THE FEASIBILITY OF USING *MELANOPSIS* SHELLS AS RADIOCARBON CHRONOMETERS, LAKE KINNERET, ISRAEL

Lilach Lev[1,2,3] • Elisabetta Boaretto[2,4] • Joseph Heller[5] • Shmuel Marco[1] • Mordechai Stein[3]

ABSTRACT. We investigated the feasibility of using *Melanopsis* shells as radiocarbon chronometers of paleolakes and springs in the Jordan Valley, Israel. For this purpose, we analyzed the ^{14}C content of aragonite of living *Melanopsis* shells from different freshwater bodies of the northern Jordan Valley and Lake Kinneret (Sea of Galilee) and compared them to the contemporaneous water values. The *Melanopsis* shells are in ^{14}C equilibrium with their habitat waters, allowing to specify a particular reservoir age for various water types. We measured ~750 yr for Lake Kinneret, ~2300 yr for northern Jordan, ~4600 yr for springs in the north Kinneret, and ~7200 yr for streams flowing directly from carbonate aquifers. These results were tested and corroborated by analyzing fossil *Melanopsis* shells of known age, measured on contemporaneous organic matter. We conclude that *Melanopsis* shells are reliable ^{14}C chronometers and have the potential to be used as paleohydrological tracers.

INTRODUCTION

The establishment of the late Pleistocene and Holocene environmental (paleoseismic and paleoclimate) history of the Dead Sea–Kinnarot basins (Figure 1) requires a high-resolution and precise chronological framework. Previous studies on the water level and the reservoir age of Lake Kinneret used mainly charcoal and organic fractions in the sediments to determine the age of the section (Stiller et al. 2001; Hazan et al. 2005). These samples are subject to uncertainties in terms of the origin of the organic matter and in the radiocarbon content: reworked material from the surrounding environment could be mixed with the organic material deposited from the water body; and charcoal could have been redeposited from its original location into the sediments. Clear archaeological contexts can help in sorting this possibility. Lake Kinneret deposited mainly primary calcite and supported fauna such as *Melanopsis* snails (Tchernov 1975; Hazan et al. 2005). *Melanopsis* (Melanopsidea) appear in most freshwater springs along the Jordan–Dead Sea basins (Heller et al. 1999) and build an aragonite skeleton, which is potentially datable by the ^{14}C method. The *Melanopsis* shells are found either as single specimens or fragments but also in clusters. Such a deposition excludes the possibility of reworked material. In this work, we assessed the possibility of using *Melanopsis* shells as a ^{14}C chronometer of the limnological conditions in the late Quaternary Lake Kinneret (Sea of Galilee).

Previous studies, mostly on freshwater and land snails, showed large deviations between the true age and measured ^{14}C age (Fritz and Poplawski 1974; Goodfriend and Hood 1983; Goodfriend 1987; Goodfriend et al. 1999; McConnaughey et al. 1997; Stott 2002). These deviations are assumed to be related to different ^{14}C contents in the nutrients, rocks, and water of the shell's habitat. Therefore, dating *Melanopsis* shells by ^{14}C requires knowledge of the behavior of the carbonate system in the particular water body. The reservoir age of the *Melanopsis* shells is defined here as the deviation of ^{14}C content in the shell carbonate from the contemporaneous atmospheric value. The ^{14}C reservoir age of *Melanopsis* shells may reflect the composition of freshwater entering the lake (i.e. dissolved old carbonates, the "hard water effect"), exchange of freshwater with the atmosphere (Belmaker et

[1]Department of Geophysics and Planetary Sciences, Tel Aviv University, Ramat Aviv, Tel Aviv 69978, Israel.
[2]Radiocarbon Dating and Cosmogenic Isotopes Laboratory, Weizmann Institute of Science, Rehovot 76100, Israel.
[3]Geological Survey of Israel, 30 Malkhei Israel St., Jerusalem 95501, Israel.
[4]Corresponding author. Email: Elisabetta.Boaretto@weizmann.ac.il.
[5]Institute of Life Sciences, Hebrew University, Givat Ram, Jerusalem 91904, Israel.
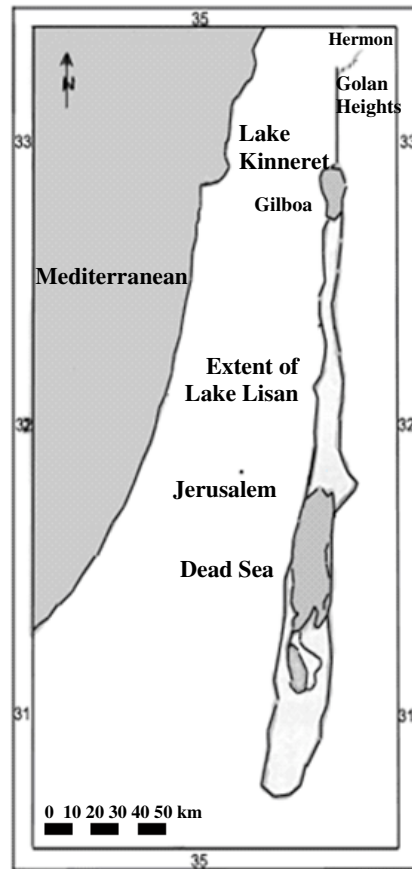
Figure 1 Water bodies along the Dead Sea Transform. Lake Kinneret gets its water mainly from the Jordan River, whose tributaries are fed from Mt. Hermon's aquifers, and from rivers draining the Golan Heights. The lake arrived to its highest stand of ~174 m bsl between 26–24 cal kyr BP, when it converged with the southern Lake Lisan.

al. 2006, this volume), or aging of ^{14}C within the lake. In the springs, the ^{14}C reservoir age reflects the water carbonate exchange reaction within the aquifer and also aging. Another hypothesis relates to whether the *Melanopsis* shell is in ^{14}C equilibrium with the water. Addressing this question opens the possibility of correcting the apparent age once the environment's geochemical characteristics are known. In this work, we analyzed the ^{14}C content of live and fossil *Melanopsis* shells and the water from various associated environments in the northern Jordan Valley and Kinneret basin, and assessed their potential as ^{14}C chronometers and as geochemical tracers.

GEOLOGICAL SETTING

The work was carried out in the surrounding environment of Lake Kinneret, from the Kinnarot basin in the south to the Beteiha Valley in the north (Figures 1, 2). The basin is one of the tectonic depressions along the Dead Sea Transform (DST). The lake gets its water mainly from the Jordan River, whose tributaries are fed from Mt. Hermon's aquifers (carbonate) and from rivers draining the Golan Heights (basaltic). Lake Kinneret, a pull-apart basin, was formed where the left lateral motion steps to the left (Garfunkel 1981). Geophysical, geological, and archaeological evidence indicates active faulting offshore and onshore and ongoing subsidence of the bottom of the lake (e.g. Ben-Avraham et al. 1990; Garfunkel and Ben-Avraham 2001; Marco et al. 2003; Hazan et al. 2004). Thus, the development of a reliable dating method for the sedimentary sequences in the lake is instrumental in recovering the tectonic history of the basin.
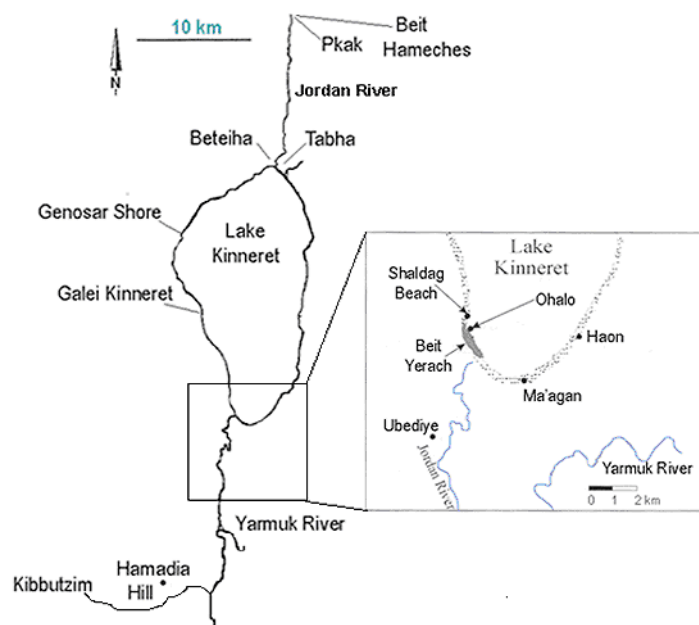
Figure 2 *Melanopsis* and water collection sites in Lake Kinneret and the Jordan River. The work was carried in the vicinity of Lake Kinneret, north Israel. Living *Melanopsis* shells were collected from Lake Kinneret and from water bodies in the vicinity of the lake. Fossil *Melanopsis* shells were collected from geological and archaeological sites around and south of Lake Kinneret.

The late Pleistocene–Holocene sedimentary section in the Kinnarot basin comprises the Kinneret Formation. It consists of laminated lacustrine sediments (mainly primary calcite and fine detrital material) intercalating with clastic sequences of sand and pebbles. Most of the sedimentological changes reflect climate changes, which controlled the water budget in the lake and its level (e.g. Hazan et al. 2005).

By dating archaeological sites and fluvial, lacustrine, and beach sediments, Hazan et al. (2005) reconstructed a level curve for Lake Kinneret during the past 40,000 yr. The lake reached its highest stand of ~174 m below sea level (bsl) between 26,000–24,000 cal BP, when it converged with the southern Lake Lisan (Figure 1). Another high stand of ~200 m bsl occurred at 5200 cal BP. Several low stands were identified: 1) before 41,000 cal BP; 2) between ~40,000 and 36,000 cal BP; 3) between 33,000 and 27,000 cal BP; and 4) between 14,000 and 10,000 cal BP. These high and low stands of Lake Kinneret are in good agreement with the level curve of Lake Lisan (Bartov et al. 2003), indicating a similar response of both lakes to the regional hydrological-climatic conditions (Hazan et al. 2005). Nevertheless, an improved and higher-resolution level curve requires a better-constrained chronology, which can be achieved by ^{14}C (or U-Th) dating of the Kinneret calcite sediments and aragonite *Melanopsis* shells that are abundant in the sediments.

MELANOPSIS SHELLS

Melanopsis (Melanopsidae) are freshwater snails that form carbonate shells by secreting the $CaCO_3$ from the snail's mantle, located within the shell. They typically live for several years and feed on algae that grow on leaves and rocks. The calcium carbonate constructing the *Melanopsis* skeleton

has the form of aragonite, which is generally more robust than calcite (Heller 1993). The shell's inorganic crystal is laid within an organic matrix (protein) that comprises about 0.03% (wt) of the shell (Addadi et al. 1991). The dark color of the living shell is due to the organic coating (termed perio-stracum), which erodes quickly after death. *Melanopsis* are widespread in Africa, north of the Sahara (excluding the Nile), southern Europe, Catalonia, throughout the Italian peninsula, Sicily, the Balearic Islands, Greece, Cyprus, Turkey, Syria, Lebanon, and Israel (Tchernov 1975). Fossil *Melanopsis* were found in many ancient freshwater sites in Israel: e.g. Ubediye, a ~1.4-Myr site in the Jordan Valley (Heller and Sivan 2001); Gesher Bnot Ya'akov, a 780-kyr site in the Hula Valley (Goren-Inbar et al. 2000); the late Pleistocene Lake Kinneret (e.g. the Ohalo-II archaeological and Beit Yerach sites [Hazan et al. 2005]); and in many other Holocene and Recent sites (see below). The migration of freshwater mollusks to the region became possible after isolation from the Tethys Ocean (Tchernov 1975). Only a few species currently occupy Lake Kinneret and its surroundings. This suggests an ecological change during the Pleistocene: many species disappeared with the flooding by Lake Lisan (perhaps due to salinity increase) and some reappeared as Lake Lisan retreated from the northern Jordan Valley (Tchernov 1975).

Several species of *Melanopsis* snails are found in the various water habitats along the Jordan Valley, differing by taxonomy (smooth/non-smooth), size, and height/diameter/width ratios. Detailed descriptions of the various species of *Melanopsis* shells in Israel are given by Heller et al. (1999).

The *Melanopsis* species used in this study are given in Figure 3. *Melanopsis buccinoidea* (bucc) lives in springs and streams, on rocks and in mud. This species is found along the Jordan Valley, from the Jordan River tributaries in the north to Jericho in the south. *Melanopsis costata lampra* (cl) (previously known as *Melanopsis costata costata*; Heller et al. 2005) is commonly found on mud and on sunken vegetation along the Jordan River banks. *Melanopsis costata jordanica* (cj) is found only along rocky shores of Lake Kinneret. *Melanopsis saulcyi* (sa) lives on rocks and in mud in springs and streams along the central Jordan Valley south of Lake Kinneret (from Hamat Gader to Jericho).

Melanopsis buccinoidea   *Melanopsis costata lampra*   *Melanopsis costata jordanica*   *Melanopsis saulcyi*
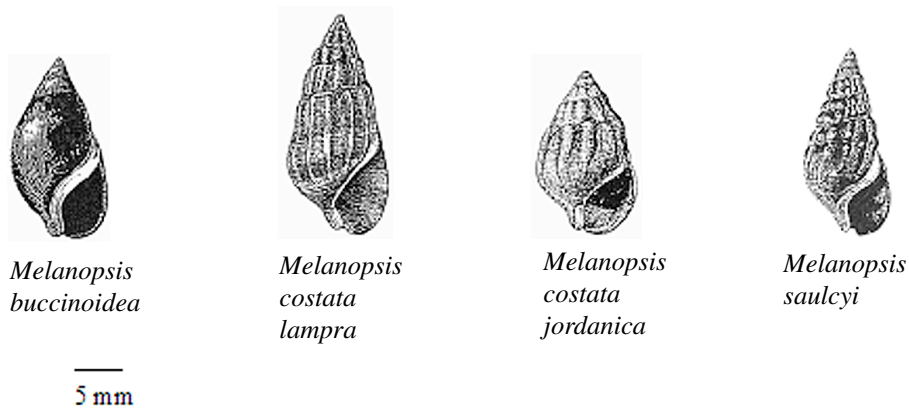
5 mm

Figure 3 *Melanopsis* species and subspecies of the Jordan Valley (Heller 1993; Heller et al. 2005). *Melanopsis buccinoidea* (bucc), which grows in springs and streams along the Jordan Valley, is the only smooth shell used in this work. All the *costata* have ribs extending almost the entire height of the whorl. *Saulcyi* are characterized by tubercle-ribbed shells in which the ribs usually extend about half the height of the whorl. Other differences between species are height-to-width proportions (after Heller et al. 1999).

METHODS

Between 10 and 20 adult living *Melanopsis* specimens and associated waters were collected at the beginning of the winter (November 2003) from Lake Kinneret and 4 other related water sources (Figure 2, Table 1). These water environments (a lake, a stream, a river, and a spring) are characterized by different values of ^{14}C and *Melanopsis* species. More details are given in the Discussion. Water samples were collected in 250-mL dark glass bottles. A few drops of saturated $HgCl_2$ were added to each bottle to stop biological activity.

All living *Melanopsis* shells were identified (Table 1); however, fossil materials were sometimes eroded and broken and were not always identifiable. *Melanopsis* shells that contain calcite might have suffered diagenetic alteration and thus indicate an open-system behavior regarding ^{14}C. Therefore, the carbonate mineralogy (i.e. aragonite vs. calcite) was determined for all studied samples by Fourier transform infrared (FTIR) analysis with a 4 cm^{-1} resolution using a MIDAC Corporation (Costa Mesa, California, USA) spectrometer.

All samples were prepared for ^{14}C dating at the Weizmann Institute and dated by accelerator mass spectrometry (AMS). $\delta^{13}C$ measurements were performed using a mass spectrometer (Finnigan MAT 250) on a small fraction of CO_2 derived from each sample.

To separate the periostracum of modern shells, samples were etched in 1N HCl for 30 seconds and rinsed with nano-pure water. The remains of the periostracum were removed physically with a knife. All shells (modern and fossil) were cleaned with a knife, broken into pieces, and etched in 1N HCl several times until all extragenous material was removed. Finally, the samples were soaked in an ultrasonic bath for a few minutes until the rinsing water was clear. Each shell was crushed into small fragments (~1–2 mm) and homogenized.

^{14}C dates on modern and fossil inorganic shell material were performed using a single specimen per analysis. About 20 mg of pretreated $CaCO_3$ from each sample (single *Melanopsis* weights ~300 mg) were converted into CO_2. Part of the extracted gas was used for $\delta^{13}C$ measurements and the rest was converted into graphite for accelerator mass spectrometry (AMS) (Yizhaq et al. 2005). For ^{14}C and $\delta^{13}C$ measurements in the waters, a portion of about 100 mL of water was used from each bottle. Extraction was performed in vacuum, adding 4 mL of 85% phosphoric acid. The produced CO_2 was collected in 3 traps in a system cooled by liquid nitrogen previously separated from the water by 2 alcohol and dry-ice traps (Boaretto et al. 1998).

In addition, we analyzed terrestrial plant (*Cyperus*) from Kibbutzim Stream, which was at the time of collection completely submerged (we assume that the plant represents the algae growing on the leaves of the plant, on which the *Melanopsis* feed). Small plant pieces were put in 1N HCl for 40 min and washed with nano-pure water. The leaf with some water and a small amount of 1N HCl was stirred while heated on a hot plate (80 C) and small amounts of sodium chlorite ($ClNaO_2$) were added to oxidize all organic matter but the cellulose. Samples were then centrifuged, rinsed, and dried in an oven at 120 C. The sample was burned with CuO at 900 C, in vacuum, for 200 min and the obtained CO_2 was used for graphitization.

The bone sample from the Galei Kinneret archaeological site (*Bos taurus*) was first cleaned externally with a scalpel. The extraction of collagen and its quality control was performed using the procedure in Yizhaq et al. (2005).

^{14}C data are reported as percent modern carbon (pMC) and as ^{14}C age (in BP) and were corrected for carbon isotope fractionation. Water samples (RTT 4839–4843) were not corrected for fractionation

because the $\delta^{13}C$ of the water bodies is the result of atmosphere-water-rock interaction, and not only due to fractionation.

RESULTS AND DISCUSSION

^{14}C data and $\delta^{13}C$ of the *Melanopsis* shells and waters are listed in Table 1 (living *Melanopsis*) and in Table 2 (fossil *Melanopsis*).

Table 1 ^{14}C ages of living *Melanopsis* and associated waters.

Location[a]	Sample name	RTT	Melanopsis species[b]	pMC	^{14}C age[c] (BP)	$\delta^{13}C‰$ PDB
Beit Hameches	BM a	4828	cl	0.3 ± 75.2	2300 ± 40	–9.0
(Jordan River, north)	BM b	4829	cl	0.3 ± 75.0	2310 ± 40	–8.2
	BM c	4830	cl	0.3 ± 72.6	2570 ± 40	–9.0
	BM d	4831	cl	0.4 ± 78.0	2000 ± 40	–9.4
	average[d]				*2300 ± 230*	
		4842	water[e]	0.4 ± 72.9	2540 ± 40	–9.9
Pekak	PK a	4875	cl	0.3 ± 73.8	2440 ± 40	–9.1
(Jordan River, north)	PK b	4876	cl	0.4 ± 74.6	2350 ± 40	–8.7
	PK c	4877	cl	0.3 ± 76.8	2120 ± 30	–9.1
	PK d	4878	cl	0.3 ± 75.4	2270 ± 30	–8.9
	average[d]				*2290 ± 140*	
		4843	water[e]	0.3 ± 73.1	2520 ± 40	–10.0
Tabha	TB a	4883	bucc	0.3 ± 56.4	4600 ± 40	–9.1
(springs north of	TB b	4884	bucc	0.3 ± 56.6	4570 ± 40	–9.2
Lake Kinneret)	*average*[d]				*4580 ± 20*	
		4841	water[e]	0.3 ± 52.7	5140 ± 50	–11.0
Genosar	GR c	4885	cj	0.5 ± 90.9	760 ± 40	–3.7
(Lake Kinneret)	GR d	4886	cj	0.3 ± 91.2	740 ± 30	–4.2
	average[d]				*750 ± 20*	
		4840	water[e]	0.4 ± 92.1	670 ± 40	–5.1
Kibbutzim	KB a	4861	sa	0.2 ± 39.6	7440 ± 50	–9.4
(stream south of	KB b	4862	sa	0.4 ± 42.6	6850 ± 80	–9.5
Lake Kinneret)	KB c	4863	sa	0.2 ± 40.1	7340 ± 50	–9.7
	KB d	4864	sa	0.3 ± 41.0	7170 ± 50	–9.6
	average[d]				*7200 ± 260*	
		4839	water[e]	0.3 ± 40.0	7360 ± 70	–12.0
	KB plt	4977	water plant	0.3 ± 39.2	7530 ± 60	–32.5

[a]See Figure 2 for locations.

[b]cl – *costata lampra*; cj – *costata jordanica*; sa – *saulcyi*; bucc – *buccinoidea*. For details, see Figure 3.

[c]Apparent age ±1 σ.

[d]Averages are of *Melanopsis* only, ±1 σ.

[e]Water was collected at same time and from same location as *Melanopsis*. Water results are not corrected for $\delta^{13}C$ (‰).

Radiocarbon in Living *Melanopsis* Shells and Their Associated Waters

The ^{14}C contents of living *Melanopsis* aragonite shells were found to be similar to their associated habitat waters (indistinguishable within analytical error, see Table 1 and Figure 4), indicating that the shell is in equilibrium with the ^{14}C in the habitat water. The $\delta^{13}C$ values in the waters are 1–2‰

Table 2 ¹⁴C ages for fossil *Melanopsis*.

Location[a]	Sample ID	RTT	*Melanopsis* species[b]	pMC	*Melanopsis* ¹⁴C age ±1 σ (BP)	*Melanopsis* calendar age ±1 σ	Historical age	Charcoal ¹⁴C age ±1 σ (BP)	Calculated reservoir age (yr)
Beteiha	T2-30	4959	cl	84.3 ± 0.4	1370 ± 45	AD 615–685	unknown	830 ± 45	560
	T10-1	4953	cj	82.5 ± 0.4	1550 ± 45	AD 430–560	unknown	680 ± 85	870
	T10-2	4957	cl	82.1 ± 0.4	1580 ± 40	AD 420–540	unknown	1045 ± 50	540
	T10-5	4952	cj	82.8 ± 0.4	1520 ± 45	AD 430–490 AD 530–610	unknown	560 ± 95	960
Galei Kinneret	GK 3-1	5105	cj	68.2 ± 0.4	3080 ± 45	1420–1300 BC	AD 749[c]	1980 ± 40[d]	1020
	GK 1-6	5104	cj	73.0 ± 0.4	2530 ± 45	790–740 BC 690–660 BC 650–550 BC	AD 749[c]	1980 ± 40[d]	550
Hamadia Hill	mh-a	4955	sa	2.8 ± 0.1	28,750 ± 320		unknown		
	mh-4	6041	cl (?)	2.9 ± 0.1	28,490 ± 280		unknown		

[a]Locations are shown in Figure 2.
[b]cl – *costata lampra*; cj – *costata jordanica*; sa – *saulcyi*. For details, see Figure 3.
[c]Marco et al. 2003.
[d]Radiocarbon age of the bone.

lighter than the shells. The water ^{14}C results were not corrected for isotope fractionation, whereas *Melanopsis* data were corrected. However, the difference between the measured age of the water and the *Melanopsis* could not exceed 400 yr and has been found to be lower (200–300 yr). Thus, the reservoir age calculated based on the *Melanopsis* can be assumed to represent the reservoir age of the water body with an uncertainty of 200–400 yr. In general, the variation in ^{14}C content between individual *Melanopsis* specimens from the same location is larger than the measurement uncertainty (see Table 1).
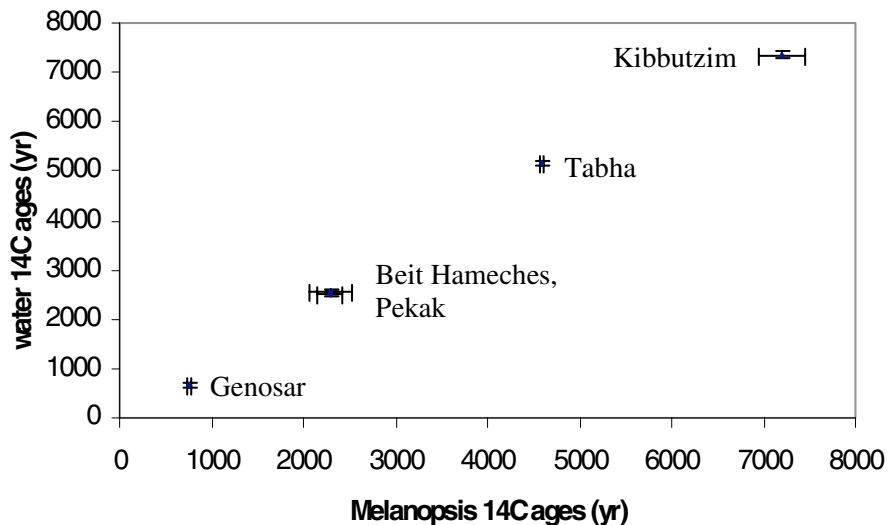

Figure 4 ^{14}C ages on living *Melanopsis* and its associated waters. *Melanopsis* ages are the average from 2–4 specimens.

The various *Melanopsis* types from the different water habitats show large variations in their reservoir ages (Table 1) (the uncertainties quoted for the reservoir age do not include the above-mentioned uncertainty due to the $\delta^{13}C$ correction). The *Melanopsis costata lampra* (species "cl" in all tables) and waters from the northern Jordan River (Beit Hameches and Pekak Bridge) yielded a reservoir age of 2300 ± 200 yr, while the *Melanopsis costata jordanica* (species "cj") from Lake Kinneret yielded 750 ± 20 yr. *Melanopsis buccinoidea* (species "bucc") from Tabha springs gave a reservoir age of 4580 ± 40 yr. The *Melanopsis saulcyi* (species "sa") from Kibbutzim Stream yielded 7200 ± 260 yr. Kibbutzim Stream is fed by freshwater emerging from the aquifers of Mt. Gilboa. The very high reservoir age might reflect both aging and water-rock interaction within the aquifer. Similar low pMC values (corresponding to high reservoir ages) are recorded by freshwater springs that emerge from carbonate aquifers, such as the Dan spring emerging from Mt. Hermon or the En Peschka springs (Carmi et al. 1985; Talma et al. 1997; Belmaker et al. 2006). The same explanation is assumed for the very high reservoir age obtained for *Melanopsis* from Tabha springs. The significantly lower reservoir ages of the *Melanopsis* shell and waters of the northern Jordan River and Lake Kinneret probably is the result of the exchange of the Jordan and Kinneret waters with the atmosphere and mixing with water coming from basaltic aquifers in the Golan Heights, characterized by high pMC values (for Lake Kinneret) (Stiller et al. 2001; Belmaker et al. 2006).

The plant sample, used as a proxy for the *Melanopsis* diet (algae), yielded similar ^{14}C content as the aragonite shell and the water (pMC 39.2 ± 0.3, Table 1), suggesting that both the organic and inor-

ganic part of the *Melanopsis* are in equilibrium with the habitat water. The $\delta^{13}C$ value of the plant sample (–32.5‰) deviates significantly from that of the water (–12.0‰) and the carbonate (–9.5‰) (Table 1), probably reflecting the large fractionation in $\delta^{13}C$ during photosynthesis (Cornett 2004).

Radiocarbon Dating of Fossil *Melanopsis*

The following step in our assessment of the potential use of *Melanopsis* shells as ^{14}C chronometers was to analyze the ^{14}C content of fossil shells from independently dated stratigraphic horizons. This allows us to test whether subtracting the reservoir ages we assign for the various *Melanopsis* types yields a reliable calendar age for each stratigraphic horizon. In turn, we may use independent known calendar ages (e.g. U-Th or archaeological information) for the specific stratigraphic strata to deduce a reservoir age and specify the type of water habitat. In the following section, we describe 4 sites with fossil *Melanopsis* shells according to chronological order.

1. The Bet Zayda Valley (also called Beteiha Valley) on the delta of the Jordan River, where it discharges into Lake Kinneret (location in Figure 2 and Trench-10 log in Figure 5), was the focus of a paleoseismic study because of its location on an active strand of the Dead Sea Transform. The Bet Zayda Valley is flooded only during extreme high stands due to its height (207 m bsl). Offset late Holocene alluvial channels were dated using detrital charcoal (Marco et al. 2005) recovered from paleoseismic trenches. We collected *Melanopsis* shells in trenches (trenches T-2 and T-10) from the same layers where the charcoal samples were collected and measured (see Figure 5 for Trench 10).
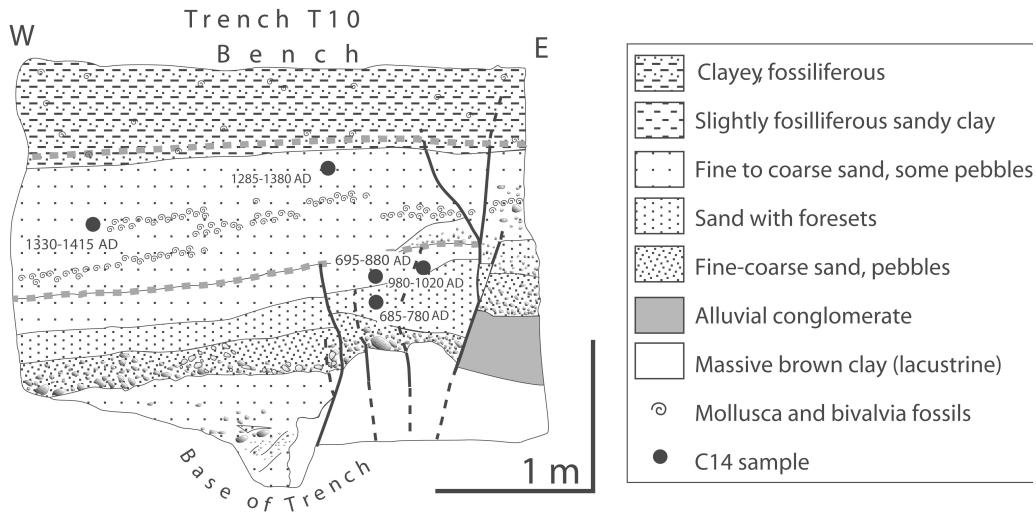

Figure 5 A schematic E-W section of Trench 10 at the Beteiha site (after Marco et al. 2005)

2. The *Melanopsis* types are *costata lampra* (cl) (Jordan River) and *costata jordanica* (cj) (Lake Kinneret). The shells from the Beteiha yielded uncalibrated ages ranging between 1370–1580 BP, compared to charcoal ^{14}C ages of 560–1045 BP (Marco et al. 2005). The reservoir age, determined as the difference between the charcoal ^{14}C age and the *Melanopsis* from the same layer, is somewhat higher for the *costata jordanica* (cj) species than for *costata lampra* (average of 915 and 550 yr, respectively, Table 2). The former reservoir age is similar to the current value of Kinneret water (Table 1), which is the typical habitat of the *costata jordanica*

(cj) species. This implies that the Beteiha Valley was influenced at that time by the Kinneret water, and the *Melanopsis* shells of the *costata jordanica* (cj) type appear to provide a reliable ^{14}C concentration.

3. The Galei Kinneret site (location in Figure 2 and description of site in Figure 6): The archaeological excavations at the site, situated on the western shore of Lake Kinneret at Tiberias between the elevations of 208 and 212 m bsl, revealed Roman, Byzantine, and Early Arabic buildings, all buried by alluvium and lake sediments (Hazan et al. 2004). *Melanopsis* shells found at this site were identified as *costata jordanica* (Lake Kinneret type). The shells were found in a post-Byzantine, pre-Abbasid strata, i.e. between AD 638 and 750 (~1300 BP) (Marco et al. 2003; Hazan et al. 2004). The shells yielded an uncalibrated ^{14}C age of 2800 ± 390 BP, which is ~1500 yr older than the archaeological dating. Nevertheless, a bone (RTT-4961) found in the same layer as the *Melanopsis* shells yielded an uncalibrated ^{14}C age of 1980 ± 40 BP, ~800 yr younger than the *Melanopsis* age from the same layer. Since the bone is considered as terrestrial organic material regarding ^{14}C, the difference between the *Melanopsis* shell and the bone (~800 yr) is similar to the current reservoir age of Lake Kinneret (Table 1). The bone-*Melanopsis* shell relationship supports the constancy of the Kinneret reservoir age during the past 2000 yr. We can reconcile the ^{14}C data of the bone-*Melanopsis* shell with the archaeological age constraints by assuming recycling of the bone and the *Melanopsis* shell in the shore environment.

Figure 6 Galei Kinneret site. Top left inset: schematic E-W section of the Galei Kinneret site. A - Columns of the Ummayad period buried by Kinneret sediments. A later wall of the Abbasid period overlies the sediments. B - Lacustrine beach ridge and *Melanopsis* (arrow) at the top of a sedimentary section, which buried an Ummayad column at the right, the same column that is on the left side of (A) (Hazan et al. 2004).

4. Ohalo-II (location in Figure 2): The archaeological excavations at the Ohalo-II site and the geological trenching and coring that was performed at this site recovered organic debris and *Melanopsis* shells, which were ^{14}C dated (Nadel et al. 2001; Hazan et al. 2005). Wood samples collected on the Ohalo shore at 213.0 m bsl yielded uncalibrated ^{14}C ages of 19,440 ± 770 BP (average on all woods [Nadel et al. 2001]), which were calibrated to ~22,500 BP. These woods were deposited on the shore after the retreat of the lake from its highest stand (Hazan et al. 2005). The sedimentary section that was deposited during the high-stand period of the lake (~26,000–24,000 BP) was recovered by trenching. Two samples of organic debris and *Melanopsis* shell found in between (at depths of 213.7, 215.5, and 214.6 m bsl, respectively) yielded uncalibrated ^{14}C ages of 20,640 ± 200, 21,120 ± 190, and 21,130 ± 180 yr, respectively. The calibrated ages of the organic debris are ~24,000 and ~26,000 BP. Considering the current deposition rate in Lake Kinneret of 1 ± 0.2 mm/yr (Koren and Klein 2000) and the calibration uncertainties in this time range, the *Melanopsis* shell would yield a calendar age of ~25,000 yr, implying a reservoir age of several hundred years. Thus, we can conclude that the late Pleistocene Lake Kinneret was characterized by a reservoir age that is not very different from the current value (of ~750 yr). This result indicates that Lake Kinneret maintained a relatively uniform reservoir age (within an uncertainly of a few hundred years) during various stages of its limnological history. This may indicate an efficient exchange of the lake water with the atmosphere.

5. The Hamadia Hill site is located above the bank of the Jordan River in Beit Shean Valley at ~170 m bsl (Figure 2). A large number of *Melanopsis* shells were recovered from the top of the Lisan Formation sediments comprising the hill, probably marking a high stand of the paleolake. Most *Melanopsis* shells were identified as *saulcyi* (the same as the Kibbutzim Stream species) and a few were identified as *costata lampra* (Jordan River species). The *Melanopsis* shells from this site yielded an uncalibrated ^{14}C age of 28,600 ± 200 BP. Assuming that the *Melanopsis* shells were recovered from the high-stand shores of Lake Lisan, the calendar age would lie in the range of ~26,000–24,000 cal BP (e.g. Bartov et al. 2003). This would indicate an uncalibrated ^{14}C age of 20,000–21,000 BP, significantly lower than the measured age. This could imply a high reservoir age of several thousand years, which is consistent with the reservoir age of the Kibbutzim Stream (~7000 yr; see Table 3) that drains into the Beit Shean Valley. This possibility is verified by the finding of *Melanopsis saulcyi*, but should be confirmed by applying other geochemical tracers such as $^{87}Sr/^{86}Sr$ isotope ratios. The geochemical tracers should be used to identify the type of habitat water of a specific *Melanopsis* suite so that the reservoir age can be specified (e.g. Lev 2006; Lev et al. 2006).

CONCLUSIONS

The main conclusions of our study are the following:

1. Live *Melanopsis* shells are in equilibrium with their habitat waters regarding the ^{14}C system. This allows specifying particular reservoir ages for various water types and *Melanopsis* species: Lake Kinneret (cj species), ~750 yr; springs in the north Kinneret (bucc species), ~4600 yr; north Jordan River, ~2300 yr (cl species); stream waters flowing from carbonate aquifers, ~7200 (sa species) (see Table 3).

Table 3 *Melanopsis* species and reservoir ages in living *Melanopsis*.

Location (see Figure 2)	*Melanopsis* species[a]	Reservoir age[b]
Jordan River, north	cl	2300
Tabha springs (north of Lake Kinneret)	bucc	4600
Lake Kinneret	cj	750
Kibbutzim Stream (south of Lake Kinneret)	sa	7200

[a]cl – *costata lampra*; bucc – *buccinoidea*; cj – *costata jordanica*; sa – *saulcyi*. For details, see Figure 3.
[b]Reservoir ages based on averages of *Melanopsis* samples.

2. Reworking processes should be considered, especially when single specimens are recovered from the site or sediments, using independent dating methods. Clusters of *Melanopsis* provide a more reliable context for dating.

3. We studied several sites where fossil *Melanopsis* shells were recovered (e.g. Beteiha, Galei Kinneret, Ohalo II, and Hamadia Hill). Applying independent stratigraphic and age information (^{14}C ages of adjacent organic debris), the fossil *Melanopsis* shells yielded reasonable reservoir ages that are consistent with their species. This indicates that fossil *Melanopsis* shells may yield reliable ^{14}C ages.

4. Determining a reservoir age of a fossil suite of *Melanopsis* shells by using independent age data (e.g. U-Th or archaeological chronology) may allow identification of the type of habitat water, which can be used for paleohydrological reconstruction.

5. The late Pleistocene *Melanopsis* shells recovered from Lake Kinneret yielded a similar reservoir age to the current value (a few hundred years), suggesting persistent rapid exchange of ^{14}C between lake water and the atmosphere during various stages in the evolution of the lake.

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