ELSEVIER
Journal of Archaeological Science xx (2005) 1–9
Journal of Archaeological SCIENCE
http://www.elsevier.com/locate/jas

Earthquakes and archaeology

N.N. Ambraseys*

Department of Environmental and Civil Engineering, Imperial College, London SW7 2BU, United Kingdom

Received 21 June 2005; received in revised form 14 September 2005; accepted 16 November 2005

Abstract

This article examines the use of archaeological evidence for the assessment of historical earthquakes in the Eastern Mediterranean region and Middle East, long before the advent of modern seismology. We ask the questions when and where have large earthquakes happened in the past? How can this evidence contribute to our scientific understanding of earthquake activity? Is it possible on literary and archaeological grounds to distinguish between earthquake damage and damage from other causes? It is found that archaeological evidence for an earthquake is not always clear or unambiguous and that there is a need for collaboration between archaeologists, historians, geologists, engineering seismologists and workers in other disciplines, to evaluate the traces of earthquakes in excavations, both for understanding their effects at the site and for the information they can provide about the nature of the earthquake implicated.

Keywords: Earthquakes; Archaeology; Historical seismicity; Archaeoseismology; Eastern Mediterranean; Middle East

1. Introduction

As it is not possible to know what will happen in the future, in order to estimate likely earthquake hazards, it is necessary to find out what happened in the past and extrapolate from there. Previous research has uncovered evidence of destructive earthquakes in areas where only small shocks have been experienced recently. This is not surprising: the timescale of geology is vastly different from that of human history, so some areas will suffer a short period of relatively large earthquakes only once in one to two years. It follows that if by taking account only of information from the last century, during which period earthquakes have been recorded by instruments (though not uniformly throughout the globe), there is no way of knowing whether an apparently "quiet" area is in fact at risk from a damaging earthquake. The use of the historical and archaeological record is, therefore, invaluable, not only for the study of earthquakes per second, but also for the climate and weather. It may also guide the engineer to design structures resistant to the forces of nature, without being taken by surprise by unanticipated events. However, further back in time, the historical record gradually disappears and the archaeological record takes over.

The purpose of this article is to examine whether archaeological evidence can be used to address some fundamental questions: when and where have large earthquakes happened in the past? How can this evidence contribute to our scientific understanding of earthquake activity? Is it possible on literary and archaeological grounds to distinguish between earthquake damage and damage from other causes?

The Dead Sea Fault zone was chosen as a test area on account of its long recorded seismic history. This zone extends for about 900 km, from 28° S in the south, to 36° N in the north, passing through western Syria, Lebanon, Israel and Jordan. Discussion is limited to the problems that arise when Biblical and archaeological information is used at face value to assess earthquakes in the Holy Land. It has also been chosen because the uncritical combination of archaeological and literary information about earthquakes before our era has tempted authors to propose catastrophe theories. This has led them to

* Tel.: +44 208 788 4219.
E-mail address: n.ambraseys@imperial.ac.uk

0305-4403/$ - see front matter © 2005 Published by Elsevier Ltd.
doi:10.1016/j.jas.2005.11.006

produce earthquakes of hypothetical location and grossly exaggerated magnitude, which have consequences for the assessment of seismic hazard. It is certain that earthquakes have frequently destroyed or damaged early settlements and towns in this zone, but it is not clear on what basis excavators have assigned this cause to destruction.

2. Data

The kind of data, which is of use to the earth scientist to assess earthquake hazard, is that which can be accorded some numerical value and can be used to determine the epicentral area, in terms of its geographic coordinates, and the size of the event, in terms of its magnitude. This requires knowledge of the distribution of the intensity of an earthquake, that is the degree of the severity of damage or shaking, at as many sites as possible, including those at great distances from the epicentre where the shock was felt. Knowledge of the effects of the event on the ground itself is also needed and of its association with primary effects, such as faulting and secondary effects, such as landslides and seismic sea waves.

Two pieces of information, which are of interest to the earth scientist and engineer, which need to be assessed from written sources or from archaeological evidence, are the location (epicentral region) and size (magnitude) of an earthquake; that is: (a) where and how large was the area of maximum destruction, and (b) how far the shock was felt. Other information such as the human and material losses incurred, the social and economic impact and the consequences of the event are of interest more to the historian than to the earth scientist, although this kind of information can help to assess the size and magnitude of the event.

Archaeological evidence for an earthquake is not always clear or unambiguous. Displaced, leaning, damaged or collapsed walls found in an excavation or in extant ruins of historical monuments are often explained as being caused by an earthquake, quite often invoked as a deus ex machina (cf. [15]). They can, however, be due to other, non-seismic causes, such as differential settlement, leaching or weathering of the foundation materials over the ages. Occasional earthquakes may assist this process of structural deterioration, particularly when these structures have been rendered more vulnerable by acts of warfare or deliberate damage.

Random or coursed rubble masonry walls laid in clay mortar may deform excessively with time, even without the help of earthquakes, while badly-aligned or built polygonal and rectangular dry walls can fracture owing to very small differential settlements of their lower courses, giving the impression of structural failure as a result of lateral or vertical inertia loading in an earthquake.

Deliberate damage and military operations can also leave effects that may be misinterpreted. Furthermore, damage can be the result, perhaps cumulative, of more than one earthquake, even a long while after the abandonment of the site.

Much is often made of evidence from excavations and from the remains of historical monuments that the ground motion at a given site during an earthquake was principally in the opposite direction to that of the collapse of freestanding walls and colonnades. This evidence is used to determine the attitude of postulated nearby surface faulting during earthquakes. Structures, however, cannot fall easily in any direction other than that of their weaker axis. For colonnades, this is usually at about a right angle to the long axis of the cella; for houses, it is perpendicular to the axis of the course of the streets they face, regardless of whether there is a suspicion of seismic origin in their collapse or not. Prostrated colonnades have been found in excavations not only near, but also far away from active faults, in areas of both high and very low seismicity, such as, for instance, in Hermopolis Magna in Egypt [12].

This mode of collapse has little to do with 'the direction from which the shock came', a notion 140 years old [37] still used by some modern authors [26,27] to calculate the position of an epicentre, which has no scientific content. Also, the belief that the direction of fall is parallel with the direction of the near-field ground motion due to strike-slip surface faulting in an earthquake is not necessarily correct.

3. Assessment of data

In order to address the most fundamental goal of understanding the mode of collapse or the damage of man-made structures resulting from earthquakes, extant historical remains need to be examined closely.

3.1. Dating

In the case of a very few earthquakes in the period before our era, information comes from inscriptions which explicitly mention earthquake destruction or extensive repairs after an earthquake. In later periods epigraphic material often refers to remission of tribute or taxes following an earthquake. Since they are almost always contemporary, inscriptions provide valuable and indisputable evidence for the location and, quite often, the effects of earthquakes, which, either because of the remoteness of the site, or for other reasons, are not recorded in literary sources.

In contrast with historical information and inscriptions, which are often specific about sites affected and the year or date of the earthquake, archaeological information is rarely so straightforward and very difficult to authenticate. Great caution is needed, therefore, in using archaeological data to locate and in particular to date earthquakes. Dating earthquake damage is frequently based on, or influenced by, literary sources rather than any precise internal archaeological indicators.

Stratigraphy alone, without some hard evidence, is insufficient to establish a chronological association between earthquakes that might have been entirely unrelated. The point here is that the documentary record is very incomplete and numerous destructive earthquakes undoubtedly occurred of which no written description survives. Nevertheless, this often develops into a circular process, whereby the conclusions of archaeologists have been taken as factual evidence of earthquake activity and then used in turn by seismologists to confirm the dates of their events.

3.2. Building stock

Buildings and ordinary dwellings of historical times differ in many respects from modern ones, and to judge earthquake damage from ruins of centuries old man-made structures can be seriously misleading. In general dwellings were top-heavy brittle constructions, liable even during their lifetime to rapid deterioration. They were sensitive to cumulative irreparable damage caused by alterations, neglect, floods, acts of warfare, deliberate damage and, in seismic areas, by the cumulative damage from previous shocks.

Modern domestic houses made of stone masonry, kiln bricks or cement blocks will crack at sometime during their service life. The appearance of cracks is a symptom of distress within the fabric of the building. Some common causes of cracking and tilting under normal conditions are, foundation subsidence or settlement, incompatibility of building materials, chemical reaction of materials with water, changes in moisture content, structural instability and construction defects. A crack can be the first indication of a serious defect that may affect the stability of the structure later. The problem is that there are many possible causes of walls of all kinds cracking, without the help of earthquakes. There may be a single cause, or a combination of several causes, or even one primary cause with several contributing factors.

In archaeological sites open vertical cracks in walls and differential settlements in pavements can be due to non-seismic causes such as small incipient tilting of the structure as a result of weathering or leaching of its foundation materials, which can be brought about by climatic changes and fluctuations of the underground water table over the ages. This is particularly true when ancient walls and other man-made structures are built on thick layers of cultural debris.

On ‘tells’ ground deformations caused by undercutting of the sloping ground, wet periods and occasionally even distant earthquakes, may trigger incipient sliding on layers of debris. This may cause finite differential settlement of the more rigid but brittle structures on the layers above.

Ground cracks due to incipient land sliding can be recognized from the lateral movements of the ground at the two ends of the scarp caused by the slide, that show opposite sense of lateral displacements.

Leaning in stonewalls laid in clay mortar can be due to loss of clay cohesion, which occurs through degradation and excessive wetting and drying out over the ages, which turn the mortar into a metastable composite material. Under small static or dynamic loads, the collapse of the brittle clay matrix of the mortar would cause the upper courses of such walls to crumble or disintegrate.

Provided there is no evidence of differential settlement of the foundations of standing ashlar-style walls or of deterioration of their lowest courses, any dislodged building blocks and open spaces between them may be an indication of ground shaking which is, most probably, the cumulative effect of more than one earthquake.

Collapsed, bulging or outwardly leaning retaining walls are unlikely to be due to earthquake damage alone. Very often these types of structure fail, without the help of earthquakes, in flash floods, abnormal seasonal fluctuations of the ground water table and undermining.

3.3. Columns

Displaced, leaning or collapsed freestanding colonnades are features that invariably are associated with earthquakes. It has been noticed, however, that in epicentral regions well built, slender, freestanding structures, such as columns, can come through an earthquake unscathed.

In almost every destructive earthquake in the Eastern Mediterranean region and the Middle East during the 19th and 20th centuries, these simple structures, such as the columns of Greek and Roman monuments and much later slender buildings, such as bell-towers and minarets, survived earthquakes, which had caused spectacular destruction of the dwellings around them.

In contrast with other types of more robust structures, that appear to be more stable under earthquake conditions, freestanding columns on competent foundations are overall more resistant to near earthquakes than might be expected. Consequently their survival over the centuries is neither surprising, nor should it be interpreted as implying low seismicity in the area.

In spite of its simplicity and uniformity, however, the earthquake response of each column is a special case for study and cannot be generalized. Its response depends not only on its material properties and those of its foundations, such as rigidity and strength, but also on how the ground moves (time history) during an earthquake. This depends on the magnitude of the earthquake and its distance from the site. Small changes in foundation compliance due to yielding during shaking can produce a chaotic and unpredictable column response. This is particularly true for corner columns whose outer sides usually rest on good quality marble stylobates while the inner face rests on inferior material. This can bring about irreversible tilting during an earthquake. Near or distant earthquakes produce ground movements of different predominant periods and their effects on the response of a column are very different.

At the early stage of shaking from a near earthquake, a column will respond by bending. This will be followed by a phase of rocking, as a result of which one or more individual drums will tend to lift up by tilting minutely resulting in the drums rotating sub-horizontally about their point of rocking. However, this small horizontal ‘drifting’ of the drum will be almost immediately arrested by the reversal of the inertia forces. At the end of the earthquake, it is these small ‘frozen’ displacements between drums that give the impression that contiguous drums had been displaced due to shearing [33,45].

Field observations and numerical analyses confirm that other things being equal, in contrast to near shocks, large distant earthquakes can produce ground motions which, although less intense, are of much longer duration and period, with the result that columns are more vulnerable to this type of earthquake than from near shocks [4,5].

Many of the columns overturned by earthquakes and by high winds in relatively recent times had been weakened by the deliberate hewing of their base drums for lead dowels. In such cases, since it is easier to hew the base of a column from the steps of the crepidoma, in the event of an earthquake the column falls outward.

It is interesting that historical sources seldom attribute the collapse of columns specifically to earthquakes. Occasionally it is ascribed to deliberate demolition for use as building materials or for making lime. In more recent times, after the advent of gunpowder, the damage that led to their premature overturning has been the deliberate hewing of their drums for lead [1,4,5].

A typical example where the reason and mode of collapse are known is the case at Çavdarhisar, which was violently shaken by the destructive earthquake of 1970 at Gediz in Turkey. The freestanding columns and the architraves of the second century A.D. Roman temple of Zeus of Aizanoi were left intact, surrounded by the ruins of the village of Çavdarhisar. Only an isolated group of three columns collapsed, already weakened by the loss of almost a third of their lowest drums which were broken away long ago, but which had been standing for about 18 centuries. The collapse was due to the fact that about 20 years before the earthquake these three columns had had their base drums 'strengthened' with concrete pillows, which was responsible for their failure [10].

A similar case of the effects of modern intervention can be seen in the recent earthquake of 1999 in Istanbul, where the only part of the old city walls to collapse was a tower that had been completely reconstructed in new masonry only a few years earlier [28].

Much is often made of evidence from archaeological sites and excavations of walls and colonnades, which have fallen in the same or different direction. In an earthquake, freestanding columns and walls of houses cannot fall easily in any direction other than in that of their weaker axis, as mentioned above. If failure is triggered from a corner column due to yielding of its foundation collapse of groups of columns in other directions is possible.

3.4. Human remains

The presence of human skeletons under collapsed ruins is often thought to be an indication of earthquake destruction, although in most cases, such ruins do not contain either human remains or valuables. The reporting of such cases and, unfortunately, the identification of skeletons of victims is a rare occurrence and often left out of archaeological reports.

Skeletons of people killed and buried under the debris of fallen buildings imply that the collapse came suddenly, without warning, and caught them in their sleep or lying down. Field experience of destructive earthquakes in the 1960s and 1970s in remote parts of the Middle East, where village dwellings are still of adobe with heavy roofs, built close together and separated by narrow lanes, in many respects similar to those of earlier times, shows that the agile group of youths, warned by foreshocks, suffered more casualties in their attempts to seek refuge outdoors than the elderly who were caught indoors. Most of those who escaped into the narrow alleys were buried as walls and houses collapsed on them from both sides.

The bodies of people, whether killed in their houses or in alleys by the main shock, or in aftershocks, were almost always recovered by the survivors and given proper burial. A few of the bodies recovered belonged, in fact, to villagers who were killed by looters, as well as looters themselves who were shot down by gendarmes. This is reminiscent of the Jericho earthquake where the only dated skeleton on site is not an earthquake victim (see below).

3.5. Extant historical structures

It is usually considered rather improbable that early structures, liable to damage by earthquakes, could stand for many centuries in seismic regions. The mere fact that several early monuments are still to be found in a tolerable state of preservation across the region has led to the belief that these parts must have been free from destructive earthquakes.

Historical and architectural evidence shows that this is not the case. The early public buildings and monuments that are still standing have, in fact, during their lifetime, been subjected to a number of destructive earthquakes and they have survived with some damage through a process of natural selection. They are a very small fraction of the number of structures that existed in early times and they represent a sample of the best final designs and construction, achieved through the ages by trial-and-error techniques or by chance.

Furthermore, there are frequent references in early literature to extensive repairs of city walls and public buildings after earthquake damage, where the opportunity was taken to introduce changes in the construction, producing a more resistant structure. Thus, the fact that some early monuments are still standing is not always an indication that their sites have been free from earthquakes.

3.6. Catastrophism

For earthquakes before our era, historical and archaeological data have attracted interpretations influenced by the dogma of catastrophism, attributing to earthquakes the obliteration of the Eastern Mediterranean region in the Bronze Age, large movements of peoples, and the demise of flourishing city-states.

In the early part of the 19th century geology was under the influence of the dogma of catastrophism: the hypothesis that changes in the earth occurred as a result of isolated major catastrophes of relatively short duration, as opposed to the idea implicit in uniformitarianism, that small changes are taking place continuously. Catastrophism passed off the scene, now more or less completely discarded, and uniformitarianism took over. However, the last few decades have seen a gradual re-emergence of neo-catastrophism, this time in the field of archaeoseismology, particularly for earthquakes before our era in the Eastern Mediterranean, bringing back into prominence the ideas of Velikovski [50]. The reason for the revival of catastrophe hypotheses is perhaps that they are easy to explain. They are too simple, too obvious and too coincidental and chiefly because they have become fashionable in recent years [31].

4. Case histories

In what follows two earthquakes mentioned in the Bible are reappraised, which have been chosen for the pseudo-objectivity with which modern writers have interpreted their effects [7,51].

4.1. The Jericho earthquake

It is generally believed that an earthquake occurred during the siege of Jericho (Tell el-Sultan) by the Israelites in ca. 1400 B.C. This event caused the strong walls of Jericho to collapse, allowing Joshua to take possession of the place and burn it down.

The Bible, the only literary source for this earthquake, does not attribute the collapse of the walls of Jericho to an earthquake, but rather to the besieging Israelites who 'by shouting and blowing their horns caused the walls to come tumbling down' (Joshua vi, 20–21).

If the timeline of the Bible is followed then the invasion of the Israelites into Palestine is usually placed 440 years before the foundation of the temple in Jerusalem by Solomon in 960 B.C. Jericho, therefore, would have been destroyed about 1400 B.C., but not necessary by an earthquake. Alternatively, if the views of those scholars who attempt to reconcile the description of events with Egyptian history are accepted, a date of 1260 B.C. is inferred. Another option would be to follow those who reject the historicity of Joshua in favour of belief in peaceful conquest and accept a date far later than 1400 B.C. [30].

Turning to the question of what archaeology can contribute to this impasse, the earliest excavation at Jericho, at the beginning of the last century, concluded that the city was already abandoned during the invasion of the Israelites, and that it had been destroyed, probably by earthquake before 1400 B.C., [44]. A second series of excavations in the 1930s supported the Biblical account of an earthquake in ca. 1400 B.C. [16]. A third series of excavations at Jericho in the 1950s, however, found no archaeological evidence to corroborate the Biblical account of the fall of Jericho, dating the event back to a period well before 1400 B.C. [23]. The walls of Jericho were repaired or rebuilt no fewer than 16 times in its known history and of the layers identified by Kenyon not one, could be singled out as providing special hints for destruction by the hand of Joshua rather than another conqueror, or by earthquake.

In 1997 a limited excavation by Nigro and Marchetti on the fringes of Kenyon's trenches, which was shrouded in political intrigues, found no evidence for destruction from the time of Joshua [40]. Wood [52], however, who examined the results of the excavations by Kenyon, Nigro and Marchetti, claimed that they had found the same evidence in earlier excavations that fitted the Biblical story for the destruction of Jericho around 1400 B.C.

The conclusion is that the date or the period of the earthquake, if an earthquake in fact occurred at all, remains highly uncertain, and archaeology does not help much to establish the invasion period with any degree of certainty. In Jericho and in other sites in the region the evidence points more towards human, deliberate destruction.

From the examination of the available data, taking into consideration the doubts of Kenyon's dating raised by Wood, and those of Garstang's raised by Kenyon, it is prudent, until archaeologists come up with a better unbiased evaluation, to accept tentatively Kenyon's estimates. Until a better consensus is reached it is important to be aware that the time of the siege and destruction of Jericho by Joshua is very uncertain, bracketed within a rather broad chronological range.

It is natural for archaeologists to seek earthquake effects in strata belonging to the conventional period of the fall of Jericho ca. 1400 B.C., a period which, as we have seen, is far from being certain. It was to be expected, with Jericho located in the Dead Sea Fault zone, which is capable of producing destructive earthquakes, there is no lack of archaeological evidence to show that during the Bronze Age the site of Jericho was damaged a number of times, probably by more than one earthquake of unknown location and magnitude.

The problem here is that archaeological evidence for an earthquake is rarely unambiguous, and its dating is frequently based on, or influenced by, literary sources, which often, as in this case, provides examples of how their assumed accuracy, coupled with occasional inaccurate commentaries, may influence archaeologists' interpretations and dating. This then develops into a circular process in which the uncertain date of an earthquake is transformed into a fact and used to confirm the dates of the proposed destruction strata.

From Kenyon's estimates there are three layers in Jericho that show some good evidence of earthquake damage, namely during the periods of 8500–7000 B.C. (stratum: PPNB); 3400–3100 B.C. (stratum: EBA I); and 2300–1950 B.C. (stratum: EBA IIIB), none of which, however, can be associated with Joshua and the fall of Jericho.

Nor does archaeological evidence from ca. 1400 B.C. support the interpretation of a catastrophic earthquake. If the fall of Jericho had been due to an earthquake that was strong enough to flatten the massive walls of the city, it should have razed to the ground all the rickety dwellings within the city, the granaries and water supply, with great loss of life, for which there is no evidence. To the contrary, we know that part of the city wall on the north side of the site was left standing (Hebrews xi, 30–31). Joshua also says that the Israelites entering Jericho 'utterly destroyed all that was in the city, men and women alike'. Had there been a destructive earthquake that flattened the city walls, the Israelites would have found very few standing houses to destroy, or people alive to slaughter. It seems unlikely that the prophets or later chroniclers would have not mentioned a 'news-worthy' event such as a catastrophic earthquake.

It is natural to attribute the presence of skeletons buried under rubble to a sudden death caused by the collapse of building in an earthquake. However, in the case of Jericho this is not a safe assumption. If we exclude the normal burials around Jericho, which date to the Middle Bronze Age and Garstang's finds, which are not dated, the only dated skeleton on site was not an earthquake victim. It belongs to a woman found in a room by the city wall and provides evidence for violence against the people. The woman was tightly contracted suggesting that she had been bound in that position before being decapitated, the vertebrae of the neck having been severed [25: 217].

Regarding the earthquake in Jericho, some Bible readers have supposed that an earthquake toppled the walls of the city. However, the account of Israelite's conquering the city contains no reference to earthquakes. Moreover there is no conclusive evidence to associate the fall of Jericho with the earthquake damage preserved on the site of the old city, nor with the damming of the River Jordan at Al-Damieh, which may be the result of a series of earthquakes over a long period of time [24: 36].

Archaeological reports give little or no technical justification to support the conclusion that destruction was due to an earthquake, and if so due to the very same earthquake mentioned by Amos. Available stratigraphic data cannot rule out the possibility that the observed damage was the result of later earthquakes.

4.2. The earthquake in Judea

Another earthquake examined here is the earthquake in Judea. According to Josephus, the only coeval source that mentions the event, an earthquake in Judea at the beginning of the spring in the 7th year of Herod (31 B.C.) caused great destruction of cattle, killing 30,000 men by the fall of their houses, but the army, which lodged in the field, escaped unhurt (Joseph. BL: I, 369/LCL.i, 172–174; Joseph. AN: xv, 5/LCL.viii, 58–60).

The earthquake happened when war in Palestine was at its peak. Late in 32 B.C. the Nabateans were defeated by Herod at Diospolis (Lydda) and early the following year Herod suffered a reverse in fortune at Canathia (m. Kanawat in the Hawran). Then in the spring of 31 B.C. there followed the earthquake which damaged Judea, but as Josephus relates, the Nabateans, who were located east of the River Jordan, were not affected. When they heard of the news about the damage in Judea, they took the opportunity to invade the territory of Herod for the third time.

Before the battle when the demoralised troops interpreted the earthquake as an evil omen, Herod convinced them in a speech that such events have physical causes and that, beyond the immediate damage caused, they had no further consequences to mankind. This is one of the earliest statements about the physical nature of earthquakes. In the end the Nabateans were defeated by Herod near Philadelphia (Amman).

There are no other details that could help assess the location of the earthquake or the extent of the area, which was seriously affected, except that, as Josephus says, it was in Judea. The earthquake had no effect on the war and there is no mention of Jerusalem or of any other urban centre in Judea, Samaria, Galilee or Perea having been damaged. Also, there is no indication that the Roman historiographers took any notice of the earthquake.

It is difficult to reconstruct logical circumstances in which an earthquake is supposed to have killed 30,000 men, excluding women and children in Judea alone, would pass in history almost unnoticed, and the uncanny similarities to other Biblical tales reporting inflated 'numbers' cannot be missed.

More specifically, before the annexation of other districts to the province in 30 B.C., Judea, which we are told was the region most affected by the earthquake, had a small area of not more than 9000 km^2. It extended from Samaria in the north to Idumea in the south, a distance of about 80 km in a north–south direction west of the Dead Sea and the River Jordan. Its capital was Jerusalem, which had a population at the time of perhaps not more than 25,000.

Josephus relates that in Judea alone the earthquake killed 30,000 men, a number to which if we add the women and children killed besides men, makes the total loss of life much greater and also excessive, particularly when we consider that in spite of the state in which Jerusalem was after the siege, there is no word about damage or loss of life in the city.

It is also strange, that the earthquake seems to have had no effect on Herod's native army, which in the case of other destructive earthquakes in the Middle East, soldiers were allowed to leave camp and return to their lands to cope with the aftermath.

The fact that the event is not mentioned in Greek and Roman sources does not support the claim for such great loss of life. Surely, had there been such a great disaster in the province of Judea, Roman historians would not have failed to mention it, or report relief measures or reconstruction work that might have been undertaken by Augustus Caesar, who was well-known for his assistance in similar situations.

The problem seems to be that Josephus' figures, throughout his works, are often grossly inflated. For example, on another occasion, not associated with this earthquake, Josephus puts no fewer than 2,700,000 as the number of people in Jerusalem partaking in the Passover (Joseph. BL:vi, 9, 422–426; viz [6]).

To make things more difficult, modern authors amalgamate this earthquake with another earthquake in Palestine in the reign of Augustus (44 B.C.–A.D. 14) which is mentioned by two Byzantine historiographers, who were writing more than six centuries later. The former, Malalas, a sixth century writer, says that 'In the reign of Augustus Caesar, Salamini a city of Palestine suffered from the wrath of God and Augustus re-erected it and named it the city of Zeus' (i.e. Diospolis; Malalas, 229/I, 296 [34–36]).

The Slavonic version of this passage is slightly different; it says that 'In the reign of A. O. Caesar, a city of Palestine, Salamina by name fell by the wrath of God. August rebuilt the town and named it the city of Zeus' (Malalas Slv.41/229 [35]). Chudov's Codex no. 51/353 of the Slavonic version of Malalas gives Palamanie instead of Salamina, but other writers attest no place of this name in Palestine. It has been suggested that the reference should be to Salaminas in Syria or to Samaria in Palestine, which is not tenable [48: 179, n. 108]. Guidoboni equates Salamine (Lod) in Palestine with Diospolis, which is also not correct, and considers it likely that Lod was also affected by the same earthquake [19: 173–174]. Elsewhere Guidoboni dates the event to A.D. 31 [18].

There is also a garbled passage in Georgius Monachos, a mid-10th century Byzantine writer who, in passing, refers to an earthquake that happened in 'Salamis in Cyprus, in the district of Syria' [17]. With some imagination it could have been Salem, the Salim of John (iii, 23), now called Salamias, which is situated in the Jordan Valley, 10 km south of Scythopolis (Bet Shean). There is no doubt that these later writers confused Salamis with Paphos and the earthquake in Palestine (31 B.C.) with that in Cyprus (17–15 B.C.) referring to an event, which may well, be spurious.

Archaeological information that could point to some evidence of earthquake damage at some specific site, which is not mentioned in literary sources, remains to be examined. Modern writers maintain that the destructive effects of the 31 B.C. earthquake extended beyond Galilee, destroying the following seven sites: Jericho, Jerusalem, Masada, Qumran and Tell Hesban.

There is no historical evidence for earthquake damage in *Jericho*. Archaeological evidence suggests that a synagogue was destroyed sometime between 39 and 31 B.C. and not rebuilt, on the site of which Herod built a winter palace. Although its proximity to the Dead Sea Fault makes it reasonable to consider that this was due to earthquake, it is more probable that since it belonged to Antigonus it was destroyed well before 31 B.C., when the place was attacked by Herod and the Romans.

Some years ago, Reches and Hoexter identified on the western border-fault of the Dead Sea Fault zone, a relatively recent fault scarp showing a 3.5 m throw near Hisham's Palace at Jericho and at Deir Hajla, which is midway between Jericho and the Dead Sea [11,41,43]. They thought it might have been associated with the 31 B.C. earthquake mentioned by Josephus. However, a fault-break with a 3.5 m throw corresponds to a catastrophic earthquake from which Jericho, Jerusalem and other urban centres could not have survived.

Amiran dates the earthquake to 2nd September 31 B.C. and assigns to *Jerusalem* an unprecedented earthquake intensity of *X* on the authority of Rahmani [11]. Rahmani though, says nothing of the sort. Referring to the collapse of massive elements in Jason's tomb, he suggests tentatively that this could have been due to an earthquake [42: 30].

There is no evidence to suggest that *Masada* was affected by this earthquake, and the conclusions drawn by Karcz and Kafri [21] stand.

For Qumran, Nur and Rom maintain that '…this earthquake destroyed the building and ruptured the water supply of the monastery of the Essene at Qumran, 22 km east of Jerusalem, which probably forced the inhabitants to abandon the town for several decades. They add that the 2000-year-old fault rupture in the stairs of the cistern, appears as fresh as if it had happened yesterday…' [41].

The suggestion of an earthquake rupture of the water supply at Qumran was originally due to Father de Vaux, who was not a geologist or an engineer and seems to have been an invention. He reported an 'earthquake crack' which ran through a few conjoined cisterns, the crack developing in one of them into a small scarp which cuts through the steps that lead down the water cistern (mikva'ot) downthrowing their east side by about 35 cm [14]. To explain this feature, De Vaux opted for the simplest solution, namely that the damage was caused by an earthquake, the evidence for which was the crack in the stairs and he identified the event with that recorded by Josephus for 31 B.C., a feature much publicised by Zeuner [53].

Recent conservation work, however, at the site established that the shearing off of the steps along a short length, was the result of differential settlement of the weathered Lisan marls of the foundations. This was caused by the leaking of the cistern, as a result of which its east side settled more than the west, clearly a local foundation problem that had nothing to do with surface faulting [20,49]. This is the same explanation which was given by geologists long ago, a type of ground failure that does not need help from an earthquake to occur [21].

There are some tenuous indications of earthquake damage associated with post A.D. 69 activity, but the conclusion seems to be that the 31 B.C. earthquake did not affect Qumran [32]. Archaeology can provide no certain evidence for the time of the alleged earthquake. Damage could well have been the result of more than one earthquake, which could have occurred even a long while after the abandonment of the site.

An earthquake which destroyed bedrock installations and closed out the Stratum 14 occupation level at *Tell Hesban* has been identified as possibly the result of the earthquake of 31 B.C. [38: 54] Again he bases this on historical rather than archaeological evidence by synchronising his finds with the alleged destruction of nearby Qumran which is mentioned by a tertiary source [22: 225].

Later studies, which were based on archaeological dating, place the demise of Tell Hesban to about A.D. 130 [38].

Finally, Sieberg, who does not quote his source, places the epicentral region of the 31 B.C. earthquake in Lake Genesareth (Galilee), as a result of which he claims that Chammath (Tiberias) was ruined [46,47].

The reappraisal of the available data reveals nothing more than that the 31 B.C. earthquake in Judea had caused damage and loss of life, which Josephus grossly exaggerates. There is no evidence that Jerusalem was affected and the destruction or damage of other historical sites in Judea is conjectural and cannot be tested on archaeological grounds. The association of the earthquake with a fault-break at Khirbet Qumran is not tenable and the addition of Diospolis to the towns affected and the dating of the event to A.D. 31 are obviously wrong [18: 660–661,19: 173].

Ben-Menahem assigned to this earthquake a magnitude 7.0, which together with equally spurious magnitudes of other historical earthquakes, he used to derive regional frequency–magnitude relations and to estimate the variation of slip and creep along the Dead Sea Fault during the past 4500 years ([13]).

5. Discussion and conclusions

In conclusion the grossly exaggerated effects of the earthquakes of ca. 1400 and 31 B.C., as well as of other historical events assessed by certain authors, seem to be the result of the pseudo-objectivity with which source material has been used. Occasionally there is also a certain amount of bias in the way events are assessed. There are authors who are supportive, neutral or hostile to views expressed in religious sources of information. Conclusions seem to be drawn from unrealistic physical considerations and sparse data, so that the propounded theories cannot actually be verified by testing the data. This is similar to searching for archaeological evidence for the earthquake destruction of, say, Jericho (an earthquake which is not mentioned in the Bible, our only source), which occurred at the time of the Israelite invasion (the period of which is uncertain). This reminds one of Kaplan's story of the drunkard searching under a street lamp for his house key, which he had dropped some distance away, but he searches there because there is more light.

Surveying and mapping an archaeological site is an art, verifying the cause of damage is science. Without the latter it is difficult to say, for instance, why leaning or damaged walls, destabilised by ancient earthquakes and rendered vulnerable, have survived later damaging shocks and are still standing. Engineering knowledge and the ability to bring historical comparanda to bear on archaeological remains add an important dimension to the analysis.

It is important, particularly for palaeoseismological investigations, to have some indication of whether a historical earthquake was associated with surface faulting. For the assessment of magnitude rupture length and offset estimated from historical sources are the best parameters (Ambraseys and Jackson, 1998). Although, in many cases archaeology can be used to study and reconstruct the evidence left behind from the past, it cannot be used always to draw conclusions about specific historical events, such as earthquakes, without new data.

The problem with neo-catastrophe theories is that their propounders do not seem to pay attention to the evidence presented by others or data from outside their own field of expertise. It seems easier to ascribe the ruins found in an excavation to earthquakes. If the solution to a problem is not immediately obvious, amateurs eagerly consider a catastrophe theory, which the pioneers of this discipline developed, for example, to account for the collapse of the Aegean Bronze Age.

In contrast with wars, epidemics and other long lasting calamities that have serious and prolonged effects, earthquakes, no matter how large, seem to have had little long-term impact on Man. The Mongol invasion, for instance, caused far greater and longer lasting damage in the Middle East than all the earthquakes in that region during that period put together. Earthquakes destroy the most vulnerable man-made structures, while warfare and deliberate damage destroy those that are most important for survival, with uncontrollable after effects that make all the difference.

It may be that people always react to the inevitable hazard, distinct from the preventable hazard, in a special way. Personal, political and economic interests seem to overshadow, and in some cases suppress, the lessons to be learnt from destructive earthquakes. Perhaps it is one of the most interesting findings that the lasting effects of major earthquakes over the last 25 centuries in the Eastern Mediterranean region would not seem to have been significant. Soon after a damaging or destructive earthquake, vested interests invariably led people to act once again with disregard for the prospect of further such calamities, and they still do.

One of the most striking conclusions that can be drawn from field observations is the comparative ease with which various types of dwellings were damaged or destroyed and also the ease with which they were quickly rebuilt.

In recent years, considerable progress has been made in 'archaeoseismology' and there is a greater awareness of the need for collaboration between archaeologists, geologists, engineers and workers in other disciplines, to evaluate the traces of earthquakes in excavations, both for understanding their effects at the site and for the information they can provide about the nature of the earthquake implicated.

The goal of studies in historical seismicity is the provision of a unified and long-term database for engineering design purposes. Guidelines for handling macroseismic data through all the stages from retrieval to end-use have been proposed by UNESCO so that workers in each field would be aware of the needs and constraints facing the others (viz. [2,3,8]; for general information about earthquakes and engineering seismology, see [29]).

Uncited references

[9,39].

Acknowledgments

I would like to thank for assistance Dr. K Kalogeropoulos, Dr. N. Wardle, and the Library of the British School at Athens. This work was supported by the project Archeoseismology and Paleoseismology for the Protection of Cultural Heritage and Archaeological Sites in the Middle East (APAME), sponsored by the European Commission, DGXII (ICA3-CT-2002-10024).

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