

Chapter 3

Late Quaternary Limnological History

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Abstract Lake Kinneret, occupying the tectonic depression of the Kinnarot basin, has channeled freshwater throughout the late Quaternary times to the terminal lakes in the Dead Sea basin. The history of the water-bodies in the Dead Sea basin commenced with the late Neogene transgression of the Sedom lagoon and was followed by the formation of several saline- to hypersaline lakes. The lakes comprise Ca-chloride brine that was initially formed by the Sedom lagoon. The brines migrated all over the Jordan Rift Valley and are expressed in the compositions of saline springs that are currently discharged into Lake Kinneret. The chapter presents a summary of the limnological history of the lake during the past 40 ka, as reflected in the sedimentary sequences that are exposed around the lake (e.g., Tel Bet Yerach, Tel Qazir) and recovered from trenches and drilled cores (e.g., the Ohalo-II archaeological site). The lake reached its highest stand of ~160 m below mean sea level during the last glacial maximum (~27–24 ka BP) and merged with Lake Lisan. At 24–23 ka BP, it declined below the modern level during the Heinrich (H2) event. Sr/Ca concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios in modern lake waters and saline springs and in fossil *Melanopsis* shells and ostracods provide constraints on contributions of the fresh and saline waters to the lake during these high- and low-stand periods.

Keywords Brines · Dead Sea rift · Heinrich events · Holocene · Lake level · Lisan · Paleoclimate · Quaternary

3.1 Introduction

During the late Neogene–Quaternary times, the tectonic depressions that were developed along the Dead Sea Transform (DST) were occupied by fresh- to hypersaline water-bodies: e.g., the late Neogene Bira and Gesher water-bodies, the Sedom lagoon, and the Quaternary lakes of Amora, Samra, Lisan, Dead Sea, Hula, and Kinneret (Sea of Galilee; Fig. 3.1). The sediments that were deposited in these water-bodies comprise the “Dead Sea Group” (Zak 1967; Fig. 3.2) that stores the

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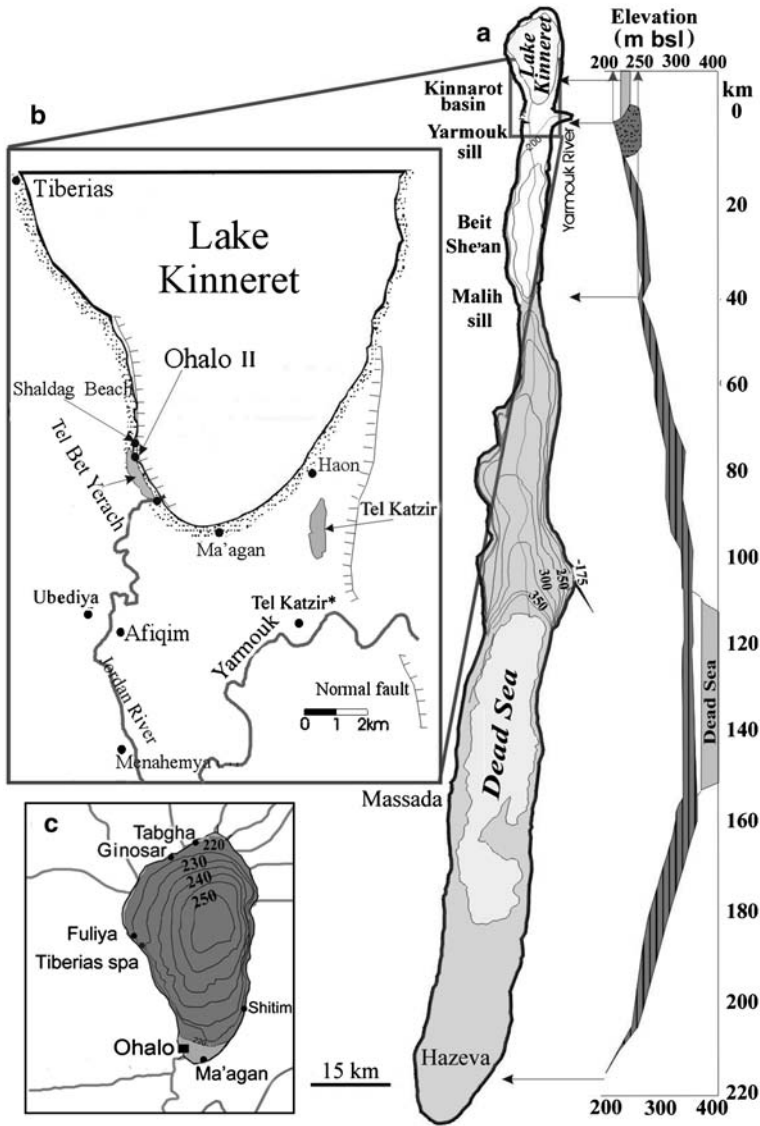


Fig. 3.1 Location map of Lake Kinneret with insets to show specific details. **a** The modern hypersaline Dead Sea and the freshwater Lake Kinneret and the maximum extent of the last glacial Lake Lisan when it reached the elevation of ~160 m b.m.s.l. and merged with Lake Kinneret. The Malih and Yarmouk sills at ~260 and 200 m b.m.s.l. are marked. A north–south section across the tectonic depressions of the Kinnarot basin, Jordan Valley, and the Dead Sea basin is shown on the *right*. **b** Details of the southern part of Lake Kinneret with locations of study sites: Tel Bet Yerach, Shaldag beach, Ohalo-II archaeological site, the Tel Qazir section, Galei Kinneret archeological site, Tiberias Ubediya archeological site, and the Menahemya section. The Erq El Ahmer section (site not marked) is located south to Menahemya. **c** The bathymetry of the modern Lake Kinneret and water and *Melanopsis* shells and ostracods sampling sites: Ohalo, Ma’agan, Fuliya (springs) Ginosar, and Tabgha

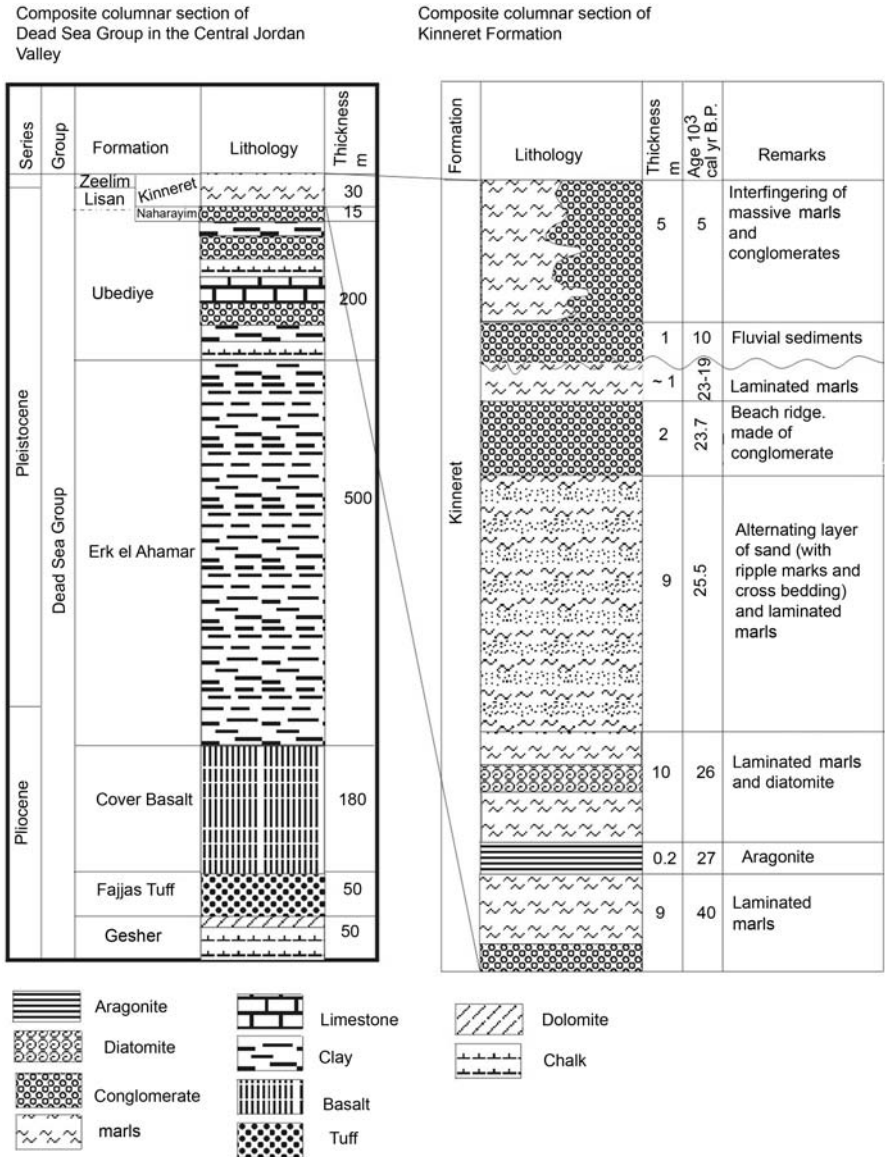


Fig. 3.2 Stratigraphy of the Neogene–Quaternary Dead Sea Group in the Kinnarot basin. The current study focuses mainly on the time interval of the past 40 ka (after Hazan et al. 2005). The main lithological units are laminated marls that contain a significant amount of primary carbonate that deposited from the lake and detrital layers composed mainly of calcite, quartz, and pebbles

environmental–hydrological history of the region (e.g., Neev and Emery 1995; Stein 2001). The water-bodies are located between the current Sahara–Arabia desert belt and the Mediterranean climate zones and their large watershed receives rains and

dust from both regions (Frumkin and Stein 2004; Haliva-Cohen et al. 2012). The waters filling the lakes comprise mixtures of Ca-chloride brine that was originally formed in the late Neogene Sedom lagoon and freshwater from the watershed. The fluxes and mixing between these solutions are dictated by the hydrological regime that in turn reflects regional and global climate. Over the past few decades, extensive efforts have been devoted to establish the geochemical–limnological history of the lakes filling the southern Dead Sea tectonic depression (from the early works of Bentor 1961; Zak 1967; Neev and Emery 1967; Starinsky 1974; Begin et al. 1974; Katz et al. 1977 to more recent works by Stein et al. 1997, 2000; Waldmann et al. 2007; Torfstein et al. 2008, 2009, 2013a, 2013b; see, also review articles in the book “New Frontiers in Dead Sea Paleoenvironmental Research” edited by Enzel et al. 2006).

Here, I focus on the geochemical–limnological history of the late Quaternary Lake Kinneret (Sea of Galilee) that occupies part of the Kinnarot tectonic basin (Fig. 3.1). Unlike the hypersaline terminal Lake Lisan and Dead Sea where water was lost through evaporation and seepage into the adjacent aquifers, Lake Kinneret was for most of its history a fresh, flow-through water-body. Nevertheless, Lake Kinneret’s composition is affected by inflows of Ca-chloride brines originated during the late Neogene ingression of the Sedom lagoon (Starinsky 1974). The mechanism of discharge and contribution of the brines to Lake Kinneret has long been a scientifically controversial issue among researchers and is discussed in this chapter in context with its geological history.

3.2 From the Late Neogene Sedom Lagoon to the Modern Dead Sea

The history of the late Neogene–Quaternary water-bodies along the DST commenced with marine ingression into the tectonic depressions of the Yisre’el and Jordan Valleys (e.g., Shaliv 1991; Zak 1967). The late Neogene sedimentary sequences comprise the Bira and Gesher Formations that were deposited between ~10–4 Ma (Shaliv 1991, Heimann et al. 1996; Heimann and Braun 2000) and the Sedom Formation that was deposited in the Dead Sea basin (Zak 1967). The Bira and Gesher Formations consist of marine-lagoonal and lacustrine sequences that are interlayered with volcanic flows and pyroclastic units (Schulman 1962; Shaliv 1991). The Sedom Formation is exposed at the salt diapir of Mount Sedom and was recovered in deep boreholes (Zak 1967). A thick sequence of salts, of marine origin, which may have been deposited in the Kinnarot basin along the same time, was recovered in the Zemah borehole (Marcus and Slager 1985). Other evidence for the sedimentation from the marine lagoon is provided by salt diapirs that were detected in the central Jordan Valley (Belitzky and Mimran 1996; Gardosh and Bruner 1998; Shaliv 1991).

3.2.1 *The Sedom Lagoon*

The Sedom Formation comprises a sequence of salts, marls, and clastic units (Zak 1967). The extensive thickness of the halite sequences (a few thousand meters) and other geochemical observations led Zak (1967) to suggest that these evaporites precipitated in a marine lagoon, probably connected to the Mediterranean Sea. Most notable of these geochemical indicators is the molar Br/Cl ratio in the halite layers ($0.03\text{--}0.18 \times 10^{-3}$) and the $\delta^{34}\text{S}$ composition of the Ca-sulfates ($19.8 \pm 0.8\%$; Raab et al. 1997; Stein et al. 2000), which attest to a marine origin of salts, and they are consistent with the sulfur isotope composition of Neogene marine water. Yet, the age of the Sedom lagoon is not well constrained and has been a matter of a long and ongoing debate. Zak (1967) used general stratigraphic and some faunal considerations to suggest a late Pliocene–early Pleistocene age for this lagoon and also estimated that the deposition of salts in this lagoon lasted ~ 1 Ma. Recently, Belmaker et al. (2013) used atmospheric ^{10}Be decay to date directly the salts of the Sedom Fm. They calculated ages in the range of $\sim 5\text{--}3$ Ma, consistent with the estimate of Steinitz and Bartov (1991) that relied on general stratigraphic correlation to the Neogene formations at the Yisre'el and Jordan Valleys. Recent efforts to date the Pliocene Erk-El Ahmer Formation, which is exposed in the Jordan Valley south to Lake Kinneret (Fig. 3.1) and considered to comprise freshwater lake deposit (e.g., Braun 1992), yielded ^{10}Be burial age of $\sim 4.3\text{--}3.6$ Ma (Davis et al. 2011). These ages are comparable to the abovementioned atmospheric ^{10}Be ages of the Sedom salts. If both age estimates were correct, they would infer that during the late Neogene period, freshwater and hypersaline water-bodies coexisted in the Dead Sea–Jordan valley, similar to the present-day configuration. This may imply that the ingression and disconnection of the Sedom lagoon from the open sea was much earlier, perhaps in the mid-Pliocene time (e.g., $\sim 7\text{--}6$ Ma, Shaliv 1991) before the Messinian salinity crisis.

3.3 Late Quaternary Lakes in the Dead Sea basin

After the disconnection of the Sedom lagoon from the open sea, a series of lakes occupied the Dead Sea basin and the Jordan Valley. The available information on the geochemical and limnological evolution of the early to mid-Pleistocene Lake Amora and the last interglacial Lake Samra is summarized and discussed in Torfstein et al. (2009), Waldmann et al. (2009), respectively. Here, I shortly summarize the histories of the last glacial Lake Lisan and the Holocene Dead Sea that coexisted with Lake Kinneret.

Lake Lisan filled the Dead Sea basin and the Jordan Valley between ~ 70 and ~ 14 ka (Haase-Schramm et al. 2004; Torfstein et al. 2013a, 2013b). At its highest stand (~ 160 m below mean sea level, b.m.s.l.), the lake extended from the Sea of Galilee in the north to the Hazeva area in the south (Fig. 3.1). In the vicinity

of the Dead Sea basin, primary aragonite and gypsum were deposited in this lake (Katz et al. 1977; Stein et al. 1997; Torfstein et al. 2008) together with silt-sized detritus material. The silty detritus material in the lacustrine formations consists of dust grains blown from the North Sahara deserts mainly during the last glacial period (Haliva-Cohen et al. 2012). The aragonite precipitating solution comprised a mixture of freshwaters that contained bicarbonate and the Ca-chloride brine (Stein et al. 1997). Most of the freshwaters originated in the Phanerozoic carbonatic terrains comprising the northern and central parts of the Dead Sea watershed (e.g., Mt. Hermon, Galilee, and Judea Mountains). The freshwaters are primarily supplied by the Mediterranean winter rains that in turn are activated by the Cyprus cyclone (Frumkin and Stein 2004; Ziv et al. 2006; Kushnir and Stein 2010).

At ~17.4 ka BP, Lake Lisan commenced its retreat from its high stand above the marginal terraces and declined to a minimum stand, and below 450 m b.m.s.l. during the Bölling-Allerod period (~14–13 ka BP). Then, during the Younger Dryas (~12–11 ka BP), it rose again and declined at 11–10 ka BP depositing thick sequence of salts (Stein et al. 2010). During the Holocene (the lake is termed the Dead Sea), it stabilized at ~400±30 m b.m.s.l. (Bookman et al. 2004; Migowski et al. 2006; Stein et al. 2010; Fig. 3.3). The lake expansion and retreat coincided with the global cooling/warming that generally imposed more wet/arid conditions in the east Mediterranean–Levant region (Stein 2001; Kushnir and Stein 2010; Torfstein et al. 2013b).

3.4 The Late Pleistocene–Holocene Limnological History of Lake Kinneret

Lake Kinneret, currently at an elevation of ~210 m b.m.s.l., is located in the northern part of the Kinnarot basin, one of the tectonic depressions that were formed along the DST (Fig. 3.1). The surrounding Golan and Galilee mountains comprise Pliocene–Pleistocene basaltic flows, Eocene limestones and chinks, and Neogene sandstones (Heimann and Braun 2000).

Freshwaters are supplied to Lake Kinneret by the Jordan River whose tributaries, the Dan, Baniyas, and Hazbani, discharge via Jurassic carbonate rocks of Mt. Hermon and rivers and streams draining the basaltic and carbonatic terrains of the Golan Heights and the eastern Galilee.

Saline-waters discharge to Lake Kinneret by several onshore and within-lake springs (i.e., Tabgha, Fuliya, and Tiberias Spa, with 300–18,000 mg Cl L⁻¹; Kolodny et al. 1999 and references therein). The mixing of the saline solutions with the freshwaters dictate the salinity of the lake (e.g., Gat et al. 1969; Goldschmidt et al. 1967; Starinsky 1974). At the beginning of the twentieth century, the chloride concentration was below 300 mg Cl L⁻¹ and dropped to ~230 mg Cl L⁻¹ after the diversion of the saline springs via the Salinity Diversion Channel (Serruya 1978; Kolodny et al. 1999).

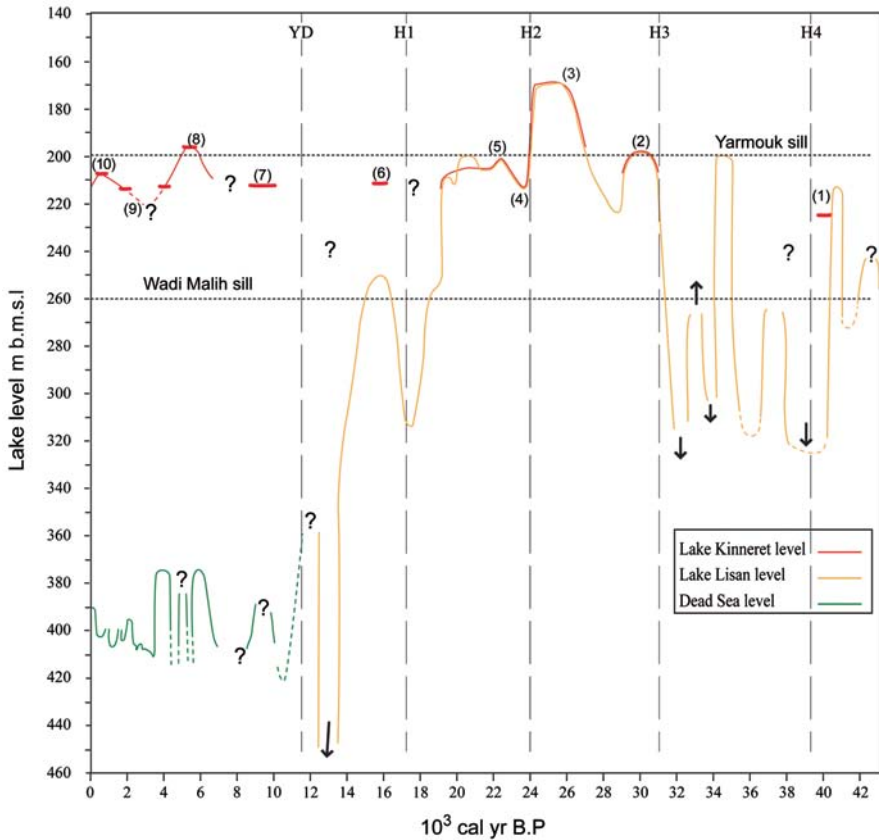


Fig. 3.3 Water level curves for Lake Lisan, Lake Kinneret, and the Dead Sea for the past 40 ka. The curves are based on the works of Bartov et al. (2002, 2003), Bookman et al. 2004, Hazan et al. 2005, Migowski et al. 2006, Stein et al. 2010, Torfstein et al. 2013b). Lake Lisan and Lake Kinneret merged at ~27–24 ka BP (during MIS2), and possibly at ~30 ka BP when Lake Kinneret water level crossed the Yarmouk sill at ~200 m b.m.s.l. Note the simultaneous mid-Holocene rise at both lakes Numbers relate to the sites where paleo- lake levels were determined and dated: (1,2) Kinneret drill at Ohalo-II (KIN2); (3) Tel Katzir; (4,5,6) Ohalo-II and Shaldag beach trenches; (7,8,9) Tel Bet Yerach; (10) Galie Kinneret archeological site

3.4.1 Origin of the Saline Springs

The origin and contributions of saline solutions to Lake Kinneret attracted the attention of many researchers (e.g., Stiller et al. (2009) and references therein). Goldschmidt et al. (1967), Mazor and Mero (1969), Starinsky (1974) classified the saline waters according to their chemistry and geographical locations, where solutions with high Ca/Mg ratios (e.g., Tiberias Spa) are limited to the western side of the lake and those with low Ca/Mg ratios are limited to the lake's eastern and southern side (e.g., Ha'on, Table 3.1).

Table 3.1 Chemical composition and $87\text{Sr}/86\text{Sr}$ isotope ratios of fresh and saline waters in the Dead Sea and Lake Kinneret hydrological system

Water source	Conc.	$87\text{Sr}/86\text{Sr}$	Sr	Ca	Sr/Ca	Mg	Na	K	Cl	SO ₄	HCO ₃	TDS	References
					eq								
	<i>g/L</i>												
Dead Sea		0.70803	0.314	16.7	0.0086	43.8	35.6	7.41	220	0.28	0.20	324	Stein et al. 1997
En Kedem spring		0.70796	0.205	11.5	0.0081	20.8	25.9	4.02	124	0.75	0.09	187	Stein et al. 1997
En Gedi 3 well		0.70798	0.198	8.3	0.0087	12.5	24.6	3.28	90.9	1.19	0.169	140	Stein et al. 1997
Tiberias spa		0.70785	0.06	3.48	0.0079	0.68	6.81	0.35	18	0.69	0.154	30.5	Stein et al. 1997
Fuliya (S-West)		0.70787	0.0015	0.16	0.0043	0.07	0.37	0.012	0.755	0.10	0.313	1.78	Klein-BenDavid et al. 2004; Bergelson et al. 1999
Ha'on			0.0044	0.56	0.0036	0.91	3.69	0.45	8.49	0.77	0.548	15.5	Klein-BenDavid et al. 2004
Rosh Pina deep				27		2.9	33.4	1.16	105	0.7	0.171	171	Klein-BenDavid et al. 2004
	<i>mg/L</i>												
Lake Kinneret ^a		0.70747	0.644	38.9	0.0076	29.6	114	6.2	218	51.8	118.2	577	Stein et al. 1997
Lake Kinneret ^b			0.766	53.5	0.0066	34.8	141	7.44	284	57.4	154	733	Klein-BenDavid et al. 2004
Jordan Arik bridge		0.70669	0.1	43.8	0.0010	9.7	12.2	1.5	18.3	21.3	200	307	Stein et al. 1997
Jordan Yoseph bridge		0.70723	0.05	59.9	0.0004	7.7	6.5	0.98	9.8	25.6	201	312	Stein et al. 1997
Runoff (Darga)		0.70811	0.39	46.2	0.0034	6.5	17.4	4.6	23	54	112	292	Stein et al. 1997

^a surface water 16/7/1995^b mixed lake

The saline spring solutions have salinities similar to that of seawaters; yet, they are depleted in Na (and therefore enriched in Ca+Mg) and enriched in Br relative to seawaters. Based on the isotope composition of oxygen and hydrogen, Gat et al. (1969) concluded that the solutions evolved through a stage with salinity higher than seawater and were later diluted. Several authors suggested that the saline solutions have their roots in the Sedom lagoon that funneled evaporated seawater into the late Neogene rift valley (Goldschmidt et al. 1967; Mazor and Mero 1969; Starinsky 1974). In the vicinity of the Dead Sea basin, the ingressing evaporated seawater interacted with the limestones comprising in the wall rocks of the lagoon (possibly by flowing in the regional aquifers), dolomitized the rocks, and changed their original composition to Ca-chloride brines (Starinsky 1974; Stein et al. 2000). It should be noted that evaporation of seawater alone would produce sulfate-rich brines rather than the observed Ca-chloride brines.

Starinsky (1974) examined the compositions of the modern saline solutions discharged into Lake Kinneret and compared them to the Dead Sea brine and other brines recovered from subsurface drills. The Kinneret saline solutions are diluted in comparison to the modern Dead Sea brine. Waters similar to those of the Kinneret saline springs were recovered from a depth of 2.5 km in the Rosh-Pinah-1 drill hole, located within the rift valley. Brine recovered from the depth of 3.8 km in this borehole shows similarity to the solution recovered from the deep Sedom-2 borehole in the Dead Sea basin attesting to the possible linkage between the subsurface brines at the Dead Sea basin and Lake Kinneret. Starinsky (1974) proposed that the Kinneret saline waters originated at the Sedom lagoon at the Dead Sea basin, where salt was deposited causing the Na/Cl ratio to decrease. Their late dilution with freshwater explains the additional Br contents. The Sedom brines migrated northward in the subsurface aquifers towards the Kinnarot basin. This migration could occur during the existence of the late Neogene Sedom lagoon and later after the disconnection of the lagoon from the open sea and existence of the Dead Sea lakes (e.g., lakes Amora and Lisan). This scenario of temporal migration of the brines could explain the different compositions (Na/Cl, Ca/Mg, Cl/Br) of the saline springs on the western and eastern sides of the modern Lake Kinneret. An alternate scenario invokes the existence of a large hypersaline lake that occupied the entire late Neogene rift valley and its solution infiltrated the mountain aquifers along the western (Judea–Galilee) margins of the rift. Currently, the ancient brines are discharging back into Lake Kinneret and the Dead Sea (e.g., Tiberias Spa and En Kedem, respectively). The evidence for the eastward migration of the ancient Ca-chloride brine can be found in waters drilled in the Yisre’el Valley.

Several mechanisms were proposed to explain the discharge of the saline springs into Lake Kinneret: location along deep faults that enable the upwelling of saline groundwater, tectonic pressure or a geothermal energy-driving mechanism (Mero and Mandel 1963; Mero and Zaltzman 1967), and the hydrological head due to the presence of freshwater aquifers in the Galilee Mountains west of LK (Goldschmidt et al. 1967). The study of the geological–geochemical archives of Lake Kinneret provides important evidence to address this issue.

3.5 The Late Pleistocene and Holocene History of Lake Kinneret

The hydrological history of Lake Kinneret is reflected in its water-level fluctuations. Modern water levels of Lake Kinneret were measured by Torrance (1901–1910) and by the Survey of Palestine (1926–1930, works for the construction of the Degania Dam). In exceptionally rainy years, the lake rose significantly above the average level. For example, in March 1929, the level reached an elevation of 208.5 m b.m.s.l., about 1 m above the normal level of the lake at that time of year. In November 1929, the lake level declined to the minimum stand of 211.7 m b.m.s.l.

The information on the late Pleistocene–Holocene limnological history of Lake Kinneret is inferred from a few exposures at the elevated hills around the lake: Tel Bet Yerach (TBY) and Tel Qazir, sediment profiles recovered from trenches and cores drilled at the Ohalo-II shore and other sites within the lake (Figs. 3.1 and 3.3). The exposures and part of the sediment cores were studied and described by Stiller et al. (1984), Marco et al. (2003), Dubowski et al. (2003), Hazan et al. (2005). The exposed sedimentary sequences were mainly deposited during the last glacial period when the lake level rose above the modern stand. Holocene sequences were mainly recovered from cores drilled in the northern part of Lake Kinneret and from TBY. The recovered sedimentary cores and trenched sequences comprise mainly layers and laminae of primary calcite that was deposited from the lake and detrital calcite, quartz, and clays that were transported to the lake by rivers, runoff, and direct deposition of settled dust. The shore sedimentary sequences, e.g., at the Tel Qazir exposure also contain coarse detritus units that were transported by the Yarmouk River. The sedimentary sequences that were recovered at the modern lake's shores (e.g., at the Ohalo-II archeological site) contain fossil fauna such as *Melanopsis* shells and ostracods that comprise archives of geochemical properties of the lake water (see further). Lev et al. (2007) investigated the potential of using *Melanopsis* shells as radiocarbon chronometers. They applied the radiocarbon contents in living *Melanopsis* and modern water to quantify the radiocarbon reservoir age correction, which is about 800 years. Fossil *Melanopsis* shells of independently known ages (e.g., archeological dates) yielded similar reservoir age. Hazan et al. (2005), Lev et al. (2014) applied Sr/Ca ratios and $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios in *Melanopsis* shells and in ostracods from the last glacial (Lisan time) to trace the water sources and degree of mixing between freshwater and Ca-chloride brines in the lake (see further).

3.5.1 Times of Convergence and Abrupt Drops in Kinneret and Lisan lakes

The freshwater Lake Kinneret and the hypersaline Lake Lisan and the Dead Sea comprise a “chained-lakes system” that are connected by the Jordan River and respond to the regional climatic–hydrological conditions in the watershed. Over the past two decades, extensive efforts were devoted to the reconstruction of lake level

curves for Lake Lisan, the Dead Sea, and Lake Kinneret considering the potential of using these curves as gauges of rains in the watershed (e.g., Neev and Emery 1995, Bartov et al. 2002, 2003; Bookman et al. 2004; Hazan et al. 2005; Migowski et al. 2006. Stein et al. 2010; Torfstein et al. 2013a, 2013b). Enzel et al. (2003) showed that instrumental annual records of rains in the modern Dead Sea watershed indicate rapid response of levels to higher/lower annual precipitation. The last significant manifestation of this behavior was recorded in the extremely rainy winter of 1991/1992, when ca. $800 \times 10^6 \text{ m}^3$ of Lake Kinneret water were released through the southern Jordan River, thus raising the Dead Sea level by 2 m. An interesting related question concerns the long-term behavior of water levels of freshwater Lake Kinneret as compared to the hypersaline Lake Lisan and Dead Sea because the magnitude of evaporation depends on salinity. The level curves for Lake Lisan and Lake Kinneret (Fig. 3.3) were constructed independently, thus allowing an evaluation of their short and long-term behavior, e.g., during different climate periods and in times of abrupt climate changes such as severe regional aridities. The resolution of the Lake Lisan–Dead Sea level curve is much higher than that of Lake Kinneret, reflecting the available shoreline data and the works that were devoted to the lakes. The curves presented in Fig. 3.3 are updated to the most recent reconstruction of Torfstein et al. (2013b).

The lake level diagram indicates the following:

1. Lake Lisan and Lake Kinneret converged between ~ 27 and 24 ka when their levels reached the maximum elevation of ~ 160 m b.m.s.l. At this stand, the lakes could rise above the sills formed by the fan deltas of Wadi Malih and Yarmouk Rivers (Fig. 1). It should be emphasized, however, that despite the convergence of lakes during this high-stand period Lake Kinneret was a freshwater lake that precipitated primary calcite while Lake Lisan precipitated primary aragonite.
2. At ~ 30 ka BP, both lakes approached the elevation of the Yarmouk sill and possibly converged.
3. Both lakes declined simultaneously to low stands during times that coincided with the Heinrich events at the northern Atlantic: at ~ 40 ka BP, coinciding Heinrich event 4 (H4), Lake Kinneret declined to ~ 222 m b.m.s.l. significantly below the Yarmouk sill. Lake Lisan declined at that time to ~ 330 m b.m.s.l. significantly below the Malih sill. At ~ 24 ka BP, coinciding with Heinrich event H2, both lakes declined below the Yarmouk sill: Lake Kinneret declined to ~ 214 m b.m.s.l. at the elevation of the Ohalo-II shore where the archeological site was excavated (see further).
4. At ~ 6 ka BP Lake Kinneret rose above the Yarmouk sill covering TBY. This lake rise coincided with the mid-Holocene rise of the Holocene Dead Sea.

It appears that when data are available and allow direct comparison between the two lakes, their levels display similar behavior—they rose and declined simultaneously, indicating the modulation of hydrological conditions by the same regional and global climatic systems. Nevertheless, independent changes in the limnological behavior of the lakes could occur reflecting the different evaporation properties and the supply of freshwater from the regional drainage. For example, southern Negev



Fig. 3.4 Study sites. **a** Trenching at the Ohalo shore, where the archaeological site Ohalo-II was excavated. Trenching recovered the late glacial section $\sim 24\text{--}20$ ka BP (Hazan et al. 2005, Lev et al. (2014)). The section comprises laminated and massive marls and silts that were deposited at the shallow lake after its drop from the last glacial (MIS2) highest stand of ~ 160 m b.m.s.l. Recently, we studied the lithology of the trenched section and analyzed chemical and isotope compositions (e.g., $\delta^{18}\text{O}$, $^{87}\text{Sr}/^{86}\text{Sr}$, Sr/Ca, Mg/Ca) of ostracods that were recovered from the section (Lev et al. (2014)). **b**, **c** Tel Bet Yerach, the archeological section overlying the geological section; the sediments comprising the section are laminated calcitic marls that were deposited in the high-stand Lake Kinneret (Hazan et al. 2005)

storms could cause major floods via the Arava–Zin River’s drainage into the Dead Sea (e.g., Waldmann et al. 2010; Haliva-Cohen et al. 2012). The floods brought waters and mostly sediments to the southern lakes with no clear documented response in Lake Kinneret.

3.5.2 Geological Studies in Sites Around Lake Kinneret

3.5.2.1 The Ohalo-II Archeological Site and the Menahemya Section

The Ohalo-II shore (Figs. 3.1 and 3.4) located on the southwestern side of Lake Kinneret beneath TBV was exposed during the low lake stand of the late 1990s. Archaeological excavations (termed Ohalo-II archeological site, see location in

Fig. 3.1) conducted by D. Nadel from the Haifa University (Nadel 1995; Nadel et al. 2001; Belitzky and Nadel 2002; Nadel et al. 2004) exposed a well-preserved prehistoric camp covering $\sim 2,000$ m² at an elevation of 211.5–213.5 m b.m.s.l. Radiocarbon dating of terrestrial organic debris from the camp yielded an age of 19.4 ± 0.8 ka BP (Nadel et al. 2004) that is calibrated to $\sim 21.3 \pm 0.8$ ka cal BP.

The settlement at the Ohalo shore was possible because of the lake retreated during H2 ~ 24 – 23 ka BP, when prehistorical people moved down from their glacial retreats in the Galilee caves.

Geological trenching and drilling that were performed in 1999–2001 at the Ohalo-II shore opened the opportunity to investigate the environmental and hydrological history of Lake Kinneret during the last glacial high stand (~ 27 – 24 ka BP) and the time of lake retreat (~ 24 – 21 ka BP). The sediments and fossil shells recovered from them were used to infer the types of waters that contributed to the lake during these time intervals (Hazan et al. 2005; Lev et al. (2014). The sedimentary interval of the last glacial lake (~ 27 – 24 ka BP) is beautifully laminated indicating a layered and rather stable lake configuration with no activity of boring organisms at the bottom. The laminae mainly comprise primary calcites that were deposited from a relatively freshwater lake. It is important to note that Menahemya, south to the Yarmouk sill, is the northernmost site where aragonitic laminae of similar age (~ 27 ka BP) to the high-stand section are exposed (see the Menahemya section in Hazan et al. 2005). Thus, it appears that the Ca-chloride brine, which controlled aragonite deposition in the hypersaline Lake Lisan, did not cross the Yarmouk sill during the high-stand period. Lake Kinneret behaved like a large estuary pushing freshwater to the south. The high-stand aragonite sequence at the Menahemya section is topped by black sands with ripple marks indicating a significant lake drop that possibly coincides with the ~ 24 ka H2 lake drop documented at the Ohalo-II shore. Above the sands, “Kinneret-type” calcitic marls that resemble the sediments described at the Ohalo-II trench (at ages of ~ 23 – 21 ka BP) are exposed at Menahemya indicating a moderate lake rise. The lack of aragonite at Menahemya indicates that at this stage, the “Lisan–Dead Sea brine” did not cross the Wadi Malih sill.

Further information on the freshwater brines contribution to Lake Kinneret during the high stand and H2 periods is provided by the $^{87}\text{Sr}/^{86}\text{Sr}$ and Sr/Ca in fossil *Melanopsis* shells and ostracods from the Ohalo-II sediments and discussed further.

3.5.2.2 Tel Bet Yerach: Sedimentary and Archeological Archive of the Late Pleistocene and Mid-Holocene Lake Kinneret

TBY, one of the important prehistoric sites in the Levant (Bar-Adon 1966; Vinogradov 1992, and references therein; Figs. 3.1 and 3.4), is located on top of the late Pleistocene sedimentary section of Lake Kinneret. The upper part of the Tel comprises archeological layers that are overlain by lacustrine sediments of a mid-Holocene age.

The sedimentary section of the late Pleistocene Lake Kinneret is exposed on the eastern side of TBY. The section comprises alternating sequences of laminated marls and sandy units with ripple marks and cross bedding (Hazan et al.

2004, 2005). A pebble unit that possibly represents beach sediments is exposed at 203.3–204.9 m b.m.s.l. The unit was dated by radiocarbon (on *Melanopsis* shells) to ~19.8–22.3 cal year BP; similar ages were recovered from the Ohalo-II archaeological site that are located at a lower elevation (~213 m b.m.s.l.). This stratigraphic configuration would imply a fast lake rise or vertical displacement of some 7–8 m between the Ohalo II site and TBY over the past 20,000 years.

TBY was inhabited from the early Bronze (EB) Age (5,300–4,300 years ago). Then, it was conquered and destroyed by the EB IV people, who resettled it until 4,200 years ago, and then abandoned it. By that time, most of the rural settlements of the Middle East including TBY were deserted. Migowski et al. (2006) documented a significant drop in Dead Sea level at that time suggesting a regional aridity that could affect the fate of the settlements including TBY. Subsequently, TBY was not resettled until the Hellenistic time, about 2,600 years BP, and later during the Arabic Period (1360–900 years BP). The settlement history of TBY was to a large extent dictated by the climatic lake level changes.

TBY is bounded to the east by the lake and to the south and west by the modern and ancient channels of Jordan River. Flooding of the Tel by the rising lake disrupted the settlements. There are several lines of evidence for rising lake levels that flooded TBY. At the lower part of the Tel at an elevation of –206.5 m, a coarse-sand layer contains numerous *Melanopsis* shells. The shells were dated to ~6000 cal year BP. A drainage channel system of post-EB IV age entrenched across the upper surface of the EB settlement (Bar-Adon 1966). The channels were filled with poorly sorted, cross-bedded sand and small pebbles, lenses, mixed with pottery shreds of EB age, as well as scattered shells of freshwater *Melanopsis* and *Unio* shells that fossils yielded radiocarbon age of ~5.5 ka BP. This flooding of TBY coincides with the mid-Holocene transgression that was documented at the Dead Sea commencing at ~6.5 ka cal BP (Migowski et al. 2006; Bartov et al. 2007).

3.5.2.3 The Late Holocene Lake—The Galei Kinneret Archaeological Site

The Galei Kinneret archeological site at the southern shore of the city of Tiberias (Fig. 3.1) located at 208–212 m b.m.s.l. was excavated in 2002 (by M. Hartal from the Israel Antiquity Authority). The excavation revealed Roman, Byzantine, and early Arabic buildings that were completely buried by alluvium and lake sediments up to an elevation of –208.5 m. The excavation revealed a fault that was attributed to the 749 CE earthquake that hit the Dead Sea–Kinneret basin (Marco et al. 2003). Other Roman and Byzantine maritime installations—jetties and small piers—are known from around the lake at elevations of ~212 m b.m.s.l. The finding of lake sediments, including beach deposits up to 208 m b.m.s.l. in Galei Kinneret, above the Roman to Umayyad structures, is surprising. This may indicate a more complicated structure of the regional hydrological climate regime during the Arabic period that is not revealed by the Dead Sea record, or that local tectonic subsidence (of ~4 m) occurred before the 749 CE earthquake.

3.6 Sr/Ca Ratios and $^{87}\text{Sr}/^{86}\text{Sr}$ Isotope Ratios Constraints on Sources of Lake Kinneret Waters

Modern Lake Kinneret waters comprise a mixture between freshwater draining the watershed (e.g., north Jordan River water, streams and runoff from the Golan Heights and the Galilee) and saline waters (e.g., Tiberias Spa, Fuliya, Tabgha, Barbutim). Comprehensive discussions of the hydrological–limnological–geochemical conditions in the modern Lake Kinneret and the behavior of the carbonate system are given by Kolodny et al. (1999) and Katz and Nishri (2013). During the high-stand period of the last glacial (~27–24 ka BP), when Lake Lisan converged with Lake Kinneret, the Dead Sea Ca-Chloride brine could migrate northward and mix with Lake Kinneret waters. Yet, as noted above, the section recovered from the Ohalo-II cores revealed laminae of primary calcite indicating that the contribution of the Ca-chloride brine was rather limited. The contribution of brines to Lake Kinneret during the modern, high-, and low-stand periods can be evaluated by using various geochemical properties (e.g., Bergleson et al. (1999)). Here, I apply the isotope ratios of $^{87}\text{Sr}/^{86}\text{Sr}$ combined with the elemental ratios of Sr/Ca in *Melanopsis* shells and ostracods that are recovered from the sedimentary sections and drilled cores to estimate the brine–freshwater relation and identify the types of waters involved (Fig. 3.5). The diagram also displays the compositions of various freshwaters, runoff, saline waters, and brines from Lake Kinneret and the Dead Sea. The Sr/Ca ratios measured in the fossil shells are transformed to Sr/Ca in their supposed habitat water by applying relevant partition coefficient (Rosenthal and Katz 1989; Hazan et al. 2005; Lev et al. (2014)). The figure shows that the modern Lake Kinneret and most of the *Melanopsis* shells-habitat waters lie on a possible mixing array between saline springs such as Tiberias Spa or Dead Sea brine and the Jordan River. The *Melanopsis* shells were collected in different stratigraphic units from modern to last glacial (e.g., at the high-stand shoreline at Tel Qazir and TBY). It is interesting that even the *Melanopsis* shell from the Pliocene Erk El Ahmer Formation lies on the same array. This points to an overall long-term “stability” in the contribution of brines and freshwaters to the mixture that makes “Lake Kinneret.” The exceptions are early Pleistocene Ubeidiya *Melanopsis* shells that lie off the “Jordan–Dead Sea array” and the late Pleistocene ostracod shells from the Ohalo-II shore that lie away from the “Jordan-brine array” and their habitat waters appear to be affected by the runoff water draining the Galilee Mountains (Lev et al. (2014)). Interestingly, the Fuliya water lies on the low side of the ostracod field and appears to lie on a mixing array between the Tiberias Spa and runoff waters. The contribution of the various water sources to Lake Kinneret during periods of low and high stand requires further consideration and is under current research.

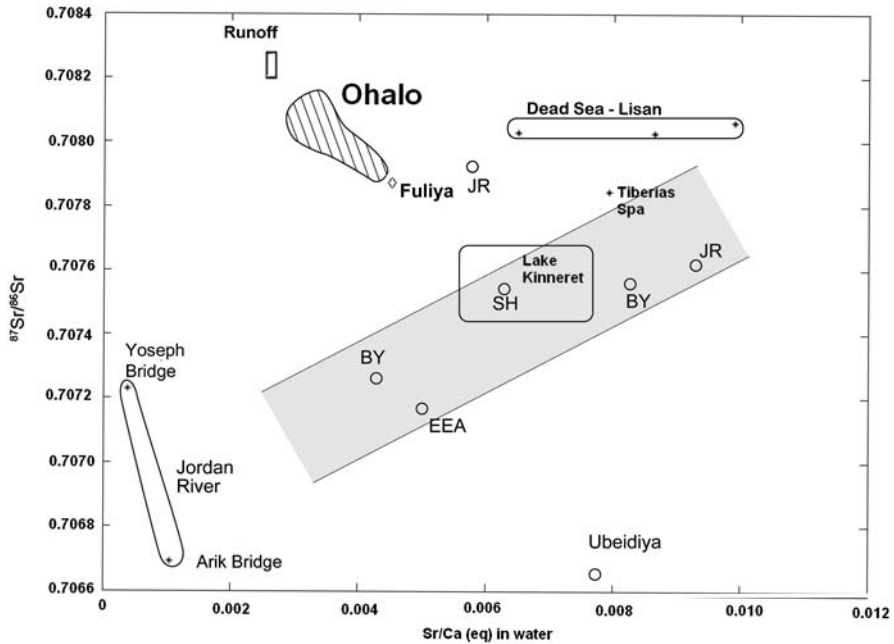


Fig. 3.5 $^{87}\text{Sr}/^{86}\text{Sr}$ versus Sr/Ca ratios in water from Lake Kinneret, the Dead Sea, Jordan River, and “late Quaternary waters” whose compositions are estimated from the $^{87}\text{Sr}/^{86}\text{Sr}$ and Sr/Ca ratios measured in *Melanopsis* shells (open circles). See locations in Fig. 3.1; BY=Tel Bet Yerach, SH=Shaldag shore a few hundred meters northwest to the Ohalo-II archeological site, EEA=the Pliocene Erk El Ahmer Formation and Ubeidiya of early Pleistocene age, see Fig. 3.2, the exposures are located east of Menahemya). The Dead Sea–Lisan field represents the compositions of primary aragonites deposited in these hypersaline lakes. The modern Lake Kinneret and the habitat waters of the *Melanopsis* shells lie between the compositions of the Jordan River and Tiberias spa or Dead Sea brine. The late glacial ostracods from the Ohalo-II shore show a contribution of runoff from the Galilee Mountains. (Data sources: Rosenthal and Katz 1989; Stein et al. 1997; Hazan 2002; Lev et al. (2014))

3.7 New Studies and Future Perspectives

Recently, several drilling operations were performed in Lake Kinneret opening new possibilities for paleoenvironmental and paleolimnological research. A ~20-m long core was drilled at the deepest part of Lake Kinneret (at station A) by a joint German–Israeli group. Preliminary dating of the core indicates that it covers the past 9,000 years. The material is currently studied for the pollen characterization, lithological composition, and geochemistry aiming to reconstruct the paleohydrological and paleoenvironmental conditions in the lake and its watershed during the Holocene (Langgut et al. 2013). A joint US–Israeli group currently works on the geochemistry of live and fossil ostracods in the shallow water environment along the shores of the lake. The ostracods are used for salinity estimation, characterization, and evaluation of the contribution of various fresh and saline water sources to the lake (e.g., by using Sr/Ca and $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in waters and ostracods, Lev et al.

(2014); see Fig. 3.5). A US–Israeli group investigates the potential of applying the new method of clumped isotopes of oxygen to deduce past water temperature and composition (Zaarur et al. 2012). A Israeli group works on the short-lived U-series isotopes in the lake and the springs (Sharabi et al. 2013), following the early works in this direction (e.g., Moise et al. 2000, and references therein). Another Israeli group investigates the late Neogene transgressions that introduced the marine waters (and brines) to the Kinnarot–Dead Sea basin and are possibly responsible for the deposition of the thick salt units in the Kinnarot basin as recovered by the Zemah borehole (Rosenbaum et al. 2013). These and other studies will certainly lead to better understanding of the history and mechanism of limnological–hydrological–geochemical system of the Lake Kinneret and its parental water-bodies.

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References

- Bar-Adon P (1966) Zinabery and Bet Yerach in light of origin and the archeological finding, Eretz-Israel vol 4. The Society of Research Israel and Antiquity
- Bartov Y, Agnon A, Enzel Y, Reches Z, Stein M (2002) Sequence stratigraphy and reconstruction of Lake Lisan levels. *Quat Res* 57:9–21. doi:10.1006/qres.2001.2284
- Bartov Y, Goldstein SL, Stein M, Enzel Y (2003) Catastrophic arid episodes in the Eastern Mediterranean linked with the North Atlantic Heinrich events. *Geology* 31:439–442. doi:10.1130/0091-7613(2003)
- Bartov Y, Enzel Y, Porat N, Stein M (2007) Evolution of sedimentary deposition in the late Pleistocene and Holocene Dead Sea basin. *J Sedim Res* 77:680–692. doi:10.2110/jsr.2007.070
- Begin ZB, Ehrlich A, Nathan Y (1974) Lake Lisan—the precursor of the Dead Sea. *Geol Soc Surv Israel Bull* 63:1–30
- Belitzky S, Mimran Y (1996) Active salt diapirism at the Zaharat El-Qurei dome, lower Jordan valley (Jordan). *Isr J Earth Sci* 45:11–18
- Belitzky S, Nadel D (2002) Late Pleistocene and recent tectonic deformations at the Ohalo II prehistoric site (19K) and the evolution of the Jordan River outlet from the Sea of Galilee. *Geoarcheology* 17:453–464. doi:10.1002/gea.10022

- Belmaker R, Lazar B, Beer J, Christl M, Tepelyakov N, Stein M (2013) ^{10}Be dating of Neogene halite. *Geochim Cosmochim Acta* 122: 418–429
- Bentor YK (1961) Some geochemical aspects of the Dead Sea and the question of its age. *Geochim Cosmochim Acta* 25:239–260
- Bergelson G, Nativ R, Bein A (1999) Salinization and dilution history of ground water discharging into the Sea of Galilee, the Dead Sea Transform, Israel. *App Geochem* 14:91–118
- Bookman R, Enzel Y, Agnon A, Stein M (2004) Late Holocene levels of the Dead Sea. *Bull Geol Soc Am* 116:555–571. doi:10.1130/B25286.1
- Braun D (1992) The geology of the Afiqim region. MSc thesis, Hebrew University, Jerusalem, p. 93 (in Hebrew, English abstract)
- Davis M, Matmon A, Fink D, Ron H, Niedermann S (2011) Dating Pliocene lacustrine sediments in the central Jordan Valley, Israel—Implications for cosmogenic burial dating. *Earth Planet Sci Lett* 305:317–327 doi:org/10.1016/j.epsl.2011.03.003
- Dubowski Y, Erez J, Stiller M (2003) Isotopic paleolimnology of Lake Kinneret. *Limnol Oceanogr* 48:68–78
- Enzel Y, Bookman R, Sharon D, Gvirtzman H, Dayan U, Ziv B, Stein M (2003) Late Holocene climates of the Near East deduced from Dead Sea level variations and modern regional winter rainfall. *Quat Res* 60:263–273. doi:10.1016/j.yqres.2003.07.011
- Enzel Y, Agnon A, Stein M (2006) (eds) *New Frontiers in Dead Sea paleoenvironmental research*. GSA Spec Paper 401
- Frumkin A, Stein M (2004) The Sahara-East Mediterranean dust and climate connection revealed by strontium and uranium isotopes in a Jerusalem speleothem. *Earth Planet Sci Lett* 217:451–464. doi:10.1016/S0012-821X(03)00589-2
- Gardosh M, Bruner I (1998) A seismic survey in the Bet Shean region. *The Geophysical Institute of Israel, Rep* 348/27/98, p. 13.
- Gat JR, Mazor E, Tzur Y (1969) The stable isotope composition of mineral waters in the Jordan Rift Valley. *Isr J Hydrol* 7:334–352
- Goldschmidt MJ, Arad A, Neev D (1967) The mechanism of the saline springs in the Lake Tiberias depression. *Geol Surv Isr Bull* 45, 19
- Haase-Schramm A, Goldstein SL, Stein M (2004) U–Th dating of Lake Lisan (late Pleistocene Dead Sea) aragonite and implications for glacial east Mediterranean climate change. *Geochim Cosmochim Acta* 68:985–1005. doi:10.1016/j.gca.2003.07.016
- Haliva-Cohen A, Stein M, Goldstein SL, Sandler A, Starinsky A (2012) Sources and transport routes of fine detritus material to the late Quaternary Dead Sea basin. *Quat Sci Rev* 49:55–70. doi:org/10.1016/j.quascirev.2012.06.014
- Hazan N (2002) Reconstruction of Lake Kinneret levels during the past 40,000 years MSc thesis, The Hebrew University (in Hebrew, English abstract).
- Hazan N, Stein M, Marco S (2004) Lake Kinneret late Holocene levels and active faulting in Tiberias. *Isr J Earth Sci* 53:199–205
- Hazan N, Stein M, Agnon A, Marco S, Nadel D, Negendank JFW, Schwab M, Neev D (2005) The late Pleistocene–Holocene limnological history of Lake Kinneret (Sea of Galilee), Israel. *Quat Res* 63:60–77. doi:10.1016/j.yqres.2004.09.004
- Heimann A, Braun D (2000) Quaternary stratigraphy of the Kinnarot Basin, Dead Sea Transform, northeastern Israel. *Isr J Earth Sci* 49:31–44
- Heimann A, Steinitz G, Mor D, Shaliv G (1996) The cover basalt formation, its age and its regional and tectonic setting: implications from K–Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ geochronology. *Isr J of Earth Sci* 45:55–69
- Katz A, Nishri A (2013) Calcium, magnesium and strontium cycling in stratified, hardwater lakes: Lake Kinneret (Sea of Galilee), Israel. *Geochim Cosmochim Acta* 105:372–394. doi:org/10.1016/j.gca.2012.11.045
- Katz A, Kolodny Y, Nissenbaum A (1977) The geochemical evolution of the Pleistocene Lake Lisan–Dead Sea system. *Geochim Cosmochim Acta* 41:1609–1626
- Klein-Bendavid O, Sass E, Katz A (2004) The evolution of marine evaporitic brines in inland basins: the Jordan–Dead Sea rift valley. *Geochim Cosmochim Acta* 68:1763–1775

- Kolodny Y, Katz A, Starinsky A, Moise T (1999) Chemical tracing of salinity sources in Lake Kinneret (Sea of Galilee), Israel. *Limnol Oceanogr* 44:1035–1044
- Kushnir Y, Stein M (2010) North Atlantic influence on 19–20th century rainfall in the Dead Sea watershed, teleconnections with the Sahel, and implication for Holocene climate fluctuations. *Quat Sci Rev* 29:3843–3860. doi:10.1016/j.quascirev.2010.09.004
- Langgut D, Stein M, Schiebel V, Litt T, Finkelstein I (2013) Paleoenvironmental conditions during the Bronze and Iron Ages (~5,000–2,500 YBP) in Lake Kinneret area, based on pollen analysis. Annual Meeting of the Geological Society of Israel, Akko
- Lev L, Boaretto E., Heller J, Marco S, Stein M (2007) The Feasibility of using *Melanopsis* Shells as Radiocarbon Chronometers, Lake Kinneret, Israel. *Radiocarbon* 49:1003–1015
- Lev L, Almogi-Labin A, Mishcke S, Ito, E, Ben-Avraham Z, Stein M (2014) Paleohydrology of Lake Kinneret during the Heinrich event H2. *Palaeog Palaeoclimat Palaeoecol* vol 396, pp. 183–193
- Marco S, Hartal M, Hazan N, Lev L, Stein M (2003) Archaeology, history, and geology of the A.D. 749 earthquake, Dead Sea transform. *Geology* 31:665–668. doi:10.1130/G19516.1
- Marcus E, Slager J (1985) The sedimentary-magmatic sequence of the Zemah-1 well (Jordan–Dead Sea Rift, Israel) and its emplacement in time and space. *Isr J Earth Sci* 34:1–10
- Mazor E, Mero F (1969) Geochemical tracing of mineral and fresh water sources in the Lake Tiberias basin, Israel. *J Hydrol* 7:276–317
- Mero F, Mandel S (1963) The hydrological mechanism of the saline springs of the western shore of Lake Kinneret (in Hebrew). TAHAL—Water Planning for Israel Ltd, p. 10
- Mero F, Zaltzman U (1967) Some geohydrological observations on the saline springs of Lake Kinneret (in Hebrew). TAHAL—Water Planning for Israel Ltd, p. 10
- Migowski C, Stein M, Prasad S, Negendank JFW, Agnon A (2006) Holocene climate variability and cultural evolution in the Near East from the Dead Sea sedimentary record. *Quat Res* 66:421–431. doi:10.1016/j.yqres.2006.06.010
- Moise T, Starinsky A, Katz A, Kolodny Y (2000) Ra isotopes and Rn in brines and ground waters of the Jordan–Dead Sea Rift Valley: Enrichment, retardation, and mixing. *Geochim Cosmochim Acta* 64:2371–2388
- Nadel D (1995) Radiocarbon dating of Ohalo II: archaeological and methodological implications. *J Archaeol Sci* 22:811–822
- Nadel D, Belitzky S, Boaretto E, Carmi I, Heinemeier J, Werker E, Marco S (2001) New dates from submerged late Pleistocene sediments in the southern Sea of Galilee, Israel. *Radiocarbon* 43:1167–1178
- Nadel D, Tsatskin A, Belmaker M, Boaretto E, Kislev ME, Mienis H Rabinovich R, Simchoni O, Simmons T, Weiss E, Zohar I (2004) On the shore of a fluctuating lake: environmental evidence from Ohalo II (19,500 BP). *Isr J Earth Sci* 53:207–223
- Neev D, Emery KO (1967) The Dead Sea. *Geol Surv Israel Bull* 41:1–147
- Neev D, Emery KO (1995) The destruction of Sodom, Gomorrah, and Jericho: geological, climatological and archaeological background. Oxford University Press, New York
- Raab M, Friedman GM, Spiro B, Starinsky A, Zak I (1997) The geological history of Messinian (upper Miocene) evaporites in the central Jordan Valley (Israel) and how strontium and sulfur isotopes relate to their origin. *Carbonates and Evaporites* 12:296–324
- Rosenbaum AG, Shaked D, Fursterberg Y, Zilberman E, Sandler A, Starinsky A (2013) Stratigraphy and lithology of Bira and Gesher formations in the Tabor Stream Area. Annual Meeting of the Geological Society of Israel, Akko
- Rosenthal Y, Katz A (1989) The applicability of trace elements in freshwater shells for paleochemical studies. *Chem Geol* 78:65–76
- Schulman N (1962) The Geology of the central Jordan Valley, PhD thesis. Hebrew University of Jerusalem, p. 103 (in Hebrew, English abstract)
- Serruya C (1978) The chemical environment, p. 184–204. In: Serruya C (ed) Lake Kinneret. Junk, The Hague
- Shaliv G (1991) Stages in the tectonic and volcanic history of the Neogene basin in the lower Galilee and the Valleys. Geological Survey of Israel Rep GSI/11/91

- Sharabi G, Kolodny Y, Halicz L., Nishri A, Lazar B (2013) Redox control on the water column distribution of Ra in a stratified lake—Lake Kinneret, Israel. Goldschmidt meeting, Florence
- Starinsky A (1974) Relationship between Ca-chloride brines and sedimentary rocks in Israel, PhD thesis, The Hebrew University, Jerusalem (in Hebrew, English abstract)
- Stein M (2001) The history of Neogene-Quaternary water bodies in the Dead Sea Basin. *J Paleolimol* 26:271–282
- Stein M, Starinsky A, Katz A, Goldstein SL, Machlus M, Schramm A (1997) Strontium isotopic, chemical, and sedimentological evidence for the evolution of Lake Lisan and the Dead Sea. *Geochim Cosmochim Acta* 61:3975–3992
- Stein M, Starinsky A, Agnon A, Katz A, Raab M, Spiro B, Zak I (2000) The impact of brine-rock interaction during marine evaporite formation on the isotopic Sr record in the oceans: evidence from Mt Sedom, Israel. *Geochim Cosmochim Acta* 64:2039–2053
- Stein M, Torfstein A, Gavrieli I, Yechieli Y (2010) Abrupt aridities and salt deposition in the post-glacial Dead Sea and their North Atlantic connection. *Quat Sci Rev* 29:567–575. doi:10.1016/j.quascirev.2009.10.015
- Steinitz G, Bartov Y (1991) The Miocene-Pliocene history of the Dead Sea segment of the rift in light of K–Ar ages of basalts. *Isr J Earth Sci* 40:199–208
- Stillier M, Ehrlich A, Pollinger U, Baruch U, Kaufman A (1984) The Late Holocene sediment of Lake Kinneret (Israel). Multidisciplinary study of a five-meter core. *Geol Sur Isr Curr Res* 4:83–88
- Stillier M, Rosenbaum JM, Nishri A (2009) The origin of brines underlying Lake Kinneret. *Chem Geol* 262:293–309. doi:10.1016/j.chemgeo.2009.01.030
- Torfstein A, Gavrieli I, Katz A, Kolodny Y, Stein M (2008) Gypsum as a monitor of the paleolimnological–hydrological conditions in Lake Lisan and the Dead Sea. *Geochim Cosmochim Acta*. 70:2491–2579. doi:10.1016/j.gca.2008.02.015
- Torfstein A, Haase-Schramm A, Waldmann N, Kolodny Y, Stein M (2009) U-series and oxygen isotope chronology of Lake Amora, Dead Sea basin point *Geochim Cosmochim Acta* 73:2603–2630. doi:10.1016/j.gca.2009.02.010
- Torfstein A, Goldstein SL, Kagan E, Stein M (2013a) Multi-site integrated U–Th chronology of the last glacial Lake Lisan. *Geochim Cosmochim Acta* 104: 210–234. doi:org/10.1016/j.gca.2012.11.003
- Torfstein A, Goldstein SL, Enzel Y, Stein M (2013b) Impacts of Abrupt Climate Changes in the Levant from last glacial Dead Sea levels. *Quat Sci Rev* 69:1–7. doi:org/10.1016/j.quascirev.2013.02.015
- Vinogradov Z (1992) “Bet Yerach” Kinneret Book. Ministry of Defense and the Kinneret Administration, p. 354
- Waldmann N, Starinsky A, Stein M (2007) Primary carbonates and Ca-chloride brines as monitors of a paleo-hydrological regime in the Dead Sea basin. *Quat Sci Rev* 26:2219–2228. doi:10.1016/j.quascirev.2007.04.019
- Waldmann N, Stein M, Ariztegui D, Starinsky A (2009) Stratigraphy, depositional environments and level reconstruction of the last interglacial Lake Samra in the Dead Sea basin. *Quat Res* 72:1–15. doi:10.1016/j.yqres.2009.03.005
- Waldmann N, Torfstein A, Stein M (2010) Northward intrusions of low- and mid-latitude storms across the Saharo-Arabian belt during past interglacials. *Geology* 38:567–570. doi: 10.1130/G30654.1
- Zaarur S, Stein M, Affek H (2012) Glacial-interglacial paleotemperatures and paleohydrology in the Jordan River Valley from clumped isotopes in fresh water snails. Goldschmidt Conference, Montréal
- Zak I (1967) The geology of Mount Sedom, Ph.D. thesis. Hebrew University of Jerusalem, p. 208 (in Hebrew, English abstract)
- Ziv B, Dayan U, Kushnir Y, Roth C, Enzel Y (2006) Regional and global atmospheric patterns governing rainfall in the southern Levant. *Int J Climat* 26:55–73