HIPPOS - SUSSITA OF THE DECAPOLIS

THE FIRST TWELVE SEASONS OF EXCAVATIONS 2000 - 2011

Volume II

MICHAEL EISENBERG

The Zinman Institute of Archaeology
University of Haifa, Mount Carmel, Israel

Hippos-Sussita of the Decapolis

The First Twelve Seasons of Excavations

2000 - 2011

Volume II

Michael Eisenberg

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This volume is dedicated to Prof. Arthur Segal
who initiated and headed The Hippos-Sussita Excavation Project
for the first twelve seasons (2000-2011).

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Geological Background

The archaeological remains of Hippos cover the hill of Sussita, located on the western flank of the Golan Heights, overlooking the Sea of Galilee. The geographical, geological and geomorphological settings of the Sussita region were summarized by Shtober-Zisu (2014). The aim of the summary here is to lay out the background for describing the earthquake effects at the site.

The Sea of Galilee occupies a tectonic depression (graben) that was formed between two branches of the Dead Sea Fault (DSF, Fig. 2.1a). The movement on the DSF commenced about 20 Myrs ago, during the Miocene epoch (Bartov et al., 1980). The interpretation of left-lateral shear along the DSF since the Middle Miocene is based on observations from four independent sources: regional plate tectonics, local geology, seismology, and geodesy. Plate tectonics shows that the opening of the Red Sea, where the Arabian plate breaks away from Africa, is transferred to the collision with Eurasia via a sinistral shear along the DSF (Freund, 1965; Garfunkel, 1981; Joffe and Garfunkel, 1987). Locally, a sinistral motion explains the systematic offset of numerous pre-Miocene geologic features by a total of ~105 km (Bartov et al., 1980; Freund et al., 1968; Quennell, 1956).

Paleoseismic studies show that historic and prehistoric seismicity was associated with sinistral offsets (e.g., Agnon, 2014; Marco and Klinger, 2014). Focal mechanisms of moderate-to-large earthquakes show left-lateral motion along the DSF (Baer et al., 1999; Hofstetter et al., 2007; Klinger et al., 1999; Salamon et al., 2003). Finally, geodetic measurements consistently confirm previous movement estimates of a 4–5 mm/yr left-lateral shear (Le Beon et al., 2008; Masson et al., 2015; Sadeh et al., 2012; Wdowinski et al., 2004). The short term as well as the long-term tectonic regime appears to be stable (Begin et al., 2005; Hamiel et al., 2009).

The hill on which Hippos is built is part of the fault-controlled eastern margin of the Sea of Galilee graben. This graben is one in a series of grabens that are associated with releasing bends along the DSF (Fig. 2.1). There is a striking dissimilarity between the faults to the south and to the north of the Sea of Galilee graben. Two parallel faults are recognized in the southern section, the eastern one bends toward the northeast and the western one bends toward the northwest near the town of Tiberias. Both faults exhibit a large vertical surface expression (Hurwitz et al., 2002). The exact location of the main strike-slip bearing fault south of the graben is unknown but is assumed to coincide with the eastern fault (Hamiel et al. 2016). However, there is no evidence of lateral motion on the current geomorphic expression of either fault. A single fault is recognized at the northern end of the lake—the Jordan Gorge Fault (JGF). There is evidence that this fault alone accommodates most of the lateral movement between the plates, at least during the Holocene epoch (Ellenblum et al., 2015; Wechsler et al., 2014).

The exposed rocks in the vicinity consist largely of pre-DSF Eocene marine carbonates, overlaid by the syn-tectonic basin fill of Miocene to Pleistocene lacustrine and fluvial sediments interspersed by sporadic layers of volcanic origin (basaltic lava flows and tuffs). The sediments lithology consists of clay, marl, chalk, limestone, sandstones and conglomerates. The sedimentary sequence is capped by the Plio-Pleistocene Cover Basalt (Mor, 1993), on top of which the major part of the ancient town of Hippos was built.

The Pleistocene tectonic activity near Sussita is manifested in several geological features. First, the ~3 ma cover basalt in the Sea of Galilee graben is found at about 2500 m depth, using seismic reflection surveys (Ben-Gai, 2010), whereas in the Golan Heights near Sussita it is exposed at the surface at elevations of 200 m and above. Several normal faults that are part of the eastern flank of the Sea of Galilee graben offset the sediments in the vicinity (Fig. 2.2). Additionally, many landslides that are common on the cliffs that surround the Sea of Galilee were triggered by earthquakes (Wechsler et al., 2008; Yagoda-Biran et al., 2010).

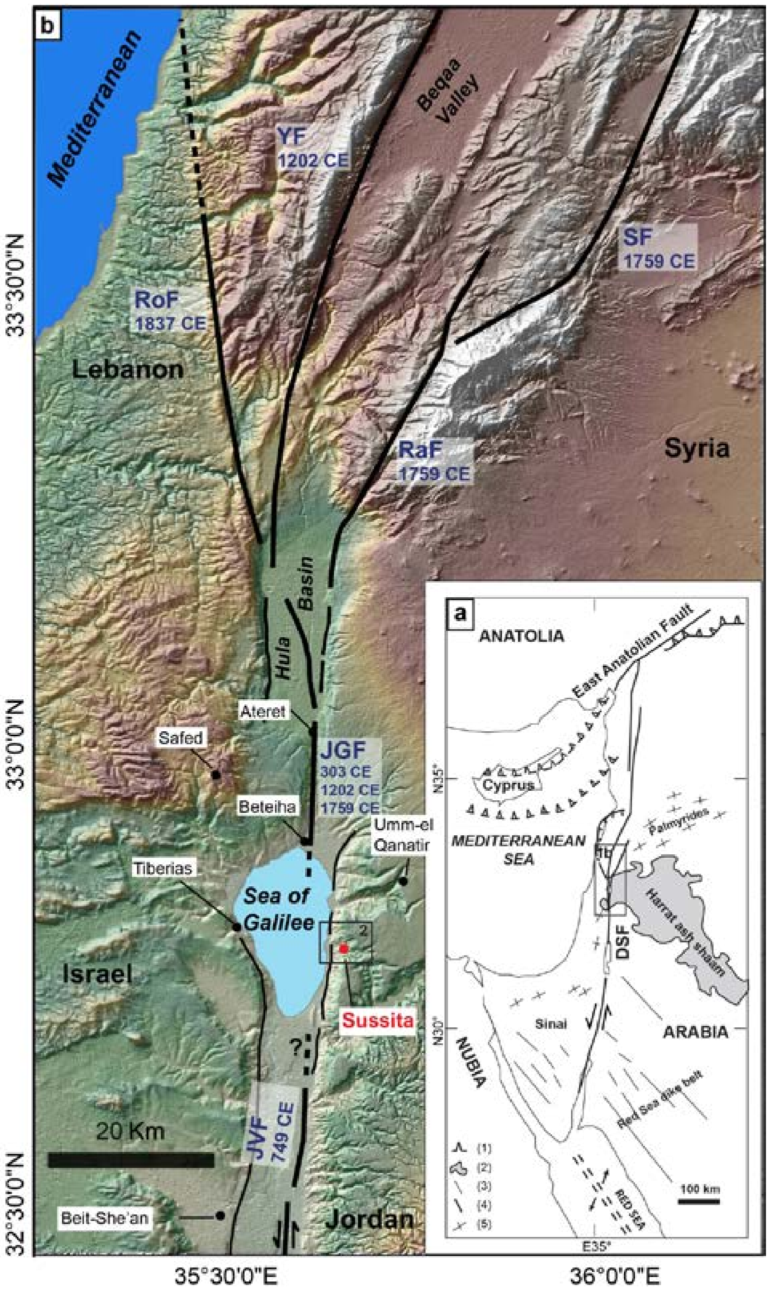

Fig. 2.1 a) Generalized tectonic framework of the Dead-Sea Fault (DSF) and other major structures in the area. The DSF is a left-lateral fault that accommodates the motion between the tectonic plates of Arabia and the Sinai. It transfers the opening at the Red Sea to the Taurus-Zagros collision zone (Freund, 1965; Quennell, 1956). Legend: (1) Collision zones. (2) Cenozioc volcanic. (3) Early Miocene dykes. (4) Plate boundary main faults. (5) Syrian arc folds (after Garfunkel, 1989). The black rectangle marks the extent of Fig. 2.1b. b). Location of major and minor faults of the DST in the vicinity of Hula Basin and the Sea of Galilee. JGF—Jordan Gorge Fault. JVF—Jordan Valley fault. RaF—Rachaya Fault. RoF—Roum Fault. SF—Serghaya Fault. YF—Yammouneh fault. Below each fault name, the relevant earthquakes known to have ruptured it are mentioned. The black rectangle marks the extent of the map in Fig. 2.2.

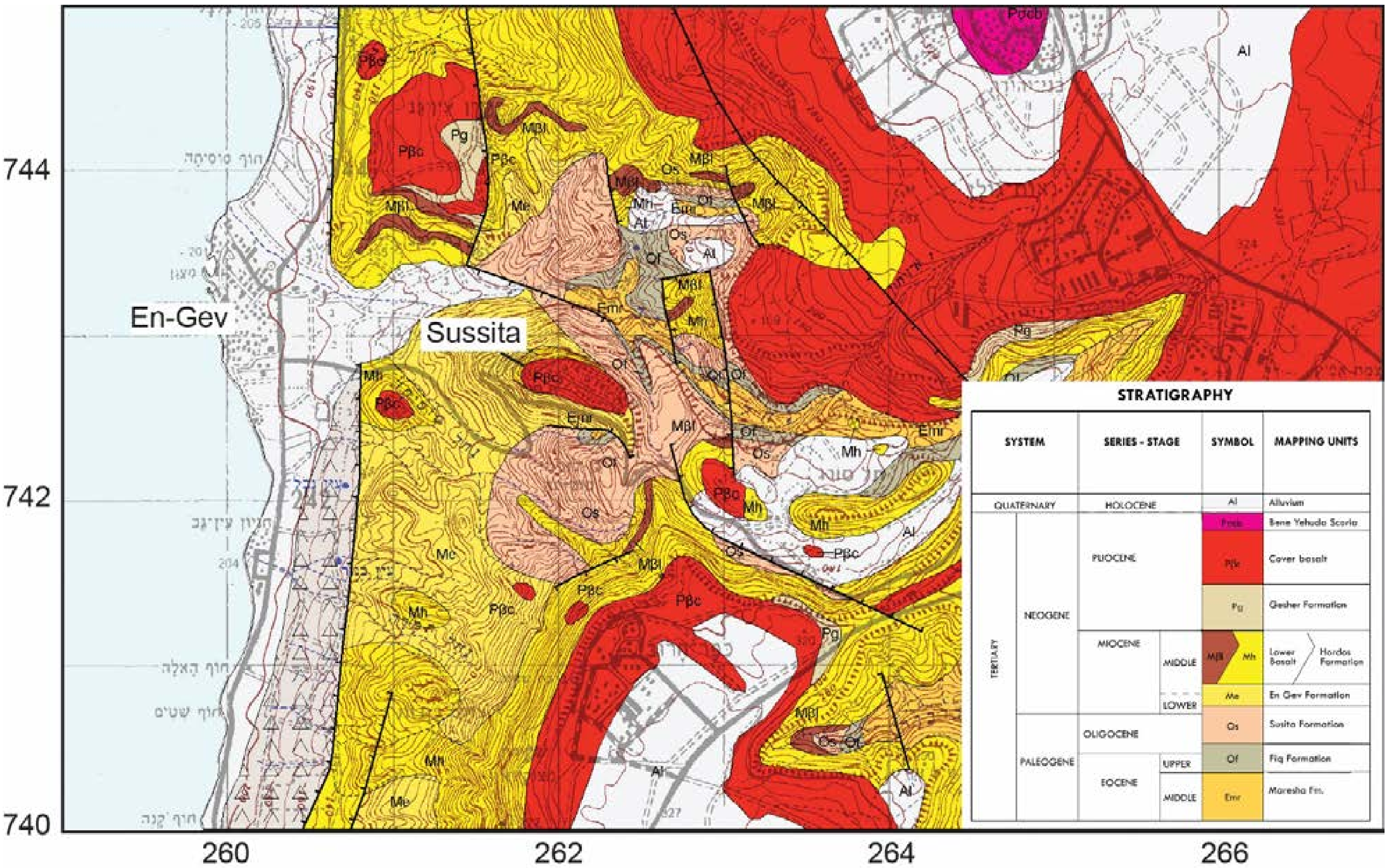

Fig. 2.2 Geological map of Sussita and vicinity, an excerpt from the geological map of Tiberias. The grid is in ITM coordinates.

Earthquake Activity

Several historically known large earthquakes reportedly affected the region around Sussita. Based on the historical, geological, and seismological records, the estimated recurrence interval of moment magnitude (Mw) 6 earthquake is in the order of 10^2 years, increasing to 10^3 years for Mw~7 earthquakes (Begin et al., 2005). The national seismic building code (S.I.I., 2004) assigns horizontal peak ground acceleration (PGA) of 0.3 g in this region with a 10% probability of exceedance in 50 years.

Historical earthquake catalogues include records of strong earthquake damage in the vicinity of the Sea of Galilee (Ambraseys, 2009; Guidoboni and Comastri, 2005; Guidoboni et al., 1994; Sbeinati et al., 2005). The historically recorded earthquakes that might have affected Hippos occurred during the years 303, 363, 551, 749, 1202, 1759, and 1837 CE.

The 303 earthquake was strongly felt in the Lebanese coastal cities of Sidon and Tyre, causing building collapses and loss of life. The earthquake may have caused damage in Gush-Halav (in the Galilee) and a tsunami in Caesarea. Supporting evidence for this earthquake include an inscription from Byblos that records the name of an earthquake survivor on an altar dedication. Evidence for shaking was found in the Dead Sea sediment cores (Kagan et al., 2011; Migowski et al., 2004) and a contemporaneous surface rupture was mapped in paleoseismic trenches on the north shore of the Sea of Galilee (Wechsler et al., 2014).

The earthquake of 363 occurred during the night of May 18–19, and came in two separate shocks. The earthquake was widely felt and caused extensive damage, from Paneas (Banyas) in the north of Israel to Petra in the south of Jordan.

The earthquake of July 9, 551 was strongly felt along the coast of Lebanon, and triggered a tsunami. Most of the coastal cities of Phoenicia (modern-day Lebanon) were devastated. Tripoli is reported to have "drowned," and Beirut was destroyed and did not recover for nearly 1300 years afterwards. Paleoseismic and geophysical studies in Lebanon and offshore indicate that the rupture was offshore, on the ~100–150-km-long active, east-dipping Mount Lebanon thrust. The moment magnitude (M_w) is estimated at 7.5 (Elias et al., 2007).

The earthquake of January 18, 749 was a strong event, with extensive damage reported to be centered along the northern part of the Jordan valley. Damage was also reported from Egypt to Turkey and from the Mediterranean coast to Iraq. Various earthquake catalogues list one or more earthquakes that caused severe damage in Egypt, Palestine, Jordan, Syria and Iraq. Several recent authors attributed the different years given in ancient texts to the inconsistent use of diverse calendars and errors in dating the same event of January 18, 749 CE. (Guidoboni et al., 1994; Tsafrir and Foerster, 1989). However, a closer examination of the historical texts shows that the authors relied on questionable sources and that the Byzantine and Arab chronicles and traditions

Fig. 2.3 Photo of the cathedral with the fallen columns, looking west.

clearly reported at least two, possibly three, discrete events up to three years apart and at a distance of hundreds of kilometers from each other (Ambraseys, 2005; Karcz, 2004).

The main earthquake that affected Hippos and the region, that of 749 CE., caused widespread damage, including the destruction of Tiberias and Beit-She'an. There is evidence of surface rupture on the western shore of the Sea of Galilee (Marco et al., 2003) and near Jericho (Reches and Hoexter, 1981) that can be correlated with this earthquake. The synagogue at Umm-el-Qanatir (northeast of Hippos) collapsed and the village surrounding it was abandoned as a result of this earthquake (Wechsler et al., 2008). Hippos as well as other villages in the area were also abandoned at the same time.

The earthquake of May 20, 1202 is probably the strongest one that affected this region in historical times. It was felt at a radius of 500 km, from Egypt in the south to Lesser Armenia in the north, and from Syria in the east to Cyprus in the west. It caused damage in Syria, Lebanon, Jordan and Israel (Ambraseys and Melville, 1988). The surface rupture was recognized in archaeoseismic research at Ateret (Ellenblum et al., 1998; Ellenblum et al., 2015) and geological paleoseismic research at the Jordan Gorge Fault (Marco et al., 2005; Wechsler et al., 2014) and along the Yammouneh fault in Lebanon (Daeron et al., 2005).

During the year 1759, two earthquakes occurred in the region, a moderate one on October 30 and a strong one on November 25. The 0.5 m left-lateral surface rupture of the October event was found in Ateret (Marco et al., 1997) and in the Bet Saida Valley (Marco et al., 2005) north of the Sea of Galilee. The November event was stronger, causing damage in northern Israel, Syria and Lebanon. Some towns such as Tiberias and Quneitra, already suffering destruction from the October event, were obliterated. The extent of damage and reported aftershock locations were centered along the DSF (Ambraseys and Barazangi, 1989; Sieberg, 1932), and the surface rupture was identified in paleoseismic research on the Yammouneh section of the fault in Lebanon (Daeron et al., 2005). Nemer et al. (2008) raise the possibility that the Rachaya and Serghaya faults were the sources of the November 1759 earthquake.

The earthquake of January 1, 1837 was also strongly felt in northern Israel and southern Lebanon, causing severe damage in Tiberias and Safed, and a seiche in the Sea of Galilee. Damage and casualties reports were centered along the Roum fault, the western branch of the DSF in Lebanon, making it the likeliest source for the earthquake (Ambraseys, 1997; Nemer and Meghraoui, 2006).

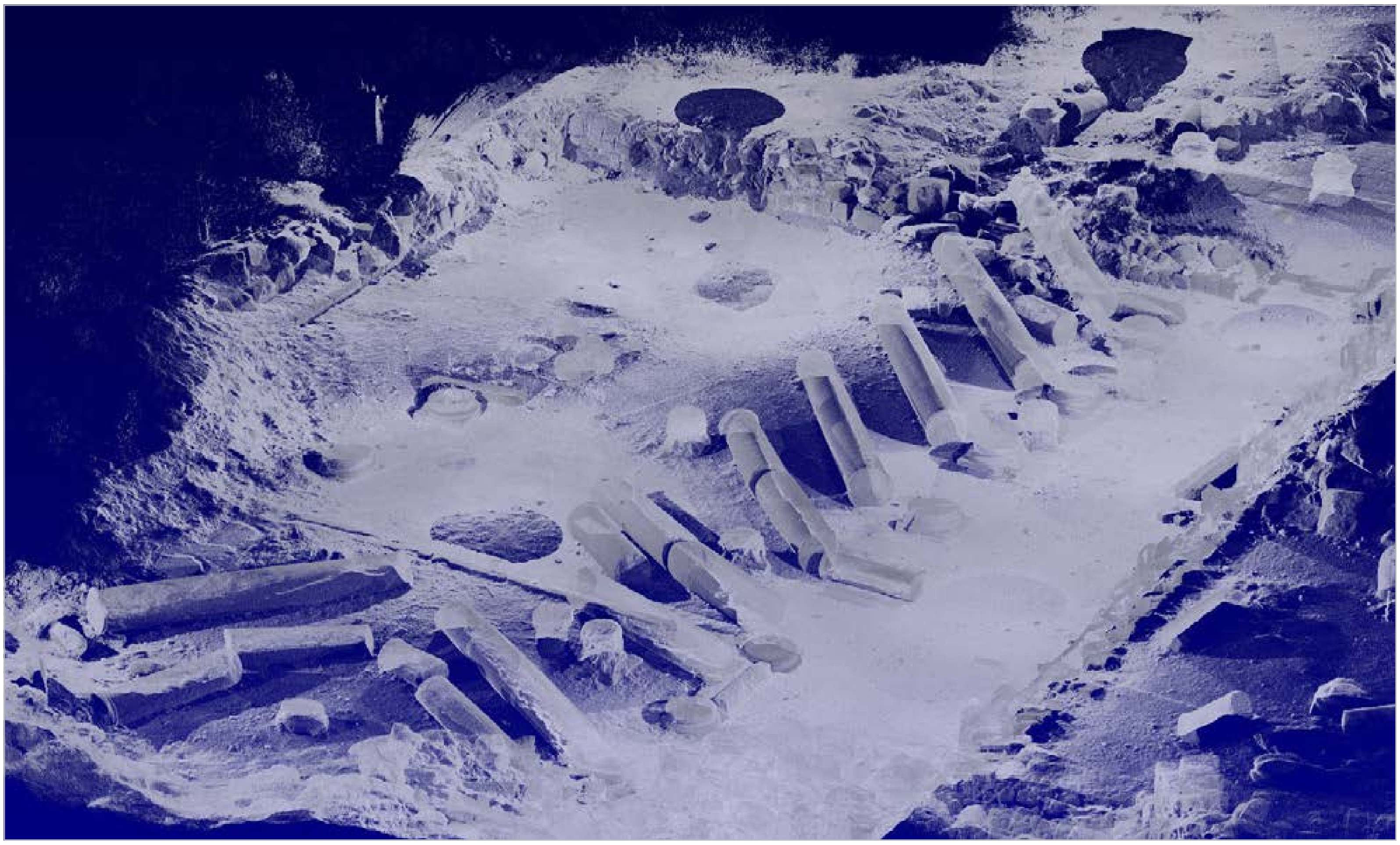

Fig. 2.4 Perspective clear view to a 3D laser scan model of the Cathedral of Hippos with a view from the northeast.

Archaeoseismological Aspects

From the archaeoseismological point of view, Hippos is an interesting and challenging site: (1) It spans more than 2000 years of building history; (2) It is in close proximity to an active plate boundary; (3) It was built at a unique location concerning both with regard to its topography and to the geologic layering of the subsurface; and (4) It includes buildings and structures of a large variety of size and construction techniques. Despite these conditions and the effects of several damaging earthquakes, little geoscientific and engineering seismological work has been done to answer open questions such as how earthquakes may be identified and dated based on the ruins of Hippos, how severe were the effects on the local site, how did they affect damage patterns, and how did the earthquakes influence the settlement history of the site?

In the context of the archaeological findings in Hippos, the fact that the site was partially abandoned during the first half of the 8th century CE points to the 749 CE earthquake as the major cause for its final abandonment. The dismantling of the Odeion during the 4th century CE (Segal, 2014b) may have been the result of it being irreparably damaged by an earthquake, perhaps by those of 303 or 363 CE. The destruction of the Roman Basilica built in the center of the city at the end of the 1st century CE is clear evidence for the 363 CE earthquake judging by the archaeological data (Eisenberg, 2016; Segal, 2014a). The latest coins found in-between the fallen architectural fragment and the basilica floor are dated to 362 CE while the floor built above its debris is dated to the 380s CE. It is possible that some of the later, strong, post-abandonment earthquakes caused some additional damage at the site.

The Cathedral, built in 590 CE (Łatjar, 2014), continued to function until the mid-8th century (Segal, 2007) making the 749 CE earthquake the causative one for the destruction of this basilica. The remaining columns of the Cathedral were unearthed in the 1950s lying on the floor of the building in subparallel directions. The original structure was a mono-apsidal basilica with an inscribed apse and two rows of nine columns with an average preserved height of 5 m, which separated the nave from the aisles. The columns were made of different types of colored marble and granite, which are not found locally in the region of Israel. Several column bases have a central hole and lead channel and others are without such holes. While the nine columns of the northern row are oriented N220°E (±10°), the two remaining columns of the southern row are oriented N295°E (±10°). This configuration was immediately interpreted as an indication of toppling by earthquake ground motions (Epstein, 1993). The spectacular setting (Fig. 2.3) even resulted in a display on the cover of the textbook 'Archaeoseismology' (Stiros and Jones, 1996). In the figure caption of this photo, the fallen columns of the Cathedral are wrongly linked to a "Roman structure" and to the 363 CE earthquake, and the column orientation was believed to indicate the direction of strong ground motion. Later, Nur and Burgess (2008) linked the columns to the 749 CE earthquake and remarked on the agreement between the toppling direction and the general movement of the Arabian Plate. Since the Cathedral was constructed only in 590 CE it cannot be assumed that it could have been destroyed during the 363 CE earthquake (Łatjar, 2014).

The Cathedral is, so far, the only structure that has been at the center of quantitative archaeoseimsic studies. Yagoda-Biran et al. (2010) tried to estimate minimum levels of peak ground acceleration (PGA) during

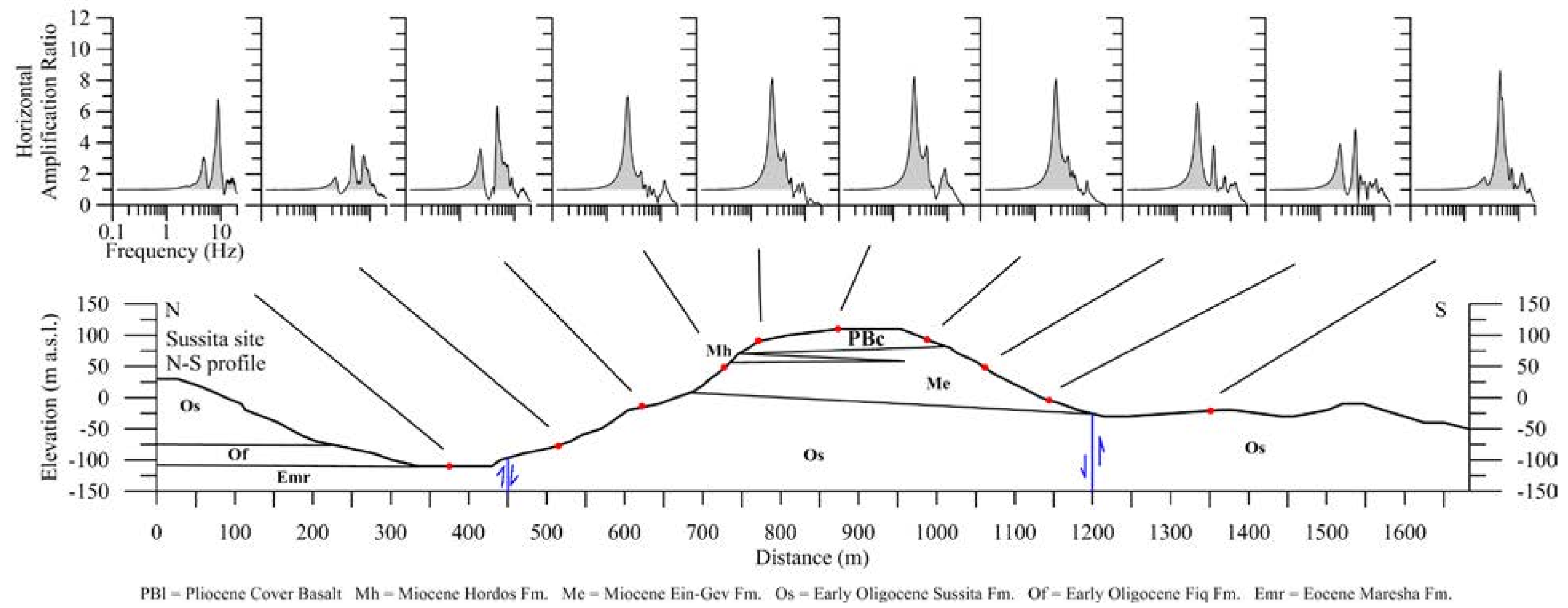

Fig. 2.5 Simplified north-south trending geological profile through the saddle-like structure of the Sussita hill. On top of the profile, a frequency-dependent seismic amplification is shown which was derived for ten one-dimensional linear elastic models of the subsurface. Abbreviations for the geologic units are given at the bottom of the figure.

the earthquake ground motion which was necessary to topple the Cathedral columns. However, they used the model of a freestanding column of the same size as the ones found in the Cathedral, but with no capital, architrave or other superstructure. Since 2D models were used and forces were applied to the center of gravity of the columns and pedestals, the reported 0.2–0.4 m/s² PGA threshold at frequencies between 0.2 and 4.4 Hz can only be regarded as a rough estimate and are not necessarily representative for the complete structure of the Cathedral which has a significantly different response to earthquake ground motions than a solitary column.

Hinzen (2009) used 3D discrete element models conforming to the size of the toppled columns of the Cathedral and showed that the toppling direction during a realistic earthquake ground motion in three dimensions is a matter of chance. A column that is being rocked by earthquake ground motions is in a nonlinear dynamic system and its behavior tends to be of a chaotic character. Small changes to the initial conditions can have a strong influence on the general dynamic reaction and significantly alter the toppling direction. The same paper shows that the parallel orientation is probably an effect of the superstructure connecting the columns mechanically and not a consequence of the ground motion character. This interpretation is also strongly supported by the fact that the two remaining columns of the southern row rest at angles of ~90° compared with the columns from the northern row, as shown in a 3D laser scan model of the site (Fig. 2.4). A similar analysis of the Hippos columns was performed by Hinzen (2010).

The saddle-like structure of the Sussita hill is prone to topographic amplification of strong ground motion during earthquakes, especially at the hilltop. The focusing effects of seismic waves in similar situations have been reported to lead to significant ground motion amplification (e.g., Massa et al., 2010). In the case of Hippos, the special geometry of the hill is combined with the unusual situation of high impedance material in the form of a basalt flow on top of weaker conglomerates. Figure 2.5 shows a simplified north-south trending profile through the site and the neighboring valleys of Ein-Gev and Sussita. Estimates of ground motion amplification of vertically traveling shear waves from 1D model calculations indicate amplification factors at the hilltop in the range of 8 at frequencies of 2–3 Hz, a frequency range at which constructions such as colonnades show high vulnerability. In any further archaeoseismic studies of the damaged structures in Hippos, the exceptional location of the site and the local conditions must be taken into account.

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