



Research Article

Destruction and resilience at Panaztepe: archaeoseismological evidence for third-millennium BC earthquakes in Western Anatolia

Ümit Gündoğan^{1,2,3}  & Ümit Çayır Tıǵı⁴ 

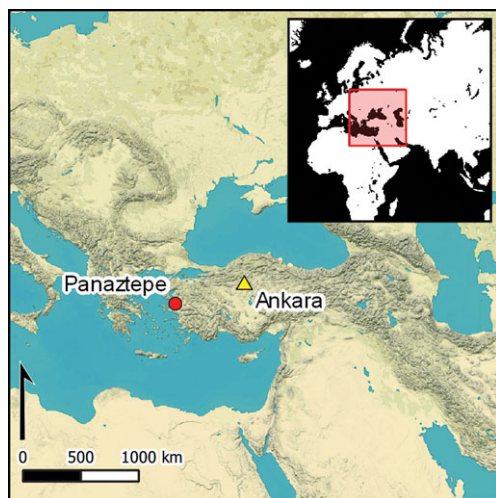
¹ Art History Department, Batman University, Türkiye

² Department of Archaeology, Durham University, UK

³ Ankara University Mustafa V. Koç Research Center for Maritime Archaeology - ANKUSAM, Urla, Türkiye

⁴ Department of Archaeology, Sivas Cumhuriyet University, Sivas, Türkiye

Author for correspondence: Ümit Gündoğan ✉ umitgndgn@gmail.com



Earthquakes and the destruction they wreak on communities and landscapes are regular features of both modern news output and historical accounts. Archaeology can add to our understanding of such disasters, demonstrated here in the discussion of architectural damage noted during recent excavations at Panaztepe, an Early Bronze Age settlement in Western Anatolia. Distinct destruction horizons illustrate the primary and secondary impacts of two earthquakes during the third millennium BC: the first was followed by reconstruction and adaptation, the second by abandonment. By focusing on evidence of seismic activity, the authors examine the resilience of communities inhabiting this geologically fragile region.

Keywords: Mediterranean Europe, Early Bronze Age, archaeoseismology, earthquake, architecture

Introduction

The North and East Anatolian fault zones have been the epicentre of devastating earthquakes throughout history (Arpat & Şaroğlu 1972; McKenzie 1976; Şengör *et al.* 2005). Located on the western side of Anatolia, the unique tectonic structure of the Aegean region, including graben systems and numerous active fault zones, has produced a fragile geology and high seismicity that have made this area prone to natural disasters (Dewey & Şengör 1979; Yılmaz *et al.* 2000; Emre *et al.* 2018; Gündoğan 2024). Historical

Received: 3 November 2025; Revised: 18 January 2026; Accepted: 11 February 2026

© The Author(s), 2026. Published by Cambridge University Press on behalf of Antiquity Publications Ltd. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<https://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

sources indicate that numerous destructive earthquakes have occurred in İzmir, on the Aegean coast of modern-day Türkiye, and the surrounding area since the first millennium BC, causing serious damage to settlements and resulting in loss of life and property. Subsequent fires and landslides exacerbated these disasters (Guidoboni *et al.* 1994; Ambraseys 2009; Tepe *et al.* 2021).

The destruction observed in archaeological excavations in Western Anatolian settlements during the first half of the third millennium BC demonstrates that earthquakes had a lasting impact on both structures and societies. Changes in post-earthquake settlement plans, the adoption of new construction techniques or the total abandonment of some settlements reflect the ways in which these communities responded to natural disasters (Gündoğan 2024). The Bakla Tepe (Gündoğan 2024), Liman Tepe (Erkanal *et al.* 2010; Gündoğan 2024), Yassitepe (Derin 2020) and Panaztepe excavations are of great importance as they reveal the earliest known seismic traces in Western Anatolia (see online supplementary material (OSM) Table S1).

Evidence of earthquakes from settlements dating back to the first half of the third millennium BC sheds light on the region's long-term seismic history (Gündoğan 2024). The first destruction phase identified at Panaztepe (Phase I, *c.* 3000–2700/2650 BC; see Table S1) coincides chronologically with destruction at other settlements in the region, consistent with a broader pattern of seismic activity. However, a destruction layer associated with Panaztepe Phase III (*c.* 2550/2500–2300 BC), dated to the second half of the third millennium BC, has no known parallels. The Panaztepe evidence is therefore crucial for filling a major gap in the record of prehistoric seismology in Western Anatolia.

The architectural damage patterns and structural deformations observed at the settlement reveal that earthquakes had a transformative impact not only on the physical environment but also on settlement layout and social organisation. In this regard, Panaztepe serves as a key site for assessing the sociospatial consequences of early seismic events, thereby contributing to the archaeoseismological framework of Western Anatolia.

The tectonic framework and seismicity of the region

The tectonic framework of Western Anatolia is characterised by the westward escape of the Anatolian Plate, accommodated by strike-slip motion along the North and East Anatolian fault zones. This lateral displacement evolves into an extensional regime in the Aegean region and along the Hellenic subduction zone (Dewey & Şengör 1979; Le Pichon & Angelier 1979). Such tectonic evolution led to the development of east–west trending horst-graben systems (alternating raised and lowered geological blocks) such as the Gediz and Büyük Menderes grabens (Yılmaz *et al.* 2000), rendering Western Anatolia a neotectonic province dominated by normal faulting with subordinate strike-slip components (Şengör 1987) (Figure 1).

The Gediz Graben, on which the Panaztepe settlement is located, is an east–west-trending tectonic structure approximately 140km long and 10–15km wide. Its southern margin is defined by the low-angle Gediz detachment fault, accompanied by younger, high-angle normal faults, while the northern margin is defined by steeper and comparatively less active normal faults. Overall, the Gediz Graben is predominantly shaped by

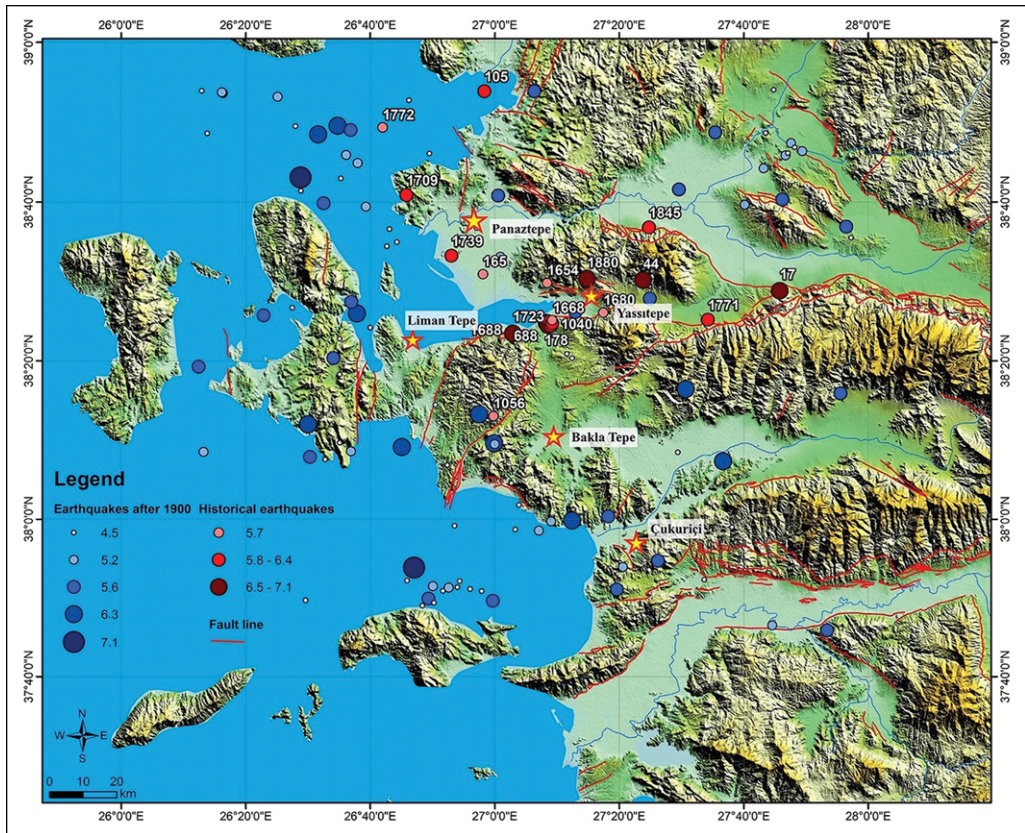


Figure 1. Locations and magnitudes of historical and post-1900s earthquakes in Izmir and surrounding areas. Only earthquakes with a magnitude of 4.5 and above are shown (figure by authors; information about historical earthquakes from Tepe *et al.* 2021; faultlines drawn from General Directorate of Mineral Research and Exploration (MTA); post-1900 earthquake data from the United States Geological Survey (<https://earthquake.usgs.gov/earthquakes/search/>).

east–west-oriented normal faulting and represents a typical product of the extensional tectonic regime that has dominated Western Anatolia (Seyitoğlu & Scott 1996; Sözbilir 2002).

Historical records and recent seismic observations indicate that the fault zones observed in the İzmir region have the capacity to generate large-magnitude earthquakes (Şengör *et al.* 1985; Şengör 1987; Drahor & Berge 2017). During the great earthquake of AD 17, which devastated many centres across Western Anatolia, the settlement of Temnus, located near Menemen, also suffered severe damage (Guidoboni *et al.* 1994). In later periods, the İzmir earthquake of 1040 and the Kemalpaşa earthquake of 1850 were strongly felt across the Gediz Plain (Ambraseys 2009). The 1860 Manisa earthquake and the 1865 İzmir earthquake caused damage in Menemen. During the 1880 Menemen earthquake, nearly half of the buildings in the town were destroyed, surrounding villages were devastated and substantial damage was also reported in İzmir.

The 1881 Chios earthquake was likewise strongly felt in Menemen and its vicinity, further exacerbating the existing destruction (Ambraseys 2009; Beyru 2011). These data demonstrate that the region has been subjected to frequent and intense seismic activity throughout both historical and modern periods (Figure 1).

Method

Archaeoseismological analyses were conducted to assess whether the destruction layers identified at the Early Bronze Age settlement of Panaztepe, dated in Western Anatolia to c. 3000–2000 BC, resulted from seismic events. Such approaches emphasise the role of natural disasters in shaping past societal transformations and offer archaeology an important interpretive framework (Nur & Cline 2000; Sintubin 2011; Drahor *et al.* 2023). The concept of Earthquake Archaeological Effects (EAE), as defined by Giner Robles and colleagues (2009), refers to the deformation of archaeological structures resulting directly from seismic stress and which may be distinguished from damage caused by non-seismic factors, such as erosion, soil instability, heavy loads, water action or human activity. This classification has been adopted as the primary framework for evaluating the architectural deformation patterns identified at Panaztepe. Block collapses, shifting and dislocation, undulation and tilting, and lateral and snake-type undulation can be regarded as critical indicators of seismic activity (Giner Robles *et al.* 2009; Rodríguez Pascua *et al.* 2011). However, the occurrence of collapsed walls, fallen columns or cracks in archaeological contexts cannot, by themselves, be taken as conclusive evidence of seismic activity as such structural disturbances may also result from various non-seismic processes (Ambraseys 2006). Therefore, evidence of post-earthquake fires, artefacts discovered *in situ* (as houses could not be evacuated due to the earthquake's sudden onset), widespread traces of destruction across the settlement, shifts in settlement patterns and the site's eventual abandonment can all be regarded as secondary archaeological indicators of seismic events. These constitute important criteria for identifying earthquake-related layers (Rodríguez Pascua *et al.* 2011; Gündoğan 2024).

Archaeoseismological evidence for third millennium BC earthquakes at Panaztepe

Panaztepe is an important Bronze Age settlement located in the Menemen district of the province of İzmir in Türkiye. It is situated in the central part of the Gediz Delta (Figure 1). Palaeogeographic findings suggest that, during the Middle and Late Holocene (c. 6200 BC to the present), the sea extended as far as the eastern foothills of the Maltepe ridges and that the Panaztepe-Limankent area was submerged for an extended period under shallow sea (shoreface) conditions (Erkanal 1997). The historical development of Panaztepe is directly linked to the Gediz River. In the third millennium BC, Panaztepe was an island or peninsula; however, as alluvial flooding gradually filled in the coastal area to the west, it is now 8.90km from the sea. The fact that Panaztepe is currently buried beneath alluvial deposits indicates that it has moved away from the

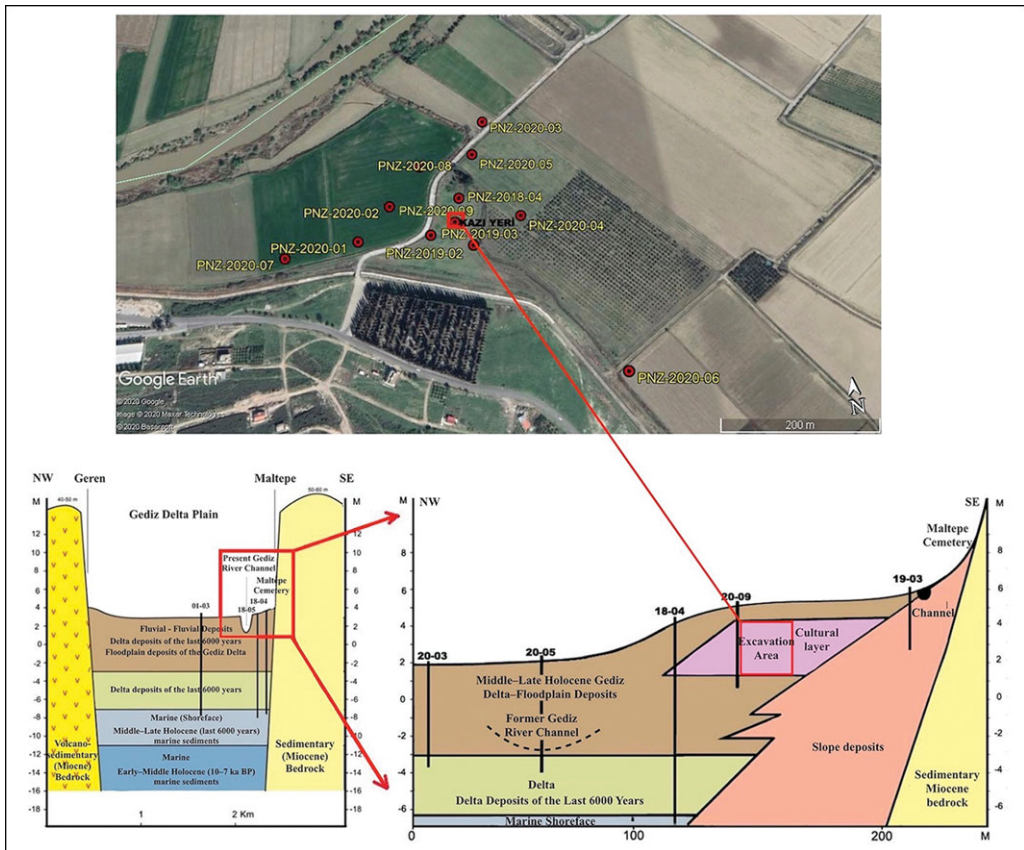


Figure 2. Core sampling locations and geological cross-section for the Panaztepe New Excavation Area. The section illustrates Middle–Late Holocene deltaic and floodplain deposits, as well as colluvial slope sediments, overlying sedimentary Miocene bedrock (after Öner et al. 2021: figs. 7 & 14).

coastline over time and acquired different geomorphological features (Öner & Vardar 2018) (Figure 2).

Excavations conducted since 1985 indicate that Panaztepe was occupied over a long time span, from the Early Bronze Age to the Ottoman period (*c.* 3000 BC to the early twentieth century AD), a longevity that is likely related to its strategic location. Commercial vessels entering the Gulf of İzmir likely followed the coastline, and this route passed close to Panaztepe, indicating that the settlement occupied a favourable strategic position for coastal transport and regional interaction networks. Settlements in the İzmir region were connected to the interior of Anatolia via the Gediz River valley, establishing links with both land and sea trade networks (Şahoğlu 2005). Thus, Panaztepe was located on a transition line between the northern–southern and inner regions of Central and Western Anatolia.

The artefacts unearthed at Panaztepe indicate that the settlement had extensive connections stretching as far as the Aegean Islands, mainland Greece and Egypt during the Late Bronze Age (*c.* 1650/1600–1200 BC). Chemical and neutron activation analyses of

a group of Mycenaean painted vessels recovered during the excavations indicate that some samples may be associated with Berbati, a Mycenaean pottery-production centre in the Argolid region of the Peloponnese (Erkanal 1993). Although limited in number, amber beads suggest indirect contact with the Baltic Sea region during the second millennium BC, while scarab specimens from contemporaneous burials point to connections with Egypt and the existence of overseas interactions (Erkanal Öktü 2018).

Panaztepe's strategic location likely also shaped its Early Bronze Age occupation, which displays architectural features characteristic of contemporaneous sites in Western Anatolia and the Eastern Aegean Islands. In the New Excavation Area (Figure 2), this is reflected in a street-organised layout of adjacent long houses, a pattern consistent with the 'Aegean settlement pattern' documented across coastal Western Anatolia and the Eastern Aegean Islands (Gündoğan 2020). These buildings exceed 10m in length, share common walls and open directly onto the street. They typically comprise a main room and a front antechamber or entrance hall. The settlement plan indicates that the houses were aligned along the main street and set at right angles to it (Figures 3 & 4).

This spatial layout, while efficient, also created structural interdependence between neighbouring buildings, making the settlement particularly vulnerable to seismic stress. Indeed, evidence of earthquake damage has been identified in the first and third phases of the cultural sequence at the New Excavation Area.

Phase I earthquake activity

Traces of the earliest earthquake activity to affect the Panaztepe settlement have been documented in two structures belonging to Phase I (c. 3000–2700/2650 BC; see Table S1). These structures, oriented along a north-east to south-west axis, represent the earliest occupation layer so far identified in the New Excavation Area. One of the structures associated with this phase, building 21, shares its L-1027 and L-1017 walls with adjacent buildings. The structure is approximately 4m wide, with 4.20m of its length excavated; the southern section could not be investigated, as it lies beneath Roman-period architectural remains. The primary effects of an earthquake are clearly documented in this building. During the seismic event, the two load-bearing side walls were subjected to substantial stress. The western wall (L-1027) developed a snake-type undulation and tilted slightly eastward; the stone foundation of the eastern wall (L-1017) exhibits a comparable snake-type undulation and eastward tilt (Figure 5). The roof of the building collapsed into the interior during the earthquake, after which the mud brick superstructure of the L-1027 wall fell as a block eastward onto the roof debris. The consistent eastward orientation of the tilting in both parallel load-bearing walls provides strong structural evidence for the directionality of ground motion, pointing to a coherent seismic impact rather than random structural failure (Figure 6).

The secondary effects of the earthquake are also visible in this building. A subsequent fire consumed the wooden beams of the roof and the intense heat turned the clay an orange-red colour. The imprints of the wooden beams in the mud mortar have been preserved, and the burnt, solidified layers reveal the severity of the fire. Pottery, large storage jars, animal bones and marine shells were recovered *in situ* from beneath the

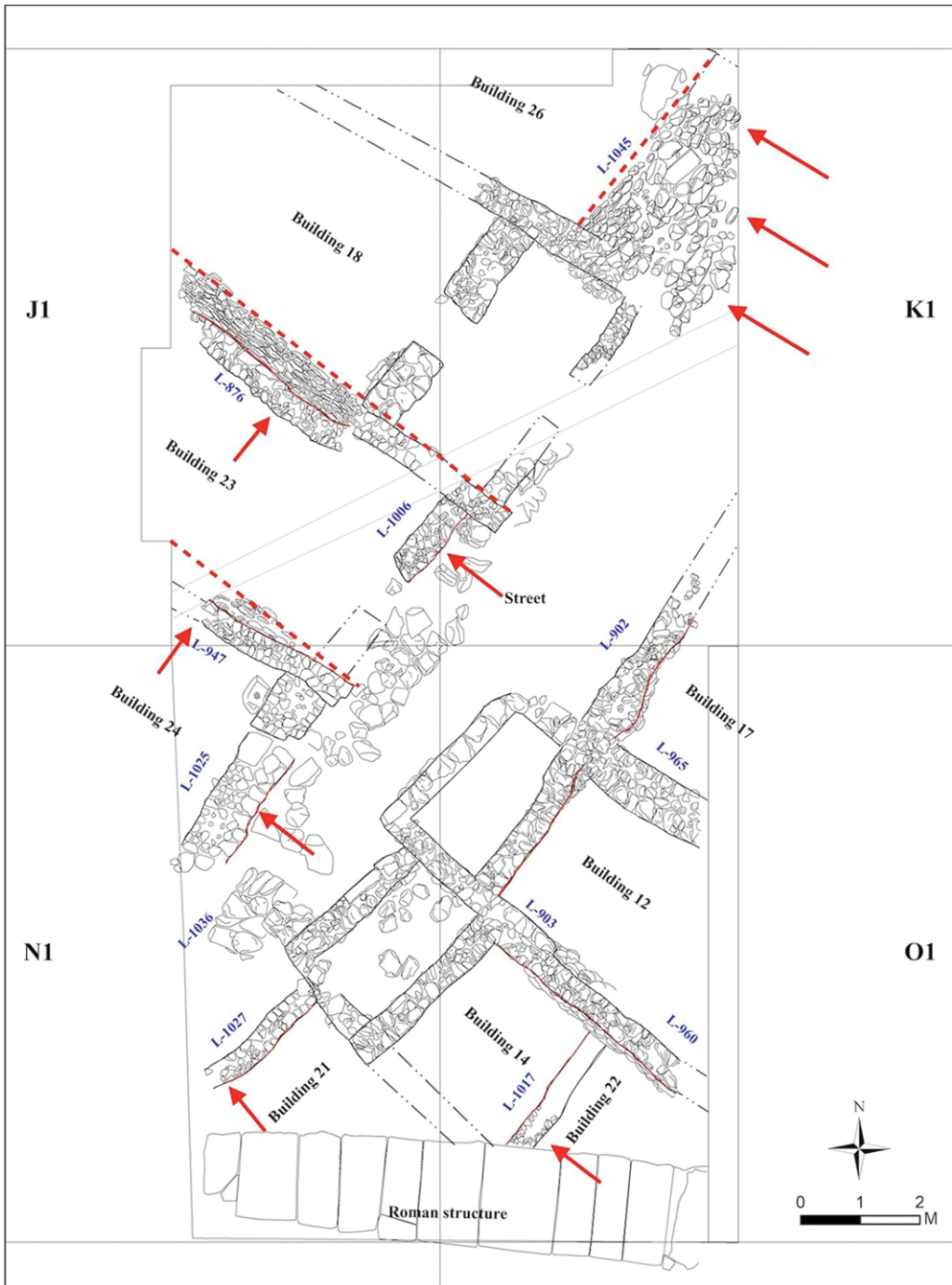


Figure 3. Architectural plan of the Panaztepe Early Bronze Age settlement, illustrating earthquake-related deformation in building walls. Red dotted lines: projected (undeformed) wall alignment; red curved lines: snake-type undulation; red arrows: direction of wall collapse or tilting (figure by authors).



Figure 4. Aerial view of the Panaztepe Early Bronze Age settlement showing earthquake-related wall deformation patterns (figure by authors).



Figure 5. Snake-type undulation and eastward tilting of walls in buildings 21 and 22. The secondary effects of the earthquake are represented by the collapsed roof, the subsequent fire and the artefacts preserved in situ beneath the destruction layer (figure by authors).



Figure 6. Eastward block collapse of the L-1027 mudbrick wall in building 21 (figure by authors).

burnt roof debris (Figure 5). These findings suggest that the building collapsed suddenly during the earthquake, leaving the inhabitants no time to collect their belongings as they evacuated. The evidence from building 21 illustrates a sequence of architectural destruction caused directly by an earthquake and ensuing fire.

Building 22 is located to the east of building 21 and shares the L-1017 wall. Although only part of the structure has been uncovered, the effects of the earthquake are observable. During the seismic event, the building's walls collapsed, and the roof fell into the interior, forming a substantial roof deposit. The subsequent fire exposed the roof to intense heat, turning it reddish-orange, and the roof remains were found to have burned en masse (Figures 5 & 6).

Phase III earthquake activity

After the first earthquake, the inhabitants of Panaztepe reorganised the settlement and undertook a phase of reconstruction. No evidence of seismic activity was identified in the second occupational layer. However, in the third phase of occupation, dating to the second half of the third millennium BC, a distinct earthquake destruction layer is identified, extending across the entire settlement (Figures 3 & 4).

Traces of earthquake-related destruction in this third phase are identified on the walls of seven adjacent buildings constructed on both sides of the street. Within the western block, which consists of four buildings, building 26 at the northernmost end exhibits the most pronounced evidence of earthquake damage. This house is connected to building 18 to the south through a shared wall. During the earthquake, the wall opening onto the street and containing the entrance door (L-1045) collapsed eastward in a single

block. Under normal, non-seismic circumstances, debris from a collapsed wall would be expected to scatter to both sides; the stepped arrangement of the exposed stones and the fact that the wall fell as a single block over an area of approximately 2.5m demonstrate that the destruction was abrupt and directional. Block-wise wall collapses like this are generally attributed to seismic activity and are classified as one of the primary effects of earthquakes (Figures 3, 7 & 8).

Building 23, located immediately south of and sharing the L-876 wall with building 18, also exhibits similar signs of destruction. During the earthquake, the L-876 wall deviated from its position and tilted approximately 40° to the south (Figures 7 & 8). This caused the mudbrick blocks at the top to collapse into the interior of building 23. The dense mudbrick debris found in both houses is direct evidence of the earthquake. The south wall of building 23 (L-947) is also tilted towards the south, and the wall opening onto the street (L-1006) exhibits lateral undulation deformation, with the rows of stones partially shifted towards the east. Therefore, traces of earthquake-induced destruction are clearly visible on three of the structure's walls. The collapse of the side walls affected the adjacent structures, causing deformation to the two central walls and significantly increasing the effects of the destruction (Figures 4 & 8).

Building 24 was also affected by the southward tilting of the L-947 wall, shared with building 23, and damage to the front façade. In particular, the snake-type undulation observed on wall L-1025 indicates eastward displacement and subsequent collapse during the seismic event.

Traces of earthquake-induced deformation have been documented across all three structures in the eastern block. These structures were built immediately after the major earthquake that occurred during the first phase of settlement. Walls belonging to the second construction phase were built to be thicker and more robust (L-965, L-903, L-1036) (Figure 3) but the third construction phase saw noticeably thinner walls rebuilt on the same foundations. This reduction in wall thickness reduced earthquake resistance, resulting in increased earthquake damage in the third phase of occupation (Figure 9).

Building 17 is located at the northernmost end of the eastern block. A snake-type undulation is apparent in the wall facing the street, which contains the entrance doorway. During the earthquake, the wall not only bent in a lateral undulation, but also bulged inwards and outwards. Similar findings were observed in structure building 12, located south of building 17. The wall containing the street-side entrance door of this house bent during the earthquake, causing a directional shift in the stone masonry. The L-960 wall, located east of building 12, is a shared side wall with building 14. The stone foundation of this wall is thicker and more solidly built, but the dimensions decreased in the upper phase. During the earthquake, this wall underwent snake-type undulation deformation (Figures 4 & 9).

Taken together, the architectural damage documented across these phases suggests that repeated seismic disturbances progressively increased structural vulnerability and may have contributed to longer-term changes in settlement organisation and eventual abandonment.



Figure 7. Eastward block collapse of the L-1045 wall and southward tilting of the L-876 wall in Phase III (figure by authors).

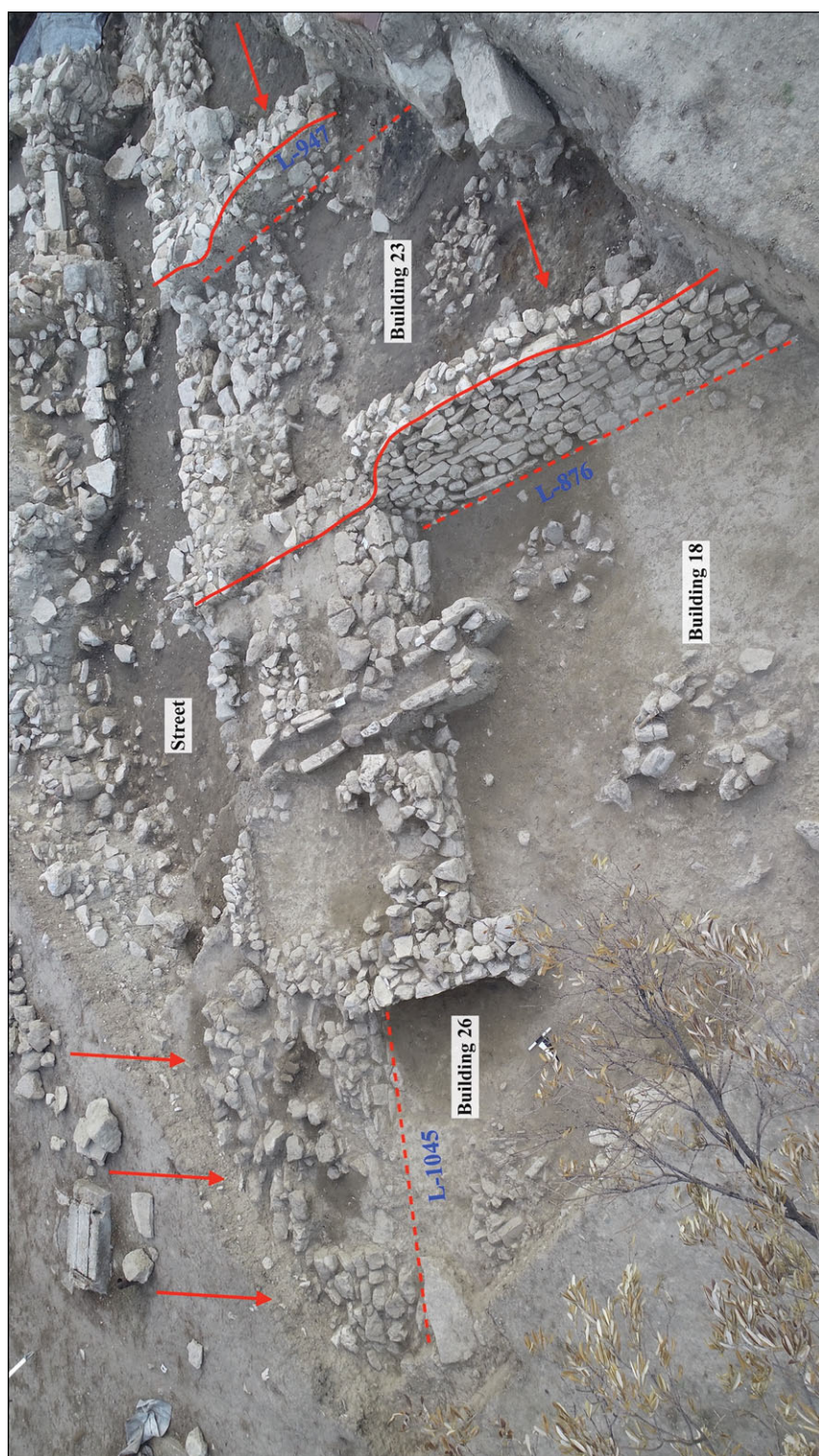


Figure 8. Collapse and tilting traces in the walls of buildings 18, 23 and 26 (figure by authors).

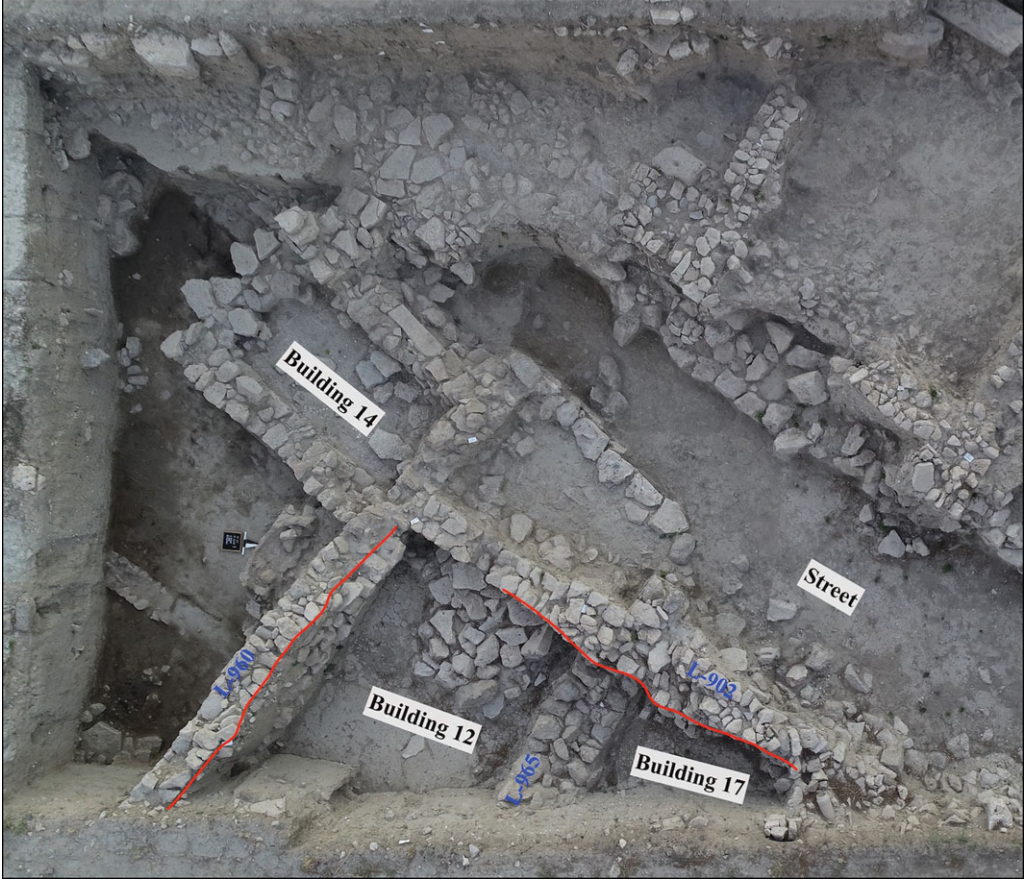


Figure 9. Snake-type undulation of the L-960 wall and lateral undulation of the L-902 wall in the Phase III settlement (figure by authors).

Discussion

The Early Bronze Age settlement of Panaztepe was ultimately destroyed by earthquakes due to its proximity to active faults, as well as its construction over the alluvial deposits of the Gediz Delta, which made the ground conditions more fragile and exacerbated the effects of the earthquakes (Figure 2).

Chronological evaluation of architectural damage at Panaztepe indicates that the settlement was affected by at least two separate earthquakes. Bowls from the earliest phase of occupation with spool-shaped handles, sharply carinated shoulders and light-brown, burnished surfaces are dated to the first half of the third millennium BC and suggest the timing of the first earthquake. Earthquake destruction layers from the first half of the third millennium BC have also been identified at several sites in the region, including Bakla Tepe (Gündoğan 2024), Liman Tepe (Erkanal *et al.* 2010; Gündoğan 2024), Yassitepe (Derin 2020) and Çukuriçi (Horejs & Weninger 2016) (Table S1). While the geographical proximity of these settlements and the fact that the destruction layers

generally date to the same period are notable, it is difficult to confirm that these destruction horizons resulted from a single seismic event. The data could also suggest that the widespread destruction was caused by a series of seismic events affecting Western Anatolia. Pottery from the third phase of occupation at Panaztepe, particularly the eight-shaped idols, is characteristic of the Early Bronze Age II in Western Anatolia (Çayır 2025), indicating a date within the second half of the third millennium BC for the second earthquake.

The structural deformations recorded in the Phase III walls at Panaztepe show a deformation pattern attributable to a single earthquake. The systematic eastward tilting of the north–south-oriented walls (L-1045, L-1006, L-1025), together with the southward inclination and characteristic snake-type undulation observed in the east–west-oriented walls (L-876, L-947, L-960), indicates a coherent deformation pattern consistent with directional seismic loading (Giner Robles *et al.* 2009) (Figures 3 & 4). The eastward overturning of the north–south-oriented walls is consistent with a dominant east–west component of horizontal ground motion. Similarly, the snake-type undulation observed in the east–west-oriented walls suggests that the dominant horizontal strain was oriented along the north–south axis, reflecting lateral flexure induced by the same seismic event. The two components together describe a strain field that affected the whole excavated area, best interpreted as the signature of one seismic event.

The destruction at Panaztepe was exacerbated by inherent structural weaknesses attributed to construction techniques. Specifically, the deformation patterns observed in the walls reveal a lack of interlocking masonry, particularly at the corners. Rather than forming a cohesive unit, the walls were built as separate segments: where one wall ended, the next began without effective bonding. This lack of integration caused structural integrity to deteriorate rapidly under seismic stress. Limited interlocking masonry is a common characteristic of Early Bronze Age settlements in the region, highlighting a widespread vulnerability in the architectural tradition of the period (Gündoğan 2022).

Insufficient thickness of the walls of structures also contributed to increased seismic damage. Following the first major earthquake, the inhabitants of Panaztepe sought to remedy this situation by doubling the thickness of the walls. The absence of clear earthquake-related damage in the second construction phase suggests that these measures were effective. However, during the subsequent third construction phase, wall thickness was reduced again, and smaller stones were used in construction. The deliberate increase in wall thickness and the conscious selection of larger building stones following the first earthquake demonstrate that the community actively implemented measures to mitigate seismic damage. The later abandonment of these measures implies that, while awareness of seismic risk and its architectural consequences was maintained in the short term, this social memory weakened over time.

Another factor contributing to increased earthquake damage was the shared use of 25m-long walls between dwellings, as also demonstrated at Liman Tepe (Kouka 2009; Erkanal & Şahoğlu 2016). At both sites, the construction of adjacent houses meant that damage to one house affected the others, leading to the collapse of the entire block (Erkanal *et al.* 2010; Gündoğan 2024).

Evidence from Western Anatolia indicates that post-earthquake rebuilding was not merely an architectural response but it also had wider social consequences. During the Early Bronze Age, communities in Western Anatolia did not immediately abandon their settlements after earthquakes; although settlements became smaller, occupation continued for some time. However, following repeated and increasingly destructive disasters, settlements were eventually abandoned. Examination of the architectural remains of Bakla Tepe reveals that this settlement was destroyed by a severe earthquake during the BT IV 2A phase (*c.* 2900–2800 BC), though the site was not completely deserted. During subsequent reconstruction, the size of the settlement was reduced by approximately half, and the fortification system was entirely reorganised, indicating the adaptation of a new settlement model (Erkanal & Özkan 1999; Gündoğan *et al.* 2019). Following a second earthquake in the BT IV 1C phase (*c.* 2800–2750 BC), the settlement again recovered; a new gate was introduced in the fortification system and, for the first time, a building interpreted as belonging to an administrative authority appeared. This situation clearly reflects post-earthquake reconstruction, suggesting the emergence of a new form of authority (Gündoğan 2024).

At Liman Tepe, houses were rebuilt following an earthquake and the continuity of settlement was ensured (Erkanal *et al.* 2010). However, at Yassitepe, the process of recovery or resistance appears to have proceeded differently. The first earthquake, radio-carbon dated to *c.* 2830 BC, was followed by reconstruction on a smaller scale, but after a second earthquake shortly afterwards (*c.* 2800–2750 BC) the settlement was completely abandoned (Derin 2020; Gündoğan 2024). This situation suggests that the resilience threshold in Yassitepe had been exceeded and the resident population's capacity for reconstruction exhausted. It is possible that the recurrence of earthquakes gradually degraded the social resilience of Yassitepe, rendering the later earthquake much harder to recover from.

Following the first earthquake at Panaztepe, the buildings, which had been arranged in a northeast–southwest direction, were rebuilt with houses extending in an east–west direction. The subsequent earthquake caused widespread destruction, severely damaging nearly all buildings within the settlement. The scale and intensity of this destruction again exceeded the community's capacity for recovery, ultimately leading to the complete abandonment of the site. The extent of the damage suggests that the settlement could no longer sustain habitation, marking the end of occupation at Panaztepe (Figure 10).

The reconstruction of settlements following a natural disaster involves more than just physical recovery; it also signifies the reproduction of social co-ordination. The construction of long-walled houses and defensive systems, as observed among Early Bronze Age communities of Western Anatolia, requires a high degree of collective co-operation, demonstrating that pre-earthquake social structures were likely organised through strong collective mechanisms. By extension, post-earthquake reconstruction must have been made possible by the continuation of this collective organisation or rendered infeasible by its dissolution. It is possible then that the continuation of construction activities as a practice of solidarity formed the basis of this institutional resilience.

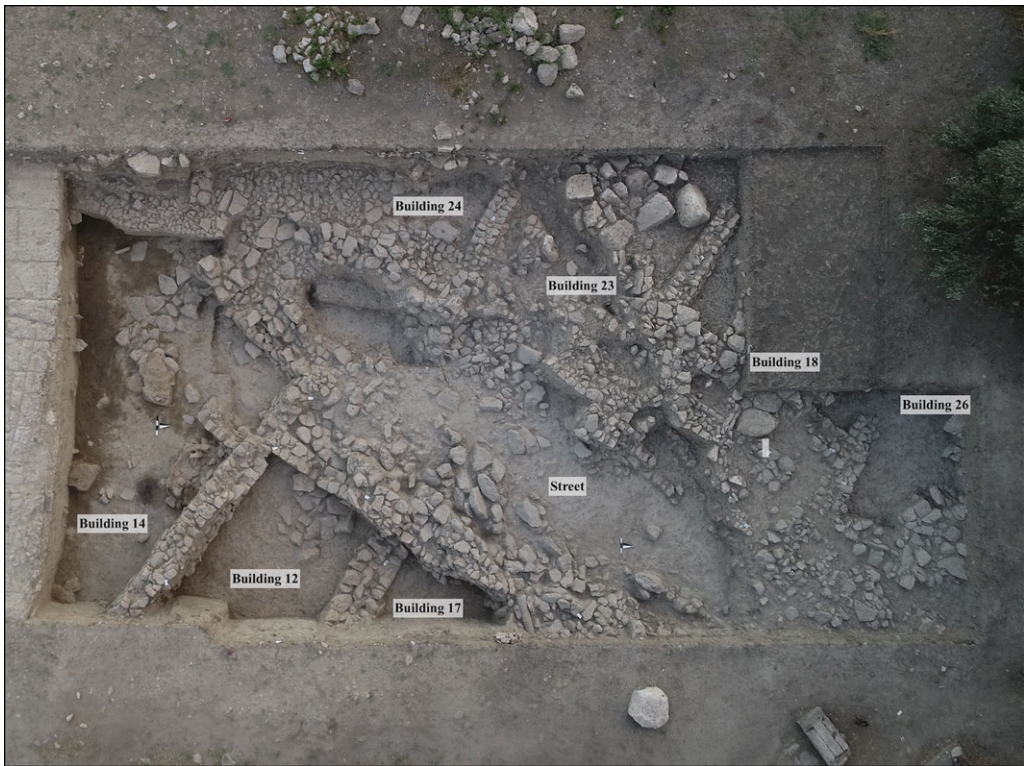


Figure 10. Collapse debris associated with the Phase III destruction horizon and coarse clast/block-rich infill observed in the street and building interiors (figure by authors).

Conclusion

The Early Bronze Age layers at Panaztepe offer the earliest and most comprehensive documented archaeoseismological findings along the Western Anatolian coast to date. Deformation evident in the walls of structures from the first and third construction phases provides direct traces of seismic stress, while evidence of fire, collapsed roof remains and numerous *in situ* artefacts demonstrate the secondary effects of the earthquakes.

Following the first earthquake during the first half of the third millennium BC, reconstruction efforts involving increased wall thicknesses, larger stones and a modified settlement pattern demonstrate the development of a conscious strategy to mitigate seismic risk. However, subsequent construction involving thinner walls and weaker structural connections built on top of some of the same foundations suggests that memories of the disaster faded over time. The second earthquake, striking during the second half of the third millennium BC, caused extensive structural damage across the settlement, exceeding the community's capacity for recovery and ultimately leading to the complete abandonment of the site.

Earthquakes have left a lasting mark on the architecture and social structures of settlements. They have led to the complete abandonment of some settlements, while others have survived by shrinking or reorganising. Therefore, partial abandonment or downsizing alongside reconstruction processes can be considered a common dynamic in Early Bronze Age settlements in Western Anatolia following sudden destruction and fire caused by earthquakes. In responding to such disasters, there is a direct correlation between the sudden abandonment of settlements and the extent of the destruction. As physical damage increases, the capacity of communities for reconstruction diminishes and, once a certain threshold is reached, their resilience may break completely. Thus, the archaeological record reveals varied responses: at Liman Tepe, recovery was rapid and structures were rebuilt in the same manner; in contrast, the redesigning and reconstructing of defensive systems at Bakla Tepe to make them more earthquake-resistant, alongside the emergence of administrative structures, exemplify different resistance strategies developed by different communities in response to similar environmental threats. In this respect, the earthquakes that shook third-millennium BC Western Anatolia not only caused physical destruction but also led to transformations that reshaped social organisation, spatial planning and collective work in the region.

Acknowledgements

We thank all our colleagues who contributed to the fieldwork at Panaztepe for their dedication and collaborative effort throughout the excavation seasons. We also extend our sincere gratitude to Lecturer Mustafa İncirli and Tuğçe Durmuş for their valuable assistance.

Funding statement

This research received no specific grant from any funding agency or from commercial and not-for-profit sectors.

Online supplementary material (OSM)

To view supplementary material for this article, please visit <https://doi.org/10.15184/aqy.2026.10376> and select the supplementary materials tab.

References

- AMBRASEYS, N.N. 2006. Earthquakes and archaeology. *Journal of Archaeological Science* 33: 1008–16. <https://doi.org/10.1016/j.jas.2005.11.006>
- 2009. *Earthquakes in the Mediterranean and Middle East, a multidisciplinary study of seismicity up to 1900*. Cambridge: Cambridge University Press. <https://doi.org/10.1017/CBO9781139195430>
- ARPAT, E. & F. ŞAROĞLU. 1972. The East Anatolian Fault system: thoughts on its development. *Bulletin of the Mineral Research and Exploration Institute of Turkey* 78: 33–39.
- BEYRU, R. 2011. 19. Yüzyılda İzmir’de Doğal Afetler [Natural disasters in İzmir in the 19th century]. İzmir: İzmir Büyükşehir Belediyesi (in Turkish).
- ÇAYIR, Ü. 2025. Early Bronze Age idol and figurines from Panaztepe. *Adalya* 28: 705–27. <https://doi.org/10.47589/adalya.1849579>

- DERİN, Z. 2020. Bornova- Yassitepe höyüğü 2010–2019 yılı çalışmaları. *Arkeoloji Dergisi* 25: 1–42 (in Turkish).
- DEWEY, J.F. & A.M.C. ŞENGÖR. 1979. Aegean and surrounding regions: complex multiplate and continuum tectonics in a convergent zone. *Geological Society of America Bulletin* 90: 84–92. [https://doi.org/10.1130/0016-7606\(1979\)90%3C84:AASRCM%3E2.0.CO;2](https://doi.org/10.1130/0016-7606(1979)90%3C84:AASRCM%3E2.0.CO;2)
- DRAHOR, M.G. & M.A. BERGE. 2017. Integrated geophysical investigations in a fault zone located on southwestern part of İzmir city, Western Anatolia, Turkey. *Journal of Applied Geophysics* 136: 114–33. <https://doi.org/10.1016/j.jappgeo.2016.10.021>
- DRAHOR, M.G. *et al.* 2023. Integrated geoscience investigations in Hittite Imperial sites affected by earthquakes, in G.M. El-Qady & C. Margottini (ed.) *Sustainable conservation of UNESCO and other heritage sites through proactive geosciences*: 463–99. Cham: Springer. https://doi.org/10.1007/978-3-031-13810-2_25
- EMRE, Ö. *et al.* 2018. Active fault database of Turkey. *Bulletin of Earthquake Engineering* 16: 3229–75. <https://doi.org/10.1007/s10518-016-0041-2>
- ERKANAL, A. 1993. 1991 Panaztepe Kazı Sonuçları. *Kazı Sonuçları Toplantısı* 14: 495–502 (in Turkish).
- 1997. 1995 Panaztepe Kazıları Sonuçları. *Kazı Sonuçları Toplantısı* 18: 281–90 (in Turkish).
- ERKANAL, H. & T. ÖZKAN. 1999. Bakla Tepe kazıları, in T. Özkan & H. Erkanal (ed.) *Tahtalı Barajı Kurtarma Kazıları Projesi / Tahtalı Dam Area Salvage Project*: 12–42. İzmir: İzmir Arkeoloji Müzesi Müdürlüğü (in Turkish).
- ERKANAL, H. & V. ŞAHOĞLU. 2016. Liman Tepe, an Early Bronze Age trade center in Western Anatolia: recent investigations, in E. Pernicka *et al.* (ed.) *Early Bronze Age Troy: chronology, cultural development and interregional contacts, proceedings of an international conference held at the University of Tübingen May 8–10, 2009*: 157–66. Bonn: Rudolf Habelt.
- ERKANAL, H. *et al.* 2010. Liman Tepe 2008 yılı kara kazıları. *Kazı Sonuçları Toplantısı* 31: 347–60 (in Turkish).
- ERKANAL ÖKTÜ, A. 2018. *Panaztepe I: die Friedhöfe von Panaztepe*. Ankara: Türk Tarih Kurumu Yayınları (in Turkish).
- GINER ROBLES, J.L. *et al.* 2009. *Structural analysis of earthquake archaeological effects (EAE): Baelo Claudia examples (Cádiz, South Spain)*. Madrid: Instituto Geológico y Minero.
- GUIDOBONI, E. *et al.* 1994. *Catalogue of ancient earthquakes in the Mediterranean area up to the 10th century*. Rome: Istituto Nazionale di Geofisica.
- GÜNDOĞAN, Ü. 2020. The “Aegean settlement pattern” in coastal Western Anatolia from the Neolithic Age to the end of the 3rd millennium BC. *TÜBA-AR* 27: 29–44. <https://doi.org/10.22520/tubaar2020.27.002>
- 2022. Erken Tunç Çağı’nda Batı Anadolu sahil kesimi mimarisi, in I. Mehmet *et al.* (ed.) *MÖ III. Binyılda Anadolu*: 151–68. İstanbul: Ege (in Turkish).
- 2024. 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. *Turkish Journal of Earth Sciences* 33: 625–43. <https://doi.org/10.55730/1300-0985.1933>
- GÜNDOĞAN, Ü. *et al.* 2019. Spatial organization and production activities at Bakla Tepe during the first half of the 3rd millennium BC. *DTCF Dergisi* 59: 1087–110. <https://doi.org/10.33171/DTCFJOURNAL.2019.59.2.16>
- HOREJS, B. & B. WENINGER. 2016. Early Troy and its significance for the Early Bronze Age in Western Anatolia, in E. Pernicka *et al.* (ed.) *Early Bronze Age Troy: chronology, cultural development and interregional contacts* (Studia Troica Monographien 8): 123–45. Bonn: Rudolf Habelt.
- KOUKA, O. 2009. Third millennium BC Aegean chronology: old and new data under the perspectives of the third millennium AD, in S. Manning & M.J. Bruce (ed.) *Tree-rings, kings, and old world archaeology and environment: papers presented in honour of Peter Ian Kuniholm*: 133–50. Oxford: Oxbow.
- LE PICHON, X. & J. ANGELIER. 1979. The Hellenic arc and trench system: a key to the neotectonic evolution of the eastern Mediterranean area. *Tectonophysics* 60: 1–42. [https://doi.org/10.1016/0040-1951\(79\)90131-8](https://doi.org/10.1016/0040-1951(79)90131-8)
- McKENZIE, D. 1976. The East Anatolian Fault: a major structure in eastern Turkey. *Earth and Planetary Science Letters* 29: 189–93.

- [https://doi.org/10.1016/0012-821X\(76\)90038-8](https://doi.org/10.1016/0012-821X(76)90038-8)
- NUR, A. & E.H. CLINE. 2000. Poseidon's horses: plate tectonics and earthquake storms in the Late Bronze Age Aegean and Eastern Mediterranean. *Journal of Archaeological Science* 27: 43–63. <https://doi.org/10.1006/jasc.1999.0431>
- ÖNER, E. & S. VARDAR. 2018. Gediz deltası paleocoğrafyasında Panaztepe'nin limanını bulma umudu. *Journal of Awareness* 3: 1–18 (in Turkish). <https://doi.org/10.26809/joa.2018145260>
- ÖNER, E. *et al.* 2021. İzmir ili, Menemen ilçesi, Maltepe Beldesi Panaztepe Arkeolojik Kazı Projesi kapsamında alüvyal jeomorfoloji, paleocoğrafya ve jeoarkeoloji araştırmaları. Unpublished research report prepared for the Ministry of Culture and Tourism of the Republic of Türkiye (Project No. BK013509/2021) (in Turkish).
- RODRÍGUEZ PASCUA, M.A. *et al.* 2011. A comprehensive classification of Earthquake Archaeological Effects (EAE) in archaeoseismology: application to ancient remains of Roman and Mesoamerican cultures. *Quaternary International* 242: 20–30. <https://doi.org/10.1016/j.quaint.2011.04.044>
- SEYİTOĞLU, G. & B.C. SCOTT. 1996. Age of the Alaşehir graben (west Turkey) and its tectonic implications. *Geological Journal* 31: 1–11. [https://doi.org/10.1002/\(SICI\)1099-1034\(199603\)31:1%3C1::AID-GJ688%3E3.0.CO;2-S](https://doi.org/10.1002/(SICI)1099-1034(199603)31:1%3C1::AID-GJ688%3E3.0.CO;2-S)
- SINTUBIN, M. 2011. Archaeoseismology: past, present and future. *Quaternary International* 242: 4–10. <https://doi.org/10.1016/j.quaint.2011.03.056>
- SÖZBİLİR, H. 2002. Geometry and origin of folding in the Neogene sediments of the Gediz Graben, western Anatolia, Turkey. *Geodinamica Acta* 15: 277–88. [https://doi.org/10.1016/S0985-3111\(02\)01093-8](https://doi.org/10.1016/S0985-3111(02)01093-8)
- ŞAHOĞLU, V. 2005. The Anatolian trade network and the İzmir region during the Early Bronze Age. *Oxford Journal of Archaeology* 24: 339–61. <https://doi.org/10.1111/j.1468-0092.2005.00240.x>
- ŞENGÖR, A.M.C. 1987. Cross-faults and differential stretching of hanging walls in regions of low-angle normal faulting: examples from western Turkey. *Geological Society, London, Special Publications* 28: 575–89. <https://doi.org/10.1144/GSL.SP.1987.028.01.38>
- ŞENGÖR, A.M.C. *et al.* 1985. Strike-slip faulting and related basin formation in zone of tectonic escape: Turkey as a case study, in K. Biddle & N. Christie-Blick (ed.) *Strike-slip deformation, basin formation and sedimentation* (Special Publications of the Society for Sedimentary Geology 37): 227–64. Tulsa (OK): Society for Sedimentary Geology.
- 2005. The North Anatolian fault: a new look. *Annual Review of Earth and Planetary Sciences* 33: 37–112. <https://doi.org/10.1146/annurev.earth.32.101802.120415>
- TEPE, Ç. *et al.* 2021. Updated historical earthquake catalog of İzmir region (western Anatolia) and its importance for the determination of seismogenic source. *Turkish Journal of Earth Sciences* 30: 779–805. <https://doi.org/10.3906/yer-2101-14>
- YILMAZ, Y. *et al.* 2000. When did the western Anatolian grabens begin to develop? *Geological Society, London, Special Publications* 173: 353–84. <https://doi.org/10.1144/GSL.SP.2000.173.01.17>