated with major seismic events such as those in the Indian Ocean (2004), Haiti (2010), Japan (2011) and Nepal (2015), alongside their prolonged coverage and documentation, have attracted Western public and scholarly attention. Scholars and experts in different fields all agree that as the world's wealth, population, and population density grow, the severity of the impact of earthquakes and other natural disasters on human societies will likely increase.[1] As a result, future events could be even more destructive. Historical seismology, the study of past seismic events (earthquakes and tsunamis), is important in this context for understanding an area's seismicity by determining the frequency and magnitude of its past seismic events. This avenue of research is also relevant for historical studies since it illuminates some of the environmental events past societies faced.

The eastern Mediterranean and Asia Minor in particular have long been recognized as seismically active.[2] Historical and epigraphic sources frequently report destructive premodern seismic events. There is written evidence for several hundred earthquakes in the entire Mediterranean area until AD 1500, most of which are concentrated in Asia Minor, the Levant and the Aegean.[3] The ubiquity of the phenomenon in the region has led premodern contemporaries to theorize about the causes of these seismic events.[4] Modern scholars reading the catastrophic descriptions in the primary sources have sometimes ascribed destruction, decline, and even collapse of whole societies to such events.[5]

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1 Matthewman 2015, 4.

2 This is the result of tectonic plate movement by (1) the Arabian plate, moving north from Arabia and Syria; (2) the Anatolian plate, moving west and southwest against the Eurasian plate in the Balkans; (3) the African plate, moving north from Egypt and the Mediterranean. The theory of tectonic plates was suggested in the early 20th century but became accepted only in the 1950s and 1960s.

3 (See Guidoboni and Comastri 2005) The latest catalog refers to 2,000 earthquakes in the Mediterranean and Middle East over the past two thousand years, (N. Ambraseys 2009, 13).

4 Explanations have shifted between natural and divine means. (Guidoboni and Ebel 2009, 147–94 for the development of the scientific understanding of earthquakes since antiquity.)

5 See the survey of the discourse about collapse at (Middleton 2012; Haldon et al. 2020; also Nur and Burgess 2008).

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Over the past few decades, however, the consensus in disaster studies has shifted away from the view that natural disasters afflict passive societies.[6] Current models ascribe more agency to the human societies that experience such events. Societies can mitigate *hazards* such as earthquakes, which become *disasters* only if they fail to do so.[7] Disasters, in this sense, highlight a society's strengths and weaknesses.[8] Contemporary evidence indicates that societies can significantly influence the outcome of a natural hazard. A comparison between the 2010 earthquakes that hit Port-au-Prince, Haiti and Christchurch, New Zealand demonstrates the differential effects of similar events. Both were of comparable magnitude and hit nearby population centers. The former was perhaps the second deadliest earthquake of the 21st century so far, causing between 100,000 and 300,000 casualties in Haiti, a country in the 145th place of the UN's Human Development Index (2010).[9] The country was still struggling to recover more than a decade after the event.[10] In New Zealand, located in the 3rd place of the same index, the Christchurch earthquake had a certain economic cost but caused only injuries. Commentators have explained the vastly different outcome by a series of variables that included construction materials, emergency services and infrastructure.[11] Recent scholarship has shown how social capital, in particular, is a key variable in determining the effects of a disaster on a society or community.[12] Much historical scholarship, however, has not caught up yet with these broader developments and still follows the obsolete model that assumes natural hazards would result in catastrophic damage.

As natural hazards, earthquakes are perceptible movements of the earth's surface.[13] They occur as a result of vibrations (seismic waves) that radiate from a sudden fracturing in the earth's crust. Most earthquakes happen near the boundaries of tectonic plates and can occur at different depths below

6 Wisner et al. 2004; Smith 2013, 1–22.

7 The Emergency Database run by the Centre for research on the Epidemiology of Disasters defines disasters post-1900 as events that conform to at least one of the following: (1) 10 or more people dead; (2) 100 or more people affected; (3) The declaration of a state of emergency; (4) a call for international assistance. See (Centre for research on the Epidemiology of Disasters 2022). The database includes all such events since 1900.

8 Fritz in Knowles 2011, 209.

9 UNDP (United Nations Development Programme) 2010, 148–50.

10 Sael, Savard, and Clormeus n.d.

11 Bilham 2010; Matthewman 2015, 27; also Kahn 2005.

12 Aldrich 2012, 15.

13 For a more detailed description of earthquakes see Guidoboni and Ebel 2009, 11–26; also N. Ambraseys 2009, 1–59.

ground.[14] The epicenter is the point directly above the fracture, where the shaking is most violent. Earthquakes are often measured on the logarithmic Moment Magnitude Scale (MMS).[15] Earthquakes under 3.0 are often imperceptible and cause no damage. Earthquakes above 7.0 can wreak havoc in large areas. Earthquake duration and frequency are closely correlated with their intensity.[16]

Earthquakes also have a significant social component since they are complex events that affect human societies in different stages. The brief tremors that cause the collapse of buildings are only the primary effect of an earthquake. Secondary and tertiary effects take place over the next days to months. Some, such as fires, are triggered directly by the shaking. Others are part of an entangled cascade of causes and effects. These could include crises of varying severity such as food shortages due to the destruction of food stocks or epidemics due to the deteriorated sanitary conditions and destroyed infrastructure. Serious events stimulate population movement and general societal unrest that can ripple across a region. Throughout this model, local environmental conditions (e.g. temperature, crop yield) interact with societal characteristics (e.g. social cohesion, central coordination of relief efforts) to create different outcomes. As a result, a high intensity earthquake does not necessarily imply a high number of casualties and vice versa.

Although premodern earthquakes sometimes strained local societies, surviving primary sources often refer only to central government involvement due to their nature. Central governments tended to react by providing temporary tax reliefs to afflicted areas, but would sometimes also send funds, manpower or supplies to augment local efforts. They tended to focus their resources on the most conspicuous buildings in cities such as major churches, or defensive structures such as city walls.[17] Governors and local representatives of the central government such as bishops were responsible for executing these plans. In antiquity and Late Antiquity there are more references to the seemingly independent actions of local elites, who tended to be local benefactors that repaired or rebuilt a certain building or small area. Their activity is often commemorated on inscriptions. There are also a few cases in antiquity in which

14 Shallow earthquakes are closer to the surface and cause more damage.

15 Thus, the amplitude of the seismic waves triggered by a 5.0 earthquake is ten times as much as those triggered by a 4.0 earthquake.

16 There are far more small earthquakes than big ones. For example, there will be about 10 times more 4.0 earthquakes than 5.0 earthquakes around the world in a given time period. Smaller earthquakes will be much shorter (a few seconds) than bigger ones (up to a few minutes of shaking).

17 Mordechai and Pickett 2018.

foreign rulers provided assistance to afflicted communities as well for propaganda purposes.[18] In this context, it seems clear that local non-elites bore the brunt of reconstruction efforts using their own means.

All in all, response efforts were inherently local, as structural limitations on communication and movement severely hindered any attempts of the imperial center to centrally manage the disaster. This in turn required decentralizing authority to local representatives and likely sanctioning their decisions retroactively. Rebuilding was not the only response communities chose, and in some cases settlements were abandoned.[19] There is no clear evidence that past societies adapted their building practices to better prepare for future earthquakes, a phenomenon that appears also in modern comparative data from rural inhabitant interviews.[20]

1 Historical Seismology: The Sources

Earthquakes are unique among natural hazards as relatively frequent short-term cataclysmic events (SCEs) that appear in the three main types of sources: historical-textual, archaeological and natural (see Fig. 6.1). These are not always independent.[21] Synthesizing all sources offers the greatest potential to learn about past seismic events and how societies reacted to them. However, the critical analysis of this multivariate source base requires an uncommon skillset that is best addressed in collaborative work. The absence of such a skillset has contributed to the circular reasoning that is frequent in the field.[22]

Historical sources – literary and epigraphic for the Byzantine period – have traditionally been the foundation of attempts to understand discrete historical seismic events. As such, they form the backbone of earthquake catalogs.[23]

18 For a famous example, see the case of Rhodes in the 3rd century BC in (Berthold 2009, 92–93).

19 This response pattern continued into the 20th century. It seems that smaller settlements were abandoned more often than larger ones. Their inhabitants could found a new settlement a few hundred meters away or move elsewhere. (Guidoboni and Ebel 2009, 364–66; N. Ambraseys 2009, 40ff for photos demonstrating the extent of damage involved.)

20 See for instance N. Ambraseys 2009, 15.

21 Agnon 2014, 202.

22 (Rucker and Niemi 2010) The circular reasoning often takes the form of an archaeologist interpreting a destruction layer as evidence for an earthquake, then using an earthquake catalog to assign a date to the destruction. This is written into the historical narrative by historians, whose research is used by future archaeologists as evidence for the earthquake, and vice versa.

23 For a detailed discussion of historical sources, (Guidoboni and Ebel 2009, 39–146).

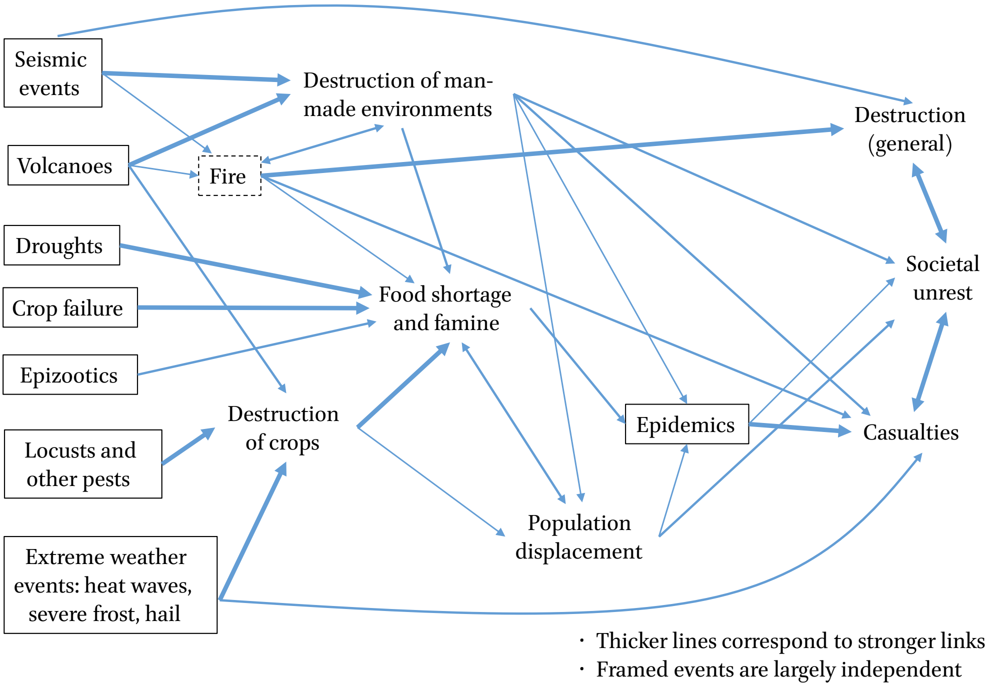

FIGURE 6.1 SCEs and their effects

Many earthquakes appear in traditional historical writings such as chronicles, but additional events have been identified through inscriptions, letters, archival material, poetry, and even liturgical references. Historical sources are the most direct in the information they provide, and they often note a seismic event that occurred at a given time and place. These are sometimes rough estimates, but it is not uncommon for sources to refer to specific locations (cities or provinces) and times (sometimes as precise as the hour in which the event occurred). The sources sometimes add information about the resulting damage and numbers of casualties. On a few occasions, direct or secondhand eyewitness reports survive.

Developments in critical historical research have called almost all of these details into question. Closer examination of the transmission between surviving texts has revealed that many sources depend on others and therefore add little value to the original accounts. Manuscript studies have revealed the instability of numbers, for instance, when a manuscript is copied. Reports can be undated or misdated by the source, causing one event to appear as two distinct earthquakes among contemporary sources, a problem known as duplication. Sources (or modern scholars) can also amalgamate earthquakes – that is, mistakenly interpret several smaller earthquakes as a single large event. Earlier earthquake descriptions can be copied to describe later events.[24] Even eyewitness reports have been called into question, as premodern authors often employ earthquakes as a literary tool that allows them to make broader claims about their society. Different literary traditions and genres, therefore, use earthquakes in distinct ways. Some, such as the medieval Armenian tradition, emphasize divine wrath, while Greco-Roman inscriptions tend to glorify a local elite or ruler who donated funds for rebuilding efforts. The terms each tradition uses are different, as are the adjectives they employ to describe an event's magnitude and effects.[25] The coverage of historical sources is partial as well. More central locations to authors, such as Constantinople or Antioch, are far better covered than peripheral areas such as northern Anatolia or post-classical Greece despite the high seismic activity in these regions. The reports about the extent of damage, the buildings destroyed and the financed rebuilding are all heavily influenced by an author's agenda. Notably, even today, local information regarding earthquake damage is "more often than not grossly exaggerated".[26] As we will see below, these issues plague earthquake catalogs.

Archaeology has been used to support historical findings.[27] Archaeology, in this regard, consists in excavating a certain site even though any findings about earthquakes tend to be incidental to the main purpose of the excavations. Compared to the historical evidence, which describes a region or a city, archaeology is often much narrower in scope, focusing on buildings and streets within a city. The result is a down-to-earth account of what happened at a specific point, including destruction layers, fires, and even post-disaster rebuilding. A recent archaeological study of a *tell* in northern Israel, for instance, demonstrated evidence for no fewer than five seismically induced slips[28] in structure walls built over the last three thousand years.[29] Technology is playing a growing role in this field. For example, LiDAR (Light detection and ranging) scanning can now identify minute changes in tilting that past earthquakes caused.[30]

Archaeological evidence brings in another set of issues. Central to this is the problem of *equifinality*, namely that a large number of causes have the same

24 For instance in (Guidoboni and Ebel 2009, 248–50).
25 For examples, (Guidoboni and Ebel 2009, 338–41).
26 N. Ambraseys 2009, 16.
27 N.N. Ambraseys 2006; Guidoboni and Ebel 2009, 418–72; Manuel Sintubin 2011.
28 Slips are defined as the movement on both sides of a fault line, displacing one side in relation to the other.
29 Ellenblum et al. 2015.
30 Yerli et al. 2010.

observed effect in the archaeological record. A collapsed building might be a result of a specific known earthquake, but it could also be the result of a different earthquake, an enemy raid, a storm, or dilapidation. Although there are ways to mitigate this problem, for instance by comparing destruction levels in several buildings and dating them with coins or other objects, this is not always possible.[31] Archaeologists are therefore forced to depend on historical sources and studies, but this can quickly lead to circular reasoning.[32] Archaeologists might ascribe destruction to an earthquake historians describe as big, and their results would be adopted by another generation of historians as independent evidence for the earthquake's magnitude. Excavations are also far more expensive and slow than historical research. Their results can remain unpublished for an indefinite period after their conclusion.[33] Since the second half of the 20th century, large-scale archaeology has become rare, partially since urban growth has prevented careful archaeological excavations in most major Byzantine-era urban centers such as Constantinople/Istanbul, Thessaloniki and Antioch/Antakya.[34] Contemporary excavations often take place in smaller centers, for which there is less textual evidence.

Natural sources are the most recent addition to the study of historical earthquakes. Several methodologies have been suggested to uncover past seismic events. Geomorphological studies can reveal changes in the landscape. Faulting, the surface fracture in the ground, is associated with powerful and shallow earthquakes.[35] Other geological processes such as uplift can also be identified *in situ*. In the AD 365 earthquake in the eastern Mediterranean, for instance, such surveys have found evidence for an uplift of up to 9–10 meters by marks of marine fossils above the water level.[36] Tsunami-inducing earthquakes can be identified by shell deposits found inland, or by underwater debris levels,

31 N. Ambraseys 2009, 36–37.

32 Rucker and Niemi 2010.

33 For example, Kletter and De-Groot pointed out in 2001 that 86 percent of seasons of excavations in the Holy Land (i.e. Israel) between 1980 and 1989 remained unpublished, see (Kletter and De-Groot 2001, 77). In the excavations in Beirut, hailed at the time as "the largest urban dig ever known", the vast majority of over 200 excavated sites were never published or published very briefly, see (Mordechai 2020, 208–11).

34 When excavations do take place in these centers they are generally classified as rescue archeology in which archaeologists attempt to rescue the information in the site as quickly as possible.

35 N. Ambraseys 2009, 26–27 listed 78 cases of actual or inferred faulting before 1900 (based on historical sources) and 72 cases after 1900.

36 Stiros 2010; see also Elias et al. 2007.

such as those caused by an earthquake around Caesarea Maritima, deposited by wave movement.[37]

Other scientific approaches can further illuminate questions relating to historical earthquakes, although their application to answer such questions is not yet widespread. Several studies have shown that speleothems (stalagmites and stalactites) can record past earthquakes.[38] Strong earthquakes would cause them to break, while weaker events can change their growth angle. By analyzing speleothems, scientists can date these changes or breakages to an annual level of precision.[39] Since speleothems develop in caves in karst landscapes, common in Anatolia, this approach could have potential for future studies. Some scholars have identified earthquake traces in short-term changes in local agriculture as reflected in pollen data.[40] A recent study has creatively used pollen in dust recovered from under amphorae in a workshop destroyed by an earthquake to date the destruction.[41] Scholars have also found evidence for past earthquakes in tree-ring data, although this seems to affect only trees that are very close to the fault zone and is more useful for more recent earthquakes in areas without a long written historical tradition.[42] Many of these scientific methods have been developed for other purposes and have only recently been used to glean information about historical earthquakes. They all require specialized technical knowledge, are costly to produce and their results depend heavily on statistics and therefore often include error margins.

A recent development with potential to contribute to the studies of past seismic events is earthquake modeling tools. These are digital models that receive a few variables as input, such as location and intensity, and return estimates of the resulting ground movements in different areas, as well as rough estimates for casualties and destruction. The models take into consideration many other variables "under the hood" such as population density, local building practices, soil composition, a country's effectiveness in mobilizing its resources, and even the time of day (night earthquakes cause more casualties since more people are in buildings). These models are implemented to analyze contemporary events and determine government and NGO response to

37 Dey and Goodman-Tchernov 2010; Goodman-Tchernov et al. 2009.
38 See for example (Lacave, Koller and Egozcue 2004; Panno et al. 2009; for an example from the region: Akgöz and Eren 2015).
39 This process requires removing them, a process scientists are reluctant to do *en masse*.
40 Leroy et al. 2010.
41 Langgut et al. 2016.
42 Bekker 2010; Stoffel et al. 2010.

immediate emergencies, but future research might use them to examine the effects of premodern seismic events.[43]

2 Earthquake Catalogs

Historical earthquake catalogs aggregate the results of historical earthquake research and make it accessible to the broader scholarly audience.[44] The Eastern Mediterranean is one of the best-documented regions and therefore several dozen publications have compiled lists of relevant earthquakes.[45] There are also a few dozen tsunami catalogs.[46] These catalogs, which have been published since the 15th century, often define their coverage through a combination of spatial and chronological criteria and vary greatly in their quality.[47] Some might be unreferenced tables of events that might include a harmonized chronological window, the estimated earthquake epicenter, other affected areas and an estimate of the earthquake's intensity. Others could include critical discussions of specific events together with the relevant historical source material and modern bibliographies. Online publishing has made some of these catalogs even more accessible. Current aggregations of catalogs cover the entire world over centuries.[48]

These catalogs, however, have several inherent issues which are easy to overlook when using their polished results. First and foremost, as discussed above, the original data is neither well-organized nor precise. The large number of events and the variety of sources used means that less editorial attention is given to each particular event. The brief and vague mentions of earthquakes in the sources or the discrepancies between sources are the cause of much confusion, sometimes causing editors to amalgamate different earthquakes as a single event, or to mistakenly duplicate a single event in multiple entries.

43 The USGS n.d. reports the results of their current model (closed access) on their website; offers open access tools GEM Foundation 2019; other institutions have developed additional tools, e.g. Geoscience Australia 2014.

44 Although there is a trend promoting a more qualitative approach, Manuel Sintubin 2011.

45 See the survey in (N. Ambraseys 2009, 4–7, the latest critical comprehensive catalog for the Mediterranean region). Other accessible catalogs are (Guidoboni 1994; Guidoboni and Comastri 2005; Guidoboni et al. 2019).

46 Maramai, Brizuela and Graziani 2014 also online; the new version is Maramai, Graziani, and Brizuela 2019; see also National Geophysical Data Center 2022; N. Ambraseys 2009, 58–59 is more critical.

47 For a survey of past cataloging practices, see Guidoboni and Ebel 2009, 26–35.

48 Albini et al. 2013.

Moreover, especially in older catalogs, the criteria that led the editors to accept certain events and reject others are not adequately explained.[49] Since a significant number of earthquakes that appear in the sources probably never happened, editorial selection processes can greatly influence the eventual shape of the catalog. Recent catalogs have begun to rectify this by also listing earthquakes that they believe did not exist.[50] Unfortunately, since all recent earthquake catalogs are based on previous catalogs, they sometimes duplicate their erroneous findings or include earthquakes that had been omitted correctly.

Even critical catalogs often differ in their estimates of a seismic event's specific time and place. Perhaps the most disputed statistic, however, is the estimated intensity of the event. To estimate earthquakes without the use of instruments, in modern or historical times, scholars have proposed over 60 different intensity scales that convey the effects of an earthquake on structures, objects and on the ground on an I–XII scale. These results can then be converted back to the MMS scale. Unfortunately, most of these scales – often used interchangeably and by non-experts – have been devised for 20th-century European constructions. As such, even medium-sized intensities of VII or VIII could cause almost complete destruction in the historical Near East, where buildings were much more vulnerable than in modern developed countries.[51] As a result of these shortcomings, the most recent critical catalog has not included intensity estimates in its analysis.[52] This, in turn, limits the usefulness of the catalog by making it more difficult to compare earthquakes.

These catalog limitations are often glossed over when compiling digital catalogs, which offer the significant advantage of quick and easy visualization of past events based on selected criteria. However, by displaying similar data (e.g. all earthquakes around the Mediterranean, AD 500–1000) from different databases and overlaying them on the same map, it is immediately clear that the agreement between datasets is much lower than one would hope.

At the current state of research, catalogs are useful as compilations of primary source references that could and should be traced back and examined critically. Their analysis often suggests the main issues concerning a specific event. Some include primary source translations which are also helpful for non-specialists. As such, they offer a quick and easy starting point for any

49 Zohar, Salamon, and Rubin 2016 have suggested a concrete method to assess the reliability of an earthquake report in catalogs.

50 See for example N. Ambraseys 2009.

51 Intensity scales have multiple other problems, see N. Ambraseys 2009, 52–55.

52 N. Ambraseys 2009; notably, the accompanying parametric catalog (online only) does include a partial list of about 600 earthquakes with intensity estimates.

investigation of past seismic events, as long as users remember their limitations, but should not be accepted as authoritative on any given earthquake.

3 Case Studies

The lack of detailed evidence for most historical earthquakes requires a certain amount of extrapolation between case studies from premodern and modern times to assess an earthquake's effect. In-depth studies of premodern events are fewer and concentrate around major disasters. The historical sources attest to a marked increase in seismic events in the Eastern Mediterranean during Late Antiquity. A major earthquake in AD 365 caused a tsunami that affected much of the eastern Mediterranean.[53] This was part of a series of up to eight strong earthquakes that occurred over less than a decade in the region.[54] The earthquake of AD 551 wreaked havoc on several cities in the Byzantine Levant.[55] Another massive earthquake in AD 749 caused much destruction in northern Palestine,[56] although Ambraseys has argued that this was an amalgamation of three different earthquakes.[57] In both the mid-6th and the mid-8th century events there is evidence for coincidental change in settlement patterns in these regions.

Over the past several decades, scholars have posited a causal connection between earthquakes and a general or specific notion of decline of the cities they affected. This catastrophist argument is often based on a combination of circular reasoning, a positivist reading of the destruction the sources describe, and the retrospective observation of the collapse of the Roman political system in the Levant during the 7th-century Persian and Arab invasions and conquests.[58] While some of these seismic events undoubtedly placed severe strains on local social structures, the automatic attribution of destruction and urban decline to an earthquake is an easy but often imprecise explanation.

53 (Shaw et al. 2008; Guidoboni and Ebel 2009, 404–13). On this event see also the recent (Stiros 2020).

54 Guidoboni and Ebel 2009, 316; Russell 1980; the interval is AD 358–363; more broadly Pirazzoli, Laborel and Stiros 1996.

55 Mordechai 2020.

56 Marco et al. 2003; Wechsler et al. 2009; Dey, Goodman-Tchernov, and Sharvit 2014; Liebeschuetz 2015, 268–69, 274 is more hesitant.

57 N.N. Ambraseys 2005; the earthquakes are dated to AD 746, 749/50 and 757.

58 (Malalas 2000, 419–24; Downey 1961, 525, 559 for Antioch; Waelkens et al. 2000; Manuel Sintubin et al. 2003 for Sagalassos; Altunel et al. 2003, 150 for Knidos; Jacobs 2009, 213 for Hierapolis; Darawcheh et al. 2000 for Beirut and its environs; Russell 1985 for a broader survey). (Liebeschuetz 2015, 267 is more hesitant.)

A closer examination of the available evidence can suggest alternative explanations or more nuanced interpretations. Antioch, which experienced at least five major earthquakes over the 6th century, is a case in point. Despite repeated references to its destruction in both primary and secondary sources, multiple sources refer to the survival of the city's population, major buildings and cultural life.[59]

Other longitudinal case studies that examine a given region are rare. Raphael has surveyed environmental disasters in the Levant during the Crusades, combining a regional interval of high seismicity with other short-term cataclysmic events such as droughts and famines, and political change.[60] Recent work has been done on sites overlapping with Byzantium's sphere of influence in Sicily,[61] L'Aquila,[62] Malta[63] and the Crimea.[64] Longitudinal surveys of other regions are still needed. Constantinople has the best documentation throughout the Byzantine period, with dozens of reported earthquakes. Nikaea and Nikomedia have been affected by major earthquakes in the 4th and 5th centuries, which may have stimulated their decline as urban centers. Salamis (Cyprus) suffered three earthquakes over the 4th century, while the archaeological excavations in it might better illuminate local responses to these earthquakes. Closer investigation of these case studies – and others – would contribute to our understanding of the broader phenomenon of seismic events and their effects on premodern societies.

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59 Mordechai 2018; for a more nuanced study of a single earthquake, see 2020.
60 Raphael 2013.
61 Bottari 2016.
62 Guidoboni et al. 2012.
63 Main et al. 2022.
64 Nikonov 2016.

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