Lake Kinneret levels and active faulting in the Tiberias area

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(Received 14 January 2004; accepted in revised form 20 September 2004)

ABSTRACT

Hazan, N., Stein, M., and Marco, S. 2004. Lake Kinneret levels and active faulting in the Tiberias area. Isr. J. Earth Sci. 53: 199–205.

Reconstruction of the Lake Kinneret level curve for the past 6000 years reveals several rises and declines that are simultaneous with similar but more enhanced changes in the Holocene Dead Sea. A significant departure from this pattern is revealed by the sedimentary section at the Roman-to-Early Arabic archeological site of Galei Kinneret (in Tiberias). Beach sediments overlying the buildings of the Early Arabic (Ummayad) period suggest a lake rise (to 208 m below mean sea level) at ~700 CE, which contradicts the significant low stand observed in the Dead Sea at the same time, between 600 CE and about 1000 CE. An alternative explanation for the lake sediments above the Arabic structure could be a tectonic subsidence of the local shoreline. Prominent faults that cross the Galei Kinneret site on its eastern side are probably responsible for the cracking and sinking of the Herodian stadium wall. Assuming that the Roman stadium was built above the high-stand level of the Roman time (>208 m bmsl), it appears that the tectonic subsidence of the Roman–Ummayad structures was more than 4 m. We speculate that such a tectonic subsidence could also be responsible for the disappearance of the Roman harbor of Tiberias.

1. INTRODUCTION

The modern and Holocene Sea of Galilee (Lake Kinneret) has evolved from ancient water-bodies that filled the Kinneret tectonic depression in the northern Jordan basin during the Late Pleistocene (Hazan et al., 2004). Lake Kinneret is located where the two segments of the Dead Sea Transform (DST) meet (Fig. 1). South of the Kinneret the main fault zone is composed of two strands, whereas to the north a single fault dominates (Garfunkel et al., 1981). The Kinneret shorelines have been affected by active faulting as well as by limnological-level changes that reflect the regional hydrological activity (Ben-Avraham et al., 1990; Belitzky and Nadel, 2002; Hazan et al., 2004). Resolving the tectonics and lake level effects on the location of the present shorelines is the focus of this work. Here we use archeological and geological data from Tiberias to constrain the age and elevation of the Late Holocene Kinneret shorelines (Marco et al., 2003). We further compare the Kinneret level curve

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0021-2164/04 $4.00

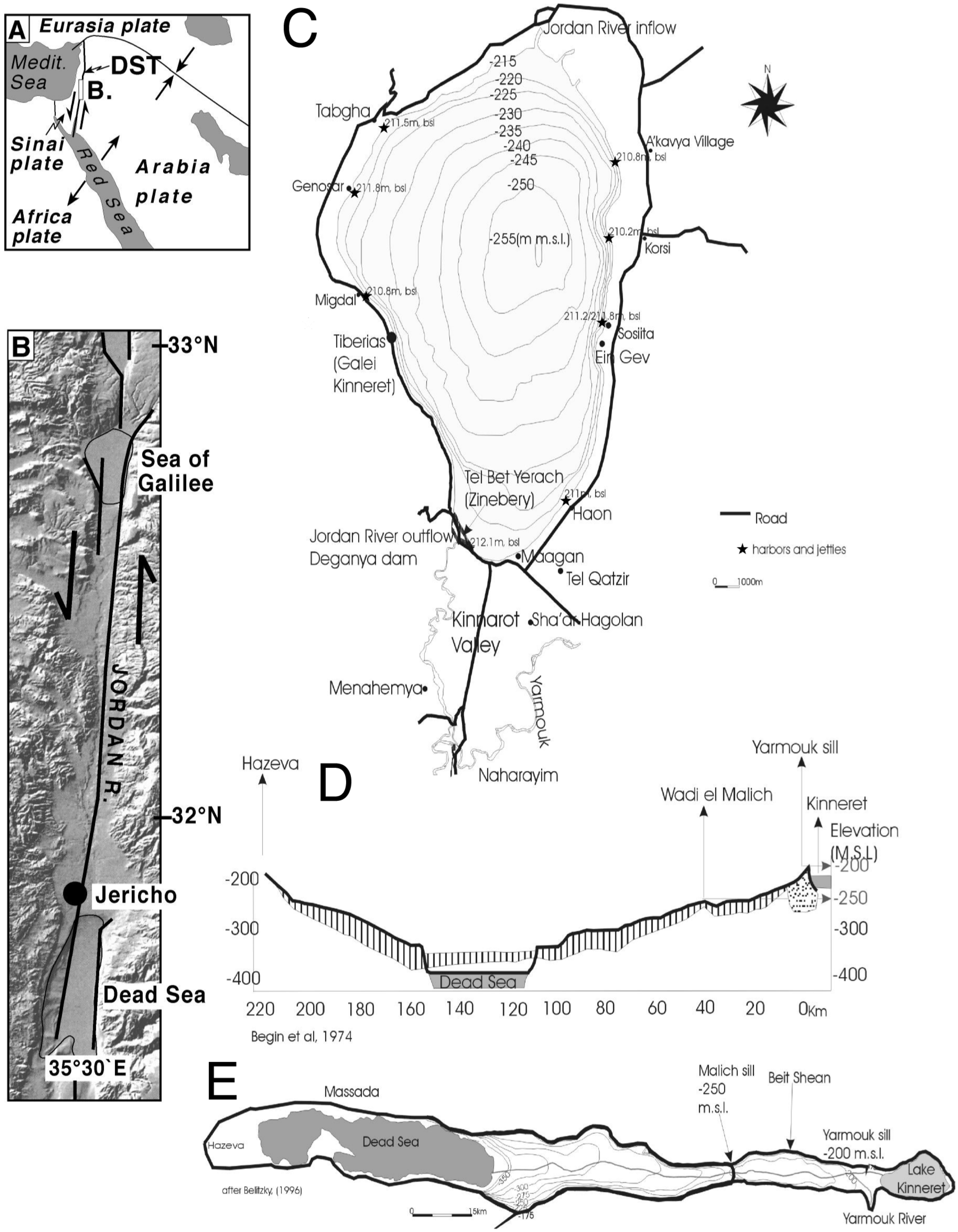

Fig. 1. Location map of the Kinneret area. A—Tectonic plates in the Middle East. B—Main faults and shaded relief of the Dead Sea–Sea of Galilee (Kinneret) area (after Hall, 1994; Ben-Avraham et al., 1996). C—Kinneret bathymetry with Roman–Byzantine harbors and jetties marked with stars and their elevations in meters (Nun, 1987). D,E—Topographic section along the Dead Sea–Kinneret depression (Begin et al., 1974).

Table 1
Historical periods in Israel

Period	Years
Early Roman	37 BCE–132 CE
Herod and his sons' reign	37 BCE–70 CE
Late Roman	132–324 CE
Byzantine	324–638 CE
Early Arabic—Ummayad	638–750 CE
Early Arabic—Abassid	750–1099 CE
Arabic and Crusader	1099–1291 CE

with the independently determined Dead Sea level curve (e.g., Frumkin et al., 1999; Bookman et al., 2004). The application of an integrated-regional lake level curve (Dead Sea + Kinneret) allows the isolation of a local tectonic component in the shoreline terraces. This work focuses mainly on an episode of relative level rise that occurred in Lake Kinneret during the Early Arabic period (Table 1) and discusses this episode in light of tectonic activity in the Kinneret basin.

2. LEVEL CHANGES IN LAKE KINNERET, LAKE LISAN, AND THE HOLOCENE DEAD SEA

The lateral extent and lake levels in the Dead Sea–Jordan Valley were controlled by the amount of input water, evaporation, and topographic and tectonic effects. The tectonic depressions limited the lakes between high stands, during which the water expanded onto the shallower margins (e.g., Bartov et al., 2002). During most of the Late Holocene, the Dead Sea level was typically at ~400 m below mean sea level (bmsl) reflecting the elevation of the sill (~401–403 m bmsl) between the deep northern and shallow southern basins. In the latter, enhanced evaporation occurs upon flooding (Bookman et al., 2004). Lake Kinneret's level could be controlled by the Yarmouk delta; for example, the delta could behave as a sill blocking the flow of the Jordan River out of Lake Kinneret (Ben-Arieh, 1964).

Level reconstruction of the Late Pleistocene Lake Kinneret revealed changes that are simultaneous with those of the southern Lake Lisan (Hazan, 2003; Hazan et al., 2004). For example, the highest stand (~170 m bmsl) of Lake Lisan at 26–24 ka is revealed by shorelines of Lake Kinneret on the margins of the Yarmouk delta, and the prominent lowstands of Lake Lisan (e.g., ~46–42 ka or 13–12 ka) are expressed by gaps in the Kinneret sedimentary record. Hazan et al. (2004) concluded that major level changes are simultaneous in both lakes, although the magnitude of change in the flow through Lake Kinneret is significantly smaller than in the terminal Lake Lisan (e.g., the maximum rise of Lake Lisan was ~120 m compared to ~40 m in Lake Kinneret). Thus, if Lake Lisan monitors the hydrological–climatic history of the region, this history is more moderately reflected by Lake Kinneret.

Evidence for smaller-scale changes in lake level that occurred over tens of years is provided by the geological outcrops and archeological sites such as Tel Qazir, Tel Bet Yerach, and Ohalo-II (Belitzky and Nadel, 2002; Hazan et al., 2004). Changes of this amplitude were documented by Torrance (reported in Ortenberg et al., 2002), who measured the Kinneret level between 1901 and 1910. The Survey of Palestine collected another set of measurements during the years 1926–1930 as part of the preparations for building the Deganya dam (Survey of Palestine, 1930, reported in Ortenberg et al., 2002). In exceptionally rainy years the lake rise exceeds the average level significantly. For example, in March 1929 the Kinneret level reached the elevation of 208.5 m bmsl, about 1 m above the normal level of the lake at this time of year. In November 1929 the lake level declined to the minimum stand of 211.7 m bmsl, more than 1 m below the typical lake level of 210.5 m bmsl. In analysis of the sedimentary section, unusual years like 1929 might be mistakenly interpreted as an interval of several years of lake level change. Thus, in order to assess the validity of significant trends in the hydrological–limnological system, it is desirable to compare two different sedimentary records. Here we compare the Middle to Late Holocene Lake Kinneret and the Dead Sea.

Figure 2 shows a comparison between Lake Kinneret and the Dead Sea level curves for the past 6,000 years. Lake levels were determined by identification of beach deposits and their radiocarbon dating (Hazan et al., 2004). However, the sedimentary information is not continuous and we chose two mineralogical–geochemical parameters that can be applied as indirect monitors of lake level: the content of authigenic $CaCO_3$, and $\delta^{18}O$ values in core recovered from the southern part of the Kinneret (data from Stiller et al., 1984). The amount of $CaCO_3$ in the sediment is an indicator of primary production in the lake, which is affected by sedimentation rate. Most of the $CaCO_3$ settles at the lake bottom and some of this is dissolved in the hypolimnion. Strong floods from the rivers around the lake bring large amounts of allochthonous sediments that settle at the lake bottom and dilute the authigenic $CaCO_3$. Figure 2E shows minimum $CaCO_3$ in the core at ~5.2 and 2 ka BP, when Dead Sea levels are high. The Dead Sea levels are well correlated with the regional precipitation (Bookman et al., 2004). Thus, the minimum $CaCO_3$ can be correlated with both high Dead Sea levels and enhanced regional precipitation, and the $CaCO_3$ curve can be used as an indirect "proxy" for flood input and possibly for level changes in Lake Kinneret. In contrast to the shallow water sedimentary environment of the Middle to Late Holocene period in Tiberias, sedimentary cores drilled near the Ohalo–Tel Bet Yerach shore recovered calcitic marls with minor allochthonous components representing the Late Pleistocene deep water environment (Hazan et al., 2004).

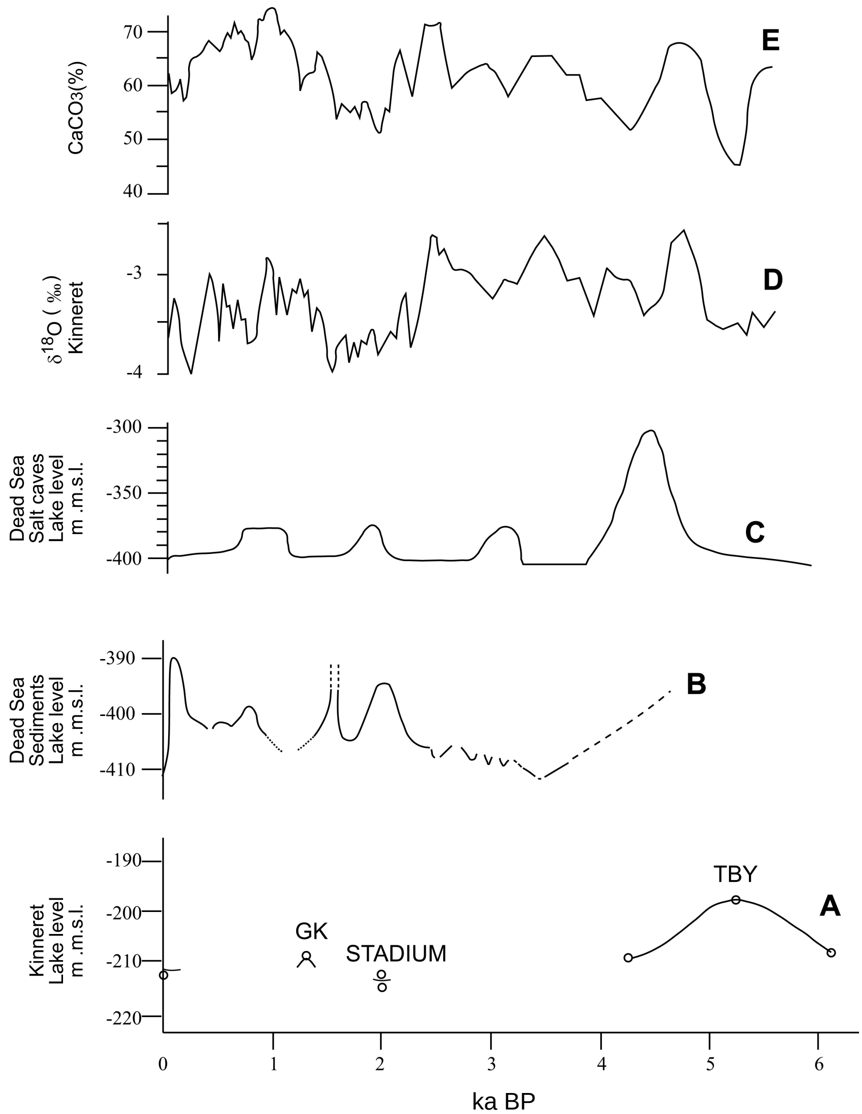

Fig. 2. Comparison diagrams in the last 6,000 years. A—Kinneret Lake level curve (Hazan, 2003). B—Dead Sea level curve, made from lake sediments (Bookman et al., 2004). C—Dead Sea level curve made from Mt. Sedom salt caves (Frumkin et al., 1991). D—$\delta^{18}O$‰ of carbonate fraction in Lake Kinneret sediments (Stiller et al., 1984). E—% $CaCO_3$ in Lake Kinneret sediments (Stiller et al., 1984). TBY = Tel Bet Yerach; GK = Galei Kinneret.

$\delta^{18}O$ in the carbonate fraction of the Kinneret sediments (Fig. 2D) can be used as an indicator of water temperature and/or amount of precipitation (Stiller et al., 1984). The curve shows a pattern similar to that of % $CaCO_3$ (Fig. 2E).

Overall, Fig. 2 suggests that during most of the past 6,000 years the Kinneret and the Dead Sea levels underwent correlated rises and declines. A clear exception appears around 700–800 CE when the Dead Sea was low (and the regional climate was dry), but the Galei Kinneret site in Tiberias indicates a high stand.

3. THE GALEI KINNERET SITE

The Galei Kinneret archeological site located some 50 m from the lake shore, south of the city of Tiberias (Fig. 1), is situated between 208 and 212 m bmsl. The site was partly flooded in the 20th century, when the lake level fluctuated between 209 and 213 m bmsl, and was exposed when the lake level dropped in recent years to a record low of 214 m bmsl (Hambright et al., 1997).

Archeological excavations in 2002, led by Moshe Hartal of the Israel Antiquities Authority, revealed that

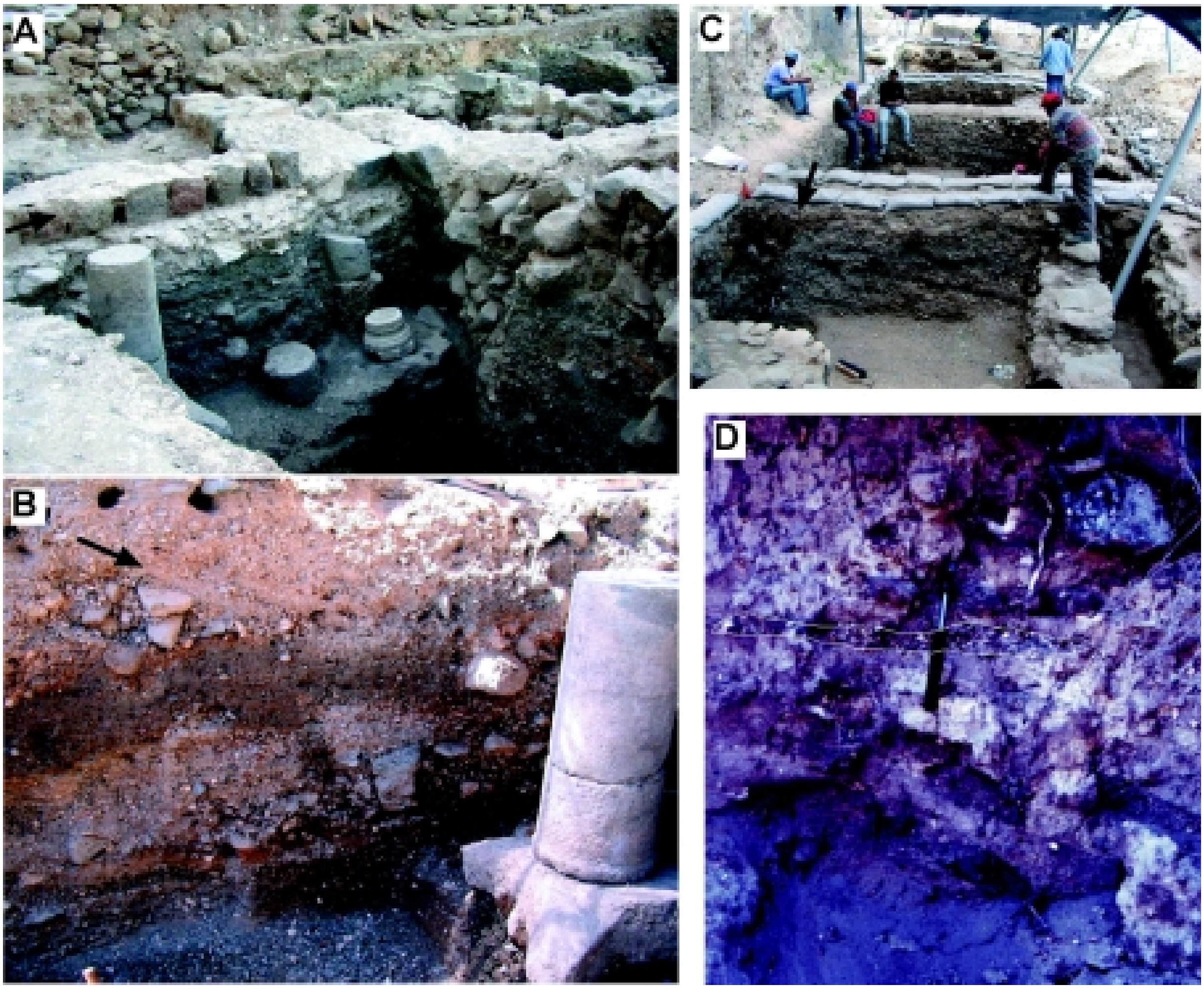

Fig. 3. A—Columns of the Ummayad period buried by Kinneret sediments. A later wall of the Abassid period (arrow) overlies the sediments. B—Lacustrine beach ridge (arrow) at the top of a sedimentary section, which buried an Ummayad column at right, the same column that is on the left side of Fig. A. C—Photo of walls from the Early Arabic period covered by lakeshore sediments. D—Photo of lens of pebbles and melanopsides (encircled by white line) in Tel Bet Yerach at 200.3 m bsl. Note the bricks from the Early Bronze below the lens. The ages in the Galei Kinneret site are based on archeology. The age of ~5.2 ka at Tel Bet Yerach are based on radiocarbon dating of Melanopsis shells assuming 1000-year hard water correction (Hazan et al., 2004).

Roman, Byzantine, and Early Arabic buildings were completely buried by alluvium and lake sediments up to an elevation of 208.5 m bmsl (Fig. 3). An important finding was a sector of an oval structure at 212 m bsl. It was interpreted as the foundation of the Roman stadium. Josephus Flavius described the stadium (Flavius, 1982). The excavation also revealed a fault that offsets the Ummayad and older buildings but does not offset the later sediments and buildings of the Abassid period. The faulting was therefore associated with the 749 CE earthquake that shook the area around the Dead Sea–Kinneret basin (Marco et al., 2003). Marco et al. argue that the Roman and Arab builders constructed the monumental stadium and other buildings in the vicinity on the shore, confident that the structures were safe and permanent. For several centuries the planning of the Roman builders proved correct, and later buildings were also planned and built at the same level during the Byzantine period and the first decades of the Early Arabic period. Other Roman and Byzantine maritime installations—jetties and small piers—are known from around the lake at elevations of about 212 ± 1 m bsl (Fig. 1). This could indicate that lake levels during these periods were at ~212 mbsl. However, the Dead Sea level and independent geochemical data from Lake Kinneret cores suggest a rainy period during Roman times (Stiller et al., 1984; Dubowski et al., 2003). Thus, we suggest that the Roman to Ummayad buildings were constructed at a higher level and subsided tectonically to their present elevation at 212 m bmsl.

The age of sediments overlying the Ummayad buildings is constrained by archeology and by the 749 CE fault, which offsets them. The finding of lake sediments, including beach deposits up to 208 m bsl in Galei Kinneret, above the Roman to Ummayad structures, is surprising. A lake rise during the early Arabic period could explain these findings but contradicts the low stand period observed in the Dead Sea from 600 till about 1000 CE discussed above. An alternative explanation for the lake sediments above the structure could be a local tectonic subsidence before the earthquake of 749 CE. Assuming that the Roman stadium, which is the lowest building at the site, was built above the high stand level of Roman times (>208 m bmsl), it appears that the tectonic subsidence of the Roman–Ummayad structures was more than 4 m. We speculate that such a tectonic subsidence could also be responsible for the disappearance of the Roman harbor of Tiberias.

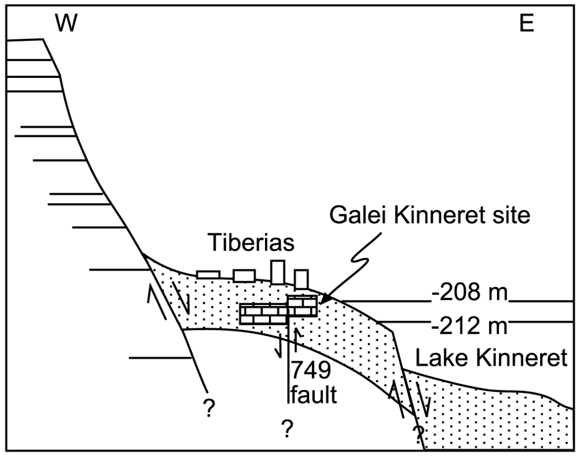

Fig. 4. A schematic E–W section in the Tiberias area.

4. TECTONICS IMPLICATIONS

The NW-striking normal fault zone in the southwestern margin of the Kinneret basin accommodates a NE–SW extension. This fault zone is linked to the N-striking fault, which forms the western boundary of the Kinnarot Valley. We suggest that the latter fault is primarily a sinistral strike slip fault, whereas the NW normal faults are part of the strike slip termination mechanism. The overall sinistral strike slip motion on the DST is compatible with NW–SE-striking compression and SW–NE-striking extension. Locally antithetic parallel faults may occur, such as in the Galei Kinneret case, where the hanging wall is the west block. Since the main Kinneret basin is subsiding east of the site, there must be another fault further east, of which the hanging wall is the eastern block (Fig. 4).

ACKNOWLEDGMENTS

We thank Moshe Hartal for his hospitality and cooperation in the exploration of the Galei–Kinneret site. The manuscript benefited from constructive reviews and suggestions of Mira Stiller, Revital Bookman, and Amotz Agnon. The Israel Science Foundation (ISF) supported the study (grant #304.02 to MS and grant #690/99 to SM).

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