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Notes

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ABSTRACT

Historical records of earthquakes can contribute significantly to understanding active faulting and seismic hazards. However, pre–twentieth century historians were unaware of the association of earthquakes and fault ruptures. Consequently, historical texts usually report the time and damage caused by earthquakes, but not the associated faults. Conversely, observed fault ruptures are often difficult to date. In order to overcome these difficulties, we have analyzed archaeological and sedimentological observations in recent excavations in the ancient city of Tiberias and have combined them with interpretation of historical accounts. Tiberias was founded in A.D. 19 by King Herod on the western shore of the Sea of Galilee (Kinneret). Herod's stadium, exposed in these excavations for the first time, was damaged by boulder-bearing flash floods and by an earthquake. Later buildings, dated as late as the early eighth century, are all covered by alluvium and lake deposits. They are also damaged and offset by normal faults, whereas buildings from the late eighth century are intact. We therefore attribute the damage to the earthquake of 18 January 749. The paleoseismic observations are in good agreement with the distribution of damage on the basis of historical records. Both data sets indicate a 100-km-long rupture segment between the Kinneret and the Dead Sea pull-apart basins, demonstrating that it is capable of generating M > 7 earthquakes.

Keywords: earthquakes, Dead Sea fault, paleoseismology, archaeoseismology.

INTRODUCTION

The earthquake occurrence on active faults can be better constrained where historical records are available. Prior to the deployment of modern seismographs in the twentieth century, dates, damage, and people's reactions to strong earthquakes were described by contemporaries. However, historians were unaware of, and therefore did not refer to, the association of earthquakes with faults. Conversely, geologic studies of past fault ruptures, commonly associated with M > 6 earthquakes, are often hindered by difficulties in dating the rupture events. We demonstrate how historical and geologic data can be correlated. The wealth of archaeological sites along the Dead Sea transform and the area's abundant historical accounts provide opportunities to combine the disciplines. We employ archaeological methods for dating faults and analyze historical accounts to delineate the geographical distribution of damage caused by the particular earthquake.

Similar coincidence of long history, literate inhabitants, and active faulting occur in other earthquake-prone regions such as China, Turkey, Greece, and Italy. Archaeoseismic research methodology (e.g., Noller, 2001), in particular deliberate surveying and documentation of archaeological structures along active faults, can significantly improve the quality of paleoseismic data in these regions.

GEOLOGIC SETTING

The Dead Sea transform is a left-lateral fault between the Arabia and the Sinai tectonic plates that transfers the opening at the Red Sea to the Taurus-Zagros collision zone (Fig. 1). The paradigm of left-lateral shear along the Dead Sea transform since the middle Miocene explains the systematic 105 km offset of numerous pre-Miocene geologic features (Freund et al., 1968; Quennell, 1956). It is also consistent with paleoseismic and archaeoseismic observations (Ellenblum et al., 1998; Gomez et al., 2001; Klinger et al., 2000; Marco et al., 2000; Meghraoui et al., 2003; Niemi et al., 2001) and with earthquake focal-plane solutions (Baer et al., 1999; Pinar and Turkelli, 1997; Salamon et al., 1996). The Sea of Galilee (Kinneret) is a subsiding basin along the Dead Sea transform. Paleoseismic and archaeoseismic studies north of the Kinneret show that the last two rupture events in the Jordan Gorge segment north of the Kinneret were the 1202 and 1759 earthquakes (Ellenblum et al., 1998; Marco et al., 2000). High-resolution seismic reflection profiles south of the lake reveal offset shallow reflectors (Zurieli et al., 2002), but to date there are no paleoseismic data from the region.

GALEI KINNERET SITE

The seismic history of the past two millennia is revealed in the sedimentary and archaeological sections excavated at the Galei Kinneret site in the city of Tiberias (Figs. 1 and 2). The site is ~50 m from the lakeshore, between 208 and 212 m below sea level (mbsl). The site was affected by lake-level changes, which fluctuated in the twentieth century between 209 and 213 mbsl, but lately dropped to below 214 mbsl. The June 2002 excavations revealed Roman, Byzantine, and Early Arabic remains (Table 1), as well as sediments that were deposited during past high lake levels. Tiberias was established in A.D. 19 by King Herod Antipas, who named it in honor of the Roman Caesar Tiberius. On the basis of indicative architecture, coins, and ceramics, the earliest structure in Galei Kinneret is a sector of an oval stadium, unearthed for the first time in the modern era. The stadium was described by the contemporary historian Josephus Flavius (Flavius, 1982). Byzantine and Early Arabic structures overlie the Roman structures.

Alluvial pebbles and fine-grained lake sediments, indicating a rise of water level, buried the Roman, Byzantine, and Ummayad buildings. The competent architects and builders of the Roman stadium were certainly aware of the seasonal fluctuations in the lake level. They built on the shore, confident that the structures were safe. For several centuries, their planning proved correct. Buildings were also built at the same level during the Byzantine period and the first decades of the Early Arabic period. The rise of the lake was therefore unexpected. More than 12 Roman and Byzantine jetties and small piers are known from around the lake at 212 ± 1 mbsl (Mendel-Nun, 1987). The rising lake and the high-energy, boulder-bearing sediment flux explain their

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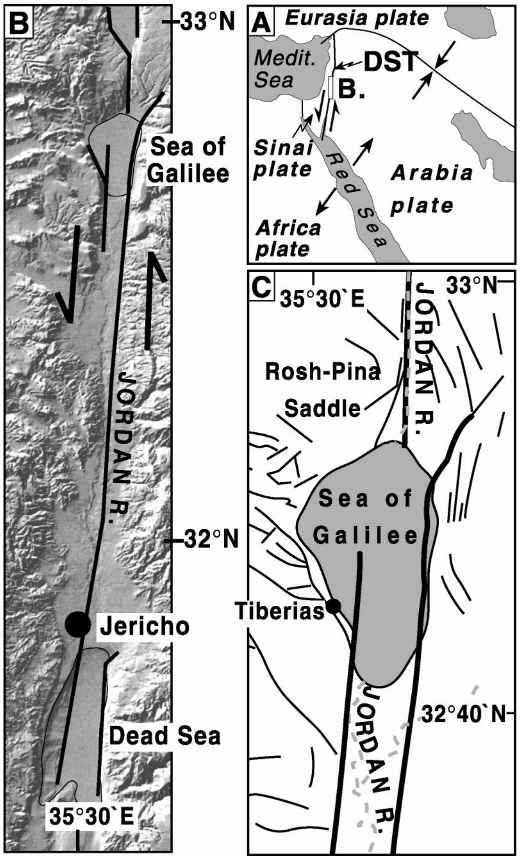

Figure 1. A: Tectonic plates in Middle East. Dead Sea transform fault (DST) transfers opening at Red Sea to Arabia-Eurasia collision. Box marked B. is shown in greater detail in B. B: Section of Dead Sea transform between Kinneret (Sea of Galilee) and Dead Sea basins. Shaded relief is from Hall (1994). C: Kinneret basin and faults around it. Solid lines are main left-lateral Dead Sea transform faults. Secondary faults (thin lines) show mostly normal slip (after Bartov, 1979). Kinneret is bounded on east by folded Miocene alluvial and lacustrine sedimentary rocks that are unconformably overlain by Pliocene–Pleistocene flood basalts. Normal faults bound Kinneret on west, and major normal fault is interpreted from geophysical surveys under water on east (Ben-Avraham et al., 1990).

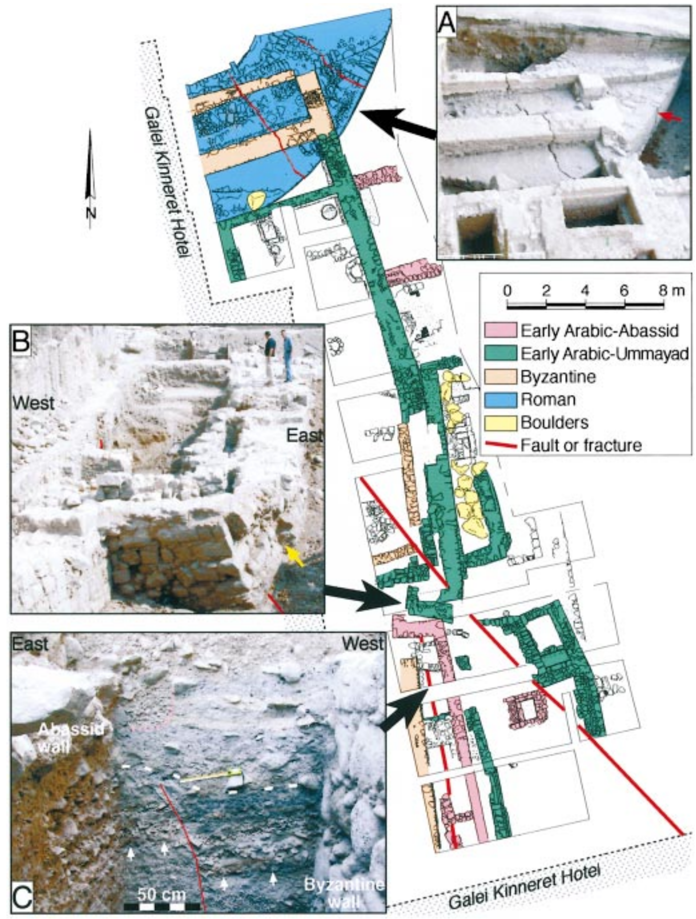

Figure 2. Galei Kinneret site map. A: Open fractures in Herod's stadium and overlying Byzantine walls. B: Ummayad room that overlies fault (red lines) is tilted 23° westward. Its right side is on footwall, and its left side is on hanging wall. Arrow shows tear in wall. C: Looking southward at section in alluvium and lake sediments, which buried Byzantine wall (right) and were later offset 40 cm by normal fault (red). White arrows point at offset layer; white bars are at bottom of unfaulted layers. Foundation (pink) of Early Arabic (Abassid) wall is built into postfault layers. This stratigraphy constrains fault to eighth century. The only strong earthquake in this area occurred on 18 January 749.

abandonment in the eighth century and their subsequent deterioration. We interpret that the missing port of Tiberias is also buried under the same pile of sediments that buried Galei Kinneret.

The sediments and the buildings also exhibit earthquake-related damage. Two extension fractures striking 320° and 305° cross the Roman stadium (Fig. 2). The fractures are as wide as 10 cm and extend upward into Byzantine and Early Arabic walls that overlie the stadium. None of the fractures are limited to the stadium, indicating no deformation between the Roman period and the construction of the Ummayad walls.

A few normal synsedimentary faults offset the lower part of the sedimentary sequence. Unfaulted layers as well as buildings of the Abassid period overlie these faults (Fig. 2). Fault planes typically dip 60°–70°. Flat pebbles and pieces of pottery are aligned with the fault planes, showing typical imbrication. In one locality, layers at the footwall near the fault are warped downward. Two major planes stand out; the western one strikes 354° with 35–50 cm offsets, and the eastern one strikes 320° with 90–100 cm vertical offsets. The downthrown side is always on the west. Smaller north-striking faults with ~10 cm offsets are also recognized, but the downthrown side is east. The ashlars from the upper part of the walls have fallen mostly westward. No liquefaction is observed in the sediments, probably owing to the large size of the clasts.

This kind of faulting cannot be the dominant long-term pattern of activity because the structure of the Kinneret basin requires a downthrown block on the east. The observed faults reflect northeast-southwest extension, normal to the 450–500-m-high fault scarps west and south of Tiberias and smaller scarps at the lake bottom (Ben-Avraham et al., 1990). The faults postdate the Ummayad buildings and predate the later undisturbed sediments and Abassid buildings.

The only strong earthquake in this period occurred on 18 January

TABLE 1. HISTORICAL PERIODS IN ISRAEL

Period	Years
Early Roman	37 B.C.–A.D. 132
Herod and his sons' reign	37 B.C.–A.D. 70
Late Roman	A.D. 132–324
Byzantine	A.D. 324–638
Early Arabic—Ummayad	A.D. 638–750
Early Arabic—Abassid	A.D. 750–1099
Arabic and Crusader	A.D. 1099–1291

TABLE 2. SUMMARY OF REPORTED DAMAGE ASSOCIATED WITH 749 EARTHQUAKE

Site	Reported damage	Intensity
Amman, Jordan	A: Disastrous, severe loss of life.	X
Amra, Jordan	E: Minor damage.	V
Arbel	A: Synagogue destroyed.	VII
Ba'albek, Lebanon	G: The city was completely swallowed.	X
Beit Qubayeh	G: The fortress (location unknown) collapsed; >80 people suffocated inside.	VII
Bet Shean	A: Disastrous, severe loss of life.	X
Bosrah, Syria	G: The city was completely swallowed.	V
Capernaum	A: Disastrous, severe loss of life.	X
Constantinople	G: Statues fell.	
Damascus, Syria	G: The city shook for days.	VI
Damietta, Egypt	A: Some damage.	V
Dar'at, Syria	G: The city was completely swallowed.	X
Dareya (Darayya)	G: Many were killed.	VI
Fustat, Egypt	A: Strongly felt, caused some fear but no damage.	IV
Gautah (al-Ghouta, Damascus)	G: Many were killed.	VI
Hammat Gader	A: Thermal baths were destroyed.	VII
Iraq el Amir, Jordan	E: This earthquake added some damage to previous one.	V
Jerash, Jordan	E: Most of the city was destroyed, including one Ummayad mosque.	X
Jericho	A: Kh. el Mefjer (Hisham's palace) was destroyed. G: Spring of water moved 6 miles out of its place.	VII
Jerusalem	G: Worst damage, city destroyed, thousands killed, churches destroyed, the sons of Shaddad ibn Aws were killed, many ran away for shelter in the desert for 40 days. A: Severe damage to El-Aqsa mosque; Ummayad buildings south of the temple were destroyed.	X
Kasrin	A: Disastrous, severe loss of life.	X
Kursi	A: Church destroyed.	VII
Lod	A: Severe damage.	
Mabbug (Manbij, northeast Syria)	G: The church of Jacobites had collapsed with all the people in it.	VII
Mediterranean coast	A: Tsunami.	
Mesopotamia	G: The groud split open over a distance of 2 miles.	
Mount Berenike (Tiberias)	A: Church was destroyed.	VII
Mount Nebo, Jordan	A: Disastrous, severe loss of life, basilica destroyed.	X
Nawa, Syria	G: The city was completely swallowed.	X
Pella, Jordan	A: Disastrous, severe loss of life.	X
Sussita	A: Disastrous, severe loss of life.	X
Syria	G: Some cities were completely destroyed, others partly, and some moved 6 miles and more from the mountains toward the plains.	
Dead Sea	A: Seiche.	
Tiberias	G, R, A: Widespread destruction; 30 synagogues were destroyed.	X
Um el Jamal	A: Disastrous, severe loss of life; R: some damage.	X
Village near Mount Tabor	G, R: The village moved 4 miles, but no damaged occurred.	VI
Villages along the coast	G: An extraordinary storm in the sea; the sea flowed over most of the cities and villages along the coast.	

Note: Estimated MMS intensities are used to delineate zone of maximum damage (Fig. 3). The data were collected from historical earthquake catalogues. A—A miran et al. (1994); E—El-Isa (1985); G—Guidoboni (1994); R—Russell (1985).

749 (Amiran et al., 1994). We adopt the date of Tsafrir and Foerster (1989), who resolved the confusion caused by reports of an A.D. 748 and/or 747 earthquake.

A historical excerpt illustrates some characteristics of the damage (see Guidoboni, 1994; Russell, 1985, p. 48):

"And that night there came great wrath from God, for there was a great earthquake in the land, and many houses were ruined in all the cities; and none was saved from them, not a single soul; and likewise on the sea many ships were sunk on that night. This happened all over the East, from the city of Gaza to the furthest extremity of Persia. And they counted the cities that were wrecked that night, and they were six hundred cities and villages, with a vast destruction of men and beasts. But the land of Egypt was uninjured, except only Damietta. And at Misr there was only great fear, without any death or ruin of houses; for though the beams in the doorways and walls were moved out of their places, they went back again to their places after two hours."

On the basis of our interpretation of the historical accounts (Table 2), we define a zone of maximum damage (MMS intensity X). The zone shows that the source fault was in the Jordan Valley. The felt zone extended to Mabbug (modern Manbij in northern Syria), Mesopotamia, and Fustat in southern Egypt (Fig. 3).

The geographical distribution and degree of damage are typical of an earthquake of magnitude 7–7.5. Hence the size of the rupture must have been larger than the northwest-striking fault at the southwest margin of the Kinneret. Rather, its major part was farther south, along the Jordan Valley, where movement is primarily sinistral. The 749 rupture was also observed in paleoseismic trenches near Jericho, 110 km south of Tiberias (Reches and Hoexter, 1981). Seismic reflection surveys and earthquake focal mechanisms were interpreted to show a broad shear zone near Jericho (Shamir et al., 2003). Based on the geometry of the faults, we suggest that the rupture stopped at the Kinneret and Dead Sea pull-apart basins. The fault length is also compatible with a $7 < Ms < 7.5$ earthquake (Ambraseys and Jackson, 1998). Rupture terminations at pull-apart basins were observed in the twentieth century earthquakes of the North Anatolian fault (Barka and Kadinsky-Cade, 1988). We suggest that the observed fault at Galei Kinneret illustrates the transformation of sinistral slip to normal slip on the north-striking fault south of the Kinneret. This type of strain is also consistent with models of strain distribution around tips of faults (Freund, 1974; Ron et al., 1984; Segall and Pollard, 1980).

CONCLUSIONS

The archaeological stratigraphy at Galei Kinneret tightly constrains the documented damage between the end of the seventh century and the beginning of the eighth century. The single deformation event since the foundation of Tiberias in A.D. 19 is attributed to the 18 January 749 earthquake. Our interpretation of historical accounts shows that the zone of maximum damage centers about the Dead Sea transform section between the Dead Sea and the Kinneret. This interpreted location is consistent with the documentation of faulting near Jericho (Reches and Hoexter, 1981), indicating that the entire 100-km-long Jordan Valley segment ruptured.

The northwest-striking normal faults in this area are too short to accommodate the large ruptures that must have occurred according to

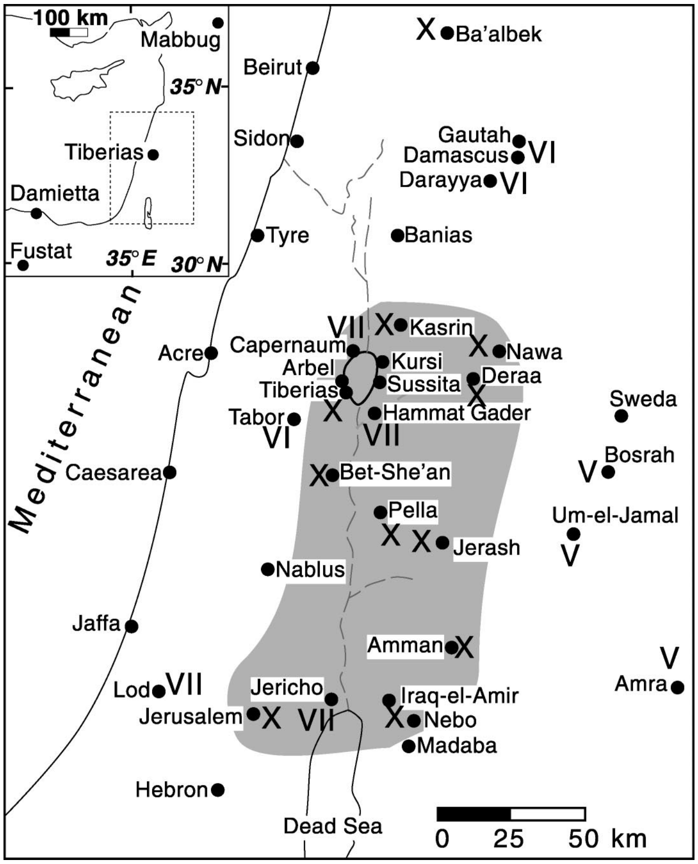

Figure 3. Damage distribution of 749 earthquake. Earthquake intensities are shown by Roman numerals. Maximum damage zone (shaded, MMS intensity X) centers about Dead Sea transform. Data are summarized in Table 2.

the extent of damage. Hence, the observed faults are part of the northern rupture termination, where sinistral strike slip is transformed to normal slip. The available data do not indicate the location of the rupture south of the Kinneret. This issue will be addressed in future paleoseismic investigations. We suggest that the segment boundaries are the Kinneret and the Dead Sea pull-apart basins, where faulting is more complex and dip-slip movements control the topography. The good agreement of the paleoseismic observations and the historical accounts indicates that when paleoseismic evidence is not available, historical accounts can be used to estimate earthquake rupture segments. The contributions of archaeology, geology, and history demonstrate the strength of such interdisciplinary studies.

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