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The AD 365 Crete earthquake and possible seismic clustering during the fourth to sixth centuries AD in the Eastern Mediterranean: a review of historical and archaeological data

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Abstract

Historical and archaeological data are used to test geological claims that, in the fourth to sixth centuries AD, the Eastern Mediterranean experienced an unusual clustering of destructive earthquakes (the 'Early Byzantine Tectonic Paroxsym'). A review of historical accounts of a notable earthquake at this time, that of 21 July AD 365, indicates that this event destroyed nearly all the towns in Crete and was followed by a tsunami which devastated the Nile Delta. The AD 365 event was also probably responsible for reported or observed destruction in ancient towns of west Cyprus and Libya. This earthquake is most likely to be identified with a Hellenic Arc subduction-zone event of 'great' ($M > 8$) magnitude, as testified by up to 9 m of uplift in western Crete dated by previous geological studies to around this time. Historical and archaeological data also support the hypothesis that the fourth to sixth centuries AD was a period of abnormally high seismicity in the Eastern Mediterranean. The high seismicity rates of this period may reflect a reactivation of all plate boundaries in the region (Dead Sea Transform, East Anatolian Fault, North Anatolian Fault, Hellenic Arc, Cyprus Arc Fault). © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Recent geological studies indicate a clustering of major seismic activity around the shores of the Eastern Mediterranean between the middle of the fourth century to the middle of the sixth century AD (Pirazzoli et al., 1996). The evidence for this 200-year earthquake 'storm' comes largely from radiocarbon-dated sea-level indicators corresponding to marine shorelines that were uplifted during this critical period (Pirazzoli, 1986; Pirazzoli et al., 1996). Although the ages of the individual dated shorelines span a range of several centuries, the dataset as a whole suggests that the Eastern Mediterranean region was affected by a major tectonic paroxysm during this time—the 'Early Byzantine Tectonic Paroxysm' (EBTP) (Pirazzoli, 1986; Pirazzoli et al., 1996). The most important of these seismic uplifts is that of Crete, which is dated to around AD 353 (±80 years) and is thought to be responsible for the up to 9 m of uplift and tilting of a lithospheric block exceeding 100 km in length (Figs. 1 and 2) (Thommeret et al., 1981; Pirazzoli et al., 1982, 1996). The scale of the uplift of Crete is broadly equivalent to that observed during the 1964 Alaska (M_s 8.4) earthquake, and so the AD 365 event probably corresponds to an earthquake of roughly the same size (i.e. a seismic moment of $\sim 10^{29}$ dyne·cm; Kanamori, 1977). Such a size of earthquake is far greater than those known to have affected the Hellenic Arc and the wider Eastern Mediterranean region in modern or recent historical times (Ambraseys and Jackson, 1990; Ambraseys et al., 1994; Papazachos and Papazachou, 1997).

The apparent clustering of historical earthquakes in the fourth to sixth centuries AD remains enigmatic, and its geodynamic implications have, with few exceptions (Ambraseys et al., 1994), gone largely unnoticed. Furthermore, the role of the 'great' earthquake of 21 July AD 365 in this EBTP remains contentious. Pirazzoli et al. (1992) assumed that the 21 July AD 365 earthquake was responsible for the uplift of Crete because this earthquake was known from ancient sources to be an event of unprecedented scale for the region, producing a major tsunami that caused major destruction in the Nile Delta and along other coasts of the Eastern Mediterranean (see Ambraseys et al., 1994; Guidoboni et al., 1994). From historical accounts, Ambraseys et al. (1994) estimated the event to have been magnitude 8 or even higher. However, the significance of the 21 July AD 365 earthquake remains open to debate. In particular, there remains considerable argument about whether this

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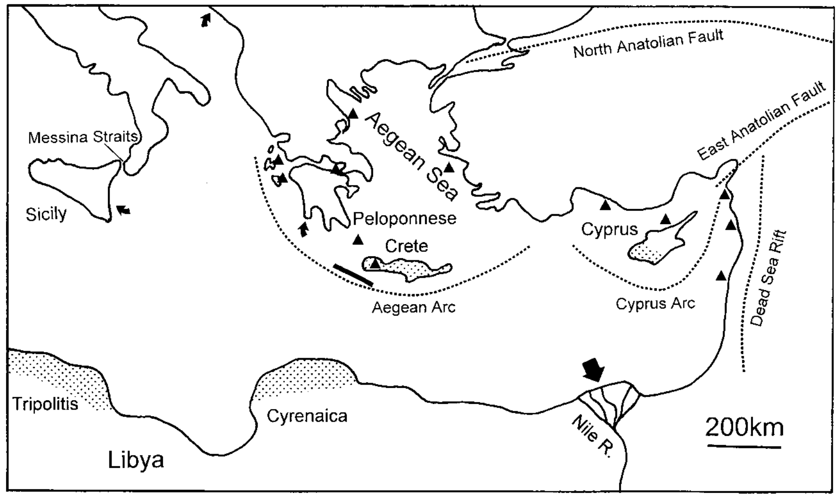


Fig. 1. Fourth to sixth century AD coastal uplifts (triangles) and plate boundaries (dotted lines) in the Eastern Mediterranean (based on Pirazzoli et al., 1996; Stiros et al., 2000). Dotted are the areas known from historical and archaeological data to have been affected by the AD 365 earthquake. A thick line offshore of Crete denotes the inferred location and orientation of the thrust fault considered to have been reactivated in AD 365. The triangles indicate areas reliably (large symbols) and possibly (small symbols) affected by the AD 365 tsunami based on contemporary historical accounts.

earthquake was indeed a regionally catastrophic ('universal') event, or instead whether it was an historical amalgamation of a number of notable earthquakes which occurred between AD 355 and 450 (see Guidoboni et al., 1994).

An important related question is to what extent there is evidence for the EBTP in the historical and archaeological records of the region during the fourth to sixth centuries AD. In particular, given the broad age errors associated with shoreline evidence on which the EBTP was postulated, the historical and archaeological data potentially provide a more precise chronology of seismic activity during this critical period. As a consequence, this paper critically reviews the historical and archaeological evidence, firstly for the AD 365 earthquake, and secondly for an increased level of seismicity during the fourth to sixth centuries AD. This study differs from previous work on this topic in several aspects. Firstly, it is limited to an appraisal of 'reliable' historical information, i.e. first-hand accounts of authors writing during the fourth to sixth centuries AD (cf. Ambraseys, 1971). Secondly, the contemporary historical information is correlated, where possible, with archaeological data for the same period, making particular use of numismatic (coins, medals etc.) dating of earthquake damage at ancient sites. Thirdly, the paper attempts to use the historical and archaeological information to constrain the geological parameters of the AD 365 earthquake and to shed light on the seismotectonics of the Eastern Mediterranean between c. AD 300 and 600. Through this approach, the paper aims to demonstrate how archaeoseismic data can be effectively used to raise important questions about the geodynamic behaviour of the Eastern Mediterranean plate margins.

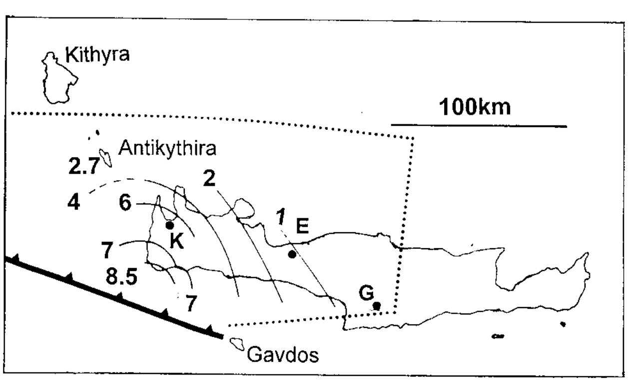


Fig. 2. Contours of the inferred uplift of Crete during the AD 365 earthquake. The dotted line is the assumed boundary of the uplifted block (simplified after Pirazzoli et al., 1996); the thick line with ticks indicates the approximate trace of the causative thrust. K, E and G indicate Kisamos, Eleutherna and Gortyn, respectively, the three ancient towns for which there is archaeological excavation evidence for seismic destruction in AD 365. See text for details.

2. Methodological approach

2.1. Previous approaches

In contrast to the emergence in the last two decades of geological studies that indicate a concentration of major earthquake activity between the middle of the fourth century to the middle of the sixth century AD (Pirazzoli et al., 1996, and references therein), this apparent seismic clustering has gone largely unnoticed amongst historians. Most historical studies of earthquakes during this period have instead focused on specific notable events, mainly the AD 363 Palestine (Russell, 1980) and the AD 365 Crete (Jacques and Bousquet, 1984) earthquakes. Reconstructing the general parameters (location, spatial extent of affected area, etc.) of such earthquakes has largely been undertaken as an historical exercise, through the interpretation of ancient texts (e.g. Guidoboni et al., 1994). In contrast, the seismological and tectonic implications (magnitude, meizoseismal areas, causative faults, etc.) of these earthquakes have only rarely been addressed (e.g. Ambraseys et al., 1994). However, the conclusions of historians are often dubious and contradictory. For example, some workers (Di Vita, 1986, 1990) propose a 'universal' earthquake in AD 365 which swept across all Mediterranean coasts from Algeria to Syria; others propose a sequence of seismic disasters which occurred between AD 361 and 450 (Guidoboni et al., 1994), or limit the effects of the AD 365 earthquake to Crete and the Nile Delta (Jacques and Bousquet, 1984) or to north-east Libya (Ambraseys et al., 1994).

The reason for this lack of consensus is simple: the fourth and fifth centuries AD coincided with the decline of the Roman Empire and consequently with a period of struggle, firstly between the ancient pagan Greek and the new Christian religion, and secondly between the formal Christian religion and various heresies. In this context, unlike some earlier periods for which accurate and reliable information is provided by contemporary historians like Thucydides or Herodotus (fifth century BC), accurate description of historical events was generally replaced by the selective use of historical events to support religious, political or rhetorical arguments. For example, Libanius and Sozomen, two fourth century AD writers who represent some of our primary sources for the AD 365 event (see Appendix A), present earthquakes as the sorrow or the wrath of God, respectively, for the death of Emperor Julian who tried to restore the pagan religion. Thus, they variously give the impression that the earthquakes mentioned occurred either after or before Julian's death in AD 363. Similarly, an account by Jerome, a fourth century AD religious writer, of St Hilarion making the symbol of the cross at Epidavros (modern Cavtat on the eastern Adriatic coast) and thereby saving the town from the waves of the AD 365 tsunami is figurative (Appendix A), and so cannot be assumed to be reliable evidence of a major tsunami in the Adriatic Sea at this time.

At the same time as questionable historical material is incorporated into earthquake catalogues, other valuable information is omitted. For example, while modern historians extensively report descriptions of the destructive effects of the AD 365 tsunami, especially in the Nile Delta, they ignore (with notable exceptions: Jacques and Bousquet, 1984; Jensen, 1985) reports of permanent coastal uplift and subsidence that are also documented in certain ancient texts (see Appendix A). Furthermore, historians tend not to accept the possibility of any event that is not historically documented. For example, Lepelley (1984) argues that since no earthquake is mentioned in two fourth century AD religious reports from North Africa, the possibility of seismic destruction in Libya ought to be rejected.

Despite the problems inherent in the interpretation of contemporary reports, the accounts of later writers are even more problematic. As is discussed later, the AD 365 event was indirectly dated in reference to kings of the period, usually with mistakes, giving the impression of multiple earthquakes which occurred between AD 365 and 396 with more or less the same effects (Guidoboni, 1989, p. 681; Guidoboni et al., 1994). Ironically, some of the 'rogue' multiple events have in turn been used as reference dates for constraining archaeological stratigraphies, as is the case with the hypothetical earthquake of AD 375 or 395/396 in Corinth (see Finlay, 1932; Rothaus, 1996). It is to overcome these difficulties that this paper utilizes only those first-hand accounts of authors writing during the fourth to sixth centuries AD and attempts to tie these accounts to well-dated archaeological evidence for earthquake damage at ancient sites.

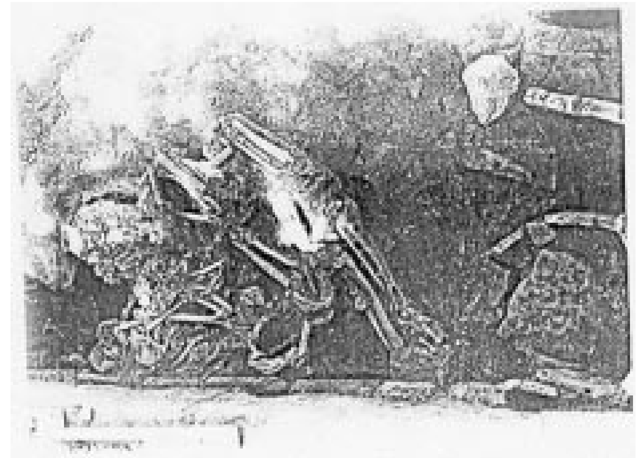
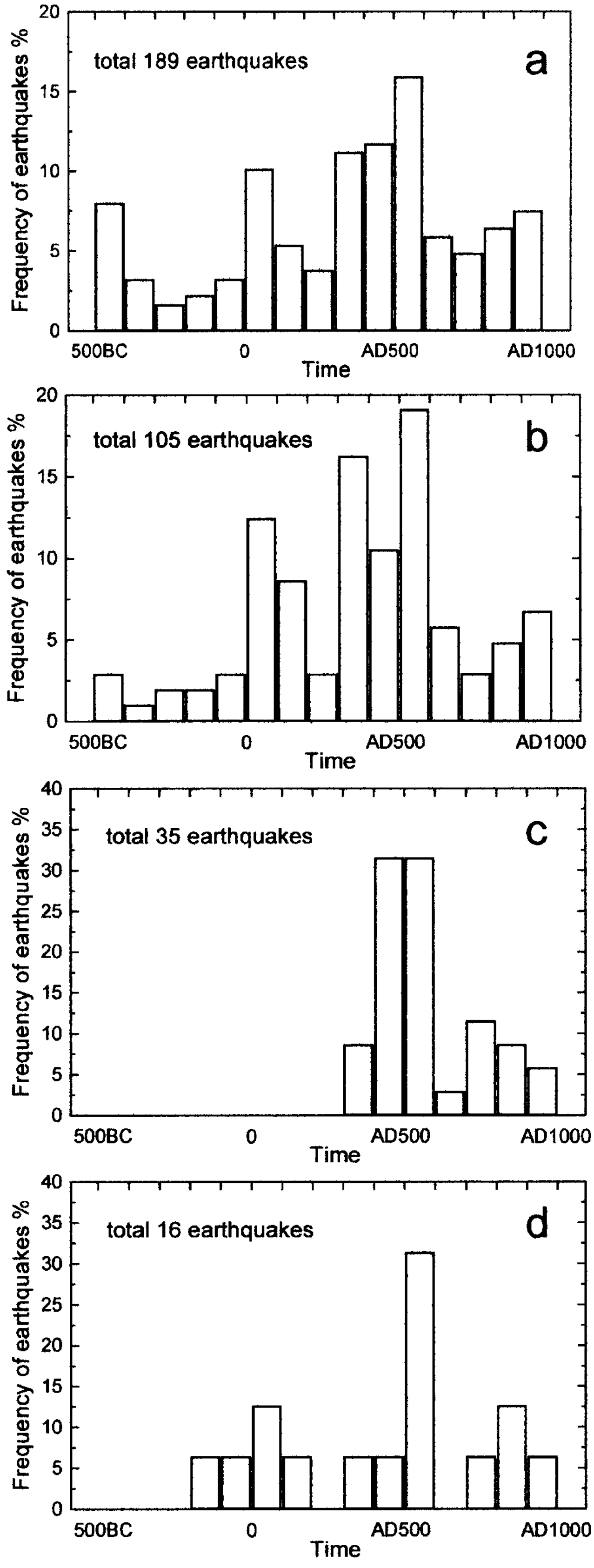


Fig. 3. Skeletons of a man and child killed and buried by an earthquake shortly after AD 351/361, as excavations at Eleutherna (Crete) reveal. As is discussed in the text, this earthquake damage could be associated with the AD 365 event.

2.2. Types and limitations of historical and archaeological data

Historical and archaeological evidence of earthquakes can be (1) direct, (2) structural or (3) indirect. Direct evidence consists of ancient texts and inscriptions that explicitly report seismic damage, subsequent repairs or abandonment of ancient buildings or whole towns, or natural effects accompanying earthquakes (tsunamis, etc.). Structural evidence constitutes remains of ancient structures bearing signs of palaeoseismic deformation, such as walls offset by surface faults, uplifted harbours, etc. (Trifonov, 1978; Zang et al., 1986; Sangawa, 1986; Stiros, 1996; Marco et al., 1997; Hancock and Altunel, 1997). Indirect, or inferred, evidence comprises reports (from ancient authors or from archaeological excavations) of damage, repairs, abandonment or environmental changes in towns and buildings for which earthquakes provide the only reasonable explanation. Details of the accuracy and limitations of this evidence have been discussed by Ambraseys



(1971) and Stiros (1996), but a few key points are repeated here.

The historical and archaeological record of seismicity in the Eastern Mediterranean covers a period of more than 2000–3000 years, but only a fraction of the significant earthquakes during this period are documented. As a consequence, estimates of the frequency–magnitude relations of ancient earthquakes deduced from historical data cannot be compared with the 20th century estimates. Thus, the modern earthquake record in Turkey averages around two magnitude 7 earthquakes every 10 years (Jackson, 1994, fig. 4), a frequency of recurrence that is several times greater than that apparent from the historical seismicity record (Fig. 4) (Guidoboni et al., 1994; Ambraseys et al., 1994; Papazachos and Papazachou, 1997).

Furthermore, earthquake data are not uniformly distributed in space and time, but are usually limited to (1) major centres of population, culture and trading, (2) sites where systematic excavations have been made, or (3) periods for which the historical record is more complete. Thus, the historical record gives the misleading impression that there was a peak in the seismicity in the fifth century BC (Fig. 4a; a period with an abnormally good historical record) and that seismicity in antiquity was clustered in major cities like Constantinople (Istanbul) and Antioch (Antiocheia, presently Antakya or Hatay in Turkey). In areas like Constantinople and Antioch, statistical analysis of the historical record may well reliably track variations in the frequency and magnitude of earthquakes over time, and especially may reveal periods of genuine seismic quiescence or of high seismic activity. However, regardless of the degree of completeness of the historical and archaeological record in an area, the silence of written sources or the lack of archaeological data should not be used as evidence of the absence of a postulated earthquake event (cf. Lepelley, 1984 and entry on Synesios in Appendix A).

2.3. Affected areas and causative faults

With the exceptions of tall, slender towers (towers, minarets, etc.), buildings in antiquity consisted of only one or two storeys. As a consequence they were, in principle, short-period structures, vulnerable to shaking by short-period

Fig. 4. (a) Plot showing the frequency of earthquakes in the Eastern Mediterranean between 500 BC and AD 1000, based on the catalogue of Guidoboni et al. (1994). Multiple entries of the AD 365 event (see text) are ignored. The peaks during the fifth century BC and the first century AD reflect a documentary bias (increased historical information); on the contrary, the peaks during the fourth to sixth centuries AD reflect a genuine increase in seismicity rates. (b) Plot showing the frequency of inferred 'major' earthquakes (intensity over VIII) in the Eastern Mediterranean between 500 BC and AD 1000. (c) Plot showing the frequency of earthquakes felt in the Constantinople (Istanbul) area. (d) Plot showing the frequency of earthquakes affecting the Antiocheia (Antioch, Antakya, Hatay) area in southeastern Turkey.

seismic waves whose effects are quickly attenuated away from the earthquake focus. Conversely, they were not generally vulnerable to the long-period seismic waves generated by distant large earthquakes (Ambraseys, 1971). Consequently, especially massive destructions of ancient towns testify to earthquakes whose epicentres lay close to or within an affected area (Stiros, 1996). Based on their analysis of Persian earthquakes in particular, Ambraseys and Melville (1982) concluded that large ($Mb > 5.5$) earthquakes are generally located within 20 km of their macroseismic epicentre.

On the other hand, major ($M > 7$) earthquakes are typically associated with large faults (Roberts and Jackson, 1991; Ambraseys and Jackson, 1990), i.e. faults that break the entire thickness of the seismogenic crust and whose surface lengths typically exceed several tens of kilometres. In many areas, a comparatively small number of large active faults achieves the bulk of the tectonic and seismic deformation. It is therefore reasonable to try to correlate ancient earthquakes for which we have well-documented damage to particular towns or buildings with nearby large faults. Although this approach is not suitable for seismic risk evaluation, it is useful when considering the seismotectonic significance of historical and archaeological accounts.

2.4. Numismatic dating of archaeological destruction layers

The dating of earthquakes deduced from archaeological data discussed here is based mainly on chronologies derived from coins (numismatic dating). Under Roman rule operating during the fourth century AD, provincial towns had the permission to issue small value, copper coins, which circulated widely and quickly throughout the Roman Empire owing to its commercial, administrative and military activities. The names of Emperors and of local administrators were featured on these coins, and new coins were struck immediately after every change of Emperor or provincial governor. These coins were of small value, low quality and rapidly produced (struck, not moulded), and used for everyday needs; consequently, they were quickly worn. As a result, the set of coins in use at any place changed progressively with time, and newly issued coins always represented a significant percentage in any coin set. Thus, if several coins or hoards of coins in use (for instance, found in the pocket of an earthquake victim and not deposited in a kind of safe) are found in a certain archaeological destruction horizon, the most recent among these coins provides a reliable minimum age constraint, very close to the real date of the archaeological layer (i.e. the date of the abandonment or destruction of a town or building; Stiros and Papageorgiou, 2000). For example, the most recent coins found in destruction layers in towns known from literary accounts to have been hit by the 18/19 May AD 363 Palestine earthquake featured Emperor Julian and would have been issued between AD 361 and June 363 (Russell, 1980).

3. The AD 365 earthquake

3.1. The debate: a ‘universal’ or a composite event?

For more than a millenium, the AD 365 event was regarded by ancient authors as a ‘universal’ earthquake, unique in terms of the intensity and extent of its felt effects and the scale of its associated tsunami. For example, it was also the only earthquake in Egypt whose anniversary was commemorated for centuries by an annual festival—the ‘day of horror’ (see Sozomenus, Appendix A). Consequently, it is widely regarded as an event of unprecedented scale in the 2500-year-long historical earthquake record of the Eastern Mediterranean, a region regularly struck by strong ($M > 7.5$–8.0) earthquakes (Ambraseys et al., 1994; Papazachos and Papazachou, 1997). However, what do we actually know about this major earthquake?

Most ancient writers appear to have been particularly fascinated by the tsunami that followed the AD 365 earthquake, and consequently, there is little or no description of its specific wider effects (areas destroyed, etc.). To compound the problem, many modern historians and archaeologists tended to give much credence to reports of later (sixth to 12th century AD) writers. Unfortunately, many of these writers erroneously assigned the effects of the AD 365 earthquakes to later kings, thereby shifting the date of this earthquake by periods ranging from between one month to several decades. For instance, Cedrenus (cited in Guidoboni et al., 1994), an 11–12th century AD historian, wrongly assigns the effects of the AD 365 earthquake and tsunami to the period of Emperor Gratian (AD 375–385). Similarly, Zosimus (also cited in Guidoboni et al., 1994) wrongly dates the major earthquake which destroyed Crete and other parts of Greece as having occurred after AD 375, possibly in AD 395 (Rothaus, 1996; Finlay, 1932).

These conflicting ancient reports fed endless debates among recent and modern historians studying this earthquake. The focus of their debate centred on whether ancient sources refer to a single earthquake, or a number of earthquakes which devastated the entire Mediterranean region in the fourth and fifth centuries AD. In particular, some historians (e.g. Guidoboni et al., 1994) date reported seismic destruction in Sicily, Central Greece and Libya to during the reign of Julian, i.e. between AD 361 and 363, and therefore before the AD 365 earthquake. This is based on a contentious interpretation of the written accounts of Libanius. An alternative view, expressed by Di Vita (1990) and previous editors of the works of Libanius, dates the Sicily and Libya earthquake to after Julian’s death and to AD 365 in particular. Recently, archaeologists have been drawn into the debate, particularly with regard to whether destruction accompanying the AD 365 earthquake extended to Libya and even beyond, to Tunisia or Algeria (Di Vita, 1986, 1990, 1995; Lepelley, 1984). The following section reviews the key historical and archaeological information that constrains our knowledge of the spatial extent of the observed effects of the AD 365 earthquake.

3.2. Spatial extent of the seismic destruction in AD 365

Despite the often equivocal and ambiguous nature of the contemporary historical record, numerous fourth and fifth century AD texts, as well as later texts, agree that: (1) a destructive earthquake occurred in the Eastern Mediterranean on 21 July AD 365; (2) it was an event of unusually large magnitude; and (3) it was associated with a huge tsunami which caused extraordinary damage in the Nile Delta (Jacques and Bousquet, 1984; Jensen, 1985; Ambraseys et al., 1994; Guidoboni et al., 1994). The reported effects of the event in the different parts of the Eastern Mediterranean are summarized by region below, based largely on historical accounts from Guidoboni et al. (1994) (Appendix A) and archaeological evidence compiled from a variety of sources (given in Appendix B).

3.2.1. Crete

In Crete, a reliable ancient text (see Athanasios, Appendix A) reports that in AD 365 an earthquake of unprecedented scale, followed by a tsunami, destroyed more than 100 towns, which were turned to ruins. This earthquake, also confirmed by later sources (e.g. Georgius Monachus), clearly ties this earthquake with the 21 July AD 365 earthquake and tsunami at Alexandria. The destruction at Alexandria is precisely dated by several sources (e.g. Ammianus Marcellinus, Appendix A) and described as "the famous calamity of Alexandria" by Sozomenus (Appendix A), the anniversary of which was commemorated each year for about two centuries. The report of the destruction of more than 100 towns in Crete implies an island-wide, near-total or total destruction, consistent with available archaeological data summarized in Appendix B. In particular, an earthquake shortly after AD 355–361 was recorded at both Kisamos in western Crete and at Eleutherna in west central Crete (Fig. 3). Similarly, at Gortyn (central Crete) an earthquake appears to have occurred about 10–20 years before AD 383 (see Fig. 2 for locations).

In addition to the extensive descriptions of the dramatic tsunami effects by ancient authors, there is also largely neglected literary evidence from Socrates Scholasticus (Appendix A) that this earthquake was associated with large-scale coastal uplift ("the sea retreated so far that the bottom of the sea was found to be dry") and subsidence ("where previously people walked they could now sail"). Unfortunately, there are no details of where these subsided and uplifted coastal areas are. However, it seems reasonable to identify the emergent area with the uplifted shores of western Crete, dated to AD 353 ± 80 from raised shorelines (Thommeret et al., 1981; Pirazzoli et al., 1982, 1996). Accepting this, the famous tsunami of Egypt, the seismic destruction of Crete and the uplift of the western part of this island likely correspond to a single destructive event on 21 July AD 365.

3.2.2. Libya

In Cyrenaica, on the northeast coast of Libya (Fig. 1), several excavated towns reveal collapsed houses containing buried skeletons, which indicates extensive seismic damage. This damage, dated by coins and inscriptions, occurred shortly after AD 364 and before AD 378. Similar damage, though on a reduced scale, is also found along the northwest coast of Libya (Tripolitis) and dated by numismatic evidence to shortly after AD 364/367 and before AD 378 (Di Vita, 1995; Appendix B). Seismic destruction of towns in Libya was mentioned by the fourth century AD writer Libanius (see Appendix A), but has been a matter of debate for years. Lepelley (1984), among others, rejected the hypothesis of an earthquake destruction, arguing that no such event was explicitly mentioned in other ancient texts and inscriptions of the period and proposing instead that certain camel-riding nomads destroyed the Libyan towns. However, Guidoboni et al. (1994) has identified letters of a fourth century AD local Bishop (Synesios of Cyrene, Appendix A) that confirm the occurrence of a late fourth century AD seismic disaster.

3.2.3. Cyprus

In Cyprus, destruction around the time of the AD 365 earthquake is mentioned in several ancient texts. The town of Paphos was reported to lie in ruins during the last decades of the fourth century AD and its destruction is indirectly dated to shortly before AD 368 (see Jerome, Libanius and Gregorius of Nyssa in Appendix A). Archaeological excavations reveal a total destruction of the town of Kourion, in southwest Cyprus. At Kourion, the latest coins found among the destruction layers were issued between late AD 364 and September AD 365 (Appendix B).

3.2.4. Mainland Greece

Ancient writers report widespread seismic and tsunami damage across central and southern Greece in c. AD 365. However, these documentary accounts are vague and possibly biased, because Athens, the centre of the ancient pagan cult of this period, is highlighted as the only undamaged town (Zosimus, Appendix A). Archaeological evidence for seismic damage during AD 365 in mainland Greece is found only at two sites in and around Corinth. At Corinth, archaeological data suggest seismic destruction before AD 364/375. At nearby Nauplion, an inscription testifies to repairs in buildings and other works completed between AD 375 and 378 in order to offer protection against earthquakes and 'marine invasions'. There is also indirect archaeological evidence for a seismic subsidence of Kenchreai (Appendix B), the eastern harbour of Corinth, during the last decades of the fourth century AD. Thus, while the destruction at Corinth could conceivably be related to the AD 365 earthquake and its associated tsunami, it seems prudent on the available evidence to associate it with a slightly later local event.

3.2.5. Adriatic coast and Sicily

Information on the possible impact of the AD 365 earthquake west of Greece is vague. The report of an AD 365 tsunami affecting the Adriatic coasts on the basis of the clearly figurative account of the miracle of St Hilarion, who saved the town of Epidauros (modern Cavtat) from the waves by making the symbol of cross (Jerome, Appendix A), remains unverified, and ought to be treated with caution. Similarly, the effect of the AD 365 event on Sicily remains problematic. A seismic destruction of its major towns post-AD 363 is vaguely reported by Libanius (Appendix A) and later by Georgius Monachus (cited in Guidoboni et al., 1994), while St Jerome (Appendix A) mentions tsunami damage in this island. Although no detailed archaeological evidence exists for a seismic destruction in the late fourth century AD, Guidoboni et al. (2000) present historical and archaeological evidence for a serious decline in the Sicilian cities of Messina and Calabria during the middle of the fourth century AD, consistent with a major earthquake event in the Straits of Messina during this time. Thus, the possibility that Sicily was affected by *both* a local seismic event and by the 21 July AD 365 seismic wave and tsunami should not be excluded.

3.2.6. Egypt

Ancient reports do not mention any seismic damage along the Egyptian coast, but this does not exclude any such possibility. Recent marine geophysical surveys in the Alexandria area by F. Goddio (personal communication), in need of authentification, suggest that collapsed columns with a preferred orientation, usually indicative of seismic oscillations (Stiros, 1996), probably indicate a fourth century AD seismic destruction. Recently identified submerged ruins in the same area occur at depths of several metres (F. Goddio, personal communication), about twice the maximum depth at which ancient ruins are found in all other Mediterranean coasts. This need not be related to seismic-induced subsidence or slumping, since sediment compaction is common in such deltaic environments, but future investigations will aim to discriminate these possible mechanisms.

3.3. Parameters and mechanism of the AD 365 earthquake

The above discussion argues that the famous tsunami of Egypt, the seismic destruction of Crete and the uplift of the western part of this island likely correspond to a single destructive event on 21 July AD 365 (Fig. 1). The geological evidence—the scale of magnitude of the uplift in western Crete (Table 1) and the localization of greatest (~9 m) uplift along the southwestern edge of the island—indicates that this earthquake probably occurred on a major subduction-related offshore thrust fault (Figs. 1 and 2). Such thrust faults accommodate the tectonic shortening between the Aegean Sea and the Mediterranean sea floor southwest of Crete (Taymaz et al., 1990). The tsunami may either have been produced by extensive sea-floor rupture or, perhaps more likely, by a great offshore slump triggered by the seismic shock.

Such geological results are broadly consistent with conclusions derived by previous investigators from mainly or entirely historical evidence (Jacques and Bousquet, 1984; Ambraseys et al., 1994; Guidoboni et al., 1994). Ambraseys et al. (1994), in particular, assumed that the AD 365 event was an intermediate-depth Hellenic Arc earthquake with a magnitude of perhaps over 8, an epicentre located between Crete and the Greek mainland, and with damaging effects limited to northwest Libya (Cyrenaica), the southwest mainland Greece and western Crete.

Experience from several strong (Ms 7.0–7.5) earthquakes along or near the Hellenic Arc in the last 100–150 years (Ambraseys et al., 1994) indicates that the associated seismic waves have a characteristic radiation pattern, preferentially propagating along the East Mediterranean coasts, but being quickly attenuated towards the Aegean Sea (Fig. 5) (Sieberg, 1932; Papazachos and Papazachou, 1997). Consequently, it is reasonable for the AD 365 earthquake, which probably was of much greater magnitude, to have been destructive in western Cyprus and Libya, and to have been strongly felt in the Middle East and Sicily. Indeed, in Sicily, the Adriatic and the Aegean Sea, the tsunami was allegedly more destructive than the seismic shock itself. In the Nile Delta, where the tsunami effects were greatest, the observed coastal effects were unlikely to be the result of tectonic subsidence, and instead were probably the consequence of tsunami-induced erosion and slumping.

The available data do not provide any support for the AD 365 earthquake being responsible for damage beyond Libya, for instance in Tunis or Algeria, as has been proposed by some authors (see discussion in Lepelley, 1984). This, however, does not indicate that the damage observed in these areas is not seismic in origin; it may simply be related to other local earthquakes. However, the seismic character of this damage remains to be demonstrated on the basis of meaningful criteria (e.g. Stiros, 1996).

4. Seismic clustering in the fourth to sixth centuries AD

4.1. Seismic clustering: documentary bias or a real phenomenon?

Bearing in mind the limitations in historical and archaeological data, it is possible to examine whether or not these data provide support for the unusual clustering of seismic activity inferred for the fourth to sixth centuries AD by palaeo-shoreline studies (Pirazzoli, 1986; Pirazzoli et al., 1996). The catalogue of Guidoboni et al. (1994) is the

Table 1
Catalogue of earthquakes compiled from historical data for the fourth to sixth centuries AD

Year	Town or region affected	Assumed causative fault system
304	Sidon(Sayda)-Tyros (Sur) (Lebanon)	Dead Sea Fault?
320	Alexandria (Egypt)	?
332	Salamis (Cyprus)	EAF? Cyprus Arc Fault?
334/335	Cos (Aegean Sea)	Bodrum fault?
341	Antioch (Antakya/Hatay Turkey) region	EAF? Cyprus Arc Fault? Dead Sea Fault?
341	Maximianoupolis (Viransehir) region (SE Turkey)	EAF?
342	Salamis (Cyprus)	EAF? Cyprus Arc Fault?
343	Neocesareia (Niksar, Turkey)	NAF
344	Rhodes (SE Aegean Sea)	Rhodes Trough? Turkey Fault?
345/346	Dyrrachium (Durres, Albania)	Ionian Front Fault system?
348/349	Beirut (Lebanon)	EAF? Cyprus Arc Fault?
	Hierapolis (Pamukkale, Turkey)	Buyuk-Menderes graben fault
358	Nicomedia (Izmit, Turkey)	NAF
362	Nicomedia (Izmit), Nicea (Iznik,Turkey)	NAF
363	Many towns in Palestine (Israel, Jordan)	Dead Sea Rift
365.07.26	Crete, Cyprus, Libya, Sicily	Aegean Arc, near Crete
368	Nicea (Iznik, NW Turkey)	NAF
	Germe (Kemalpasa, NW Turkey)	NAF
Before 380	Pisidia (Isparta area, Turkey)	Golhisar Fault?
Before 380	Paphlagonia (Kastamonu area, N Turkey	NAF
394–412	Constantinople (Istanbul, Turkey), 6 events	NAF?
417	Cibyra (Golhisar, Turkey)	Golhisar Fault
419	Palestine	Dead Sea Fault
447	Constantinople (Istanbul), Bithynia, Phrygia, Hellespont (Turkey)	NAF
454–457	Tripolis (Tarabulus, Lebanon)	EAF?
458	Antiocheia (Antakya, Hatay, Turkey)	EAF?
460	Cyzikus (Erdek, Turkey)	NAF
478	Sea of Marmara, Nicomedia (Izmit, Turkey)	NAF
474–478	Rhodes	Hellenic Arc?
475	Gabala (Jableh, Syria)	EAF-Cyprus Arc?
484	Kallipolis (Gelibolu), Tenedos Island, Marmara Sea (Turkey)	NAF
494	Hierapolis (Pamukkale, Turkey)	Buyuk-Menderes graben fault
499	Neocaesaria (Niksar, Turkey), Nicopolis (Islahiye, Turkey)	NAF
502	Sidon, Tyre, Ptolemais (Lebanon)	EAF-Cyprus Arc?
515	Rhodes	Hellenic Arc Fault
521	Dyrrachium	Ionian Sea Front Faults
521/522	Corinth	?
523	Anazerbus (Aysehoca, Turkey)	EAF
526	Antioch (Antakya, Hatay, Turkey)	EAF, Cyprus Arc?
528	Antioch (Antakya, Hatay, Turkey), Laodikeia (Latakia, Syria)	EAF, Cyprus Arc?
529	Amasia (Turkey)	NAF
530	Myra	Cyprus Arc?
532	Antioch (Antakya, Hatay, Turkey)	EAF, Cyprus Arc?
542	Constantinople (Istanbul, Turkey)	NAF?
543	Cyzicus (Erdek, NW Turkey)	NAF
551	Central Greece (several events)	?
	Lebanon coasts	EAF, Cyprus Arc?
554	Nicomedia (Izmit), Nicea (Iznik,Turkey)	NAF
554/558	Cos Island	?
557	Constantinople (Istanbul, Turkey)	NAF
570	Antioch (Antakya, Hatay, Turkey)	EAF, Cyprus Arc?
580	Antioch (Antakya, Hatay, Turkey)	EAF, Cyprus Arc?
584/585	Arabissus (Yarpuz, Cagilhan, Turkey)	EAF
587/588	Antioch (Antakya, Hatay, Turkey)	EAF, Cyprus Arc?

Modified after Guidoboni et al. (1994) and Ambraseys et al. (1994). For location of most sites, see Fig. 6.

most complete and homogeneous one for the Eastern Mediterranean, spanning the period 500 BC to AD 1000. From this catalogue, corrected to ignore multiple entries of the AD 365 event (also see Table 1), the frequency of all earthquakes, and of earthquakes with estimated intensity IX or higher, in the Eastern Mediterranean were determined (Fig. 4a, b). The resulting plots clearly show peaks during the critical period, as well as during the fifth century BC and

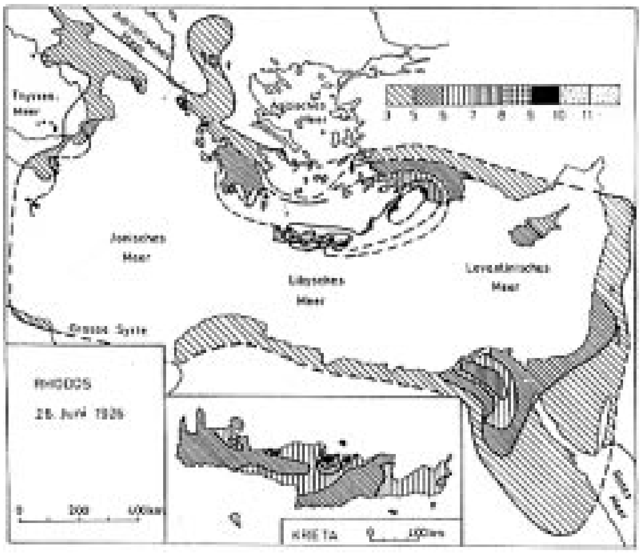


Fig. 5. Isoseismal contours of the 1926 Aegean Arc earthquake (after Sieberg (1932)). Intensities (inset scale) are possibly exaggerated, but the map clearly indicates a characteristic propogation of maximum seismic energy in this region away from the arc and not towards its interior (the Aegean Sea).

the first century AD; the most pronounced peak is during the sixth century AD.

As discussed above, historical data for the fourth to fifth centuries AD are imprecise, dubious and limited. However, since the sixth century AD (the Justinian era in which the Byzantine Empire was formed), the amount and quality of historical information increases, and this is also reflected by an increased frequency of reported earthquakes. Thus, the apparent peak in the frequency of seismic events during the fourth to fifth centuries AD cannot be explained as an artefact of the limitations of the historical information, since the paucity of historical records during this period should, on the contrary, produce an apparent decrease in reported seismicity. Historical records for the fifth century BC and for the first century AD are also more complete, as these periods are characterized by the most notable and reliable historians and geographers of antiquity. Thus, the increase in the amount and quality of historical information during these periods probably adequately accounts for the apparent increased frequency of reported earthquakes. In short, only the fourth to sixth centuries AD appear to have witnessed a real increase in the frequency of seismic events.

There is evidence that abnormally high seismicity levels during the fourth to sixth centuries AD in the historical records of Constantinople (Istanbul), capital of the Eastern Roman/Byzantine Empire, and Antioch, the empire's important cultural and economic centre in the East. The number of earthquakes felt in Constantinople, whose history is far better known than any other provincial centre, during the fifth to sixth centuries AD is much higher than in the period AD 600–1000 (Fig. 4c), and double the average during the remaining period between AD 0 and 1800. Conversely, these centuries of heightened seismicity appear to be followed by a 200-year-long period of seismic quiescence, which from the historical catalogue lasted from AD 557 to 740, with the exception of a felt shock in AD 611 (Ambraseys, written communication). Such fluctuations in the seismicity rates in this city are real and not an artefact of the quality and amount of available data (Ambraseys, 1971; Ambraseys and Finkel, 1991). A peak in the seismicity of Antioch during the sixth century AD is also apparent (Fig. 4d). The fact that scholars of the fourth to sixth centuries AD made special comment on the notable frequency and strength of earthquakes during this period (albeit explaining this as either a reaction of Nature to the death of the ancient religion and the birth of Christianity; Appendix A) suggests that the level of seismic activity was recognized as being exceptional even by contemporary observers. In summary, therefore, it seems that the available historical data are broadly consistent with the geological hypothesis of a tectonic paroxysm during the fourth to sixth centuries AD.

4.2. Stress triggering on a plate boundary scale?

Pirazzoli et al. (1996) argued that the enhanced seismicity experienced in the Eastern Mediterranean during the fourth to sixth centuries AD reflected an unusually active period of plate interaction in which the western and southern boundaries of the Anatolian–Aegean plate were reactivated (Fig. 1). Their evidence, raised marine shorelines, was necessarily geographically limited to the coastal portions of these plate margins, but they speculated that this seismic clustering may also extend to the linked strike-slip boundaries of the North Anatolian Fault (NAF) and the Dead Sea Rift. Historical and archaeological evidence provide an opportunity to test their speculation that, during the EBTP, all the main plate boundaries were reactivated. Below, the key historical and archaeological data on earthquakes in the region during this period are summarized (see Table 1 and Fig. 6), derived largely from the catalogue of Guidoboni et al. (1994).

4.2.1. Dead Sea Rift

The seismic history of the Dead Sea Rift is disappointingly obscure during the critical period, and only a few earthquakes can be related with some confidence to this plate boundary. One is the AD 363 earthquake, which was a very large event, probably above $M = 7.5$, because it caused major destruction in a 150- to 200-km-long zone along the rift (Russell, 1980). There are also historical accounts for an earthquake in Palestine at AD 419. Several other major earthquakes which destroyed Antioch and coastal towns in the Lebanon during the critical period may be associated with strands of the Dead Sea Rift. However, as discussed in the following section, these events are more likely to have been associated with the East Anatolian Fault and its offshore linkage with the Cyprus Arc.

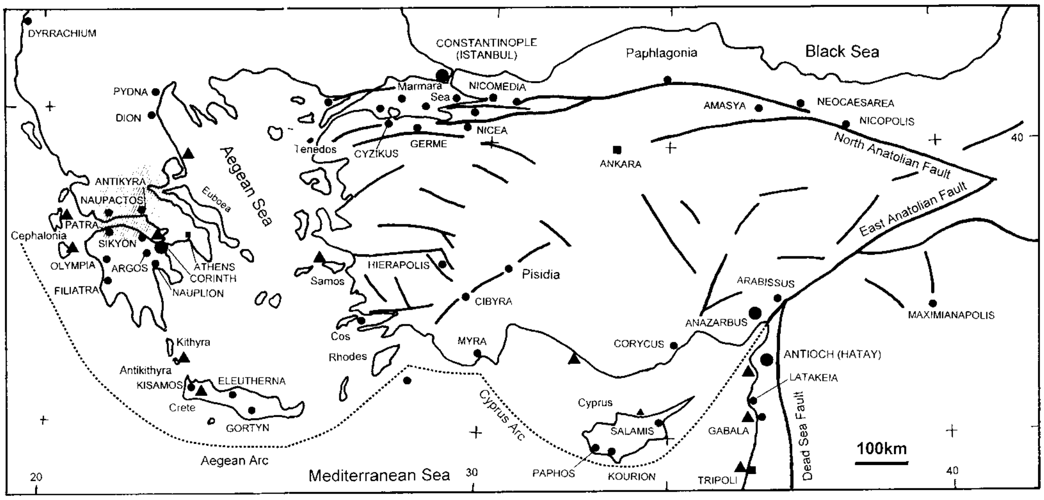


Fig. 6. Epicentres (circles) of earthquakes (after Ambraseys and Finkel, 1991) or reported seismic destructions of ancient towns during the seismic paroxysm of the fourth to sixth centuries AD, based on historical and archaeological evidence; large circles indicate multiple events. Main active faults in the Turkish sector are from Saroglu et al. (1992); solid lines denote known faults, whereas dotted lines indicate inferred faults. Triangles indicate coastal uplifts (after Pirazzoli et al., 1996; Stiros et al., 2000).

4.2.2. East Anatolian Fault and Cyprus Arc

The East Anatolian Fault (EAF) is likely to have been responsible for the AD 341/338–340 earthquake and the cluster of large earthquakes which destroyed many towns in southeastern Turkey and along the Cyprus Arc. Among them, however, only Maximianapolis (Viransehir, Turkey), located close to the EAF, is specified. Maximianapolis was the only notable town in this economically and politically unimportant region and, according to Malalas (cited in Guidoboni et al., 1994, p. 249), just before its destruction it had been reconstructed and renamed Constantina in honour of Emperor Constantin. More convincing evidence for reactivation of the EAF comes from the destruction of the town of Anazarbus (Aysehoca) in southern Turkey in AD 523. This was reported to be the fourth earthquake affecting this town, indicative of strong but undocumented seismic activity in the area during the critical period. Another earthquake struck this region in AD 584/585, known mainly because it destroyed Arabissus (near Jarpuz and Caglayan), the birthplace of the Emperor Mauricius, who provided funds for its reconstruction.

A number of earthquakes may be linked with reactivation of the Cyprus Arc and the probable offshore continuation of the EAF, especially those that were accompanied by tsunamis (Ambraseys, 1962). An earthquake in AD 332 destroyed Salamis in eastern Cyprus; the AD 303/304 and 502 earthquakes destroyed the coastal towns of Sidon (presently Saida) and Tyros (presently Sour) in southern Lebanon, the AD 348/349 earthquake destroyed Beirut, and the AD 551 earthquake destroyed probably the whole of the Lebanon and affected the wider area. The damaging AD 530 earthquake at Myra may be related to the western part of the Cyprus Arc Fault system.

The earthquake record of Antiocheia (Antioch; Antakya or Hatay in Turkey) is especially rich because of the cultural importance of this town and clearly indicates a seismic clustering in the sixth century AD (Fig. 4d). Major or total destruction of this urban centre, and of the wider region, are reported for AD 341, 458, 526 [described by Malalas as its fifth (seismic?) calamity], 528, 532, 570, 580 and 587/588. A destruction of the town of Gavala (Jableh) in the coast of Syria is also reported for AD 475.

4.2.3. North Anatolian Fault

Historical reports and seismic catalogues provide sufficient data to conclude that numerous destructive earthquakes occurred along the North Anatolian Fault (NAF) during the fourth to sixth centuries AD, mainly because of their effects in Constantinople. The summary here is abridged from Ambraseys and Finkel (1991).

Seismic activity appears to have started in AD 343 with the Neocaesareia (Niksar) earthquake, at the eastern part of the NAF. The AD 358 Bithynia earthquake, which devastated Nicomedia (Izmit), was followed by the AD 362 earthquake, further west, which destroyed both Nicomedia and Nicea (Iznik). Nicea was again ruined by the AD 368 earthquake, while a month later seismic activity (a possible aftershock, according to Ambraseys and Finkel, 1991) migrated westward to destroy Germe at Helespont (close to Kemalpasa).

Between AD 394 and 412, six earthquakes for which no details are available struck Constantinople (in AD 394, 396, 402, 403, 407 and 412). In AD 447, a strong earthquake hit Bithynia (the ancient province around Nicomedia), Phrygia (the ancient province south of Nicea) and Hellespont (the Straits connecting the Aegean and the Marmara Sea). In AD 460, a strong earthquake hit Cyzicus (Erdek) further west, but the epicentre of the AD 478 earthquake was again close to Nicomedia, while in AD 484 another strong earthquake hit the Dardanelles and caused damage in the nearby Aegean island of Tenedos. In AD 499, an earthquake destroyed Neocaesaria (Niksar) and Nicopolis (Susehri), this time at the eastern end of the NAF. After an apparent brief quiescence, Constantinople was hit again by earthquakes. An AD 533 event was harmless, but one in AD 542 caused serious damage. The following year, a seismic shock destroyed half the city of Cyzicus (Erdek) and probably caused minor damage in Constantinople. In AD 554, a strong earthquake caused widespread collapse across much of Nicomedia and was also destructive in Constantinople, and the city suffered another serious seismic destruction in AD 557. After this, there was a period of seismic quiescence that lasted, almost uninterrupted, for two centuries.

Among the earthquakes that struck Constantinople, literary accounts of the affected areas of the AD 358, 362, 447, 460, 478, 484 and 554 events would suggest they were of magnitude higher than 7 (Ambraseys and Finkel, 1991).

The AD 358 and 362 earthquakes can be identified with the Vithynia and Phrygia (Mt Sangarious) earthquakes reported in vague terms in c. AD 380 by Gregorius of Nyssa (PG 45, 108), a well-informed and powerful bishop of Central Anatolia. Interestingly, Gregorius also reported a seismic destruction of Paphlagonia, an ancient province in the area of Kastamonu, west of Amasya, crossed by the NAF. Because this earthquake is reported together with other major events and in terms of a province, rather than an individual town, it may indicate a major seismic destruction in Paphlagonia. This is significant because it is the only report for an earthquake on this segment of the NAF (which also broke in AD 1943). If true, the collective data indicate that probably all segments of the NAF between 26.5°E and 37°E broke between AD 343 and 554, mostly in a westward progression.

4.2.4. Western Anatolia and eastern Aegean Sea

Certain earthquakes reported between AD 334 and 494 suggest reactivation of major faults in the Western Anatolian extensional province. The AD 334/335 and 554/558 Cos earthquakes are most likely to have occurred on the normal fault system controlling the adjacent Bodrum peninsula. The AD 344 Rhodes earthquake might correlate either with an offshore fault along the Aegean Arc or with the onshore Golhisar Fault that was probably responsible for the AD 417 Cibyra earthquake. Gregorius of Nyssa (cited in Guidoboni et al., 1994), who died in AD 394 and wrote around AD 380, mentioned a seismic destruction of Pisidia, the ancient province around Isparta. No other report of this earthquake exists, but as it is included in a list of strong earthquakes and again is ascribed to a province rather than a town, it is likely to correspond to a strong earthquake, possibly again on the Golhisar Fault. Waelkens et al. (2000) present archaeological evidence for a major seismic destruction affecting Sagalassos during the first half of the sixth century AD (probably AD 518), though the epicentre may have been 100 km to the south and the causative fault is not known.

The Hierapolis (Pamukkale) earthquakes in the middle of the fourth century AD and in AD 494 are probably related to seismicity associated with normal faults bordering the Buyuk–Menderes and Denizli graben systems. At Hierapolis, offset ancient buildings reported by Hancock and Altunel (1997) appear to record earthquake damage after the reconstruction of the city following the AD 60 earthquake, and testify to recent reactivation of the Hierapolis Fault bounding the Denizli basin (Hancock et al., 2000). Coin evidence dates a later seismic destruction of Hierapolis to AD 602–603 (Guidoboni et al., 1994, pp. 350–351).

4.2.5. Aegean Arc

It is somewhat surprising that, with the exception of the AD 365 earthquake (sequence?), only the AD 515 Rhodes earthquake appears to have been a major destructive event during the critical period according to the available historical data. The earthquake was possibly associated with the fault system controlling the major trough southeast of Rhodes, a structure that regularly produces earthquakes with $M > 7.5$, the last one of which occurred in AD 1926 (Papazachos and Papazachou, 1997). The aforementioned AD 344 Rhodes earthquake may also originate from this area.

4.2.6. Central Greece

Precise historical evidence of earthquakes in Central Greece in the fourth to sixth centuries AD is limited to two events: a Corinth earthquake at AD 521/522, and the description of seismic destruction in both the Gulf of Corinth and the Gulf of Euboea in AD 551 (Papazachos and Papazachou, 1997).

As discussed earlier, inscriptions testifying to earthquake (and tsunami?) damage in the Gulf of Corinth and the adjacent towns of Argos and Nauplion during the last decades of the fourth century are probably not directly related to the 21 July AD 365 earthquake, but instead reflect a later event. There is also skeletal evidence of at least two strong earthquakes at Corinth, shortly after AD 491/518 and 565/578, respectively (Appendix C). While the first earthquake may be identified with the AD 521/522 event known from literary accounts, the second earthquake definitely postdates the AD 551 event. The AD 551 event was described by Procopius (cited in Guidoboni et al., 1994, pp. 331–332), who records the destruction of numerous towns around the Gulf of Corinth, including Patras and Naupactos, and destruction due to a large tsunami further north in the Gulf of Euboea. The distance between the two gulfs (100 km) suggests that the AD 551 event may be the amalgamation of two separate destructive earthquakes closely spaced in time. Archaeological excavations show that, while nearly all palaeochristian basilicas (Early Christian, fourth to sixth century AD, churches), some of monumental dimensions, were destroyed in the sixth century AD

(Appendix C), only some of the collapsed basilicas (for instance, at Naupactos, Antikyra and Corinth) date to the AD 521/522 and 551 earthquakes. Together, the available evidence suggests that mainland Greece was likely to have been struck by numerous strong earthquakes in the sixth century AD.

4.2.7. Western Greece

Geological evidence of earthquakes in the Ionian Islands of western Greece comes from radiometric dating of raised shorelines in Cephalonia and Zante, which suggests seismic coastal uplifts in c. 350–710 and 200–500 AD, respectively (Pirazzoli et al., 1996). However, the western Greece mainland and the Ionian Islands represent a real 'terra incognita' for historical seismology during the critical period. Although this need not imply seismic quiescence, information is only available for the AD 346 earthquake which destroyed Dyrrachium (Durres, Albania) and whose effects were strongly felt in central Italy (Guidoboni et al., 1994).

The archaeoseismic record of the region is similarly poorly known, but it provides some evidence of several destructive earthquakes for which the historical sources are silent: for example, major seismic destruction at Patra, possibly during the critical period, as well as the collapse of the Temple of Zeus at Olympia and of a basilica at Philiatra at the end of the sixth century AD (Appendix C).

5. Conclusions

The available historical and archaeological information for the critical period of the fourth to sixth centuries AD suggests that (1) the 365 AD earthquake was probably an exceptional event in the seismic history of the area, and (2) that levels of seismic activity across the region were abnormally high at this time and in the two centuries that followed. This is most evident for those areas in which the historical record is most complete (Constantinople and Antioch), where the frequency of destructive earthquakes during this period is demonstrably greater than in preceding or suceeding times. Furthermore, although the historical and archaeological data are patchy, it does appear that major earthquakes affected all the main plate boundaries (Dead Sea Rift, EAF, Cyprus Arc, NAF, Aegean Arc, western Greece) during the fourth to sixth centuries AD. However, the data are not sufficient to verify that *all* the principal segments of the various plate boundaries experienced reactivation. Nevertheless, large ($M > 7.3$) earthquakes are expected every few hundred years in these plate-boundary zones (Jackson and McKenzie, 1988), so the reactivation within a few hundred years of portions of all the plate boundaries in the region is perhaps unexpected. During this century, for example, the NAF has been very active (Barka, 1992), but the EAF, the Cyprus Arc and the Dead Sea Fault have been quiescent (Ambraseys, 1971; Jackson and McKenzie, 1988). Ambraseys and Finkel (1991) have drawn attention to distinct phases of the clustering of seismicity in the Marmara Sea region during the last 1000 years. Thus, short bursts of seismotectonic activity are known to be characteristic of individual plate-boundary zones in the region, but perhaps on a regional scale they are also characteristic of the long-term behaviour of the Eastern Mediterranean as a whole.

An important but still unresolved question emerging from this review is whether the AD 365 Crete earthquake, and the earthquake 'storm' during the two centuries that succeeded it, was a unique seismotectonic episode in the history of the Eastern Mediterranean region? If the answer is yes, then what were the peculiar geodynamic conditions that led to this enigmatic activity? For example, are we seeing the expression of short-lived changes in plate motions, comparable to the scenario invoked a decade or so by Mercier et al. (1979) to explain alternating phases of extension and compression in the Aegean domain? In this respect, an acceleration of the northward velocity of Arabia (consistent with regional deformation models; Le Pichon et al., 1994) during or shortly before the critical period might conceivably explain the inferred clustering of seismotectonic activity in the Eastern Mediterranean. However, it is noteworthy that Nur (1998) envisages a comparable regional sequence of destructive earthquakes coinciding with the demise of the Late Bronze age civilizations (c. 1500–1200 BC). Intriguingly, raised marine shorelines that are dated to Late Bronze age times have also been identified along the coasts of southeastern Turkey, Syria and Lebanon (Pirazzoli et al., 1996, table 3), and elevated shorelines are common along other parts of the Eastern Mediterranean coastline though their ages remain unknown.

Resolving the question is important in the context of the current debate concerning the role of seismic triggering of earthquakes, as exemplified by the western progression of seismicity on the NAF during the latter part of this century. The contentious suggestion that such dynamic coupling may extend between plate boundaries is postulated by Vita-Finzi (2001) and would certainly find support in the available historical and archaeological data for the fourth to sixth centuries AD in the Eastern Mediterranean. In raising these issues, however, this review aims to show how historical and archaeological evidence can usefully contribute to the debate. Although improved archaeological and historical evidence may serve to shed more light on it, it is likely that independent testing and refining of the hypothesis of the EBTP will rely on high-resolution palaeo-seismological studies of onshore portions of the main plate-boundary faults in the Eastern Mediterranean.

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In 1989, at the IGCP-206 Project final meeting in Mammoth Lakes, California, Paul first encouraged me to publish the first results of my archaeoseismic research in a

Special Issue of the Journal of Structural Geology. With his customary foresight, he assured me that the structural geology community would soon find an interest in 'Archaeoseismology'. I missed that opportunity (much to Paul's, and my own, disappointment), but there would be no excuse for not presenting my contribution in his memorial issue. I am indebted to P. Themelis for excavation data from Eleutherna and Fig. 4, to S. Markoulaki for providing excavation data from Kisamos, to E. Tsourti for numismatic data, and to A. Di Vita and M.A. Rico for information on the fourth century AD destruction of Gortyn. Some of the bibliographic research is due to Sophia Papageorgiou. Careful reviewing by N. Ambraseys and an anonymous referee is acknowledged. This article benefitted from detailed reviewing by I. Stewart, which is greatly appreciated.

Appendix A. Summary of fourth and fifth century AD reports of the AD 365 earthquake

References to the specific sections of the work of ancient authors are in italics and follow the usual abbreviation style of historians. PG and PL in particular refer to the basic J.P. Migne, 1857 (Paris) Edition of the ancient Greek (Patrologiae Graecae) and Latin (Patrologiae Latinae) texts, reprinted by various editors (e.g., Brepols, Turnhot, Belgium, 1992). Inscriptions marked by IG and IC refer to the Corpus of ancient Greek and Latin Inscriptions.

Ammianus Marcelinus *(26.10.15-19)*, who lived between c. AD 330 and 400, and is considered the last important (and reliable) historian of the ancient world, mentions a universal earthquake precisely dated on 21 July 365. This earthquake was followed by a clearly described tsunami which destroyed Alexandria and possibly many other coastal towns. The dating of these events is confirmed by other fourth accurate century AD texts (for example, *Consularia Constantinopolitana (240)*, a fourth century anonymous catalogue of Kings of the last days of the Roman Empire). Ammianus also vaguely reports that many years later he saw a ship left in the land by the tsunami at Mothone; this site is usually identified with Methone in SW Peloponnese, but the possibility of two other towns called Mothone in central Greece (in the Pagasitic Gulf, Aegean Sea) or in Macedonia (Northern Greece) cannot be excluded (Jensen, 1985).

Jerome (Saint, Hieronymous), who lived between AD 347 and 420, in different books mentions a 'universal' earthquake followed by a tsunami which caused much destruction in Sicily (also see Libanius below) and other islands *(Chron., 244c; PL 27, 693-694)*. He erroneously associates the tsunami with an earthquake at a town close to the Dead Sea Rift *(Comm. Is. PL 24, 15, 168)*, no doubt mixing effects of the AD 363 and 365 earthquakes (see Russell, 1980). He associates the universal earthquake after Emperor Julian's death in AD 363 (or his successor Emperor Jovian's death in AD 364; see Jensen, 1985) with a huge tsunami at Epidaurus, modern Cavtat in the Dalmatia coasts; a miracle of St Hilarion *(V. Hil. 29.1)*, however, stopped the waves before they hit the town. This last information is either figurative, or may indicate that the Epidaurus was unaffected by the propagating tsunami waves, possibly due to its geographical position. After this event, St Hilarion went to Cyprus (where he died in AD 371) and shortly after his arrival there he was visited by residents of various Cypriot cities, including Kourion *(PL 23, 52)*. Since no mention is made of the ruinous situation of this town, it may be assumed that the destruction of this town, deduced from archaeological data (see Appendix B), is not related to the AD 365 earthquake (cf. Jensen, 1985). However, the seismic destruction of a town in antiquity does not mean a total physical destruction of the corresponding community. Historical testament to this comes from the dramatic description of Ammianus Marcellinus *(17.7.1-8)* of the effects of the AD 358 earthquake Nicomedia. Four years later, the same town (modern Izmit, hit by the 1999 NAF earthquake) still existed and was reported to have been hit by another earthquake (see Guidoboni et al., 1994). In another passage *(V. Hil. 30.2)* it is stated that Paphos, the city in Cyprus which had frequently been destroyed by earthquakes, was lying in ruins possibly at c. AD 370.

Zosimus *(5.6.2)*, a fifth century AD pagan writer, reports very strong shocks in Crete and less strong in the Peloponnese and the whole of Greece, with the exception of the Athens area. However, the dating of the events may range between AD 363 and 375.

Athanasios of Alexandria, a fourth century AD church leader in Egypt and Libya, reports in one of his letters (which survives in later editions) that the first year of kingdom of Valens and Valentinian (i.e. in AD 365) more than 100 towns were destroyed in Crete by an earthquake of unprecedented magnitude, followed by a tsunami observed in many coasts *(Life of Athanasius, PG 25, ccx)*. The precise date of the earthquake is given in a Syriac translation of his work.

Sozomenus *(Hist. Eccl. 6.2; Migne, PG 67, 1297 A)*, a fifth century historian, states that God was displeased with Emperor Julian (who was trying to restore the pagan religion) and sent great calamities, earthquakes and the famous calamity of Alexandria; the anniversary of the disaster in this city was celebrated each year, information confirmed by independent historical sources—a Coptic text of the late sixth century AD referring to the 'day of horror'. Sozomenus' reference to this event as '*the* famous' indicates that he refers to the AD 365 earthquake which occurred two years after Julian's death; the apparent error in the year of the earthquake by Sozomenus is only due to his effort to explain such a calamity as the wrath of God. Sozomenus *(6,32; PG 67, 1392 A)* also reports that, before AD 368, Constantia replaced Paphos as metropolis of Cyprus (Jensen, 1985), information consistent with the destruction of the Paphos–Kourion area shortly after AD 364/365 (see Appendix B).

Libanius *(Or. 18.292)*, who lived between AD 314 and

393, disappointed by the death of Emperor Julian in AD 363, stated in his epitaph that "the Earth was aware of the event [the loss of Julian] and honored him with earthquakes … many towns in the Palestine, all in Libya, the largest in Sicily, all but one in Greece lye in ruins. Nicea is destroyed and the most beautiful of towns [probably referring to Nicomedia] has been shaken by the earthquake and has no future". This is the best description of specific regions affected by earthquake(s), but it mainly represents a rhetorical piece of work lacking historical completeness and accuracy, since at least some of the earthquakes reported by Libanius either predate or postdate the death of Julian. In particular, Libanius appears to mix the AD 365 earthquake with the AD 358, 362 and 368 earthquakes which destroyed towns along the NAF, and the AD 363 earthquake which destroyed towns along the Dead Sea Rift. In another passage, Libanius *(Or. 2.52)* states that "we are not Cypriots and we have not seen our town laying down in ruins", probably referring to the earthquake which destroyed Paphos and Kourion (see entry on Sozomenus above, and Appendix B).

The text of Libanius, written in Greek but specifying Sicily, helps remove an ambiguity concerning Sicily in Jerome's text, for "*Siciliae*" in Jerome's text written in Latin could in fact reflect a corruption of the term "*Ciliciae*", indicating the continental region of southern Turkey north of Cyprus (Russell, 1980). However, some historians (e.g. Guidoboni et al., 1994) date the destruction of Sicily, Central Greece and of Libyato between AD 361 and 363, i.e. during the reign of Julian. This interpretation appears to conflict with the ancient accounts of the Earth having produced earthquakes because of its sorrow for the loss of Julian in June AD 363, i.e. after his death. Furthermore, it assumes that Libanius completed his text in the first months of AD 365 (i.e. shortly before July AD 365), because the last event mentioned in it is a Germanic raid on the Rhine which took place in January of this last year (Guidoboni et al., 1994, p. 260). However, it seems likely that it would have taken at least several months for news of the military incursion on the Rhine to reach Libanius in Antioch, a main administrative and cultural centre in the region. The alternative view, expressed by Di Vita (1990) and previous editors of the works of Libanius, dates the Sicily and Libya earthquake to after Julian's death and to AD 365 in particular.

Gregory of Nyssa *(PG 45.108)*, a fourth century AD bishop of Cappadokia (SE of Ankara), the religious capital of the Eastern Empire at this period, and hence a very well informed cleric, refers to earthquakes in various provinces of Anatolia, Mt Sangarius (probably referring to the area around Sangarius River, close to Nicomedia), Vithynia (the province of Nicomedia), Paphlagonia (the province around Kastamonu, west of Amasya), Pisidia (the province around Isparta), and also in Cyprus and Greece.

Socrates Scholasticus *(Hist. Eccles. 4,3; Migne PG 67, 468)*, a fifth century AD writer, reported that "the sea changed its familiar boundaries; for in some places the quaking was so severe that places where previously people walked they could now sail. In other places the sea retreated so far that the bottom of the sea was found to be dry. And this happened in AD 365 ("in the first year of administration of the two rulers" Valens and Valentinian; Jensen, 1985). This is the only near-contemporary report for a permanent marine regression accompanying the earthquake. It is loosely confirmed by later sources, for instance the ninth century historian Georgius Monachus, who specifies that this phenomenon happened in the Adriatic and the Aegean (see Jacques and Bousquet, 1984).

Filostorgios *(Comm. Art. 35)*, a fifth century AD religious person, quoted by the ninth century AD Patriarch at Constantinople, reports that the request by the Emperor Julian for guidance from the famous Delphic oracle was not possible since the Apollo Temple had been destroyed. This information is usually interpreted as evidence of a strong earthquake in the northern part of the Gulf of Corinth in AD 361–363, but the evidence is poor and may only reflect a rhetorical argument.

John Cassian *(Comm., xi 3)*, bishop in Egypt between AD 419 and 426, who probably visited the area of the Nile Delta many years after the destructive tsunami, reports that after the earthquake "the land has been covered by the sea … what was formerly fertile land was covered by salt marshes … the hills were turned into islands by the flood, thus providing the desired solitude for holy men …".

Synesios of Cyrene, in two different letters *(Epistola 42 and 61)* mentions that a destructive earthquake, a locust raid and a war had destroyed Cyrenaica many years before AD 412 and destroyed the fortress of Hydrax (see Bacchielli, 1995; Di Vita, 1995). Prior to their discovery, Lepelley (1984) had argued that since no earthquake is mentioned in two fourth century reports for Northern Africa [by Optatus, Bishop of Milevi (Modern Mila in Algeria) and St Augustinus], no earthquake occurred, and that the destruction of numerous buildings should be assigned to the raids of nomads. This hypothesis was rejected in favour of a seismic destruction by Di Vita (1986) on the basis of archaeological and historical evidence from Sabratha (Tripoli area) in Libya.

Appendix B. Archaeological evidence for a destruction at c. AD 365 in the Eastern Mediterranean

Kisamos, west Crete. Since AD 1965, more than 50 excavations permit an excellent knowledge of the archaeological stratigraphy and of history of the ancient prosperous town of Kisamos in west Crete. These data indicate that, between c. AD 300 and 650, Kisamos was destroyed by an earthquake (minimum intensity X +) which left many of its inhabitants buried under ruins. The latest coins recognized below the fallen roofs and walls of houses, even in the pockets of victims, were struck between AD 355 and 361;

hence, the destruction occurred shortly after this period but certainly before AD 400, when the town was at least partially reconstructed. There are no signs of small-scale reconstruction or repairs just after the destruction and before its final recovery, thereby excluding the possibility that this town had been repeatedly affected by a swarm of damaging earthquakes in the fourth century AD (Stiros and Papageorgiou, 2000).

Eleutherna, central-west Crete. Small-scale excavations indicate a seismic disaster similar to that at Kisamos, with tools and precious objects and human skeletons (Fig. A1) being found under debris of fallen houses. Coins of Emperor Constant II, struck between AD 351 and 361, again provide a lower bound for the dating of the causative earthquake (Themelis, 1988, and unpublished data).

Gortyn (central Crete). The building history of the *Preatorium* (Governor's palace) provides evidence of an earthquake a few years to decades before AD 383. Below the remains of a sixth century AD Praetorium, an older Praetorium was built in AD 383, which an inscription suggests *(I.C. IV, 284, a-b; 285)* was partly on ruins of a bath complex (which in its turn was built on the ruins of a first century Gymnasium) using material from the ruined baths. This clearly indicates that the baths were in a ruinous situation before AD 383. A wall of the southwest entrance of the baths was found toppled down, possibly indicative of a destructive earthquake (see Guidoboni et al., 1994). Given that Gortyn was a major provincial capital, the lag time between the seismic collapse and the inauguration of the new building in AD 383 was probably not longer than 10–20 years, so this earthquake could easily correlate with the AD 365 event.

The only historical corroboration for this earthquake comes from Malalas, a later, sixth century AD writer, who reported that "during his [the Emperor Theodosius] reign … Crete suffered from a calamity … the surrounding area suffered too … and the public baths of Gortyn built by Julius Caesar collapsed" *(Malalas, 359)*. This report is ambiguous, for two Emperors with the same name are known, Theodosius I (AD 379–395) and Theodosius II (AD 408–450), and it is not clear which one is referred to. Furthermore, the archaeological excavations revealed that the baths in question had lain in ruins long before the critical period. Finally, historians argue that Malalas is probably not a very reliable source and may have confused various second hand information (see Di Vita, 1986, 1995; Guidoboni et al., 1994).

Kenchreai, Corinth, Greece. A major part of the harbour complex of Kenchreai is under the water, and about 80 cm of this subsidence occurred at the end of the fourth century AD (Scranton et al., 1978). This subsidence was abrupt, for buildings which were in the process of renovation were found to have collapsed and sunk below sea level. Underwater excavations brought to light precious decoration glass panels and other material abandoned inside the buildings at the time of the earthquake (Ibrahim et al., 1976). A coin found in this excavation was struck between AD 364 and 378 (Ibrahim et al., 1976), providing a lower age limit for this seismic subsidence. The excavators dated the event to AD 375, biased by a report by Zosimus (see Appendix A), who erroneously associated the effects of the AD 365 earthquake to a later Emperor *(Zosimos, IV, 18, 2)*. Rothaus (1996) proposed an even later date, c. AD 400, on the basis of unpublished ceramic material.

Corinth, Greece. There is evidence of two phases of destruction in various buildings of Corinth, which can be assigned to earthquakes, dated to c. AD 365 and 400, but this dating is rather imprecise. Two inscriptions, dated between AD 364 and 375, mention repairs to buildings destroyed due to ageing and earthquakes (see Rothaus, 1996).

Nauplion, NE Peloponnese, Greece. An inscription found at Nauplion *(IG 4.674)* acknowledges reconstruction of the cathedral and of other buildings of Nauplion in order to offer protection against earthquakes and marine invasions. These public works were funded by emperors Valentinian and Valens (AD 375–378). This inscription may indicate a tsunami and an earthquake some or many years before AD 375–378, but it may simply indicate coastal erosion in the harbour of this town.

Argos, Greece. Archaeological studies reveal that the town of Argos, near Nauplion, underwent great destruction at the end of the fourth century AD (Rothaus, 1996).

Leptis Magna, Tripolitis, Libya. A coin struck between AD 364 and 367 provides a lower bound for the dating of a seismic destruction, the evidence for which can be observed in the remains of this town (Di Vita, 1995).

Sabratha, Tripolitis, Libya. Destruction of fourth century AD buildings was assigned to an earthquake shortly after AD 364–367, as evident from the discovery of a coin struck during this period (Di Vita, 1995). An inscription testifies to an AD 378 repair of the baths which were in ruins (see Lepelley, 1984).

El Beida (Balagrae), Cyrenaica, Libya. Extensive damage assigned to an earthquake which occurred shortly after AD 364, inferred from dating of a coin hoard, was found in a modest house built on the ruins of the Sanctuary Theatre of Asclepius. Another small house built after this earthquake was destroyed by another earthquake, as the skeleton of a person killed by fallen debris suggests (Bacchielli, 1995). Cyrenaica was therefore affected by at least two major seismic events, one shortly after AD 364 and another one at a later period. At least one of them occurred several decades before AD 412, as reported in literary accounts (see Synesios, Appendix A).

Cyrene, Cyrenaica, Libya. Extensive damage in the Agora of Cyrene can be assigned to a devastating earthquake. The evidence comprises blocks fallen after an 180° rotation, columns standing erect, though rotated around their axis, whole walls and vaults fallen as by a sudden push, and also includes several skeletons of earthquake victims. A hoard of coins, the lattermost of which were struck between AD 350 and 361, somewhat similar to those found at Balagrae, provides a lower bound for the dating of this earthquake (Bacchielli, 1995).

Ptolemais, Cyrenaica, Libya. Excavations in the Palace of Columns provided evidence of a destructive earthquake, including skeletons of people with bones crushed under rubble in the pool of the Great Peristyle. The building was repaired during the Valentian and Valens reigns (AD 364–378). Year AD 378 therefore represents an upper age limit for the earthquake (Pesce, 1950; Bacchielli, 1995).

Kourion, Paphos area, Cyprus. A whole Roman town destroyed by a destructive earthquake has been brought to light during archaeological excavations. The theatre collapsed, a temple was overthrown with courses of blocks fallen in a specific direction and with a remarkable order; skeletons of people and of horses, still tethered in feeding troughs, have been found buried by destruction debris (Sorren, 1985, 1988; Sorren and Lane, 1981; Sorren and Davis, 1985). Coins date the earthquake to between late AD 364 and September AD 365 (Sorren and Davis, 1985; Sorren, 1985). Indirect evidence (Appendix A) indicates that the post-earthquake relocation of the capital to the southeastern end of the island occurred before AD 368, and the town of Paphos is reported to have been in ruins c. AD 370.

Sicily. There is some evidence for late fourth century AD destruction in several ancient buildings excavated in Lilibeo, Gela, Palermo and Agrigento, which have been correlated with the AD 365 earthquake (Di Vita, 1990). Guidoboni et al. (2000), however, argue that an earthquake in the Messina Straits (the straits between mainland Italy and Sicily) is possibly responsible for an apparent late fourth century AD decline of the towns in Sicily.

Appendix C. Archaeological evidence for seismic destruction in Greece during or around the sixth century

Corinth, central Greece. A hoard of 742 coins was found along the remains of the so-called Justinian Wall alongside the bones of a man covered by debris, apparently from the local collapse of the wall. The youngest of the coins was from the reign of Emperor Anastasios (AD 491–518) (Scranton, 1957). The causative earthquake may be identified with the AD 521/522 earthquake known from literary accounts.

Two skeletons were also found in a building west of the Lechaion Road, apparently killed by collapse of the building's walls. Coins on one of the victims were dated up until the reign of Justin II (AD 565–578) (Broneer, 1926; Scranton, 1957). This earthquake can certainly be dated after AD 565/578.

Remains of the so-called basilica at Skoutela testify to two episodes of destruction. A first destruction event caused the partial collapse of the building, which was abandoned and partly covered by a 10- to 15-cm-thick layer of silt. Several years later, the buildings collapsed. The excavator assigned these two phases of destruction to the AD 522 and 551 earthquakes known from literary sources (Pallas, 1957).

Lechaion, Corinth, central Greece. Remains of a monumental palaeochristian basilica, one of the largest of the period, was found at Lechaion, close to the uplifted ancient harbour. The basilica was constructed possibly at the end of the fifth century AD, but soon after was ruined and buried by debris of various periods. Coins of Justin II (AD 565–578) and of Constant II (AD 641–668) were found in a later construction above the destruction layer, constraining the collapse in the sixth century AD.

Sikyon, near Kiato, Corinth area, central Greece. Remains of a fourth to sixth century AD church (palaeochristian basilica) have been excavated at Sikyon. Bases of columns have been found incorporated as simple building material to remains of a slightly later church, built above the ruins of the older building (Orlandos, 1957). The destruction seems coeval with the destruction of basilicas at Corinth (Pallas, 1961).

Patra, western Greece. Archaeological excavations in the centre of the modern city have revealed fallen columns from the facade of a large, luxurious house that appears to have collapsed onto and blocked a main street in the Roman town of Patra. This street was subsequently abandoned, and during a later phase, new houses were built on top of the ruins (Stavropoulou-Gatsi, 1985). The style of collapse of columns and the subsequent change in the plan of the town, at least in this area, indicates a major destructive earthquake (cf. Stiros, 1996). Unfortunately, there is no information on the date of the collapse.

Naupactos, central-western Greece. Archaeological excavations in the centre of the town have revealed a monumental palaeochristian basilica which collapsed probably in the sixth century AD. A skeleton found below the ruins suggest that a destructive earthquake is the most obvious reason of its collapse. The causative earthquake may be that of AD 551, known from literary sources. The event was probably very strong, since it is assumed to be responsible for the destruction of all buildings of the period in Naupactos, as the lack of remains of this period reveal (Zias, 1973/74).

Antikyra, central Greece. Remains of a Palaeochristian basilica reveal that it collapsed soon after its construction in the middle of the sixth century AD, probably by an earthquake (Kourenta-Raptaki, 1980).

Olympia, SW Greece. The monumental temple of Zeus was totally destroyed by an earthquake, as the domino-style arrangement of the drums of its columns suggest (Stiros, 1996; Stiros and Jones, 1996). This destruction definitely took place after AD 174, i.e. after the visit by the ancient writer Pausanias, and probably after AD 395, when the last Olympic Games took place. It also must have occurred before the sixth century AD, for the temple was never transformed into a church, as was the case with all pagan temples of the period. The destruction has been assigned to the AD 522 or 551 earthquakes, although there is no evidence that they had affected this part of Greece. The earthquake which caused the destruction was also probably responsible for a landslide which blocked the flow of a nearby stream, which flooded the area and eroded a part of the antiquities. Soon after the event, the land surface above the ruins was reoccupied by some peasants, as two coins issued in AD 565 and 575 were found among their remains, and a fourth to sixth century AD church (palaeochristian basilica), also damaged by the earthquake, was restored. This village was, in its turn, swept away by the stream, and buried to a depth of 4 m beneath flood deposits (Gardiner, 1925), probably in the seventh century AD (Dinsmoor, 1985).

Filiatra, SW Greece. An excavation revealed that a fourth to sixth century AD church (palaeochristian basilica) was damaged and subsequently repaired. Inside the walls of the renovated building, a hoard of coins dated to between AD 582 and 602 was deposited, dating the damage of the basilica to before this period.

Pydna, Katerini, NW Aegean coast. A monumental basilica built in c. AD 450–500 was destroyed about 100 years later and was subsequently poorly repaired. A second, nearby basilica built in c. AD 525–550 was destroyed in c. AD 550 or soon after. A seismic destruction is inferred as the cause of destruction of both buildings (Marki, 1993).

Dion, Katerini, NW Aegean coast. Excavations reveal the destruction layer of a palaeochristian basilica in which two coins cut in Thessaloniki between AD 527 and 538 date the period of use of this church to the sixth century AD. The destruction seems, however, to have been contemporaneous with the destruction of other basilicas in both Dion and Pydna (Marki, 1993). Evidence for possible earthquake damage at Dion includes a collapsed building facade (D. Pantermalis, Guide to the archaeological site of Dion, leaflet).

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