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Paleohydrology of Lake Kinneret during the Heinrich event H2

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ABSTRACT

During the last glacial period Lake Kinneret (the Sea of Galilee) fluctuated between high and low water levels reflecting the hydrological conditions of the lake watershed. Here, we focus on the hydrology of the lake after its retreat from the last glacial MIS2 (~27–25 ka BP) highest stand of ~170 m below mean sea level (m bsl) to the low stand of ~214 m bsl at ~24–21 ka BP. The limnological–hydrological history of this time interval is recovered from trench and borehole that were dug and drilled in the southwestern shore of the lake at Ohalo-II archeological site. *Cyprideis torosa* (Ostracoda) recovered from the trench yielded elemental, $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotope data that provide information on the shore environment during the low stand period. The $^{87}Sr/^{86}Sr$ and Sr/Ca ratios in the ostracods, varying between ~0.70789 and ~0.70815 and 0.0017 and 0.0030, respectively indicate contributions of waters from the last glacial lake and regional runoff. The increase in the $^{87}Sr/^{86}Sr$ ratios reflects the decreasing effect of the last glacial Lake Kinneret waters and enhanced contribution of local runoff that washed down dried mountain soils that were previously developed during the wet and vegetated glacial.
The lake retreat at ~24 ka BP coincided with the Heinrich event H2 at the northern Atlantic. H2 was expressed by severe aridity in Lake Kinneret–Dead Sea watershed. The limnological–hydrological change at post H2 was accompanied by 2‰ decrease in the $\delta^{18}O$ value from −2‰ to −4‰ reflecting the change in the composition of the east Mediterranean rain sources.
The last glacial lake $^{87}Sr/^{86}Sr$ ratio is similar to the Tiberias Spa saline waters and distinctly different from the modern Lake Kinneret fresh waters: $^{87}Sr/^{86}Sr$ ~0.70785 compared to ~0.70760, respectively. This difference is explained by enhanced contribution of Ca-chloride brines with high $^{87}Sr/^{86}Sr$ values to the last glacial lake and reduced Jordan River contribution due to cold freezing conditions at its headwaters, while the modern Lake Kinneret is more affected by low $^{87}Sr/^{86}Sr$ freshwater from the Jordan watershed.

1. Introduction

Lake Kinneret (Sea of Galilee) is a freshwater lake that currently fills the northern part of the Kinnarot basin, which extends from the Bethsaida Valley in the north to the outlet of the Yarmouk River in the south comprising one of the morphotectonic depressions along the Dead Sea Transform (DST, Fig. 1). While Lake Kinneret evolved as a flow-through lake fed and drained by the Jordan River, southern lakes occupying the tectonic depression of the Dead Sea basin were terminal and hypersaline (Stein, 2001 and references there).

The water compositions and limnological configurations of these lakes (e.g. surface level and water column structure) reflect the hydrological conditions in the watershed, which in turn reflect the regional climatic conditions (Neev and Emery, 1995; Stein, 2001). During the past 40 kyr, the water level of Lake Kinneret fluctuated between <220 m and ~170 m below mean sea level (bsl) (Hazan et al., 2005). The highest Lake Kinneret level was reached between ~27 and 25 ka BP (modified after Hazan et al., 2005, according to Oxcal 4.1) when also the southern hypersaline Lake Lisan arrived to its maximum elevation of ~170 m bsl crossing the Wadi Malih sill and extending all the way to the northern Kinnarot basin (Fig. 1). At ~24 ka BP Lake Lisan and Lake Kinneret retreated and separated to a hypersaline and fresh flow-through water bodies, respectively. This lake drop and retreat coincided with the timing of Heinrich event 2 (H2) in the north Atlantic (Bartov et al., 2003). After the lake retreat the southernmost part of the modern Lake Kinneret basin became exposed and accumulated fluvial sediments (Hazan et al., 2005, Fig. 2). Late Upper Paleolithic (Kebaran) people established at Ohalo shore the Ohalo-II hunter–gatherer–fisher camps that were exceptionally preserved at the lake floor (Nadel et al., 2004).

Archaeological excavations and geological trenching and drilling that were performed in the drought years of 1999–2001 at the Ohalo shore (Figs. 1–2) provided the opportunity to investigate the environmental

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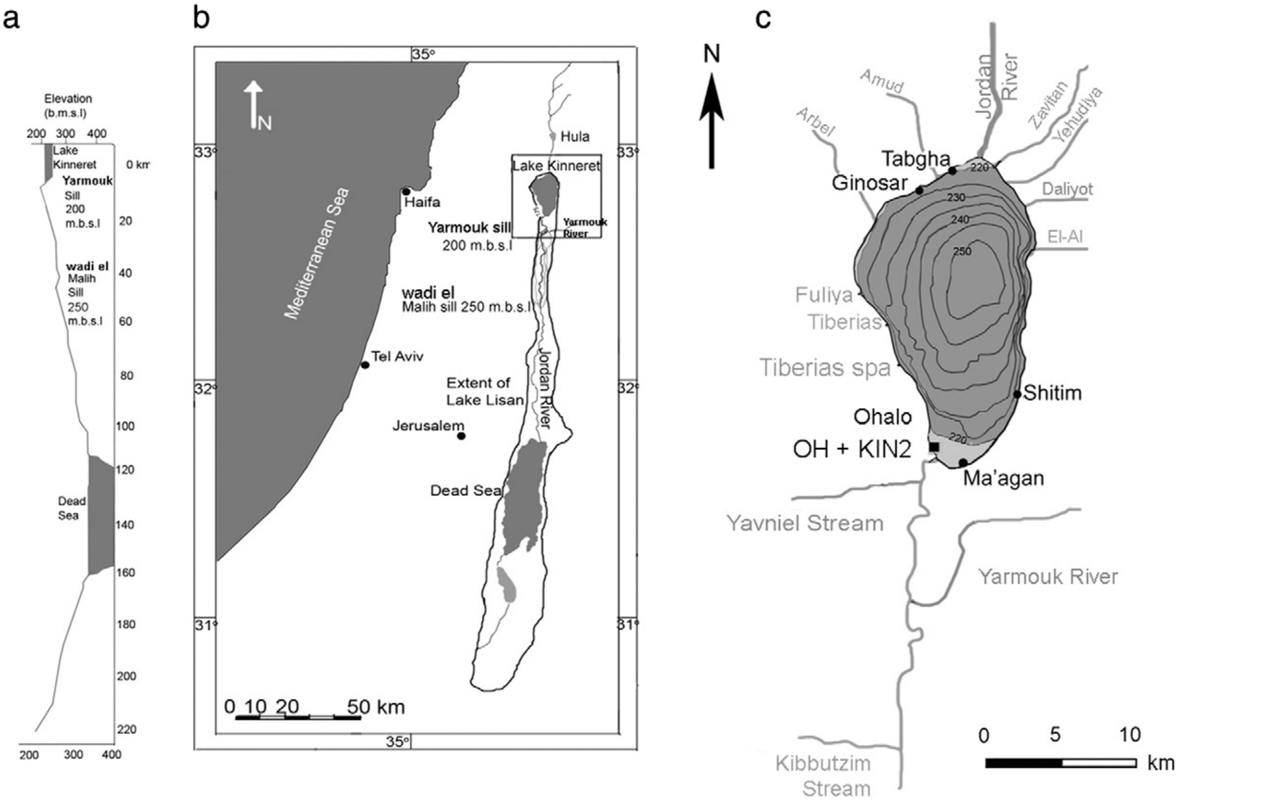

Fig. 1. (a) Cross section along the Jordan Valley showing the Yarmouk and Wadi el Malih thresholds (after Begin et al., 1974). (b) Location map. The Hula and Lake Kinneret are fresh water bodies located in the northern part of the Dead Sea Transform. The Dead Sea is a hypersaline water-body located in the southern part of the transform. Shown: the contour line that describes the highest water level, when Lake Kinneret merged with Lake Lisan and the Yarmouk and the Malih sills (200 and 250 m bsl, respectively). (c) Sampling sites around Lake Kinneret. Circles mark water and sediment sampling sites. Square marks the Ohalo-II archeological site, where trenching and coring were conducted. The shaded areas at the southern and northern most parts of the lake represent the low stand after the retreat of the lake at ~23 ka cal BP from its last glacial high stand (~170 m bsl, Hazan et al., 2005). Bathymetry is after Ben-Avraham et al. (1990).

and hydrological history of the transition of Lake Kinneret from high to low stand. We studied the stratigraphy and lithology of the Ohalo trench and the adjacent KIN borehole section, studied the ostracod and benthic foraminiferal distribution in these sediments and determined their geochemical and isotope composition.

2. Geological and hydrological background

Lake Kinneret is located in the northern part of the Kinnarot basin, which is a pull-apart basin bordered by Miocene–Pleistocene basalts, Mesozoic and Cenozoic limestones and chalks and Neogene marls and sandstones (Heimann and Braun, 2000). The modern sediments at Lake Kinneret consist mostly of primary calcites and fine detritus of dust origin (Stiller and Kaufman, 1985; Ganor et al., 2000; Hazan et al., 2005). Based on the composition of sediment cores drilled in the central part of the lake, Stiller and Kaufman (1985) estimated the content of "endogenic" carbonate as 70–85% of the total carbonate. Because Lake Kinneret is a stratified lake, ostracods are absent in the modern lake below water depth of ~15 m, where the environment is anoxic during most of the year (Serruya, 1975).

Paleolimnological information on Lake Kinneret is derived mainly from the sedimentary sequences deposited in the lake and its surroundings. The late Pleistocene–Holocene sedimentary section in the Kinnarot basin comprises the Kinneret Formation (Hazan et al., 2005). The formation consists of laminated lacustrine sediments (mainly primary calcite and fine detritus material) intercalated with clastic sequences of sand and pebbles (Hazan, 2003). The Ohalo-II archeological site, where our sampling took place, is located on the southwestern shore of Lake Kinneret at an elevation of 211.5–213.5 m bsl. Archeological excavations exposed a well preserved prehistoric camp, covering ~2000 m^2. Radiocarbon dating of terrestrial organic debris from the camp yielded an age of 19.4 $\pm$ 0.8 ka (e.g. Nadel et al., 2001, 2004) that is calibrated to 21.3 $\pm$ 0.8 cal ka (OxCal4.1).

Lake Kinneret is currently a monomictic lake with winter water temperature of ~15 °C. In summer, the depth of the epilimnion is 15–25 m, its maximum temperature is 29 °C and the temperature of the hypolimnion is ~15 °C (Serruya, 1977). The Jordan River contributes about 70% of the fresh water inflow to the Lake Kinneret (Flexer et al., 2000). The tributaries of the Jordan River (Fig. 1c) are the Dan, Banias and Hazbani, which are discharged from Jurassic carbonate aquifers of Mt. Hermon and rivers draining the basaltic terrains of the Golan Heights. Additional freshwater comes as runoff from the surrounding hills and from the carbonatic and basaltic aquifers of the Galilee and Golan Height. The pH of the Kinneret water fluctuates from 8.0 to 9.1 and the major dissolved ions in the lake water are Na^+, Ca^{+2}, Mg^{+2}, K^+ and Cl^-.

The salinity of Lake Kinneret (~400 mg/l before 1967) is much higher than its freshwater resources (Katz, 2003). It reflects the mixtures of onshore and underwater saline springs (i.e., Tabgha, Fuliya and Tiberia Spa, 300–18,000 mg/l, Goldstein, 2004; Klein-BenDavid et al., 2005) and of meteoric waters (e.g., Goldshmidt et al., 1967; Gat et al., 1969; Starinsky, 1974). The origin of the saline water and their discharge mechanism to the lake are still under debate. It was suggested that the brines originated in the Sedom lagoon that invaded into the Jordan Valley-Dead Sea basin possibly in the Pliocene and precipitated evaporitic halite and gypsum (Zak, 1967). Several mechanisms were proposed to explain the discharge of the saline springs into Lake Kinneret: 1. location along deep faults that enable the upwelling of saline groundwater (Golani, 1962); 2. hydrological head driven by tectonic pressure or a geothermal energy mechanism (Mero and Mandel, 1963; Mero and Zaltzman, 1967); and 3. the hydrological head due to