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Archaeoseismology: Earthquake traces studies in ancient settlements; a chronological evaluation from the World focusing on Türkiye

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ABSTRACT
Archaeoseismology is a field of science that investigates the remains of ancient human structures of destructive earthquakes that occurred in their ancient history and in this respect makes inferences on the possible effects of earthquakes whose origins will be may occurred in the future. Although many authors wrote the effects of ancient earthquakes in various periods, the first modern archaeoseismology studies in the world gain momentum starting from the end of the 19th century at the same time with Türkiye. In this understanding, the geography of Anatolia (Asia Minor), which has hosted a wide variety of cultural layers since its Mesolithic end, is an open-air research laboratory for modern archaeoseismological studies. This study is a reference work that summarizes the historical past of the discipline of archaeoseismology chronologically in the perspective of studies on Earth and Anatolia, presents suggestions about the future of archaeoseismology and is a literature summary for the new generation of archaeoseismologists.

1. An Overview Of Archaeoseismology

During the transition to settled life, human beings preferred areas that were topographically, geologically and hydrogeologically suitable for settlement, containing the blessings bestowed upon them by nature. In this sense, when the settlements on the seashores are kept separate, areas that lean their back on a high topography for safety, contain agricultural plains in front of them, close to water resources and preferably with plenty of thermal water outlets have become indispensable. At the same time, corridors that facilitate transportation from land to sea coasts have also hosted very dense settlements. From an earth science perspective, these areas mostly correspond to areas shaped or indirectly affected by faults. Today, as in the past, human beings establish their settlements in areas made more suitable for life by courtesy of faults. In this direction, just like today, ancient settlements were also affected by the past earthquakes. These effects occur during earthquakes, in the form of direct cutting of structures on surface faulting, with severe convulsions of seismotectonic and/or farther or nearby structures and seismogravitationally damage to two main types according to the simple classification of Dramis and Blumetti (2005). In this sense, it is also connatural that many major earthquakes that caused damage in historical or prehistoric periods affected the ancient structures, which are located on or near the faults, causing destructions and postponements in them, and left important traces in the history of ancient

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settlements. While the elemental traces of these earthquakes disappear significantly after the erosional and depositional processes, ancient buildings carry the traces of earthquakes to the present day. These earthquake traces preserved in ancient structures are a unique and important data source in understanding the seismicity of that region and the characteristics of the faults that may be related. The field of science that deals with the traces of these historical and prehistoric earthquakes in archaeological structures is called archaeoseismology (Stewart and Hancock, 1994). In terms of etymological origin, 'Archaeoseismology' is opened in the form of 'scientific studies on ancient earthquakes' as the integrity of meaning with the combination of the ancient Greek words ἀρχαῖος (arkhaîos) 'old/ancient', σεισμός (seismós). Galadini et al. (2006) defines archaeoseismology as a range in the time window of Paleosiesmology, and states that it is a safer scientific branch in terms of ensuring control with many different methods and data in terms of methodological, both archaeological and geological and dating. In this context, the application intervals and chronological efficiency of paleoseismological, archaeoseismological, historical and instrumental seismological records are summarized in Figure 1. While archaeoseismology easily reveals the types of earthquake traces preserved in archaeological structures, events that cause damage can also be dated when the dates of construction and renovation of the structures are known (Stiros and Jones, 1996). Archaeoseismology primarily systematically documents the damage/ effects in an archaeological site during and after an earthquake the relevant archaeological period, and tries to relate the earthquake records in historical and archaeological data. The most important point that should not be forgotten and paid attention to here is that the observed damage or deformational structures must be addressed and considered with all possible thinkable alternative causes. Besides, it tends to data the deformation elements caused by the earthquake by using many different absolute dating methods. It clearly determines the type of faulting and the amount of offset by examining the structures cut by the surface rupture. At the same time, when the construction, repair and/or abandonment dates of these structures are known, confines the earthquake that occurred within a time interval. In addition, based on the damage caused during the earthquake, the intensity of the earthquake and from there its magnitude with certain approaches, it also aims to determine the seismic source by performing deformation analysis of damage distributions (Figure 2). Thus, by making use of archaeoseismological studies, it is possible to obtain information about prehistoric and historical earthquakes that occurred especially from the emergence of sedentary human life to the present day. Such information can also be used in earthquake risk analysis related to devastating earthquake activity that faults in that region can produce in the future; It contributes to the creation of data sets of parameters such as earthquake size, impact area and earthquake

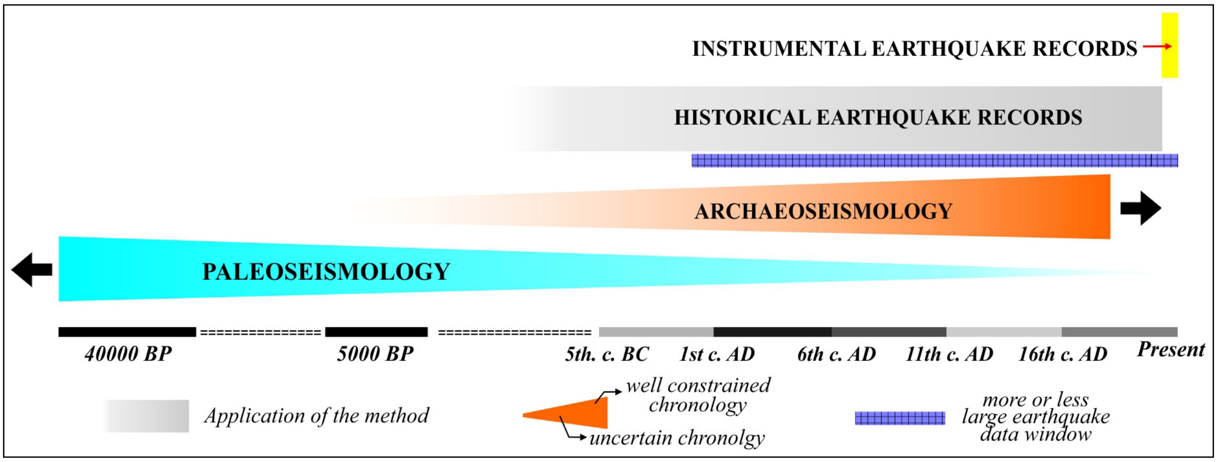

Figure 1- Application intervals and efficiency of paleoseismological, archaeoseismological, historical and instrumental period seismological records in Anatolia (slightly modified and colored from Galadini et al., 2006).

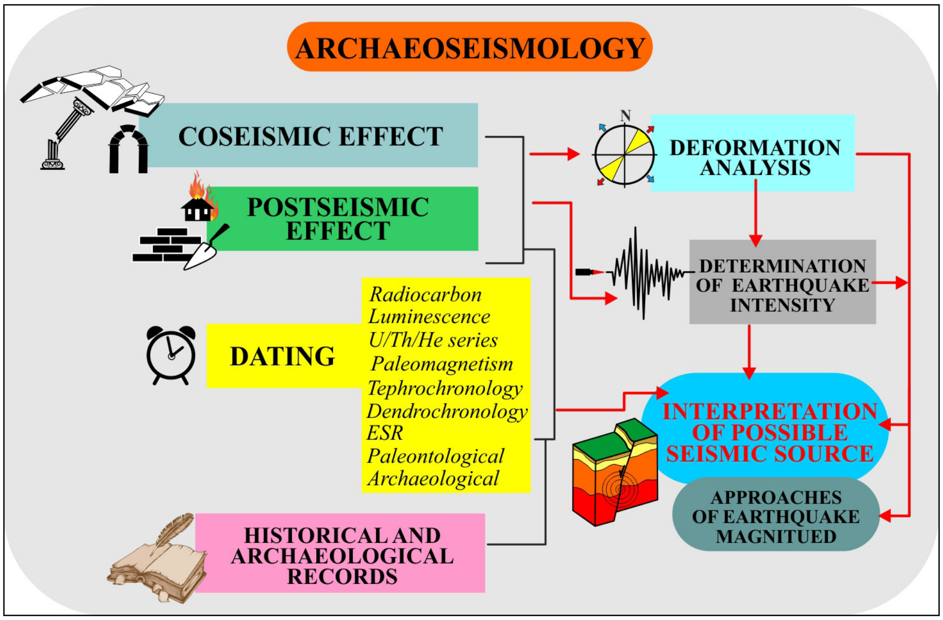

Figure 2- A simple flow chart of the use of archaeoseismological data and the steps of the methods applied (combined and modified from Galadini et al., 2006; Giner-Robles et al., 2009; 2012 and 2018).

recurrence period. Therefore, archaeoseismology is not only a field of science related to historical and prehistoric earthquakes in itself, but also a scientific discipline that sheds light on a better understanding of earthquakes that will occur today and in the future.

2. The First Archaeoseismological Observations In The World And Chronological Development Of Modern Scientific Studies

The first progress stages of the interpretation of the earthquake phenomenon as a natural event, especially in the memory of human beings, took place from about the end of the Archaic period (5th century BC). Pythagoras of Samos is the first person known to observe and convey the deformations and effects created by earthquakes (Sümer et al. 2018). In the different chapters of the 4th, 5th, 6th, 7th, and 8th books of The Historia, which consists of 9 books written by Herodotus in ancient times ~ BC 430, he noted the earthquakes that occurred especially in the land of Skyth, Aigina, Delos and Thessalia (Godley, 1928; 1930; 1938 translations). The 1st, 7th, 8th, 12th, 13th, 14th, and 15th books of Strabo's 17-volume huge work Geography, written at the beginning of the 1st century AD, include sections on earthquakes in Anatolia (Asia Minor), Greek mainland and Aegean islands (Jones, 1917; 1924; 1927; 1928; 1929; 1930 translations). In particular, quoting the words of Democles in paragraph 17 of chapter 3 of the book 1, he stated that earthquakes occurred a long time ago in Lydia and Ionia, and even as far north as Troy. This approach is important as it is an indicator of awareness that similar regions are affected by earthquakes with repeated periods. Gaius Cornelius Tacitus, in his work Annales (Church and Brodribb, 1906 translation), described how the damage caused by the event that we know today as the 17 AD earthquake in Western Anatolia in 13 ancient cities, in particular Sardis was rebuilt with the help of Roman Emperor of the time Tiberius Caesar Augustus. Many chapters of Gaius Plinius Secundus' 37-volume work, The Natural History, contain approaches to the causes and effects of earthquakes, and simple descriptions of earthquake-structure relationships. In fact, the 84th chapter of the 2nd book (Bostock and Riley, 1855 translation) includes approaches that can be considered as the first evaluations in terms of earthquake engineering within the framework of earthquake-soil interaction and that the angular relations of arched structures or load-bearing walls with each other increase earthquake resistance. The 24th chapter (Jones, 1933 translation) of the 7th book of the Greek traveler and geographer Pausanias, in which he describes the Achaia province in his book Description of Greece, written around the middle of the 2nd century AD, is quite interesting. While the author divides the earthquakes into two according to their types and the way they occur, he states that these types cause different damage and deformations in buildings and architectural structures.

The foundations of modern archaeoseismological studies in today's understanding begin in the second half of the 19th century. While De Rossi (1874) presents data showing that the Basilica of S. Petronilla near Rome was destroyed by an ancient earthquake, he states that the directions of the deformation caused by the earthquake are parallel to the axes of the Tiber and Almone valleys which are located within large volcanic fractures/fissures in central and southern Italy. Especially the NE-SW extension of the Tiber River in Rome is similar and compatible with the deformations in the archaeological structure. Perhaps this study can be qualified as the first archaeoseismological study in the modern sense that examines the morphological data for determining the seismic source of an ancient earthquake in an archaeological structure. While Lanciani (1899) states in his work entitled "The Destruction of Ancient Rome" that the walls and some architectural structures were systematically destroyed in the same direction and that this was caused by an earthquake, he pointed out that the obelisk of the Sallust Gardens was destroyed during the shaking and was found as it was during the excavation and he also adds a drawing documenting it to his work (Figure 3a). This figure is perhaps the first image to document an ancient earthquake inside an archaeological excavation site. Similarly, Lanciani (1918) presents the data of the last excavation season in 1871, in the form of a drawing, showing that two granite columns

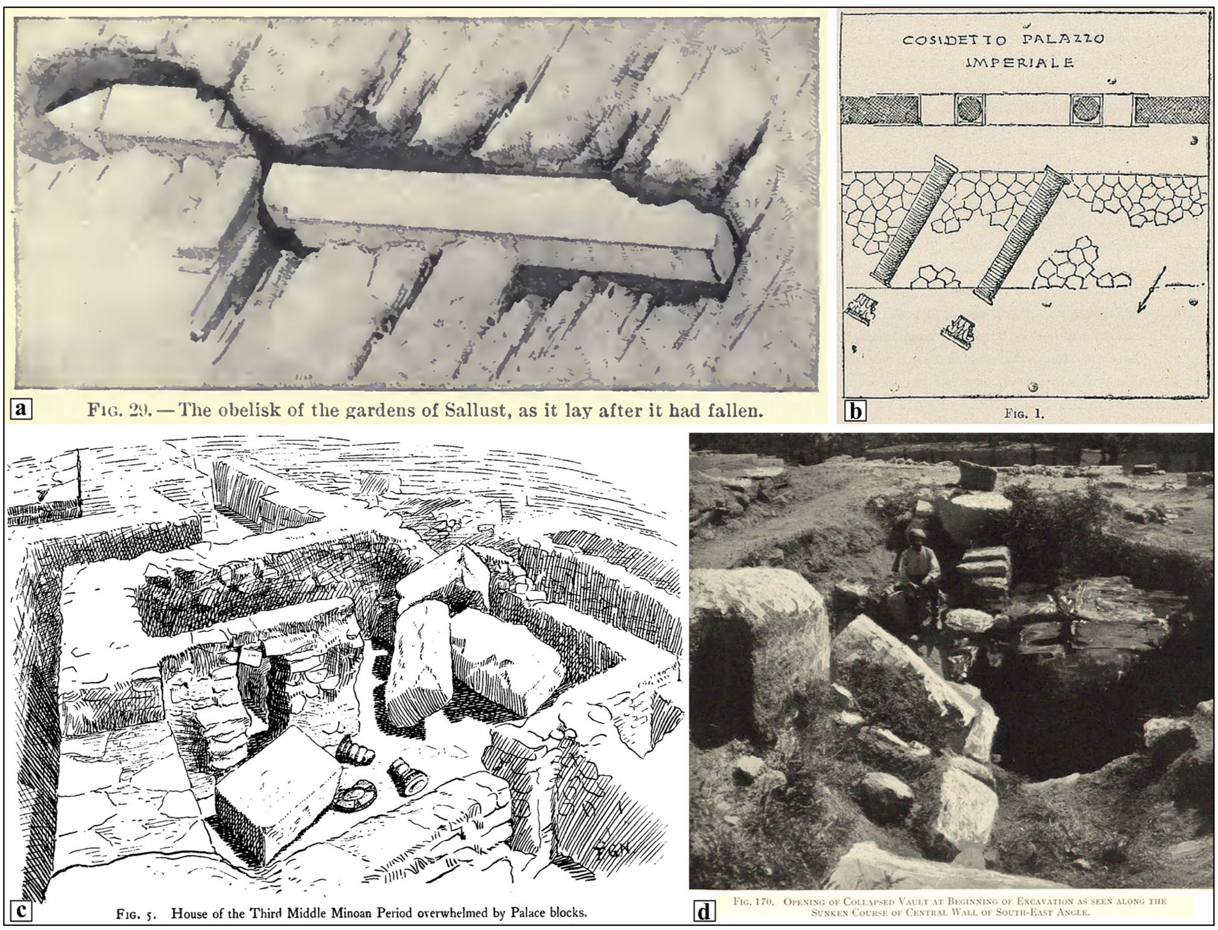

Figure 3- Images/photos presented in some important scientific studies that have pioneered archaeoseismological research on Worldwide. a) Rodolfo Lanciani's work, which deals with the destruction in ancient Rome, the drawing of the overturned obelisk in the Sallust Gardens, b) Illustration of systematically falling in the same direction columns of the Imperial Palace. Drawing, c) photo, d) of earthquake data observed by Arthur Evans in Knossos.

were found separated from their pedestals at the rear entrance of the imperial palace facing the river, and were found toppled in the N-NE direction, parallel to each other (Figure 3b). This schematic drawing is one of the first images of systematic series of aligned fallen columns, one of the best-known data we frequently use in modern archaeoseismology today. Evans (1922), during his archaeological excavations in Knossos, for the first time found that the blocks belonging to the Minoan Palace wall were blocks that reached 1 ton, some of which were thrown 20 feet (about 7 meters) away, and this could only be caused by a large earthquake, and this case is documented by a drawing by F.G. Newton (Figure 3c). Afterwards, Arthur Evans experienced the effect of the earthquake on the building while he was reading in bed in the basement of the excavation house on June 26, 1926, and by understanding the destructive power of the earthquake and its effect on the building, he expressed that he became more aware of the destruction of the Palace of Knossos by an earthquake (Evans, 1928). As a result of this event, Evans prepared a chapter in his book in which he approached that the historical earthquakes of 1508 and 1856 and the earthquakes of 1921 affecting Crete could be have same epicenters, and the effects of earthquakes on Minoan Culture (Evans, 1928). This book chapter is the first approach in which historical earthquakes and a current earthquake are evaluated and interpreted together in terms of archaeoseismology. While these events allowed Knossos, where he directed the archaeological excavations, to lean more in terms of earthquake phenomena, it was instrumental in photographing the data of possible earthquake traces for the first time in the new excavation finds (Figure 3d).

Increasing excavation work between second half of 19th century and beginning of 20th century, awareness of traces of ancient earthquakes in archaeological sites begins to accelerate (e.g. Schliemann, 1880 and 1884; Butler, 1922 and 1925). From the 1940's, with Dinsmoor (1941) and Kunze and Weber (1948), an "Archaeological Earthquake" terminological approach was developed for the first time, while the earthquake traces observed in structures in archaeological sites were defined more clearly and numerically. The book "Stratigraphie comparée et chronologie de l'Asie Occidentale", published by French archaeologist Claude Frédéric Armand Schaeffer in 1948, is a milestone in comparing earthquake traces in archaeological sites with both chronological and regional correlations. In the evaluation chapter of this magnificent book, which is mainly focused on the Ugarit cities, Schaeffer examines the destruction data in separate chronologies of different archaeological sites in Palestine, Syria, Persia, Caucasus, Cyprus, Aegean and Anatolia, while marking the ancient cities on the relevant intensity maps in *Erdbebengeographie* published by August Heinrich Sieberg in 1932. This work is also the first to pioneer publications that suggest catastrophic natural events related to the end of some archaeological periods, such as Bronze Age (e.g. Drews, 1993; Nur and Cline, 2000; Bachhuber and Roberts, 2009). Especially since the 1950's, we entered a period in which historical earthquake catalogs became widespread and traces of these data began to be sought in archaeological sites. In this period, the determination of ancient earthquakes in archaeological sites and the association of every unusual situation with earthquakes without applying specific and accurate scientific methods lead to great debates. Charles Richter (1958)'s statement "Ancient accounts of earthquakes do not help us much; they are incomplete, and accuracy is usually sacrificed to make the most of a good story" in 1958 may seem partially valid for his era, but in fact it is a document of how much we need modern archaeoseismology.

Towards the end of the 1970's, Karcz and Kafri (1978) conducted a study that questioned and compared consistent and questionable archaeoseismological data for the first time within the framework of the logic and methods we use today, and proposed a general mainstream framework in this direction. In the light of these developments, the late 1980's and early 90's can be defined as the birth of modern archaeoseismology. Stiros (1988) publishes his work revealing how much of an effective and important role archaeological data plays in active tectonic studies. In this way, the importance of ancient earthquake traces for understanding current earthquakes is revealed much more clearly. In addition, while the "The Engineering Geology of Ancient Works, Monuments and Historical Sites Preservation and Protection" series, which was published in 4 volumes, was published in 1988, chapter 4 of volume 3, containing 19 articles entitled "Earthquakes, vibrations and other hazards in relation to the study and the protection of monuments and historical sites; Marinos and Koukis 1988", is very valuable in terms of determining the importance to be taken in the name of engineering and protection of the damage caused to ancient structures by both ancient and modern earthquakes. At this point, for the first time, it paves the way for the evaluation of archaeological structures in terms of earthquake and engineering geology. Simultaneously, in the same year, in 1988, Japanese geomorphologist and archaeologist Akira Sangawa (1988, 1993) published a Japanese publication titled "Declaration of earthquake archaeology" emphasizing the importance of using liquefaction structures in archaeological sites (in fact, seismites with the meanings known today) as a tool for the determination of ancient earthquakes. Its 1993 publication, also in Japanese, is titled "地震考古学" "Earthquake archaeology", but also tries to establish a relationship in terms of approaching the recurrence period of earthquakes by combining historical and instrumental earthquakes in southern Japan with data from archaeological cities. International conference held in Athens in 1991 used the term "Archaeoseismology" as it is used today for the first time and it is described as "the study of ancient earthquakes from the complementary standpoints of their social, cultural, historical and physical effect" as quoted by Stiros and Jones (1996) in their foreword. Towards the mid-90's, in 1996, the British School at Athens published by the Fitch Laboratory and edited by Stathis Stiros and Richard Jones, the first joint studies aimed at developing the discipline of archaeoseismology, the foundations of which have just sprouted, were combined and published for the first time in book form under the title "Archaeoseismology" as we use today. For many scientists, this special issue becomes a stepping stone for the recognition and dissemination of modern archaeoseismology. At this point also, the branch of Quantitative Archaeoseismology, which also emerged in 1990's and developed in the first decade of the 21 century, begins to use engineering seismological techniques to measure quantify ground motion parameters based on observed damage features (Papastamatiou and Psycharis, 1996; Alexandris et al., 2004). The 2000's represent a period of increase and acceleration in archaeoseismological studies. For the first time in Türkiye, Ferry etc. (2004) an Ottoman period buried water channel in İzmit, Similox-Tohon et al. (2004) in Sagalassos, Hinzen (2005) in Tolbiacum in Germany, Drahor (2006) in Sardis, Negri and Leucci (2006) in Hierapolis, and then Silva et al. (2009) at Baelo Claudia in Spain, shallow geophysical data begins to be used in the discipline of archaeoseismology. Sintubin et al. (2007) and a project titled "Archaeoseismology along the Alpine-Himalayan seismic zone" is developed within the scope of the International Geoscience Programme (IGCP-567). With this project, which has the participation of more than 50 scientists from 20 countries, the steps of the first scientific project are taken internationally and regionally. The work done with this project brings results and studies that lay the foundations of today's modern archaeoseismology are published in the INQUA-IGCP 576 workshop held in Cádiz/Spain in September 2009. For example, after using the LIDAR system for the first time in ancient water structures cut by active fault arms in Karabacak et al. (2007) and displacement measurements on roads; studies such as Yerli et al. (2009) and Schreiber et al. (2009) use LIDAR for numerical modeling architectural structure deformations in archaeological sites. Hinzen et al. (2009) proposes a schematic flow chart of quantitative methods that can be used in archaeoseismological studies. Caputo et al. (2011) applied that scheme and used synthetic seismograms in their study. Sintubin et al. (2009) draws attention to the trends of archaeoseismology's focus in different disciplines today and in the future. Giner-Robles et al. (2009) proposes a method of identifying the possible seismological source by bringing a perspective from the kinematic analysis to deformation structures previously seen in different archaeological sites and studies. Finally, Rodríguez-Pascua et al. (2009) develops a comprehensive classification called Earthquake Archaeological Effects (EAE), based on the INQUA ESI 07 (Environmental Seismic Intensity – 2007), which Michetti et al. (2007) began to develop since 2003. After this classification, Rodríguez-Pascua et al. (2013) is developed by adding it in The European Macroseismic Scale (EMS-98) proposed by Grünthal (1998). Giner-Robles et al. (2018) revises the post seismic part of this classification. In the light of all these developments, the Earthquake Archaeological Effects (EAE) classification we use today becomes the most up-to-date (Figure 4). On similar subject, in classical monuments and buildings, arches are a frequently used indicator in determining the effects of earthquake ground motion, Hinzen et al. (2016) also proposed a scheme to evaluate the damage of arches called "Arch Damage Grade (ADG)" based on three categories. In the same years, Schweppe et al. (2017) introduced the concept of Precariously Balanced Archaeological Structures (PBAS) to estimate ground motions that were not exceeded since the structure is in its delicate state. Schweppe et al. (2021) were the first to estimate dynamic source parameters of an earthquake based on damage to an archaeological structure. The latest developments in the world show that archaeoseismology is in the common monk cluster of some disciplines in the field of archaeology, geology, geophysics, architecture, civil engineering, earthquake engineering and even sociology.

3. Archaeoseismological Chronology and the Potential of Anatolian Geography

The potential of the inventory of ancient buildings in geography is directly related to the history of the transition to settled life in that region. For example, the human settlement in North America defined by several centuries but the settlement in Anatolia goes back to the end of the Mesolithic (~ 11000 years). In this sense, especially the geographical area where Türkiye is located has a relatively dense inventory of ancient buildings with a chronologically older record of settled life (for example, the Mediterranean coast, the Aegean islands, Anatolia, the Levant, and Mesopotamia, etc.). In addition, Türkiye and especially Anatolia are one of the most important areas on Earth that have been geologically shaped by active faults with very high earthquake activity and are still continuing to be shaped. The combination of these two main elements puts Türkiye in a unique position in terms of archaeoseismological richness. At this point in Türkiye, especially the archaeological studies that started after the second half of the 19th century which increased rapidly also have a great impact. The formation of new data sets with the acceleration of systematic archaeological research after the 1950's contributed to the growth and development of archaeoseismology in Türkiye. In this direction, sections and developments from important studies that are the source of modern archaeoseismology studies in our country are summarized below with a chronological approach.

Although the first archaeological excavations in Türkiye were started in Halicarnassus in October 1856, the first simple earthquake observations in an ancient city are found in the excavation reports of Heinrich Schliemann, who conducted excavations in Troy. Schliemann (1880) emphasizes a severe earthquake related to the scattered finding of blocks belonging to the wall of a house under the ruins of the Hellenistic period at a depth of about 10 meters in a trench on the northern slope of Hissarlık. In Schliemann (1884), he noted that in the trench geometry trench with a length of 110 m and a width of 3 m, which they opened in the southern part of Hissarlık, columns in syenite composition with Chorint-type marble heads stretched to the NW on a rubble of 30 cm and fell, emphasizing that these data may be related to a late-stage earthquake. In fact, in the notes of 1884 excavation report stated Mr. Calvert's warnings him that Pliny informed about the earthquakes in Asia that coincided with the reign of Tiberius are quite remarkable. The observations of Howard Crosby Butler from Princeton University pointing to the repairs in the Temple of Artemis during the excavations of Sardis and the pause in attempts to finish the temple in ancient times have been associated with possible earthquakes of 17 AD and older (Butler, 1922). In particular, William Warfield, who wrote the additional geology section of the 1922 excavation report, mentions the possibility of earthquakes affecting Sardis based on mass movements in the Acropolis and sedimentological observations in Paktolos. This section has chronological importance in terms of laying the basic foundations of geoarchaeological approaches, as it also includes geological observations as a contribution to an archaeological excavation report in Türkiye and even in the world. Salomon-Calvi (1940) presents how the columns of the Asclepieion Temple collapsed in the same direction in an ancient earthquake, in the 2nd part of the report titled "Studies Related to Earthquakes in Türkiye", about the 1939 Dikili - Bergama earthquake, while presenting with an

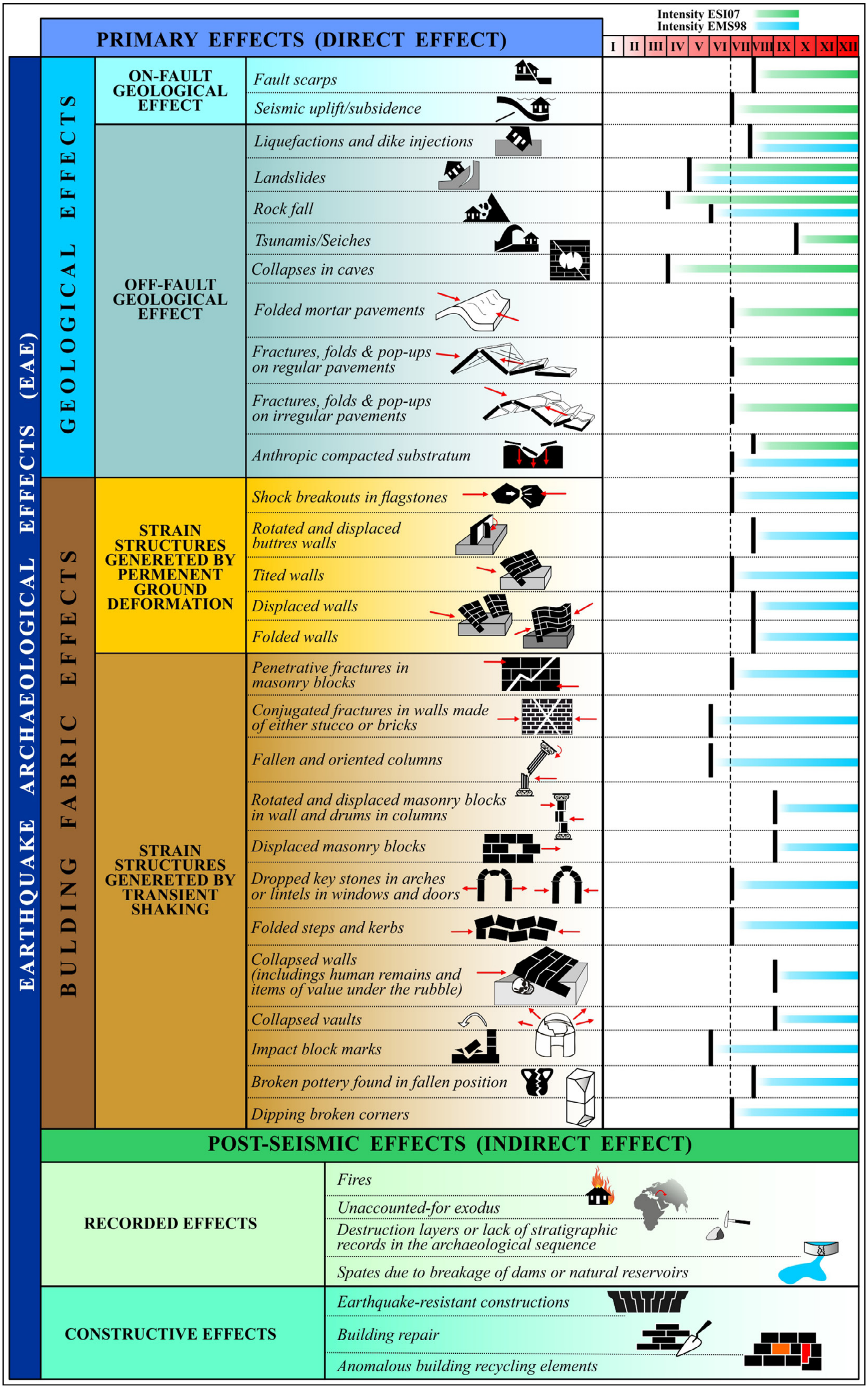

Figure 4- The Earthquake Archaeological Effects (EAEs) classification (combined from Rodríguez-Pascua et al., 2009, 2011 and 2013 and Giner-Robles et al., 2018).

archive photograph the columns that were restored and rebuilt shortly before the earthquake. While he states that the earthquake did not affect the columns (Figure 5a and b), he draws attention to the fact that the ancient earthquake should have also been very strong. This study is very important in terms of representing the first example of two different earthquakes in historical and instrumental periods in an archaeological city, where their effects on the same architectural structure are documented side by side. Duyuran (1945) stated that the large column on the southern leg of the eighth arch, which was revealed on the ground floor of the Basilica during the 1944 excavations in İzmir Agora, was destroyed by an advanced earthquake in the direction of NW from SE, but pointed out that more data was needed to date the earthquake. İzmir Museum Director Rüstem Duyuran who was the first person to document an ancient earthquake data uncovered by excavations at an archaeological site in Türkiye with photographs (Figure 5c). By publishing a more detailed report after Naumann and Kantar (1950), they evaluate the possibility of this event being an 178 BC earthquake by placing the artifacts made after the earthquake and spolia, plan changes and superior rapid repairs on different architectural structures in the reconstruction of the Agora. Carl William Blegen presents the earthquake data he determined during the 1932-1938 excavation periods in Troy in his 1951-1958 excavation reports. While considering the earthquake data, which is also emphasized in the foreword of Blegen et al. (1953), where the Troy VI layer presents its data, under separate headings in the excavation report, it combines the data and allocates an archaeological level in the form of "Earthquake stratum", he states that this earthquake is likely to occur in the middle of the 13th century BC. He also lists the photos of this earthquake data in the second part of the report (Figure 5d). In the 1960's, data begins to come in Sardis (Modern Sart), which contains the traces of earthquakes of different periods in terms of archaeoseismological data richness and which is the one of the archaeoseismology laboratories in Türkiye. The most important reason for the pause of data production in this ancient city can be the suspension of excavations after 1922 until 1958. During the excavations that started under the direction of Harvard University Archaeology Professor George M. A. Hanfmann, Hanfmann (1961) mentioned the suspicion of a possible early 7th century earthquake other than the 17 AD, while he collected photographs of earthquake data from different areas of the city, especially during the 1962-1972 excavations, in the excavation archive (Figure 5e-f) and most of them published in Hanfmann (1963). Collecting all the data in Hanfmann and Mierse (1983), he chronologically lists the earthquakes of 17 AD, early 7th century, 12th century, 16th and/or 17th century that influenced Sardis. New earthquake data for Sardis are also reported during excavations led by Crawford H. Greenewalt in the 1980's (Figure 5g). Although earthquake data were also recorded during archaeological excavations in Hierapolis (Modern Pamukkale) in the same period, these data were removed from the archives much later and evaluated by D'Andria et al. (2008) (Figure 6a). In the early 1970's, the Nature article titled ''Value of Historical Records of Earthquakes'' was published by Nicholas Ambraseys (1971). With this regional-scale study, which touches on the relationship between the historical earthquake records affecting Western Anatolia, especially the Gediz River and around 17 AD, and İstanbul's earthquakes, the importance of bringing a perspective by including the structural elements in the relevant area, apart from looking at the ancient records within the phenomenon of earthquakes, is emphasized. This publication would actually be the study that sprouted today's archaeoseismological perspective and guided the necessary right angle. Rudolf Naumann, an expert on Ancient Anatolian Architecture, who had previously worked in many ancient cities and worked in the earthquake effects in archaeological sites in the İzmir Agora, transferred to the area after the 1970 Gediz earthquake and reported the damage to architectural structures in both the modern and Aizanoi ancient city (Modern Çavdarhisar), emphasizes the earthquake affected modern structures other than ancient ones. He documented the deformations in the Theater, the Temple of Zeus, the Bath and some floor coverings with photographs (Figures 6b and c). Naumann (1971) is one of the first examples in the world where the effect of an instrumental period current earthquake on an ancient city is studied in this detail.

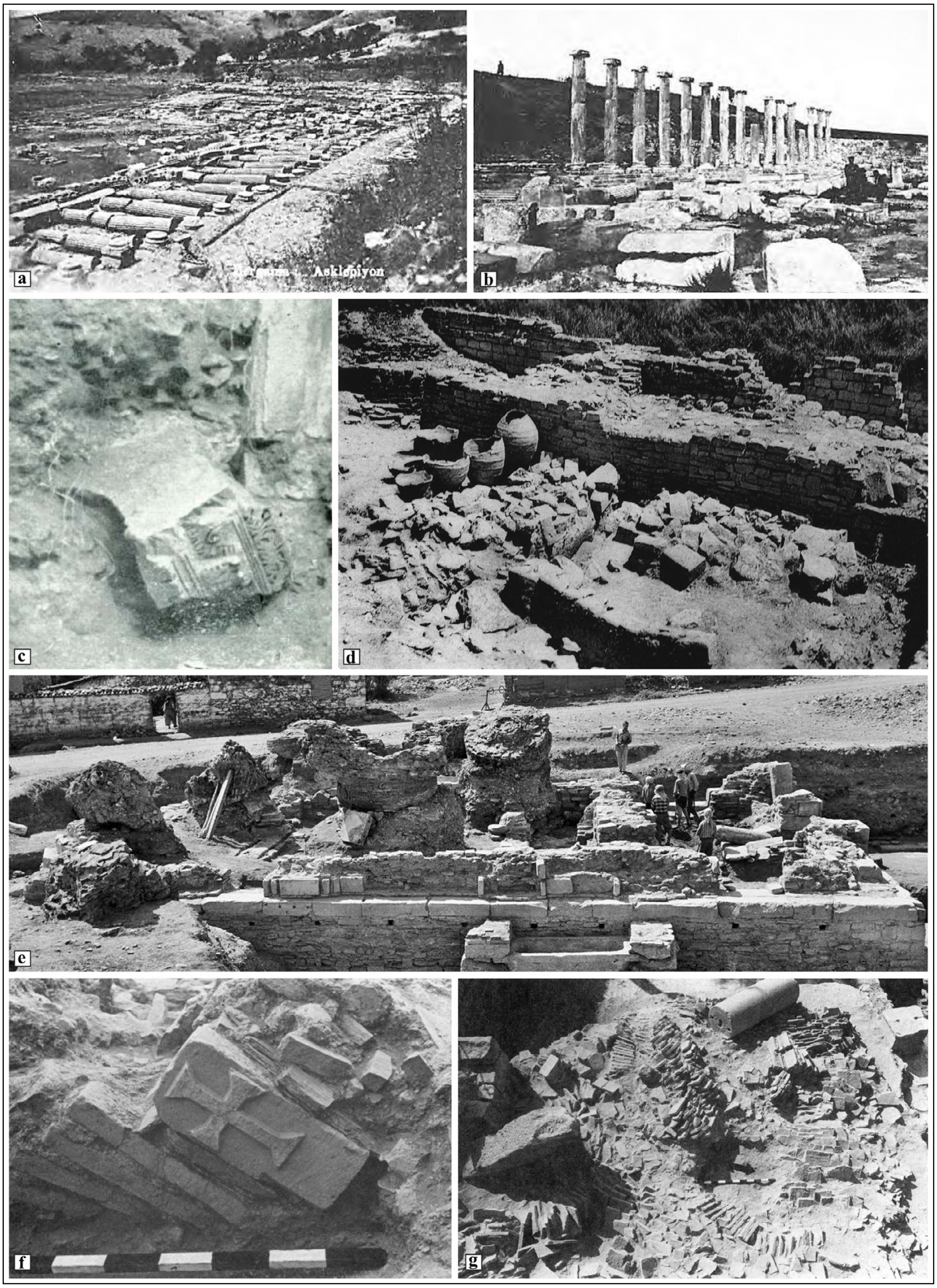

Figure 5- Old and new photographs (a and b), respectively, presented by Wilhelm Salomon-Calvi of the Shrine of Asklepieion in Pergamon, c) The head of the overturned column and column photographed by Rüstem Duyuran in the İzmir Agora, d) One of the photographs that Carl William Blegen observed in the Troy VI layer and presented about the earthquake data on the defensive wall. Photographs of earthquake findings presented in Sardis excavation reports and archive; e) The great destruction in Church E, which dates back to the Byzantine Period (11 – 12 century AD), this photograph belongs to the 1962 excavation archive, it was also used for the possible AD 1595 earthquake data in Buchwald and McClanan (2015). f) This photograph is from the 1970 excavation archive and presented in Hanfmann and Thomas (1971) the excavation report; imbricated marble keystone with Cross from major brick arch of the Colonnaded Street. g) Fallen brickwork and inscribed columnar monument in south colonnade of Marble Road, from the 1979 and 1980 excavation periods and presented in Greenewalt et al. (1983).

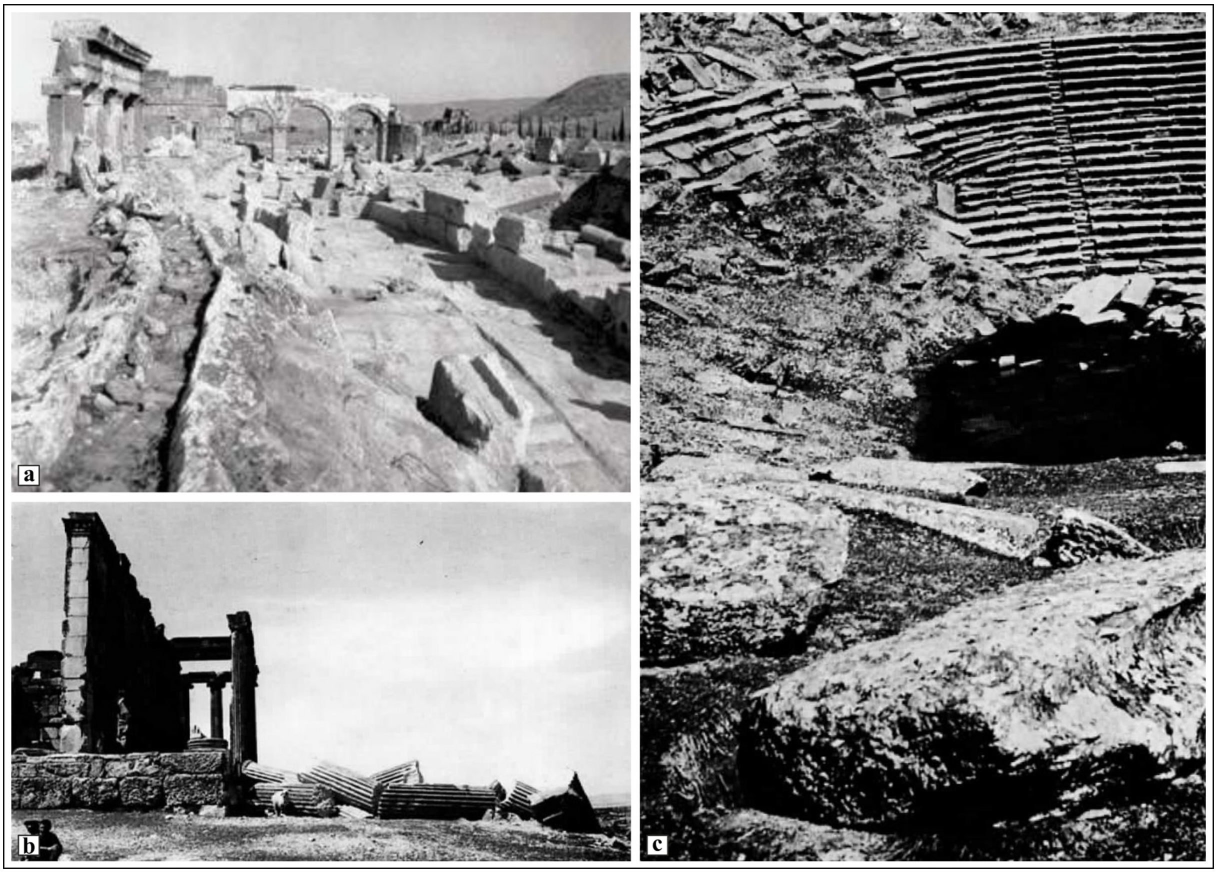

Figure 6- a) Photo presented in D'Andria et al. (2008) showing the deformations that occurred during the 7th century earthquake on the Plateia (city square) extending to the Frontino Gate, which was taken during the 1963 excavations in Hierapolis. Some photos in Rudolf Naumann's work documenting damage after the March 28, 1970 Gediz Earthquake in the ancient city of Aizanoi; b) systematic aligned fallen columns of the Temple of Zeus, c) deformations in the cavea of Theater and lateral displacements in large buried marble blocks.

Ünal (1977) draws attention to 3 main events by referring to earthquakes between 2000 BC and 1000 BC based on Hittite tablets and data in the literature. These are in chronological order according to the author; (1) In 1365 BC, in Ugarit during the time of I. Suppiluliuma, (2) in 1290 BC, that is, in Samuha in the last reign of Urhi-Teîmb, and (3) in the end of the III. Hattusili era or at the beginning of the IV. Tuthalya era (~ 1250 BC) are likely to have occurred in Ninive. In the early 1980's, George Rapp publishes Troy's work (Rapp, 1982), which deals with earthquakes in Troy and draws attention as the first chapter to compile earthquake data in an archaeological site in a monograph in which the Archaeological Geology (Geoarchaeology in the sense we use today). In this section, based on the data of author Carl William Blegen and John Manuel Cook, he lists various demolitions in Troy, especially in layer VI, while synthesizing current earthquake data for the destruction in the region and archaeological site. The author also highlights the roof in Karcz and Kafri (1978), bringing a 5-point analytical methodological framework proposal for identifying structural damage to archaeological sites. Finally, the author notes in his chapter that the most valid hypothesis for great destruction at the Troy IV level lies in the underlying immigrations caused by ground movements during the earthquake in the bottom unconsolidated materials. In his studies at Ephesus, Stefan Karwiese comments that the architectural building deformations, especially in terrace houses, may have occurred in the 3rd quarter of the 3rd century AD using numismatic data from the Gallienus period, and that this event may be related to the 262 AD earthquake in historical earthquake catalogs (Karwiese, 1985). While evaluating the possibilities of the Got attack, which coincided with the same period in Ephesus, the researcher also touches on the changes in the post-earthquake use of different structures in the city, such as the eastern Stoa of the Agora. The excavation team of Sagalassos (Modern Ağlasun), led by Marc Waelkens, reports possible post-earthquake restorations in the Temple of Apollo Clarios, addition on the Roman Bath and deformations in Hellenistic aqueducts in the 1989 excavation results report (Waelkens et al., 1990). He then makes a proposition to this earthquake in Waelkens (1993) based on archaeological finds 138/139 AD or 139/140 AD. Following the developments in the world in the mid-1990's, Türkiye's archaeoseismology also becomes a leap point for. Chapter 6 of Erhan Altunel's doctoral thesis (Altunel, 1994) represents the first example of modern archaeoseismology studies within the borders of Türkiye. In this section, where geological, geomorphological and structural elements are blended with deformations in ancient urban architecture, the deformation elements in the architectural structures of the ancient city of Hierapolis are shown in the city plan for the first time, and the NNW trending left lateral component oblique-slip surface rupture passing through the city is also mapped. At this point, he is stated that this surface crack is also compatible with the general structural geological main discontinuities of the region. Although there is no clear opinion on the history of this earthquake in the study, it is recommended that it may be related to the 60 AD earthquake, which is frequently mentioned in the literature. Another importance of this study is that the term 'Archaeoseismology' was used for the first time in a study in Türkiye. After this study, archaeoseismological interest in Hierapolis increases and studies such as Altunel and Barka (1996); Hancock and Altunel (1997); Hancock et al. (2000) are produced, respectively. In these studies, it is emphasized that the city may have more than one earthquake history such as 60 AD, possible 4th century AD, 7th century AD or 14th century AD by interpreting the data in historical earthquake catalogs and deformations in architectural structures belonging to different archaeological periods. In the same period, a 7-page extended abstract titled "A discussion on some concepts of the archaeoseismology" was published in the booklet of the 4th National Earthquake Engineers Conference in 1997 by Engin Karaesmen and Erhan Karaesmen, who have been dealing with archaeological architectural structures in terms of earthquake engineering since the late 1980's. (Karaesmen and Karaesmen, 1997). In the conclusion section of this work, it is emphasized that the phenomenon of earthquakes is not considered important in archaeological protection and that the measures of the protection of architectural structures should be discussed in terms of earthquake engineering. While modern archaeoseismological studies have started to focus in different ancient cities since the end of the 1990's, it is seen that these studies have been manly distributed with in the Western Anatolian Extensional Province, and mostly in Hellenistic and Roman cities. Altunel (1998) maped a NE-SW trending damage corridor within the city, pointing to deformations in the sacred hall, street, agora and Athena Temple and some lateral displacements in the ancient city of Priene, which is located at the northwestern end of the Büyük Menderes Graben System. He states that these damage in the city may occur with earthquake(s) in the 12th century AD and beyond. In the early 2000's, two archaeoseismology-based Tübitak projects were carried out (Altunel, 2000; Altunel et al., 2001). The first contains limited data from the ancient cities of Priene and Miletus within the Büyük Menderes Graben System, and the second from the ancient cities of Ephesus, Sardis and Philadelphia within the Gediz and Küçük Menderes graben systems. The biggest reason why these projects remain poor in terms of archaeoseismological data rich is that there are no researchers of archeology origin in the team conducting the projects. At this point, it becomes once again manifested that archaeoseismology is a multidisciplinary scientific study. Waelkens et al. (2000), based on the different data they have collected during the Sagalassos excavations, it produces a separate and only archaeoseismology-specific work for the city since 1989. In this publication, they drew attention to the deformation patterns in the architectural structures of the city from various periods dated from Hellenistic to Byzantium, especially the library floor and theater. They reported the probability of at least 4 earthquakes in the city; in the second half of the 1st century AD, the middle of the 3rd century AD, the first quarter of the 6th century AD, and the middle of the 7th

century AD. Akyüz and Altunel (2001) in the ancient city of Cibyra (Modern Gölhisar), located in the middle part of the Fethiye – Burdur Fault Zone which is an important structural discontinuity for the Southwest Anatolia, reported the deformation of the southern flank of the Roman Stadium and the damage of some other architectural structures. Evaluating from the historical earthquake catalog data that the city was affected by the possible 417 AD earthquake, they state that the surface rupture of this earthquake originated from the Kibyra Fault Zone within the city border. Altunel et al. (2003) In their archaeoseismological observations in the ancient city of Cnidos at the westernmost end of the Datça Peninsula, they divided the deformations in architectural structures of different periods in the city, especially the Temple of Aphrodite and the Demeter Sanctuary, into faulting phases, and emphasized that the first earthquake should have been occurred between 2nd or 3rd centuries BC in the Hellenistic period and the second earthquake might be related to the 459 AD earthquake on the Knidos Fault, which developed surface faulting. Şimşek and Ceylan (2003) associated their archaeological excavation results in the ancient city of Laodicea with historical earthquake catalogue, stating that the city was affected by earthquakes such as 27 BC, 47 AD, 60 AD, late 3rd century AD, early 4th century AD and 494 AD. In the following period; From 2003 to 2006, the works were produced by similar teams in Sagalassos, Sintubin et al. (2003); Similox-Tohon et al. (2004); Similox-Tohon et al. (2005); Similox-Tohon et al. (2006) is seen to be concentrated in such studies. From these studies, which point to earthquakes dated using archaeological chronology and similarly compressed between the 6th and 7th centuries, Similox-Tohon et al. (2004 and 2005) are important in terms of applying shallow geophysical and trench-based paleoseismological studies together in archaeoseismology for the first time. Crawford H. Greenewalt, the Sardis Excavation Director at the time pointed out to the earthquake findings in Field 55, where it has been concentrated since the early 2000's, and the presence of a fracture extending 10 cm wide and 2.5 meters deep in Greenwalt (2003; 2006 and 2007), while evaluating the earthquake affecting this area with archaeological finds and associating it with a possible 7th century and/or later event. Drahor (2006) refers to archaeologists in his publication, in which he gave the results he obtained from shallow geophysical studies in the same field, pointing to the existence of the same fracture. At this point, Karabacak (2007) produces a doctoral study in Türkiye by combining both geological, geophysical, LİDAR using, and trench-based paleoseismological data were used by combining historical earthquake catalog data. This study is also a turning point as it is the first archaeoseismological study conducted in Türkiye in a location other than Western Anatolia, and the integrated use of almost all methods in modern archaeoseismology studies today. While Sintubin and Stewart (2008) re-evaluate the data of previous studies in Sagalassos within the framework of an archaeoseismological logic tree, and propose a new measurement method in practice, in the form of Archaeoseismic Quality Factor (AQF), in this approach, it is stated that the earthquake hypothesis in Sagalassos contains some weaknesses and uncertainties, and indicate that they need to be re-evaluated. Another importance of this study is that before them, methodological staged diagrams, suggestions for archaeoseismology studies, propose a much more harmonious, efficient new and developed methodological scheme on the foundations of all studies. Since the late 2000's, studies in different archaeological cities and tectonic regions have gained momentum. Some of these studies are; Birinci (2006) and Piccardi (2007) in Hierapolis, Akan (2009) and Akan et al. (2012) in Rhodiapolis, Altunel et al. (2009) at the northern end of the Dead Sea Fault Zone, Çetin-Yarıtaş (2009) in Termessos, Yönlü et al. (2010) in Priene and Ramazanpaşa Bridge, Karabacak (2011) in Cibyra, Hinzen et al. (2010, 2013*a* and *b*) and Yerli et al. (2010 and 2011) in Pinara. Here, Hinzen et al. (2010)'s work in Pinara is distinguished from other studies in terms of being an archaeoseismological study based on deformation analysis using ground motion simulations. Perinçek (2010) and Bony et al. (2012) take an archaeoseismological approach by using the data of a Byzantine period shipwreck and tsunami within the ruins of Theodosius Port in the north of Istanbul Yenikapı, and interpret that this event was related to the 557 AD earthquake. These publications are the first studies in Türkiye where underwater data is used and an archaeoseismological approach is made. Yönlü (2012), at the south-west end of Eastern Anatolian Fault Zone; he makes evaluations by blending its archaeoseismological observations in Anavarza, Kastabala, Toprakkale, Ayas, Magarsos with trench-based paleosmological data. This study is the first study in which archaeoseismological studies are carried out in the Eastern Anatolia Fault Zone. Karabacak et al. (2013), on the other hand, states that while performing absolute dating method with the Optical Stimulated Luminescence (OSL) technique on different types of materials such as sediments and ceramics, which are under the architectural structures destroyed by the earthquake in the Cibyra. They suggested the earthquake caused great damage to the city in the 10th- 11th centuries AD. This study is the first example of the use of the OSL method, which has also started to be used in trench-based paleoseismology studies, in an archaeoseismology study. Passchier et al. (2013) from a different point of view, attributing the deformations on the ancient water channels connecting to Ephesus caused by an earthquake originating from the İçme Tepe Fault, and presented an approach based on both the archaeological data and the annual laminated carbonate precipitation rate in the channel. For the timing of the vertical displacement on the channel, they suggested that this event occurred in the second half of 2nd century AD, it may be related to the AD 178 earthquake. Aydan and Kumsar (2015) show an approach to the 17 AD earthquake by evaluating geotechnical data such as acceleration and liquefaction potential recorded in current earthquakes together in regions close to archaeological sites with earthquake history in Western Anatolia. Benjelloun et al. (2015), on the other hand, carries out a study focusing on the dating of the restorations made after the deformation of the Antioch water channels in Antakya. In terms of this study dating method, although the age results are very weak, it is very remarkable in terms of the first use of archaeomagnetism data other than radiocarbon data within the Anatolia. Since the mid-2010's towards the present day, there has also been a diversity in the studies and fields carried out. Some of these works are; Söğüt (2014) in Stratonikeia, Buchwald and McClanan (2015), Cahill (2016, 2019), Hallmannsecker (2020), Sümer et al. (2022) in Sardis, Bachmann et al. (2017) and Pirson (2017) in Pergamon, Kumsar et al. (2016) in Hierapolis and Laodicea, Karabacak (2016) in Lagina, Benjelloun (2017) and Benjelloun et al. (2018) in Nicaea, Stewart and Piccardi (2017) offering data from some ancient cities in a large area covering the Aegean Region and Greece, Softa et al. (2018) in Myra, Altunel and Pınar (2021) in Ephesus. At the same time, the studies conducted outside of Western Anatolia (classical ancient cities in the Aegean and Mediterranean regions) are Drahor et al. (2016, 2017 and 2023) and Sümer et al. (2019, 2021), which documents the deformations in Hittite cities such as Ḫattuša and Šapinuwa and Barış et al. (2021), which evaluates the archaeoseismological data in Bathonea together with ancient earthquake data. Benjelloun et al. (2021), who documented the archaeoseismological deformations of defensive walls, towers and other different architectural structures in the ancient city of Nicaea, on the borders of İznik in the area of the Northern Anatolian Fault Zone middle branch, differs in terms of evaluating deformation structures for the first time within the scope of Earthquake Archaeological Effects (EAEs-98) in Türkiye.

All these archaeoseismological studies, briefly summarized above and carried out on the borders of Türkiye, have been brought together for the first time in terms of both their location of the ancient settlements, dominate archaeological provenance, and their relationships with active fault perspective. In this direction, we also present a chart (Table 1) and the relevant map (Figure 7). Readers can access the details of these related scientific studies from the archaeoseismological perspective by means prepared in chronological order and presented in the appendix of this study (Appendix-1). Additionally, a timeline visual, highlighting the milestones of archaeoseismology studies carried out specifically for Türkiye, is presented in Figure 8.

4. Approaches and Suggestions For The Future

While this paper presents a chronological approach to the development of archaeoseismological studies up to the present, it largely focuses on presenting an inventory of studies conducted in Türkiye. In addition, these studies, which are cataloged together for the first time in the literature, have offered the chance to make some inferences that can contribute to a critical evaluation of archaeoseismological studies.

Table 1- Distribution of archaeoseismological studies carried out in Türkiye, which were mentioned in this study. Please follow up the archaeological tectonic and geographical distribution of location numbers from Figure 7 and follow the Reference numbers from the "No*" column of the chart presented in Appendix-1.

Location Numbers (LN)	Archaeological Site/ Region / City	References	Total Number of Studies
1	Troy, Çanakkale	1, 5, 6, 12, 51	8
2	Sardis, Manisa	2, 7, 23, 26, 56, 58, 59, 69, 73	15
3	Pergamon, Asklepieion, İzmir	3, 63	3
4	Agora of Smyrna, İzmir	4	2
5	Tralleis, Aydın	9	1
6	Hierapolis, Denizli	9, 15-18, 21, 32, 35, 60, 65	11
7	Ephesus, İzmir	13, 23, 54, 56, 65, 71	6
8	Sagalassos, Burdur	14, 22, 27, 30, 31, 33, 36	8
9	Priene, Aydın	19, 20, 44	3
10	Miletos, Aydın	20	1
11	Philadelphia, Manisa	23	1
12	Cibyra, Burdur	24, 45, 53	3
13	Cnidos, Muğla	25	1
14	Laodicea, Denizli	28, 60	2
15	Colossae, Denizli	35	1
16	Rhodiapolis, Antalya	37	2
17	Amik Plain Sıçantarla Hill and ancient road, Antakya	34, 38	2
18	Termessos, Antalya	39	1
19	Yenikapı, İstanbul	41, 50	2
20	Pinara, Muğla	42, 43, 46, 52	5
21	Ramazanpaşa Bridge, Priene, Aydın	44	1
22	Anavarza, Kastabala, Toprakkale, Ayas, Magarsos	48	1
23	Seyitömer Mound, Kütahya	49	1
24	Stratonikeia, Muğla	55	1
25	Magnesia, Aydın	56	1
26	Antioch water channels, Antakya	57	1
27	Šapinuwa, Çorum	61	2
28	Lagina, Stratonikeia, Muğla	62	3
29	Nicaea, İznik	64, 66, 72	3
30	Myra, Antalya	67	1
31	Ḫattuša, Çorum	68, 74	3
32	Bathonea, İstanbul	70	1

The archaelogical potential of a region opens a new windows into the seismotectonics of that region. The most important key data in terms of the seismotectonics of a region, older than instrumental earthquakes, can be provided by paleoseismological studies and analytical dating methods. Sites with archaeological potential provide us with the historical record, often without the need for analytical methods. Unlike paleoseismology, much smaller budgets and observational analyses allow us to access seismotectonic data with increasing resolution as we approach the present (see Figure 1). For example, seismotectonic records, which were insufficient along the Fethiye-Burdur Fault Zone due to the limited paleoseismological data in southwestern Anatolia, filled this gap with data from ancient cities such as Sagalossos, Cibyra and Pinara. In this regard,

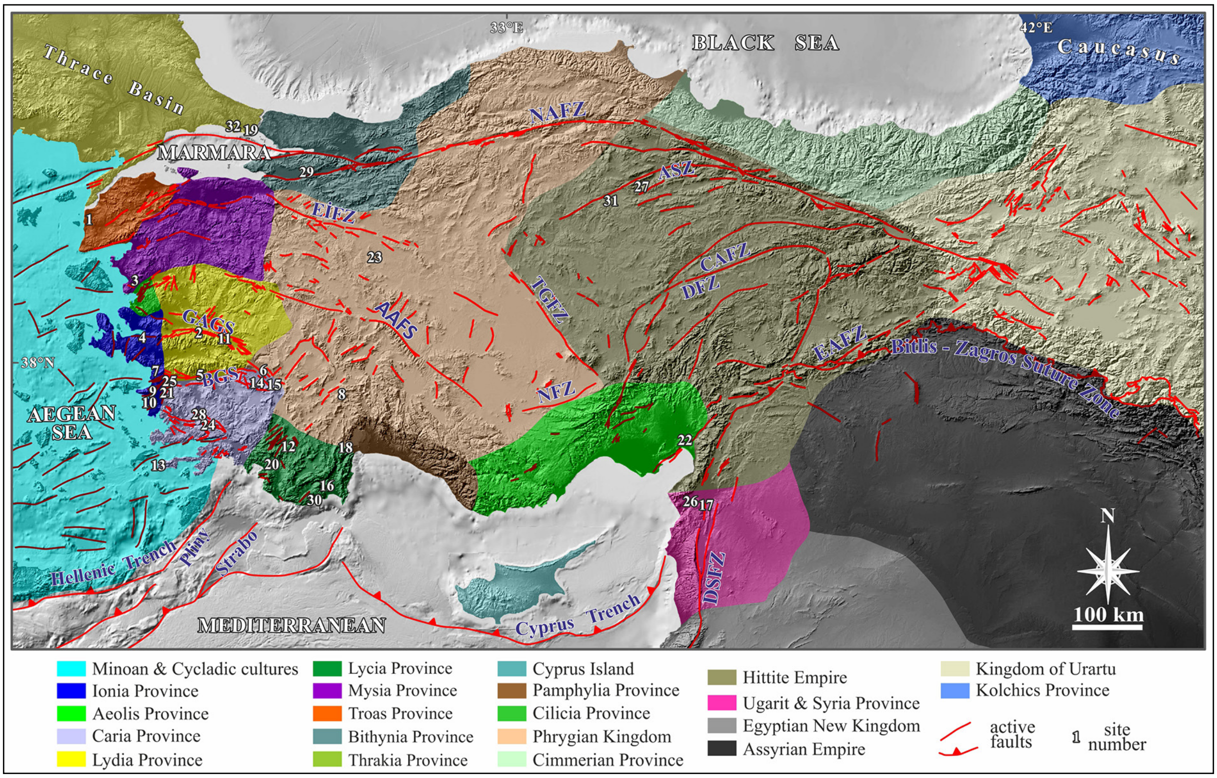

Figure 7- Integrated Archaeotectonic Map of Türkiye and its surroundings, specially prepared for this study for the first time, showing active fault zones and dominant archaeological provinces together. The approximate boundaries of archaeological province (were combined using data from Shepherd, 1923; Freeman, 1996; Sabin et al., 2007; Morris and Scheidel, 2009; Picón and Hemingway, 2016; Schachner, 2019). Active tectonic structures (compiled from Şengör et al., 1985; Koçyiğit, 2003; Emre et al., 2018; Pavlides et al., 2014 and Sümer et al., 2019). For location numbers please take advantage of the first column of Table 1. AAFS: Afyon Akşehir Fault System; ASZ: Amasya Shearing Zone; BGS: Büyük Menderes Graben System; EAFZ: Eastern Anatolia Fault Zone; DFZ: Deliler Fault Zone; EIFZ: Eskişehir İnönü Fault Zone; GAGS: Gediz Alaşehir Graben System, NAFZ: North Anatolian Fault Zone; CAFZ: Central Anatolian Fault Zone; DSFZ: Dead Sea Fault Zone; TGFZ: Tuzgölü Fault Zone.

one of the most important outcomes that the inventory created within the scope of this study shows us is the scarcity of archaeoseismological studies carried out in the ancient settlements on and around the most important active fault zones of Anatolia, such as North Anatolian Fault Zone (NAFZ), East Anatolian Fault Zone (EAFZ) and Dead Sea Fault Zone (DSFZ). At this point, it is clear that archaeoseismological studies must be expanded in settlements different archaeological periods around these main structural lines.

Archaeoseismological investigations also provide data for seismic hazard assessment. Not only the dating of earthquake-related deformations, but also the precise measurement of deformation amount offers the chance of a precise projection of future earthquakes. At this point, the seismic source of the earthquake, the relationship of this sources with the archaeological site or structure, the soil characteristics of the relevant area, and inferencess about the intersity and magnitude of the earthquake provides very important data sources for future seismic hazard analyses. Data from the ancient cities such as Cibyra, Lagina and Hierapolis can be counted among the successful examples in this respect. Although approximately 150 years have passed since the production of the first simple archaeoseismological data in the world and in Türkiye, and about 30 years have passed since the beginning of the first modern archaeoseismological studies, it is seen that numerical data production in this branch of science is still in its infancy. It is clear that today's technologies (laser and spectral imaging techniques, shallow geophysical methods, archaeo-engineering/archaeo-architecture and absolute dating methods, to study the dynamic behavior of structures

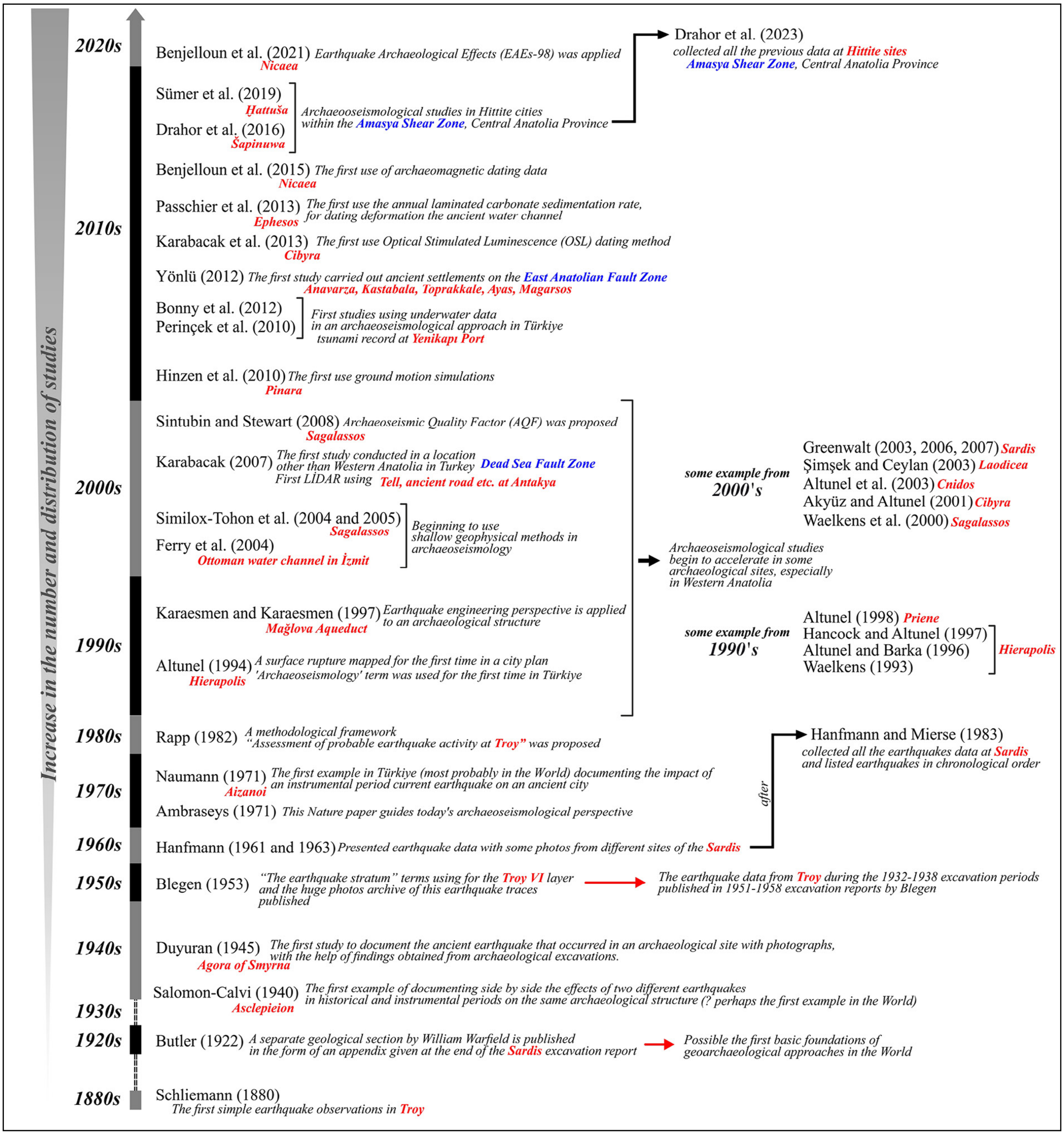

Figure 8- Chronological timeline of prominent and pioneering archaeoseismology studies carried out in Türkiye.

finite and discrete element models, engineering seismological methods, etc.) should be used more in an archaeoseismological perspective. The acceleration of scientific studies at this point seems possible by producing interdisciplinary collaborations and projects. On the other hand, one of the biggest obstacles in the development of archaeoseismology is the incorrect interpretation/incomprehension of the seismogravitational and/or seismotectonic deformation structures revealed during excavations and research in archaeological sites, and mostly restoration and deletion of traces. In this regard, it is necessary to work with experts in archaeoseismology during the systematic excavations in order not to miss these data and to evaluate and interpret them correctly. In the light of all the information summarized above, it is seen that archaeoseismology is a field that produces data sets both for active tectonic studies, archaeological research, earthquake engineering and earthquake risk analysis. Anatolia (formerly Asia

Minor) has a unique potential among the areas in the world where this discipline can be applied, due to its geological and archaeological location. However, the fact that this scientific discipline is currently little known by both geologists, archaeologists, and scientists specialized in archaeological architecture and engineering is the most important factor that reduces the number of trained scientists considerably. Along with this, the research and understanding of past earthquakes and their effects on society is of inestimble value both for our intellectual self and for the perception of the inevitable fact of living with earthquakes phenomenon. This situation seems that can only be reduced by raising society awareness and with practices within the framework implementing public measures.

The most important lesson learned about the integration of archaeoseismology into earthquake geology is that the advantages and disadvantages of this method for earthquake records do not conflict with other paleoseismological methods, on the contrary, they support and fill the gaps. When we look at the inventory created in this study, it is seen that archaeoseismological researches carried out in Türkiye are mostly concentrated in the Western Anatolian Extensional Province in tectonic terms and in Hellenistic - Roman cities, which include periods when historical period records were more productive. In this direction, earthquake data in archaeological sites, cities and civilizations in earlier periods (Neolithic, Bronze and Iron ages, etc.) should be investigated with modern archaeoseismological studies such as comprehensive study HERACLES (Hypothesis-Testing of Earthquake Ruined Argolid Constructions and Landscape with Engineering Seismology) project (Hinzen et al., 2018) related with Bronze age earthquakes performed at Greece main land and Crete. Especially to large-scale active fault zones in Anatolia (e.g. Archaeological sites close to NAFZ, EAFZ, DSFZ, ASZ, etc.) should be investigated more carefully at this point and archaeoseismological research should be increased in other important areas of the country. On the other hand, the Earthquake Archaeological Effects (EAE) classification, which we use in modern archaeoseismological studies today, has been mostly adapted to Hellenistic - Roman and later architectural structures. The application of similar classifications to civilizations such as Hittite and/or Urartu, which have monumental architectural stone structures that spread intensively in the Anatolian geography, especially in Central and Eastern Anatolia, stands out as a very important requirement in the archaeoseismological perspective.

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APPENDIX 1- Some parameters of important archaeoseismological studies carried out in Turkey. AD: Archaeological data (inscription and excavation), HEC: Historical Earthquake Catalogue, RC: Radiocarbon, L: Luminescence, C: Cosmogenic nuclide, U/Th: Uranium/Thorium series, GD: Geophysical data, PM: Paleomagnetism, GMD: Geological and morphological data, O: Other data types. No* indicates the chronological order of studies. Please follow the sites/regions from the location numbers in Table 1.

No*	Reference (s)	Tectonic Region / Related Fault or Fault Zones	Archaeological Site / Region / City	Archaeological Structure Period	Findings	Type of Work / Dating	Determined Earthquake (s)
1	Schliemann (1880 and 1884)	North Anatolian Fault Zone?, Aegean Sea ?	Troy, Çanakkale	Bronze ? / Roman?	Collapsed blocks in house wall and overturns in Corintic syenite columns	AD	pre-Hellenistic ? / Roman period
2	Butler (1922 ve 1925)	Middle part of Gediz-Alaşehir Graben System	Sardis, Manisa	Hellenistic	Restoration and strengthening traces at the Artemis Temple	AD	17 AD
3	Salomon-Calvi (1940)	Bergama Graben, Aegean Sea	Pergamon, Asklepieion, İzmir	Roman	He states that how ancient earthquake effected the Asklepieion systematically destroyed the temple pillars and how the pillars that were erected afterwards were not affected by the 1939 earthquake	AD,HEC	? / 1939
4	Duyuran (1945); Naumann and Kantar (1950)	İzmir Fault ?	Agora of Smyrna, İzmir	Early Byzantine ?	Earthquake findings in the trench around the Basilica in addition sloppy restorations with spolia pieces used for the reconstruction of the Agora	AD, HEC	153 AD ? / 178 AD
5	Blegen et al. (1951 and 1953)	North Anatolian Fault Zone?, Aegean Sea ?	Troy, Çanakkale	Bronze	Findings at Troy III, IVb, IVc, Vc and VI layers	AD	mid 13th century BC
6	Schaeffer (1948)	Eastern Mediterranean Basin	Predominantly Ugarit sites, for Anatolia Troy, Boğazköy (Ḫattuša), Alacahöyük and Tarsus	Mostly Bronze	In particular, it evaluates earthquake data within the chronology of Palestine, Syria, Persia, Caucasus, Cyprus, Aegean and Anatolian areas separately	AD	2100 – 2200 BC / 1365 BC 2 main earthquakes; 1610 – 1620 BC Hiatus ?
7	Hanfmann (1961); Hanfmann and Mierse (1983)	Middle part of Gediz-Alaşehir Graben System	Sardis, Manisa	Roman and Byzantine	Demonstrates a simple probabilistic earthquake chronology by identifying fires and deformational structures of different areas and periods at Sardis	AD	17 AD / 7th / 12th/ 16th or 17th centuries
8	Ambraseys (1971)	Eastern Mediterranean Basin	Western Anatolia, especially with 17 AD earthquake which was affecting the Gediz River and its surroundings, and Istanbul, A regional-scale study addressing the relationship between historical and instrumental period earthquakes			HEC	17 AD / Earthquakes affecting İstanbul
9	Bean (1971)	Büyük Menderes Graben System and its eastern termination	Tralleis, Hierapolis	Roman (Imperial)	Based only on historical records	HEC	27 BC ? – 14 AD Tralleİs 60 AD Hierapolis
10	Naumann (1971)	Emet – Gediz Fault Zone	Aizanoi, Kütahya	-	Overturned columns and damaged building walls	-	1970 Gediz Earthquake
11	Ünal (1977)	Hittite , Hatti and Ugarit regions ?	Ugarit, Šamuḫa (Kayalıpınar), Ninova	Late Hittite	Based on Hittite tablets and literature	AD	Hatti period ? / 1365 BC / 1290 BC
12	Rapp (1982 and 1986)	North Anatolian Fault Zone?, Edremit Fault Zone?	Troy, Çanakkale	Troy VI (~ BC 1800 -1300)	Various destructions in Troy VI layer	AD, HEC	1365 BC ?

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13	Karwiese (1985)	Küçük Menderes Graben System, Aegean Sea, Ephesus Fault ?	Ephesus, İzmir	Roman	Deformations of the 2^{nd} house at terrace houses and 6^{th} and 7^{th} settlements; Numismatic data belonging to the Gallienan period; the changes of buildings after the earthquake.	AD, HEC	3^{rd} quarter of the 3^{rd} century; 262 AD Aegean Sea earthquake?
14	Waelkens et al. (1990); Waelkens (1993)	Fethiye Burdur Fault Zone, its northeastern termination	Sagalassos, Burdur	Hellenistic – Roman	Restoration of the Temple of Apollo Clarios after a probable earthquake, Deformations in ? Roman Bath and ? Hellenistic aqueducts	AD	138-140 BC
15	Altunel (1994)	Eastern parts of the Gediz-Alaşehir and Büyük Menderes graben systems	Hierapolis, Denizli	Roman	Various deformations on archaeological structures along the active NW-SE line passing through the city, hot water outlets and travertines, etc.	AD, HEC, GMD	60 AD ?
16	Altunel and Barka (1996)	Hierapolis fracture zone		Roman and Byzantine	Damages in architectural structures of different periods	AD, HEC, GMD	60 AD and 1354 ?, 1702(1703) ?, 1717 ?
17	Ferrero (1997)	Gediz-Alaşehir and Büyük Menderes graben systems ?		Byzantine	Based on the abandonment of some Byzantine structures and Doric Building	AD	early 7^{th} century ?
18	Hancock and Altunel (1997)	Hierapolis Fault Zone		Roman and Byzantine	Damages in architectural structures of different periods	AD, HEC, GMD	60 AD and 4^{th} century ?; 7^{th} century ? or 14^{th} century ?
19	Altunel (1998)	Western part of the Büyük Menderes Graben System	Priene, Aydın	Hellenistic - Roman	Deformations at the Holy Hall, Street, Agora and Temple of Athena	AD, HEC, GMD	Earthquake(s) in the 12^{th} century AD or after
20	Altunel (2000)	Büyük Menderes Graben System	Priene and Miletos, Aydın		Some deformations in Miletos and Priene	AD, HEC	~ 350 BC / 26-25 BC / 60 AD
21	Hancock et al. (2000)	Hierapolis Fault Zone	Hierapolis, Denizli	Roman and Byzantine	Damages in architectural structures of different periods	AD, HEC, GMD	excluding 60 AD, no specific earthquake is given
22	Waelkens et al. (2000)	The northeast end of the Fethiye Burdur Fault Zone, Kırkkavak Fault ?	Sagalassos, Burdur	Hellenistic - Byzantine	Mainly Neon Library floor, Theatre, upper Agora, and other architectural structures	AD, GD	Second half of the 1^{st} century AD / mid 3^{rd} century AD / first quarter 6^{th} century AD / mid 7^{th} century AD
23	Altunel et al. (2001)	Gediz and Küçük Menderes Graben systems	Ephesus, Sardis and Philadelphia	Mostly Roman	Deformations and various repairs some architectural structures for 3 ancient cities	AD, GD	17 AD / 4th century / 1595 / 1928 / 1969
24	Akyüz and Altunel (2001)	Burdur - Fethiye Fault Zone, Kibyra Fault Zone	Cibyra, Burdur	Roman - Byzantine	Damages at the Stadium and other architectural structures in the city	AD, HEC, GMD	417 AD
25	Altunel et al. (2003)	Datça Peninsula, Knidos Fault	Cnidos, Muğla	Hellenistic - Byzantine	Deformations in the architectural structures of different periods in the city, especially the Temple of Aphrodite and the Demeter Sanctuary	AD, HEC, GMD	Between 2^{nd} - 3^{rd} century BC / 459 AD
26	Greenewalt (2003; 2006; 2007)	Middle part of Gediz-Alaşehir Graben System	Sardis, Manisa	Roman - Byzantine	Traces of a possible surface faulting event that destroyed the structures in Field 55	AD	7^{th} century AD or later
	Drahor (2006)				Using geophysical methods at Field 55	GD	
27	Sintubin et al. (2003)	The northeast end of the Fethiye Burdur Fault Zone, Isparta–Eğirdir Fault Zone ? / Ağlasun mountain front ?	Sagalassos, Burdur	Hellenistic - Byzantine	Damages in different architectural structures of the city	AD, GMD	early 6^{th} century AD / mid 7^{th} century AD

APPENDIX 1- *continued*

28	Şimşek and Ceylan (2003)	Eastern parts of the Gediz-Alaşehir and Büyük Menderes graben systems	Laodicea, Denizli	-	Emphasizes that many earthquakes affect the city based on historical and archaeological data	AD, HEC	27 BC / 47 AD / 60 AD / end of 3rd or beginning of 4th centuries AD / 494 AD
29	Ferry et al. (2004)	North Anatolian Fault Zone, İzmit Segment	Nicaea, İzmit	Ottoman water channel	Displacement data of a buried Ottoman water channel	AD, GD	After 1591 AD three (3) earthquakes
30	Similox-Tohon et al. (2004)	The northeast end of the Fethiye Burdur Fault Zone, Reactive active normal fault passing through Sagalassos	Sagalassos, Burdur	Hellenistic - Byzantine	Interpretations on six resistivity profiles	AD, GD, GMD	mid 7th century AD
31	Similox-Tohon et al. (2005)			Byzantine	Trench-based archaeoseismological data	AD, GMD Problematic U/Th	6th or 7th century AD
32	Birinci (2006)	Pamukkale Fault, Hierapolis Fault Zone	Hierapolis, Denizli	Roman and beyond	Geological observations on archaeological structures and travertine channels	AD, HEC, GMD	60 AD/ 494 AD / 7th century AD / 1354 AD
	Negri and Leucci (2006)	Hierapolis Fault Zone ?	Hierapolis, Denizli	Hellenistic - Roman	Active normal fault determined under the Temple of Apollo using geophysical methods	AD, GD	No specific earthquake is noted
33	Similox-Tohon et al. (2006)	The northeast end of the Fethiye Burdur Fault Zone ? Theater and Necropolis fault segments	Sagalassos, Burdur	Hellenistic - Byzantine	By using many techniques, then all data is combined going for an interpretation	AD, GMD, GD, O	~ 500 AD / mid or second half of the 7th century AD
34	Karabacak (2007)	Northern extension of the Dead Sea Fault Zone, Hacıpaşa and Karasu faults	Structures such as tells, ancient roads, castles, Antakya	Pre-Hittite, Hittite and Late Roman	Deformation analyses on the structures such as mounds, ancient roads, castles by using instrumental measurement techniques (geophysics and geodesics)	AD, GMD, GD, O, RC	526 AD / 859 AD / 1408 AD / 1822 AD / 1872 AD
35	Piccardi (2007)	Hierapolis Fault Zone	Hierapolis and Colossae, Denizli	Roman (Imperial)	Deformations on Nymphaeum, Plutonium , correlation of tectonic data with historical/mythological data	AD, HEC, GMD	60 AD
36	Sintubin and Stewart (2008)	The northeast end of the Fethiye Burdur Fault Zone	Sagalassos, Burdur	Hellenistic - Byzantine	By compiling the data of previous archaeoseismological studies in the city, they propose a new measurement method in practice entitled Archaeoseismic Quality Factor (AQF)		They note that the earthquake hypothesis in Sagalassos contains some weakness and uncertainty and needs to be re-evaluated
37	Akan (2009), Akan et al. (2012)	Rhodiapolis Fault ?	Rhodiapolis, Antalya	Hellenistic - Roman	Deformations in various archaeological structures	AD, GMD	141 AD / 7th century AD
38	Altunel et al. (2009)	Northern extension of the Dead Sea Fault Zone, Hacıpaşa Segment	Amik Plain, Antakya	Pre-Hittite, Hittite	Cut and offset by the fault; a mound settlement dating to ~ 5000 BC and an ancient road dating to ~ 2000 BC	AD, GMD, GD, O	1408 AD / 1872 AD
39	Çetin-Yarıtaş (2009)	Termessos Fault	Termessos, Antalya	Roman ?	Deformations in architectural structures; such as Theatre, bath, Corinthian Temple etc.	AD, GMD	?
40	Yalçıner (2009)	Büyük Menderes Graben System	Archaeological structures at the northern part of the graben	Roman - Ottoman	Offsets on Ramazan Paşa Bridge, Roman wall and road	GMD, GD	-
41	Perinçek et al. (2010)	North Anatolian Fault Zone	Yenikapı, İstanbul	Byzantine	Tsunami and shipwreck findings	AD, GMD, RC	557 AD
42	Hinzen et al. (2010)	Fethiye Burdur Fault Zone ?	Pinara, Muğla	Classical	Deformation analyses on the Arttumpara Sarcophagus	AD, O	?
43	Yerli et al. (2010)			Classical - Byzantine	Deformations on the Roman Theatre	AD, O	?

APPENDIX 1- *continued*

44	Yönlü et al. (2010)	Western part of the Büyük Menderes Graben System	Ramazanpaşa Bridge, Priene, Aydın	Hellenistic-Ottoman	Deformations on different architectural structures in the city and the Ottoman bridge	AD, GMD, O	1846 AD
45	Karabacak (2011)	Fethiye Burdur Fault Zone, Kibyra Segment	Cibyra, Burdur	Hellenistic - Roman - Byzantine	Deformations on mainly Stadium and Theatre, and minor other architectural structures	AD, GMD, HEC, GD, O	417 AD / after 7th century AD
46	Yerli et al. (2011)	Fethiye Burdur Fault Zone	Pinara, Muğla	Classical - Byzantine	They're testing the archaeological logic tree method set for the city, and reveal Archaeoseismic Quality Factor (AQF); They assumed low seismic hazard potential of the region needs serious reconsideration.		
47	Tokmak (2012)	Western Anatolia	Various ancient cities	The relations between active faults and seismicity with morphological, lithological and distance/density parameters in the locations where ancient cities were established are examined			
48	Yönlü (2012)	Southwest extension of the East Anatolian Fault Zone	Anavarza, Kastabala, Toprakkale, Ayas, Magarsos	Roman	Deformations in different architectural structures belonging to different archaeological periods	AD, GMD, GD, O, HEC, RC, L	?
49	Altınok et al. (2012)	Kütahya Fault Zone	Seyitömer Mound, Kütahya	Neolithic – Bronze	Seyitömer Mound and trench-based paleoseismological data	AD, GMD, O, L	~ 6000 BC / ~ 1800 BC
50	Bony et al. (2012)	North Anatolian Fault Zone	Yenikapı, İstanbul	Byzantine	Tsunami and shipwreck findings	AD, GMD, RC	557 AD
51	Kürçer et al. (2012)	Troy and Kumkale faults	Troy, Çanakkele	-	Trench-based paleoseismological data	RC	> 760 BC / 130 – 780 AD / 1000 AD – 1300 AD; 3 or 2 earthquakes
52	Hinzen et al. (2013a,b)	Fethiye Burdur Fault Zone ?	Pinara, Muğla	Roman	Deformations in the Roman theater and mausoleum	AD, O	Deformation analysis and numerical data of the event
53	Karabacak et al. (2013)	Fethiye Burdur Fault Zone	Cibyra, Burdur		Deformations in Stadium and other architectural structures	AD, GMD, L	10 – 11th century AD
54	Passchier et al. (2013)	Büyük Menderes Graben System, İçme Tepe Fault	South of Ephesus, Kusadası	Roman (Imperial)	Vertical offset exceeding 3 m in Roman water channels	AD and annual carbonate lamination	earthquake after the second half of the 2nd century AD, probable 178
55	Söğüt (2014)	Muğla and Yatağan faults ?	Stratonikeia, Muğla	Byzantine	Collapsed city street	AD	Street rebuilt during the between 4th-5th century AD
56	Aydan and Kumsar (2015)	Normal faults of Western Anatolia Province ?	Magnesia, Ephesus, Sardis, Smyrna	-	Deformations in different architectural structures in different cities	AD, HEC	17 AD / 10th century AD
57	Benjelloun et al. (2015)	Northern extension of the Dead Sea Fault Zone, Antakya-Samandağ corridor	Antioch water channels, Antakya	Roman	Deformation and restoration of ancient water channels	AD, RC, PM, O	?
58	Buchwald and McClanan (2015)	Middle part of Gediz-Alaşehir Graben System	Sardis, Manisa	Byzantine	They attributes the destruction of "Church E" to the earthquake and relates it to the 1595 earthquake in historical earthquake data	AD, HEC	1595 AD
59	Cahill (2016 ve 2019)			Roman	The monumental arched structure collapsed and hit the floor and left a trace	AD	?
					Deformations at Area 55		Probably the early 6th century AD
60	Kumsar et al. (2016)	Pamukkale Fault Zone and Laodikya Fault	Hierapolis and Laodicea, Denizli	Roman - Byzantine	NE and SW oriented collapsed walls and columns and channels affected by surface rupture	AD, HEC	early 7th century AD
61	Drahor et al. (2016 ve 2017)	Amasya Shear Zone ?	Šapinuwa, Çorum	Middle Hittite	Systematic deformations in probable Middle Hittite buildings	AD, GD, GMD	after 14th century BC earthquake(s) ?

APPENDIX 1- *continued*

62	Karabacak (2016)	Muğla Fault	Lagina sanctuary, Stratonikeia, Muğla	Roman – Early Byzantium	Deformations on Propylon, Sunaki Stoa, Temple and Chapel	AD, GMD, RC, L	just after the 4th century AD
63	Bachmann et al. (2017)	Western Anatolian and/or Aegean Sea faults?	Pergamon, Asklepieion, İzmir	Roman	Some destructions observed in Room 4 of Building Z at the Acropolis	AD	Probably 178 AD ?
	Pirson (2017)				Based on the many changes in the city and decline in settlement activities		
64	Benjelloun (2017)	Middle branch of the North Anatolian Fault Zone	Nicaea, İznik	Hellenistic -Byzantine	Combining and interpreting deformation elements in different architectural structures and different data in the study	AD, GMD, O, RC, C	AD: 3rd century / 13th century / after mid 15th century Dating: 527 – 787 AD / 858 – 1097 AD
65	Stewart and Piccardi (2017)	Aegean Region and Greece	Ephesus, Hierapolis, Delphi, Knidos etc.	Bronze - Byzantine	Various deformations in some architectural structures	AD, GMD	various earthquakes from the literature
66	Benjelloun et al. (2018)	Middle branch of the North Anatolian Fault Zone	Nicaea water channels, İznik	Roman - Modern	Interpretations based on the repairs in the buildings	AD, GMD, GD	1065 AD ?
67	Softa et al. (2018)	Kale and Kekova faults ?	Myra, Antalya	Classical - Byzantine	Deformations in architectural structures around the Harbour and Theatre	AD, GMD, HEC	141 AD ?/ 240 AD ? / 344 AD ?
68	Sümer et al. (2019)	Amasya Shear Zone ?	Ḫattuša, Çorum	Early Hittite	Traces of systematic deformation in the Great Temple	AD, GMD	after 16th century BC earthquake(s)
69	Hallmannsecker (2020)	Western Anatolia	Sardis, Manisa	Roman	Approach to the 17 AD earthquake on an inscription found in Sardis	AD	17 AD
70	Barış et al. (2021)	Northern branch of the North Anatolian Fault Zone	Bathonea, Küçükçekmece Lake, İstanbul	Late Roman – Early Byzantine	Deformations in Cistern and tunnels	AD, GD, HEC, O	6th century AD earthquakes
71	Altunel and Pınar (2021)	Aegean Sea, Kusadasi Bay, Ephesus Fault ?	Ephesus, İzmir	Roman ?	Possible deformations in the Terrace houses, the Celsus Library and the Domitian Temple	AD	-
72	Benjelloun et al. (2021)	Middle branch of the North Anatolian Fault Zone	Nicaea, İznik	Roman - Ottoman	Deformations in defence walls, towers, Yeşil Mosque and different architectural structures and dating the repairs; in addition, the damages are evaluated in the light of EAEs criteria	AD, GMD, O, RC	3 different earthquake probabilities before and after 1331 AD
73	Sümer et al. (2022)	Middle part of Gediz-Alaşehir Graben System	Sardis, Manisa	Roman - Byzantine	They make an approach by evaluating their own observations, data in the literature and the historical earthquake catalogues.	AD, HEC	17 AD / early 7th century AD ? / 1595 / 1771 / 1845 AD
74	Sümer et al. (2021), Drahor et al. (2023)	Amasya Shear Zone ? or North Anatolian Fault Zone ?	Ḫattuša and Šapinuwa, Çorum	Hittite	The deformations at the Ḫattuša and Šapinuwa; make a relative approach according to the age of the architectural structures in the cities	AD	after the 15th-14th centuries BC earthquake(s) ?