UNIVERSITY OF CALIFORNIA
RIVERSIDE

Ostracodes and Gastropods of the Waucobi Lake Beds: Significance for Pliocene
Environmental and Climate Conditions in the Eastern Sierra Nevada, California

A Thesis submitted in partial satisfaction
of the requirements for the degree of

Master of Science

in

Geological Sciences

by

Joanna Rosalie Oseguera

March 2012

Thesis Committee:
       Dr. Mary L. Droser, Chairperson
       Dr. Richard A. Minnich
       Dr. Nigel C. Hughes

The Thesis of Joanna Rosalie Oseguera is approved:

_____

_____

_____

Committee Chairperson

University of California, Riverside

ACKNOWLEDGMENTS

DEDICATION

This thesis is dedicated to my family—for their patience and generous support. I cannot thank

you enough for believing in my academic ability. Thank you.

ABSTRACT OF THE THESIS

Ostracodes and Gastropods of the Waucobi Lake Beds: Significance for Pliocene Environmental
and Climate Conditions in the Eastern Sierra Nevada, California

by

Joanna Rosalie Oseguera

Master of Science, Graduate Program in Geological Sciences
University of California, Riverside, March 2012
Dr. Mary L. Droser, Chairperson

The fossil record of lake strata typically provide a high resolution record of past ecosystems and

environmental conditions. The faunal records of the Pliocene Waucobi Lake beds provide such

an opportunity to interpret environmental and climate conditions for the eastern Sierra Nevada.

These lacustrine sediments cropping out in Soldier Canyon, Owens Valley, Inyo County, CA are

composed primarily of clay beds with several freshwater species of ostracodes and gastropods.

This presence and absence of key taxa and the relative abundance of various gastropod and

ostracode taxa for the Sierra Nevada during the late Pliocene demonstrate that there were changes

in salinity in the Waucobi Lake associated with an open- and closed-basin lake system, driven by

the Sierra Nevada rainshadow climate control. Lake beds containing gastropods were interpreted

as freshwater events. In this study two sections were stratigraphically analyzed for fossil

ostracode and gastropod variability. The high resolution sampling revealed the presence of

ostracode assemblages suggests interruptions of saline conditions occurred more frequently than

previous reported.

Table of Contents

List of Figures

List of Tables

Results

Introduction

The Waucobi beds (also referred to as the Waucoba beds, Bachman, 1974) are late Pliocene lacustrine deposits cropping out as hills at the base of the western White-Inyo Mountains, in eastern California and ~ 24 kilometers west of the Sierra Nevada (Fig. 1 and 2, Bachman, 1974; Walcott, 1897; Luddecke et al., 1997; Hay, 1964). Several rhyolite tuffs interbedded with the lake sediments constrain the upper age between 2.3 - 2.8 Ma (Sarna-Wojcicki et al., 2005; Luddecke et al., 1998; Hay, 1964, 1966). The beds were first described by Walcott (1897) followed by Knof et al. (1918), Hay (1964), and later thoroughly investigated by Bachman (1974) in relation to the uplift of the White-Inyo Mountains.
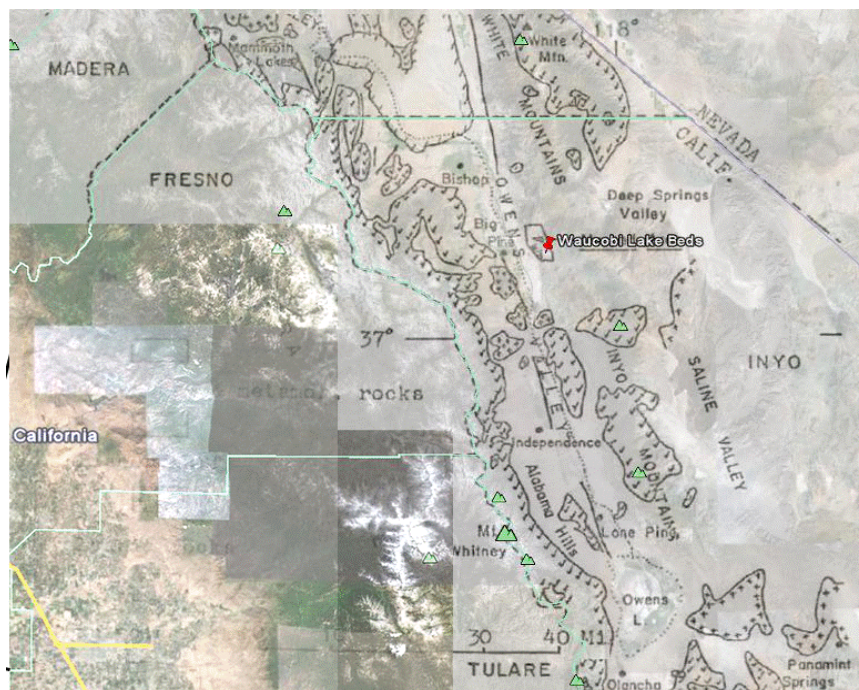
Figure 1. Locality of the Pliocene Waucobi lake beds in relation to surrounding cities and geo-topography (adapted from Bachman, 1974).

Previous studies of the Waucobi lake beds established one to ten meter alternating episodes of saline/alkaline (closed lake) and freshwater conditions (open lake)

based on the presence of zeolites, evaporates, and fossil freshwater gastropods (Bachman, 1974; Hay, 1964). Using silt and tuff deposits, Hay (1964) reconstructed the Waucobi lake system, describing two lake phases that fluctuated in size and salinity: 1) an extensive shallow freshwater lake system and 2) a restricted small saline lake. Hay (1964) provided no explanation for environmental conditions related to the salinity phases. Bachman (1974) reasoned the alternating phases were due to the presence or

absence of overflow outlets from the lake, but did not relate it to evaporation or precipitation rates due to possible climate forcings, or tectonic activity that changed the basin settings.

Figure 2. Waucobi Lake sediments (foreground) with the Sierra Nevada to the west.

Lake sediments archive a record of changing past depositional conditions and environments. The lithological record in lake basins archives different levels of lake variation (Carroll et al., 1999; Fritz, 1996; Cohen, 2003; Migowski et al., 2006, Willman, 1985). A relationship between climate change, environment response, and depositional processes can be resolved in lake beds with high resolution (mm-cm) analyses (Brauer et al., 1999). Paleolake studies with 1 to 2 mm sample resolutions have reconstructed saline lake phases, record small variations in evaporation and precipitation, their effect on the physiochemical conditions, and changes in lake levels including highstands and lowstands (Rodó et al., 2002; Bonnefille et al., 2004; Allen et al., 2000; Moberg et al.,

2005; Abbott, 1997; Battarbee, 2000). High resolution data are also useful for reconstructing quantitative large-scale temperature changes (Jones et al., 1998; 2004).

The fossil record in lakes is also considerably useful for interpretations of environmental conditions as well as providing age constraints (Eardley et al., 1960). High resolution studies using the biotic component of lake sediments have shown to capture more subtle variation in lake conditions (Fritz, 1996) and climate changes on a millennial-scale to submillenial scale (Lotter et al., 1992, Wick et al., 2003). Fossils provide high temporal resolution by recording short-lived, less extreme fluctuations in the limnological environment (Palacios-Fest, 1993; Fritz, 1996, Eardley et al., 1960) because these taxa are restricted to the aquatic environment (Willman, 1985). In small lakes, population size is small, and there is less reworking and redeposition of sediments (Willman, 1985). Fritz (1996) asserts that fossils in lacustrine sediments provide a record that is more influenced by climate change, whereas sedimentological records of lakes record more complex interaction between the climate, hydrologic basin, and indirect climate influences of lake levels.

Bachman (1974) described the sedimentology and stratigraphy of the Waucobi lake beds. However, fossils from the beds have only anecdotally been included in any previous study of the Waucobi beds. This study evaluates the fossil ostracode and gastropod record and is used to test whether a high resolution signal of alternating lake phases can be resolved and if so, to test if a climate signal can be interpreted for the eastern Sierra Nevada region. While three species of gastropods were previously reported; ostracodes were discovered for the first time in this study.

This study will establish a baseline for environmental conditions in the absence of Sierra glaciation to better interpret terrestrial climate records following the late

Pliocene and to examine the variability tied to climate conditions in paleo-Owens Valley. Current impacts of recent and future climate changes require a baseline to measure the magnitude of observed or predicted changes (Hoffert et al., 1991; Fritz, 1996). Short stratigraphic sections were sampled at cm-scale resolution for fossil ostracodes and gastropods and taxonomic identification required. The identification of specific species yield information on general ecological habitat, salinity ranges, solute composition, and temperature ranges of the water they inhabit (Curry, 1999).

Background

Fossils of the Waucobi Lake beds

Walcott (1897) and Bachman (1974) reported three fossils gastropod species from the Waucobi beds. Three additional species were found in this study. Fossil ostracodes were not previously reported, but they are abundant. Additionally fossil algae are present.

Ostracodes as proxies for past conditions

Ostracodes are microscopic bivalved crustaceans that develop via molting and whose shells, composed of low magnesium-calcite, (Chivas et al., 1995; Deckker, 1988; Engstrom et al., 1991; Ikeya, Holmes, 2002; 2005, Frenzel et al., 2005; van der Meeren et al., 2010) reflect the lake water chemistry (Chivas et al., 1986; Engstrom et al., 1991). Ostracode shells are commonly found as fossils in sediments and sedimentary rocks (Benson, 1981; Delmore, 2001; Frenzel et al., 2005; Ikeya, 2005, van der Meeren et al., 2011). The reconstruction of aquatic environments from ostracode shells can be

used for qualitative or quantitative changes in the terrestrial environment and infer

climate influences (Fritz, 1996; Külköylüoğlu, 2003, 2005).

They are often used as a proxy for both marine and non-marine setting for past

environmental and climate conditions (Ikeya, 2005) because they require specific

physical and hydrochemical conditions, and are highly responsive to changes reflected in

their biogeographical distribution (Neale, 1983; Park et al., 2003; Cohen, 2003; Holmes,

2002; Külköylüoğlu, 2004, 2005, 2006). Ostracodes are a strong proxy for saline waters

because they are sensitive to varying lake conditions (Neale, J.W., 1983; Carbonel et al.,

1988; De Deckker, P., 1981; Delmore, 1989; Engstrom et al., 1991, Williams et al., 2001)

because the group spans the entire salinity range from freshwater to marine conditions

(Frenzel et al., 2005).

Ostracode as individual species and assemblages are used as a biochemical proxy

for the ionic concentration and composition as these are the major factors that determine

abundance and distribution of non-marine ostracodes (Forester, 1986; Curry, 1999; Ikeya,

2005, Frenzel et al., 2005). Ostracodes provide a list of hydrochemical indexes of lake

waters: pH, ionic composition, temperature, and total dissolved oxygen (Delorme, 1969,

1989; Carbonel et al., 1988; Forester, 1986; De Deckker, 1988; Holmes, 1992;

Külköylüoglu, 2004; Palacios-Fest, 1993; Frenzel et al., 2005; Mezquita et al., 2005).

The primary proxy used in this study is the salinity tolerance ranges of ostracodes as an

index for past lake conditions. pH tolerances of some species can indicate whether a lake

is in a closed or open hydrologic basin (Delmore, 1989). The hydrochemical limits of

ostracodes can also indicate general limnological conditions: hyperhaline, euhaline,

mixohaline, polyhaline, mesohaline, oligohaline, limnetic (Pfaff, 2004; Deckker, 1988).

In saline lakes ostracode distribution is correlated with both ionic concentration and

composition, in which different species indicate different water chemistry, such as calcium-enriched waters versus carbonate-enriched (Fritz, 1996).

Ostracodes distribution and assemblage composition, however, is not a simple linear relationship. Biotic factors such as aquatic vegetation, competition, predation, parasitism, and predation also affect their distributions (Delorme, 1969; Mezquita et al., 2005). Additionally physical factors such as currents, flow energy, and permanence of the water body are additional variables. In reconstructing past lake conditions from species composition of ostracodes, ionic composition and concentration are suggested to be most significant variables determining species distribution (Delmore, 1969; Carbonel et al., 1983; Forester et al., 1985; Forester, 1986; De Deckker et al. 1988; Smith, 1993; Curry, 1999), however additional variable that can influence species distribution must be kept in mind (Herbst, 2001, Mezquita, et al., 2005).

Gastropods as proxies for past conditions

Using gastropod fossils as a climate proxy is more complicated as their distribution does not fall on a uniform continuum because physiochemical parameters including water temperature, current velocity, substrate composition, water depth, aquatic vegetation, competition, predation and permanence of the body of water create a myriad of varied environments that result in varied assemblages (Lodge et al., 1987; Sharpe et al., 2007; Costil et al., 1996). The numerous ecological parameters affecting their distribution are nonetheless able to indicate general environmental conditions. The physical parameters of depth and predator biomass have successfully predicted species composition in modern ecological studies (Turner et al., 2009).

Important chemical parameters that determine ostracode distribution are primary productivity, solute composition (HCO3 and Ca content in particular), pH and alkalinity (Aho, 1984; Sharpe et al., 2002, 2007). Water hardness and pH are important factors in determining gastropod distribution because these factors correlate with relative abundance patterns and gastropod densities (Brown, 2001). Low pH values limit calcium availability, and gastropod shell development at a regional scale (Lodge et al., 1987). Shell development requires water with adequate calcium at or above 5 mg/L $CaCO_3$ (Brown, 2001). Solute composition is another critical chemical factor (Sharpe et al., 2007). The total dissolved solid (TDS) range of non-marine aquatic gastropods may not be directly related to the distribution of species; but it does relate to the changes in kind and amount of ions in the solute composition. Key anions to gastropod distribution are HCO_3 (CO_3) and calcium (Sharpe et al., 2007).

Species richness (SR) for modern freshwater gastropod assemblages provides varies ecological aspects (i.e. calcium, pH, total alkalinity, humic substances, and lake surface area) of physiochemical environment. Species richness for present freshwater gastropod has a positive correlation to comparative water body size (Aho, 1978; Browne, 1981) with lakes and rivers showing a higher SR value than ponds and creeks (Pip, 1987). Such a correlation might have application to paleo-communities of freshwater gastropods.

Geological Setting

Owens Valley is bounded by the Sierra Nevada on the west and the White Mountains on the east, both ranges having summit altitudes >4000 m (Bierman et al., 1991; Luddecke et al., 1998; Ernst et al., 2003). The Pliocene Waucobi lake basin was

located on the east side of present Owens Valley, as evidenced by ancient shorelines (Bachman, 1974). The Waucobi beds predate the uplift of the White-Inyo (Bachman, 1974). From mid- to late Pliocene, the Owens River drainage feeding Waucobi Lake likely resided in a broad, moderately elevated, low relief plateau that drained to the Pacific Ocean, Great Basin, and Mojave and Colorado drainages, and responsible for the modern linear deep valleys seen today in Owens Valley (Phillips, 2008). The beds were exposed by tectonic uplift of the White-Inyo Mountains (Luddecke et al., 1998) and eroded and dissected during episodes of alluvial fan formation and by modern streams (Bachman, 1974). The aerial extent of the exposure is 8 km by 4 km. The exposed lake beds are ~91 m thick, dipping westward at an angle of 6°. The base of the Waucobi beds is not exposed (Bachman, 1974).

The water source for the Pliocene lake came from the Sierra Nevada (Bachman, 1974). Sediments of the lake basin have a Sierra Nevada source (Bachman, 1978). Waucobi sediments are evidence that low-topographic relief existed between the valley and Sierra Nevada (Lueddecke et al., 1997). There was a rainshadow in the Pliocene at the time of Waucobi Lake, though perhaps as a less effective barrier to eastbound storms (Orme, 2008).
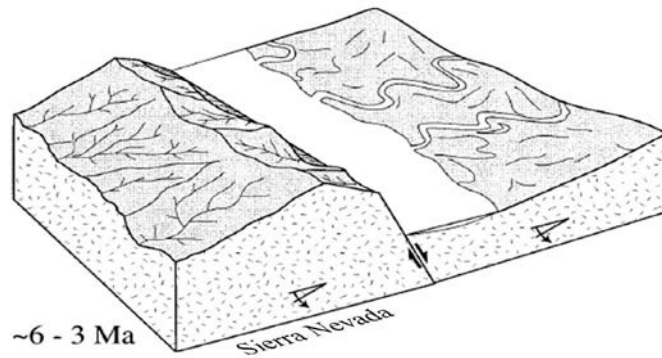
Figure. 3 Block model of the tectonic stage of the Sierra Nevada and Owens Valley at the latitude of the town of Bishop before the uplift of the White-Inyo Mountains (Adapted from Lueddecke, 1997).

Location

The Waucobi lake beds are a prominent sedimentary deposit along the west face of the White-Inyo Mountains (Trowbridge, 1911). The beds in Soldier Canyon are located 80 north of Owens Lake and 5 km northeast of Big Pine, Owens Valley, Inyo County, California. The beds outcrop as hills 4.8 km east of highway 395 on California 168. The measured sections in this study are found at the GPS coordinates of: 37 10 34N, 118 11 33W (base of section); 37 10 35N, 118 11 (top of section).

Tectonic Basin

Syndepositional faulting of the lake beds resulted in the 6° dip to the west during and after Waucobi Lake (Luddecke et al., 1998). The lake likely formed in a depression due to extension basin and range tectonism that became active at 6 to 3 Ma in the region (Burn et al., 2009; Phillips, 2008; Thompson, 1991) in what was a previously unbroken Sierra Nevada-White-Inyo block (Bachman, 1978). Extensional breakup just east of paleo-Owens River drainage began in the mid-Pliocene (Phillips, 2008). Tectonic activity reactivated Miocene faults, resulting in a north-south trending valley (proto-

Owens Valley) and the opening of basins by separating detachment structures (Phillips, 2008).

The White-Inyo Mountain fault is suggested to have first developed 3Ma (Luddecke et al., 1997). The White-Inyo Mountain fault intersects two other major faults: the Owens Valley fault and the Deep Springs fault (Jager et al., 2002). The Waucobi sediments were deposited a tectonically active basin similar to Owens Lake. Range-front faulting reconfigured block tilting of the White-Inyo Mountains and Owens Valley. There was also a shift in tilt polarity (Luddecke et al., 1997) as well as mafic volcanism (Thompson, 1991). This range-front faulting rotated the lake beds' original position to the west relative to Owens Valley (Bachman, 1974; Orme, 2008; Luddecke et al., 1998). Evidence for a westward shift of the Waucobi lake basin is based on the movement of the lake depocenter, movement of shorelines, and detritus from the Sierra Nevada and the White-Inyo Mountains as the White-Inyo Mountains were uplifted and Owens Valley was depressed (Bachman, 1978).

The landscape development of Owens River basin is only partially understood. Present Owens Lake and Waucobi lake beds lie in the same structural basin, and received runoff from the Sierra Nevada (Hay, 1964). Source rocks for the two lakes were almost the same. Hence the waters of the two lakes should have similar hydrochemistry with respect to dissolved ions (Hay, 1964). Climate controlled lake parameters were also similar. According to Hay (1964), the hydrochemistry was very likely alkaline and rich in dissolved sodium carbonate and bicarbonate during the saline lake phase of the Waucobi beds, similar to Owens Lake (Hay, 1964). Carbonate enriched lakes are common to lakes groundwater discharge area of the U.S. and Mexico with pH ranges of ~9.6-10.5

(Delmore, 2001) which is higher than the average pH lake range of ~6-9 (Bronmark et al., 2005; Delmore, 2001).

The Waucobi is located within the rainshadow of the Sierra Nevada, an intense rainshadow for the region east of the range (Bierman et al., 1991). The rainshadow created by the uplift of the Sierra Nevada influences the amount of precipitation that reaches the eastern Sierra Nevada region (Thompson, 1991). The cold north Pacific oceanographic conditions strongly influence precipitation patterns, resulting in arid condition for the leeward side. Cold waters off the Pacific tend to produce low convecting layers (Minnich, personal communication, 2012). These factors contribute to the arid conditions for the eastern Sierra Nevada region.

There is no consensus on the timing the Sierra Nevada uplift and its affect on Cenozoic climate in the western United States (Poage et al., 2002; Phillips, 2008; Hay et al., 2002; Figueroa et al., 2010). The long-standing view is that the Sierra Nevada topographic development primarily occurred at 10 Ma with a mean elevation comparable with the modern range (Mulch, 2008; Pelletier, 2007; House et al., 1998, 2001; Small et al., 1995). The Sierra Nevada may in fact have lost elevation in the Late Cenozoic (Poage et al., 2002). The alternate view is that the Sierra Nevada was not a major topographic feature until 5-3 Ma (Ducea et al., 1998; Farmer et al., 2002; Molnar, 2004; Zandt, 2004; Huber, 1981; Unruh, 1991; Dalrymple, 1964; Wakabayashi et al., 2001; Axelrod, 1962; Jones et al., 2004). Thompson (1991) estimated elevation of the Sierra Nevada crest is at 2100 m at 3Ma, while Orme (2008) suggest it was possibly 1000 m lower. The fossil plant record supports the idea that tectonic activity contributed to the rapid rise of the Sierra Nevada beginning in the late Miocene into the Pliocene (Minnich,

2007). Late Tertiary paleobotanical data support the idea of developed arid conditions in the Great Basin (Axelrod, 1948; Jones, 2004).

Age constraints

Overlying alluvial deposits, consisting of pebble, cobble, and boulder conglomerates with angular to sub-rounded clasts, referred to as fanglomerates (alluvial fan gravels) by Bachman (1974) unconformably cap the lake beds. Ashes from the White-Inyo Mountain range front are widespread and easily identifiable stratigraphic markers (Lueddecke et al., 1997). Lueddecke et al. (1997) found an ash within the fanglomerate sequence that is similar to an ash in Black Canyon and correlated the two. High-precision $^{40}Ar/^{39}Ar$ radioactive age dating yielded an age of 2.82 Ma ± 0.02 Ma for the Black Canyon ash (Lueddecke et al., 1997). Based on the correlation, this ash in the fanglomerates overlying the lacustrine deposits sets the upper minimal age constraint for the lake beds at 2.8 Ma ± 0.02 Ma.

However, younger inferred ages from tephra correlation are reported by Bachman (1978), Izett (1981), and Sarna-Wojcicki et al. (2005) and place the Waucobi beds closer to ~2.1 Ma. This discrepancy is a result of numerous correlations of different ashes from the eastern Sierra Nevada region to ashes within the Waucobi sediments. A bed in the Waucobi sediments identified as containing the Taylor Canyon-C tephra by Izett (1981) yielded an age of approximately 2.1 ± 0.02 Ma dated by K/Ar. Feldspar crystals from upper portion of the Waucobi lake beds dated at 2.3 Ma with K/Ar (Hay, 1966; Thompson, 1991; Bachman, 1978). Using electron-microprobe analysis (EMA) of glass from Waucobi tephra layers, Sarna-Wojcicki et al. (2005) correlated Blind Spring Valley ashes dated at 2.2 Ma to two samples of Waucobi tuffs. Using instrumental

neutron activation analysis (INAA) the same samples correlated to two other tuffs: Emigrant Pass dated at 2.1 Ma and lower tuffs of Glass Mountain dated at 1.98 Ma, while two samples did not match any tephra (Sarna-Wojcicki et al., 2005). Two other ash samples from Waucobi beds examined by Sarna-Wojcicki et al. (2005) correlated best to Willow Wash ash dated at 2.84 to 2.57 Ma.

The tephrachronology method in Sarna-Wojcicki et al. (2005) does not date actual material from the Waucobi beds; no study to date use ash directly from the Waucobi Lake beds to obtain a radioactive date. All these studies precision relies in the accuracy of correlations between ashes found throughout the region. Although there are other papers that yield younger dates besides Sarna-Wojcicki et al. (2005), the correlations have less agreement in matching the ashes from the Waucobi beds. The most consistent age currently, hence, for Waucobi beds is at this time here reported as 2.3 - 2.8 Ma.

Sedimentological Setting

The strata of the Waucobi lake beds are primarily fine calcareous and argillaceous deposits (Walcott, 1897), alternating in color between light white/gray to buff/brown. Near the steeper slope of the White-Inyo Mountains, the sediments become coarser and coarser, and brown arenaceous beds predominate over the light gray sediments as ½ -16 cm beds of unlithified mudstone, claystone, sandstone, tuff, and cinder beds (Bachman, 1974) with about half a dozen rhyolite tuffs 1 to 30 cm thick scattered throughout the layers (Hay, 1965; Sarna-Wojcicki, 2005) that have not been dated.

Evaporites in the Waucobi beds recognized by Bachman (1974) include gypsum, halite, polhalite, sylvite, and trona. Gypsum is readily found as a secondary feature within the lake beds. Calcite was the only cementing agent (Bachman, 1974). A sharp fanglomerate contact unconformably overlies the beds, marking an abrupt end of lacustrine conditions. The flanglomerate layer is formed of fragments of arenaceous limestone, siliceous shale, and quartzite that have eroded from the White-Inyo mountain slopes (Walcott, 1897).

The lake beds share similar characteristics to Lake Bonneville and Lake Lahontan basins (Walcott, 1897). Bottom coarse material was washed from the mountains to near the shoreline with the finer sand and silt carried farther out and deposited with the calcareous sediment and shell remains (Walcott, 1897). Kodama et al. (1978) interpreted some lake sediment to be derived from glacial activity, but no other studies confirm this finding.

The tuffs varied from pumice lapill tuffs to massive, silty, fine-grained vitric tuffs (Sarna-Wojcicki et al., 2005). Evenly bedded unaltered tuffs and gastropod fossils were assigned to represent a large freshwater lake phase (Hay, 1965). In the saline phase, the rhyolite tuff was altered to the zeolites phillipsite and clinoptilolite (Hay, 1965). The alternating saline and freshwater conditions described by Bachman (1974) occur on a low resolution stratigraphic on the meter scale. The average facies thickness described by Bachman (1974) for the area in this study was 11 meters. The beds containing fossils are primarily claystone with minor amounts of siltstone and unlithified sandstone.
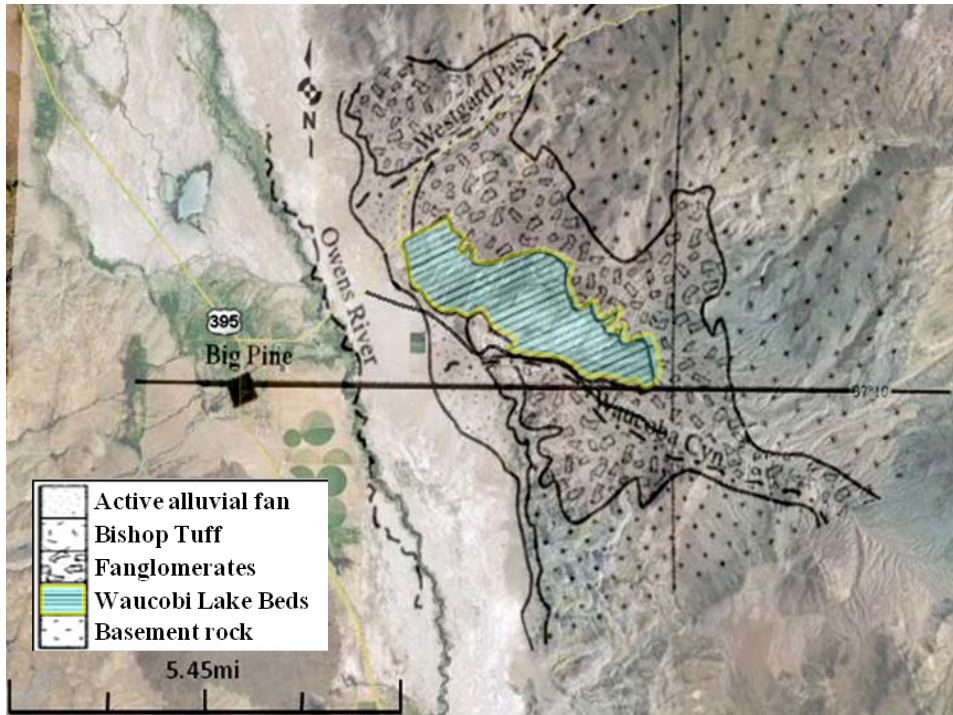
Figure 4. The Waucobi lake beds and generalized geologic units (adapted from Bachman, 1974).

Methods & Materials

Samples were collected from the Waucobi lake beds from two sites. Locality 18 of Bachman (1974), renamed WB-B18, was chosen as a sampling site because of the presence of a 5.5 m section described as having abundant gastropods (Figure 5). The sampling interval was found by locating locality 18 and measuring down 39 m from the fanglomerates capping the lake beds. Sampling started from a distinct marker bed characterized by light buff very coarse grain sand lithology. The sites were trenched inward from 0.25 m to 0.6 m until weathered sediments and modern roots were no longer visible. Both sections were measured stratigraphically described, and photographed.

Locality 18
NE ¼, SW ¼ of Sect. 7, T.9S., R.35E.

A.

3.7m — Top of beds, flanglomerates
18H 12' — Sltst and fine ss

20m — 18G 65' — Fine ss, several 30 cm med to crs ss beds, gastropoda, algal material, burrows

6m — 18F 20' — Med to crs Ss

9m — 18E 30' — Clyst, w/ minor intbdd sltst and fine ss.

5.5m — 18D 18' — Clyst and sltst, abundant gastropoda,

B.
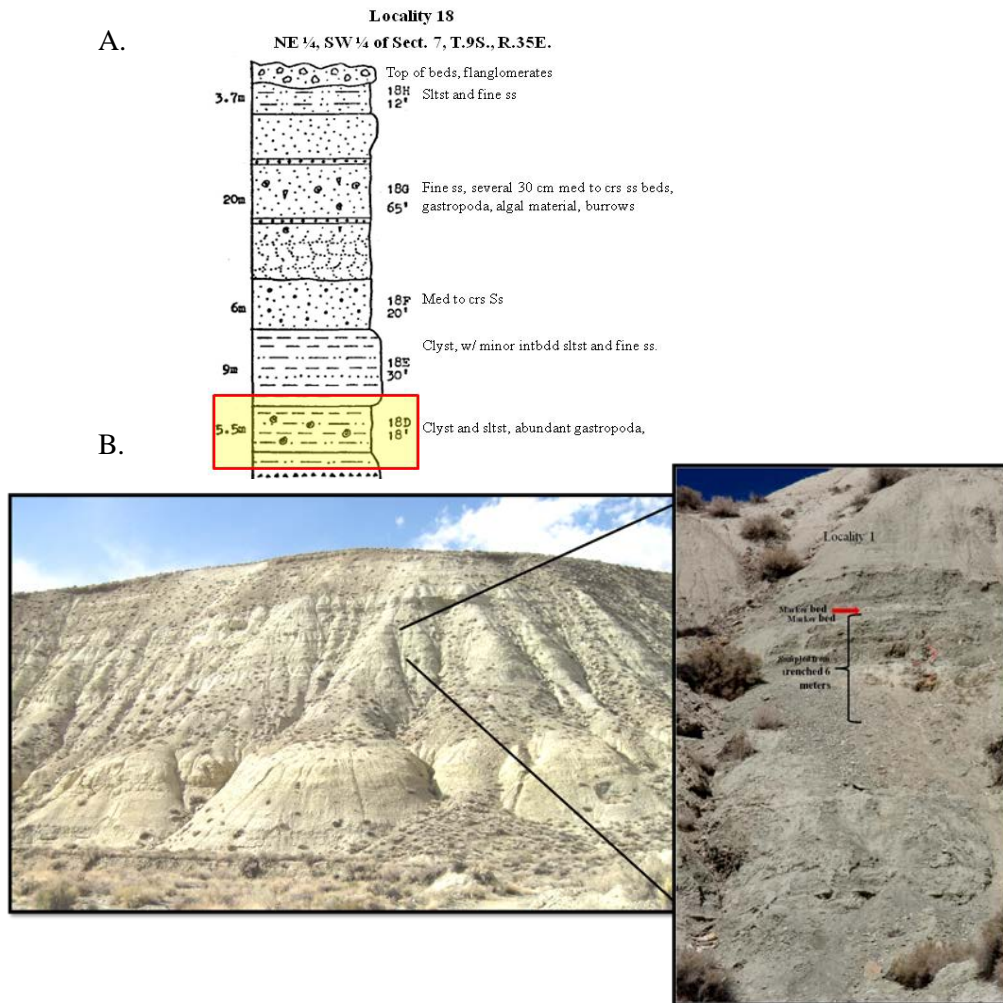
Figure 5. A. WB-B18 described and measured by Bachman, 1974 highlighting the 5.5 m interval sampled for gastropod fossils (Adapted from Bachman, 1974). B. Sampled section WB-J1.

Sedimentary columns

For each section, sedimentary columns were constructed to record the ostracodes and gastropod content in relation to the sedimentology (e.g. sorting, color, texture, grain size, etc.) and lithology (e.g. bedding, evaporate content, grading, other sedimentary structures, lithological percentage, etc.) for both sites. Lithology, grain size and shape, unweathered color, sedimentary structures, fossil content were used to identify preliminary facies in the field.

Field Sampling Methods

The beds with gastropods and ostracodes were traced laterally 3 m each way to ensure sampling represented the bed's fossil content. The samples were collected in ~ 4 liter bags at cm intervals based on visible original bedding planes, 3- 5 cm for fossil-containing beds, and 5-10 cm for lithology samples absent of fossils for a total of ~3 m for site WB-B18 and ~5 m for the second site WB-J1. Bulk lithology samples of ~3 liters were collected for fossils-containing beds, totaling ~3 m over the ~5 m interval at WB-J1 and ~1 m for the ~3 m interval at WB-B18. The sites were directly across from each other, separated by an eroded channel 15-20 m in width with an intermittent dry stream bed. In several instances additional sub-samples were taken between 3- 5 cm fossil-bearing beds that appeared as a different facies by a change in color, lithology, and fossil content.

Fossil Extraction

In the laboratory, gastropod and ostracode specimens were extracted using various methods, depending on the lithologic composition of the bulk sample. Fossils within clay and sand beds were extracted by softening the clay by spraying the sample's surface with water without saturating it. The soften sample was then pulled apart along planes of separation the water created upon infiltration. Sample of harder well-cemented clays were soaked in water to create infiltration water fractures. Molds, cast, and original shell material were picked by partially etching out the shell with dental tools. Partial extraction from the cement around the sample kept the gastropod shells from fragmenting. A small percentage of gastropod shells weathered out unbroken with sufficient exposure for identification. The ostracodes were extracted with fine-tip

brushes and water. The number of gastropods and ostracode shells counted varied for each bulk sample.

Fossils Identification

Fossil gastropods were identified by comparing images with the *Freshwater Gastropods of North America* (FWGNA) guide (http://www.fwgna.org/) and the *Field Guide to the Freshwater Mollusks of Colorado* (Harrold, 2010) and from Pliocene to recent mollusks sources (Burch, 1989; Hershler, 1996, 1999; Wootton, 1974; Hovingh, 2004; Baker, 1922; Pilsbry; 1891; Henderson et al., 1917; Taylor, 2002, 2003; Hubbard et al., 1985, Beauchamp, 1981, 1986, 1988; Sterki, 1920; Harman et al., 1970; Thompson, 2004; Wethington, 2004). Ostracode fossils were identified with a table made of images of the carapaces from various literature sources (Palacios-Fest, 2009; Forester, 1985; Kiss, 2007; Delorme, 1967, 1978, 1989; Dennison-Budak, 2010; Stout, 1975; Curry, 1999; Bhatia, 1971; Bright et al., 2011; Gutentag et al., 1962; Wilkinson et al., 2008; Prámparo, 2005; Pérez, 2010; Nagorskaya et al., 2005; Smith, 1993; Burke, 1987; Scharf, 1998; Holmes, 1992; Pieri et al., 2009; Alvarez-Zarikian et al., 2008; Mischke, 2010; Hanai, 1988; Kienast et al., 2011; Staplin , 1963; Bunbury et al. 2009). Guides used for identification include the UCL Microfossil Image Recovery and Circulation for Learning and Education (MIRACLE) website, and the North America Freshwater Ostracode database. Ostracode specimens were photographed with a Lecia microscope, using Lecia software to enhance the image, and submitted to Dr. Manuel Palasio-Fest from Terra Nostra Earth Sciences Research, to confirm identification. Unidentifiable fossils were not included in the final dataset for analysis.

Analysis

Relative Abundance

Fossil counts were normalized to relative abundance. Relative abundance was graphed in stratigraphic context for each measured section to create a signal of salinity and freshwater conditions for the lake beds. Presence/absence logs were used to view species distribution through the sampled intervals. Species abundances were further normalized by processing the same amount of bulk sample for each bed.

Clustering Method

The statistical program Paleonotological Stastics (PAST) ver. 2.10 was used to cluster ostracode and gastropod into assemblages and generate rarefaction curves to determine whether sampling was sufficient. The cluster analysis was performed using Ward's method to determine the number of major groups because the method tends to yield fewer clusters than other clustering methods (Holland, 2006). The large dataset generated in this study would result in numerous small groups with less diversity using other clustering methods, making patterns less obvious and clusters less manageable. Fewer clusters yield a lower degree of similarity between species in the assemblages, and higher SR values. Four major clusters from relative abundance were generated, in which only clusters greater than two taxa were considered. The fourth cluster was divided into two sub-clusters, totaling six ostracode assemblages.

Species Diversity Calculation

$$\text{The Shannon-Weiner index (H) equation} \quad H' = \frac{N \ln N - \Sigma (n_i \ln n_i)}{N}$$

was used to calculate species diversity. Charts of physical and chemical ecological information for identified gastropod and ostracode species were created to compare and constrain environmental conditions between species.

XRD Analysis

Analysis using Rigaku Ultima IV X-ray Diffractometer (XRD) was performed to confirm the presence of evaporative and/or zeolites in the sediment. Ten samples analyzed were from section WB-J1.

Results

Litholology

Clay, silt, and sand characterize the fossil-rich sampled sections. The sections are primarily composed of well-bedded clay with less than twenty beds ranging from 10 to 0.5 cm in thickness of sand and silt interbedded within the clay (Figure 6). Evaporites occur in the clay at the upper section of WB-J1. The clay occurs as thick- to medium-bedded planar light gray absent of discernible sedimentary structures. Sand beds, 0.5 cm to 10 cm on thickness, range from well-sorted medium to very coarse planar gray and brown thin beds with iron oxidized grains and are prevalent throughout the lower portion of the WB-J1 section and throughout the WB-B18 section. The silt beds are characterized as gray planar thin-bedded, 3 cm or less, beds absent of discernible sedimentary structures that interfinger the clay beds. Lenses of secondary gypsum occur throughout both sections. An 8 cm very coarse, well-cemented gray silty sand bed occurs 11 cm from the bottom of WB-J1. Just stratigraphically above is an unconsolidated grayish white ash layer. The clay grades into the sand beds on several occasions.

With ten powdered samples of clay and sandy clay from the upper portion of section WB-J1, XRD analysis confirmed the presence of evaporates and zeolite in the beds. The samples analyzed were absent of fossil gastropods and ostracodes. Evaporates confirmed being present include polyhalite, sylvite, and trona. XRD analysis confirmed the presence of the zeolite erionite.

Depositional Environment

Both sections can be generally characterized as lacustrine mixed with some minor fluvial deposits. The most common lithofacies is thin-bedded planar clay. The clay beds represent a well-developed lacustrine sequence consisting of ostracode and gastropod fossils from species that occupy both fluvial and lacustrine habitats. Results from this study indicate an extensive and well-developed open lacustrine sequence for the clay beds, indicating deep calm water near or at the depocenter of a lake. Concentrations of broken gastropod shells in the clay represent transport indicating a change to a fluvial environment or storm events flushing in the material.

Minor lithofacies include thinly bedded sandstone and siltstone, at times interfingering the clay beds. The sand and silt beds indicate a marginal lacustrine environment receiving river or stream discharge. In section WB-J1, sands overly clay beds and in both sections ostracode fossils are found in the sands and silts; it appears as though the sands represent a coarser facies being deposited contemporaneously with finer-grain deposits of silt and clay. Changes from clay to sand beds likely represent a change to a marginal lacustrine setting rather than a fluvial environment. The lack of sedimentary structures, such as cross-bedding or ripples, in the sand beds further argue against a fluvial environment. The sand beds are more suggestive of lacustrine deposition

by their planar thinly-bedded well sorted characteristics. The silt beds are also interpreted

as marginal lacustrine deposits for the same reason.
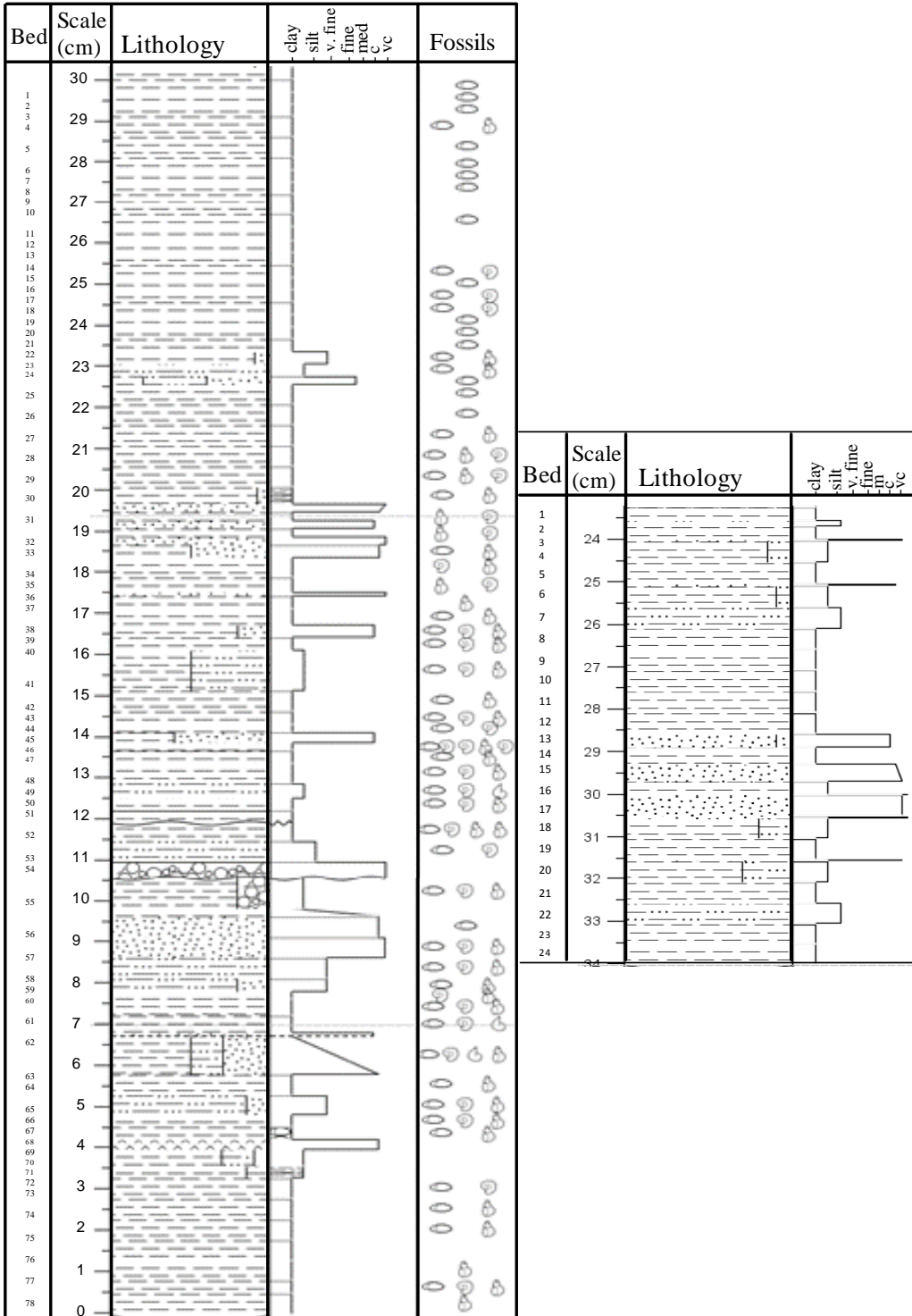
Figure 6. Lithological logs for site WB-J1(right) and WB-B18 (left).

Calculated Temporal Scale

Ash beds correlated from to ashes within the Waucobi beds constraint the upper age of the beds at 2.3 to 2.8 Ma. Based on the average sedimentation rate for Owens Lake of about 40 cm/kyr (Bischoff et al., 1998), the estimated temporal resolution for the Waucobi beds is approximately 7.5 ± 0.5 ky for the 3m WB-J1 sections. Table 1 gives the temporal resolution for section WB-J1 and the total thickness of the exposed beds. The estimated time represented resolution for the total thickness of 90 m for the Waucobi beds (Bachman, 1974), is 2,250 kyr.

Table 1. Temporal scale estimations based on thickness and depth from top.

	Thickness (m)	Depth from top (flanglomerate cap)	Average sedimentation rate of Owens Lake	Temporal Resolution
Section WB-J1	3 m	~30 m	40 cm/kyr	7, 500 years
Section WB-B18	1.5 m	~32 m	40 cm/kyr	3,750 years
Entire Waucobi beds	90 m*	NA	40 cm/kyr	2,250,000 years

*Base of the Waucobi beds is not exposed, does not represent total thickness.

Paleontology

Nearly eighteen thousand specimens were collected and identified from bulk samples. Three fossil groups were found: ostracodes, gastropods, and algae. A total of twenty seven species occur, six gastropods and twenty one ostracodes. Fossil algal material occurs throughout in every bed but was not used because it was beyond the scope of the project. Hay (1964) reported the presence of bivalves in the Waucobi beds but none were readily identifiable in this study. More bulk samples were collected from section WB-J1 than section WB-B18; results will be reported with an emphasis to WB-J1. The stratigraphic section from WB-J1 includes approximately 2 m more of section with fossils than WB-B18.

Taphonomy

Paleoecological interpretations require understanding how taphonomy has modified the remains of organism (Cohen, 1989). Although studies have established interpretation can still be made from the fossil assemblages that have undergone taphonomic processes of biostratinomy and diagenesis, it affects degree of resolution in paleoecological reconstructions (Izuka et al., 1986).

Biostratinomy

For the paleoenvironmental reconstruction of ancient lakes using assemblages of lacustrine fossils, it is important to know if horizons were formed primarily through transported shell accumulation, through biologic concentration mechanisms, or concentrations lags of autochthonous shell material (Cohen, 1989). Biostratinomic processes affected the distribution of major taxa, in varying amounts in the two sections. In general, the relationship is beds with coarse sediment, in particular sand, resulted in low species diversity and specimen counts. Fossils preserved in sand showed the poorest preservation and sandy beds typically yielded few or no fossils, with slight increase in species counts when sand beds where mixed with silt and clay. Sandy beds, thus, yielded the least diverse assemblages and are also likely the artifact of biostratinomic processes.

Beds prominently composed of silt were similar to the sandy beds in yielding low fossil counts and species diversity. Fossil counts increased moderately when mixed with clay. The clay beds produced the most diversity and highest absolute abundances of fossils and the fossils were the best preserved with the least evidence of breakage as a result of biostratinomic processes. Although the sandy beds yielded lower counts and diversity, sand was a minor constituent of the overall lithology and did not affect the data.

The variation of ostracode and gastropod fossil distribution was recorded in the clay beds, the bulk of the lithology, which produced large N values.

Too fragile to extract whole, gastropod shells did not exhibit fragmentation from transport. In a few beds, the gastropods appeared as clusters of high shell concentrations in which shells were overlying each other (Figure 7). Some ostracodes shells did show evidence of transport and accumulation with shells uniformly disarticulated. The abundance and wide distribution of gastropod *Valvata sincera* in the Waucobi beds is likely due to its higher chance for preservation. It had the ability to adapt to fluctuations in the trophic state of the habitat because it is both a nektonic and benthic species (Mezquita et al., 1999). It tends to inhabit permanent aquatic and relatively large deep lakes. *V. sincera* extant relatives live in cold water enriched with calcium, in large oligotrophic lakes in depths greater than 2 m (MA Natural heritage endangered species program, 2008). Deep lakes likely allow for high shell preservation and can further account for its abundance in the Waucobi sediments. In well-preserved ostracode fossil beds, disarticulated valves were smooth, and found in random orientation, supporting little or no transport.

Variation in valves sizes belonging to individual species that contain an entire or incomplete life assemblage can indicate whether or not a sample has undergone sorting or reworking (De Deckker, 1988). Most of the ostracodes beds consist of a mix of juveniles and adult valves from different species. These same beds of mixed assemblage of species from different life stages yielded high species counts, suggesting the assemblages closely represent the live assemblages.

Diagenesis

Diagenesis includes the processes of altering the original specimen, visible as surfaces that are pitted, dissolved, or recrystallized (Bennett et al., 2011). Ostracode fossils show the best preservation, preserved as disarticulate isolated valves. Preservation was poor for most gastropod fossils. Preservation varies from no original shell material, fragile molds and casts, to full and intact shells. Taphonomic effects caused the gastropod fossil shells to be susceptible to fragmentation, and difficult to extract from the clay matrix without causing fragmentation. The effects of diagenesis altered the colors of some fossils. In some cases parts of the ostracode valve edge was fragmented and the deteriorated overall shape of the carapace, allowing identification to only genus level.

Although original shell material was present, many gastropods and ostracodes were preserved as molds and casts. Molds lacking morphological features and fragmented shells were identified by genus level, but not included in the dataset.
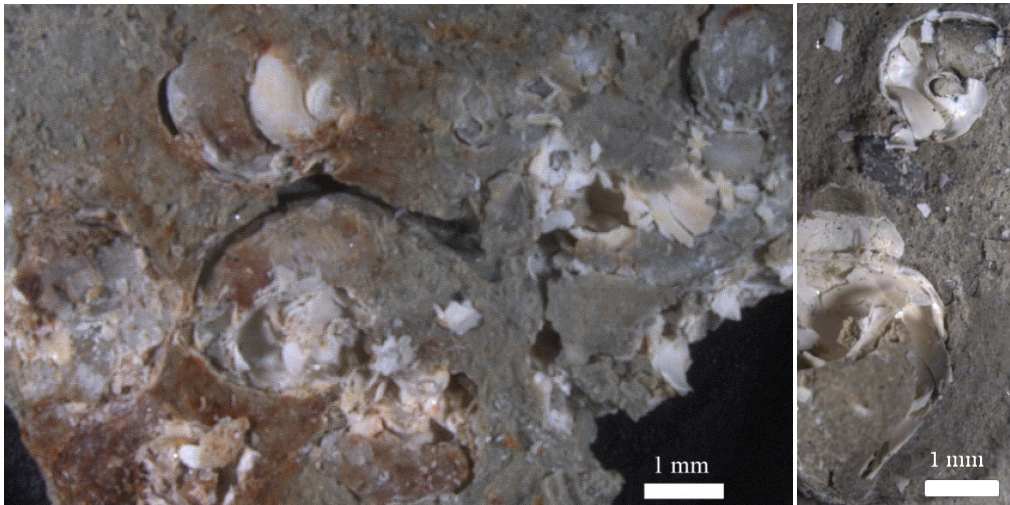
Figure 7. Fragmented gastropod shell clusters from bed 40.

Ostracodes

Ostracodes are abundant at both sites with twenty one species from eleven genera, all extant. Nine species are freshwater, eight cosmopolitan, and four high salinity tolerant species (Table 3). Most ostracodes are found in modern ponds and lakes that can be viewed as belonging to a transitionary system, i.e., falling on a continuum from shallow to deep water (Delorme, 1989). Ostracode species can be classified as either cosmopolitan species with wide environmental tolerances, or indicator species with limited geophysiochemical distributions (Fernandes-Martins et al., 2010; Külköylüoğlu 2004). Although ostracodes in general constrain the ecological parameters of their aquatic habitat, indicator species are critical to paleoreconstructions. Most species have a more limited distribution than would be predicted by their physiological tolerances (Lampert et al., 1997), and the presence of indicator species constrain parameters further, yielding a less generalized interpretation of the paleosalinity of their aquatic environment. Specifically, **s**aline-lake conditions are indicated by limnocytherid ostracode species, and absence or near absence of gastropods (Kowalewska et al., 1998). The limnocytherid ostracodes in this study are *Limnocythere ceriotuberosa* and *Limnocythere inopinata.*

Ostracode Distribution and Abundance

Freshwater and cosmopolitan species are the most commonly distributed ostracodes in both sections. The two sections primarily contain cosmopolitan and freshwater ostracodes. *Darwinula stevesoni , Fabaeformiscandona acuminata , Candona caudata*, and *Candona candida* are the most abundant species and are the most widely distributed in the sampled interval of section WB-J1. *D. stevesoni* and *C. caudata* are cosmopolitan, and F. acuminata and C. candida are freshwater-indicators. *D.*

stevesoni is the most stratigraphically distributed taxa, commonly occurring with *F. acuminata*. *D. stevesoni* and *F. acuminata* stratigraphic distribution is greatest over three intervals, reaching their maximum distribution in lower part of the section for approximately 60 cm (Figure 9). For the other section, WB-B18, *F. acuminata* and *C. candida* are the most widely distributed stratigraphically and are the most abundant (Figure 10).

For the section of WB-J1, the saline-tolerant ostracodes occur with cosmopolitan ostracode over short stratigraphic intervals as eight discrete intervals spanning from 2 to 8 cm stratigraphically. Several discrete beds preserving saline-tolerant species occur with freshwater gastropods. Included in the saline-tolerant assemblage are *Fabaeformiscandona acuminata, Darwinula stevensoni,* and *Candona caudata. F. acuminata* has a significantly lower salinity/TDS tolerance. *Limnocythere ceriotuberosa* occur each time as the most abundant or second most abundant species in the interval. *Candona rawsoni* also commonly occurs; it is the most saline-tolerant abundant species, and *L. ceriotuberosa* is present as the second or third abundant and occurs each time in the eight intervals of saline-tolerant species assemblages. The most abundant salinity tolerant ostracodes are *Cyprideis beaconensis* and *L. ceriotuberosa*. These two species with the highest salinity tolerances were the relatively least abundant; however it does not curtail their significance.

Ostracodes Assemblages

Based on the species total abundance in the beds, six ostracode assemblages were identified with cluster analysis. Of the six assemblages, two assemblages contain taxa with high salinity tolerances. The saline assemblages are characterized by *Limnocythere*

ceriotuberosa for Assemblage II and by *Candona rawsoni* for Assemblage IVa (Figure

9). The remaining assemblages are dominated by cosmopolitan and freshwater taxa:

Assemblage I by *Fabaeformiscandona acuminata*, Assemblage III by *Candona candida*,

Assemblage IVb by *Darwinula stevensoni*, and Assemblage V by *F. acuminata* and

Candona candida. The ostracode fossil assemblages occur in two patterns: (1) without

gastropods, and (2) when gastropod *Valvata sincera* is not the most abundant species.

The entire taxa composition for each assemblage is listed in Table 4.
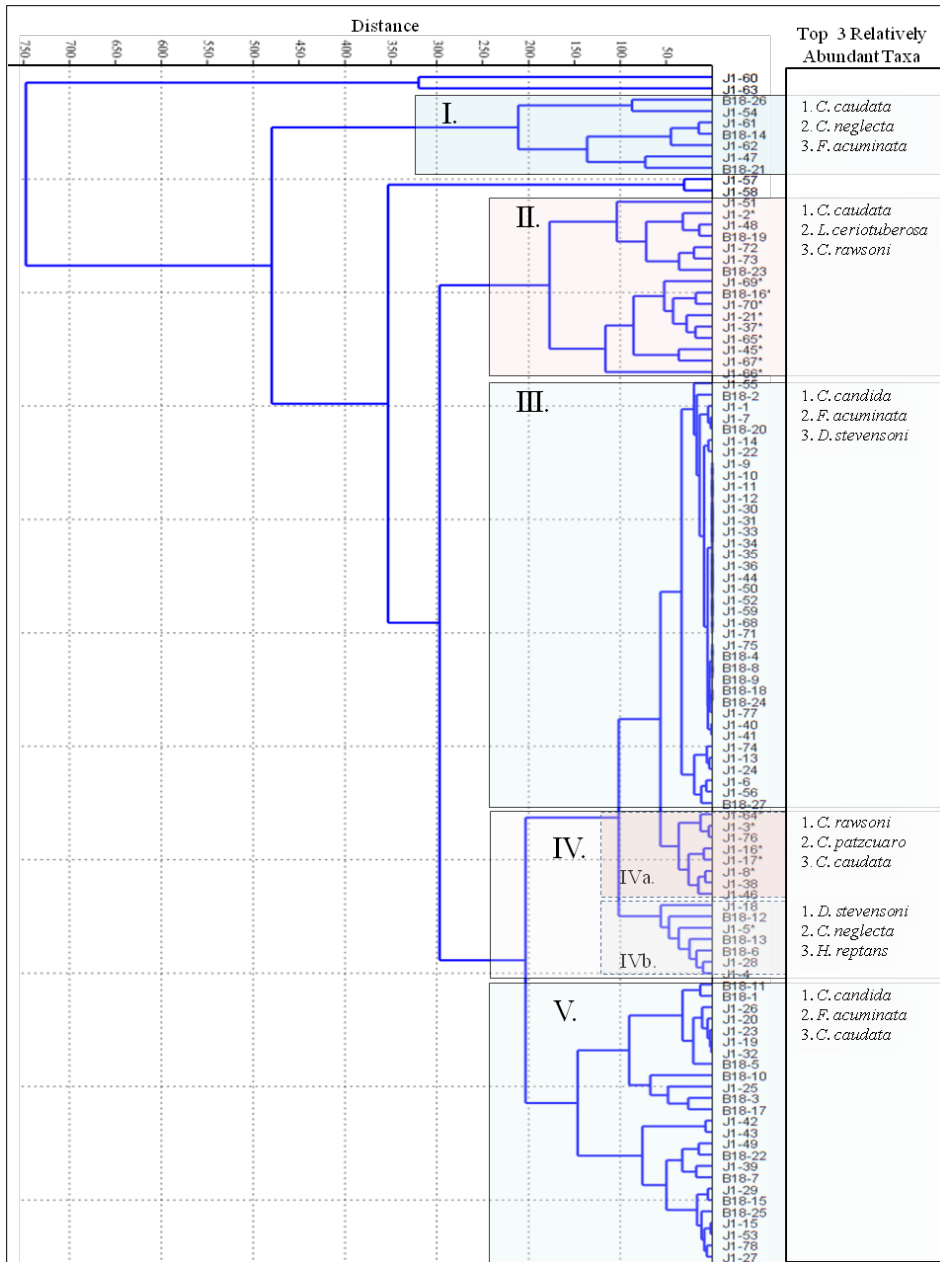
Figure 8. Dendrogram of the cluster analysis of the beds showing the similarity level between ostracode assemblages using Wards method in PAST, in which distance from the lower values represent less similarity between the clustered taxa. I, II, III, IV, V refer to major species groups and IVa and IVb represent sub-groups of ostracodes. The three most relatively abundance species are shown on the right.

Table 2. List of taxa comprising the assemblage generated from cluster analysis.

Assemblage I	Assemblage II	Assemblage III	Assemblage IVa	Assemblage IVb	Assemblage V
C. acuta	*C. glaucus*	*C. caudata*	*L. ceriotuberosa*	*C. beaconensis*	*C. rawsoni*
C. caudata	*C. beaconensis*	*C. neglecta*	*C. patzcuaro*	*C. patzcuaro*	*C. acuta*
C. neglecta	*L. ceriotuberosa*	*D. stevensoni*	*C. rawsoni*	*C. rawsoni*	*Ilyocpris sp.*
H. incongruens	*C. patzcuaro*	*H. incongruens*	*C. caudata*	*C. caudata*	*C. caudata*
F. wegelini	*C. rawsoni*	*E. meadensis*	*C. neglecta*	*C. neglecta*	*C. neglecta*
Candona sp.	*C. acuta*	*F. acuminata*	*P. unicaudata*	*D. stevensoni*	*D. stevensoni*
C. candida	*Ilyocpris sp.*	*C. lacustris*	*D. stevensoni*	*H. incongruens*	*H. incongruens*
D. stevensoni	*C. caudata*	*C. candida*		*C. ophthalmica*	*C. ophthalmica*
F. acuminata	*D. stevensoni*			*H. reptans*	*E. meadensis*
	H. incongruens				*F. acuminata*
	H. reptans				*C. candida*
	F. acuminata				*Candona sp.*
	Limnocythere sp.				

The five major clusters generated using PAST, do not tease out the effects of taphonomy because it was based on species occurrence in each bed. One way to work around effects of taphonomy is to deduce what species coexist based on the community composition of living relatives (Keen, 1977). Fossil assemblages grouped together based on co-existence of taxa in beds are assumed to have had similar environmental requirements and species not belonging to such an assemblage indicate reworking. A few beds showed evidence of reworking. Assemblages, such as those in a 2 cm interval at 135 cm of WB-J1, have one or two ostracode species that have conflicting environmental conditions with the ostracode assemblage.

The WB-J1 section has more freshwater and cosmopolitan assemblages spanning a greater proportion of the section than saline-tolerant assemblages. The saline-tolerant ostracode assemblages in section WB-J1 span eight short intervals from 2 to 8 cm stratigraphically. The saline intervals consist of the saline-tolerant ostracode from Assemblage II for most of the section starting from the bottom. *Limnocythere*

ceriotuberosa is the most abundant or second most abundant species in this assemblage. The second saline-tolerant ostracode assemblage, IVa, occurs in the upper portion of the section replacing the previous Assemblage II. *Candona rawsoni* is the most abundant species in Assemblage II, although *L. ceriotuberosa* is also present. The saline-tolerant ostracodes assemblages show a strong co-occurence with the cosmopolitan ostracodes *C. caudata* and *D. stevensoni*.

Ostracode Assemblages: Species Richness & Diversity

For both section WB-J1 and WB-B18, the highest diversity beds consist of ostracodes from Assemblage II and IVa, which consist of high saline-tolerant species that are followed by beds with low diversity of freshwater ostracodes. In section WB-J1 ostracode richness is low in beds 39, 38, 37 over 12 cm when gastropod richness is at maximum. Species richness reaches a maximum of nine species at 45 cm and is represented by two types of assemblages with high salinity tolerances. The freshwater and cosmopolitan ostracode assemblages reach a richness of eight species in the upper portion at 233 cm. *Fabaeformiscandona acuminata* distribution dominates the intervals of the freshwater ostracodes assemblages. Diversity declines to minimum levels when the dominant ostracodes *Darwinula stevensoni* and *F. acuminata* are the most relatively abundant of the assemblage.
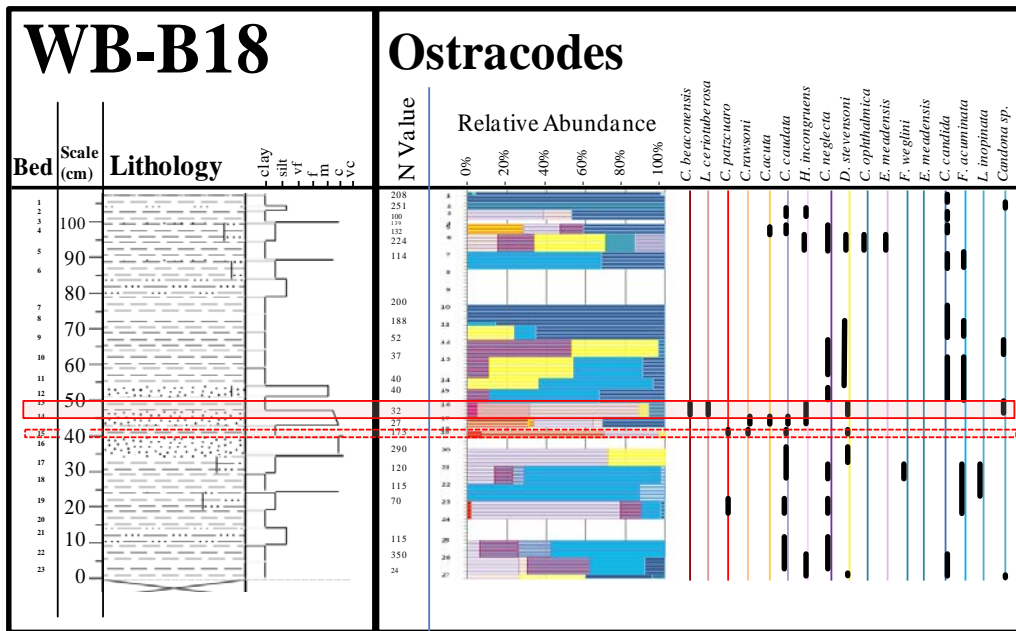
Ostracode salinity signal

Candona rawsoni, Cyprideis beaconensis, and *Limnocythere ceriotuberosa* assemblages commonly occur in the both section of the Waucobi beds, indicating saline to very saline lake conditions. Based on occurrence of *C. beaconensis, L. ceriotuberosa,*

and *Cyprinotus glacucus* suggest ion composition of water types II or III. Water type is defined by a high or low Ca/alk value between three major solute types: (I) dilute waters dominated by Ca and alk or in which those solutes are common; (II) waters in which alk is enriched relative to Ca, and (III) waters Ca-enriched relative to alk. Type I is associated to freshwater and types II and III are commonly associated to saline water (Jayko et al., 2008).

C. beaconensis, a littoral lacustrine species, occurs today in ground-water fed marshes and littoral zone of lakes. In the Waucobi sediments, the dominance of *C. beaconensis* coexisting with *C. rawsoni* likely indicates a marsh, or saline to brackish water at the margins characterized by high benthic productivity (Kowalewska et al., 1998). The optimum salinity for *C. rawsoni* was established by Engstrom et al. (1991) reported to be 1-10‰. *C. rawsoni* indicates high benthic productivity as evidenced in modern marshes and eutrophic lakes having high ostracode abundance and diversity (Kowalewska et al., 1998). Eutrophic lakes in the Great Basin are characterized by high ostracode abundance and diversity (Kowalewska et al., 1998).

The relative abundance and wide distribution of *Candona candida*, *Darwinula stevesoni*, and *Fabaeformiscandona acuminata* are characteristic of freshwater conditions and low salinity with a maximum salinity tolerance of 2,000 ppm. Waucobi Lake was composed of ionically freshwater rather than saline. The anion composition based the presences of *D. stevesoni* suggest the water of Type I: Ca, Mg, K, Na, Cl, SO4, HCO_3 (CO_3).

In section WB-J1, five salinity intervals do not have gastropod fossils, but three events occur with gastropods, including *Valvata sincera*. The salinity events are short-lived stratigraphically relative to the phases of longer-lived freshwater conditions.

Figure 9. Intervals highlighted in red bar the occurrence saline-tolerant ostracodes assemblages for section WB-B18.
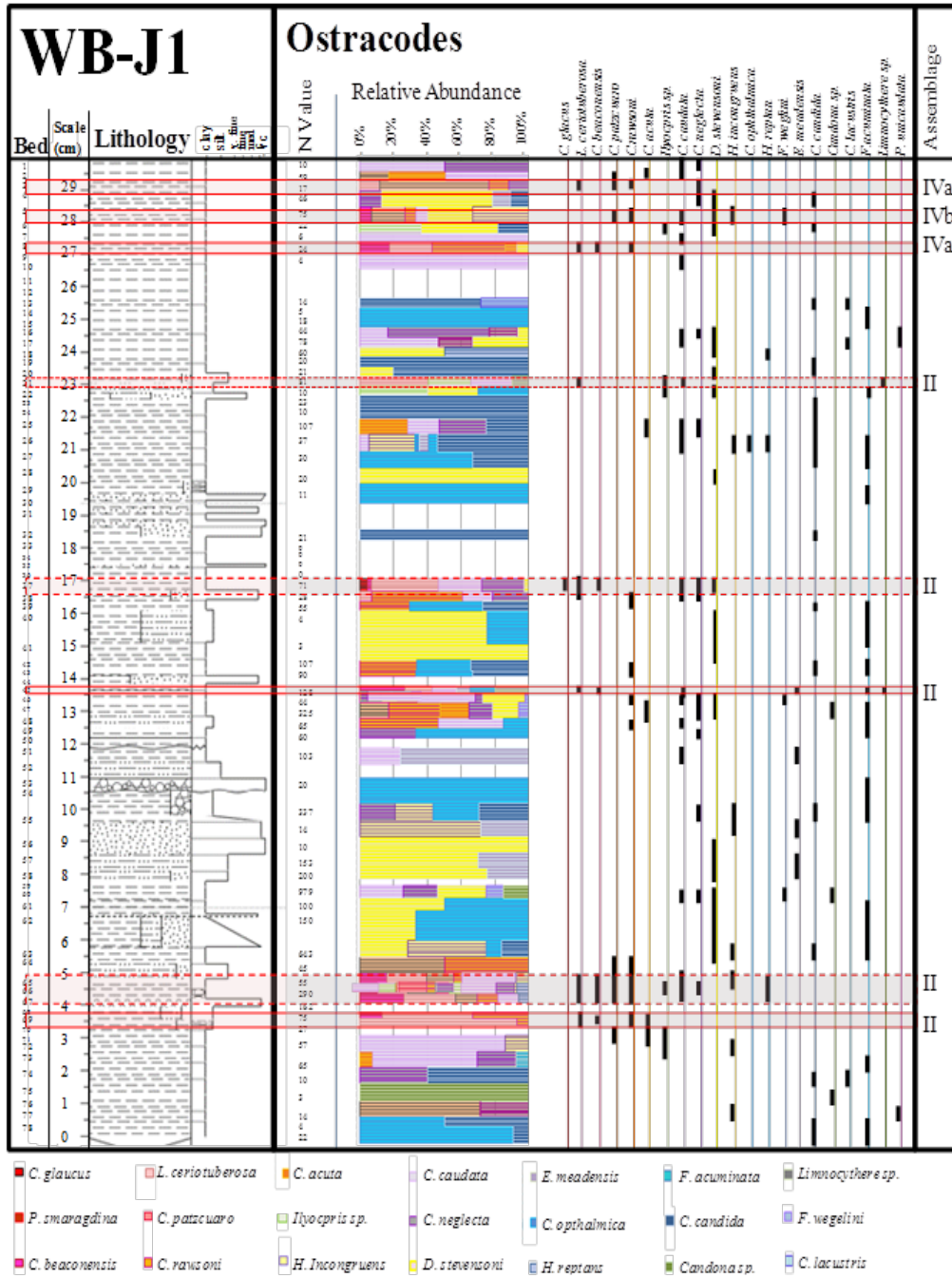
Figure 10. Ostracode distribution highlighting in red bar the saline-tolerant assemblages for section WB-J1.

Table 3. Ostracode species identified from Waucobi beds listed with physical and hydrochemical parameters of their ecological habitat with an emphasis on salinity tolerances.

Species	Physical Environment & Conditions	Salinity/TDS Index	pH	Temp. (°C)	Water Chemistry
Candona acuta Hoff, 1942	Lakes[12], temporary & running water[23], sluggish parts of streams[3], edges of small usually temporary streams with clear cool flowing water[60]	100 - 4,000 ppm[1] 150 - 1,500 mg/L[40] 50 - 5,000 mg/L[3c] 150 - 1,500 mg/L[5]	6 - 9[3]	13-32[1]	Type I- Ca, Mg, K, Na, Cl, SO4, HCO3 (CO3) Type II: Ca-rich/HCO3-depleted, dominated by SO4, Cl, K; Type III: Ca-depleted/HCO3-rich, dominated by SO4, Cl, K[1]
Candona candida O.F. Müller, 1776	Euryplastic for pH, titanoeuryplastic, ligothermophilic, & oligohalophilic species...not tolerant of water >18°C[8], ponds, springs[9,8], bog, canal, brook, oxbox lake, river, reservoir[9], streams, lakes, both still & turbulent at various water depths[8], peat bogs, acidic moorland tarn, brackish waters, silt-bottomed springs[19], shallow part of ponds, lakes, & streams[3]	100 - 4,000 ppm[1] 20-500 mg/L[40] <5300[8] 10 - 900 mg/L[3c]	5 - 7.9[2,8] 5.4-13[3] 5.4 - 13[19] 7 - 9[39] 4.6-13[57]	17-18[2]	Electric Conductivity: 674-680[2] Found in low E. Conductivity: 134 cm/µS[18] Dissolved Oxygen content: 2.55-4.56[2], ~4 l/mg[18]
Candona caudata Kauffman, 1900	Oxbox lake, pond, reservoir[9], streams and at considerable depth in lakes[3a], permanent waters, lakes with some current action, streams[28], lake, ponds[1]	100 - 4,000 ppm[1] 10 - 5,000 mg/L[1a] 20 - 2,000[3] 70 - 5,000 mg/L[5]	5.3 - 9.1[3]	13 -32[1] 2 -32[1]	Electric conductivity: 450-1400 cm/µS[20] Type I- Ca, Mg, K, Na, Cl, SO4, HCO3 (CO3) Type II: Ca-rich/HCO3-depleted, dominated by SO4, Cl, K Type III: Ca-depleted/HCO3-rich, dominated by SO4, Cl, K[1]
Candona neglecta Sars, 1887	Euryoecious[19a], benthic species found in brackish waters[42], bogs, oxbox lakes, ponds, reservoir, temporary waters[9], springs, brooks and ponds connected to springs, & lakes[59]	0 - 15,000 ppm[15] 500 -16,000[8] Optm 260 ppm[36]	7.13 - 7.54[36] 7.23-7.81[2] Optm 7.4[36]-7.8 [18]	3.7-27.9[19a]	Dissolved Oxygen content: 2.55-4.56 Water depth: 70-82 Electric Conductivity: 488-652[2], optimum 556.2[36] Tolerant of water with a low oxygenation[51a]
Candona rawsoni Tressler, 1957	Eurytopic[10] & benthic species of closed basin lakes[21], open water, both permanent & temporary[4], shallow lakes (up to 20m deep) & permanent rivers[28], indicator species of increasing ionic concentration[22] permanent & temporary bodies of water[3a], hypolimnion of temperate lakes[11]	100 - 4,000 mg/L[40] 50-12,000mg/L[3c] 200 - 4,000 mg/L[15] 141-42,770ppm[3d]	7 - 12[3b]	2.6 -18.9[5] 5.5-30.2[3d]	Found in both in bicarbonate-enriched and bicarbonate-depleted sulfate-dominated waters[10]
Candona patzcuaro Tressler, 1954	Benthic[26], springs[1,25], euryhaline waters[25], prefer deeper, openwater[26], ephemeral ponds[27] semi-arid regions[3a], streams, lakes1, prairie potholes, southwestern playas, wetlands[29], ponds[1a]	100 - 5,000ppm[1] 200 - 4,000 mg/L[40] 200 - 5,000 mg/L[1a]		13 -32[1]	Type I- Ca, Mg, K, Na, Cl, SO4, HCO3 (CO3) Type II: Ca-rich/HCO3-depleted, dominated by SO4, Cl, K Type III: Ca-depleted/HCO3-rich, dominated by SO4, Cl, K[1]
Cypria ophthalmica Jurine, 1820	Eurytopic species[47], active swimmer found in temporary & permanent still waters of shallow parts of lakes, ponds, ditches & bogs where current action is negligible, oligohaline waters[7]	100 - 1,000 ppm[1] 0 - 6,000 ppm[15] 10 - 2,000[3] 15 -1,500 mg/L[15]	5.7-8.15[2] 5.2-13[3] 5 -13[57]	13 -32[1]	Type I- Ca, Mg, K, Na, Cl, SO4, HCO3 (CO3)[1] Water depth: 2-102, conductivity: 405-1012, Dissolved oxygen: 0.11-10.122 Found in high salinity (1.3‰) & low pH(5) waters[47]

Species	Physical Environment & Conditions	Salinity/TDS Index	pH	Temp. (°C)	Water Chemistry
Cypridies beaconensis Leroy, 1943	Lives in algal mats, in the sediments[35], estuaries[37,12], spring fed, permanent waters[12], saline-brackish waters at the margin of the Salton Sea[34], shallow water among algae bloom, salt marshes, lakes, marshes[37], swims up the water column between aquatic plants[35]	100 - 10,000 ppm[1]; 3,000 - 4,000 mg/L[40]	7.5 - 8 [38]	13 -32[1]	Type I- Ca, Mg, K, Na, Cl, SO₄, HCO₃(CO₃); Type II: Ca-rich/HCO₃-depleted, dominated by SO₄, Cl, K; Type III: Ca-depleted/HCO₃-rich, dominated by SO₄, Cl, K[1]
Cyprideis torosa Jones, 1850	Brackish pond, salt marsh, lives on a various substrates including muds, sandy muds, sands & weeds; wide tolerance to temperature & shows preference for shallow waters of less than 30 m[6,8]	400 - 150,000 mg/L[15]; 500 - 150,000 ppm[44]			Bicarbonate-poor waters [44]; Electric Conductivity: 2 - 5 mS/cm[56]
Cyprinotus glaucus Furtos, 1933	Eurythermic species[1a], found in bicarbonate-enriched sulfate-dominated waters[10], lakes, ponds, streams[1a]	200 - 12,000 ppm[40]; 20 - 20,000 mg/L[3]; 10 - 10,000 mg/L[1a]	6.5 - 10 [3]	18 -32[1]	Type I- Ca, Mg, K, Na, Cl, SO₄, HCO₃ (CO₃); Type II: Ca-enriched/HCO3-depleted, dominated by Cl, K.[1]
Cytherissa lacustris G.O. Sars, 1863	Limnetic species, permanent water[41], deep lakes[50], oligo-mesotrophic lakes[8], deep, well oxygenated, cold-water lake[22], common in up to 200m deep in boreal forest[28], cool, dilute lakes that have bottom waters unsaturated with respect to calcite[41], hypolimnion of temperate lakes[11]	250 mg/L[3]; 100-10,000 ppm[1]; 10-200 mg/L[3]; < 300 mg/L[41]	6.5 - 8.9[3]	13 -32[1]; Min: 4[11]	Type I- Ca, Mg, K, Na, Cl, SO₄, HCO₃(CO₃); Type II: Ca-rich/HCO₃-depleted, dominated by Cl, K; Type III: Ca-depleted/HCO₃-rich, dominated by Cl, K[1]
Darwinula stevensoni Brady and Robison, 1885	eurythermal & euryhaline species[16], lake[61,8], ponds[1,8], rivers, slow running streams[8], & tolerate salinities in the mesohaline range[8], littoral & sublittoral zone[48], well-oxygenated waters, muddy & sandy substrates, marshes[18]	100 - 2,000 mg/L[1]; 0 - 1500 ppm[15]; 800 - 3000 mg/L[18,19]	7.34-9.04[17]; 7.4-8.9[16]; 8.85-9.15[18]; 6-9.27[57]	13 -32[1]	Type I- Ca, Mg, K, Na, Cl, SO4, HCO3 (CO3)[1]; Dissolved Oxygen: 6.46-16.478[17], 2 - 14L/mg[18]; Electric Conductivity: 346-540.8[17] & 300 - 400 µS /cm[18]
Eucypris meadensis Gutentag & Benson, 1962	Springs[32,1], streams, lakes[1], freshwater[4]	200 - 800 ppm[1]; 300 -1000 mg/L[1a]		0 -14[1]	Type I- Ca, Mg, K, Na, Cl, SO₄, HCO₃ (CO₃)[1]
Fabaeformiscandona acuminata Fischer, 1851	Oligohalophilic species[39], oxbox lake, pond, river[9], interstitial habitats[9]	400 - 12,00 mg/L[40]; 0 - 300 mg/L[15]	7.5 - 9 [39]		Carbonate alkalinity/CA: 1-6 meq/L; Electric Conductivity: 3.5-9 mS/cm[39]
Fabaeformiscandona wegelini Danielopol, 1980	Hypogean[54], ecotonal dwelling species lives generally in the superficial alluvial sediments[52], lakes, streams[46], wells, springs, rivers, creeks, interstitial habitats[51], groundwater habitats[53]	90 - 1,000 mg/L[40]		3.4 - 14.6[55]	Water chemistry is of minor importance in determining stygobiotic occurrences at the regional scale[54a]
Herpetocypris reptans Baird, 1835	Muddy bottoms of lakes, ponds, streams with laminar flow[19], shallow, slackwater habitat[31]	1,000 - 16,000 mg/L[19]; 400 - 1,200 mg/L[58]; 0 - 1,500 mg/L[15]	7.3 - 9[19,57]		Conductivity: 134-619 cm/µS; Dissolved Oxygen: 3.8-7.6 mg/L; Mg/Ca: 0.4-0.56

Species	Physical Environment & Conditions	Salinity/TDS Index	pH	Temp. (°C)	Water Chemistry
Heterocypris incongruens Ramdohr, 1808	Euryoecious species[36] found in temporary ponds[33], shallow dwelling, temperary pond or shore zone at ~0.3m depth, tolerant of very low oxygen conditions[36]	Upward of 4000 mg/L[43]; 2400 - 4400 mg/L[19a]	6 - 9.8[36]; 8 - 12.8[19a]	6 - 29[36]	Electric Conductivity: 56 - 2580 µS/cm[19a]; Dissolved Oxygen: 0.4 - 14.5 mg/L[19a], 1.3-4.3mg/L[36]
Il yocypris bradyi Sars, 1890	Oligohaline waters, slow flowing rivers, streams, ponds, lakes, prefers water bodies fed by springs,...suggested when present in lakes probably fed by spring water[8], streamflow indicator[1a]	100 - 4,000 ppm[1a]; 300 - 4,500ppm[45]; 50 - 6,000 mg/L[3,58]	7 - 9.8[3]	13 -32[1]	Type I- Ca, Mg, K, Na, Cl, SO$_4$, HCO$_3$ (CO$_3$); Type II: Ca-rich/HCO$_3$-depleted, dominated by SO$_4$, Mg[1]; Mg/Ca: 0.75 - 1.05
Limnocythere ceriotuberosa Delorme, 1967	Permanent lakes in shore zone ~0.9m depth[4], cold, fresh to saline, high alka/Ca solute dominated waters, a filling or through-flowing lake that is not losing much water to evaporation[14]	500 - 10,000 ppm[1]; 30 - 300 mg/L[13]; 74 - 2,780 mg/L[3]; 70 - 5,000 mg/L[3]	7.3 - 9.5[3b]	4 -32[1]	Type I-Ca, Mg, K, Na, Cl, SO$_4$, HCO$_3$(CO$_3$); Type III: Ca-depleted/HCO$_3$-enriched, dominated by CO$_3$, Cl, Mg[1]
Limnocythere inopinata Baird, 1843	Small ponds, slow streams & rivers, large lakes, restricted to very shallow, littoral conditions[8,3], streams[3a], interstitial water, salt lakes, small ponds, alpine lakes, the Baltic Sea[18], freshwater to oligo-mesohaline	150 - 400 mg/L[40]; 0 - 2500 ppm[14]; upward of 40g/L[43]	8.16-8.97[18]	22-28[18]	Dissolved Oxygen content: 6.37-8.23, Electric conductivity: 270.31-336 mg/L[18]

Given physical habitat, salinity range, pH ranges, temperature ranges, and hydrochemistry from records all over the world. [1]Palacios, 2007; [1a]Palacios et al., 2008; [2]Anita Kiss, 2007; [3]Delorme, 1978, 1989; [3a]Delorme, 1970; [3b]Delorme, 1991; [3c]Delorme, 2001; [3d]Delorme, 1969; [4]Dennison-Budak, 2010; [5]Curry, 1999; [7]Bhatia, 1971; [8]Wilkinson et al., 2008; [9]Nagorskaya1 et al., 2005; [10]Smith, 1993; [11]Burke, 1987; [12]Tweeter, 1970; [14]Jayko et al., 2008; [15]Holmes, 1992; [16]Gangdolfi et al., 2001; [17]Külköylüoğlu et al., 2007; [18]Mereen et al., 2011; [19]Külköylüoğlu et al., 2000; [19a]Külköylüoğlu et al., 2009; [20]Smith 1992; [21]Xia et al. 1997; [22]Schwalb et al., 2002; [23]Scott et al., 1943; [24]Colman et al., 1990; [25]Stout 1981; [26]Bridgwater et al., 1999; [27]Markgraf et al., 1986; [28]Poplawski 1981; 29Murrell 2006; [30]Rogers 1992; [31]Eshelman 1975; [32]Swain 1999; 33Malmqvist et al., 1997; [34]Reynolds et al. 2008; [35]Kuperman et al., 2000; [36]Külköylüoğlu et al, 2005; [37]Cohen et al., 2007; [38]Carter 1992; [39]Wetterich et al., 2008; [40]NANODe; [41]Forester 1994; [42]Moreno 2011; 43Ito et al, 2005; [45]Mischke et al., 2005; [46]Pieri et al., 2009; [47]Martins et al., 2010; [47a]Martins et al., 2009; [48]Rieradevall et al., 1994; [49]Thorp, 2001; [50]Staplin, 1963; [51]Danei1opol et al., 1994; [51a]Danei1pool et al., 1993; [52]Rouch et al., 1997; 53Baltanas et al., 2003; [54]Dole-Olivier et al., 1992; [54a]Dole-Olivier et al., 2009; [55]Estimate from the study area from study Castellarini et al., 2007; [56]Mischke et al., 2010; [57]Na et al., 2009; [58]Mourguiart et al., 2002; [59]Meisch et al., 2004; [60]Teeter, 1970

Gastropods

Six extant species of fossil gastropods (five families) were recovered from Waucobi lake beds: *Valvata sincera*, *Planorbia parvus*, *Paludina integra*, *Amnicola limosa*, *Aplexa elongate,* and *Radix sp cf.*, Table 1. The most relatively abundant taxa are *V. sincera*, *P. parvus*, and *P. integra* (Figure 10)*.* The gastropods identified in previous Waucobi studies are *P. integra* by Bachman (1974) as *Cincinnatis cincinnatiensis Anthony*, and *V. sincera* and *P. parvus* by Walcott (1897).

Gastropods not identified in previous studies are *Amnicola limosa*, *Aplexa elongata*, and *Radix sp* cf. Five of the six gastropod species have since been renamed at one point. *Cincinnatis cincinnatiensis* had been renamed several times and both *Paludina integra* (Hersler, 1996) and *P. integra* are in use in current literature for this species. It is referred here as *P. integra*. Walcott (1897) noted the possible presence of gastropods from the genera *Amnicola* and *Pampholyx*. This study confirms the presence of genus *Amnicola.*

Table 4. Pliocene gastropod species identified from Waucobi beds listing their physical and chemical environments from modern ecological studies

Family	Species Name	Physical Habitat	Chemical Environment
Hydrobiidae	*Amnicola limosa* Say, 1817	Creek, river, slow-moving, shallow creek with a silty bottom and bullrushes present[3], eutrophic lake[16], slow-moving rivers and swamps of the coastal plain[8], sensitive to water hardness and pH[8]	pH: 7.2-8 [1] Water conductivity: 0-750 µmhos[1] Water hardness: 0-320 mg $CaCO_3$/l [1] sensitive to water hardness and pH[8]
Hydrobiidae	*Paludina integra* Say, 1821	Littoral zone , creek, river, lakes esp. rivers, variety of substrate from soft ooze to sand with or without vegetation[1]	Hard-water marl lakes[9]
Valvatidae	*Valvata sincera* Say 1824	Deep lakes, streams, ditches, muddy to sandy muddy substrates, oligotrophic & mesotrophic lakes, associated with submerged and rooted vegetation, deep lakes[10]	pH: 7.6 or greater*
Planorbidae	*Planorbia parvus* Say, 1817	Habitats with abundant vegetation , rocks, sticks, lives in standing water, flowing bodies of water with mud substrate, muddy banks of large lakes[5]	Limited to calcium-rich waters[2]
Physidae	*Aplexa elongata* Say, 1821	Swamps[14] ,marshes, weedy ditches, edges of intermittent ponds, slow-moving streams, wooded ponds with rich detritus food base[2], temporary wood pools or ditches, sometimes found in extremely shallow streams, found mostly floating at the surface in pairs when their habitat is inundated[6], common to creeks & ponds, and springs, sometimes large permanent lakes and rivers[12.13]	One live specimen found at pH: 7.8 Water conductivity of 0.82 mS[13]
Lymnaeidae	*Radix sp.* cf	Lakes, genus Radix live in peaty waters on muddy, or stony, ground near the bank of rivers, lakes, and smaller water bodies[11]	Freshwater to high salinity[4]

Given physiochemical parameters from global records: [1]Mackie et al., 1989, 1983; [2]Brown, 1979, 1997; [3]Nelson, 2010; [4]Piscart et al. 2005; [5]von Oheimb et al., 2007; [6]Wethington, 2004; [8]Shaw et al., 1989, 1990; [9]Owen et al. 1983; [10]Regan et al., 2005; [11]Moser et al., 2009; [12]Clark, 1981; [13]Prescott, 2004; Strong et al., 2007.
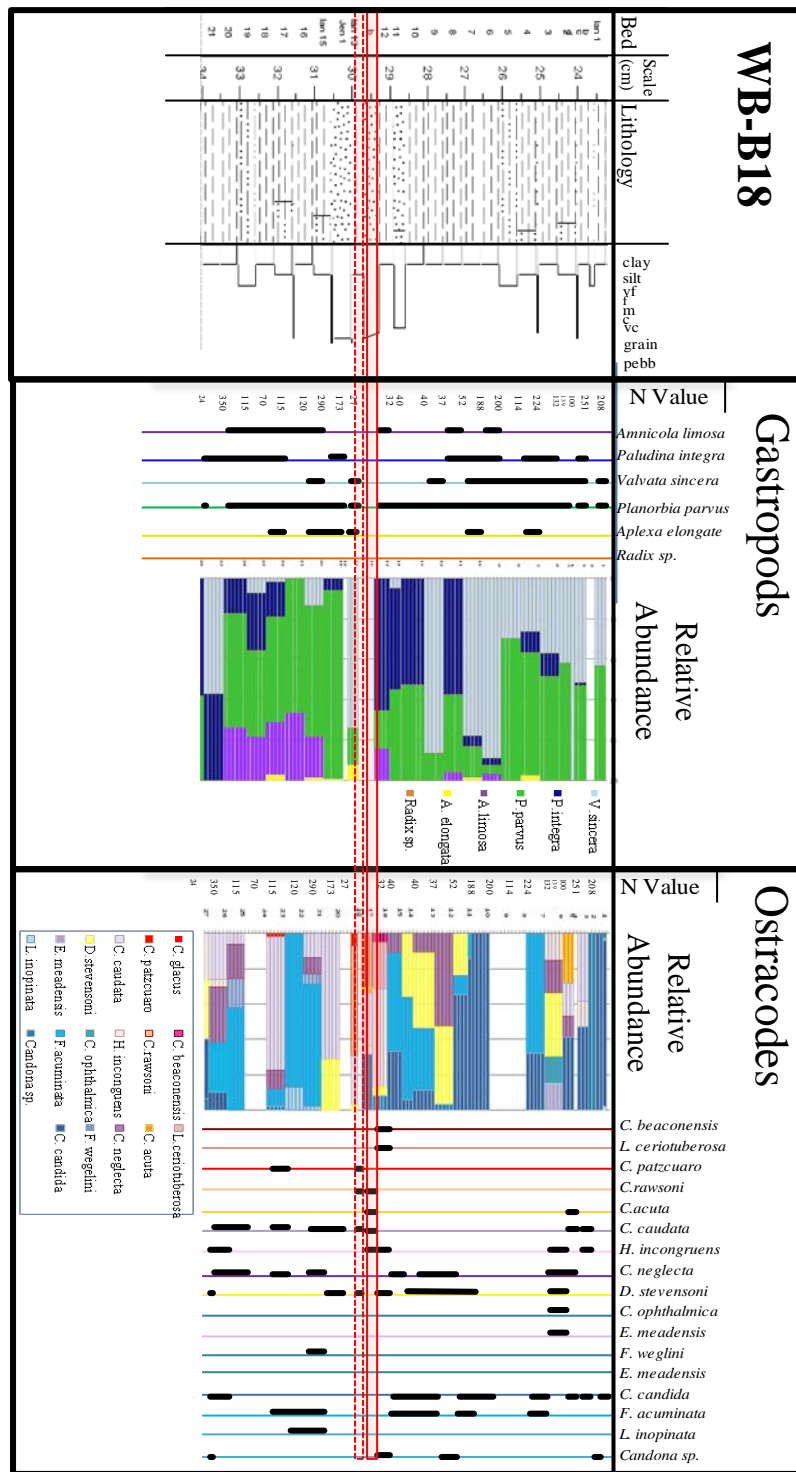
Figure 11. Stratigraphic column of WB-B18 plotted with distribution and relative abundance of fossil gastropods and ostracodes through a ~3m interval showing two events in which the ostracode assemblage suggest high salinity conditions.
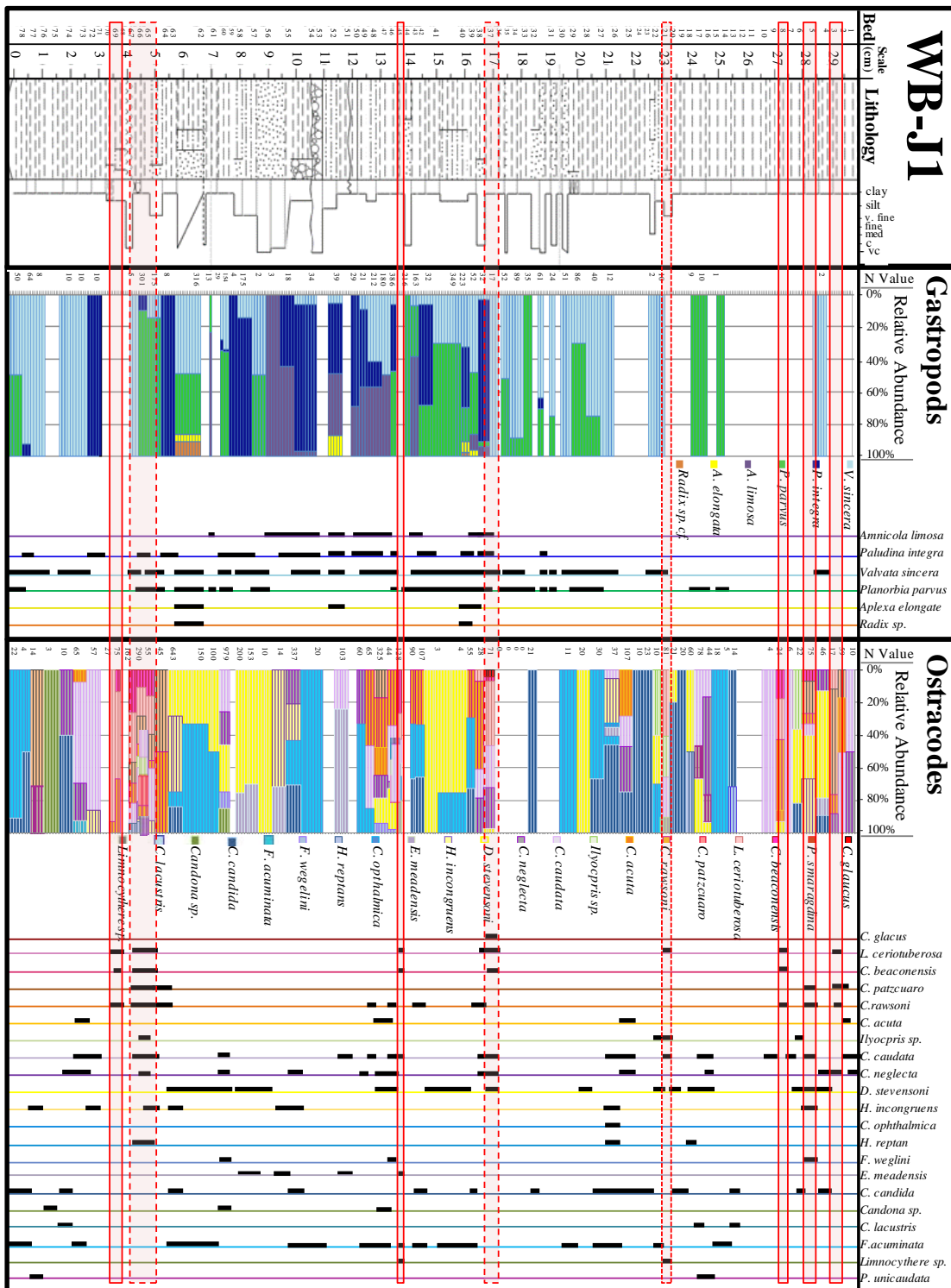
Figure 12. Stratigraphic columns of WB-J1 locality plotted with distribution and relative abundance of fossil gastropods and ostracodes through an ~3m interval highlight saline events in red bars.

Gastropod Distribution and Abundance

Gastropod fossils were not analyzed as clusters because species richness was too low to provide the resolution needed to constrain interspecific physiohydrochemical environment for the species. In general for both sections, *Valvata sincera* is the most stratigraphically distributed species. Its stratigraphic distribution is most prevalent in the upper and lower portion of the sections for both sites. When it is not common, it is replaced by either *Paludina integra*, *Planorbis parvus*, or both. For section WB-J1, *V. sincera* is the most stratigraphically distributed species, comprising ~38% of the gastropod species, but not the most relatively abundant (Figure 12). It occurs in the presence and absence of ostracodes in both sections, occurring most often with ostracodes *Darwinula stevensoni* and *Fabaeformiscandona acuminata*. In section WB-B18, it occurs with ostracodes *F. acuminata* and *Candona candida.*

Planorbis parvus occurs as the species with the highest relative abundance with a total sampling N value of 2,839, comprising 43% of all the gastropod fossils. In section WB-J1, *P. parvus* is the dominant relative abundant species. *P. parvus* is the second most stratigraphically distributed species for both sections. In section WB-J1, it replaces *Valvata sincera* as the dominant species for the first time stratigraphically 25 cm. It is the most distributed over 60 cm at 110 cm of WB-J1. It dominates a second interval of 25cm as the most abundant species 140 cm. The upper 5 cm of this interval overlaps a high saline-tolerant assemblage of ostracodes that includes *Limnocythere ceriotuberosa* and *Cyprideis beaconensi*s (Figure 10). Three additional examples occur in which *P. parvus* dominates in relative abundance over an interval: 25 cm, 10 cm, 9 am at about 135cm, 170cm, and 240cm of the WB-J1 section. At 168 cm, *P. parvus* does not

reappear for the remaining section. It occurs with the ostracodes *Fabaeformiscandona acuminata* and *C. candida*.

Paludina integra* and *Amnicola limosa* together comprise 23% of the gastropod fossils. *P. integra* is the third most stratigraphically distributed species. *A. limosa* is the fourth most stratigraphically distributed species. *A. limosa* and *P. integra* first appears at 165 cm for WB-J1. For site WB-B18, *A. limosa* occurs for the first time at 30 cm and *P. integra* occurs for the first time at 100 cm. *A. limosa* and *P. integra* show a high occurrence of co-occurrence and replacement of *V. sincera* as the dominant species at 40 cm of WB-J1. For WB-J1 *P. integra* is the relatively abundant dominant species over three intervals: 6, 13, and 4 cm at 75 cm and 100 cm, and 164 cm of the WB-J1 section.

The rarest gastropods are *Radix* sp cf. and *Aplexa elongata,* in beds with high sampling N values greater than 220 for WB-J1 section. *A. elongata* appears at 110 and 56 cm, for 5 cm and 9 cm. *Radix* sp. is the least stratigraphically distributed species and found in only the section of WB-J1. *Radix sp cf.* occurs twice in an interval with high species richness in the lower portion of the section 55 cm of WB-J1, and does not reappear for the remainder of the section (Figure 9). Although *Radix sp.* occurs in 20 cm of the 3 m interval of the WB-J1 section, they have 50% co-occurrence for WB-J1. *Radix sp.* was the only species not found in both localities. Diversity changes between beds may represent species density (Gotelli, 2001; Simpson 1964).

Gastropod Species Richness and Diversity

Low species richness, evenness, and diversity generally characterize the Waucobi beds. Five identified species were found for the gastropod fossils for the section of WB-J1 and four for the section of WB-B18. *Radix sp*. cf. was not found at site WB-B18.

Low species richness can be a product of low rates of colonization, sampling bias, ecological disturbance, or a combination of the three. Species richness averages two species per bed for half of the section of WB-J1 and one species per bed for approximately a fourth of the same section. Species richness for the WB-J1 section is highest at four and five species for five beds: 62 at 68 cm for 9 cm, 51 at 118 cm for 5 cm, 39 at 163 cm for 3 cm, 38 at 166 cm for 3 cm, and 37 at 170 cm for 4 cm. Species richness averages higher for the WB-B18 section with three species per bed for 40% of the section. Using the Shannon-Weiner index (H) to calculate species diversity with a H index of 1.3 for the section of WB-J1 and a H index of 0.87 for the section of WB-B18.

Salinity Intervals

The high salinity tolerating ostracode assemblages appear as short spans over the sections, marking end of long phases of freshwater intervals indicated by the dominance of gastropod *Valvata sincera*, often occurring with the freshwater ostracode *Fabaeformiscandona acuminata*. In section WB-J1, there are eight salinity events recorded in this interval of Waucobi lake sediments as evidenced by high salinity-tolerant ostracode assemblages, the last three might have been one long-lived saline phase briefly interpreted by a freshwater incursion. Three of the saline events include freshwater gastropod fossils, while the other five events occurred in the absence of any gastropods. The three events co-occur with gastropods occur with *Planorbis parvus* and *Paludina integra*, in the absence of the most abundant gastropod *V. sincera*.

The first five saline intervals in Figure 7 are characterized by Assemblage II ostracodes and the last three by Assemblage IVa ostracodes. The dominant species varies for each saline interval. The presence of *L. ceriotuberosa* in Assemblage II likely

indicates a closed-lake in semi-arid to arid climate with varied seasonal temperatures and water chemistry (Forester, 1991). In addition with the presence of *C. glaucus*, *C. beaconensis*, *C. patzcuaro*, and *C. rawsoni*, lake conditions were highly likely saline during these intervals. Half of the assemblage consists of ostracodes that have a high salinity tolerance, ranging from 200 up to 110,000 ppm, Table 3. Assemblage IVa in addition to *C. rawsoni* contains *C. patzcuaro* and *L. ceriotuberosa*, representing a salinity range between 100 to 10,000 ppm. All three species occur together at the top of the section 270 from the bottom (Figure 8) over 3 cm.

Discussion

Based on the sedimentation rates of Owens Lake, the estimated time represented for the 3m sections is approximately 7.5 ± 0.5 ky each. The estimated temporal resolution for the total thickness of the beds for 90m (Bachman, 1974) represents ~2,250 ky.

The variation seen in the sections as intervals of freshwater and saline biotic assemblages indicates two significantly different water chemistries have alternately dominated Waucobi Lake. The Waucobi Lake fluctuated between saline and fresh. The transition to saline conditions may reflect the shift from an open- to closed-basin lake. The processes governing an open- or closed-basin lake are moisture availability, which is a primary control on lake levels (Fritz, 1996; Laird et al., 1996; Battarbee, 2000) and hydrochemistry. In closed-basin lakes, lake level decreased below an outlet threshold, showing a rapid salinity change. The rapid shift in salinity indicates a climate changing slowly (Kennedy, 1994).

Open-basin Lake

An open-basin lake is suggested by the freshwater gastropods and freshwater ostracodes assemblages indicative of freshwater conditions. Modern habitats of the gastropod species found in this study all inhabit freshwater environments. Based on the wide occurrence and distribution of the ostracode *Fabaeformiscandona acuminata* and gastropod *Valvata sincera*, Waucobi was a large deep fresh lake at times, likely overflowing and above sill level. The interval with the most distributed and diversity of freshwater gastropod species at 156 of section WB-J1 for 10cm strongly suggest a large lake. Aquatic organisms are known to respond to the climate parameters of temperature in topographically open-basin lakes (Fritz, 1996). The jet stream produces variable precipitation patterns and winter storms provide moisture via precipitation and runoff to produce such a lake, implying a direct climate control on an open-basin lake.

Closed-basin Lake

The saline-tolerant assemblages are strong indications that Waucobi Lake was saline at time. Ostracode distribution is strongly influenced by the ionic composition of the aquatic habitat. Salinity of the lake water is a function of ionic composition (Fritz, 1996; Frenzel et al., 2005). Lake-water salinity is controlled by the hydrologic cycle mass balance (Fritz et. al, 1999, Laird, 1996). Changes to the hydrologic cycle mass change include, evaporation, shift in groundwater source, river and stream diversion, basin composition, and amount of inflow unrelated or indirectly related to climate and that affect lake level (Whitehead et al., 1961; Battarabee, 2000; Bradbury et al., 1989; Smith, 1991). Rapid lake-level changes cause changes in salinity concentrations (Fritz, 1996).

For the case of the Waucobi beds, the saline phase can be explained in term of climate. Saline-tolerant ostracodes and the near or complete absence of gastropods could be tied to a close-basin phase, which would yield the high possibility it was driven by an arid climate. Closed-basin lakes tend to be more responsive to climate controls. Ionic composition of lakes in closed basin varies predictably depending on initial conditions of geologic setting, hydrology, and concentration of evaporatives (Fritz, 1996). The waters from modern closed-basin lakes of California (e.g. Mono Lake) generally have similar chemical composition of high ionic concentrations (Battarbee, 2000) but wide ranges in concentrations (Whitehead et al., 1961). Salinity and lake level in closed basin are also influenced by short-term climate fluctuations (Carroll et al., 1999). A topographically closed-basin lake responds more rapidly to changes in the balance of precipitation-evaporation processes than an open system. Closed-basin lakes are found in semi-arid and arid regions in which evaporation is the main control on output with little to no surface or groundwater flow (Battarbee, 2000). Evaporation can result in lake salinity variations recorded geochemically and biologically in sediments and resident organisms (Battarbee, 2000; Engstrom, 1991).

The phases in which saline ostracode assemblages occur can be the result of watersheds receiving less input than output, lakes drop below sill level with mineral precipitation, clay-mineral exchange, and/or redox reaction governing the solute composition of natural waters, increased temperature, and/or deficit precipitation throughout the year (Jayko et al., 2008; Ahrens, 2011). Salinity change may be much larger when output is governed by evaporation rather than groundwater seepage (Sanford et al., 1991; Fritz, 1996). Salinity processes are additionally governed by decreased moisture availability because of tectonics shifts in the hydrologic basin or presence of a

rainshadow, increased weathering of rock increasing concentration of ions via tectonic uplift (Jayko et al., 2008).

Geomorphic Basin Controls

A lake system responds to a basin's topography and hydrology. A lake can be in a topographically closed-basin, yet hydrographically open, and conversely in a topographically open-basin (Curry et al., 2010). Basin controls, such as threshold levels, also an important role in the ionic composition of a lake, but not often lake with high salinity concentration. Threshold dynamics are extremely influential on lake dynamics in open basins that often host freshwater lakes (Last et al., 2001).

Hay (1964) inferred Waucobi Lake was closed at times because the Waucobi beds are the deposits of a lake with influent streams. Influent streams are feed by groundwater because water levels are higher in the stream than an adjacent aquifer (Bear et al., 2010), and often associated to closed lake systems. Closed lake systems are influenced by climate conditions.

At this time there is no discrete geomorphic evidence at this time to attribute the fluctuation to physical changes in the basin by tectonic activity. The faulting along White Inyo Fault and the uplift of the White-Inyo Mountains altered the proximate landscape after the lake was established. The fanglomerates capping the beds were deposited from the uplift of the mountains (Luddecke, 1997). Paleotopography of Waucobi is not consistent with active faulting before or during deposition of the lake sediment. No discrete evidence of tectonic evidence can explain the variation in the data. In general, lakes form in depressions in relatively flat surrounding topography. Extreme changes such as tectonic activity would change the basin morphology. Changing the

threshold would change a lake to another state that change would be relatively longer-lived, not producing a fluctuating signal seen in the data. Further the resolution of the data does not geomorphic changes—the short lived phases especially.

The uplift of the White-Inyo suggests changes from low relief topography to high relief. The uplift was after the existence of the Waucobi Lake. Further this magnitude of change would have likely caused the demise of a lake, altering the low-relief topography associated to lakes. An modern examples of drastic tectonic changes is Lake Manix of Death Valley.

Climate Influence of the Sierra Nevada

The rainshadow of the Sierra Nevada is an effective barrier and direct climate control on producing arid condition. The saline-tolerant ostracodes assemblages of the Waucobi beds support the onset of regional aridity for the late Pliocene. Aridity, as product of the Sierra Nevada rainshadow, droves the fluctuation in the changes from freshwater phases to brief saline phases, recorded as intervals of freshwater gastropod and freshwater ostracode assemblages, and brief intervals of saline-tolerant ostracode assemblages. In general, the transition from a wet tropical Miocene climate in the Great Basin shifted to arid condition.

An arid climate driven by the Sierra Nevada rainshadow can explain the variation in the data. The San Bernardino and San Gabriel Mountains, and the Owen Cascades demonstrate the effectiveness of a rainshadow influencing climate for the region. Modern analogs at south latitudes of about N33˚ the San Bernardino (elevation range 700 to 3500m) and San Gabriel Mountains ranges with moderate elevation produce intense rainshadows on the leeward side. The Oregon Cascades at about latitudes N45˚, with an

elevation range of 1200 to 3000 m have a rainshadow that results in a dry and arid

climate leeward juxtaposed the moist windward side with substantial precipitation (90 cm

average annual precipitation).

Besides being a powerful rainshadow, the Sierra Nevada was the moisture source

for the basin of the Waucobi beds that fed the river system, and therefore the lake

represented by the Waucobi beds. The gastropod assemblages suggest the hydrologic

basin configuration for Waucobi Lake had a large river or other surface-water input (i.e.

streams, springs). White-Inyo Mountains were not a moisture source at the time because

uplift was after the deposition of the lake sediments. At best, any moisture source east of

the Sierra Nevada were regional springs, suggested by the presence of freshwater

gastropod *Aplexa elongata* that is not common to lakes rather springs and streams

(Nelson et al., 2010; Moser et al., 2009) and freshwater ostracodes *Ilyocypris bradyi*,

Eucypris meadensis, *Herpetocypyris reptans*, *Candona candida*, and *Candona neglecta*

that inhabit various habitats that include springs.

The moisture source for the Sierra Nevada is the cold Pacific Ocean that has been

producing stable columns with low convection. Cold Pacific coastal waters off of

California were established through the Tertiary (Zachos, 2001). In the Pliocene global

changes that affected the Sierra Nevada regions were a cooling climate resulting in

changes in the ocean circulation, heat transfer patterns for the Pacific and Atlantic

oceans, the atmospheric pressure gradient and wind regimes (Cane et al., 2001; Molnar,

2002; Lunt et al., 2007; Haug et al., 1998; Prange et al., 2004). Before in the early

Tertiary upwelling deep ocean waters produced high convecting clouds that would made

a rainshadow insignificant. After the Sierra Nevada established height and the ocean

further cooled producing low convecting layers with less moisture.

Although the Sierra Nevada may not have reached modern elevation, it still was an effective barrier to precipitation brought in by the jet stream because most moisture is concentrated at the bottom on the air column and descending air decreases rainfall for land that is further inland. This is governed by Clauius-Clapeyron relation and atmospheric lapse rates. Low convecting clouds makes a rainshadow at elevation heights averaging <2000 m effective because of a first principle of physics, the Clausiun Clayien relationship that determines the atmospheric water content over large ocean regions. The Clausiun Clayien equation specializes in the case of a gas at low temperatures and pressures, gives the relationship between the latent heat associated with a transition from liquid to vapor phase, and is the single most important equation in cloud physics. Wentz et al. (2000) found there is "a strong association between sea surface temperature, lower-atmospheric air temperature and total column water-vapour content (Makarieva et al., 2004). This rate is more pronounced as air becomes more stable.

Arid Conditions Supported by the Paleo-botanical Pliocene Record

Independent paleobotanical data supports the onset of aridity during the late Pliocene. The flora shifted from deciduous and tropical plants to pinons and chaparral-like plants. Terrestrial records by Axelrod 1948 and Wolfe (1997) suggest arid conditions occurred in the late Miocene in the Great Basin. Late tertiary paleobotanical data support the idea of developed arid conditions in the Great Basin (Axelrod, 1948; Jones, 2004).

The plant record supports the idea that tectonic activity contributed to the rapid rise of the Sierra Nevada beginning in the late Miocene into the Pliocene. In the Miocene subtropical chaparral, oak-laurel floras, and pinyon-juniper woodlands existed in the Sierra Nevada and Great Basin. In the central range of the Sierra Nevada there is

evidence that mixed-conifer forests were present in the Pliocene (Minnich, 2007). The

flora indicative of arid conditions could be related to the either the subsidence of the

Great Basin or uplift of the Sierra Nevada in the Mio-Pliocene (Minnich, 2007). The

Sierra Nevada is suggested to be at an elevation that allowed for a rainshadow and thus

influenced the growth of a rich deciduous forest with abundant evergreen dicots

(Axelrod, 1948, Minnich, 2007). The rainshadow created by the Sierra Nevada uplift

replaced montane conifers with pinyon-juniper-chapparral woodlands. The climatological

impact of the Sierra rainshadow over the western Great Basin demonstrates a complex

relationship between late Tertiary climate change and floral evolution in the Great Basin

(Jones, 2004).

Conclusion

Sedimentological lake records can be interpreted in terms of either direct or

indirect climatic influences on lake dynamics (Battarbee, 2000), as a shift in the

hydrologic basin (Currey, 1990), and whether a close- or open-basin persisted (Fritz,

1996). In all cases, a lake system's response to climatic change is mediated by the

hydrologic basin. Variables indirectly controlled by climate are nutrient and ionic

concentration, a critical role affecting the biotic component of a lake (Fritz, 1996). These

parameters are governed by dynamics of the hydrologic basin, such as erosion rates,

basin composition, and basin accommodation rate and climate.

The fossil record of Waucobi lake strata reveals a pattern of change of the

community composition of ostracode and gastropod assemblages in both sections.

Variability of the distribution of fossil ostracode and gastropod assemblages indicates

that lake conditions alternated between saline and freshwater conditions. The processes responsible for assemblage composition are strongly governed by the solute environment.

The interplay of the basin and climate influences are responsible for fluctuated between a freshwater to saline lake in Waucobi Lake. The interpretation is not simple and involves complex interaction with the climate, dynamics of the hydrologic basin, and the response of the biotic community. The relationship of climate on terrestrial ecosystems, on surface, and subsurface hydrology affect a lake's hydrochemistry, influencing the structure and function of aquatic communities and the rainshadow of the Sierra Nevada is the best explanation for the Waucobi lake beds record.

Lake conditions and the variability of the fossils in the sediment of Waucobi are assumed to likely be driven by fluvial input derived from the Sierra Nevada and the Sierra Nevada rainshadow effect. If arid periods are assumed to be recorded by saline ostracodes, a more arid climate state on some millennial scale climate change might have occurred. Arid intervals are relatively brief (~100 yrs). In summary, the biotic fossil assemblages of ostracodes and gastropods support briefs events in which the lake was either below sill, not overflowing, or rainfall did not exceed evaporation, or a combination of the three factors. In conclusion, the rainshadow controlled the phases of open- and closed-basin shifts.

References

Abbott, M.B., Binford, M.W., Brenner, M., Kelts, K.R., 1997, A 3500 14C yr high-resolution record of lake level changes in Lake Titicaca, Bolivia/Peru. Quat. Res. 47, 169-180.

Aho, J., 1984, Relative importance of hydrochemical and equilibrial variables on the diversity of freshwater gastropods in Finland. In: Solem, A. and van Bruggen, A.C. (eds), World-Wide Snails: Biogeographical Studies on Non-Marine Mollusca, p. 198-206.

Ahrens, C. D., 2011, Essentials of Meteorology: An Invitation to the Atmosphere, 6th ed.

Allen, B.D., and Anderson, R.Y., 2000, A continuous, high resolution record of late Pleistocene climate variability from the Estancia basin, New Mexico: Geological Society of America Bulletin, v. 112, p. 1444-1458.

Alvarez Zarikian, C.A., Stepanova, A.Yu., and Grützner, J., 2009, Glacial-interglacial variability in deep sea ostracod assemblage composition at IODP Site U1314 in the Subpolar North Atlantic: Marine Geology, 258, 69-87.

Alvarez-Zarikian, C.A., Soter, S., Katsonopoulou, D., 2008, Recurrent submergence and uplift in the area of ancient Helike, Gulf of Corinth, Greece: microfaunal and archaeological evidence. Journal of Coastal Research 24, p. 110–125.

Axelrod, D. L., 1962, Post-Pliocene uplift of the Sierra Nevada, California: Geol. Soc. America Bull., v. 73, p. 183-197.

Axelrod, D. L., and Ting, W. S., 1960, Late Pliocene floras east of the Sierra Nevada: California Univ. Pubs. Geol. Sci., v. 39, p. 1-118.

Axelrod, D.L., and Ting, W.S., 1961, Early Pleistocene floras from the Chagoopa surface, southern Sierra Nevada: California Univ. Pubs. Geol. Sci., v. 39, p. 119-194.

Bachman, S.B., 1978, Pliocene-Pleistocene break-up of the Sierra Nevada- White-Inyo Mountains block and formation of Owens Valley: Geology, v. 7, p. 461-463.

Bachman, S.B., 1974, Depositional and structural history of the Waucobi lake bed deposits, Owens Valley, California: Los Angeles, University of California, unpublished M.S. thesis, p. 1-129.

Baker, F. C. 1920. The molluscan fauna of the Big Vermillion River, Illinois. Ill. Biol. Monog., v. 7, no. 2, p. 1-126

Baker, F. C., 1922, Pleistocene Mollusca from Northwestern and Central Illinois, The Journal of Geology, v. 30, no. 1, p. 43-62.

Battarbee R.W., 2000, Palaeolimnological approaches to climate change, with special regard to the biological record, Quaternary Science Reviews 19, p. 107–124.

Bear J., Cheng A.H-D., 2010. Theory and applications of transport in porous media – Modelling Groundwater flow and contaminant transport: Springer, v. 23.

Beauchamp, W. M., 1981. Notes on familiar mollusks: The Nautilus, v. 5, no. 5, p. 52–53.

Bennett C. E., Williams, M., Leng, M. J., Siveter, D. J., Davies, S. J., Sloane H. J., and Wilkinson I. P. 2011, Diagenesis of fossil ostracods: Implications for stable isotope based palaeoenvironmental reconstruction: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 305, no. 1–4, p. 150-161.

Benson, R. H. 1981, Form, function, and architecture of ostracode shells Ann. Rev. Earth Planet. Sci., v. 9, p. 59–80.

Bhatia, S.B., Singh, D., 1971, Ecology and distribution of some recent ostracodes of the Vale of Kashmir, India. Micropalaeontology, v. 17, p. 214–220.

Bischoff, J.L., Stafford, T. W., and Rubin, M., 1993, AMS radiocarbon dates on sediments from Owens Lake drill hole OL-92. U.S.: Geological Survey Open-File report, p. 93-683.

Bonnefille R. , Potts R., Chalie F., Jolly D., Peyron O., 2004, High resolution vegetation and climate change associated with Pliocene Australopithecus afarensis: PNAS, v.101, no. 33, p. 12125-12129.

Bradbury, J.P., 1989. Late Quaternary lacustrine environments in the Cuenca de Mexico: Quaternary Science Reviews, v. 8, p. 75-100.

Brauer, A., Endres, C., GuK nter, C., Litt, T., Stebich, M., Negendank, J.F.W., 1999, High resolution sediment and vegetation responses to Younger Dryas climate change in varved lake sediments from
Meerfelder Maar, Germany: Quaternary Science Reviews, v. 18, p. 321- 329.

Bright, J., Kaufman, D.S., 2011. Amino acid racemization in lacustrine ostracodes, part I: effect of oxidizing pre-treatments on amino acid composition: Quaternary Geochronology, v. 6, p. 154-173.

Brown, K. M. 1979. The adaptive demography of four freshwater pulmonate snails: Evolution, v. 33: p.417-432.

Brown, K. M., 1997. Temporal and spatial patterns of abundance in the gastropod assemblage of macrophyte beds: American Malacological Bulletin, v. 14: p. 27–33.

Bunbury, J and Gajewski, K., 2009, Biogeography of freshwater ostracodes in the Canadian Arctic: Arctic.

Burke, C.D., 1987, The Effects of Late-Quaternary Climatic Change and Glacioisostatic Rebound on Lake Level and Benthos of Lake Michigan: Palaios, v. 2, p. 514-522.

Cane, M. A., and P. Molnar, 2001, Closing of the Indonesian Seaway as a precursor to East African aridification around 3 – 4 million years ago: Nature, v. 411, p. 157 – 162.

Carroll, A.R., and Bohacs, K.M., 1999, Stratigraphic classification of ancient lakes: balancing tectonic and climatic controls: Geology, v. 27, p. 99 - 102.

Carter, C., 1997, Ostracodes in Owens Lake core OL-92: Alternation of saline and freshwater forms through time: Geology Society of America Special Paper, v. 317, p.113-118.

Chivas, A. R., De Deckker, P. and Shelley, J. M. G., 1985, Strontium content of ostracods indicates lacustrine palaeosalinity: Nature, v. 316, p. 251-253.

Chivas, A. R., De Deckker, P. and Shelley, J. M. G., 1986, Magnesium content of non-marine ostracod shells: a new palaeosalinometer and palaeothermometer: Palaeogeogr., Palaeoclimatol., Palaeoecol., v. 54, p. 43-61.

Cohen AS., 2003, Paleolimnology–the history and evolution of lake systems. Oxford University Press, Oxford

Cohen, A.S. 1987, Fossil Ostracodes from Lake Mobutu (L. Albert): Paleoecologic and Taphonomic Implications: Paleoecology of Africa, v. 18, p. 271-281.

Costil, K., and Clement, B. 1996, Relationship between freshwater gastropods and plant communities reflecting various trophic levels: Hydrobiologia, v. 321, n. 1, p. 7–16.

Currey D.R., 1990, Quaternary palaeolakes in the evolution of semidesert basins, with special emphasis on Lake Bonneville and the Great Basin, U.S.A: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 76, no. 3–4, p. 189-214

Curry, B. B, 1999, An environmental tolerance index for ostracodes as indicators of physical and chemical factors in aquatic habitats: Palaeogeogr. Palaeocol. V. 148, p. 51-63.

Curry, B. B., 2010, Episodes of low dissolved oxygen indicated by ostracodes and sediment geochemistry at Crystal Lake, Illinois, USA: Limnology and Oceanography, v. 55, no. 6, p. 2403–2423.

De Deckker, P., 1988. An account of the techniques using ostracods in palaeolimnology in Aust ral ia. Palaeogeogr., Palaeoclimatol., Palaeoecol., 62: 463-475.

Delorme, L.D., 1967, Field key and methods of collecting freshwater ostracodes in Canada: Canadian Journal of Zoology, v. 45, p. 1275-1281.

Delorme, L.D., 1969, Ostracodes as Quaternary paleoecological indicators: Canadian Journal of Earth Sciences, v. 6, p. 1471-1476.

Delorme, L. D., 1978, Distribution of freshwater ostracodes in Lake Erie: J. Great Lakes Res., v. 4, p. 216 220.

Delorme, L. D., 1989, Methods in Quaternary Ecology #7. Freshwater Ostracodes: Geoscience Canada, v. 16, p. 85-90.
Delorme, L.D., 2001, Ostracoda. Pp. 811-849 in Thorp, J.H., and A.P. Covich (eds.). Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego. 2nd edition.

Delorme, L. Denis., 1989, Chapter 19: Ostracoda. In: Ecology and Classification of North American Freshwater Invertebrates. Academic Press, New York.

Dennison-Budak, C. W., 2010, Thesis. Ostracodes as Indicators of the Paleoenvironment in the Pliocene Glenns Ferry Formation, Glenns Ferry Lake, Idaho: Kent State.

Eardley, A. J. and Gvosdetsky, V., 1960. Analysis of Pleistocene core from Great Salt Lake, Utah: Geologic Soc. American Bull., v. 71, p.1323 1344.

Engstrom D.R., S.R. Nelson, 1991, Paleosalinity from trace metals in fossil ostracodes compared with observational records at Devil's Lake, North Dakota, USA: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 83, p. 295–312

Fernandes Martins, M.J., Namiotko, T., Cabral, M.C., Fatela, F., Boavida, M.J. (2010) Contribution to the knowledge of the freshwater Ostracoda fauna in continental Portugal, with an updated checklist of Recent and Quaternary species. J. Limnol., v. 69, no. 1, p. 160-173.

Frenzel, P., Henkel, D., Siccha, M. & Tschendel, L. 2005, Do ostracode associations reflect macrophyte communities? A case study from the brackish water of the southern Baltic Sea coast: Aquatic Sciences v. 67, p. 142–155.

Fritz, S.C., Juggins, S., Battarbee, R.W., and D.R. Engstrom, 1991, Reconstruction of past changes in salinity and climate using a diatom-based transfer function: Nature, v. 352, p. 706–708.

Fritz, S. C., 1996, Paleolimnological records of climate change in North America: Limnology and Oceanography, v. 41, p. 882-889.

Fritz, S.C., Cumming, B.F., Gasse, F., and Laird, K.R., 1999, Diatoms as indicators of hydrologic and climatic change in saline lakes. *In* The diatoms: applications to the environmental and earth sciences, Edited by E.F. Stoermer and J.P, Smol: Cambridge University Press, New York. p. 41–72.

Forester, R. M., 1983. Relationship of two lacustrine ostracode species to solute composition and salinity: implications forpaleohydrochemistry: Geology, v. 11: p. 435–438.

Forester, R. M., 1985,. Limnocyrhere bradburyi n.sp.: Modem ostracode from Central Mexico and a possible Quaternary paleoclimate indicator: Journal of Paleontology, v. 59, p. 344-369.

Gillespie, A.R., 1991, Quaternary subsidence of Owens Valley, California, in Hall, C.A., Jr., Doyle-Jones, Victoria, and Widawski, Barbara, eds., Natural history of eastern California and high-altitude research: Los Angeles, University of California, White Mountain Research Station Symposium, v. 3, p. 365–382.

Gutentag, E. D., & Benson, R. H., 1962, Neogene freshwater ostracodes from the central High Plains:
Kansas: Geol. Survey, Bulletin, v.157, p. 1-60.

Hanai, T., Ikeya, T. and Ishizaki, K., editors, 1988, Evolutionary biology of Ostracoda. Its fundamentals and applications: Kodansha: Elsevier.

Harman, W., and J. Forney., 1970, Changes in the molluscan community on Oneida Lake, N.Y. between 1917 and 1967: Limnol. Oceanog., v. 15, p. 454-460.

Harrold, M.N., Guralnick R. P., 2010,. A field guide to the freshwater mollusks of Colorado, Colorado. Division of Wildlife, Edition 2: Colorado Division of Wildlife.

Hay, R.L., 1964, Philipsite of saline lakes and soils: Am. Mineral. V. 49, p. 1366– 1387.

Hay, R.L., and Moiola, R.J., 1963, Authigenic silicate minerals in Searles Lake, California: Sedimentology,v. 2, p . 312- 332.

Hay, R.L., 1966, Zeolites and zeolitic reactions in sedimentary rocks: Geol. Soc. America Spec. Paper 85, p. 130.

Henderson. Junius and L. E. Daniels. 1917. Hunting Mollusca in Utah and Idaho in 1916: Proc. Acad. Nat. Sci. Phila., v. 69, p. 48-81.

Hershler, R., 1996, Review of the North American aquatic snail genus Probythinella (Rissooidea: Hydrobiidae) Invertebrate Biology v. 115, p. 120 - 144.

Hershler, R., 1999, A systematic review of the hydrobiid snails (Gastropoda: Rissooidea) of the Great Basin, western United States. Part II, Genera Colligyrus, Eremopyrgus, Fluminicola, Pristinicola, and Tryonia. Veliger, v. 42, p. 306 - 338.

Hoffert M. I., and Covey, C., 1992, Deriving global climate sensitivity from paleoclimate reconstructions: Nature, v. 360, p. 573–576.

Holland, S. M., 2006. Cluster Analysis: Department of Geology, University of Georgia, Athens, GA 30602-2501.

Holmes, J.A., 1992, Nonmarine ostracods as Quaternary palaeo-environmental indicators: Prog. Phys. Geog., v.16, p. 405–431.

Hovingh, P., 2004, Intermountain freshwater mollusks, USA (Margaritifera, Anodonta, Gonidea, Valvata, Ferrissia): geography, conservation, and fish management implications. Monographs of the Western North American: Naturalist, v. 2, p.109-135.

Hubbard, D.A., Jr., Giannini, W.F., and Lorah, M.M., 1985, Travertine-marl deposits of the Valley and Ridge province of Virginia – A preliminary report: Virginia Division of Mineral Resources, Virginia Minerals v. 31, n. 1, p. 1-8.

Ikeya, N., Tsukagoshi, A., Horne, D. J. 2005 Preface: the phylogeny, fossil record and ecological diversity of ostracod crustaceans. In Special issue: evolution and diversity of Ostracoda, vol. 538 (eds N. Ikeya, A. Tsukagoshi & D. J. Horne). Hydrobiologia, pp. vii–xiii.

Izuka, S. K., R. L. Kaesler. 1986. Biostratinomy of ostracode assemblages from a small reef flat in Maunalua Bay, Oahu, Hawaii. Journal of Paleontology, 60:347–360.

Izett, G. A., 1981, Volcanic ash beds; recorders of upper Cenozoic silicic pyroclastic volcanism in the western United States: Journal of Geophysical Research, v. 86, no. B11, p. 10200-10222.

Jayko, A. S., et. al., 2008, Late Pleistocene lakes and wetlands, Panamint Valley, Inyo County, California, in Late Cenozoic Drainage History of the Southwestern Great Basin and Lower Colorado River Region: Geologic and Biotic Perspectives: Geological Society of America Special Paper 439, p. 151-184.

Jones, P.D, Briffa KR, Barnett TP, Tett SFB (1998) High-resolution palaeoclimatic records for the last millennium: interpretation, integration and comparison with general circulation model control-run temperatures. Holocene 8(4): p.455–471.

Jones, P. D., Mann M.E., 2004) Climate over past millennia:. Rev Geophys, v. 42.

Keen M.C. 1977. Ostracods assemblages and depositional environments of the Headon, Osborne and Bembridge Beds (Uppper Eocene) of the Hampshire Basin.- Palaeontology, London, vol. 20, part 2, p. 405-445.

Kienast, F. et al., 2011, Paleontological records indicate the occurrence of open woodlands in a dry inland climate at the present-day Arctic coast in western Beringia during the Last Interglacial Quaternary Science Reviews (August 2011), 30 (17-18), pg. 2134-2159

Kiss, A. 2007. Factors affecting spatial and temporal distribution of Ostracoda assemblages in different macrophyte habitats of a shallow lake (Lake Fehér, Hungary). Hydrobiologia 585: 89-98.

Knopf, A., 1918, A geologic reconnaissance of the Inyo Range and the eastern Slope of the southern Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 110, p. 130.

Kodama, K. P. and A. Cox, 1978. The effects of a constant volume deformation on the magnetization of an artificial sediment; Earth and Planet.Sci. Letters; Vol. 38, No. 2, 436-442.

Kowalewska, A., Cohen, A.S., 1998. Reconstructions of paleoenvironments of the Great Salt Lake Basin during the late Cenozoic. Journal of Paleolimnology 20, 381–407.

Külköylüoğlu, O. 2004. On the use of ostracods (Crustacea) as bioindicator species in different aquatic habitats in the Bolu region, Turkey. Ecological Indicators. 4: 139-147.

Külköylüoğlu, O. 2005c. Ecological requirements of freshwater Ostracoda (Crustacea) in two limnocrene springs (Bolu, Turkey). Ann. Limnol. –Int. J. Lim. 41: 237-246.

Külköylüoğlu, O. and Yılmaz, F. 2006. Contribution to the knowledge of ecological requirements of Ostracoda (Crustacea) in three kinds of springs. Limnologica. 36: 172-180.

Laird, K.R., Fritz, S.C., Grimm, E.C. and Mueller, P.G., 1996, Century-scale paleoclimatic reconstruction from Moon Lake, a closed-basin lake in the northern Great Plains: Limnol. Oceanogr. V. 41, p. 890-902.

Lambert, P., 1997. La sedimentation dans le Lac Neuchâtel (Suisse): processus actuels et reconstitution pal´eoenvironnementale de 1500BP `a nos jours. Ph.D. Thesis, Neuchâtel.

Last, W. M., and Smol, J. P., Tracking environmental change using lake sediments: Basin analysis, coring, and chronological techniques: Springer, 548 p.

Lotter, A.F., H.J.B. Birks, W. Hofmann and A. Marchetto, 1997. Modern diatom, cladocera, chironomid,
and chrysophyte cyst assemblageges as quantitative indicators for the reconstruction of past environmental conditions in the Alps. I. Climate. Journal of Paleolimnology 18: 395–420.

Lotter, A.F., H.J.B. Birks, W. Hofmann and A. Marchetto, 1998. Modern diatom, cladocera, chironomid, and chrysophyte cyst assemblageges as quantitative indicators for

the reconstruction of past environmental conditions in the Alps. II. Nutrients. Journal of Paleolimnology 19: 443–463.

Lueddecke, S.B., N. Pinter, and P. Gans, 1998. Plio-Pleistocene ash falls, sedimentation, and rangefront
faulting along the White-Inyo Mountains front, California. Journal of Geology, 106: 511-522.

Mackie, G.L. & Flippance, L.A. (1983) Relationships between buffering capacity of water and the size and calcium content of freshwater mollusks. Freshwat. Invertebr. Biol. 2: 48-55.

Mackie, G. L. (1989). Tolerances of five benthic invertebrates to hydrogen ions and metals (Cd, ph AI). Arch. Environ. Contain. Toxicol., 18, 215-23.

Mezquita, F., G. Tapia & J. R. Roca, 1999. Ostracoda from springs on the eastern Iberian Peninsula: ecology, biogeography and palaeolimnological implications. Palaeogeography, Palaeoclimatology, Palaeoecology 148: 65–85.

Mezquita, F., V. Olmos & R. Oltra, 2000. Population ecology of Cyprideis torosa (Jones, 1850) in a hypersaline environment of the Western Mediterranean (Santa Pola, Alacant). Ophelia 53: 119–130.

Mezquita, F., H. I. Griffiths, M. I. Domı´nguez & M. A. Lozano-Quilis, 2001. Ostracoda (Crustacea) as ecological indicators: a case study from Iberian Mediterranean brooks. Archiv fu¨r Hydrobiologie 150: 545–560.

Migowski, C., Agnon, A., Bookman, R., Negendank, J.F.W., Stein, M., 2004. Recurrence pattern of Holocene Earthquakes along the Dead Sea transform revealed by varve-counting and radiocarbon dating of lacustrine sediments. Earth and Planetary Science Letters 222/1, 301–314.

Mischke, S., Almogi-Labin, A., Ortal, R., Schwab, M.J., Boomer, I., 2010. Quantitative reconstruction of lake conductivity in the Quaternary of the Near East (Israel) using ostracods. Journal of Paleolimnology. 43: 667-688.

Moberg A, Sonechkin DM, Holmgren K, Datsenko NM, Karle´n W (2005) Highly variable northern hemisphere temperatures reconstructed from low-and high-resolution proxy data. Nature 433(7026):613–617.

Molnar, P., and Cane, M.A., 2002, El Niño's tropical climate and teleconnections as a blueprint for pre-Ice Age climates: Paleoceanography, v. 17, no. 2.

Moser, M., 2009, Niederhöfer, H-J. and Falkner,G., Continental molluscs of the fossil site Sandelzhausen (Miocene; Upper Freshwater Molasse from Bavaria) and their value for palaeoecological assessment: PalÄontologische Zeitschrift, v. 83, no. 1, p. 25-54.

Nagorskaya, L. and Keyser, D. 2005. Habitat diversity and ostracode distribution patterns in Belarus. Hydrobiologia. 538:167-178.

Nelson, M. and R. P. Guralnick. 2007. A Field Guide to the Freshwater Mollusks of Colorado. Colorado Division of Wildlife, Colorado USA. Colorado Division of Wildlife. p.

Ormes, A.R., 2005, Late Pleistocene Climate and Tectonic Impacts on the Owens River Cascade, Conference Abstract, p. 2.

Owen, R. M., and B. H. Wilkinson. 1983. Miner- alogical and biological controls on the Fe/Ca and Mn/Ca ratios of lacustrine carbonate allochems. Chem. Geol. 38: 175-181.

Palacios-Fest, M., Cohen, A.S., Ruiz, J. and Blank, B. 1993 Comparative Paleoclimatic Interpretations from Nonmarine Ostracodes using Faunal Assemblages, Trace Element Shell Chemistry and Stable Isotope Data. In Swart, P., Lohman, K., McKenzie, J. and Savin, S. (eds.) Climate Change in Continental Isotopic Records. AGU Monograph 78: 179-190.

Palacios-Fest, M., Cohen A. and Anadon, P. 1994 Use of Ostracodes as Paleoenvironmental Tools in the Interpretation of Ancient Lacustrine Records. Rev. Paleo. Espanola 9: 145-164.

Pérez, Liseth et al. Extant freshwater ostracodes (Crustacea: Ostracoda) from Lago Petén Itzá, Guatemala. Rev. biol. trop [online]. 2010, vol.58, n.3 [citado 2012-03-11], pp. 871-895

Pieri, V., Caserini, C., Gomarasca, S., Martens, K. and Rossetti, G. 2007. Water quality and diversity of the recent ostracod fauna in lowland springs from Lombardy (northern Italy). Hydrobiologia 585: p. 79-87.

Pieri, V., Martens, K., Stoch, F., and Rossetti, G., 2009, Distribution and ecology of non-marine ostracods (Crustacea, Ostracoda) from Friuli Venezia Giulia (NE Italy): Journal of Limnology, 68(1):1-15.

Pilsbry, H. A. 1891. Land and freshwater mollusks collected in Yucatan and Mexico. Proceedings of the Academy of Natural Sciences of Philadelphia 43:310–334.

Piscart, C., Moreteau, J. C. and Beisel, J. N.: 2005, Biodiversity and structure of macroinvertebrate
communities along a small permanent salinity gradient, Meurthe River, France, Hydrobiologia.

Prámparo M., Ballent S., Gallego O.F., and Milana J.P. 2005. Paleontología de la Formación Lagarcito (Cretácico Inferior alto), provincia de San Juan, Argentina. Ameghiniana 42 (1): 93-114.

Regan, H.M., Y. Ben-Haim, B. Langford, W.G. Wilson, P. Lundberg, S.J. Andelman, and M.A. Burgman. 2005. Ecological Applications 15:1471-1477.

Rodó X., Santiago Giralt, Francesc Burjachs, Francisco A Comín, Rafael G Tenorio, Ramon Julià, High-resolution saline lake sediments as enhanced tools for relating proxy paleolake records to recent climatic data series, Sedimentary Geology, Volume 148, Issues 1–2, 12 April 2002, Pages 203-220.

Sanford, L.P., Panageotou, W. and Halka, J.P. 1991. Tidal resuspension of sediments in northern Chesapeake Bay: Marine Geology, v. 97, p. 87-103.

Sarna-Wojcicki, A.M., Reheis, M.C., Pringle, M.S., Fleck, R.J., Burbank, D., Meyer, C.E., Slate, J.L., Wan, E., Budahn, J.R., Troxel, B.W., Walker, J.P., 2005. Tephra layers of Blind Spring Valley and related upper Pliocene and Pleistocene tephra layers. California, Nevada, and Utah: Isotopic ages, correlation and magnetostratigraphy. US Geological Survey Professional Paper 1701.

Scharf, B. W. 1993. Ostracoda (Crustacea) from eutrophic and oligotrophic maar lakes of the Eifel (Germany) in the Late and Post Glacial. In Ostracoda in the Earth and Life Sciences, Proceedings of the 11th International Symposium on Ostracoda, Warrnambool, Victoria, Australia (McKenzie, K. G. & Jones, P. J., eds), p. 453–464.

Sharpe, S. E., Richard M. Forester, Continental-aquatic mollusk hydrochemical occurrence patterns: Implications for population dynamics and paleoenvironmental reconstruction, Quaternary International, Volume 188, Issue 1, September 2008, Pages 105-116.

Shaw, M.A. & Mackie, G.L. 1989. Reproductive success of Amnicola limosa (Gastropoda) in low alkalinity lakes in south-central Ontario. Can. J. Fish. Aquat. Sci. 46: 863-869. Molluscan Family Planorbidae. Urbana: University of Illinois Press.

Shaw, M. A. & Mackie, G.L. 1990, Effects of calcium and pH on the reproductive success of Amnicola limosa (Gastropoda). Can. J. Fish. Aquat. Sci. 47: p. 1694-1699.

Smith, A.J., 1991. Lacustrine ostracodes as paleohydrochemical indicators in Holocene lake records of the North-Central U.S. Ph.D. Diss. (unpubl.): Brown Univ., p. 306

Smith, A.J. 1993. Lacustrine ostracodes as hydrochemical indicators in lakes of the north-central United States. Journal of Paleolimnology 8:121–134.

Staplin, F.L. 1963. Pleistocene Ostracoda of Illinois: part I. Subfamilies Candoninae, Cyprinae: general ecology, morphology: Journal of Paleontology v. 37, p. 758–797.

Sterki, V. 1920. Marl deposits in Ohio and their fossil Mollusca. Ohio Jour. Sci. 20: p. 173-184.

Stout L. N., Polytypic species and hybridization in quaternary freshwater ostracods of North America, Palaeogeography, Palaeoclimatology, Palaeoecology, Volume 17, Issue 4, June 1975, Pages 257-266

Taylor, D. W., 2002, New data on biogeography, classification and phylogeny of Physidae (Gastropoda: Hygrophila). Proceedings of the Ivan Franko Zhytomyr Pedagogical University] (Zhytomyr), 10: p. 24–26, Ukraine, 13–15 May 2002.

Taylor, D.W. 2003. Introduction to Physidae (Gastropoda : Hygrophila); biogeography, classification, morphology.   Revista de Biología Tropical 51(suppl. 1), p.1-287.

Taylor, D.W. 2004. Revisión morfológica de caracoles dulceacuícolas, familia Physidae. Comunicaciones de la Sociedad Malacológica del Uruguay 8: 279-282.

Thompson, R.S., 1991, Pliocene environments in the western United States: Quaternary Science
Reviews, v. 10, p. 115–132.

Thompson, F.G. 2004, An identification manual for the freshwater snails of Florida.

Trowbridge, A. C., 1911, The terrestrial deposits of Owens Valley, California: Jour. Geology, v. 19, p. 706–747.

van der Meeren G.I. , Lorentsen S.H., Skjoldal HR. 2010. Hav (bunn og peagisk) (The ocean - bottom and pelagic). P. 25-45 in Nybø S, ed. Naturindeks for Norge 2010, DN-Utredning 3-2010.

van der Meeren T., Ito, E., Verschuren, D., Almendinger, J. E., Martens, K. 2011, Valve chemistry of Limnocythere inopinata (Ostracoda) in a cold arid environment — Implications for paleolimnological interpretation: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 306, no. 3–4, p. 116-126.

von Oheimb V., K Oheimb, CM Heiler., 2007 The mollusc fauna of a degraded European lowland river system: the lower Havel (Brandenburg, Germany) Mollusca (2007) volume: 25 issue: 2 page: 153

Walcott, C. D., 1897, The post-Pleistocene elevation of the Inyo Range and the lake beds of Waucobi embayment, Inyo County, California: Jour. Geology, v. 5, p. 340–348.

Wethington AR, 2004. Family Physidae. A supplement to the workbook accompanying the FMCS Freshwater Identification Workshop, University of Alabama, Tuscaloosa, p. 24.

Whitehead, D. C., and Feth, J. W., 1961, Recent chemical analyses of waters from several closed-basin
lakes and their tributaries in the western United States: Bull. Geological. Society of America, v. 722, p. 1421-1426.

Wick, L., Lemcke, G. & Sturm, M. (2003): Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: high resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. The Holocene, 13: 665–675.

Wilkinson, I.P., Williams, M., Young, J.R., Cook, S.R., Fulford, M.G. & Lott, G.K. 2008. The application of microfossils in assessing the provenance of chalk used in the manufacture of Roman mosaics at Silchester. Journal of Archaeological Science, 35: 2415–2422.

Willmann, R. 1985: Responses of the Plio-Pleistocene freshwater gastropods of Kos (Greece, Aegean Sea) to environmental changes. In Bayer U. & Seilacher A. (eds): Sedimentary and Evolutionary Cycles 295–321.
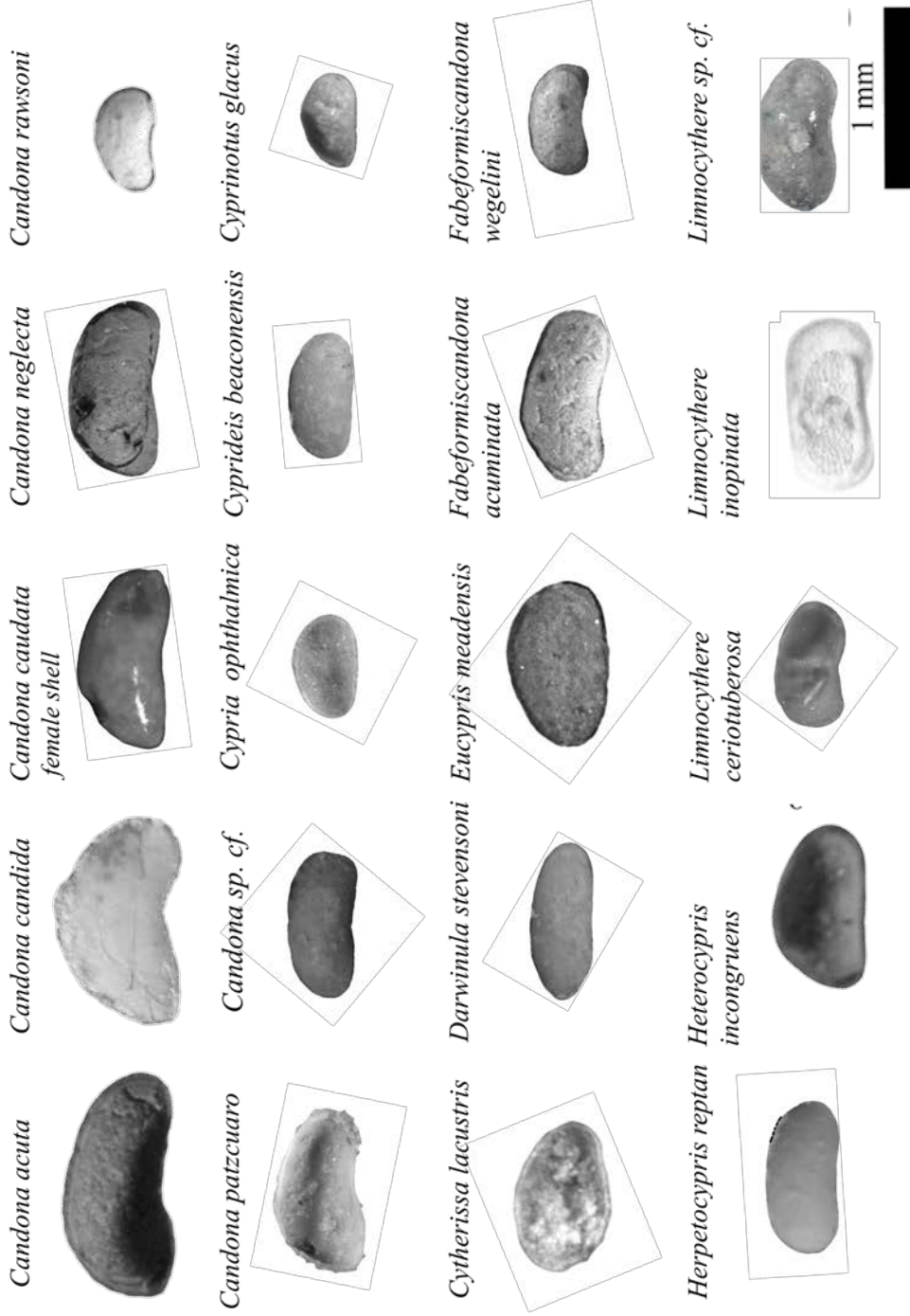
Wolfe, J.A., Schorn, H.E., Forest, C.E., and Molnar, P., 1997, Paleobotanical evidence for high altitudes in Nevada during the Miocene: Science, v. 276, p. 1672–1675.

Wootton, C. F. 1975. Pleistocene Mollusca of the Colon Deposit, St. Joseph County, Michigan. Sterkiana 57: 1-17.

Zachos, J., Pagani, M., Sloan, L., Thomas, E., and Billups., K, 2001, Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present: Science, v. 292, no. 5517, p. 686-693.

Plate 1. Ostracode Species

Candona acuta

Candona candida

Candona caudata female shell

Candona neglecta

Candona rawsoni

Candona patzcuaro

Candona sp. cf.

Cyprinotus glacus

Cyprideis beaconensis

Cypria ophthalmica

Cytherissa lacustris

Darwinula stevensoni

Eucypris meadensis

Fabeformiscandona wegelini

Fabeformiscandona acuminata

Herpetocypris reptan

Heterocypris incongruens

Limnocythere ceriotuberosa

Limnocythere inopinata

Limnocythere sp. cf.

1 mm

Plate 2 Gastropods Species

Amincola limosa

Planorbia parvus

Paludina integra

Valvata sincera

68