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GEOLOGY

A PLIO-PLEISTOCENE RECORD OF LACUSTRINE OSTRACODES FROM BUTTE VALLEY, CALIFORNIA: FAUNAL RESPONSES TO TECTONIC AND CLIMATIC CHANGE (89 pp.)

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A 3-inch diameter, 102 meter core was collected from the Butte Valley Lake near Siskiyou, California in the fall of 1991 as part of a USGS project to study Quaternary climatic conditions in western North America. The floor of Butte Valley lies at an altitude of 4200 feet and has been the site of a lake for at least 3-million years, with deposits ranging in age from Pliocene to Holocene and exceeding 900-feet in thickness. It is presently subject to active, extensional tectonism.

Ostracode samples from this core now reside at Kent State University. Analysis of fresh water ostracodes from this core address changes in the Butte Valley paleolake. Changes in ostracode species type and abundance provide insight into the impact of paleoclimate and tectonic changes of the Pacific Northwest. The Butte Valley data has been compared with existing studies from large Quaternary western North American pluvial lakes.

This study addresses paleoclimate and tectonic activity and their relation to Pleistocene climate oscillations (and the uplift of the coast range), dominant reproductive strategies (sexual vs. parthenogenetic) as indicators for paleoclimate and ecosystem stability, and assemblage consistency with the distribution of extant northern hemisphere ostracode taxa.

A PLIO-PLEISTOCENE RECORD OF LACUSTRINE OSTRACODES FROM
BUTTE VALLEY, CALIFORNIA: FAUNAL RESPONSES TO
TECTONIC AND CLIMATIC CHANGE

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ACKNOWLEDGEMENTS

Campbell's Ordinary Soups Do Make People Pale. As a youth, I spent many summer days hiking with my Dad down the broad, flat limestone bed of Cassidy Creek in rural Nicholas County, Kentucky, not far from where he grew up. Wearing swim trunks and a pair of old tennis shoes, we'd slap through the warm, shallow water, pausing now and again to turn over the large, flat limestone rocks that collected by the hundreds at bends in the meandering course. We were looking for snakes and crawdads.

Early on I had noticed that every rock was chock-full of sea shells and what looked like tiny tree branches and miniature ice-cream cones, all turned to stone. Dad informed me that they were fossils, remnants of a lost world from long before the dinosaurs. He told me that once, after a tedious search, he had found the prize of prizes, a trilobite! Trilobites, he added, were far more ancient than dinosaurs and had ruled the world far longer before going extinct. So it was that while my chronological age was still in single-digits, my brain was primed for Deep Time. How to make sense of these vast stretches of time? Dad shared a mnemonic he had invented in his undergrad days, "Campbell's Ordinary Soups Do Make People Pale". Cambrian, Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, Permian.

To my wonderful wife Catherine, whose patience passeth understanding, I wish to express my love and deep gratitude for allowing me to follow my dream. To my precious daughters Bridget

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To Dr. Joseph Ortiz I would like to express my appreciation for being a welcoming, friendly face when I was a new graduate student. I learned much in your classes and benefited from your ongoing interest in my thesis topic, especially in bringing to my attention the new and exciting research developments from Lake El’gygytygyn.

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In conclusion, I am indebted to the United States Geological Survey and the work of David Adam and others who retrieved Butte Valley Core 1 in 1991 and to Claire Carter who prepared the sample slides from the raw core material.

INTRODUCTION

Background

In 1991 the USGS drilled a 102m core (Butte Valley Core 1) from a dried lakebed near Meiss Lake, the relict lake in Butte Valley, Siskiyou county, California. After initial sorting and preparation of slides, funding for this work stopped and the core material lay unstudied for two decades. The core material has now been revisited and analyzed for this thesis. With this newly completed analysis of the core material, the Butte Valley site tells a compelling story of climate change and rainshadow effects in Plio-Pleistocene western North America.

This singular site contains, at this writing, the only North American paleolacustrine sediment core record reaching into the Pliocene that a) has carbonates, and b) is continuous. These two points are important because in the future, isotopic and other types of records based on carbonates used to analyze this core, will give us our only view of Western Pliocene hydroclimatology in continuous change. In addition, faunal analysis of the Butte Valley core has provided an unexpected insight into one of the key questions in evolutionary biology; the evolutionary maintenance of sexual reproduction (Bell, 1982).

The purpose of this thesis study was to determine paleoenvironmental conditions of Butte Valley, Siskiyou county, California using ostracodes as indicators. The primary goal of this project was to evaluate the following hypotheses:

1. Hypothesis: Butte Valley ostracode distributions can track solute changes in the paleolake through time, and by extension, regional climatic changes.
2. Hypothesis: The lacustrine record at Butte Valley is consistent with other lacustrine records of similar age in western North America.
3. Hypothesis: Butte Valley proxy (ostracodes and pollen) distributions can be used to differentiate between global (glacial/interglacial cycles) and regional (rainshadow) climatic signals.
4. Hypothesis: Butte Valley was the site of a large, geologically stable (10^5 to 10^6 years) freshwater lake in the Pliocene.



FIGURE 1: Butte Valley, Siskiyou county, California. Looking southwest down Route 97, the white-capped peak of Mt. Shasta is visible above telephone poles at far left. Meiss Lake and core site are visible as a thin white strip between mountains and valley floor at far right. *Photo: Google Maps*

Location and modern climate

Butte Valley, California is located in northeastern Siskiyou county approximately 15-miles south of the California/Oregon border and approximately 70-miles west of the California/Nevada border. Butte Valley is within the Cascade Range and Modoc plateau (Wood, 1960). Meiss Lake is a small, relict lake occupying the low, southwestern end of the valley floor. It is the modern remnant of a much larger Plio-Pleistocene lake that once filled this valley and whose sediments underlie the region's grassy farmland. The modern climate in Butte Valley region is "semiarid, characterized by warm, dry summers and cool, humid winters" (Wood, p. 13, 1960).

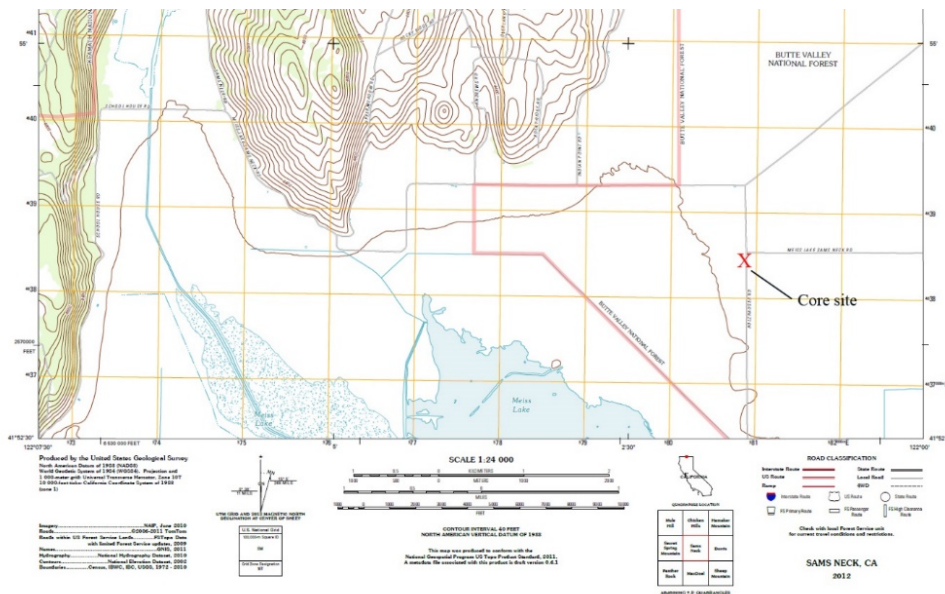


Figure 2 : Clipping from USGS topographic map Sam's Neck Quadrangle (2012). Southeastern portion of Butte Valley showing northwest corner of Meiss Lake and core site (marked).

Geology and Hydrology of Butte Valley

The geologic units of this region are divided into two groups: a) volcanic rocks that range in age from Eocene to recent; b) sedimentary rocks which range in age from Pliocene to recent (Wood, 1960).

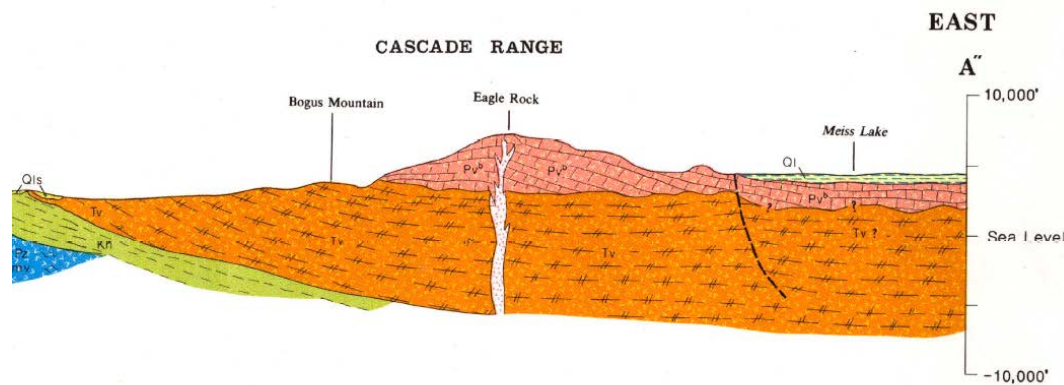


Figure 3: Clipping from Geologic Map of the Weed Quadrangle, California (1987). Cross-section of Cascade Range with Butte Valley and Meiss Lake at far right. Butte Valley underlain by Quaternary lake deposits, Pliocene volcanic basalt and Tertiary volcanics.

The oldest rocks in the Butte Valley region are volcanic rocks of the Western Cascades, which “range in age from late Eocene to late Miocene. These rocks are chiefly pyroxene andesite, and andesitic tuff-breccia, but include lesser amounts of basalt, rhyolite, and associated pyroclastic rocks. The volcanic rocks of the ‘Western Cascades’ are at least 12,000 feet thick” (Wood, p. 1, 1960). Lying unconformably atop the ‘Western Cascade’ volcanics are the volcanic rocks of the ‘High Cascades,’ which “are Pliocene and Pleistocene in age and consist chiefly of basalt and basaltic andesite that spread out in successive sheets from a chain of northward-trending shield volcanoes built along the crest of the Cascade Range” (Wood, p. 1, 1960). In Butte Valley these

volcanic rocks of the 'High Cascades' appear as "several large dome-shaped lava cones and most of the northwestward-trending fault block called Mahogany Mountain ridge and are highly fractured and moderately permeable; they serve as a large intake area and groundwater reservoir" (Wood, p. 2, 1960). The floor of Butte Valley is shown in cross-section (Figure 3) to consist of Quaternary lake deposits. "The area east of Meiss Lake contains an extensive remnant of undisturbed lake deposits and this area consists of exposed Quaternary lake beds of silt, clay, and fine sand that highly resembles a playa surface. Evidence from well logs indicates that the Butte Valley lake sediments are hundreds of meters deep in places (Wood 1960: 39)" (King, p. 48, 1991).

Water that finds its way into the Butte Valley basin, either as precipitation or from incoming streams such as Butte Creek, which is "the largest stream draining into the valley" (Wood, p.11, 1960), is either diverted for agriculture or "infiltrates the porous lavas" (Wood, p. 11, 1960) that make up the alluvium in the basin. Groundwater percolating through these "volcanic rocks of high calcium content" (Mack, p. 48, 1960) have concentrated "considerable calcium carbonate" in the subsoil, "cementing the subsoil into a hardpan" (Mack, p. 48, 1960). The high-calcium Plio-Pleistocene volcanic basalts underlying the Butte Valley basin are the source of the carbonate-rich water which has collected in the basin since the late Cenozoic and Quaternary.

Tectonics: The Rise of the Cascades and Klamath Mountains

Butte Valley is a small part of the vast Cascade Range, “a continental volcanic arc that results from the subduction of the Juan de Fuca plate beneath North America” (Kohn et al., p. 152, 2002). The geologic history of the Cascades is complex, ongoing and beyond the scope of this thesis. “Different models of Cascade topography include progressive uplift since the Eocene, pulsed uplift during the mid-Miocene and early Pliocene, and rapid post-Miocene uplift. In short, interpretations run the gamut of tectonically continuous to catastrophic processes” (Kohn et al., p. 153, 2002). Butte Valley is subject to ongoing extension and the “basin is tectonically active. Prominent fault scarps, generally parallel to the Mahogany Mountain ridge, are common throughout the area, and many of these features offset not only the younger volcanic rocks around the margins of the basin, but also the lacustrine deposits” (Adam et al., p. 2, 1994).

A specific timing for uplift of the Klamath Mountains is difficult to establish, due to the complexity of the underlying faults and subduction zones. Currently, it appears that the Klamath Mountains were at sea-level in the Pliocene and that significant uplift of the Klamath Mountains occurred from the mid-Pleistocene onward. “The presence of Idaho detritus throughout the Neogene Wildcat Group indicates that the Klamath Mountains remained low during the Pliocene and early Pleistocene” (Stone et al., 1993). “Based on the Idaho signature in sediment provenance, the uplift of the Klamath peneplain to elevations as high as 1220m may be viewed as chiefly a Pleistocene-Holocene event” (Aalto, p. 461, 2006).

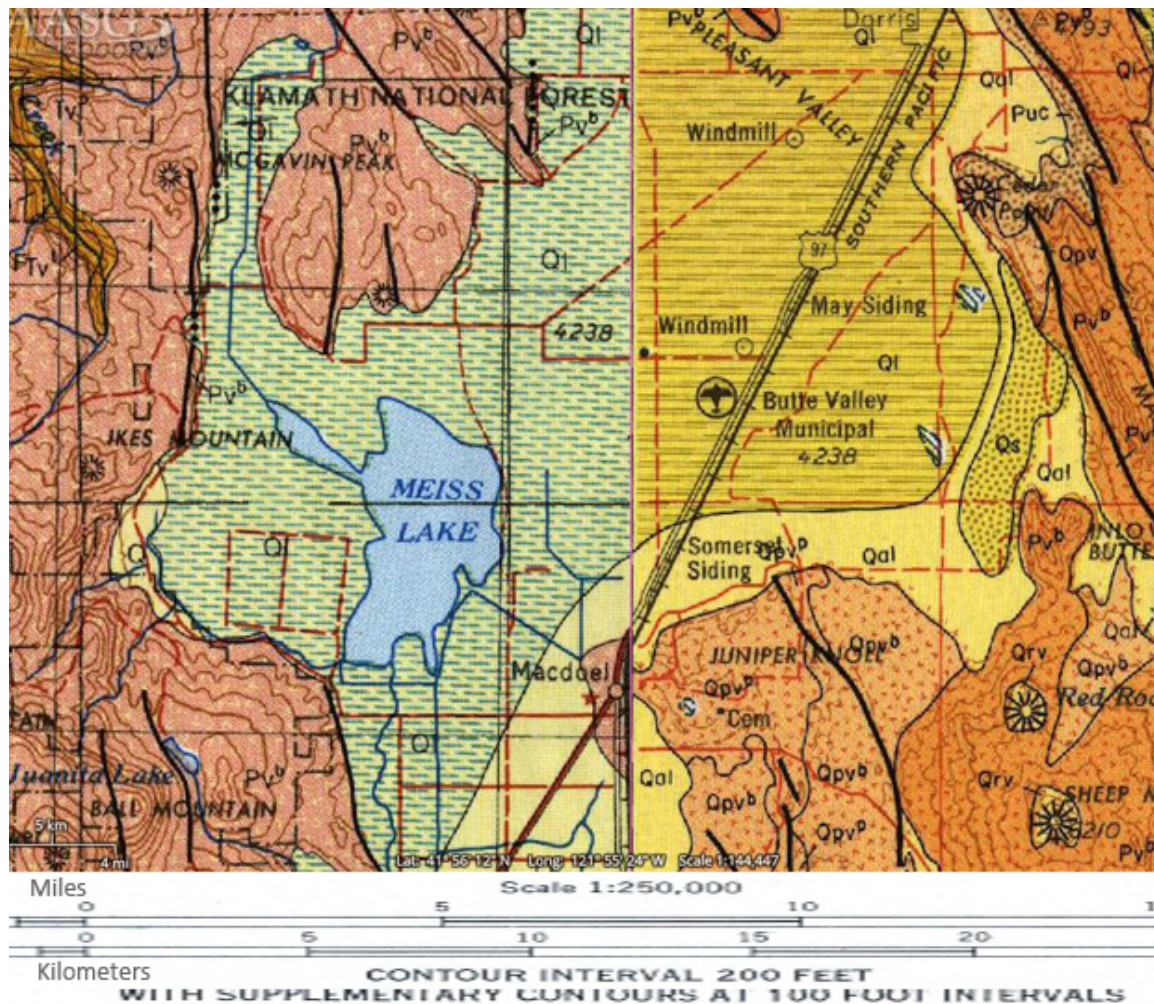


Figure 4 : Clipping from composite geologic map, USGS Mapview <http://ngmdb.usgs.gov/maps/mapview/>. Gay, T.E. and Aune, Q.A., 1958, Geologic map of California : Alturas sheet: California Division of Mines and Geology, scale 1:250,000. Strand, R.G., 1963, Geologic map of California : Weed sheet: California Division of Mines and Geology, scale 1:250,000.

Ostracodes

Ostracodes are found in a wide variety of lacustrine habitats, including freshwater lakes. The properties of these freshwater lakes are coupled to the global and regional climate. Thus, the effect of climate on important lacustrine parameters such as water temperature and total

dissolved solids (TDS) has a major effect on ostracode occurrence and productivity. For this reason, ostracode valves formed in these freshwater lakes provide detailed information on past climates affecting lakes (Forester, 1991). The presence of a specific species of ostracode reveals the ecological conditions in which that ostracode lived, though the original ecosystem may have vanished. Likewise, two or more ostracode species co-occurring can give more refined information of past ecological and climatic conditions based upon similarities or differences in their specific ecological requirements. (Forester, 1986) Presently, there are 56 genera and about 420 species of non-marine ostracodes identified in North America and it is likely that these numbers will increase as groundwater sampling efforts increase in the future (Smith & Delorme, 2010).

Pollen

The pollen record from Butte Valley provides a means to corroborate and expand upon insights from the ostracode record. The varying percentages of different regional pollen types through time provides a picture of the overall distribution of species during any given period, and identifying these species allows us to make general assumptions about the kind of climate existing in the region when the pollen was deposited. “The best available modern pollen surface-sample transect data are from the Sierra Nevada (Adam, 1967), where *Quercus* pollen was found in highest frequencies below an elevation of about 750 m, *TCT* (*Taxodiaceae-Cupressaceae-Taxaceae*) between 750 and 2,000 m, and *Pinus* above 2,000 m” (Adam et al., p. 373, 1981). Species’ altitude preferences give a simplified ‘Goldilocks’ indication of the kind of climate each species prefers. *Quercus* will generally indicate a warmer climate, *TCT* will indicate an

intermediate climate and *Pinus* will indicate a cooler climate. In addition, Haywood & Valdes state “*Pinus* and *Taxodiaceae-Cupressaceae-Taxaceae* (TCT) dominate the pollen spectra of middle Pliocene age, with these two types exhibiting an inverse correlation and displaying eight or nine major peaks of dominance between 3 and 2.5 Ma BP. This inverse correlation between *Pinus* and TCT pollen was evident in the graph of Butte Valley pollen percent for the length of the core (Figure 26). High levels of *Pinus* are interpreted to represent cooler/moister climates, whereas high levels of *TCT* are thought to reflect warmer and drier conditions (Thompson & Fleming, 1996)”(Haywood et al., p. 5, 2002). I used these climatic assumptions to guide my analysis of the pollen from Butte Valley.

Table 1 – Basic pollen autecology

	Climate type	Elevation analog	Citation
Quercus	Warm, temperate	< 750m	Adam, 1967, 1981; Thompson & Fleming, 1996; Haywood & Valdes, 2002
Pinus	Cool, moist	>2,000m	Adam, 1967, 1981; Thompson & Fleming, 1996; Haywood & Valdes, 2002
TCT	Warm, dry	750-2,000m	Adam, 1967, 1981; Thompson & Fleming, 1996; Haywood & Valdes, 2002

Pliocene climate

The Pliocene Epoch (5.33-2.58 Ma) marked the end of the Neogene and the gateway to the climatically turbulent Quaternary. It was a period of “transition from relatively warm global climates when glaciers were absent or greatly reduced in the Northern Hemisphere to the generally cooler climates of the Pleistocene with expanded Northern Hemisphere ice sheets and prominent glacial-interglacial cycles.” (Dowsett et al., p. 1, 1999).

The Pliocene shared several boundary conditions with our own time. Like the present day, atmospheric pCO₂ levels in the Pliocene were ~400 ppm (Pagani et al., 2010) and global geography was also similar to the present (Zachos et al., 2001). In addition, “the closure of the Central American seaway initially pushed the climate system toward warmer conditions, the so-called Pliocene Warm Period between 4.7 and 3.1 Ma (e.g., Budyko et al., 1985)” (Haug, p. 210, 2001). But there were key differences between the Pliocene and the present. The global surface temperature was 3°C warmer than the present day (Haywood & Valdes, 2004) and there was virtually no Northern Hemisphere Glaciation (NHG) (Zachos et al., 2001). “It is clear that the reduced volume of land ice cover is an important forcing mechanism on Pliocene climates with sea ice cover, ocean temperatures and subsequently atmospheric temperatures responding to the forcing delivered by the cryosphere” (Haywood & Valdes, p. 373, 2004).

Pliocene climate was in a condition described by many researchers as a ‘permanent El Niño’, a matter of current debate (Fedorov, 2006). A recent study compared “Pliocene oxygen isotope profiles of pedogenic carbonates across the western US to modern isotopic anomalies in precipitation between phases of the El Niño–Southern Oscillation (ENSO)” (Winnick et al., p. 903, 2013).

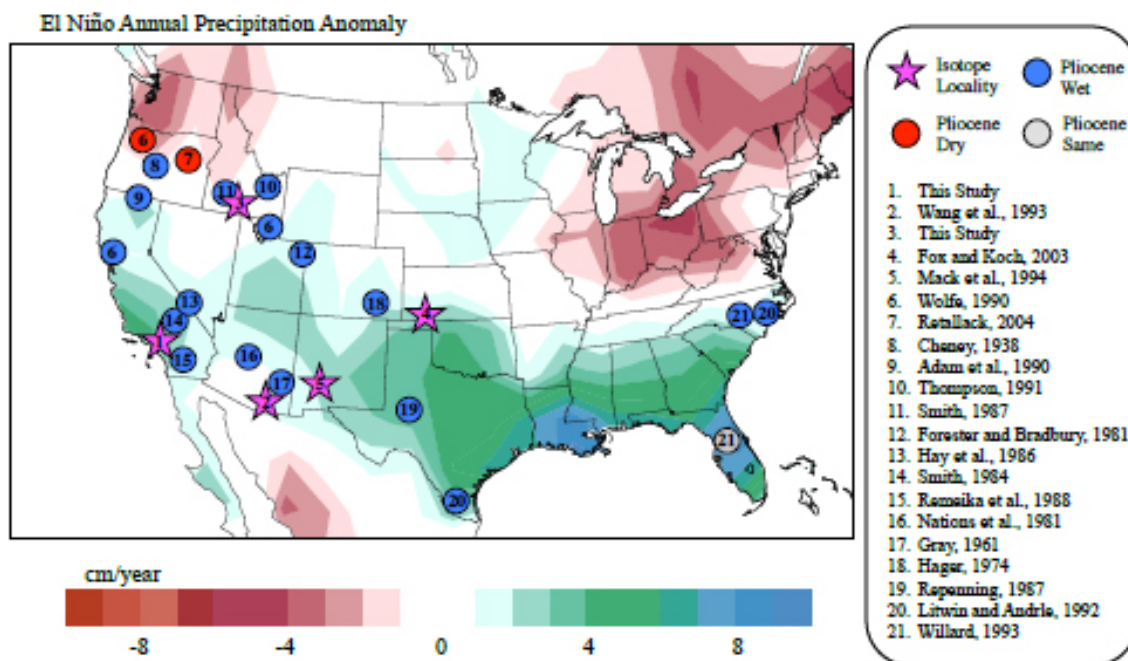


Figure 5: Modern El Niño precipitation anomalies, isotope localities, and reconstructed Pliocene conditions. Anomalous annual El Niño precipitation calculated with CMAP precipitation data from 1979–2008; CMAP precipitation data provided by the NOAA/OAR/ESRL PSD, Boulder, CO, USA, from their Web site at <http://www.esrl.noaa.gov/psd/>. Purple stars show isotope record localities used in this study. Blue circles represent reconstructions of wetter-than-modern Pliocene conditions, and red circles represent reconstructions of drier-than-modern Pliocene conditions. *Reproduced under terms of Creative Commons Attribution 3.0 license from Winnick et al., p. 904, Fig. 1, 2013.*

This isotopic comparison found that in the Pliocene, “much of the western and southern US were characterized by wetter-than-modern conditions, while a few areas in the Pacific Northwest were drier than modern” (Winnick et al., p. 904, 2013)(Figure 5). These “wet Pliocene” conditions are corroborated by floral, faunal and sediment reconstructions across western North America (Forester, 1991). The cause of these wet conditions in western North America seems to be associated with the migration of the westerly storm track “northward through the late Pliocene with the development of the modern cold tongue in the east equatorial Pacific” (Winnick et al., p. 903, 2013). The westerly storm track “then returned southward with widespread glaciation in the

Northern Hemisphere – a scenario supported by terrestrial climate proxies across the US.

Together these data support the proposed existence of background El Niño-like conditions in western North America during the warm Pliocene” (Winnick et al., p. 903, 2013).

The onset of the pronounced glacial/interglacial cycles of the Pleistocene “is marked by the appearance of ice-rafted debris (IRD) in North Atlantic and North Pacific sediments at 2.7 Ma (Shackleton, 1984) (Maslin et al., 1998), associated with increased stratification of North Pacific surface water”(Sosdian & Rosenthal, p. 306, 2009).

Pliocene Lakes

The Butte Valley paleolake is one of many sites in western North America (and worldwide) where Pliocene lake sediment has been analyzed. This section provides a summary of research done at these sites, including one site (Lake El’gygytygyn) from Russia whose paleolacustrine cores are providing new climate insights. An overview of these sites, along with Butte Valley, combine to form a clearer picture of climate change in western North America during the Pliocene and Pleistocene.

Tule Lake, Siskiyou County, California

Tule Lake provides a regionally useful analog for Plio-Pleistocene changes like those recorded in nearby Butte Valley, California. Cores of lake sediment at Tule Lake have been dated by radiometric, tephrochronologic and paleomagnetic techniques to about 3 million years

(Bradbury, 1991). “Tule Lake’s fossil diatoms document the late Cenozoic paleolimnologic and paleoclimatic history for the northwestern edge of the Basin and Range Province” (Bradbury, p. 205, 1991). Like the Pliocene climatic trends found in the Butte Valley core, the Tule Lake record indicates that “between 3.0 and 2.9 Ma, the dominance of *Stephanodiscus asteroides* and *Cyclotella elgeri* suggests Tule Lake was comparatively deep, fresh and seasonally stratified.” (Bradbury, p. 221, 1991). The period from ~2.0 to 1.67 Ma records the first appearance of two distinctive *Stephanodiscus* species (*S. carconensis* and *S. rhombus*) in Tule Lake (Bradbury, 1991). “The ecology of these *Stephanodiscus* species is unknown, but presumably they relate to strong, seasonal nutrient fluxes characteristic of spring and fall circulation periods. It is reasonable to assume that the climate became colder and more seasonal at that time” (Bradbury, p. 222, 1991). As the Tule Lake record moves further into the Pleistocene “the diatom flora of the later part is increasingly modern in composition, and suggests that typical temperate lacustrine environments are becoming prevalent after 1.7 Ma” (Bradbury, p. 223, 1991). The Tule Lake story is one of transition from stable Pliocene deep lake conditions to ever stronger seasonal fluxes as the Pleistocene progressed.

Lake Idaho

Lake Idaho is a paleolake located in south-central Utah. Evidence from fish fossils in the Glenns Ferry Formation indicate that Lake Idaho was part of an interconnected intermountain lacustrine system in the Pliocene, with Lake Idaho at that time being comparable in size to present day Lake Ontario (Smith & Patterson, 1993). In the mid-Pliocene (~3.0 Ma) “the presence of fossil sculpins (*Myoxocephalus*) in the Glenns Ferry Formation indicates arctic or north temperate deep

water habitats and suggests that the Laurentian Great Lakes or Lake Baikal would be likely modern limnological analogs for Lake Idaho” (Bradbury, p. 221, 1991). Studies of otolith aragonite from fossil fish indicate “early and middle Pliocene climates on the Snake River Plain were more equable than subsequent climates” (Smith & Patterson, p. 292, 1993). The climate of the Lake Idaho/Snake River Plain region during the Pliocene did not experience large seasonal shifts but instead experienced a more even, less seasonal environment throughout the year. “Sustaining a lake of this nature indicates an annual moisture surplus, cold winters and mild summers. Boreal forest lakes have these characteristics. Mild-wet summers at 3.7 Ma compared to the modern warm-dry summers would result in a colder mean annual temperature” (Forester, p. 141, 1991). Finally, evidence from fish fauna indicates interconnections between many of the Pliocene lakes and rivers of western North America. “The Chalk Hills and Glenns Ferry stages of Lake Idaho contained several genera of fishes also found in the Recent fauna of the Great Valley in California: *Mylopharodon*, *Orthodon*, *Ptychocheilus*, and *Archoplites*. The distribution of these fishes and several molluscs supports the hypothesis of a late-Miocene-early-Pliocene drainage from the Snake River Plain to the Pacific through northern California” (GR Smith, p. 174, 1981). Thus, the fish fauna of Lake Idaho provide evidence of a vast, interconnected lacustrine system and a wet Pliocene climate capable of sustaining this large, deep lake.

Lake El’gygytgyn

Lake El’gygytgyn is a 3.6 million year old lake within a meteorite impact crater in northeastern Russia, 100 km north of the Arctic Circle (Melles et al., 2011). The Lake El’gygytgyn core is a continuous 3.58 Ma core that affords a “time-continuous reconstruction of the climatic and

environmental history of the terrestrial Arctic back into the mid-Pliocene” (Melles et al., p. 30, 2011).

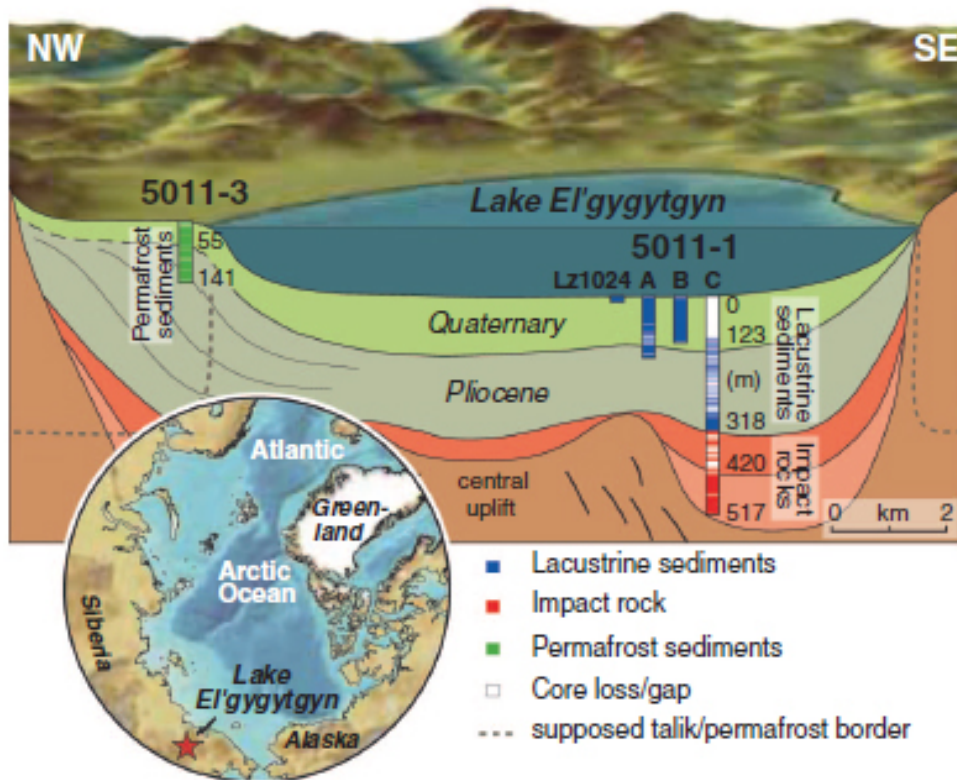


Figure 6: Location of Lake El’gygytgyn in northeastern Russia (inserted map) and schematic cross-section of El’gygytgyn basin stratigraphy and core sites. *Melles et al., Fig. 1, p. 315, 2012. Reproduced with permission from Science/AAAS.*

The 3.58 My continuous lacustrine record from Lake El’gygytgyn offers a fascinating chance for comparison with the 3.37 My continuous lacustrine record from Butte Valley. Since both are continuous, Pliocene, terrestrial lacustrine records it seems likely that they would share some global climatic signals occurring during this enormous stretch of time. Between October 2008

and May 2009, the International Continental Scientific Drilling Program (ICDP) co-sponsored a campaign at Lake El'gygytgyn, drilling "three holes in the center of the 170-m-deep lake, utilizing the lake ice cover as a drilling platform, plus one hole close to the shore in the western lake catchment. At the lake's center the entire 315-m-thick lake sediment succession was penetrated. The sediments lack any hiatuses (i.e., no evidence of basin glaciation or desiccation), and their composition reflects the regional climatic and environmental history with great sensitivity. Hence, the record provides the first comprehensive and widely time continuous insights into the evolution of the terrestrial Arctic since mid-Pliocene times" (Melles, p. 29, 2011). Findings from this campaign were used in comparison with my findings from the Butte Valley core in this thesis.

Searles Lake, California

Searles Lake in the southwestern Great Basin has a climate history stretching back into the Pliocene (3.2 Ma). This history has largely been gleaned from a 930-m core (KM-3) drilled in 1968. "The lake is now dry, but the valley contained perennial lakes during less arid parts of late Cenozoic time, when water from upstream basins, lying along the east side of the Sierra Nevada, overflowed into it" (GI Smith, p. 2, 1984). Overflowing upstream basins like these may have provided connections throughout the western Great Basin during the wetter Pliocene, as studies of fossil fish from other Great Basin Pliocene lakes have indicated (GR Smith, 1981).

Studies of Searles Lake sediments (no biological proxies) have divided the core into 9 distinct hydrologic regimes, based upon the sediment types found at various depths. "Units dominated by lacustrine marl and clay are interpreted as indicators of climatic regimes when moist climates

promoted high runoff and perennial lakes. Others, dominated by salt beds and playa sediments, are interpreted as indicators of regimes like the present, in which arid climates promoted low runoff and shallow or dry lakes. Still other units are characterized by interbedded salts and deep-water lacustrine sediments indicating repeated alternations between apparent extremes” (GI Smith, p. 4, 1984).

The pattern described in the Searles lake sediments, and their chronological placement in the history of this paleolake, are familiar from the emerging story of Butte Valley. Like Butte Valley, Searles Lake experienced a wet Pliocene, with the Searles Lake record indicating a wet period ~3.2 Ma to ~2.56 Ma. (GI Smith, 1984). The wet Pliocene climate at Searles Lake may have been due, in part, to the fact that “the Sierra Nevada were almost 1000 m lower 3 my ago (Huber, 1981, p. 26), and this may have allowed eastward-moving air masses to retain as much as 50% more moisture than the range allows today” (Smith et al., 1983, pp. 21-23)”(GI Smith, p. 6, 1984). The predominant climate through much of Searles Lake’s history throughout the early-to-mid Pleistocene (and again in the late-Pleistocene) was one of repeated swings between extremes (GI Smith, 1984). This increased seasonality is also evident in the Pleistocene Butte Valley core record. The Searles Lake record, taken as a whole, supports the story of a wet Pliocene in western North America with a trend toward increasing aridity as the Pleistocene progresses: a story with echoes in Butte Valley.

Bonneville System, Idaho and Utah

In the 1970’s, AMOCO drilled five deep wells in the Great Salt Lake. The cuttings from these deep wells were revisited in the late 1990’s enabling a low resolution but extremely long

paleoenvironmental reconstruction for the last 5 million years at the Bonneville Basin. The well cuttings were dated using tephrochronology (Kowalewska, 1998). The period ~4.2 – ~3.1 Ma had a very low abundance of ostracode valves recovered, and the recovered valves were poorly preserved. Still, the four taxa recovered (*Candona* sp., exotic candonids, *Limnocythere* sp., and *Tuberocypris* sp.) are consistent with taxa found in the Glenns Ferry formation and at Butte Valley during the latter part of this time period (Kowalewska, p. 389, 1998). Ostracode valves representing the period ~3.1 - ~2.4 Ma were “more common, more diverse and much better preserved than below”(Kowalewska, p. 389, 1998). These included valves from *Tuberocypris acuminatus*, *Tuberocypris quadralis* and *Candona rawsoni*, among others (Kowalewska, 1998). Although extinct, the presence of *Tuberocypris* species at Bonneville indicates a wet Pliocene climate in this region. *Tuberocypris brighti* at Butte Valley typically co-occurs with *Cytherissa lacustris*, an extant species with a tight ecological preference for long-term, stable climatic conditions and fresh water. Thus, the presence of *Tuberocypris* species and the mention that “there are few occurrences of brine shrimp fecal pellets”(Kowalewska, p. 389, 1998) indicate more dilute lacustrine conditions than subsequent periods. After ~2.4 Ma the exotic species disappear from Bonneville, a signal of increased seasonality in the region (Forester, 1991). “The presence of exotic ostracodes with affinities to the Snake River Plain (Lake Idaho) fauna during this time suggests that there was at least an intermittent hydrologic interconnection between the two lake systems during the late Pliocene” (Kowalewska, p. 393, 1998). Thus, the paleolimnologic evidence from Bonneville supports the general model of a wet Pliocene.

Core chronology

Magnetostratigraphy of this core provided a chronology for the trends found during analysis of the core material (Roberts et al., 1996). A graph, modified from Roberts et al., (1996), shows the rate of sediment accumulation versus time (Figure 7). There is a significant increase in sediment accumulation just above the 78m level in the core (corresponding to ~930 ka). This increase in the sedimentation rate in Butte Valley coincides roughly with the Mid-Pleistocene Transition (MPT). “The magnetostratigraphy indicates that this record is one of the longest continuous records of lacustrine environmental change in the western United States, comparable to that of the nearby Tule lake record (Adam et al., 1989; Rieck et al., 1992)” (Roberts et al., p. 2860, 1996).

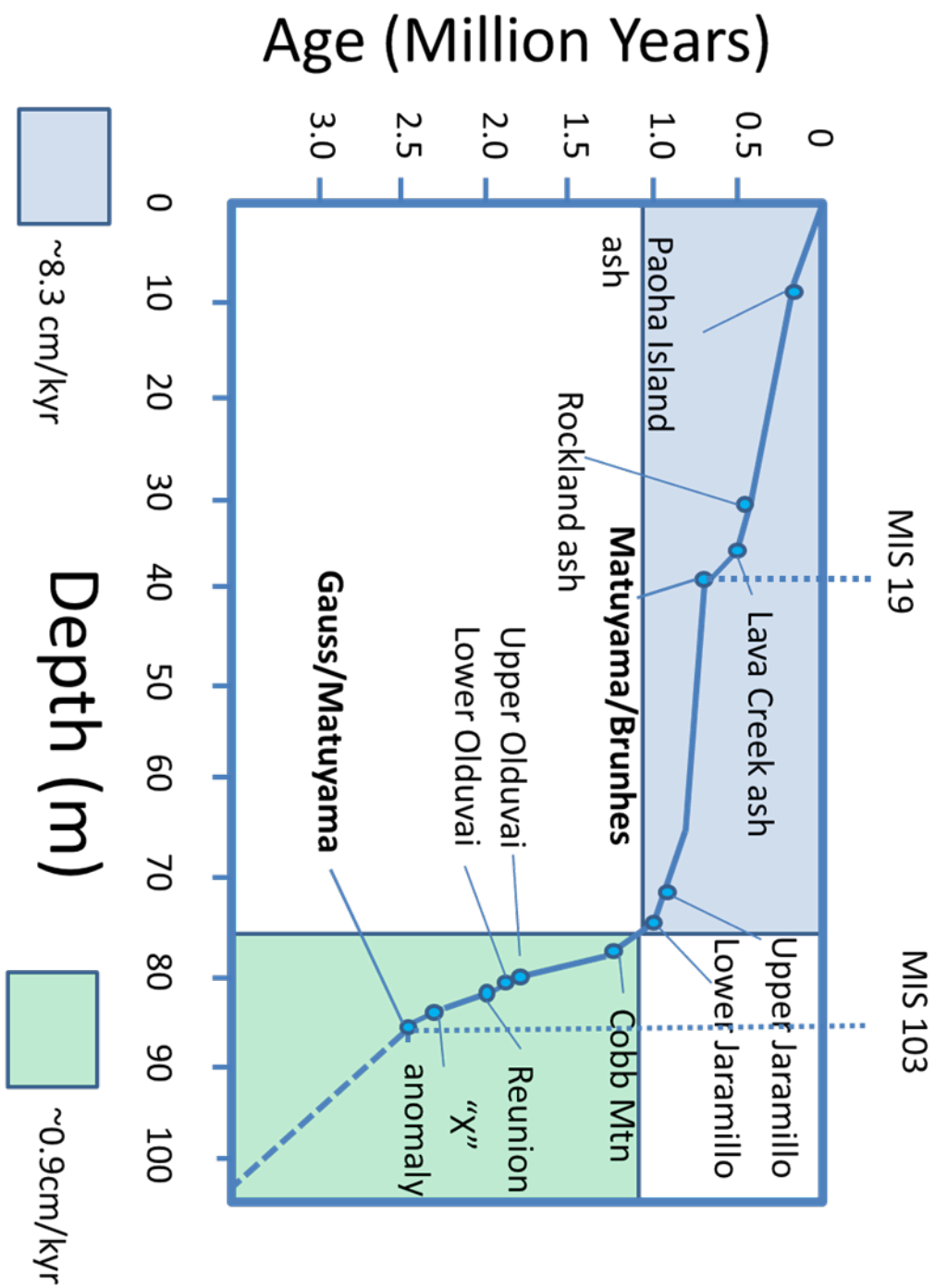


Figure 7: Sediment Accumulation Rate, Butte Valley Core, Siskiyou county, California. Modified from Roberts et al., 1996, JGR, Figure 1B

METHODS

The materials from USGS 94-593 used for this study were originally collected as part of the USGS Marine-Terrestrial Correlations Project in the Klamath Falls, Oregon/California region in Fall, 1991. (Adam et al., 1995) The condition of the Butte Valley core recovery was described as “excellent”, with the core containing “both perennial and ephemeral lake deposits; numerous tephra; carbonate also preserved.” (Adam et al., 1995) Material from the core was later provided to Kent State University, where it is now housed, for further research. The core material arrived in the form of 91 slides containing ostracode valves. The ostracode valves had been washed and cleaned and then placed loose on the slides. Ostracode species identification and counts were obtained from these slides.

Processing of Ostracode samples

The recovered core was initially shipped to the USGS refrigerated core storage facility in Menlo Park, California, where it was sampled for ostracodes (it now resides in the USGS Denver Core Repository). Following standard procedures (Forester, 1988) each of the samples was placed in a steel beaker, treated with approximately 300ml of hot water and a rounded teaspoon of baking soda, frozen and thawed.

After thawing, about 2 tablespoons of Calgon $\text{Na}_4[\text{Na}_2(\text{PO}_3)_6]$ were added and each sample was allowed to sit for 24 hours. Following wet sieving over a 100 mesh sieve, the residue was air dried, then dry-sieved to obtain size fractions, which were then examined and picked for adult carapaces and valves (Carter, 1994). The 91 processed samples, with the valves preserved loose on the slides, form the collection analyzed in this study.

Processing of Pollen Samples

The pollen record from the Butte Valley core was analyzed by Dave Adam in the 1990's. Eighty-six pollen samples were counted and a preliminary pollen diagram was generated with major variations in the percentages of pollen types through time evident (Adam et al, 1995). Pollen preparation followed standard methods and pollen was identified using published pollen keys (Moore & Webb, 1978). This resulted in the identification of 11 separate pollen species. For this study I discarded pollen species that remained below 10% of pollen percentage for the duration of the core length and used only the more abundant pollen species: *Pinus*, *TCT*, *Artemisia*, *Quercus* and *Gramineae*. The pollen percentage counts for these species were then paired with the ostracode species data to generate a Principal Components Analysis.

Processing of Tephra samples

The position of the Butte Valley site downwind from many Cascade Range volcanoes and the availability of the tephra record from the Tulelake core (Rieck et al., 1992) made retrieval of

tephra samples from this core a promising opportunity (Adam et al., 1995). However, although the tephra samples were collected from Butte Valley and a preliminary “best guess” (Adams et al., p. 11, 1995) comparison was performed between the Butte Valley tephra and the Tulelake tephra, no radiometric analysis was undertaken due to lack of funds. “Two types of samples were collected for chemical analysis of tephra layers: (1) channel samples taken vertically across visible discrete tephra layers and (2) spot samples taken where tephra was suspected on the basis of sedimentologic and other physical characteristics, or was suspected on the basis of stratigraphic position relative to identified horizons. Where visual inspection indicated multiple emplacement units within a single layer, each unit was sampled individually to test for multiple compositional modes. For detailed sample preparation procedure, see Sarna-Wojcicki (1976) and Sarna-Wojcicki and others (1979,1984)” (Rieck et al., 1992).

Processing of Rock Magnetism

The entire core has been logged for magnetic susceptibility. Paleomagnetic studies by Roberts identified the Brunhes/Matuyama reversal at 65 m depth. The processing of paleomagnetism was detailed by Roberts et al (1996):

Samples were collected in plastic boxes (9.4 cm³) at 15 cm intervals, where possible, from depths of 2 m to 102 m. After measurement of the natural remanent magnetization, stepwise alternating field (AF) demagnetization was conducted with at least 5 steps (10, 20, 30, 40, 50 mT). Mass-specific magnetic susceptibility (χ) was measured for each

sample and the saturation isothermal remanent magnetization (M_{rs}) was estimated by applying a field of 1.2T to the samples. Hysteresis parameters were measured on bulk sediment subsamples (20-40 mg), up to fields of 1T. Temperature-dependence of magnetic susceptibility was measured on selected samples, to temperatures of 720°C. Magnetization acquired in a 0.2 T inducing field was measured during heating to 640° C. Low-temperature analyses were made on several samples by imparting a saturation remanence with an applied field of 2.5T at 5K, followed by measurements of M_{rs} at regular intervals up to room temperature. In some intervals, magnetic minerals were extracted from the sediment by pumping a sediment slurry at low velocity past a permanent magnet, using a technique similar to that of Petersen et al. [1986]. The extracts were subjected to thermomagnetic analysis and polished grain mounts were examined by reflected-light petrography (Roberts et al., p. 2860, 1996).

Lithology

A summary of the lithology of the Butte Valley Core is shown in Figure 8. Lacustrine facies are more common at depth in the core than near the surface, and core recovery was also somewhat better at depth. (Adam et al., 1995)

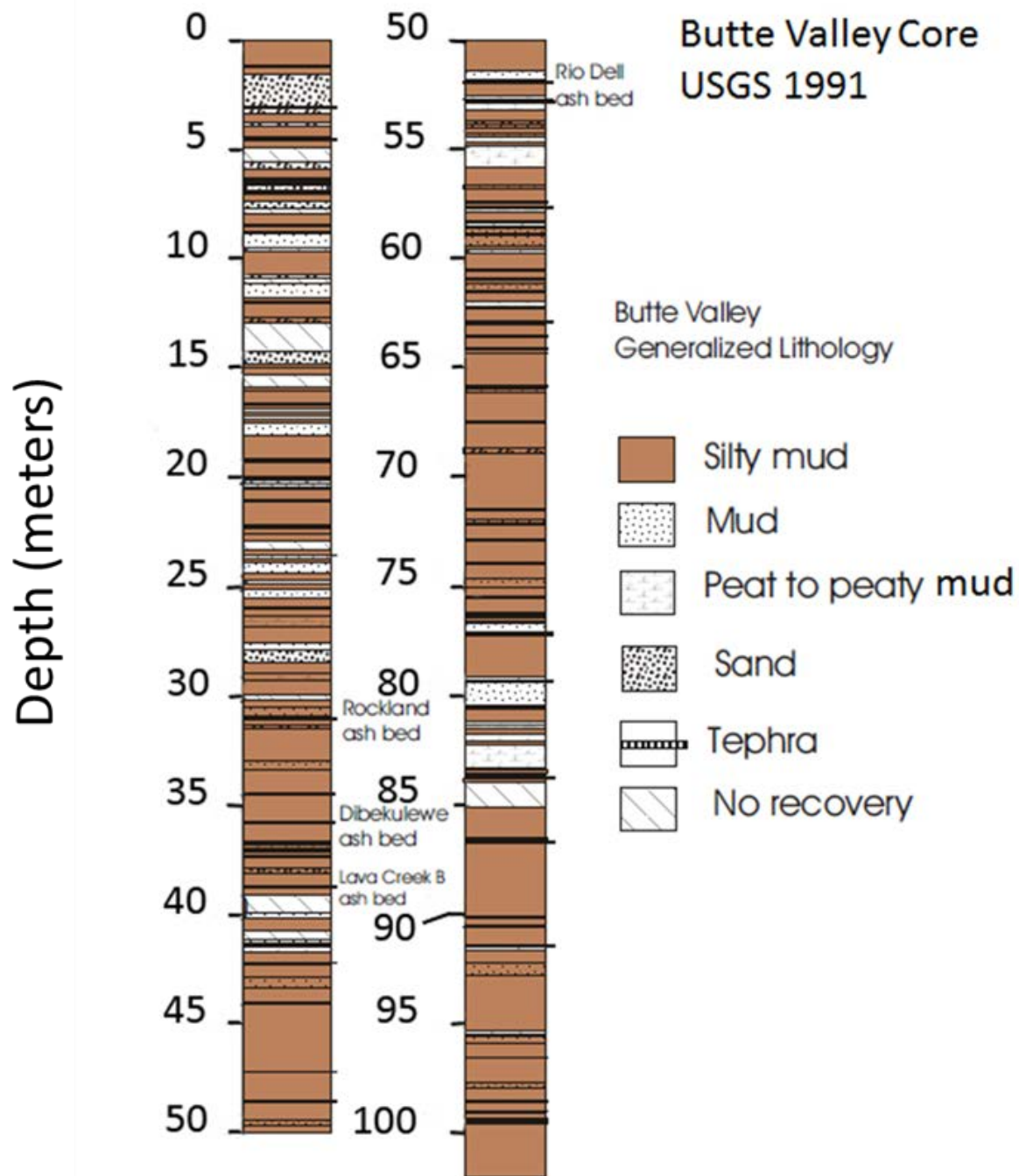


Figure Credit: Adam et al., USGS OFR, 1994

Figure 8: Butte Valley Core diagram

Lab Work

Research on Butte Valley Core 1 was conducted at Kent State University in the Paleolimnology lab and did not require a visit to the field site in Siskiyou County, California. The ostracode reference collection, ostracode literature collection, NANODE database, microscopes, microscope camera, and a multi-variate statistical package, MVSP (Kovach, 1985-2010), were used to determine ostracode taxonomy and interpret assemblages of the core. Lab supplies, such as micropaleontology slides (round cavity and 60 grid), aluminum holders, and glass slides were made available in the lab.

Species: Counting, Resources and Identification

Ostracode species in the samples were identified by reference to Fossil Nonmarine Ostracoda of the United States by Frederick M. Swain (1999); Ecology and Classification of North American Freshwater Invertebrates edited by James H. Thorp & Alan P. Covich, Chapter 19: Ostracoda by Alison J. Smith & L. Denis Delorme (2009); Pliocene-Climate History of the Western United States Derived from Lacustrine Ostracodes by Richard M. Forester (1991). To further aid in species and gender identification I referred to the ostracode type collection provided by Dr. Alison J. Smith in the Paleolimnology lab at Kent State University and the NANODE database. Using a binocular microscope I counted all valves on each sample slide, identified the species of each valve and, where possible, noted the gender of each. I recorded this information in a

Microsoft Excel 2007 spreadsheet, with separate columns for male and female of each species, where applicable.

Statistical Analysis

Principal Components Analysis

For this study, I used the Multi-Variate Statistical Package (MVSP) 3.2 (Kovach, 1985-2010) to run principal component analysis (PCA) on the ostracode data (species/gender) that I recorded from my species counts. In my Principal Components Analysis I looked for orthogonal relationships between variables so that in two-dimensions (using a Euclidean bi-plot) I could see which variable was of greatest importance. The important variables (species) showed up as larger numbers (both positive and negative) in the PCA. Each axis was given a title, based upon the known ecological preferences (temperature, salinity, etc.) of its representative ostracode species. I then assigned a title to that axis (salinity axis, freshwater axis) depending upon the environment preferred by the modern analog of the ostracode as found in Swain (1999) and NANODE (Forester et al., 2005) and www.kent.edu/NANODE. This ostracode species then became the proxy for that axis.

Principal components analysis (PCA) for the ostracode and pollen samples was conducted in R-mode, which examines the relationships among variables, as distinct from Q mode, which examines the relationships among samples (Davis, 2002). Count data for juvenile ostracodes were excluded, both because species identification of juveniles was impractical and overall percentage of juveniles compared to adults was negligible. Gender was determined by valve

morphology where practical, and gender data for each species (except *Tuberoocypris brighti*) was initially recorded separately. The additional variables in analysis of separate genders were later summed for all species except *Limnocythere sappensis*, where samples containing only females were labeled *Limnocythere inopinata*. This allowed for further minimization of noise in the results and a reduction of the dimensional space of the dataset. The axes produced were orthogonal and independent, and they explained the variance within the dataset. Most of the variance (78.6%) was explained by the first 3 axes.

Cluster Analysis

Cluster analysis describes a suite of techniques “designed to perform classification by assigning observations to groups so each group is more or less homogeneous and distinct from other groups” (Davis, p. 487, 2002). The use of cluster analysis in analyzing the Butte Valley data was in the form of constrained hierarchical clustering. Hierarchical clustering “joins the most similar observations, then successively connects the next most similar observations to these. First an $n \times n$ matrix of similarities between all pairs of observations is calculated. Those pairs having the highest similarities are then merged, and the matrix is recomputed. This is done by averaging the similarities that the combined observations have with other observations. The process iterates until the similarity matrix is reduced to 2×2 . The progression of levels of similarity at which observations merge is displayed as a dendrogram.” (Davis, p. 488, 2002)

The distance between samples was measured using Squared Chord Distance. Squared Chord Distance weighted the ostracode percentages, emphasizing the “signal” component of the differences between ostracode counts at the expense of the “noise” component (that portion of

the variance related to random effects). This eliminated a common problem with other cluster analysis methods that use equal-weight coefficients (like Canberra or standardized Euclidean distance), namely that they may give equal weight to the small-valued, potentially noisy, ostracode counts (Overpeck, 1985). Constrained cluster analysis was performed, in which the clustering process was constrained by stratigraphic order. The Squared Chord distance measure, combined with farthest neighbor clustering, produced a dendrogram with no reversals that showed the underlying structure in the data. . “Reversals in a dendrogram can occur where the distance (and therefore the branching level) between two objects is greater than that between the cluster of those two and the next object in the hierarchy. In sequences where there is a lot of variability, this can cause the dendrogram to be almost uninterpretable.” (MVSP ver 3.22, 1985-2013) The structure in the resulting dendrogram was consistent with both the PCA results as well as my own faunal observations from the core.

The squared chord distance dissimilarity coefficient (SCD) is represented by the following formula:

$$SCD_{ij} = \sum_k (p_{ik}^{1/2} - p_{jk}^{1/2})^2$$

The farthest neighbor clustering method measures the distance between the two farthest points within each stepwise clustering step (Kovach, 1985-2010) and generally provides the clearest down-core dendrogram.

RESULTS

Background

Fourteen species of ostracode were identified from 91 slides containing ostracode valves. These slides were processed from a total of 124 samples taken from the Butte Valley core. The valves were identified by species and, where possible, differentiated by gender and whether adult or juvenile. The identified ostracode species were recognized as inhabitants of freshwater, lacustrine environments (Swain, 1999 and NANODE (www.kent.edu/NANODE)) with thirteen of the identified species extant and one species, (*Tuberocypris brighti* , Frederick M. Swain, 1986), extinct.

Abundance and zonation

After completion of the sorting and counting of the 91 slides, the abundance for each species (in valves/gram) was plotted against core depth of the sample (in meters). The resulting graph of Relative Abundance of Ostracodes (valves/g) vs. depth (m) (Figure 9) provided a starting point for interpreting the data from the core. Initial impressions were that:

1. No species maintained high abundance for the entire core length.

2. Several species had period(s) of high abundance (*Cytherissa lacustris*, *Tuberocypris brighti*, *Limnocythere sappaensis*, *Candona cf. sigmoides*, *Candona caudata*, and *Limnocythere ceriotuberosa*)
3. Some species had no period(s) of high abundance (*Limnocythere sp. A & B*, *Candona cf. ohioensis*)
4. Species appearances in the core were generally confined to specific core depths.
5. There was an area of low-valve abundance in the core (~68m to ~39m).

Based upon these initial impressions the core was divided into three zones. Zone-1 included samples taken from the core-top down to a depth of approximately 40m and contained abundant valves of *Limnocythere ceriotuberosa*, *Candona sp.* and *Limnocythere platyforma*. Zone-2 included the mid-core and included samples taken from depths of approximately 40m to approximately 85m. Zone-2 contained abundant valves of *Limnocythere sappaensis*, *Candona cf. sigmoides*, *Candona caudata* and *Limnocythere cf. bradburyi*. Zone-3 was located in the bottom-most portion of the core and included samples taken from depths of approximately 85m to 101m. Zone-3 contained abundant valves of *Cytherissa lacustris*, *Tuberocypris brighti*, *Cypria sp.*, *Candona caudata* and *Candona cf. sigmoides*. The relative abundance of ostracodes with depth in Butte Valley Core 1 can be seen in Figure 9.

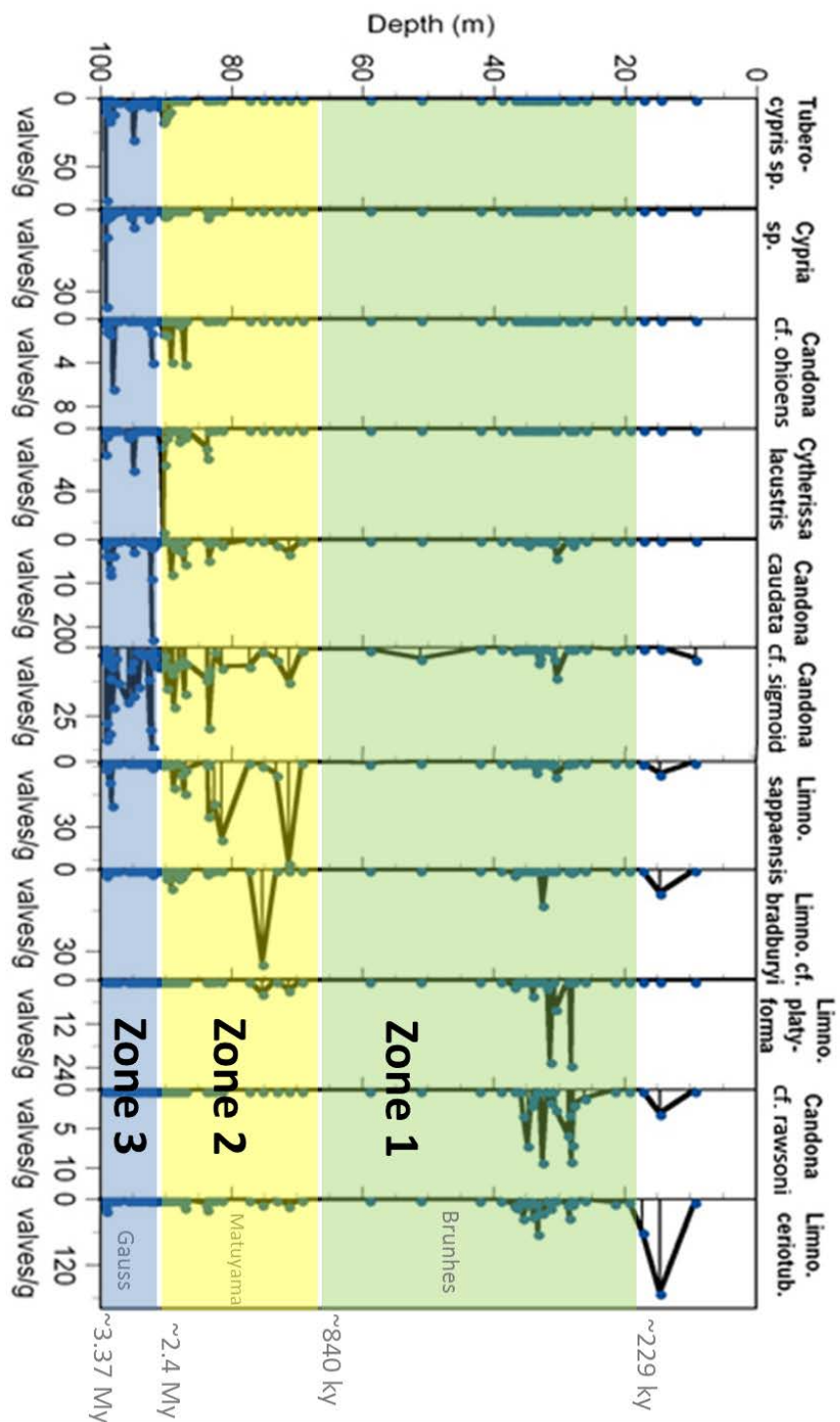


Figure 9: Relative Abundance of Ostracodes (*valves/g*) vs. depth(*m*)

Cluster Analysis

Statistical analysis of the data was performed using the Multivariate Statistical Package (MVSP) version 3.22 (Kovach, 1985-2013). Environmental reconstructions of each assemblage could then be described based on established environmental preferences of modern species and estimated environmental preferences of extinct species. Species environmental preferences are discussed in the Zone Ecology section.

Constrained cluster analysis using the Multivariate Statistical Package (MVSP) generated a dendrogram with three distinct assemblages of ostracodes. I used the ‘farthest neighbor’ clustering method and ‘Squared Chord’ distance measure as this combination provided the clearest view of the data. I chose farthest-neighbor clustering with squared chord distance after trying the similarity measure ‘Spearman coefficient’, and distance measures that included ‘squared Euclidean’, ‘standardized Euclidean’ ‘Chi-squared’ and ‘Canberra’. I double-checked the resulting distance measures against core ‘depth’ in Excel. In this way I was able to see graphically which distance measures discriminated better than others. In the end I found that both Squared Chord distance metric and Chi-square distance metric provided good discrimination. I chose Squared Chord because the dendrogram output was clearer and thus easier to read. The Squared Chord distance measure also seemed to be most consistent with what I saw in my examination of the core. The resulting dendrogram clusters defined the three major zones in the core (Figure 10). A brief description of each zone follows.

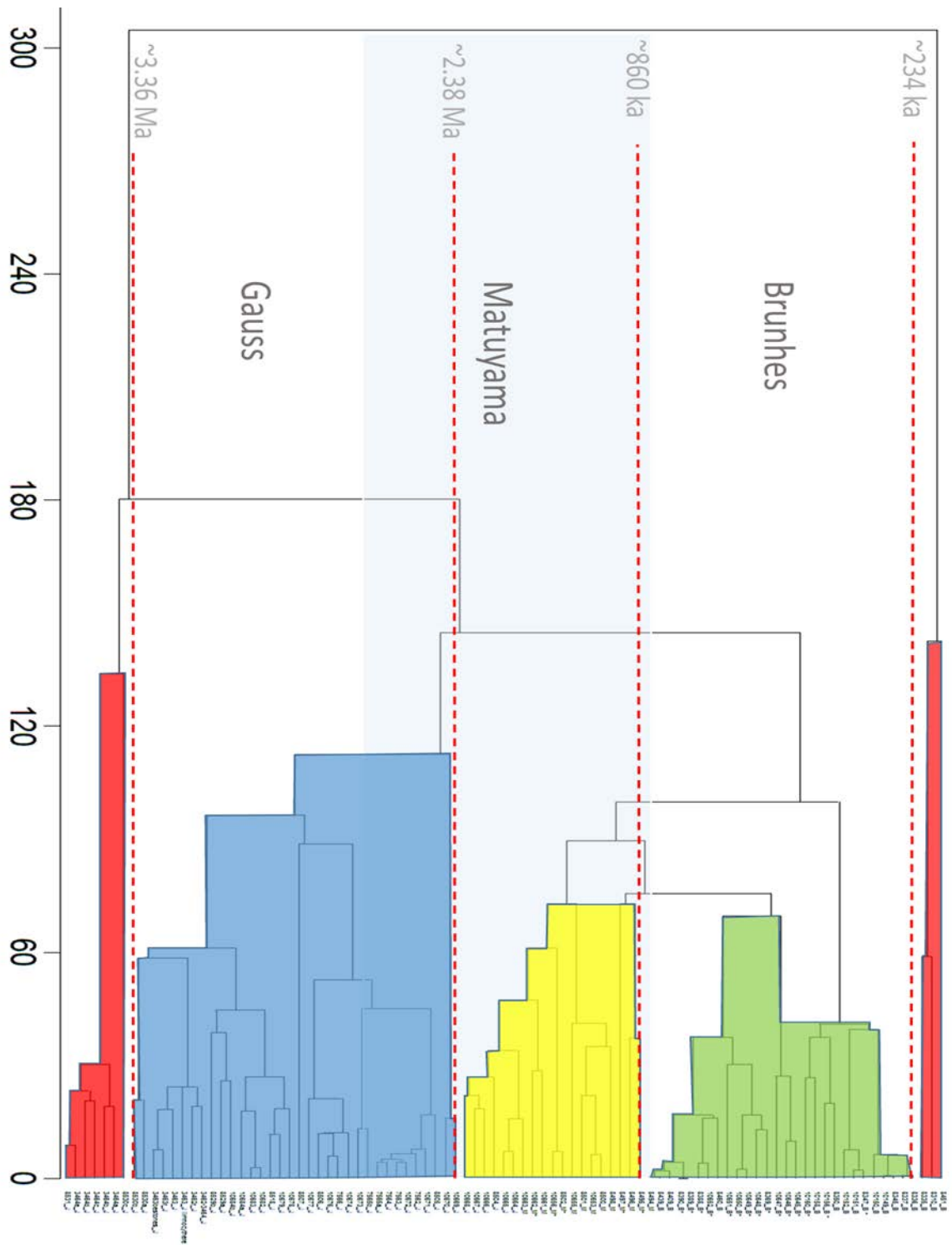


Figure 10: Dendrogram from Cluster Analysis (*Farthest neighbor, constrained*)

Zone Ecology

Zone-1 (Figure 10, green cluster) represents samples from the interval 19.413 m to 69.323 m, which magnetostratigraphy has corresponded to a time slab from ~229 ka to ~840 ka. The ostracode assemblage comprising this cluster is indicative of a saline, bicarbonate-enriched, calcium-depleted lacustrine system with periodic freshening episodes.

Zone-2 (Figure 10, yellow cluster) begins at 71.33 meters and persists to a depth of 89.963 m, which magnetostratigraphy has corresponded to a time slab from ~850 ka to ~2.35 Ma. The major ostracode species in this section (*L. sappaensis*, *Candona* cf. *C. sigmoides* and *C. caudata*) indicate a lake in transition due to the establishment of a seasonal climate in the region.

Zone-3 (Figure 10, blue cluster) represents a core interval from 90.343 m to 99.153 m, which magnetostratigraphy has corresponded to a time slab from ~2.372 Ma to ~3.372 Ma and represents a permanent, cold, fresh water lacustrine system as indicated by the presence of the syngamic form of the ostracode species *Cytherissa lacustris*.

Red mini-clusters at Core-top and Core-bottom (Figure 10, red clusters)

The cluster analysis dendrogram also generated two mini-clusters, one at the top of the constrained analysis and one at the bottom. The top mini-cluster, consisted of three sample slides representing an interval from 9.333 meters to 17.343 meters (~112 - 208 ky). These three slides contain a dramatic increase in the numbers of *Limnocythere ceriotuberosa* valves and at a core depth (14.6m) at which ostracode valves were recovered from a layer of sandy strata, indicating a near shore, littoral environment at the time of deposition. This suggests optimal, low water conditions for *Limnocythere ceriotuberosa* allowing it to crowd out other species. One ubiquitous ostracode species like this usually points to a salinity signal. (Smith, 1993). The

mini-cluster at the bottom of the constrained dendrogram consists of two sample slides at the core bottom that contained a very large increase in valves of the species *Tuberocypris brighti*. This “sudden” profusion of *Tuberocypris brighti* valves suggests a “telescoping” or compression of several layers of core bottom strata which obliterated an accurate ostracode valve count chronology for the bottom 2m of the core (Curry et al., 2012). Despite this, the large number of valves show that conditions in the Pliocene were quite productive for *Tuberocypris brighti*, and by association for *Cytherissa lacustris* as well.

The overall hydrochemical trend for the Butte Valley paleolake through time can be traced in Figure 11.

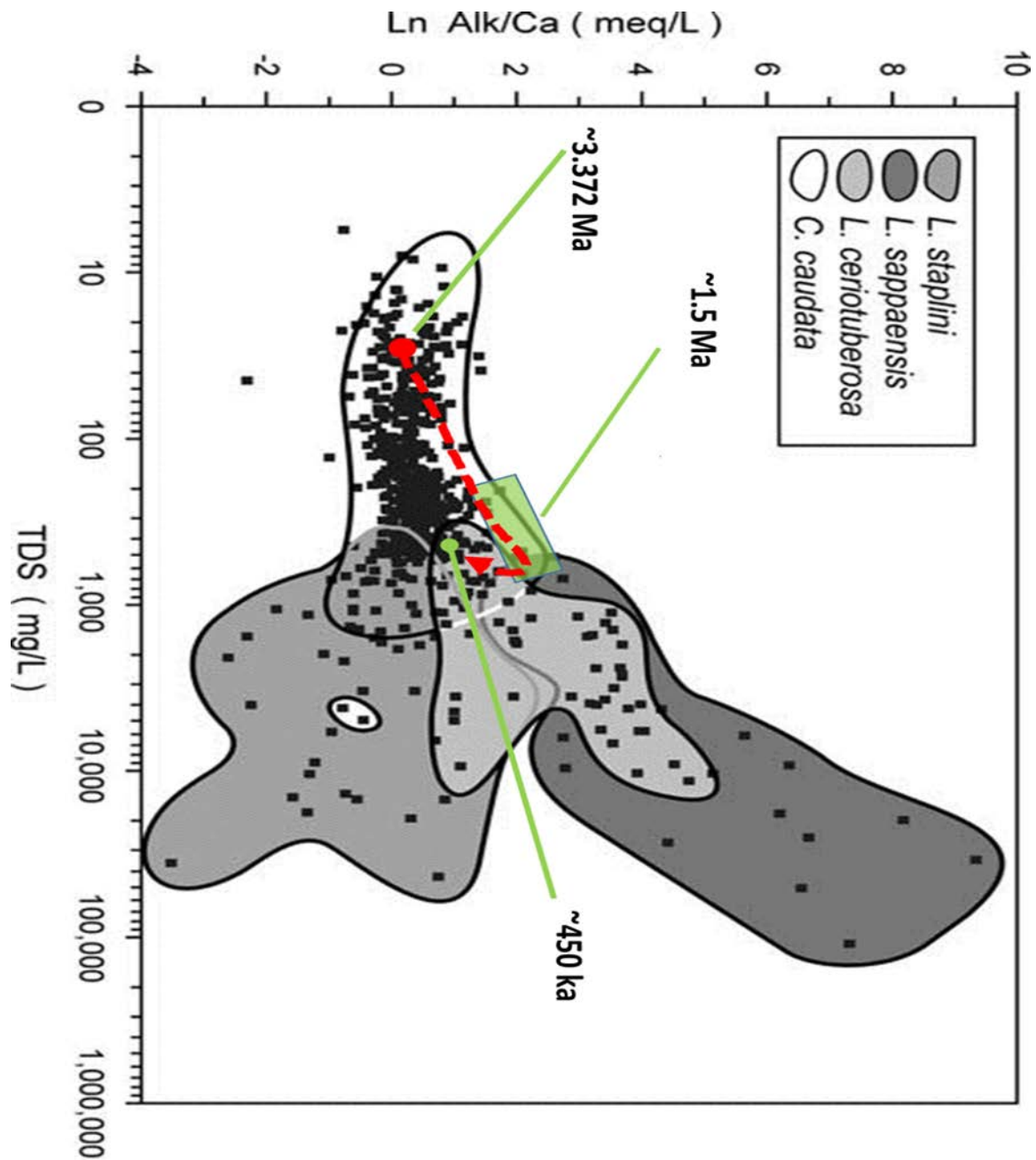


Figure 11

Lacustrine hydrochemical evolution through time in Butte Valley Generalized response of common continental ostracode species to the solute evolutionary parameter, the alkalinity/calcium ratio (alk/Ca), and total dissolved solids (TDS). Sample sites are from NANODE (www.kent.edu/NANODE) represented by data points include springs, wetlands, and lakes throughout the United States and, to a lesser extent, Mexico. Image modified from Forester et al., 2005, figure 3, p. 1382

The dotted arrow in the solute diagram tracks the ratio of HCO_3 to Ca, and the total dissolved solids (TDS) in the lake through time. In Figure 11, the presence of *Candona caudata* in the *Limnocythere sappaensis* zone anchors the general rise of salinity to a solute path occupied by both species. The solute path may have been higher at times (around 10,000 mg/l) because the drilling process may have compressed some assemblages together in the core.

***Limnocythere ceriotuberosa* and *Limnocythere platyforma* Assemblage (Zone 1)**

The *Limnocythere ceriotuberosa* and *Limnocythere platyforma* assemblage encompasses the top portion, or Zone 1, of the core and represents samples from a depth of 69.323-19.413 meters (~233 ka to ~835 ka). *Limnocythere ceriotuberosa* was the dominant species in this section of core (as measured in valves/gram). *Limnocythere ceriotuberosa* is an indicator species for “fresh and saline lakes exhibiting seasonal variability in temperature and chemistry common to semi-arid and arid regions”. (Forester, p. 140, 1991) This section also saw several temporally isolated appearances of the species *Limnocythere platyforma*. These increases in abundance of *L. platyforma* indicate “freshening episodes” (Smith, p. 96, 1996), relatively short periods of time in which the lacustrine system was flooded with large amounts of fresh water (possibly via stream input), after which *Limnocythere ceriotuberosa* resumed dominance. This section of the core also contains a region (68m to 39m) containing very few valves. This period of low valve abundance has been shown by magnetostratigraphy to correspond to a period from ~820 ka to ~470 ka.

***Limnocythere sappaensis*, *Candona caudata* and *Candona cf. sigmoides* Assemblage (Zone 2)**

This assemblage represents ostracodes found within Zone 2, at core depths from 90.343-71.33 meters (~2400 ky to 850 ky). The most successful ostracode species during this period (as measured in valves/gram) were *Limnocythere sappaensis*, *Candona caudata* and *Candona cf. sigmoides*. The absence of permanent, freshwater indicator species (*Cytherissa lacustris* and *Tuberocypris brighti*) and the presence of *Limnocythere sappaensis* indicates that we have transitioned toward a more seasonal environment as we have moved up the core (and temporally into the Pleistocene). This assemblage represents a seasonal, more unpredictable climate with a changeable lacustrine system alternating between fresh and mildly saline.

***Cytherissa lacustris* and *Tuberocypris brighti* Assemblage (Zone 3)**

The *Cytherissa lacustris* and *Tuberocypris brighti* assemblage encompasses the basal portion of USGS 94-593, designated Zone 3. Zone 3 represents core depths ranging from the core bottom at 101.493 m up to a depth of 90.343 m. Magnetostratigraphy (Roberts et al., 1996) has shown that these core depths correspond to a time span from circa 3.372 Ma to circa 2.4 Ma. Ten ostracode species in total were identified in this assemblage. The most productive species (as measured in valves/g) were *Cytherissa lacustris*, *Tuberocypris brighti* (extinct), *Cypria* sp., and *Candona caudata*. All were present throughout the time period represented by the assemblage. Both *Cytherissa lacustris* and *Tuberocypris brighti* are exotic species, meaning that they have “ornate carapace morphology”. (Forester, p. 134, 1991) The presence of the exotic species *Cytherissa lacustris* and *Tuberocypris brighti* (extinct) implies “a geologically stable ($10^5 - 10^6$

yr) lake” (Forester, p. 134, 1991). *Cytherissa lacustris* (and *Tuberocypris brighti*) indicate that this stable, freshwater environment was the dominant paleolacustrine environment in Butte Valley in the Pliocene. Modern *Cytherissa lacustris* is known to live in “dilute, cold, stenotopic, boreal forest lakes and is typically large in size and more ornate than other non-marine ostracodes” (Forester, 1991, p.141). This assemblage represents a stable, cold, wet, mid-to-late Pliocene environment with little seasonality.

In addition to ostracode valve data, the Butte Valley core yielded 86 pollen samples that showed variations in the percentages of pollen types from the mid-Pliocene through the Pleistocene (Adam et al., 1995). Though I did not have access to the original pollen data tables, I was able to reconstruct the data using a preliminary pollen diagram from the open file report (USGS Open File 95-34, page 16) (Figure 12).

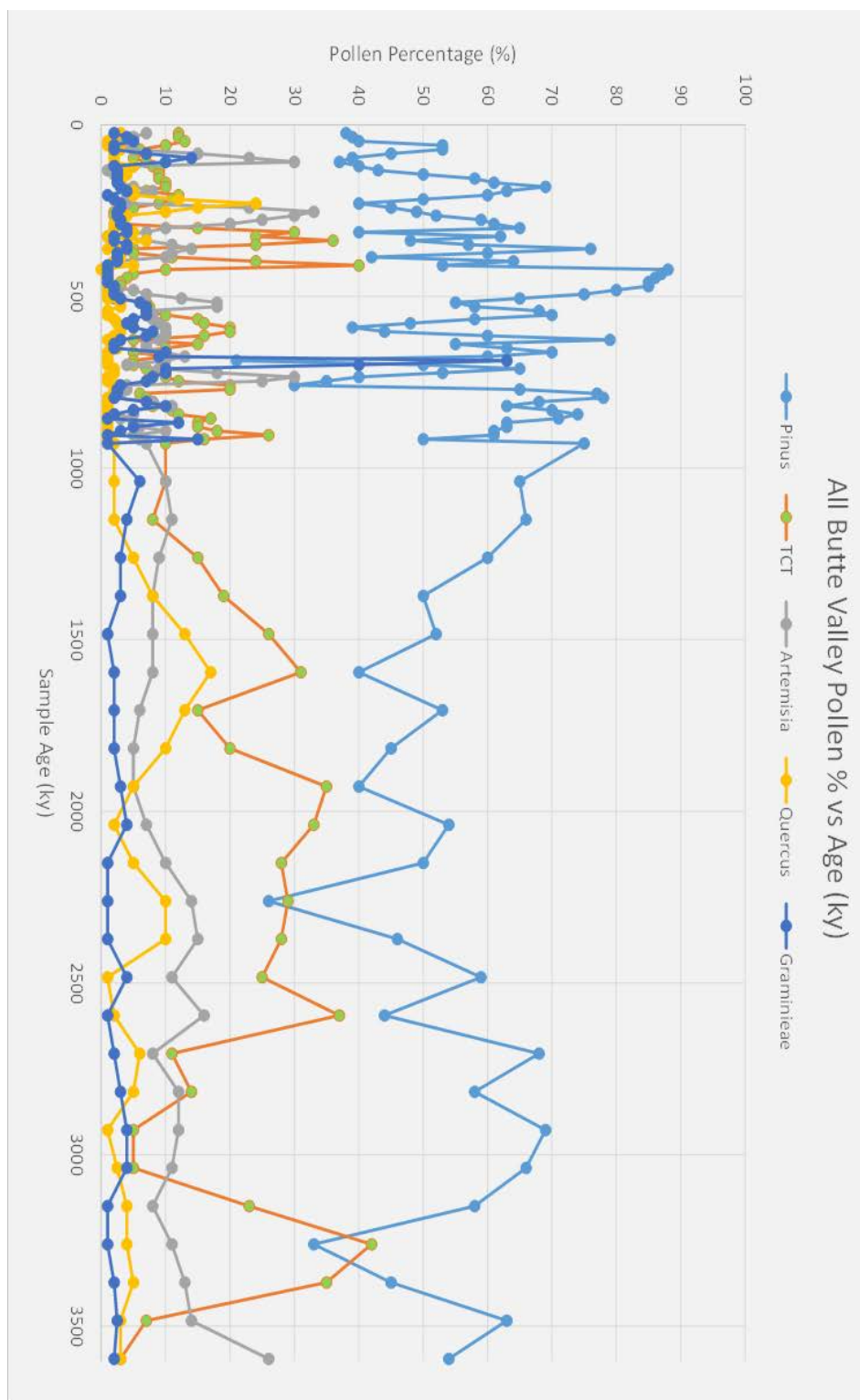


Figure 12: Butte Valley Pollen % vs. age

While counting and identifying ostracode valves and reviewing the pollen data, several trends were noticed. The raw data showed that, in some instances, the major variations in pollen percentages coincided with trends in ostracode productivity in the Butte Valley data. It is important to note that *Pinus* pollen is by far the dominant pollen type throughout the core record. I have interpreted this *Pinus* dominance to largely reflect “long distance transport of this prolific pollen producer” (Thompson & Fleming, p. 29, 1996).

Table 2: Butte Valley Species Autecology

Genus	Species	Author	Year	Citation	Ecology
<i>Limnocythere</i>	<i>platyforma</i>	Delorme	1971	Smith, 1996; Balch et al., 2005	Indicates water freshening, lake receiving more surface runoff, water was fresher and seasonality was enhanced (cooler winters). Freshwater ecophenotype of <i>Limnocythere ceriotuberosa</i>
<i>Limnocythere</i>	<i>ceriotuberosa</i>	Delorme	1967	(Forester, 1983, 1985, 1987; Smith, 1993)	Benthic, euryhaline species that inhabited saline water in which calcium was depleted relative to bicarbonate. Temperature control on life cycle, <i>unable to reproduce and thrive in regions that DO NOT HAVE <u>strong seasonal</u> temperature fluctuations.</i>
<i>Limnocythere</i>	<i>sappaensis</i>	Staplin	1963	Smith & Delorme, 2009; Forester, 1991, 2005	Bicarbonate-rich, warm, saline lake. <i>L. sappaensis</i> becomes less common as TDS and composition approaches fresh water. Eurythermic . Typically lives in lakes that receive a seasonal pulse of surface water or ground water followed by a period of evaporation.
<i>Cytherissa</i>	<i>lacustris</i>	G.O. Sars	1863	Delorme, 1991	Dilute, cold, stenotopic boreal forest lakes.
<i>Candona</i>	<i>cf. sigmoides</i>	Staplin	1963	Smith, 2011	Springs, fresh water
<i>Candona</i>	<i>ohioensis</i>	Turner	1894	Lister, 1975	Permanent and temporary ponds, neararctic. Fresh but variable environment.
<i>Fabaeformis-candona</i>	<i>caudata</i>	Kaufmann	1900	Smith & Delorme, 2009; Balch et al., 2004	Benthic, freshwater indicator, narrow salinity tolerances, large lakes with bottom currents.
<i>Candona</i>	<i>rawsoni</i>	Tressler	1957	Lister, 1975; Smith, 1993	Ponds and lakes, tolerant of moderately-high amounts of dissolved minerals, neararctic. Eurytopic (<i>found in both bicarbonate-enriched and bicarbonate-depleted sulfate dominated waters</i>).
<i>Tuberoocypris</i>	<i>brighti</i>	Swain	1986	Swain, 1999	Extinct; ecological requirements likely similar to <i>Cytherissa lacustris</i> since the two species were found together in the core.
<i>Cypria</i>	<i>species</i>	Jurine	1820	Curry, 1999; Smith & Delorme, 2009	Very fresh water that is evaporatively unevolved. Can survive anoxia for extended periods.
<i>Limnocythere</i>	<i>bradburyi</i>	Forester	1985	Smith & Delorme, 2009; Forester, 1983, 1985, 1987; Smith, 1993	Wetlands, lakes, warm indicator species. Benthic, euryhaline species that inhabited saline water in which calcium was depleted relative to bicarbonate.
<i>Limnocythere</i>	<i>species A</i>	Swain	1986		
<i>Limnocythere</i>	<i>species B</i>	Swain	1986		

Table 3: Table to accompany Figure 13.

A	<i>Tuberocypris brighti</i> , female, right valve, reflected light. BV Core 99.153 m depth.
B	<i>Limnocythere platyforma</i> , female, right valve, transmitted light. BV Core 1, #10158.
C	<i>Limnocythere ceriotuberosa</i> female (above), male (below), left valve, reflected light. BV Core 1, #8310.
D	<i>Limnocythere bradburyi</i> female, right valve, transmitted light. BV Core 1, #10645.
E	<i>Limnocythere bradburyi</i> male, right valve, transmitted light. BV Core 1, #10645.
F	<i>Cytherissa lacustris</i> , female (left), male (right), dorsal view, reflected light. BV Core 1, #3464.
G	<i>Cytherissa lacustris</i> , female (above), male (below), right valve, reflected light. BV Core 1, #3464.

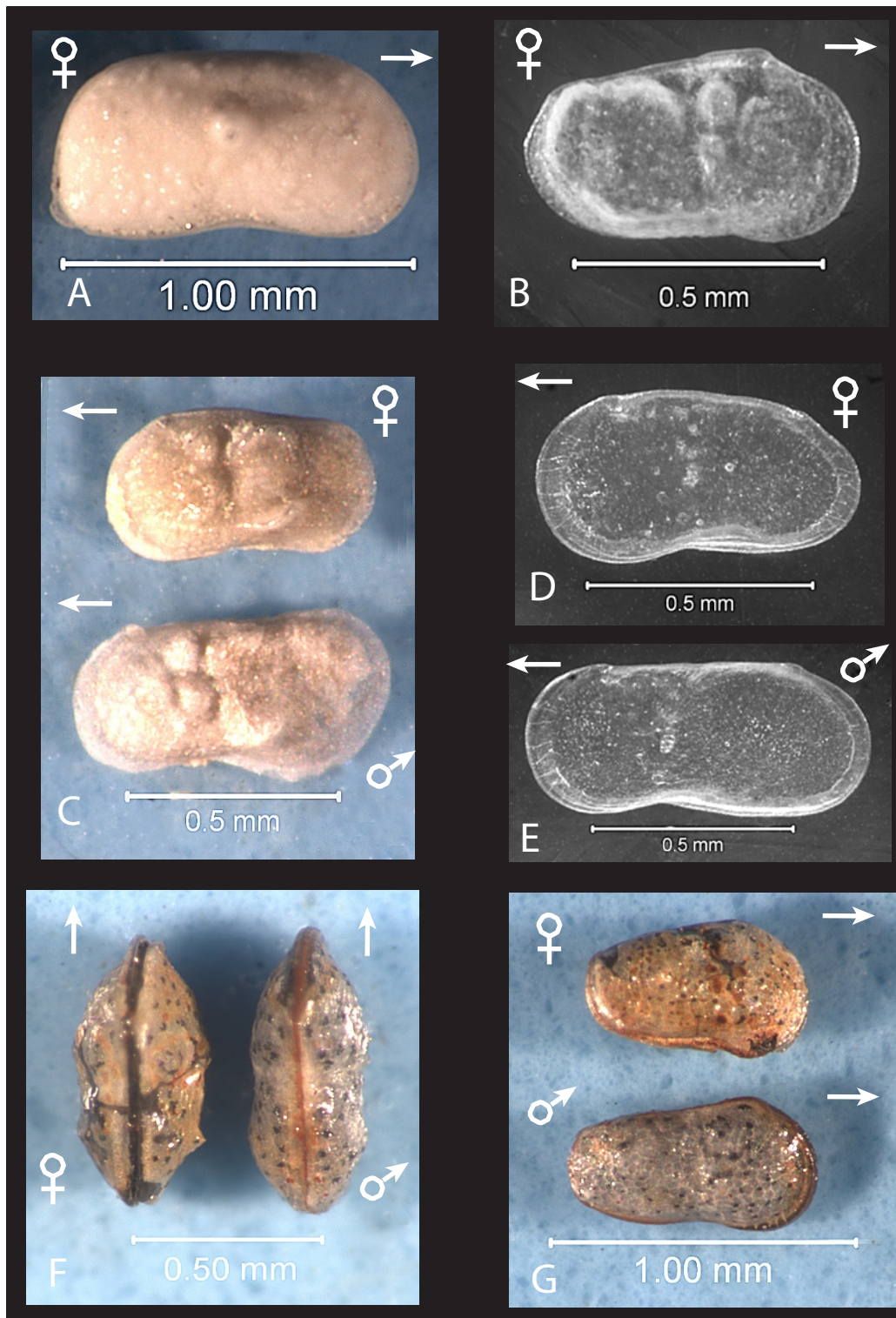


Figure 13: Common ostracode species found in USGS Butte Valley Core 1

Multivariate Statistics (PCA)

The first three axes of the PCA accounted for 78.59% of the total variance in the dataset (Table 4). Axis 1 (Saline, Shallow, Arid Axis) is dominated by *Limnocythere ceriotuberosa* and accounts for 54.32% of the variance in the dataset. Axis 2 (Pliocene, Stable, Freshwater Axis) is dominated by *Tuberocypris brighti*, *Cytherissa lacustris*, *Cypria sp.* and *Candona caudata*, which accounts for 13.76% of the variance. Axis 3 (Enhanced Seasonality Axis) is dominated by *Candona cf. sigmoides* and *Limnocythere sappensis*, which accounts for 10.51% of the variance. This means that among all of the specimens counted, *Limnocythere ceriotuberosa* is unlikely to be found with *Tuberocypris brighti*, *Cytherissa lacustris*, *Cypria sp.* and *Candona caudata*. In turn, both of these assemblages are unlikely to be found with *Limnocythere sappensis*. The independence of these three assemblages relative to each other in PCA is consistent with their ecological significance, as Axis 1 is indicative of fresh to saline water, Axis 2 is indicative of geologically stable (10^5 to 10^6 yrs) fresh water and Axis 3 is indicative of a changeable environment, trending from fresh to saline.

Butte Valley pollen data (taken from the same core) was transcribed from USGS Open File 95-34 (Adams et al., year) in order to compare trends in the raw ostracode data and to use Principal Components Analysis (PCA) to further refine relationships between flora and fauna (Table 5). Since the ostracode data and the pollen data are both counts of number of individuals per volume, the multivariate statistics software was able to provide meaningful analysis for both in the same PCA run.

Table 4

Principal Components Analysis (PCA) without pollen

14 variables X 91 cases

Tolerance of eigenanalysis set at 1E-007

Eigenvalues

	Axis 1	Axis 2	Axis 3
Eigenvalues	406.607	103.022	78.673
Percentage	54.315	13.762	10.509
Cum. Percentage	54.315	68.077	78.587

PCA variable loadings

	Axis 1	Axis 2	Axis 3
L. platyforma	-0.001	-0.096	-0.125
L. cerio	0.995	0.073	0.032
L. sappa	0.012	-0.037	0.497
C. lacust	-0.028	0.497	-0.139
C. cf. sigmoides	-0.055	0.233	0.824
C. ohioensis	-0.003	0.013	0.033
C. caudata	-0.015	0.006	0.116
C. rawsoni	0.023	0.053	-0.023
Tuberocypris	-0.053	0.774	-0.131
Cypria sp.	-0.015	0.275	-0.069
L.aff.bradburyi	0.045	-0.023	-0.034
Limno A	-0.003	0.066	0.000
Limno B	-0.007	0.012	0.005

Table 5

Principal Components Analysis (with 5 pollen species added)

Analyzing 20 variables X 91 cases

Tolerance of eigenanalysis set at 1E-007

Eigenvalues

	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	426.151	275.070	104.139	93.045
Percentage	35.457	22.887	8.665	7.742
Cum. %	35.457	58.344	67.008	74.750

PCA variable loadings

	Axis 1	Axis 2	Axis 3	Axis 4
L. platyforma	0.006	0.034	-0.097	0.006
L. cerio	0.935	-0.328	0.085	0.068
L. sappa	0.005	0.089	-0.045	0.076
C. lacust	-0.027	0.003	0.471	0.117
C. cf. sigmoides	-0.072	-0.073	0.253	-0.010
C. ohioensis	-0.007	-0.015	0.013	0.005
C. caudata	-0.018	-0.008	0.012	-0.013
C. rawsoni	0.022	-0.002	0.056	-0.025
Tubero	-0.051	0.021	0.766	0.057
Cypria	-0.011	0.025	0.277	-0.013
L.aff.br	0.042	-0.019	-0.029	0.070
Limno A	0.000	0.013	0.065	0.007
Limno B	-0.002	0.023	0.014	-0.007
Pinus	0.303	0.768	-0.038	0.502
TCT	-0.130	-0.533	-0.093	0.765
Artemisia	-0.080	-0.004	0.089	-0.148
Quercus	-0.013	-0.035	0.018	-0.047
Gramineae	-0.005	-0.010	-0.076	-0.325

PCA Variable loadings: *Ostracodes*

Figure 14: Axis 1 vs Axis 2: In these PCA variable loadings the Pliocene populations of *Cytherissa lacustris*, *TuberoCypris brighti*, *Candona cf. sigmoides* and *Cypria* sp. show up as strongly orthogonal to, and independent of, *Limnocythere ceriotuberosa*.

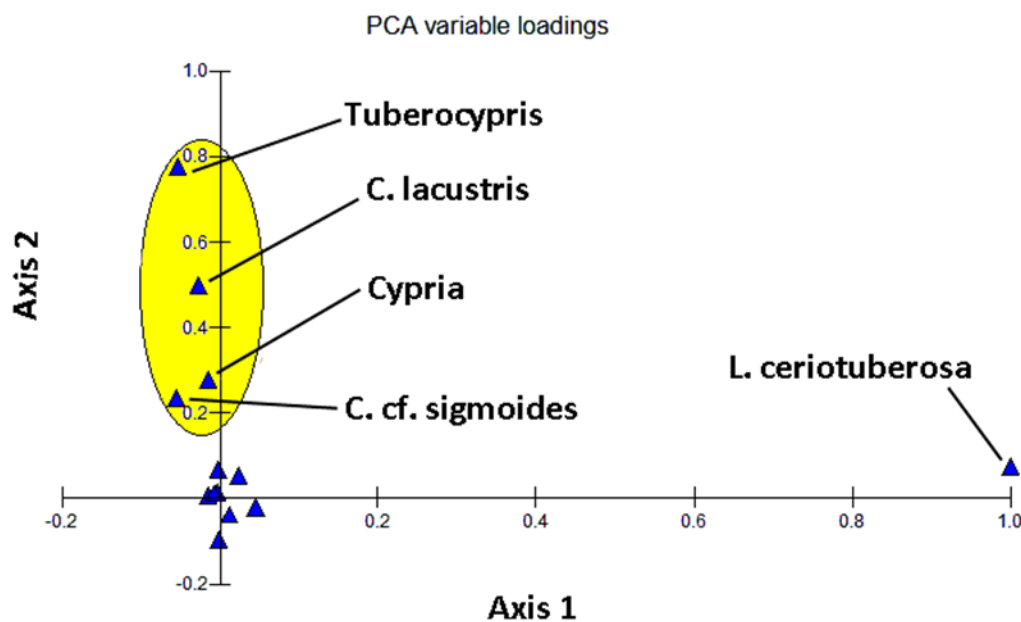


Figure 14: PCA Variable Loadings – Axis 1 vs. Axis 2

This orthogonality represents a clear climatic demarcation between the two assemblages. Axis-1 represents a drier and more seasonal climate with generally more saline lacustrine conditions and low faunal diversity than in previous time periods. Axis 1 shows that in the late-Pleistocene, *Limnocythere ceriotuberosa* was the dominant species. Axis-2 is independent of and orthogonal

to Axis-1. Axis-2 represents a geologically stable (10^5 to 10^6 yrs), cold, wet Pliocene climate in which large lakes were established and maintained and in which the syngamic form of *Cytherissa lacustris* became established in response to conditions similar to those found in present day Lake Baikal.

Figure 15: Axis 1 vs Axis 3: The PCA variable loadings for Axis-1 vs. Axis-3 graphically indicate differences between the preferences of *Limnocythere ceriotuberosa* and *Limnocythere sappensis*. The solute diagram (Figure 16) shows that *Limnocythere sappensis* tolerates bicarbonate-enriched conditions and a high level of total dissolved solids (TDS) and becomes less common as TDS and composition approach fresh water.

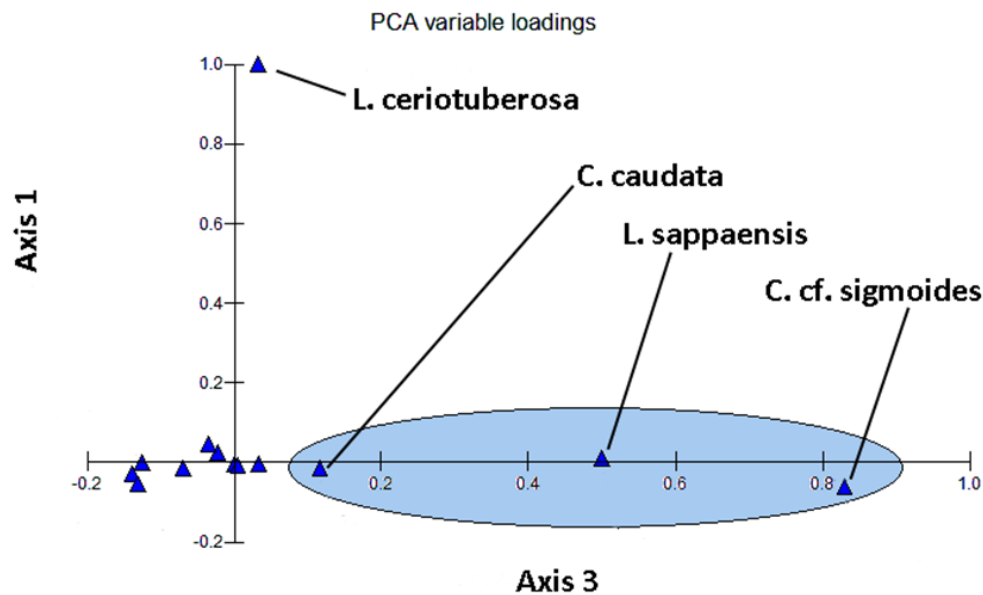


Figure 15: Axis 1 vs. Axis 3

The fact that *L. sappaensis* is found in this assemblage including strong populations of *Candona cf. sigmoides* and *Candona caudata* indicates that the paleolake was still a large, freshwater body but was subject to seasonal change and evaporation.

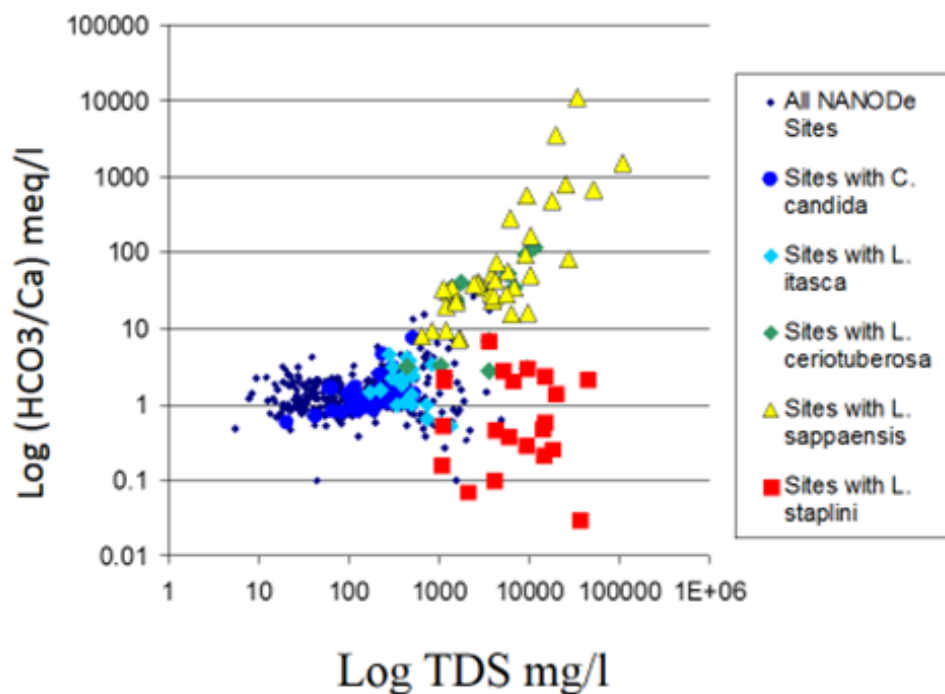


Figure 16

5-Species Distribution in Solute Space: The x axis is total dissolved solids (TDS in mg/L), and the y axis is the ratio of Bicarbonate and Carbonate to Calcium in meq/L, both axes are shown on a log scale. Image and text modified from *North American Non-Marine Ostracode Database Project (NANODE)* www.kent.edu/NANODE

Limnocythere sappaensis and *Candona cf. sigmoides* indicate a trend toward a more seasonal climate in the region in the Pleistocene. “Stratigraphic horizons that are dominated by ostracodes that tolerate a wide range of environmental conditions may imply shallow water; such

environments (relative to deep-water environments) are prone to more changeable conditions such as diurnal thermal variability, and to the development of wind-driven currents” (Curry, p. 62, 1999).

Figure 17: Axis 2 vs Axis 3: The PCA variable loadings show Axis-3 (Enhanced Seasonality), represented by *Limnocythere sappaensis*, *Candona caudata* and *Candona cf. sigmoides* as orthogonal to, and independent of, Axis-2 (Pliocene freshwater axis).

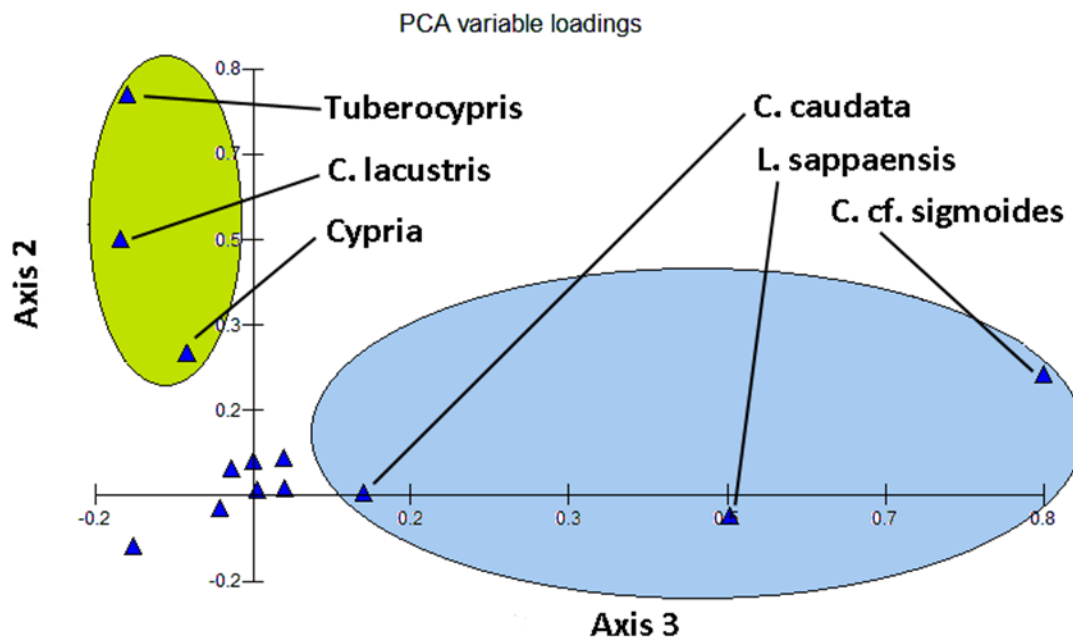


Figure 17: Axis 3 vs. Axis 2

This represents a clear change in lacustrine conditions between the time periods represented by the two axes. However, strong productivity of *Candona cf. sigmoides* indicates that the paleolake was still a large, freshwater body with a diversity of ostracodes supported. This

Pleistocene fauna supports the model that the major difference in lacustrine conditions in the early-to-mid Pleistocene in Butte Valley was due to enhanced seasonality.

PCA Variable loadings: Ostracodes and Pollen

Figure 18: Axis-1 vs Axis-2: *Pinus* appears to have thrived, and been more singularly dominant, during periods when the regional climate was cooler and wetter overall (Thompson, 1996). During warmer, dryer periods (periods favorable to productivity for *Limnocythere ceriotuberosa*) the pollen record indicates lower levels of *Pinus*.

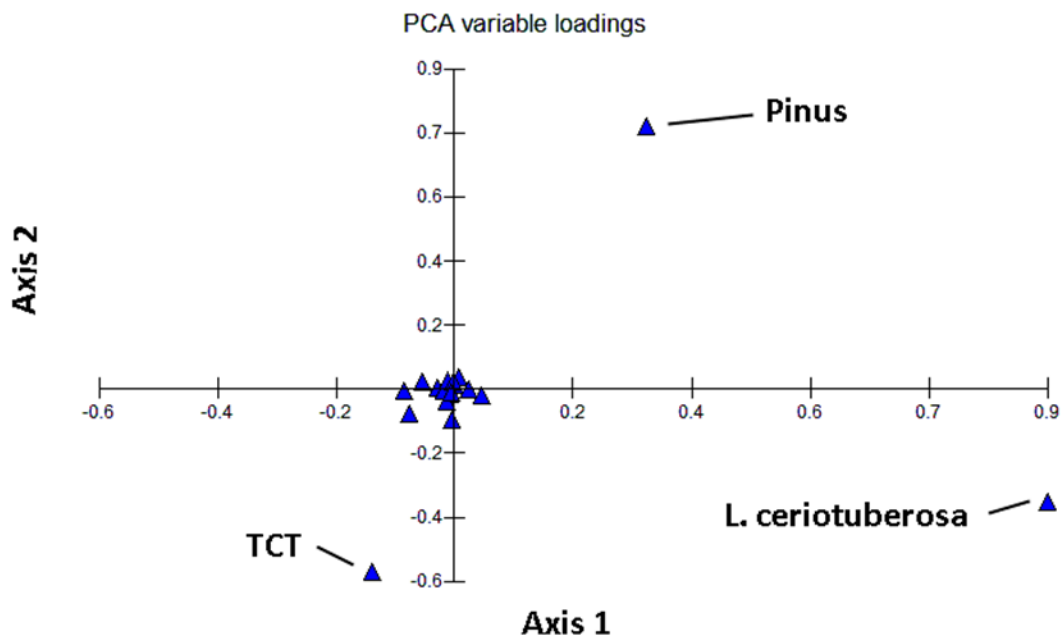


Figure 18: PCA Variable loadings - Ostracodes and pollen; Axis 1 vs. Axis 2

The PCA variable loadings support this, showing *Limnocythere ceriotuberosa* strongly independent and orthogonal to *Pinus* and also showing that the grasses (*Gramineae*) are compatible with *Limnocythere ceriotuberosa* on Axis-1, indicative of their similar climatic niche.

Figure 19: Axis 3 vs Axis 2: The PCA variable loadings for Axis-3 vs. Axis-2 (Figure 19) show the ostracodes *Cytherissa lacustris* and *Tuberoocypris brighti* orthogonal to *Pinus* pollen. This orthogonality indicates that the ostracode populations and the pine populations were mutually exclusive. This seems unlikely.

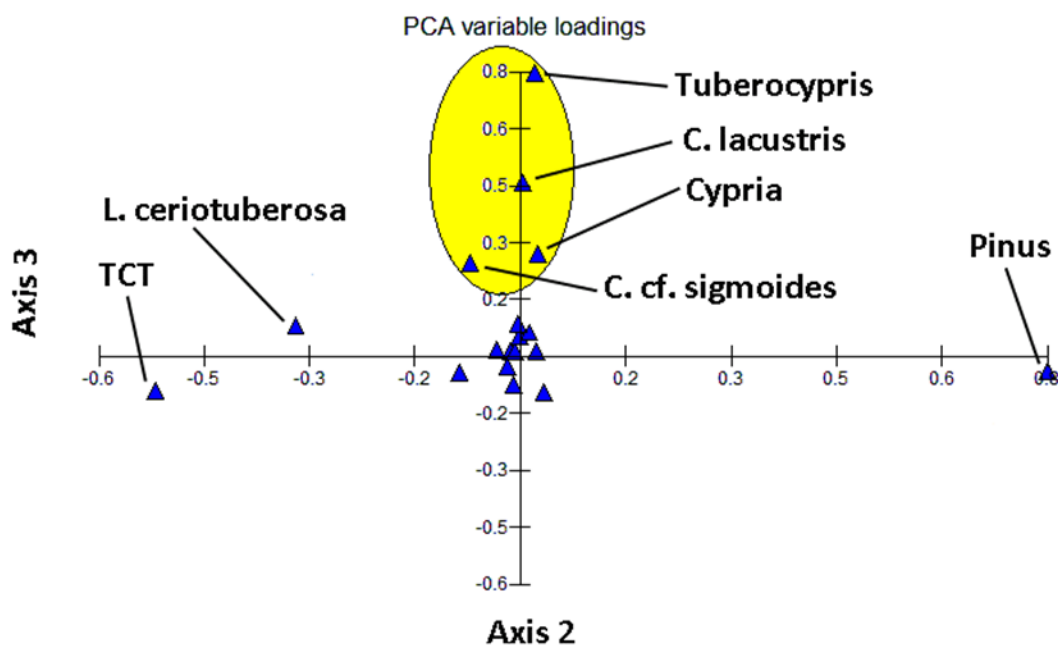


Figure 19: PCA Variable Loadings – Ostracodes and pollen; Axis 2 vs. Axis 3

To resolve the question of orthogonality raised by the PCA result, a cluster analysis was performed on the Pliocene *Pinus* pollen percentages and *Cytherissa lacustris* valves/gram counts. This cluster analysis produced a dendrogram (Figure 20) with a close clustering between *Pinus* and *C. lacustris* for all samples, except for two outlying samples.

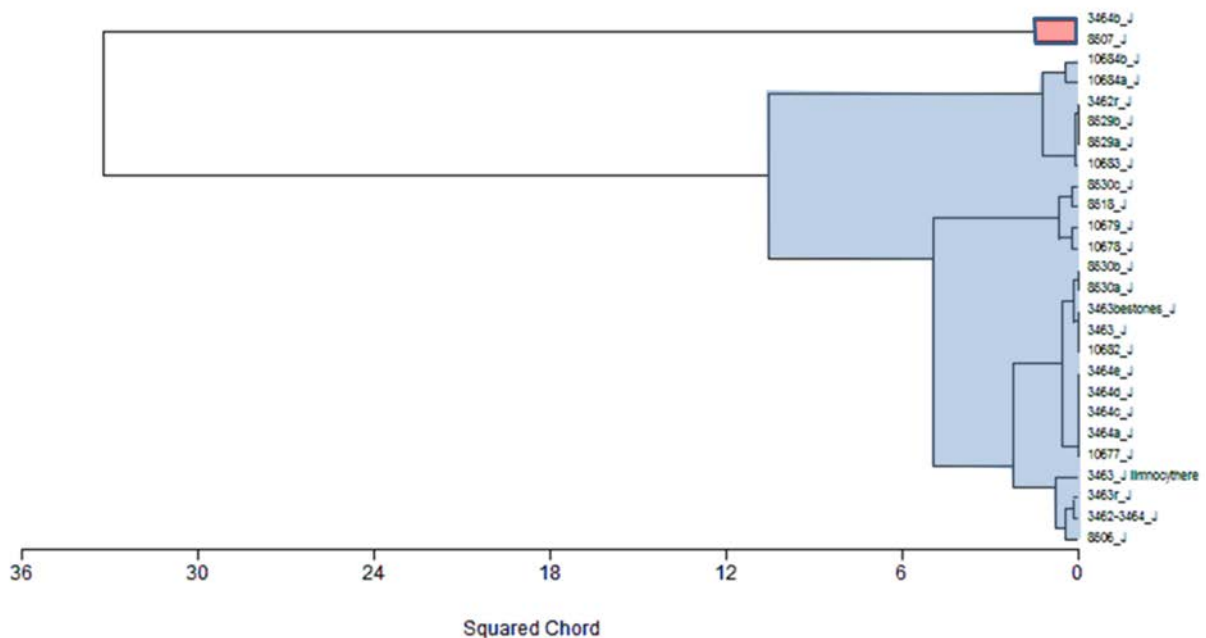


Figure 20: *Pinus* and *Cytherissa lacustris* cluster (Pliocene), farthest neighbor, unconstrained

A second cluster analysis was performed on the Pliocene *Quercus* pollen percentages and *Cytherissa lacustris*. This cluster analysis produced a dendrogram (Figure 21) with a close clustering between *Quercus* and *C. lacustris* for all samples, except for two outlying samples (the same outliers seen in the previous dendrogram).

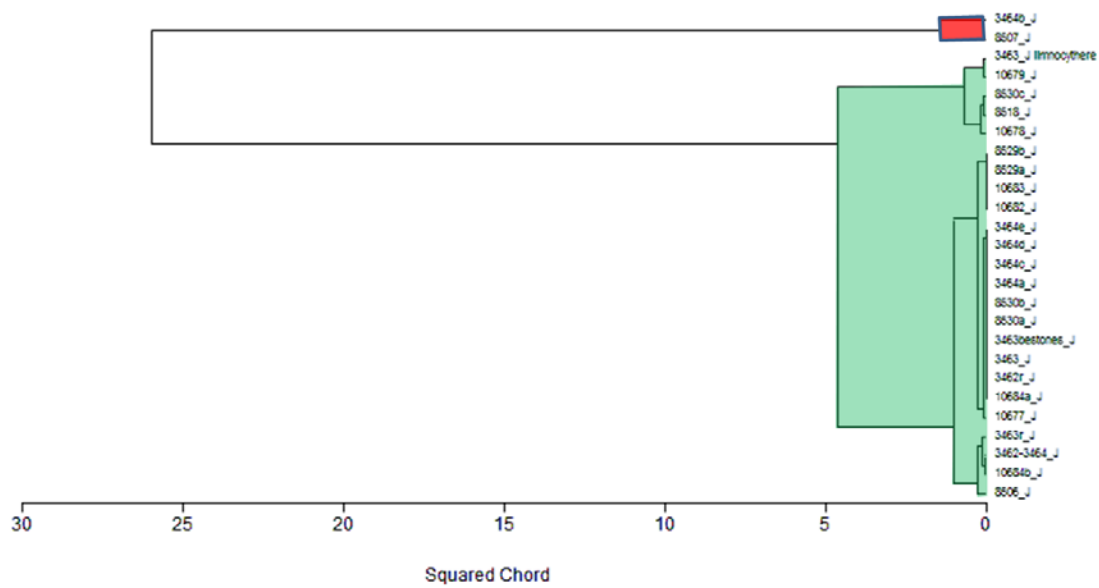


Figure 21: *Quercus* and *Cytherissa lacustris* cluster (Pliocene), farthest neighbor, unconstrained

These clusters indicate that *Cytherissa lacustris* and either *Pinus* or *Quercus* pollen were not mutually exclusive. Thus their relationship was not orthogonal and independent as the PCA results suggested. The two outlier samples (red clade in Figures 20 and 21) contained, by far, the greatest abundance of *Cytherissa lacustris* as measured in valves/g.

The graphs of pollen percentages for Pliocene *Quercus* and *Pinus* show a gradient structure (Figure 22, 24) and since PCA is a method that looks for linear relationships it may not identify nonlinear distributions or gradient patterns.

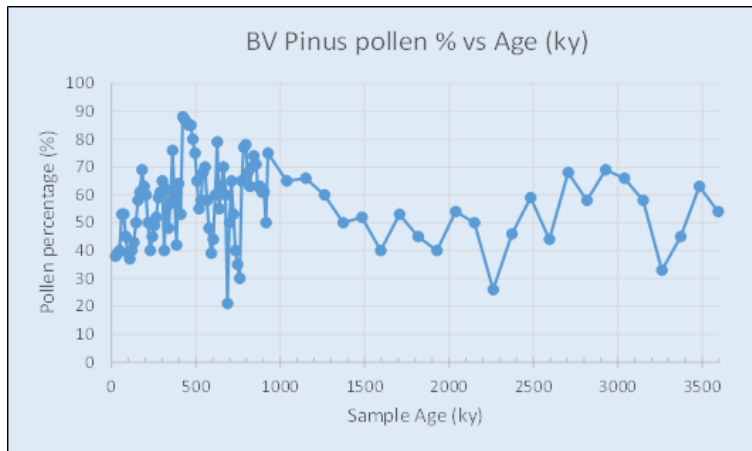


Figure 22: Butte Valley Pinus Pollen % vs Age (ky)

DISCUSSION

Butte Valley Core 1 follows a general lacustrine trend from a geologically stable (10^5 to 10^6 years), fresh, equable lacustrine environment progressing to a more unstable, variable environment with large swings in salinity (perhaps as high as 10,000 mg/L) and finally to a variable, semi-arid environment punctuated by warmer, wetter interglacials. The ultimate causes of these climatic trends in Butte Valley are complex, with possible global and regional explanations.

The stable, wet Pliocene climate represented by Butte Valley Zone 3 is likely due to the ‘permanent El Niño’ condition that characterized the mid-Pliocene (Federov, 2006). The maintenance of an extensive Pliocene lacustrine system in western North America requires a geologically stable (10^5 to 10^6 years), uninterrupted and virtually inexhaustible source of moisture. This is because “an excess of precipitation over evaporation in the drainage basin is necessary to maintain large, permanent lakes for long periods” (GR Smith, p. 300, 1994). The idea of a “permanent El Niño” condition in the Pliocene is currently subject to debate, however the presence of the large, stable Pliocene lake system in western North America indicated by faunal studies requires a consistent delivery of enormous quantities of Pacific moisture to the western North American continental interior, and a permanent El Niño condition provides such a delivery system.

The Pliocene Butte Valley *Cytherissa lacustris* population was syngamic, which is remarkable since the only other site, worldwide, in which syngamic *Cytherissa lacustris*

is currently found is in Lake Baikal. Syngamy in ostracode species is generally accepted as an indicator for the long term stability of the lacustrine habitat, and by inference, the climatic stability of the wider region in which this habitat is imbedded (Smith & Delorme, p. 731, 2009).

Bell (1982) indicated that parthenogenesis is more common in disturbed habitats, whereas syngamy is more common in stable habitats, such as permanent or ancient lakes. Further, it has been proposed that these geographic and habitat distributions of parthenogens versus sexual populations may be linked to both ecological and geological habitat stability, with parthenogens being more successful in establishing populations in stable environments in the short term (Smith & Delorme, 2009; Bell, 1982).

Extant *Cytherissa lacustris* populations allow confidence in discussing this species' narrow environmental requirements. "It is known from Holarctic *Cytherissa lacustris* that this ostracod species requires cold, well-oxygenated habitats" (Danielopol et al., 1990). "*Cytherissa lacustris* indicates less seasonality than in the region today. Water-temperature would have remained below 20°C and perhaps below 15°C (Delorme, 1978). Similarly, the inference by this species of a dilute fresh water lake implies precipitation was high and evaporation low" (Forester, p. 141, 1991).

Ongoing research suggests that *Cytherissa lacustris* distributions may trace the summer position of the polar front in the northern hemisphere and it may be assumed that this held true in the Pliocene as well (Smith, 2012). Recent genetic analysis of Lake Baikal's *Cytherissa lacustris* flock strongly suggests that the species arose in Baikal (Schön & Martens, 2012), making Lake Baikal the likely source for all subsequent Holarctic *Cytherissa lacustris* populations, including Butte Valley's Pliocene syngamic *Cytherissa lacustris* flock. Since syngamic *Cytherissa lacustris* is now found only in Lake Baikal (where lacustrine conditions have remained stable for millions of years) it is likely that Butte Valley's syngamic *Cytherissa lacustris* flock arrived in North America and flourished due to similar stable (10^5 to 10^6 yrs) climatic and lacustrine

conditions. Lake Baikal's stability and longevity have made it "an engine for regional, continental and even global biodiversity"(Schön & Martens, p. 103, 2012). The discovery, in Butte Valley Core 1, of the syngamic form of the ostracode *Cytherissa lacustris* has biological, ecological and biogeographical implications. Analysis of this core has provided a date (3.37 Ma) for the first appearance of syngamic *Cytherissa lacustris* in North America.

In addition, the presence of syngamic *Cytherissa lacustris* (and extinct *TuberoCypris brighti*) in Zone 3 strongly indicate that in the Pliocene, a large, cold, fresh, geologically stable ($10^5 - 10^6$ years) lacustrine environment existed in Butte Valley, which in turn indicates a long-term stable regional climate with abundant moisture to support these large lacustrine systems. The presence of *Cytherissa lacustris* indicates "less seasonality" in the climate which is in keeping with what is known of Pliocene climate at the time (Forester, 1991).

The transition to the drier, more seasonal and unpredictable climate represented by the Pleistocene Zone 2 assemblage "likely represents the southward migration of the westerly storm track caused by growth of the Laurentide ice sheet" (Winnick et al., p. 903, 2013). The delivery of enormous amounts of moisture, which had characterized western North America during the Pliocene, came to an end. A Pleistocene trend of seasonality and increasing aridity was established. The appearance and long term productivity of *Limnocythere sappaensis* seemed at first to indicate a much more saline lake at the Butte Valley site in the early-to-mid-Pleistocene, and indeed "when *Limnocythere sappaensis* occurs alone, or other species are rare or in low abundance, waters are relatively saline" (Fournier, USGSOF 89-413). But other species, *Candona cf. sigmoides* and *Candona caudata* in particular, also experienced increased productivity during this time period. This changed the model from one of increased salinity to one of increased climatic instability due to the establishment of a seasonal climate in the region.

The decline (and subsequent disappearance) of *Cytherissa lacustris* in the core record after ~1.8 Ma strengthens the case for increasing seasonality. By ~1.5 Ma, populations of *Limnocythere sappaensis* and *Candona cf. sigmoides* were thriving, along with a population of *Candona caudata*. This period of species diversity with *Limnocythere sappaensis* sharing dominance with *Candona cf. sigmoides* and *Candona caudata* suggests a lacustrine environment, and a climate, in transition.

“*Limnocythere sappaensis* lives in alkaline-enriched saline water becoming less common as the TDS and composition approach fresh water (Forester, 1983, 1986). *Candona caudata*, by contrast, lives in fresh water. These taxa co-occur when a lake is in transition from fresh to saline water or when a fresh water stream flows into a saline lake. The saline lake implies a dominant dry season punctuated by seasonal runoff. The eurythermic nature of the taxa, as with examples described above, means thermal seasonality. Cold winters, warm summers and a moisture deficit” (Forester, p. 142, 1991).

The Zone 1 assemblage contained abundant *Limnocythere ceriotuberosa* valves punctuated at intervals by valves of *Limnocythere platyforma*. *Limnocythere ceriotuberosa* is an indicator species for “fresh and saline lakes exhibiting seasonal variability in temperature and chemistry common to semi-arid and arid regions”. (Forester, p. 140, 1991) Increases in abundance of *L. platyforma* indicate “freshening episodes” (Smith, p. 96, 1996), relatively short periods of time in which the lacustrine system was flooded with large amounts of fresh water (possibly via glacial meltwater), after which *Limnocythere ceriotuberosa* resumed dominance.

Beginning in the Pliocene and stretching across the Pleistocene the global record is punctuated by several periods of extreme warmth and wetness. The most pronounced of these warm, wet periods are now referred to as “super interglacials” (Melles et al., 2012) and may represent a

collapse of the West Antarctic Ice Sheet and the Greenland ice sheet. ‘Super interglacials’ are one of the many interesting findings from the extensive research conducted at Russian Lake El’gygytygyn over the past decade.

The results from the Lake El’gygytygyn core are quite new and are currently the subject of much analysis and interpretation. The remarkable state of preservation of El’gygytygyn’s continuous 3.58 My core record has yielded many proxies for investigation. Concentrating on one Lake El’gygytygyn proxy, the facies proxy, it is interesting to speculate about possible connections between not only the Lake El’gygytygyn and Butte Valley continuous Pliocene cores, but other wide-ranging cores of global significance from Antarctica, the North Atlantic, and Lake Baikal.

The extraordinary record of lacustrine facies changes revealed at Lake El’gygytygyn give evidence of extreme warming of the global climate many times throughout the last few million years (Melles et al., 2012). The ‘super interglacials’, in particular, show up in the Lake El’gygytygyn facies record as areas “where lake sediments reflect high diatom and terrestrial plant productivity” (Wei et al., p. 3, 2014). Using analysis of these “super interglacials” from the facies proxy of the continuous 3.58 My Lake El’gygytygyn core one may speculate about connections between the El’gygytygyn core and the Butte Valley core. A speculative comparison of the changes in overall abundance of the Butte Valley proxies (ostracodes and pollen) with the Lake El’gygytygyn facies proxy showed perhaps three ‘super interglacials’ (MIS 11c, MIS 55 and MIS 103), the former two in the Pleistocene and the latter in the late Pliocene, very near the Plio-Pleistocene boundary (Figure 23). Jumps in data on the ostracode abundance graph represent zones of no recovery.

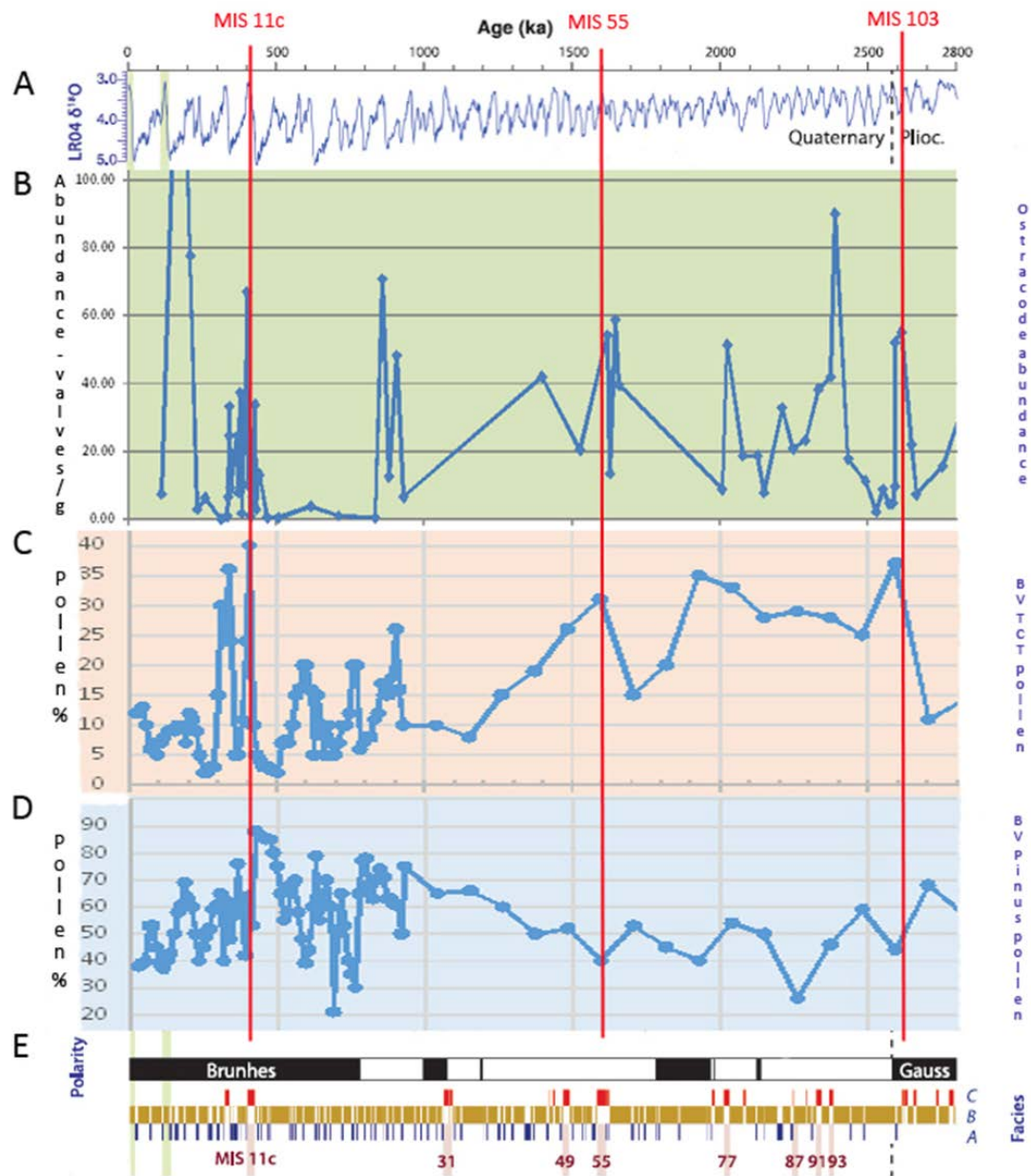


Figure 23: (A to E) (A) LR04 global marine isotope stack (B) Total ostracode abundance (valves/g), Butte Valley, California (C) TCT pollen percent, Butte Valley, California (D) *Pinus* pollen percent, Butte Valley, California (E) Polarity and El'gygytyn facies changes. Super interglacials recorded by Lake El'gygytyn facies are highlighted with red bars. *Modified from Melles et al., Fig. 1, p. 317, 2012.*

These ‘super interglacial’ signals are “expressed globally in ice cores from Antarctica (EPICA Community Members, 2004), North Atlantic marine sediment core records (Lawrence et al., 2010), as well as in Asian lacustrine sedimentary records from Lake Baikal, which indicate a prolonged interglacial period of ca 30 kyr [for MIS 11] (Prosenko et al, 2010)” (Wei et al., pg. 2, 2014).

In comparing the Butte Valley proxies to those from a terrestrial core of similar length, like El’gygytygyn, one can speculate that global signals of ‘super’ interglacials MIS 11c, 55 and 103, stretching from the late-Pleistocene back into the Pliocene, may someday be identifiable in future cores taken at the Butte Valley site (Figure 23). With improved chronology for the Butte Valley core, these speculative signals could be analyzed in much greater detail. Notably, these very warm and wet periods (Melles et al., 2012) are characterized in the Butte Valley core by, among other things, a steep decline in *Pinus* pollen, a large increase in *TCT* pollen and a surge in ostracode abundance. All of these changes in Butte Valley flora and fauna are consistent with a warmer, wetter climate during these periods. “Marine Isotope Stage (MIS) 11 has been proposed as an analogue to modern climate conditions, with orbital configurations similar to today and greenhouse gas concentrations at preindustrial levels (Loutre and Berger, 2002; EPICA community members, 2004)” (Wei, p. 1, 2014). The Butte Valley core thus provides a potential record for North America into this global climate analog.

The Butte Valley core also records a regional signal. The zone of low valve abundance in Zone 1 (circa 820 ka to circa 470 ka) begins during the mid-Pleistocene transition. A graph of oak (*Quercus*) pollen % vs. time for this period shows a considerable increase in oak pollen-percentage throughout the early-to-mid Pleistocene from which we can infer an increase in deciduous forests in the region (Figure 24).

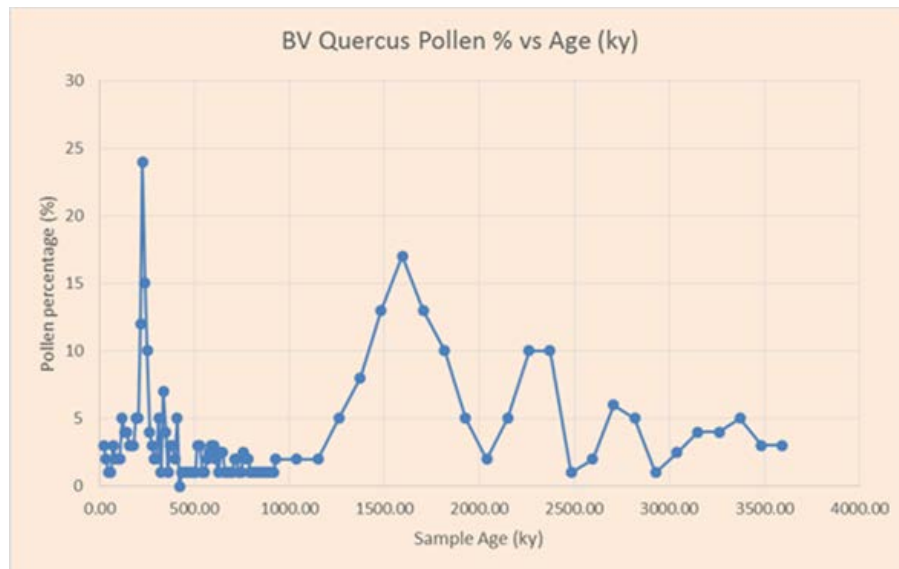


Figure 24: Butte Valley Quercus Pollen % vs Age (ky)

The zone of low valve abundance, coupled with pollen data, indicates aridification of the Butte Valley site, reflecting the development of a rain shadow in the region due to the ongoing uplift of the Klamath Mountains to the west during the mid-to-late Pleistocene. The pollen record for this period includes a large spike in pollen % from grasses (*Gramineae*), by far the largest such spike in the > 3 Myr pollen record for this site.

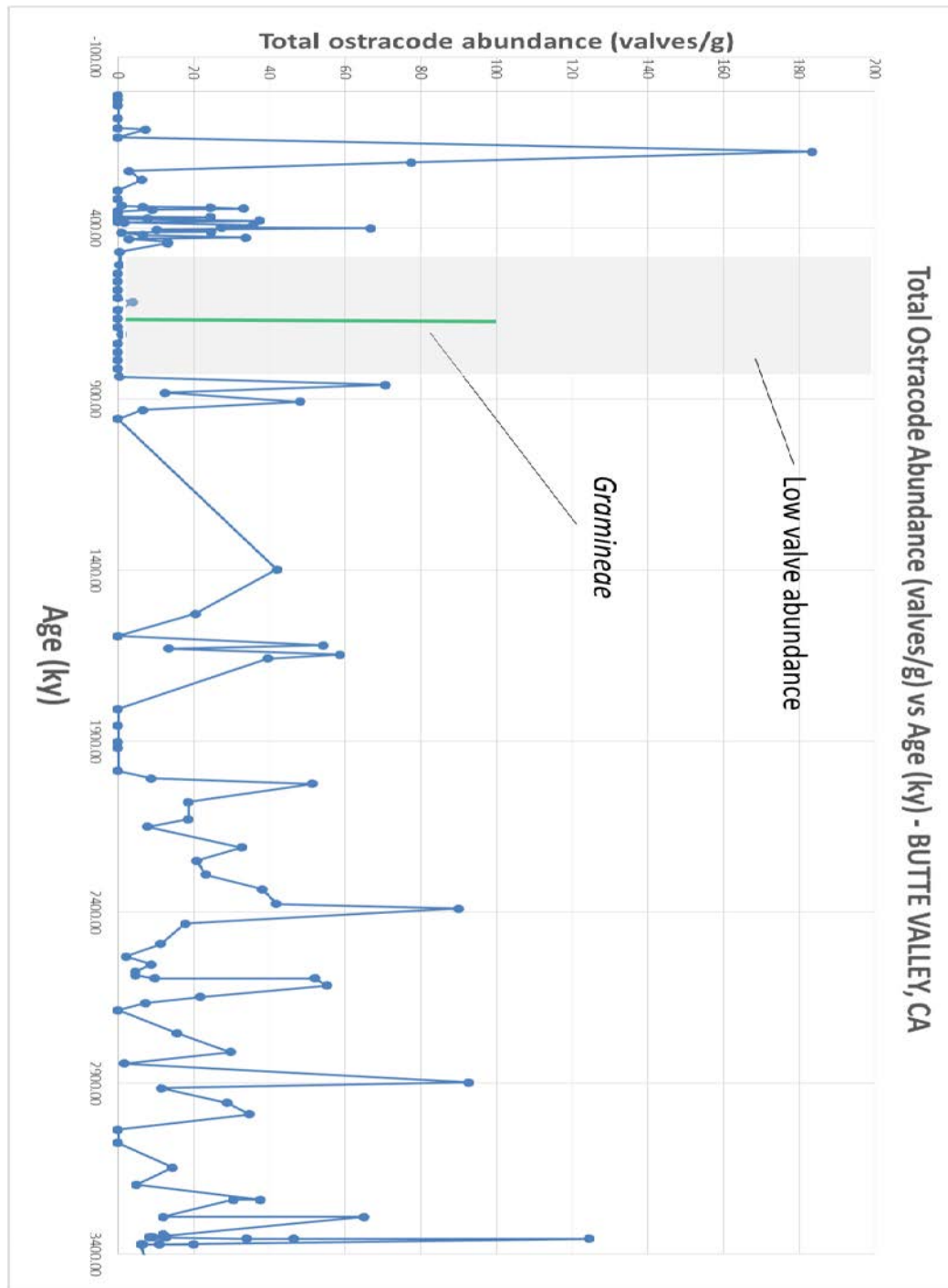


Figure 25: Total ostracode abundance vs. age, with *Gramineae* pollen spike and zone of low valve abundance noted.

This spike in pollen % from grasses occurred circa 686 kya (Figure 25) and indicates lake desiccation and development of extensive grasslands during this period. The period of low valve abundance ends at a depth of 39m (470 ky). The timing of the zone of low valve abundance and the generally accepted beginning and end times for the Mid-Pleistocene transition do not make a compelling match. It seems more likely that this zone of low valve abundance was due to the late-Pleistocene rise of the Klamath mountains to the west of Butte Valley and the establishment of a rainshadow in the region. Reviewing the facies data from Lake El'gygytygyn and global benthic isotope data for this period seem to strengthen this conclusion, in part due to the fact that the zone of low valve abundance ends rather abruptly with the onset of the most intense 'super interglacial' of the Pleistocene, MIS 11c.

The reconstruction of past climates using ostracodes as indicators is a powerful tool, providing information about lacustrine environments worldwide. The proxies of Butte Valley Core 1 have afforded us means to evaluate climatic trends back into the Pliocene, nearly unique in the world for a terrestrial site. It has corroborated and strengthened work from other sites in western North America as well as sites of global significance like Lake El'gygytygyn, and Lake Baikal. It is to be hoped that this is just the beginning for research opportunities at the Butte Valley site. The Butte Valley Core 1, at 102m, penetrated to Pliocene sediment but could have gone much deeper, and further into the Pliocene. Future work at Butte Valley, along with evaluation of the worldwide network of past and present lacustrine environments can help to gain a broader understanding of the large scale changes driving events of the past, which can in turn be invaluable for planning for scarcity of precious resources in an uncertain future.

CONCLUSIONS

Butte Valley Lake is unique in western North America as a carbonate rich, continuous window into climate change stretching back deep into the Pliocene. The results from the analysis of Butte Valley Core 1 for this thesis demonstrate that faunal changes can be used to track changes in paleolake hydrochemistry and thus the changing paleoclimate for a time period with important connections and ramifications for our own time. Butte Valley Core 1 was extracted in 1991 and no further cores have been taken in the Butte Valley region since. Future cores taken in Butte Valley should be able to penetrate further into the Pliocene to provide invaluable new information for the evolving picture of climate change over the last several million years. It is hoped that the urgent need for greater understanding of the changing climate in our own time can spur further research and deeper cores from Butte Valley.

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Appendix A: Butte Valley Core 1 Sample Inventory
Ostracode Samples (Species 1-5)

Sample	Depth (m)	Age (ky)	Weight (g)	Total Abund ance (valves /g)	L. platyf orma	L. ceriotub erosa	L. sappa ensis	C. lacust ris	C. cf. sigmoi des
8451	9.33	112.45	2.05	7.32	0.00	3.42	0.00	0.00	3.90
8310	14.68	176.90	2.06	183.50	0.00	169.90	5.34	0.00	0.00
8335	17.34	208.95	2.07	77.60	0.00	58.28	0.48	0.00	0.00
8336	19.41	233.89	2.07	2.90	0.00	2.90	0.00	0.00	0.00
8337	21.60	260.28	2.09	6.22	0.00	5.74	0.00	0.00	0.48
8345	26.17	315.34	2.06	0.00	0.00	0.00	0.00	0.00	0.00
10149	27.77	334.61	2.28	0.88	0.00	0.88	0.00	0.00	0.00
10150	28.06	338.11	2.18	6.42	0.00	6.42	0.00	0.00	0.00
8347	28.24	340.28	2.00	24.42	23.00	0.00	0.00	0.00	0.00
10151	28.48	343.17	2.32	33.19	33.19	0.00	0.00	0.00	0.00
10152	28.75	346.42	2.32	9.05	9.05	0.00	0.00	0.00	0.00
8350	30.61	368.83	2.09	24.40	7.66	0.00	6.22	0.00	10.53
10156	30.92	372.57	2.28	7.78	0.00	0.44	0.00	0.00	3.51
10158	31.43	378.71	2.04	37.25	22.06	13.73	0.98	0.00	0.49
10160	31.90	384.37	2.36	1.69	1.69	0.00	0.00	0.00	0.00
10645	32.62	393.05	2.08	35.58	0.00	23.08	0.00	0.00	0.00
10646	33.12	399.07	2.12	27.36	0.00	23.11	0.00	0.00	3.30
10647	33.31	401.36	2.23	66.82	0.00	60.99	0.90	0.00	4.93
8369	33.61	404.98	2.07	10.14	0.00	5.80	0.00	0.00	0.00
10648	34.11	411.00	2.31	24.68	4.33	20.35	0.00	0.00	0.00
10649	34.32	413.53	2.21	0.90	0.00	0.91	0.00	0.00	0.00
10650	34.90	420.52	2.15	6.51	0.00	6.51	0.00	0.00	0.00
10651	35.56	428.47	2.26	33.67	24.78	7.97	0.00	0.00	0.00
8460	35.92	432.81	2.10	2.86	0.00	0.00	0.00	0.00	0.00
10652	36.54	440.28	2.27	13.22	0.00	13.22	0.00	0.00	0.00
8388	36.94	445.10	2.07	13.04	1.45	7.73	0.48	0.00	0.48
8389	38.97	469.55	2.00	0.50	0.00	0.50	0.00	0.00	0.00
8390	42.20	508.47	2.05	0.49	0.00	0.49	0.00	0.00	0.00
8409	51.26	617.63	2.09	3.83	0.00	0.00	0.00	0.00	3.83

8439	59.03	711.24	2.09	0.96	0.00	0.00	0.48	0.00	0.48
8494	69.32	835.22	2.07	0.48	0.00	0.00	0.00	0.00	0.48
8495	71.33	859.43	2.05	70.73	2.44	10.24	45.85	0.00	12.20
8496	73.20	881.96	2.00	12.43	0.00	0.00	5.50	0.00	4.00
8497	75.35	907.87	2.08	48.12	3.37	7.21	1.44	0.00	0.96
8498	77.34	931.84	2.15	6.51	0.00	0.00	0.00	0.00	6.51
8500	81.54	1398.5	2.00	42.00	0.00	0.00	35.00	0.00	7.00
10653	82.71	1528.5	2.27	20.38	0.00	0.00	18.50	0.00	0.88
8501	83.54	1620.7	2.05	54.15	0.00	0.00	24.39	0.49	28.78
10655	83.62	1629.6	2.21	13.44	0.00	0.91	0.00	0.00	7.24
8502	83.78	1647.4	2.06	58.70	0.00	16.51	0.97	17.96	9.22
10656	83.89	1659.6	2.05	39.51	0.00	7.81	0.00	11.71	11.22
10661	87.04	2009.6	2.29	8.73	0.00	0.00	3.06	0.00	5.24
10662	87.18	2025.2	2.53	51.38	0.00	13.04	13.83	4.35	16.21
10663	87.66	2078.5	2.52	18.63	0.00	2.38	5.16	0.00	3.97
10664	88.11	2128.5	2.53	18.59	0.00	0.00	0.00	7.11	5.93
10665	88.31	2150.7	2.39	7.83	0.00	0.00	0.00	0.42	5.44
8504	88.86	2211.8	2.05	32.68	0.00	0.00	11.22	0.00	20.98
10666	89.20	2249.6	2.38	20.79	0.00	0.00	0.00	0.00	8.82
10667	89.57	2290.7	2.25	23.12	0.00	0.00	0.89	0.00	6.22
10668	89.96	2334.1	2.23	38.12	0.00	0.00	0.45	4.93	14.35
10669	90.34	2376.3	2.15	41.86	0.00	0.00	0.00	21.86	2.33
10670	90.47	2390.7	2.48	89.92	0.00	0.00	0.81	65.32	5.24
8505	90.86	2434.1	2.09	17.70	0.00	0.00	0.00	10.53	6.70
10671	91.40	2494.1	2.31	11.26	0.00	0.00	0.00	0.00	6.49
7562	91.73	2530.7	13.01	2.08	0.00	0.15	0.38	0.38	1.15
10672	91.93	2553.0	2.41	8.79	0.00	0.00	0.00	0.00	5.39
7563	92.12	2574.1	15.15	4.66	0.00	0.00	0.00	0.00	0.53
7564	92.22	2585.2	17.50	4.55	0.00	0.00	0.17	0.00	3.54
7565a	92.30	2594.1	12.50	9.67	0.00	0.00	1.68	0.00	2.56
7565b	92.30	2594.1	12.50	52.16	0.00	0.00	2.00	0.00	35.84
10673	92.49	2615.2	2.39	55.12	0.00	0.42	0.00	0.00	29.29
10674	92.79	2648.5	2.11	21.75	0.00	0.00	0.00	0.00	10.90
7566	92.95	2666.3	14.93	7.30	0.00	0.00	0.00	0.00	1.27
10676	93.74	2754.1	2.45	15.51	0.00	0.00	0.00	0.00	2.04
8506	94.24	2809.6	2.05	29.68	0.00	0.00	0.00	0.49	13.66
10677	94.54	2843.0	2.46	1.63	0.00	0.00	0.00	0.00	0.81
8507	95.04	2898.5	2.06	92.72	0.00	0.00	0.00	25.73	16.99

10678	95.19	2915.2	2.47	11.33	0.00	0.00	0.00	2.83	4.45
10679	95.58	2958.5	2.43	28.81	0.00	0.00	0.00	1.65	7.41
8518	95.88	2991.8	2.07	34.78	0.00	0.00	0.00	4.35	19.32
10682	97.28	3147.4	2.43	14.40	0.00	0.00	0.00	0.00	12.35
10683	97.73	3197.4	2.49	4.82	0.00	0.00	0.00	0.00	3.21
10684a	98.13	3241.8	2.40	37.50	0.00	0.00	0.00	0.00	21.25
10684b	98.13	3241.8	2.36	30.45	0.00	0.00	19.49	0.42	6.36
8529a	98.58	3291.8	2.36	11.86	0.00	0.00	0.00	0.00	10.59
8529b	98.58	3291.8	2.09	65.04	0.00	0.00	8.61	0.00	30.62
3462-3464	99.12	3351.8	6.24	8.14	0.00	0.00	0.00	0.64	0.00
3462r	99.04	3343.0	6.24	12.02	0.00	0.00	0.00	0.00	1.92
3463 limno	99.12	3351.8	20.27	12.69	0.00	0.05	2.91	1.68	0.00
3463	99.12	3351.8	20.27	12.58	0.00	0.00	0.00	0.00	0.99
3463r	99.12	3351.8	20.27	9.23	0.00	0.00	0.25	0.20	0.49
3463best	99.12	3351.8	20.27	11.99	0.00	0.00	0.00	0.00	0.00
8530a	99.15	3355.2	2.09	33.92	0.00	0.00	0.00	0.00	33.01
8530b	99.15	3355.2	2.09	46.41	0.00	19.62	0.00	0.00	26.79
8530c	99.15	3355.2	2.09	124.40	0.00	0.00	0.48	3.83	4.78
3464a	99.30	3371.8	19.98	6.55	0.00	1.40	0.20	0.00	2.30
3464b	99.30	3371.8	19.98	20.07	0.00	0.00	0.00	15.27	1.15
3464c	99.30	3371.8	19.98	10.86	0.00	0.00	0.00	2.83	4.45
3464d	99.30	3371.8	19.98	10.96	0.00	0.00	0.00	1.65	7.41
3464e	99.30	3371.8	19.98	5.96	0.00	0.00	0.00	4.35	19.32
8531	101.49	3615.18	2.15	13.95	0.00	0.00	3.72	0.00	5.58

Butte Valley Core 1 Sample Inventory
Ostracode Samples (Species 6-10)

Sample	Depth (m)	Age (ky)	Weight (g)	Total Abundance (valves /g)	C. aff. ohioensis	C. caudata	C. aff. rawsoni	Tube rocypris	Cypria sp.
8451	9.33	112.45	2.05	7.32	0.00	0.00	0.00	0.00	0.00
8310	14.68	176.90	2.06	183.50	0.00	0.00	0.00	0.00	0.00
8335	17.34	208.95	2.07	77.60	0.00	0.00	18.84	0.00	0.00
8336	19.41	233.89	2.07	2.90	0.00	0.00	0.00	0.00	0.00
8337	21.60	260.28	2.09	6.22	0.00	0.00	0.00	0.00	0.00
8345	26.17	315.34	2.06	0.00	0.00	0.00	0.00	0.00	0.00
10149	27.77	334.61	2.28	0.88	0.00	0.00	0.00	0.00	0.00
10150	28.06	338.11	2.18	6.42	0.00	0.00	0.00	0.00	0.00
8347	28.24	340.28	2.00	24.42	0.00	0.92	0.00	0.00	0.00
10151	28.48	343.17	2.32	33.19	0.00	0.00	0.00	0.00	0.00

10152	28.75	346.42	2.32	9.05	0.00	0.00	0.00	0.00	0.00
8350	30.61	368.83	2.09	24.40	0.00	0.00	0.00	0.00	0.00
10156	30.92	372.57	2.28	7.78	0.00	3.83	0.00	0.00	0.00
10158	31.43	378.71	2.04	37.25	0.00	0.00	0.00	0.00	0.00
10160	31.90	384.37	2.36	1.69	0.00	0.00	0.00	0.00	0.00
10645	32.62	393.05	2.08	35.58	0.00	0.00	0.00	0.00	0.00
10646	33.12	399.07	2.12	27.36	0.00	0.00	0.00	0.00	0.00
10647	33.31	401.36	2.23	66.82	0.00	0.00	0.00	0.00	0.00
8369	33.61	404.98	2.07	10.14	0.00	0.00	0.00	0.00	0.00
10648	34.11	411.00	2.31	24.68	0.00	0.00	0.00	0.00	0.00
10649	34.32	413.53	2.21	0.90	0.00	0.00	0.00	0.00	0.00
10650	34.90	420.52	2.15	6.51	0.00	0.00	0.00	0.00	0.00
10651	35.56	428.47	2.26	33.67	0.00	0.93	0.00	0.00	0.00
8460	35.92	432.81	2.10	2.86	0.00	0.00	0.00	0.00	0.00
10652	36.54	440.28	2.27	13.22	0.00	0.00	0.00	0.00	0.00
8388	36.94	445.10	2.07	13.04	0.00	0.00	0.00	0.00	0.00
8389	38.97	469.55	2.00	0.50	0.00	0.00	0.00	0.00	0.00
8390	42.20	508.47	2.05	0.49	0.00	0.00	0.00	0.00	0.00
8409	51.26	617.63	2.09	3.83	0.00	0.00	0.00	0.00	0.00
8439	59.03	711.24	2.09	0.96	0.00	0.00	0.00	0.00	0.00
8494	69.32	835.22	2.07	0.48	0.00	0.00	0.00	0.00	0.00
8495	71.33	859.43	2.05	70.73	0.00	0.00	0.00	0.00	0.00
8496	73.20	881.96	2.00	12.43	0.00	2.93	0.00	0.00	0.00
8497	75.35	907.87	2.08	48.12	0.00	1.00	0.00	0.00	0.00
8498	77.34	931.84	2.15	6.51	0.00	0.00	0.00	0.00	0.00
8500	81.54	1398.5	2.00	42.00	0.00	0.00	0.00	0.00	0.00
10653	82.71	1528.5	2.27	20.38	0.00	1.00	0.00	0.00	0.00
8501	83.54	1620.7	2.05	54.15	0.00	4.39	0.00	0.00	0.49
10655	83.62	1629.6	2.21	13.44	0.00	0.45	0.00	0.00	0.90
8502	83.78	1647.4	2.06	58.70	0.00	0.00	0.00	0.00	2.43
10656	83.89	1659.6	2.05	39.51	0.00	0.00	0.00	0.00	0.0
10661	87.04	2009.6	2.29	8.73	0.00	0.00	0.00	0.44	0.0
10662	87.18	2025.2	2.53	51.38	3.95	0.00	0.00	0.00	0.0
10663	87.66	2078.5	2.52	18.63	0.00	5.14	0.00	0.00	0.0
10664	88.11	2128.5	2.53	18.59	0.40	2.38	0.00	0.00	0.0
10665	88.31	2150.7	2.39	7.83	0.00	1.98	0.00	0.00	0.0
8504	88.86	2211.8	2.05	32.68	0.00	0.00	0.00	0.49	0.0
10666	89.20	2249.6	2.38	20.79	3.78	1.46	0.00	0.42	0.0

10667	89.57	2290.7	2.25	23.12	0.00	7.56	0.00	8.44	0.0
10668	89.96	2334.1	2.23	38.12	1.35	0.00	0.90	10.76	1.79
10669	90.34	2376.3	2.15	41.86	0.00	0.00	0.00	14.42	1.86
10670	90.47	2390.7	2.48	89.92	1.21	0.00	0.00	16.13	0.00
8505	90.86	2434.1	2.09	17.70	0.00	0.00	0.00	0.48	0.00
10671	91.40	2494.1	2.31	11.26	0.00	0.00	0.00	4.76	0.00
7562	91.73	2530.7	13.01	2.08	0.00	0.00	0.00	0.00	0.00
10672	91.93	2553.0	2.41	8.79	0.00	0.08	0.00	3.32	0.00
7563	92.12	2574.1	15.15	4.66	0.00	0.83	0.00	2.05	0.07
7564	92.22	2585.2	17.50	4.55	0.11	0.73	0.00	0.00	0.00
7565a	92.30	2594.1	12.50	9.67	1.12	1.43	0.00	2.16	0.32
7565b	92.30	2594.1	12.50	52.16	3.84	8.48	1.36	0.00	0.16
10673	92.49	2615.2	2.39	55.12	0.00	22.48	0.00	1.26	1.26
10674	92.79	2648.5	2.11	21.75	0.00	0.42	0.00	4.74	2.84
7566	92.95	2666.3	14.93	7.30	0.47	0.00	0.00	1.54	0.74
10676	93.74	2754.1	2.45	15.51	0.00	0.00	0.00	1.22	0.00
8506	94.24	2809.6	2.05	29.68	0.00	0.41	0.00	3.41	0.00
10677	94.54	2843.0	2.46	1.63	0.00	0.00	0.00	0.81	0.00
8507	95.04	2898.5	2.06	92.72	0.00	0.00	0.49	29.13	5.83
10678	95.19	2915.2	2.47	11.33	0.00	2.43	0.00	1.62	0.00
10679	95.58	2958.5	2.43	28.81	0.00	0.00	0.00	4.94	2.06
8518	95.88	2991.8	2.07	34.78	0.00	0.00	2.42	3.38	0.00
10682	97.28	3147.4	2.43	14.40	0.00	0.00	0.00	2.06	0.00
10683	97.73	3197.4	2.49	4.82	0.00	0.00	0.00	1.61	0.00
10684a	98.13	3241.8	2.40	37.50	6.25	0.00	0.00	10.00	0.00
10684b	98.13	3241.8	2.36	30.45	0.00	3.33	0.00	0.00	0.85
8529a	98.58	3291.8	2.36	11.86	1.27	0.00	0.00	0.00	0.00
8529b	98.58	3291.8	2.09	65.04	0.96	7.63	0.00	15.31	1.91
3462-3464	99.12	3351.8	6.24	8.14	0.00	6.22	0.80	0.00	0.00
3462r	99.04	3343.0	6.24	12.02	0.16	0.00	0.32	9.62	0.00
3463 limno	99.12	3351.8	20.27	12.69	0.25	3.37	0.00	0.00	0.00
3463	99.12	3351.8	20.27	12.58	0.99	0.00	2.12	8.49	0.00
3463r	99.12	3351.8	20.27	9.23	0.15	3.16	0.15	2.57	1.97
3463best	99.12	3351.8	20.27	11.99	0.05	0.69	1.83	0.10	9.32
8530a	99.15	3355.2	2.09	33.92	0.00	0.90	0.00	0.00	0.00
8530b	99.15	3355.2	2.09	46.41	0.00	0.00	0.00	0.00	0.00
8530c	99.15	3355.2	2.09	124.4	0.00	0.00	7.18	73.21	34.93
3464a	99.30	3371.8	19.98	6.55	0.10	0.30	0.00	1.15	1.10

3464b	99.30	3371.8	19.98	20.07	0.00	0.00	0.55	0.05	3.05
3464c	99.30	3371.8	19.98	10.86	0.00	0.00	0.00	7.81	0.00
3464d	99.30	3371.8	19.98	10.96	0.00	0.00	0.00	0.00	0.00
3464e	99.30	3371.8	19.98	5.96	0.25	0.00	3.40	0.30	0.00
8531	101.5	3615.2	2.15	13.95	0.00	0.00	0.47	2.33	0.93

Butte Valley Core 1 Sample Inventory
Ostracode Samples (Species 11-13)

Sample	Depth (m)	Age (ky)	Weight (g)	Total Abundance (valves /g)	L. aff bradburyi	Limn A	Limn B
8451	9.33	112.45	2.05	7.32	0.00	0.00	0.00
8310	14.68	176.90	2.06	183.50	8.25	0.00	0.00
8335	17.34	208.95	2.07	77.60	0.00	0.00	0.00
8336	19.41	233.89	2.07	2.90	0.00	0.00	0.00
8337	21.60	260.28	2.09	6.22	0.00	0.00	0.00
8345	26.17	315.34	2.06	0.00	0.00	0.00	0.00
10149	27.77	334.61	2.28	0.88	0.00	0.00	0.00
10150	28.06	338.11	2.18	6.42	0.00	0.00	0.00
8347	28.24	340.28	2.00	24.42	0.50	0.00	0.00
10151	28.48	343.17	2.32	33.19	0.00	0.00	0.00
10152	28.75	346.42	2.32	9.05	0.00	0.00	0.00
8350	30.61	368.83	2.09	24.40	0.00	0.00	0.00
10156	30.92	372.57	2.28	7.78	0.00	0.00	0.00
10158	31.43	378.71	2.04	37.25	0.00	0.00	0.00
10160	31.90	384.37	2.36	1.69	0.00	0.00	0.00
10645	32.62	393.05	2.08	35.58	12.50	0.00	0.00
10646	33.12	399.07	2.12	27.36	0.94	0.00	0.00
10647	33.31	401.36	2.23	66.82	0.00	0.00	0.00
8369	33.61	404.98	2.07	10.14	4.35	0.00	0.00
10648	34.11	411.00	2.31	24.68	0.00	0.00	0.00
10649	34.32	413.53	2.21	0.90	0.00	0.00	0.00
10650	34.90	420.52	2.15	6.51	0.00	0.00	0.00
10651	35.56	428.47	2.26	33.67	0.00	0.00	0.00
8460	35.92	432.81	2.10	2.86	0.00	2.86	0.00
10652	36.54	440.28	2.27	13.22	0.00	0.00	0.00
8388	36.94	445.10	2.07	13.04	1.45	0.00	0.00

8389	38.97	469.55	2.00	0.50	0.00	0.00	0.00
8390	42.20	508.47	2.05	0.49	0.00	0.00	0.00
8409	51.26	617.63	2.09	3.83	0.00	0.00	0.00
8439	59.03	711.24	2.09	0.96	0.00	0.00	0.00
8494	69.32	835.22	2.07	0.48	0.00	0.00	0.00
8495	71.33	859.43	2.05	70.73	0.00	0.00	0.00
8496	73.20	881.96	2.00	12.43	0.00	0.00	0.00
8497	75.35	907.87	2.08	48.12	34.13	0.00	0.00
8498	77.34	931.84	2.15	6.51	0.00	0.00	0.00
8500	81.54	1398.5	2.00	42.00	0.00	0.00	0.00
10653	82.71	1528.5	2.27	20.38	0.00	0.00	0.00
8501	83.54	1620.7	2.05	54.15	0.00	0.00	0.00
10655	83.62	1629.6	2.21	13.44	0.00	0.00	0.00
8502	83.78	1647.4	2.06	58.70	0.97	10.19	0.00
10656	83.89	1659.6	2.05	39.51	0.00	8.78	0.0
10661	87.04	2009.6	2.29	8.73	0.00	0.0	0.0
10662	87.18	2025.2	2.53	51.38	0.00	0.0	0.0
10663	87.66	2078.5	2.52	18.63	1.98	0.0	0.0
10664	88.11	2128.5	2.53	18.59	2.77	0.0	0.0
10665	88.31	2150.7	2.39	7.83	0.00	0.0	0.0
8504	88.86	2211.8	2.05	32.68	0.00	0.0	0.0
10666	89.20	2249.6	2.38	20.79	6.30	0.0	0.0
10667	89.57	2290.7	2.25	23.12	0.00	0.0	0.0
10668	89.96	2334.1	2.23	38.12	2.69	0.45	0.45
10669	90.34	2376.3	2.15	41.86	0.00	1.4	0.0
10670	90.47	2390.7	2.48	89.92	0.00	1.21	0.0
8505	90.86	2434.1	2.09	17.70	0.00	0.0	0.0
10671	91.40	2494.1	2.31	11.26	0.00	0.0	0.0
7562	91.73	2530.7	13.01	2.08	0.00	0.0	0.0
10672	91.93	2553.0	2.41	8.79	0.00	0.0	0.0
7563	92.12	2574.1	15.15	4.66	1.19	0.0	0.0
7564	92.22	2585.2	17.50	4.55	0.00	0.0	0.0
7565a	92.30	2594.1	12.50	9.67	0.00	0.24	0.16
7565b	92.30	2594.1	12.50	52.16	0.24	0.24	0.0
10673	92.49	2615.2	2.39	55.12	0.42	0.0	0.0
10674	92.79	2648.5	2.11	21.75	0.00	1.42	1.42
7566	92.95	2666.3	14.93	7.30	0.00	2.01	1.27
10676	93.74	2754.1	2.45	15.51	0.00	1.63	10.61

8506	94.24	2809.6	2.05	29.68	0.00	4.39	7.32
10677	94.54	2843.0	2.46	1.63	0.00	0.0	0.0
8507	95.04	2898.5	2.06	92.72	0.00	11.65	2.91
10678	95.19	2915.2	2.47	11.33	0.00	0.0	0.0
10679	95.58	2958.5	2.43	28.81	0.00	2.88	9.88
8518	95.88	2991.8	2.07	34.78	0.00	0.0	5.31
10682	97.28	3147.4	2.43	14.40	0.00	0.0	0.0
10683	97.73	3197.4	2.49	4.82	0.00	0.0	0.0
10684a	98.13	3241.8	2.40	37.50	0.00	0.0	0.0
10684b	98.13	3241.8	2.36	30.45	0.00	0.0	0.0
8529a	98.58	3291.8	2.36	11.86	0.00	0.0	0.0
8529b	98.58	3291.8	2.09	65.04	0.00	0.0	0.0
3462-3464	99.12	3351.8	6.24	8.14	0.00	0.0	0.48
3462r	99.04	3343.0	6.24	12.02	0.00	0.0	0.0
3463 limno	99.12	3351.8	20.27	12.69	1.63	1.28	1.53
3463	99.12	3351.8	20.27	12.58	0.00	0.0	0.0
3463r	99.12	3351.8	20.27	9.23	0.00	0.0	0.3
3463best	99.12	3351.8	20.27	11.99	0.00	0.0	0.0
8530a	99.15	3355.2	2.09	33.92	0.00	0.00	0.00
8530b	99.15	3355.2	2.09	46.41	0.00	0.0	0.0
8530c	99.15	3355.2	2.09	124.4	0.00	0.0	0.0
3464a	99.30	3371.8	19.98	6.55	0.00	0.0	0.0
3464b	99.30	3371.8	19.98	20.07	0.00	0.0	0.0
3464c	99.30	3371.8	19.98	10.86	0.00	0.0	0.0
3464d	99.30	3371.8	19.98	10.96	0.00	0.0	0.0
3464e	99.30	3371.8	19.98	5.96	0.00	0.0	0.0
8531	101.5	3615.2	2.15	13.95	0.00	0.0	0.93

Butte Valley Core 1 Sample Inventory – *Pollen Samples*

<i>Pinus</i>	<i>TCT</i>	<i>Artemisia</i>	<i>Quercus</i>	<i>Gramineae</i>	Total Pollen %	Depth (m)
35	6	27	2	15	85	9.333
68	10	3	4	4	89	14.683
55	13	7	5	4	84	17.343
42	5	5	20	4	76	19.413
52	2	23	14	4	95	21.603
48	30	7	4	4	93	26.173
55	29	4	5	4	97	27.773
40	35	5	6	4	90	28.063
46	20	9	4	4	83	28.243
51	24	10	8	4	97	28.483
55	17	13	9	4	98	28.753
72	3	12	3	6	96	30.613
65	6	11	2	4	88	30.923
40	10	13	3	4	70	31.433
36	13	10	4	4	67	31.903
69	20	4	3	3	99	32.623
61	29	3	3	3	99	33.123
49	32	3	3	4	91	33.313
46	40	3	2	4	95	33.613
63	30	2	3	2	100	34.113
75	18	2	2	3	100	34.323

86	4	3	4	3	100	34.903
85	4	3	4	4	100	35.563
83	5	4	3	4	99	35.923
82	4	3	1	4	94	36.543
82	3	3	1	4	93	36.943
79	3	2	1	4	89	38.973
59	5	12	1	4	81	42.203
63	3	9	2	8	85	51.263
21	7	5	1	62	96	59.033
67	11	4	3	9	94	69.323
66	20	4	2	3	95	71.333
59	17	5	3	10	94	73.203
60	26	10	2	2	100	75.353
65	13	10	2	10	100	77.343
41	22	8	8	3	82	81.543
35	26	11	15	3	90	82.713
48	15	11	16	3	93	83.543
47	14	6	15	3	85	83.623
46	17	5	14	3	85	83.783
45	19	4	13	2	83	83.893
45	30	5	4	2	86	87.043
44	28	5	3	2	82	87.183
43	30	7	3	2	85	87.663
42	30	9	3	2	86	88.113

35	29	11	3	2	80	88.313
32	30	12	3	2	79	88.863
30	30	15	8	2	85	89.203
26	30	16	9	2	83	89.573
43	26	17	12	2	100	89.963
57	19	7	6	4	93	90.343
47	24	10	4	5	90	90.473
46	34	11	3	4	98	90.863
36	35	13	3	2	89	91.403
35	37	14	3	2	91	91.733
44	32	16	3	2	97	91.933
47	25	15	3	2	92	92.123
48	15	18	3	2	86	92.223
49	4	16	3	2	74	92.303
49	4	16	3	2	74	92.303
59	10	15	3	2	89	92.493
61	10	15	3	2	91	92.793
70	10	15	3	2	100	92.953
65	12	9	3	3	92	93.743
60	14	12	6	2	94	94.243
62	10	12	5	2	91	94.543
66	10	11	3	4	94	95.043
66	7	12	3	4	92	95.193

63	5	9	3	3	83	95.583
62	5	7	3	3	80	95.883
51	26	7	3	2	89	97.283
35	39	9	3	2	88	97.733
29	41	10	4	1	85	98.133
29	41	10	4	1	85	98.133
39	46	11	3	1	100	98.583
39	46	11	3	1	100	98.583
51	15	14	4	1	85	99.123
38	35	13	4	1	91	99.043
51	15	14	4	1	85	99.123
51	15	14	4	1	85	99.123
51	15	14	4	1	85	99.123
51	15	14	4	1	85	99.123
56	7	14	4	1	82	99.153
56	7	14	4	1	82	99.153
56	7	14	4	1	82	99.153
61	7	15	4	1	88	99.303
61	7	15	4	1	88	99.303
61	7	15	4	1	88	99.303
61	7	15	4	1	88	99.303
61	7	15	4	1	88	99.303