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An archaeological and archaeoseismological perspective on earthquakes in the coastal cities of Western Anatolia in the 3rd millennium BCE: Settlement abandonment and changes in social structures

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Abstract: This study investigates the impact of the earthquakes that occurred in the first half of the 3rd millennium BCE on Western Anatolian settlements, aiming to determine the dates of the earthquakes that happened during the prehistoric period using the earthquake layers of the settlements and associated C^{14} data. The focus of the paper is the investigation of the effects of two earthquakes that occurred in the region during the first half of the 3rd millennium BCE on the settlements of the region. The first earthquake occurred around 2800 BCE and damaged settlements in the area of İzmir. Evidence of this damage is provided by traces of fire and destruction in the archaeological layers. In addition to the building materials and techniques of the period, the common use of side walls of buildings 25 m in length and their construction in blocks increased the destructive effects of earthquakes. In the wake of earthquakes, some structural changes were made, and the masons of the period tried to take measures against earthquakes by using new construction techniques. The earthquakes of the first quarter of the 3rd millennium BCE may have caused political turmoil in Western Anatolia, as they had the potential to create social unrest. The earthquakes that hit the İzmir region in the first half of the 3rd millennium BCE led to the abandonment of settlements, a reduction in the sizes of settlements, or changes in social organisation. In this paper, the earthquake layers of Bakla Tepe and Liman Tepe, which contain the oldest archaeological earthquake remains found to date in Western Anatolia, are analysed in detail for the first time. Highlighting the importance of archaeological data, this paper also offers new perspectives for understanding the profound and permanent impacts that natural disasters had on ancient societies.

Key words: Early Bronze Age, earthquake, archaeoseismology, Western Anatolia, architecture

1. Introduction

With its favourable climate and natural resources, Anatolia is among the regions that were home to the world's earliest settlements. The Anatolian subplate is a region of high seismic activity and has been the scene of many large and destructive earthquakes throughout history, especially with the effect of two tectonic discontinuities: the Eastern Anatolian Fault Zone (EAFZ) and the Northern Anatolian Fault Zone (NAFZ) (Arpat and Şaroğlu, 1972; McKenzie, 1976; Barka, 1992; Şengör et al., 2005; Yönlü et al., 2017; Şengör and Zapçı, 2019). This makes Anatolia a region where archaeoseismological data can be found and observed in greater volumes and with greater clarity (Sümer and Karabacak, 2024). Although archaeoseismology is regarded as catastrophism by some scholars (Ambraseys, 2005; Sintubin et al., 2011; Hinzen et al., 2018), recent interdisciplinary studies have shown that some of the natural disasters of the past were much larger than initially thought (Nur and Cline, 2000, 2001; Johnston et al., 2014; Şahoğlu et al., 2022). In this context, it is necessary to define the damages observed during archaeological excavations using the methodologies of archaeoseismology, although it is still a new field in archaeological studies (Galadini et al., 2006; Hinzen et al., 2011; Sintubin, 2011). Since archaeoseismological data will help in examining the changes and effects of earthquakes on social phenomena, it is necessary to examine these phenomena as well, if possible. Otherwise, archaeoseismological studies would be confined to merely archaeological and geological records (Sintubin, 2011).

Due to the geological structure of the İzmir region and its active fault lines, large destructive earthquakes have occurred, and due to the location of the settlement, it has been exposed to large earthquakes (Figure 1). A large earthquake occurred in Çeşme-Bağlararası in the first half of

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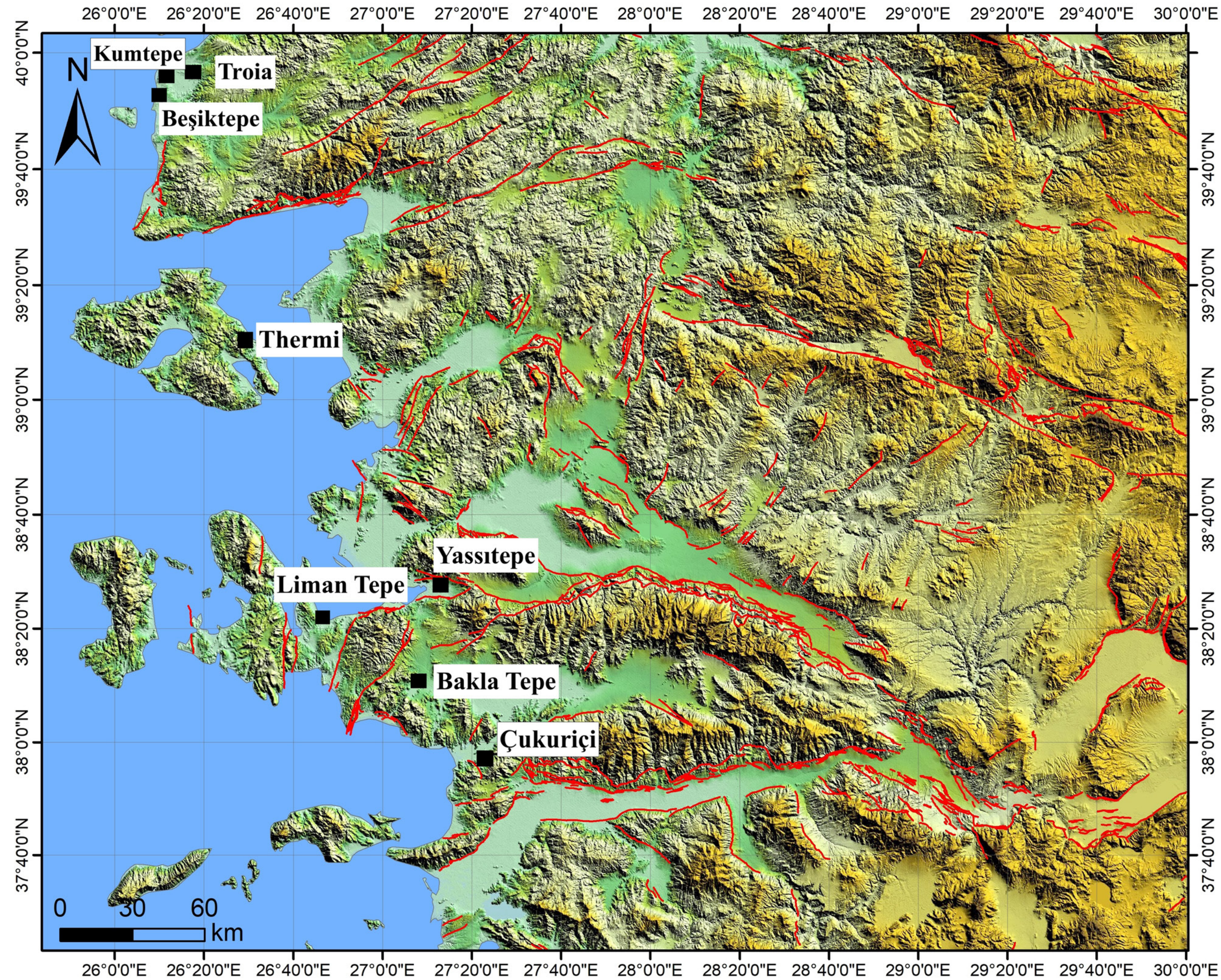

Figure 1. The active fault lines in Western Anatolia and settlements mentioned in the text from the 3rd millennium BCE (faults lines are taken from the General Directorate of Mineral Research and Exploration [MTA]; Map: Dr. Ümit Gündoğan).

the 2nd millennium BCE and the buildings of the settlement were rebuilt after that earthquake (Şahoğlu et al., 2018, 2020). In Çeşme-Bağlararası, the tsunami waves caused by the eruption of the Thera volcano reached the settlement, and the skeleton of a young individual was found under the remains of the tsunami's destruction (Şahoğlu et al., 2022). According to the information obtained from written sources, geological studies, and archaeological evidence, approximately 20 moderately destructive earthquakes occurred in the İzmir/Smyrna region from 496 BCE to 1900 CE (Ergin et al., 1967; Poirier and Taher, 1980; Guidoboni et al., 1994; Ambraseys, 2009; Tepe et al., 2021). Among these earthquakes, the earthquakes of 17, 44/47, and 177/179 caused particularly great destruction in 13 Ionian cities including Smyrna and Ephesus (Ergin et al., 1967; Guidoboni et al., 1994; Ambraseys, 2009; Aydan and Kumsar, 2015; Tepe et al., 2021; Şengöçmen Geçkin et al., 2022). After these devastating earthquakes, further events in Ephesus in 262 (Ladstatter, 2002; Karagöz, 2005; Ambraseys, 2009), Smyrna in 1040, and Chliara and Bergama in 1296 damaged the settlements. Major earthquakes also occurred in the region between 1500 and 1900 AD. Among those earthquakes, the one that occurred in 1653 at Büyük Menderes (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009), the 1668 İzmir earthquake, and the 1739 Foça earthquake can be listed among the most destructive. In 1880 in Menemen and then in 1983 in Çeşme, successive earthquakes caused damage to buildings and loss of life and property (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009; Beyru, 2011).

Earthquakes may constitute great disasters and have been the breaking point in the lives of many people. The ways in which the walls of the structures collapsed as well as the traces of fire, the abandonment of settlements, and the signs of reconstruction all serve as archaeological evidence of the impact of these earthquakes (Galadini and Galli, 2004; Sintubin, 2011; Drahor et al., 2023). The postearthquake recovery process in each period was difficult and the earthquakes had devastating effects on the societies.

2. Tectonic framework of the region

The geological units of the İzmir region consist of the Menderes Massif, the Sakarya Continent, and the İzmir–Ankara Suture Zone (Yılmaz et al., 2000; Aydan and Kumsar, 2015). The North Aegean region is affected by the NAFZ. On the other hand, the South Aegean region is affected by Hellenic subduction and the Pliny–Strabo Fault Zone (Dewey and Şengör, 1979; Şengör et al., 1985; Ocakoğlu et al., 2005). The initial phase of regional tectonics may have been associated with the closure of the Tethys Ocean (Seyitoğlu and Scott, 1996). The tectonic structure in West Turkey results from the pushing of the Anatolian Plate by the North Anatolian Fault and the East Anatolian Fault towards the Hellenic Arc south of Greece and the Aegean Sea. This led to the formation of north-south compressive forces in Western Anatolia and shaped the present-day morphologies such as horsts and grabens extending east-west (Dewey and Şengör, 1979; Le Pichon and Angelier, 1979; Yılmaz et al., 2000; Coşkun et al., 2017). In addition to these east-west trending grabens, there are northeast-northwest trending secondary grabens and horsts between them (Koçyiğit et al., 1999). These grabens have normal faulting mechanisms and are very important in the neotectonism of Western Anatolia because they produce very destructive earthquakes (Emre and Barka, 2000; Ocakoğlu et al., 2005) The horst-graben system in Western Anatolia includes the Gediz, Büyük Menderes, Denizli, Acıgöl, Çivril-Dinar, and Burdur grabens (Yılmaz et al., 2000). The Büyük Menderes and Gediz graben systems are characterised by low-angle normal faults and various synthetic and antithetic faults along these faults (Seyitoğlu et al., 1992).

Western Anatolia’s seismic activity is significantly influenced by various fault types and structures. The region also contains the fault of grabens, with right lateral and left lateral strike-slip faults that trend in the northeast-southwest and northwest-southeast (Şengör, 1987; Aktar et al., 2007). These faults have significant roles in characterising the earthquake generation in this region (Emre et al., 2018). The tectonic configuration and faults in Western Anatolia considerably affect the region’s earthquake activity (Coşkun et al., 2017). The earthquakes occurring in and around İzmir are directly linked to these active tectonic movements.

These earthquakes are caused by normal and lateral thrust faults. There are NE-SW, NW-SSE, NW-SE, NW-SE, and E-SE oriented faults in and around İzmir (Şengör et al., 1985; Şengör, 1987; Yılmaz et al., 2000; Bozkurt, 2003; Drahor and Berge, 2017). These faults consist of the NE-SW trending Güzelhisar Fault and Tuzla Fault, NW-SE trending Menemen Fault Zone and Bornova Fault, N-S trending Yenifoça Fault and Gülbahçe Fault Zone, and E-W trending İzmir Fault, Seferihisar Fault, Gümüldür Fault, and Gediz Graben System Fault (Emre et al., 2005; Ocakoğlu et al., 2005; Sözbilir et al., 2008; Uzel and Sözbilir, 2008; Uzel et al., 2012; Coskun et al., 2017; Şengöçmen Geçkin et al., 2022).

The Gulf of İzmir is characterised by several fault zones, including the İzmir Fault Zone, which extends east-west along the southern coast of the gulf (Emre and Barka, 2000). On the east coast, the Uzunada Fault Zone exhibits a complex opening mechanism. Additionally, the area features the İzmir Central Graben and the Foça-Süzbeyli Fault, a relatively young normal fault running from the west to the east of the gulf (Coşkun et al., 2017). Particularly, the Karaburun Reverse Fault extends southward, covering the entire gulf, while another significant fault, extending to Uzunada and referred to as the Urla Fault, loses its reverse fault character within the gulf and transforms into a strike-slip fault system (Ocakoğlu et al., 2005). In addition, there are prominent strike-slip faults such as the Tuzla Fault, which extends from offshore of Doğanbey Cape to the land and in a NE-SW direction up to the city of İzmir (Emre and Barka, 2000; Ocakoğlu et al., 2005). Moreover, secondary strike-slip faults extending from the offshore areas of Alaçatı-Teke and Kuşadası towards the land are also observed in the region (Coşkun et al., 2017).

From recent earthquake data, the focal mechanisms of earthquakes in the region have been found to be mainly normal and strike-slip faults (Taymaz et al., 1990; Yolsal-Çevikbilen et al., 2014). Active strike-slip faults and extensional tectonics have been identified in Sığacık Bay, the Karaburun Peninsula, and the İzmir region (Ocakoğlu et al., 2005; Uzel and Sözbilir, 2008; Uzel et al., 2013).

3. Seismicity of the İzmir region

The geological structure of the İzmir region has led to the occurrence of many earthquakes in the region, and with the transition to sedentary life, earthquakes have had devastating effects on structures. No traces of earthquakes were found in the Neolithic remains of the Ulucak, Yeşilova, Çukuriçi, and Ege Gübre settlements in the İzmir region (Derin, 2005, 2007; Çilingiroğlu et al., 2012; Horejs, 2012; Sağlamtimur and Ozan, 2012). The architecture of the region in the Early Chalcolithic period is very poor (Çevik, 2018). During the Middle and Late Chalcolithic period, buildings constructed in the İzmir region were built using wattle and daub construction techniques that included light organic materials (Derin et al., 2009; Schwall, 2018; Tuncel and Şahoğlu, 2018; Tuğcu, 2019). This makes it difficult to find evidence of earthquakes in prehistoric settlements. At the beginning of the 3rd millennium BCE, the settlements were surrounded by defensive systems. Within the fortifications there are long houses built of mud bricks on stone foundations. The number of settlements in the region increased during this period (Erkanal, 1996, 1999; Gündoğan, 2020, 2022). The layers of destruction seen in settlements established in close proximity to each other in the same time interval provide the earliest examples of earthquakes affecting the region. So far, the earliest earthquake traces in Western Anatolia have been found at Bakla Tepe, Liman Tepe, Yassıtepe, and Çukuriçi, which are contemporaneous with each other. Evidence of an earthquake in the time of the Troia I settlement was discovered mainly in the area known as Schliemann's Trench. Although the interiors of the structures did not exhibit any clear marks of an earthquake, the repairs on the wall of the structure numbered 102 and the mudbrick walls found toppled on the floors of the houses show that phases b and c of Troia 1 might also have been damaged during an earthquake (Blegen et al., 1950; Ivanova, 2016).

Traces of earthquakes in the first half of the 2nd millennium BCE have been found at Çeşme-Bağlararası (Şahoğlu et al., 2018, 2020). The settlement of Liman Tepe, which was contemporary with Çeşme-Bağlararası, also shows traces of earthquakes on architectural elements, albeit very few. Although earthquake traces have not been detected to date in Late Bronze Age settlements in the İzmir region, it is thought that earthquake storms were experienced in the region (Nur and Cline, 2000). The data from Troia VI in Northwestern Anatolia can also be considered within the scope of the Late Bronze Age earthquakes (Blegen et al., 1953; Easton, 1985).

Archaeological evidence and historical inscriptions indicate that the region has frequently experienced devastating earthquakes, resulting in significant loss of life and property. One notable earthquake in Sardis in the 7th century BCE caused extensive ground cracking and collapse (Karagöz, 2005). Many Hellenistic cities were destroyed as a result of the earthquake that occurred near Smyrna and the Samos and Chios islands in 304–303 BCE. The ancient city of Teos was also damaged by this earthquake (Guidoboni et al., 1994; Karagöz, 2005; Ambraseys, 2009). Similarly, Tralles (Aydın) was severely damaged by an earthquake in the Menderes valley in 27–24 BCE (Ambraseys, 2009).

The earthquakes that struck the region in 1000 CE and particularly those in 17, 44/47, and 178/179 were highly destructive (Ambraseys, 2009). Among these, the earthquake in 17 CE stands out as one of the most devastating in Western Anatolia due to its magnitude and the extent of the cities it affected (Aydan and Kumsar, 2015). This earthquake nearly obliterated 13 cities, including Ephesus, Magnesia, Sardis, Mostene, Aegae, Hierocaesarea, Philadelphia, Tmolus, Temnus, Myrina, Cyme, Apollonia, and Hyrcania (Ergin et al., 1967; Guidoboni et al., 1994; Ladstatter, 2002; Drahor, 2006; Ambraseys, 2009). The earthquake in 47, centred in Samos, was also significant. It impacted a large part of Ionia, including Miletus, Samos, Ephesus, Halicarnassus, Smyrna, Chios, Erythrai, and Teos (Guidoboni et al., 1994; Ambraseys, 2009; Şengöçmen Geçkin et al., 2022). Additionally, the earthquake of 177/179 severely damaged the city of Smyrna. The temple, theatre, agora, and dwellings of the settlement were destroyed by the earthquake and subsequent fires and landslides (Ergin et al., 1967; Ambraseys, 2009). Besides the major earthquakes in the region, there was an earthquake in 105–107 that affected the cities of Cyme, Myrina, Elaea, and Pitane around the Gulf of Adramytteion (Ergin et al., 1967; Guidoboni et al., 1994; Ambraseys, 2009). In 262, an earthquake in Ephesus caused significant ground cracks that led to the collapse of the Temple of Artemis. The earthquake also destroyed the city's library and terrace structures (Ladstatter, 2002; Karagöz, 2005; Ambraseys, 2009).

In 1040, an earthquake centred on Smyrna caused serious damage to the settlement. It probably affected both Smyrna and the surrounding area. After these earthquakes, earthquake activity continued in the region, causing great destruction and loss of life in İzmir, Manisa, Turgutlu, Menemen, Karaburun, Çeşme, Aydın, Ödemiş, Nazilli, and their surroundings. Among these earthquakes, the Chliara earthquake of 1296 was particularly felt in and around Bergama. An earthquake occurred near the island of Chios in 1389, a large part of Kastro on the island of Chios was devastated, part of the castle walls of İzmir were destroyed, and the castle of Yenifoça was also destroyed by this earthquake (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009).

The examined earthquakes that took place in the region between the years 1500 and 1900 had enormously negative impacts. In 1653, an earthquake in the province of Aydın and particularly in the Büyük Menderes valley was severely destructive as it led to much devastation and claimed the lives of over 3000 people in the city. This earthquake also caused damage in İzmir province as well (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009). Among the İzmir earthquakes, the one in 1668 was the most destructive. This earthquake caused great destruction in the city. It particularly caused significant damage in the lower parts of the settlement and a fire started in the city after this earthquake (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009;

Beyru, 2011). The earthquake in 1739 affected Foça and led to the destruction of buildings in Eskifoça and Yenifoça. This particular earthquake also impacted the city of İzmir, with worse impact for structures in the lower parts of the settlement. It was felt in Chios as well, where it damaged buildings (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009; Beyru, 2011). In 1778/1779, three consecutive earthquakes occurred in İzmir, damaging public buildings, mosques, and houses. The second and last earthquake, which took place over the course of 2 days, led to a fire in the settlement. The final earthquake was most effective in the area where European merchants gathered (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009; Beyru, 2011). Another important earthquake was the Kemalapaşa/İzmir earthquake of 1850, which was accompanied by a large fire. The İzmir Menemen earthquake (1880) destroyed almost half of the buildings in the settlement. The effects of the earthquake were also felt in İzmir itself. A year later, in 1981, an earthquake on Chios Island was felt strongly in Çeşme and its surroundings. Two years after that earthquake, many public buildings and houses were damaged in the 1983 Çeşme earthquake (Ergin et al., 1967; Ambraseys and Finkel, 1995; Ambraseys, 2009; Beyru, 2011).

4. Methodology

Archaeological findings can provide information about historical and prehistoric earthquakes (Caputo and Helly, 2005; Kovach and Nur, 2006). Structures at archaeological sites are subject to seismic movement, slope processes, soil instability, excessive loads, water effects, and human intervention. This diversity is critical in identifying and classifying the causes of damage to archaeological remains, particularly in distinguishing between seismic and nonseismic sources (Rodríguez-Pascua et al., 2011).

Evidence of earthquakes in protohistoric settlements could be found by comparing the collapse patterns of the walls of abandoned structures with the collapse of entire walls at the time of an earthquake. After the abandonment and the slow deterioration of houses, wall fragments accumulate and generally gather in piles on both sides of the walls (Galadini et al., 2006). This type of accumulation has maximum thickness at the bottom of the wall with a gradual decrease in amount upwards. Particularly, the remains of mudbricks disintegrate and crumble down as if in streams as a result of the fragile structure, accumulating at the bottom of the walls. The superstructure walls of structures that collapse due to an earthquake usually topple over as a whole (Guidoboni et al., 2002; Galadini and Galli, 2004; Galadini et al., 2006; Giner-Robles et al., 2009; Ökse et al., 2010; Rodríguez-Pascua et al., 2011). Wall stones are usually found displaced with the foundations significantly deformed (Giner-Robles et al., 2009; Rodríguez-Pascua et al., 2011). Furthermore, a large number of artefacts are found inside the structures, as people who fled outside during earthquakes did not have time to take their belongings from the interior of the structures. At an archaeological site, a fire that starts after the destruction caused by an earthquake can be considered a secondary effect of the earthquake (Galadini et al., 2006; Rodríguez-Pascua et al., 2011). One of the most significant pieces of evidence of an earthquake might be the presence of people trapped under collapsed walls (Lamb, 1936; Sakellarakis and Sapouna-Sakellaraki, 1981). However, such findings are quite rare (Galadini et al., 2006).

In historical times, earthquakes in the İzmir region resulted in the destruction of settlements and structures in the region and loss of life and property as in many other regions. Various pieces of archaeological evidence and historical records show that Western Anatolia had considerable earthquake activity in the past, and these earthquakes had a strong influence on settlements (Ergin et al., 1967; Poirier and Taher, 1980; Guidoboni et al., 1994; Ladstatter, 2002; Karagöz, 2005; Ambraseys, 2009; Tepe et al., 2021; Şengöçmen Geçkin et al., 2022; Sümer and Karabacak, 2024). It is therefore very likely that settlements of the first half of the 3rd millennium BCE were erased by earthquakes.

In the first half of the 3rd millennium BCE, the settlement patterns, building plans, and pottery forms of contemporaneous settlements in the İzmir region were similar (Erkanal, 1996; Ivanova, 2016; Gündoğan, 2020). It is very difficult to identify earthquake layers in prehistoric settlements and to understand whether those layers are contemporary with the settlements in the region and whether the structures were destroyed by the same earthquake or as a result of independent earthquakes. However, C^{14} dating and comparative pottery forms from the settlements can help identify contemporaneous levels. In addition, earthquake layers obtained from among the layers of the same period can be associated with an earthquake that affected the region. Fault lines that produce major earthquakes in the İzmir region are likely to destroy settlements located close to each other with a single earthquake. Especially in the İzmir region, due to the density of active fault lines that produce destructive earthquakes, it is very difficult to determine which fault the earthquake traces of the first half of the 3rd millennium BCE originate from. It may not be possible to determine the centre of an earthquake because there are no written records from the period and no observations were made directly at the fault breaks. Regarding the Gülbahçe fault zone, it is known that the earthquakes of 47, 177, 688, 1040, 1296, and 1389 occurred in the vicinity of this zone and affected a wide area up to the ancient city of Smyrna, the island of Chios, the city of İzmir, and the district of

Bergama (Şengöçmen Geçkin et al., 2022). It is also known from historical sources that the earthquake in the region in 17 CE almost entirely destroyed 13 Ionian cities (Ergin et al., 1967; Guidoboni et al., 1994; Ambraseys, 2009). Although it is not possible to determine which fault caused the earthquakes in the region in prehistoric times, the pottery forms of the settlements in the first half of the 3rd millennium BCE and the remains of the earthquake layers strengthen the possibility that these settlements were destroyed by the same earthquake.

Traces of earthquakes in the settlements can be detected by carefully evaluating walls that have come out of their foundations, the remains of walls that have collapsed as blocks, and ground fluctuations. However, it has been observed that the mudbrick and stone materials of the walls of normal abandoned buildings fall to the bottom of the walls and accumulate in that area. In the Early Bronze Age settlements in the İzmir region in the first half of the 3rd millennium BCE, the walls of the buildings collapsed as blocks, with shifting and dislocation, undulation and tilting, tilting, lateral undulation, and snake-type lateral undulation. Furthermore, the fact that the interiors of collapsed walls and fire-exposed buildings are much richer in archaeological finds than naturally collapsed buildings may be due to the fact that the interiors of the houses were not evacuated due to sudden earthquakes.

The abandonment of settlements or other archaeological evidence such as architectural changes could help to identify ancient earthquakes (Galadini and Galli, 2004; Sintubin, 2011). The changes following the natural disasters that occurred in Western Anatolia, such as the abandonment of settlements (Korfmann, 1988; Riehl, 1999; Derin et al., 2022; Gündoğan, 2022; Grasböck et al., 2023), reduction in the size of settlements (Gündoğan et al., 2019), and signs of the emergence of new rulers or administrators (Kouka, 2016; Gündoğan, 2022), may have been the result of the impact of the natural disasters on societies.

5. Evidence of earthquakes in Western Anatolia in the first half of the 3rd millennium BCE

Bakla Tepe, located within the boundaries of Bulgurça village in the Menderes district of İzmir, occupies a commanding position overlooking Cumaovası. Today, the settlement at Bakla Tepe is submerged under the waters of the Tahtalı Dam. The settlement exhibits five distinct cultural layers (Erkanal and Özkan, 1999; Gündoğan et al., 2019). Through excavations, it has been revealed that the settlement experienced two instances of destruction due to earthquakes, followed by subsequent reconstruction. Evidence of earthquake activity at Bakla Tepe has been identified on the northern, southern, and eastern slopes of the mound.

The fortification wall at Bakla Tepe during the BT IV 2A phase, of which a 19-m section was excavated, was toppled as a single block to the north over an area of approximately 5 m (Erkanal and Özkan, 2000; Gündoğan et al., 2019) during an earthquake (Figures 2 and 3). The occurrence of collapsed building walls in block formations is typically attributed to seismic activity, further strengthening the association of this event with the earthquake sequence. These wall collapses, which will be evaluated within the scope of the strain structures generated in the building fabric, can be evaluated among the primary effects of the earthquake. In addition, another seismic indicator belonging to the same phase was identified on the eastern side of the mound. The fortification wall was reinforced by a ditch wall, as there is no significant slope in the area. However, towards the top of the mound, the walls appear to have shifted against the slope. As a result of archaeological excavations, earthquake traces were found on both walls in this area. The eastern part of the fortification wall, which gradually rises from the ground, shifted towards the west. As a result of that movement, a snake-type lateral undulation formed in the western section of the fortification wall. The northern part of the adjacent ditch wall, which was used in the same period, collapsed and separated from the other part (Figure 4). The damage to these structures belonging to the BT IV 2A phase of Bakla Tepe can be evaluated within the scope of the direct impact of the earthquake.

House-23, which is an important building of this phase, probably collapsed inwards due to the primary effect of the earthquake, while a fire broke out inside the building as a secondary effect. The discovery of many valuable artefacts in the house during the archaeological excavations in the area (Gündoğan, 2019) is probably due to the fact that the house may not have been evacuated during the earthquake. Both direct and indirect effects of the earthquake are observed at Bakla Tepe. Evidence such as the density of burnt and solidified areas, the discovery of many artefacts from the BT IV 2A phase at Bakla Tepe, the fact that the fortification wall was toppled as a block, and the deterioration of other walls indicate major destruction that was probably caused by seismic activity.

Yassıtepe is located near the Manda Stream within the borders of the Bornova district of İzmir Province. The settlement began in the late 4th millennium BCE and continued until the first quarter of the 3rd millennium BCE (Derin, 2020). Yassıtepe, 32 km from Bakla Tepe, is another centre destroyed by an earthquake that happened during the first half of the 3rd millennium BCE. Almost all of the structures show signs of an earthquake in the form of snake-type undulations, tilting, and lateral displacement of their walls in the IIB2 phase (Derin, 2020, Figures 4 and 5.1). The C^{14} data indicate that the IIB2 layer of Yassıtepe was destroyed by an earthquake around

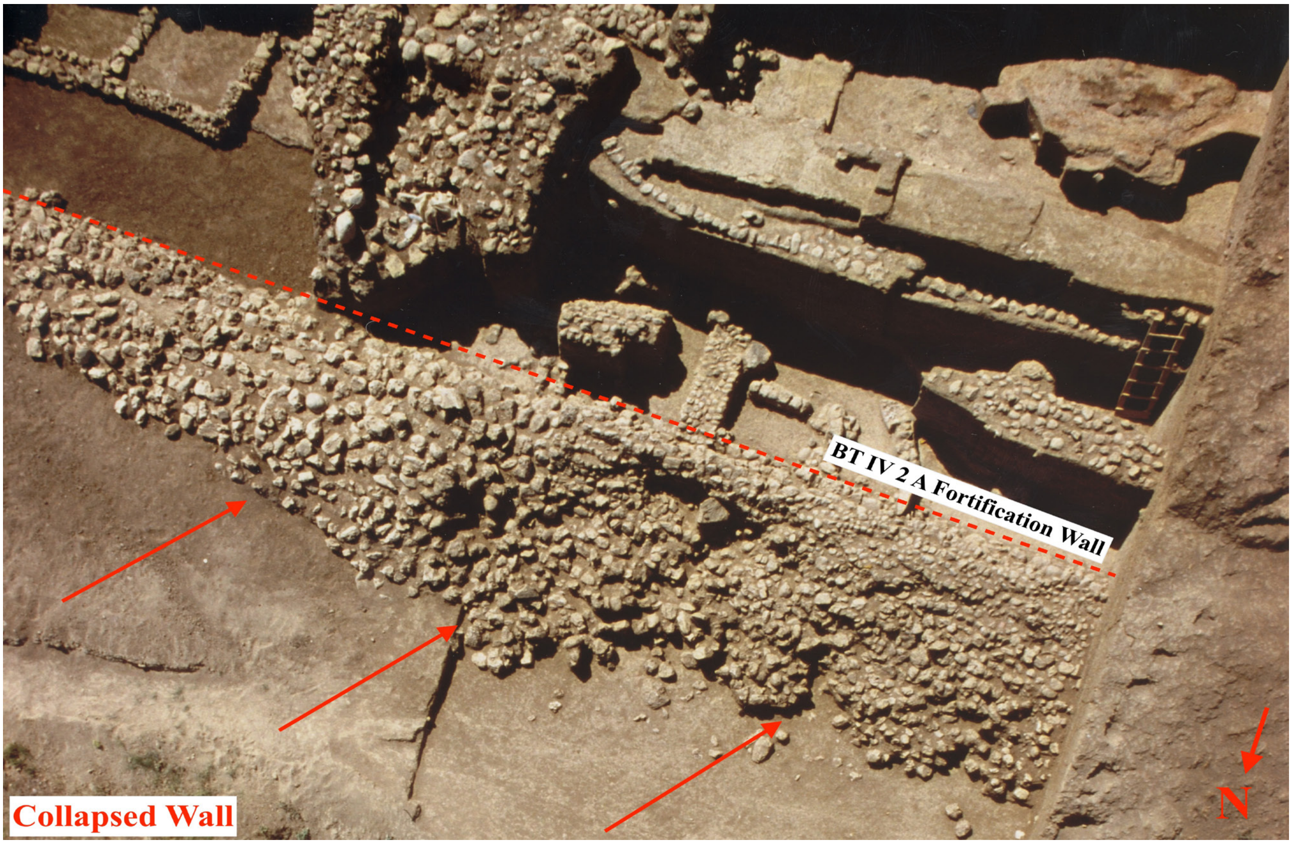

Figure 2. The collapse of the fortification wall of Bakla Tepe BT IV 2A, toppling as a single block towards the north during the earthquake (Photograph: Jan Driessen, IRERP Archive).

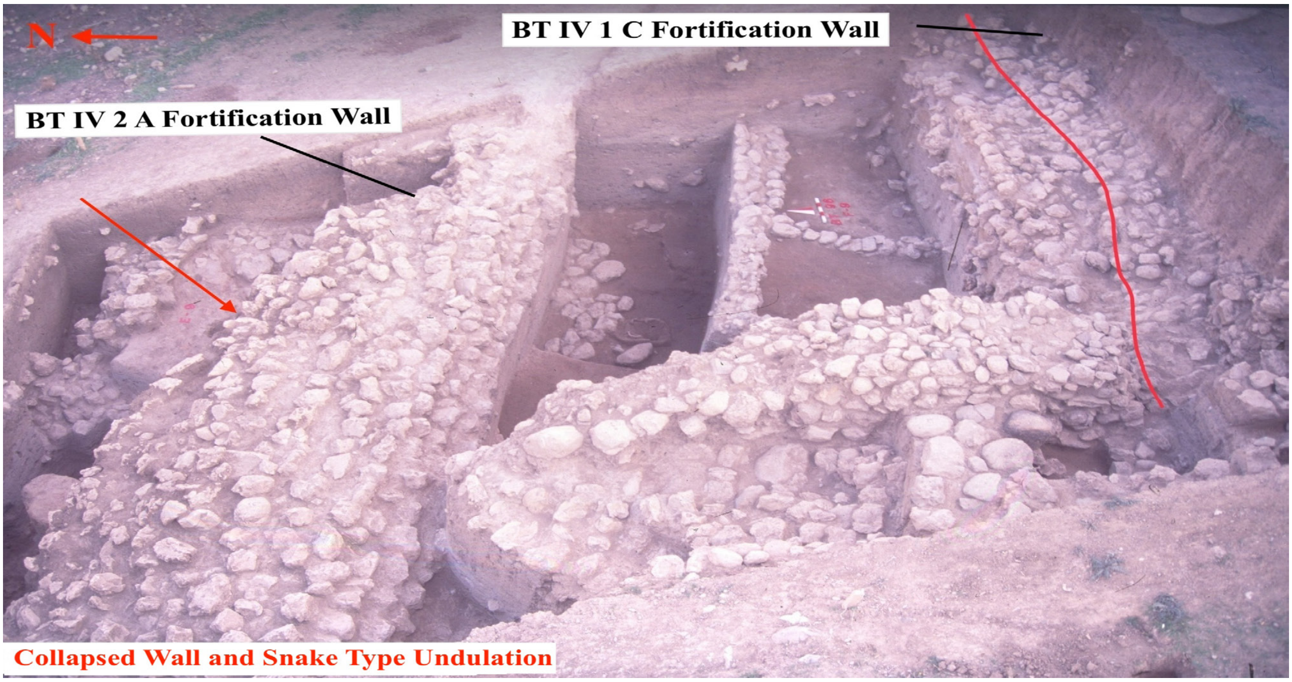

Figure 3. The collapsed fortification wall of Bakla Tepe BT IV 2A, its detailed features, and the snake-type undulation of the fortification wall belonging to the BT IV 1C phase (Photograph: Prof. Hayat Erkanal, IRERP Archive).

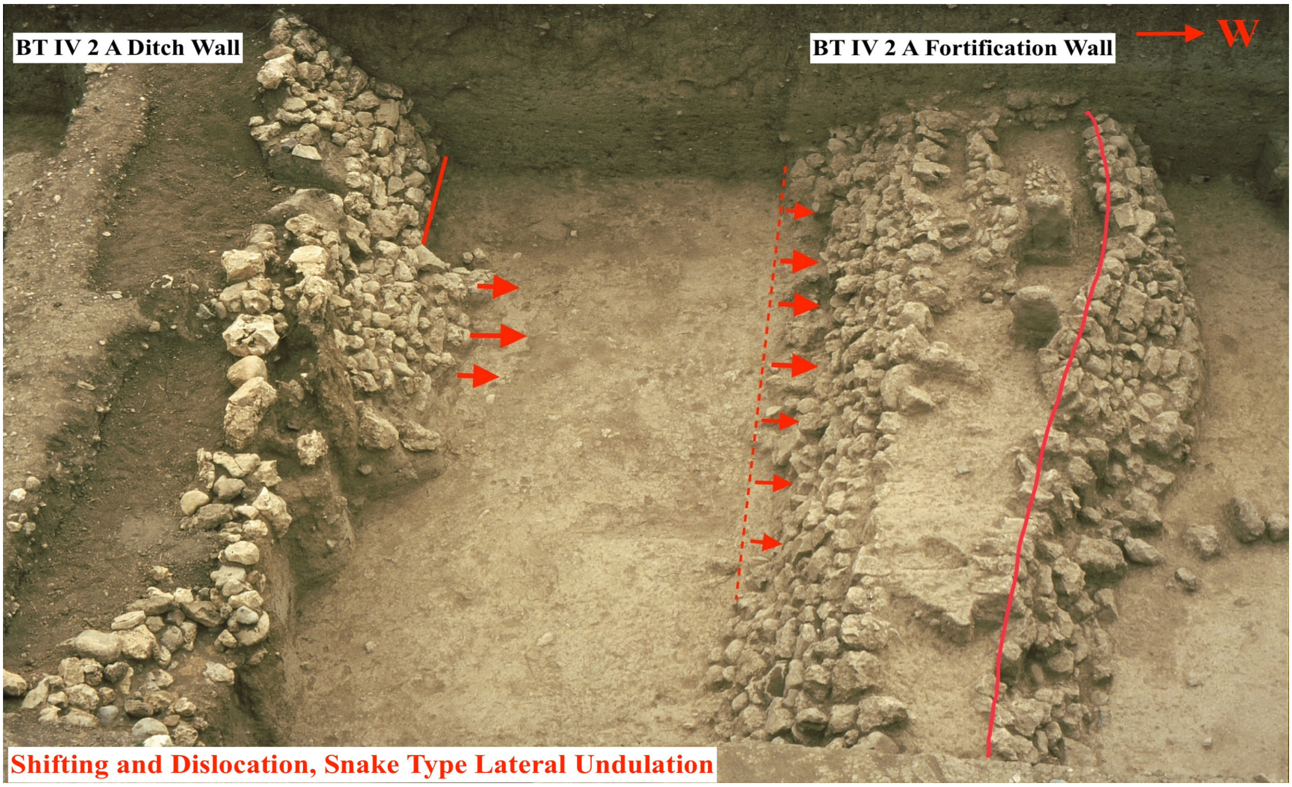

Figure 4. The shifting and dislocation of the ditch wall belonging to the BT IV 2A phase located in the eastern area of Bakla Tepe and the snake-type lateral undulation of the fortification wall sliding westward in the same direction (Photograph: Professor Vasıf Şahoğlu, IRERP Archive).

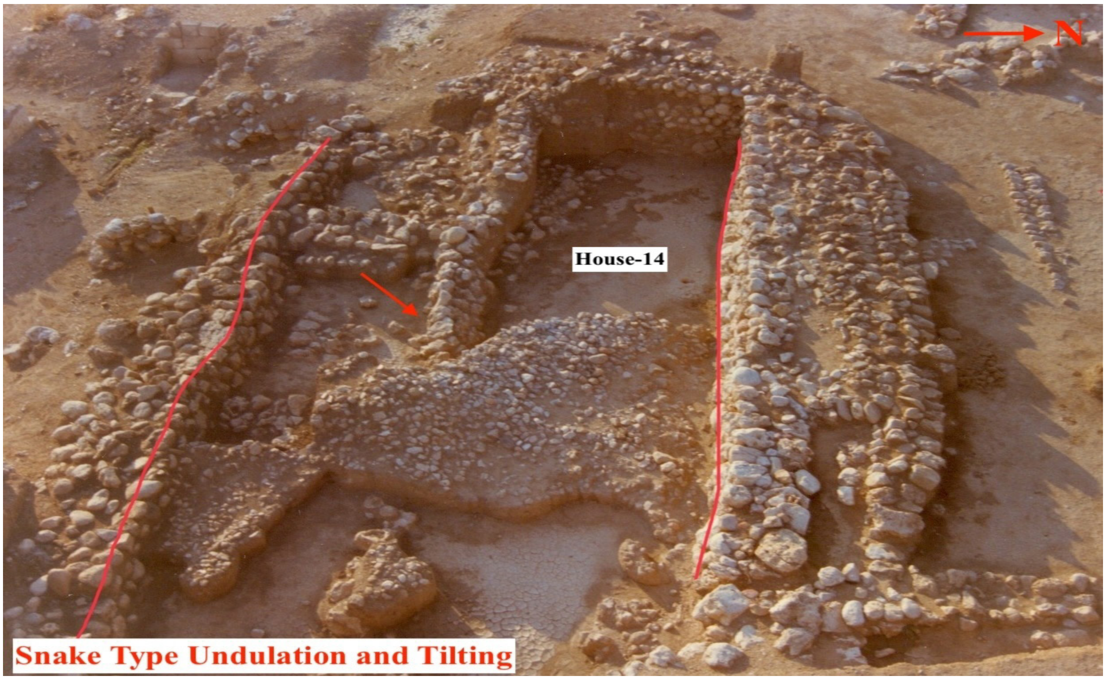

Figure 5. The eastern view of a snake-type undulation in the fortification wall of phase BT IV 1C and southward tilting of the partition wall of the house in the southern part of Bakla Tepe (Photograph: Prof. Hayat Erkanal, IRERP Archive).

2830 BCE, and after its destruction the settlement was completely abandoned except for a few buildings (Derin, 2020; Derin et al., 2020, 2022). Level IIB2 of Yassıtepe was destroyed by the earthquake, and since the buildings were not evacuated at the time of that earthquake, a very rich assemblage of finds was encountered (Derin, 2020). The nearly complete abandonment of the settlement after the earthquake can be considered as a secondary effect of the earthquake.

At the settlement of Thermi on the island of Lesbos, structures in layers III A–B were discovered in a much more damaged state than the buildings in other layers (Lamb and Brock, 1933). It is possible that this layer, which bears the marks of a great catastrophe, was destroyed by an earthquake. A human skeleton found on a street with a broken skull and other bones and the nearby skeleton of a young adult of less than 25 years of age trapped under a collapsed wall are the earliest earthquake victims discovered in the region to date (Lamb, 1936). After layers A–B of Thermi III, the settlement pattern changed radically (Lamb, 1936, plans 3 and 5). The settlement of Thermi, located on the island of Lesbos, is geographically far from the İzmir region. Therefore, it is plausible that Thermi was destroyed as a result of a different earthquake that occurred in the vicinity of the island of Lesbos.

Archaeological evidence and earthquake traces detected in the destruction of walls suggest that Bakla Tepe's BT IV 2A phase and Yassıtepe's IIB2 phase may have been affected by a severe earthquake in the first quarter of the 3rd millennium BCE in the İzmir region. After the first earthquake in the İzmir region, Yassıtepe was almost completely abandoned, while the settlement at Bakla Tepe was nearly halved. After this earthquake, the buildings in the settlements were rebuilt, and this can be considered an indirect effect of the earthquake. At the beginning of the second quarter of the 3rd millennium BCE, new data from Bakla Tepe BT IV 1C, Liman Tepe VI-1b, Yassıtepe IIB1, and Çukuriçi III suggest that a second earthquake may have occurred in the region.

After the first earthquake, the settlement of Bakla Tepe went into a decline and decreased in size from nearly 100 × 100 m to about 50 × 50 m during phase BT IV 1C, in which a new defensive system was built directly on the cone of the mound. This new system was redesigned to withstand earthquakes. Unlike the previous layer's fortification wall, which was built as a single unit, this wall system was constructed in a saw-tooth pattern where separate walls were built at angles. During the second earthquake, only the eastern portion of the saw-toothed defensive system experienced a snake-type undulation, causing it to collapse by tilting northward. The eastern part of the fortification wall extends in a snake-type undulation (Figure 3). Another trace of the earthquake in the Bakla Tepe BT IV 1C phase was found on the fortification wall in the southern part of the settlement. The fortification wall, which was curved in a snake-type undulation, was damaged, coming out of its line. House-14, which leaned against the damaged fortification wall and was used in the same period, was also damaged by the earthquake and the partition wall of this building also collapsed, tilting to the south. The north wall of the house was also affected by the earthquake and there are traces of snake-type undulation (Figure 5).

The northern wall of House-10, an eastern block structure from Phase BT IV IC, also caused a snake-type undulation during the earthquake and tilted out of its axis to the south (Figure 6). The traces of collapse in the walls of Bakla Tepe IV 1C can be considered within the framework of strain structures generated by ground deformation, evaluated as a primary effect of the earthquake. The remains of the burnt and hardened ground floor of House-10 can be assessed as part of the indirect effects of the earthquake.

Liman Tepe is situated on the southern coast of the Gulf of İzmir and located opposite of Karantina Island, 39 km away from Bakla Tepe. Situated by the sea, this settlement was built on rocky terrain during the 5th to 4th millennia BCE. By the 3rd millennium BCE, the settlement had expanded towards the coastal plain, sloping southward (Erkanal and Şahoğlu, 2016). Liman Tepe, where the VII cultural layer has been identified, represents the longest stratigraphic settlement in Western Anatolia. The structures of Liman Tepe, over 25 m long, are the largest structures from the first half of the 3rd millennium BCE (Erkanal, 2011; Erkanal and Şahoğlu, 2016).

At Liman Tepe, earthquake traces were found in the northern area of the settlement. The effects of the earthquake in the first half of the 3rd millennium BCE are evident in the long houses of Liman Tepe. In particular, in Liman Tepe phase VI-1b, the eastern wall of House-2 collapsed into House-3 and the western wall collapsed onto the floor of the house. These 25-m-long structures, built on the soft soil of the older levels, suffered more from the earthquake. The stone foundation of the east wall of House-2 also buckled and collapsed. In addition, the white plaster on the west wall of House-3 was damaged by the earthquake and exposed in fragments (Figure 7).

The most intense traces of the earthquake are found in the front room of House-2. In all three walls of the entrance room, destruction caused by strain structures generated by ground deformation due to the earthquake can be observed (Figure 8). The northern wall of the room extends as a snake-type undulation, with the wall tilting northward. The eastern wall of the house shifted in a lateral undulation towards the west. In the entrance section of the

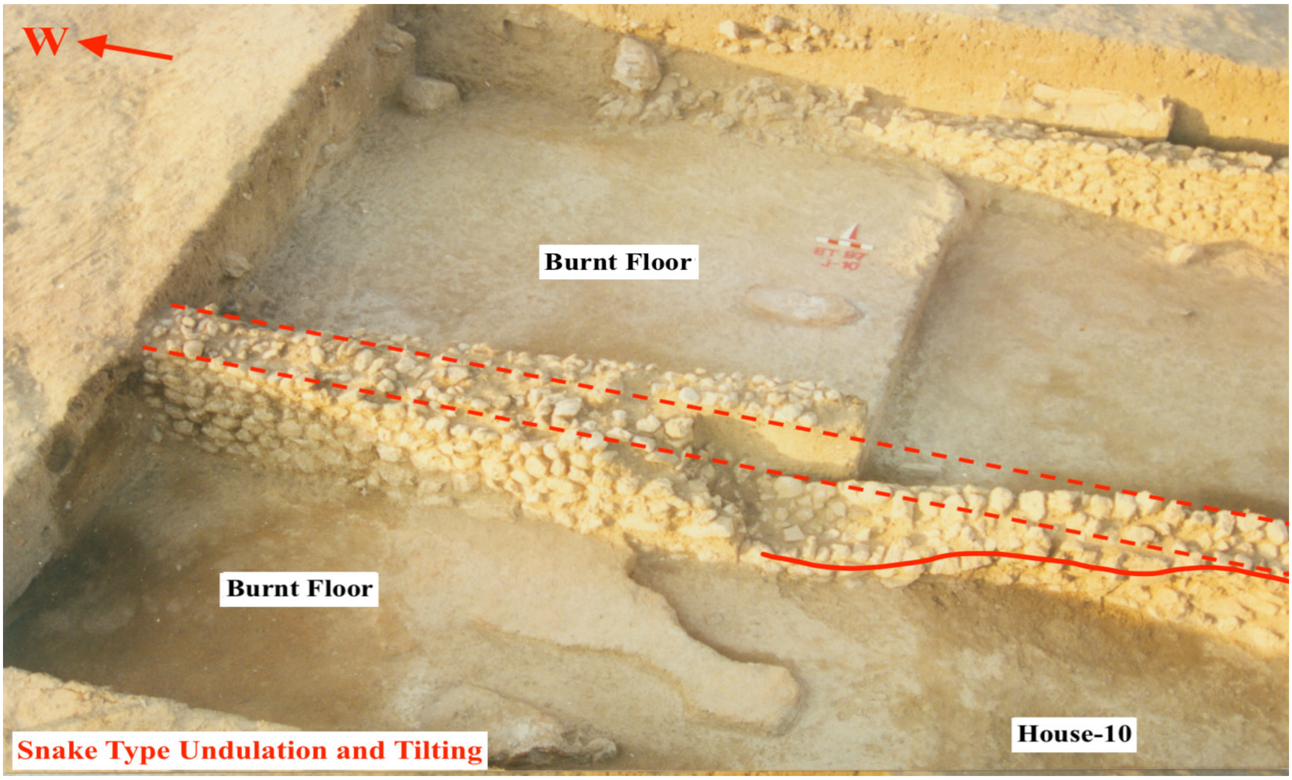

Figure 6. The wall of House-10, belonging to the BT IV 1C phase, exhibits a snake-type undulation and tilting southward, along with burn marks found on the floor of the house (Photograph: Prof. Hayat Erkanal, IRERP Archive).

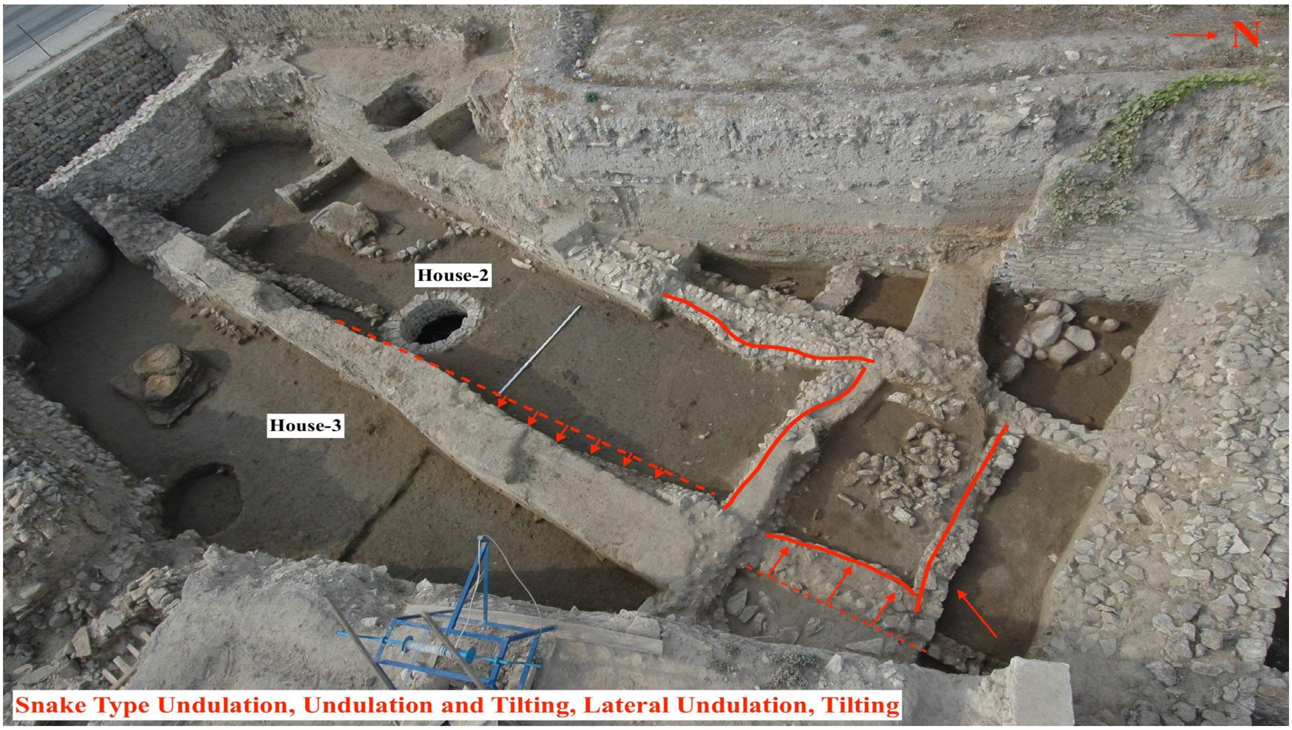

Figure 7. Destruction marks the long houses of the Liman Tepe VI-1b phase. The eastward tilting of the shared wall between House-2 and House-3 and the damage on the walls of the entrance room of House-2 are visible (Photograph: Dr. Ümit Gündoğan, IRERP Archive).

Figure 8. Western view of the tilting, snake-type undulation, and lateral undulations of the walls in the front room of House-2, belonging to the Liman Tepe VI-1b phase (Photograph: Dr. Ümit Gündoğan, IRERP Archive).

main room of the house, the wall, bent with a snake-type undulation, tilted towards the north as it bent (Figures 7 and 8). Examples of postearthquake repairs, which can be considered an indirect effect of the earthquake, can also be seen in these buildings. After the earthquake, the area was levelled and the buildings were rebuilt according to the original plans. The stone foundations of the rebuilt walls are thicker than the old foundations (Erkanal et al., 2010). The construction of new structures after the earthquake on top of the debris led to the elevation of the living level of the settlement; consequently, large stone steps were placed at the entrances of the houses (Erkanal et al., 2010) (Figure 7).

Çukuriçi is located about 1.5 km southeast of the ancient metropolis of Ephesus in the Selçuk district of İzmir Province (Grasböck et al., 2023). According to the C^{14} data, the settlement of Çukuriçi was abandoned around 2750 BCE. There are no conclusive data linking the abandonment of the settlement to any incidents of earthquake or fire (Grasböck et al., 2023, p. 234). The only finding that may be related to the earthquake is the very weak trace identified in the building called Room 1 in phase III of Çukuriçi (Horejs and Weninger, 2016).-

The Yassıtepe 2B2 layer was affected by an earthquake around 2830 BCE. As a result of that impact, while some structures in the settlement were rebuilt, others were repaired and continued to be used (Derin, 2020). The structures of Yassıtepe 2B1, which are contemporaneous with the BT IV 1C phase of Bakla Tepe, the VI 1b phase of Liman Tepe, and the Çukuriçi III phases, have walls with snake-type undulation showing signs of deterioration upon examination (Derin, 2020, Figures 4 and 5.1; Derin et al., 2022, Figure 4). The settlement at Yassıtepe was abandoned after this construction phase (Derin, 2020).

6. Chronology of coastal Western Anatolia in the first half of the 3rd millennium BCE

The 3rd millennium BCE marks a significant period in Anatolia as urbanisation accelerated (Şahoğlu, 2005; Massa and Palmisano, 2018). The changes observed in the region's political and social structure during this period led to radical transformations in societal classes, settlement patterns, and architectural plans (Kouka, 2002; Gündoğan et al., 2019). In the first half of the 3rd millennium BCE, the settlement pattern in Western Anatolia consisted of structures reliant on defence systems, characterised by contiguous long houses (Erkanal, 1996; Kouka, 2002; Ivanova, 2016; Gündoğan et al., 2019, Gündoğan, 2020).

The chronology of Western Anatolia is based on the excavations at Troia. Recent excavations in the İzmir region have helped to establish correlations between the different regions. The Liman Tepe and Bakla Tepe layers from the first half of the 3rd millennium BCE correspond to Troia I (Erkanal and Özkan, 1999; Şahoğlu, 2005, Figure 2). The Troia I settlement was dated to 2920–2700 BCE by Korfmann and Kromer (1993, Figure 23). In light of more recent studies, Weninger and Easton (2014) placed the first phase of Troia I at about 2880 BCE.

Liman Tepe, located in Western Anatolia and constituting one of the longest inhabited settlements in terms of stratigraphy, has made significant contributions to Anatolian chronology through its interregional relationships. The connections of Liman Tepe with the Cyclades Islands and mainland Greece allow for interregional comparisons (Şahoğlu, 2005). The LMT VI (1a–d) phases of Liman Tepe and the early phases of LMT V (3a–b) have been dated to the first half of the 3rd millennium BCE (Kouka, 2009, Table 8; Erkanal and Şahoğlu, 2016, Figure 2). The LMT VI 1d phase of Liman Tepe shares similar characteristics with the Early Cycladic I–II Kampos phase (Kouka, 2009). Manning dated the Early Cycladic I–II Kampos phase to between 2950/2900 and 2650 BCE, while Renfrew placed the same period between 3000 and 2800 BCE (Manning, 2008, 2010; Renfrew, 2010). Kouka (2009) based the architectural phase LMT VI 1d on approximately the year 2950 BCE, drawing on both Cycladic frying pans and early ceramic findings from the 3rd millennium BCE. The fragments of Early Cycladic urfirnis sauceboats found within architectural phase LMT VI 1a of Liman Tepe enable the establishment of a chronological connection with urfirnis sauceboats of Troia (Şahoğlu, 2004, 2008a, 2011). This chronological connection provides evidence that the Early Kiklad II Keros-Syros phase and the early layers of Early Hellas II were contemporary with the final phases of Early Bronze Age I on the Western Anatolian coast (Şahoğlu, 2004, 2005, 2008a). The Early Kiklad II Keros-Syros phase was dated to approximately 2650–2500 BCE by Manning (2008).

In the BT IV 2B phase of Bakla Tepe, which is dated to the first half of the 3rd millennium BCE, pottery assigned to Troia A6 and representing a new form emerging in the early phase of the 3rd millennium BCE has not been found. In this context, the BT IV 2B phase precedes the Troia Ia and Liman Tepe VI Id phases. Another architectural phase of Bakla Tepe's early layer is the BT IV 2A phase. Within this phase, pottery forms assigned to Troia A6 have been discovered, appearing for the first time. These pottery forms have been found along with Troia A12 forms and fragments of Cycladic frying pans. This layer containing fragments of Cycladic frying pans is contemporaneous with the Early Kiklad I–II Kampos phase and the Aplomata group (Şahoğlu, 2008a, 2011). After the early layer of Bakla Tepe was destroyed by an earthquake, the late layer of Bakla Tepe was constructed. The late layer is divided into three architectural phases: BT IV 1C, BT IV 1B, and BT IV 1A. Cycladic urfirnis sauceboats and Keros-Syros painted pottery, which emerged during the Early Hellas II period, are found in the middle and late phases of Troia I, as well as at the end of the layers of Liman Tepe VI and the beginning of layer V. However, the absence of urfirnis sauceboats and Keros-Syros painted pottery within the latest architectural phase of Bakla Tepe, BT IV 1A, suggests that Bakla Tepe was abandoned prior to 2700–2650 BCE (Şahoğlu, 2008a, 2008b; Gündoğan, 2019, Table 2; Gündoğan et al., 2019, Figure 2).

In Çukuriçi, where three architectural phases from the first half of the 3rd millennium BCE have been uncovered, the results obtained from C^{14} samples indicate the beginning date of ÇuHö Va as 3050 BCE and the end date of ÇuHö III as 2750 BCE (Horejs, 2017, Figure 1.5; Grasböck et al., 2023). Comparison of the carbon dates and the recovered ceramic forms led to the conclusion that the IV and III layers of Çukuriçi are contemporary with the early layers of Troia I (Horejs and Weninger, 2016).

According to the ageing carried out on carbon samples from Yassıtepe, the IIB6 (IC3f) phase dates back to around 3020–2900 BCE, while the IIB2 (IC3b) phase dates back to around 2880–2830 BCE (Derin and Caymaz, 2014; Derin et al., 2022). The dating of Yassıtepe's IIB1 (IC3a) phase was performed with the comparison of ceramic forms. Common ceramic forms during this phase include Troia A12, Troia A6, cylindrical-bodied jars, and beaked jugs (Derin and Caymaz, 2014). The IIB2 phase of Yassıtepe ended around 2830 BCE according to C^{14} results. Yassıtepe's IIB1 phase had weak architecture and the settlement ceased shortly thereafter (Derin, 2020) (Figure 9).

7. Discussion

While records from the ancient period contain information on the dates of historical earthquakes, for prehistoric settlements such dates can be derived from the C^{14} data obtained from earthquake layers. Carbon samples taken from earthquake layers and evidence of earthquakes from other sites contemporary with these layers could provide the approximate dates of the earthquakes that occurred during the prehistoric period. The dates obtained from C^{14} samples from Yassıtepe indicate that an earthquake might have happened around 2800 BCE (Derin et al., 2020, 2022). Layer IIIA of Thermi has also been chronologically dated to 2800 BCE (Kouka, 2002, Table 1). Phase IV 2A of

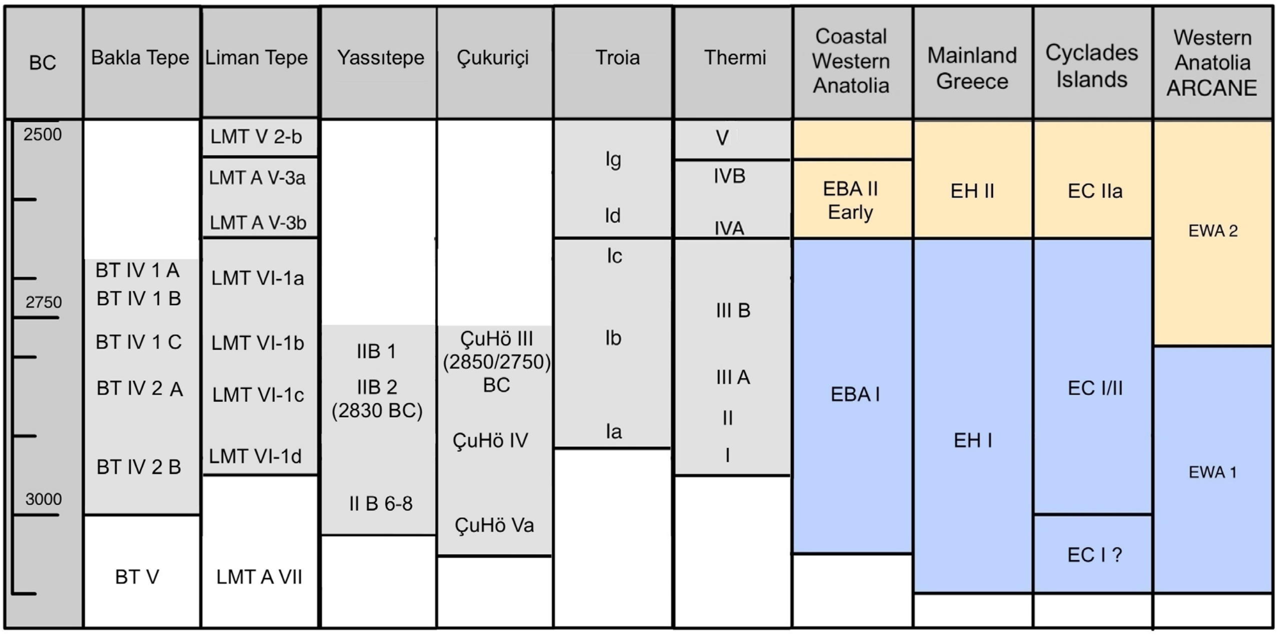

Figure 9. Stratigraphy and chronology of settlements in the first half of the 3rd millennium BCE in Western Anatolia (Korfmann, 1989; Korfmann and Kromer, 1993; Weninger, 1995; Kouka, 2002, tab. 1; Şahoğlu, 2005, fig. 2; Kouka, 2009; Derin and Caymaz, 2014; Horejs, 2017; Lebeau, 2018; Gündoğan, 2019, tab. 2; Derin, 2020).

Bakla Tepe dates to the same period. In this context, an earthquake may have occurred in the vicinity of Bakla Tepe and Yassıtepe around 2800 BCE. As for the second earthquake, it is almost impossible to make a conclusive judgement because C^{14} data related to this earthquake are not present for settlements other than Çukuriçi. The results of the C^{14} samples from layer III of Çukuriçi date the layer to between 2850 and 2750 BCE. The settlement was abandoned around 2750 BCE (Horejs and Weninger, 2016; Horejs, 2017, Figure 1.5; Grasböck et al., 2023). The settlement of Yassıtepe was abandoned in phase 2B1 (after 2800 BCE) (Derin, 2020). After the destruction of the Bakla Tepe settlement in phase BT IV 2A, the settlement immediately resumed in phase BT IV 1C. Bakla Tepe was abandoned at the end of phase IV 1A (late Early Bronze Age 1) (Şahoğlu, 2008a, 2008b; Gündoğan, 2019).

As a result, traces of the first earthquake that could have affected the İzmir region were found in the Bakla Tepe BT IV 2A phase (Gündoğan et al., 2019) and in the Yassıtepe IIB2 phase (Derin, 2020; Derin et al., 2020, 2022). Soon after, traces of a second earthquake were found in the BT IV 1C phase of Bakla Tepe, the LMT VI-1b phase of Liman Tepe (Erkanal et al., 2010), and the 2B1 phase of Yassıtepe (Derin, 2020, Figures 4 and 5.1; Derin et al., 2022, Figure 4). The earthquake traces in level III of Çukuriçi are very weak, as they were found only in one room (Horejs and Weninger, 2016).

The geological composition beneath the settlements, coupled with the reconstruction of walls on the soft soil of the mound and potential weaknesses in construction techniques, likely contributed to increased damage to the structures during the earthquake. The fact that corner stones were not used in the construction of the walls of the structures (Gündoğan, 2022) resulted in greater destruction during earthquakes. As for Yassıtepe, since the round river stones did not interlock with each other, the use of these stones for construction caused the damage to be more pronounced (Derin et al., 2022). The structures were generally constructed on stone foundations with mudbrick superstructures. Since no timbers were placed between the blocks of mudbricks, the walls were not flexible.

The architectural designs of structures during the first half of the 3rd millennium BCE in Western Anatolia and the Eastern Aegean Islands, characterised by long houses with shared common walls (Erkanal, 1996; Ivanova, 2016; Gündoğan et al., 2019) (Figure 7), inadvertently exacerbated the destructive potential of earthquakes. These long houses, constructed in blocks with interconnected walls, proved vulnerable to seismic stress, particularly for walls measuring 15 m or longer. The strain induced during earthquakes led to displacements in wall joints, raising the risk of collapse. This risk was further amplified by the potential for a domino effect, where the collapse of one wall could trigger cascading failures affecting neighbouring structures within the block. Although the use of common walls aimed to economise on material, manpower, and time, it paradoxically increased the vulnerability of these structures to seismic events. Additionally, the poor architectural techniques and the limited durability of construction materials in ancient settlements also contributed to heightened destruction and property loss during seismic events. Therefore, while shared common walls served practical purposes, they inadvertently amplified the destructive impact of earthquakes on these settlements in the region.

The masons of the period developed and employed new techniques to make structures more durable. The first example is an attempt to make the walls more robust by increasing their thickness, and the Liman Tepe Level V structures are instances of this (Erkanal et al., 2016, Figure 6). As a second example, since the fortification wall in the early phase of Bakla Tepe was built as a single wall and the entire wall toppled during the earthquake, the defensive wall system in the later phase was divided into sections in a saw-tooth pattern on the sloping side, which both enabled the wall system to turn according to the surface features of the mound and prevented the entire wall from being toppled as a single unit. Indeed, only the eastern fortification wall in the late layer of Bakla Tepe was toppled during the second earthquake. These findings are important in that they show how expert masons made risk assessments regarding the construction of the defensive system and constructed the fortification walls according to the topography of the settlement. In Western Anatolia, defensive systems with similar saw-tooth or saw-edged patterns were also employed at Troia, Demircihüyük, and Hacılar Büyük Höyük (Korfmann, 1983, 1989; Umurtak and Duru, 2017).

The earthquakes that happened in the first quarter of the 3rd millennium BCE in Western Anatolia may have caused political turmoil in the region. Although it is known that settlements in Western Anatolia were abandoned in the first quarter of the 3rd millennium BCE and coastal settlements developed as a result, the factors that led to this situation are unfortunately not clear (Gündoğan, 2022). The settlements could have been abandoned because of the growing political instability in the region, with their dwellers conceivably moving to other large centres. However, it is noteworthy that the settlements were abandoned in the first half of the 3rd millennium BCE, at a time when lower cities had not yet emerged and centres such as Liman Tepe and Troia had yet to undergo urbanisation. Although it was not the case for settlements such as Troia and Liman Tepe, the settlements of Beşik-Yassıtepe and Kumtepe in the region of Troas and Yassıtepe and Çukuriçi in the region of İzmir were abandoned (Korfmann, 1988; Riehl, 1999; Derin et al., 2022; Gündoğan, 2022; Grasböck et al., 2023). The settlement of Bakla Tepe was heavily impacted by the earthquake and most of its structures were found to have collapsed. Although the houses were rebuilt and habitation continued in Bakla Tepe for a while after the earthquake, like the other settlement of the region it was abandoned (Gündoğan et al., 2019).

The responses to earthquakes in Western Anatolia during the first half of the 3rd millennium BCE were either to abandon the settlements or to remain in the region while constructing new buildings. The decline of settlements as well as the abandonment of settlements might have led to migration in the region. The settlements, though smaller in size after the first earthquake, might also have continued to exist, as in the case of Bakla Tepe. After the second earthquake, the Bakla Tepe settlement was rebuilt again and a megaron structure was constructed for the rulers. All the metal finds in this phase were unearthed from only this structure and the nearby workshop area. A stone-paved and ramped entryway supported by two towers was added next to the megaron, which is situated on the northern part of the mound. These findings indicate that a significant change took place in the social structure at Bakla Tepe after the earthquake and a ruler emerged (Gündoğan, 2019, 2022). Structures belonging to a ruling class are seen in Western Anatolia for the first time in this period. This may indicate the impact of postearthquake changes in social organisation and settlements on the social structure.

8. Conclusion

As a consequence of the geological structure of Western Anatolia, large and destructive earthquakes have been frequently occurring in the region since the beginning of the Quaternary period until the present day. Data from the archaeological excavations conducted in prehistoric settlements of Western Anatolia and the related C^{14} dates indicate that an earthquake might have occurred there around 2800 BCE. It is also possible that a second earthquake occurred shortly after the first.

The abandonment of settlements or other archaeological evidence, such as architectural changes, may help in determining ancient earthquakes. The changes after the natural disasters that occurred in Western Anatolia, such as abandonment of settlements, decline in the sizes of settlements, and the signs of the emergence of ruling individuals or administrators, must have been the resulting effects that natural disasters had on societies. In addition, structures belonging to individual rulers or administrators became more easily recognisable at Bakla Tepe. As for Thermi, the earthquake led to the adoption of a new settlement model. In the 3rd millennium BCE, collapsed structures were rebuilt in the same places, adhering to ownership rights. However, change in the settlement plan shows that ownership rights could be violated in the said period as well.

Archaeological studies demonstrate how natural disasters of the past had an impact on human life and cultural structures, as well as shedding light on the postearthquake recovery efforts and structural transformations of the affected societies. Following the earthquakes, the defensive systems of the settlements were built in a way considered to be more durable. While some of the houses were repaired and reused, some were rebuilt after the area of debris was levelled.

In conclusion, the data presented here indicate that the earthquakes that occurred in Western Anatolia during the first half of the 3rd millennium BCE had a significant impact on its settlements, leading to structural, social, and cultural changes. These data offer an important archaeological perspective in understanding the ways the natural disasters of the past affected the structures and lives of ancient societies.

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