Possible Millennial-Scale Climate Cycles and their Effect on Tulare Lake, CA during the Late Pleistocene

By

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Abstract

Tulare Lake level predominantly fluctuates due to varying amounts of runoff from the Sierra Nevada as a result of changes in regional climate. It is important to constrain the details of such change because they allow us to capture the range of natural hydrologic variability for the San Joaquin Valley. This study attempts to extend this record back into the late Pleistocene beyond the past 25 ka reported in previous works. A multi-proxy approach is used including: % total inorganic carbon, % total organic carbon, % nitrogen, CN ratios, granulometry, and magnetic susceptibility. Resulting clay percentages are affected by increases or decreases in Sierran runoff, while low TOC, N, CN, and TIC values throughout the core suggest that Tulare lake was unproductive, sterile, and fresh from resulting glacial stream runoff. Fluctuations in clay % versus depth are found to have similar morphology to the Dansgaard-Oeschgard (D-O) oscillations found in North Atlantic region marine ice cores, wherein increases in clay % correspond with interstadials (warm/deeper lake conditions) and decreases with stadials (cold/lower lake conditions). Samples analyzed from core drives 7-10 of the Tulare Lake TL05-4A core did not result in sufficient ^{14}C for dating. Instead, ages were extrapolated using data from higher in the core. Also, an alternative age model for the sediments of this study was hypothesis-based on the presumed correlation of lake-level with climate conditions associated with the well dated GICC05 Greenland ice core record. The latter hypothesis suggests an age range of 25,000-35,000 cal yr BP and thus predicts the presence of the Mono Lake Excursion (MLE) in the TL05-4A core.

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1. Introduction

Several Northern Hemisphere paleoclimate records indicate the presence of Dansgaard-Oeschgard (D-O) cycles during the late Pleistocene, leading to the suggestion that these events most likely affected the climate of the whole Northern Hemisphere (e.g., Bond et al., 1993); Benson et al., 2003). D-O stadials are most often associated with cold and dry conditions in the Great Basin of the western U.S. while D-O interstadials were associated with warm and wet conditions in the Northern Hemisphere (Benson et al., 2003). Other studies show contrasting results by associating interstadials with cold and dry conditions and stadials with warm and wet conditions (Oster et al., 2014). The working hypothesis for this study is that Tulare lake sediment may record these millennial scale climate changes. To test this hypothesis this study will generate a lake-level proxy record and compare it to the D-O climate oscillations (See Appendix Table 1.1 for a list of approximate D-O ages). In doing so, this study will extend the chronology of the TL05-4A core into the end of marine isotope stage 3(MIS 3) (~29-59 ka) beyond the age range of previous studies (Blunt and Negrini., 2015; Van Grinsven 2015).

1.1 Study Site

Tulare Lake is located in the San Joaquin Valley approximately 60 miles NW of Bakersfield, CA (Figure 1). The lake is currently dry due to stream diversion for agricultural purposes although it was once the largest body of freshwater by area west of the Mississippi River (Davis et al., 1999; Atwater et al., 1986). The present lake bottom elevation of Tulare Lake is ~55 masl and it reached elevations of ~66 masl prior to diversion (Atwater et al., 1986). Its surface area during a historic high stand was 1,600 km^2 corresponding to a water volume of 7 km^3 (Atwater et al., 1986).

1.2 Previous Work

Past studies have demonstrated that Tulare Lake level has fluctuated by several tens of meters over the past hundreds of thousands of years due to regional climate change and changes in the elevation of the lake's spillover sill (Atwater et al., 1986;Davis et al., 1999; Negrini et al., 2006; Blunt, 2013; Blunt and Negrini, 2015; Van Grinsven, 2015). Davis (1999) used pollen to reconstruct late Pleistocene and Holocene Tulare lake level from a core from the lake's depocenter. Negrini et al. (2006) used lithologic description in trenches and mapping of shoreline features to constrain Tulare Lake-level. Blunt et al. (2013) generated a higher resolution lake-level reconstruction for the late Pleistocene and Holocene, with geochemical and geophysical proxy data sampled from a core at 1 cm intervals, representing, on average, ~50 years of deposits per sample.

Other studies completed on Northern Hemisphere terrestrial and marine locations have constrained the effects of millennial-scale global climate events on the western US. A study from an Ocean Drilling Program (ODP) core off the coast of Santa Barbara, CA recorded Dansgaard-Oeschgard (D-O) events from 60- 25 ka based on lithologic descriptions and planktonic foraminifera isotopic and assemblage changes (Hendy and Kennett, 1999). They found that the climatic response correlation between the GISP2 $\delta^{18}O$ core and planktonic foraminifera was evidence of D-O events being a global phenomenon. Kirby et al. (2006) reconstructed the first record of terrestrial based evidence for millennial scale climate variability for Southern California from a core at Baldwin Lake, CA using total carbonate (TC), total organic carbon (TOC), and magnetic susceptibility proxy analyses. This study compared the Baldwin Lake sediment core analyses with the GISP2 $\delta^{18}O$ core and suggested that warm Northern Atlantic interstadials correspond to wet intervals in coastal southwestern North America. Benson et al.

(2003) compared oscillations in changing lake levels of four Great Basin Lakes with Dansgaard-Oeschgard events suggesting D-O stadials were associated with wet conditions as well. All these records support the hypothesis that D-O events affected climate throughout the whole Northern Hemisphere during marine isotope stage 2 (MIS 2) (~10-29 ka) and 3 (MIS 3)(~29-59 ka).

Zic et al. (2002) used an isothermal remanent magnetization (IRM) record from Summer Lake, Oregon and compared it to the GISP2 $\delta^{18}O$ record. A study conducted by Negrini et al. (2000) at the same lake showed that low IRM corresponded with low lake stands. The high stand (high IRM values) or wet periods in Summer Lake matched the time frame for D-O events (Zic et al., 2002). A peak in ^{36}Cl data in the GRIP ice core between D-O events 6 and 7 at ~32 yr BP corresponds with the geomagnetic dipole minimum that is typically associated with the Mono Lake Excursion (MLE) (Wagner et al., 2000). This low intensity of the magnetic field is also present in the Summer Lake record between D-O events 6 and 7 (Zic et al., 2002; Negrini et al., 2014). The detection of this excursion in ^{36}Cl in the GRIP core suggests that the MLE is a global phenomenon and can be used as a time marker to correlate sediment and ice cores (Wagner et al., 2000).

In contrast to the wet interstadial conditions documented by the records discussed above (Hendy and Kennett, 1999; Benson et al., 2003; Kirby et al., 2006), speleothem proxy records from the McLean's cave in the Central Sierra Nevada document changes in precipitation during MIS 3(~29-59 ka) and 4(~59-80 ka), suggesting wetter/colder conditions during northern hemisphere stadials and drier conditions during interstadials (Oster et al., 2014). These records were consistent with foraminifera isotopic and assemblage changes during MIS 3(~29-59 ka) that suggested that stadials were related to a decrease in sea-surface temperature (SST) (Hendy and Kennett, 1999). These drops in SST purportedly result in a strengthened Aleutian low that displaced the North Pacific high-pressure cell to the south, increasing the amount of precipitation to the Sierra Nevada (Oster et al., 2014). Oster et al. (2014), argues that the studies completed in the Great Basin Lakes by Benson et al. (2003) are problematic, as their dating methods are not reliable. They argue that the lake records are too complex and ages are based on cross-correlations between radiocarbon dates and ash layers. Oster et al. (2014) states that using speleothem records results in a more precise and accurately dated paleoclimatic record. Paleomagnetic excursions are a potential solution to the chronology problem. They can be used in combination with tephrochronology and radiometric dating to give an absolute date to lake sediment (Cohen, 2003). For example, there is a possibility of the MLE being present in the bottom of the TL05-4 record, the focus of this these. If so this would result in an absolute age for a segment of the core allowing for more concrete age control.

2. Regional Setting

2.1 Modern Climate

The Central Valley is characterized as a Mediterranean climate, i.e., warm dry summers, and mild wet winters (Null et al., 2010). Unlike the northern and southern parts of California, the Central Valley experiences more extreme temperatures as a result of the Coast Range blocking incoming fog and sea breezes (Preston, 1981). A weakened high pressure system is most common in the winter season, thus providing occasional moisture in the form of Pacific storms during the winter months (Cayan and Peterson, 1989). Most of the precipitation from these storms falls on the windward slope of the Coast Range (Preston, 1981). Therefore, the valley is arid to semi-arid and receives only an average of 13-40 cm/yr of rain (Galloway et al., 1999). The amount of Tulare lake-surface evaporation exceeds the amount of precipitation it receives by

1.0 m/yr. It can then be inferred that the major source of water for Tulare lake is runoff from incoming Sierran streams (Atwater et al., 1986).

2.2 Geological Setting

Tulare Lake formed as part of a contiguous basin in the San Joaquin Valley over the last 2.2 million years (Saleeby et al., 2004). Presently, it is bounded by the Coast Ranges to the west and the Sierra Nevada to the east and is fed by the Kern, Tule, and Kings Rivers, that account for 95% of the runoff for the southern San Joaquin Valley (Figure 2) (Atwater et al., 1986). The depositional environment in the San Joaquin Valley has been mainly nonmarine and has varied from alluvial fan to lacustrine settings (Negrini et al., 2006).The Los Gatos Creek and the Kings River alluvial fans were formed during MIS 2(~23 ka) at the northern boundary of Tulare Lake (Atwater et al., 1986). These coalesced fans serve as dams. Thus, Tulare Lake behaved as a closed basin during the Holocene (Atwater et al., 1986).

3. Methods

3.1 Core Acquisition

Core TL05-4A was extracted from the northwestern part of the Tulare lake bed, ~100 m from Lake Plain Trench A of Negrini et al. (2006). The core consists of ten drives (Figure 3), reaching a depth of 15.1 mbgs and is located at: 36.0066094, -119.936270. Core drives 1-3 of TL05-4A were analyzed by Blunt (2015) and drives 4-6 were analyzed by Van Grinsven (2015). 0-14 cm of TL05-4A core drive 9 was not recovered during the coring process. Core drives TL05-4A-7-10 (9.0-15.1 mbgs) were described, photographed, and sampled every 4-cm for sediment analysis.

3.2 Sediment Analyses

Approximately 1 g of sediment was taken every 4-cm from core drives TL05-4A-7-10 for grain size analysis. Samples were placed into vials along with a solution of 5 mL Calgon and 10 mL deionized water for 24 hours to disaggregate sediment. They were then sieved to < 1mm and sonicated for 5 minutes each to promote further disaggregation. All grain size analysis was done with a Malvern Mastersizer 2000 particle analyzer and followed the technique of Sperazza et al. (2004). Two different analyses were run. The first method splits the sediment solution in order to reach the ideal laser obscuration for analysis. The second method consists of vigorously stirring the remaining solution and removing the suspended fine sediment after with a pipette to allow analysis of the remaining coarse fraction of the grain size distribution. Detrital grain size can be used as a proxy for lake level (Blunt, 2013).

Samples were also analyzed every 4-cm from TL05-4A-7-10 for total inorganic carbon (TIC), total carbon (TC), and nitrogen (N) to determine %TIC and C/N Ratios. TIC was measured using a UIC 5020 Carbon Coulometer CM150 and a UIC CM5230 Acidification module. Prior to TIC, TC, and N analysis samples were dried in an oven at 105 ºC for 24 hours. The dried samples were then ground into a powder with a mortar and pestle, and dried again for another 24 hours. For TIC analysis, ~100 mg of sediment was placed into a silicone cup and acidified. The resulting CO_2 from the reaction in the acidification module was then measured by the coulometer and its mass % was recorded. For TC and N analysis, ~20-25 mg of the ground, dried, sediment was placed into tin cups. The cups were then placed into a Costech 4010 Elemental Analyzer and the sediment underwent a combustion reaction to determine the mass % for TC and N. Total carbonate can be used as a proxy for lake level where high (low) carbonate levels infer low (high) lake levels. This is due to the amount of carbonate precipitation increasing as lake level drops and saturating the water column with calcium and carbonate (e.g., Kirby et al., 2005). To calculate TOC, TIC was subtracted from resulting TC. TOC and N were converted to molar data by dividing each by their molar mass and then TOC/N to determine CN ratios using the equation from McFadden et al. (2005). The source of sedimentary organic matter from terrestrial plants versus aquatic plant sources can be determined by using their CN ratios (Meyers et al., 1999).

3.3 Magnetic Susceptibility

Samples were taken from TL05-4A-7-10 at 4 cm intervals and placed into ~ 5 cc plastic cubes for magnetic susceptibility analysis. All samples were measured with a Bartington MS2 instrument and standardized by mass. Magnetic susceptibility is a measure of the ratio between the magnetization of the magnetic material in a sample and the strength of the inducing magnetic field (Cohen, 2003). The amount of magnetic material in a sample varies depending on the amount of weathering, dilution of magnetic minerals by organic or chemical processes, and the dissolution and the alteration of minerals (Cohen, 2003). Nevertheless, it can provide valuable information about the sediment input and the balance between autochthonous productivity and terrigenous input (Oldfield et al., 2013), though it is imperative to use a multi-proxy analysis alongside magnetic data when attempting to correlate the results with environmental processes.

3.4 Age Control

Five samples were obtained throughout the studied interval core for bulk sediment AMS ^{14}C dating. The spacing between these samples was approximately every 100 cm, as well as a sample taken at the bottom of the core. In the end because none of the samples had insufficient ^{14}C for dating, extrapolation of previous age models constructed from ^{14}C dates on TL05-4A core drives 1-6 from Blunt (2013) and Van Grinsven (2015) were used instead as an attempt to estimate a time frame for this study. Alternatively, the TL05-4A core clay % data was correlated with the Greenland Ice Core Chronology (GICC05) (Svensson et al., 2008), to develop a working chronology hypothesis to supplement the extrapolated chronology. This approach is supported by the observation that, higher in the core, clay % represents lake-level, from which paleoclimates (i.e., precipitation in the Sierra) can be inferred (Blunt & Negrini, 2015).

4. Results

4.1 Core Description

Each core drive of TL05-4A-7-10 is described individually and is reported here from core drive 10 to the shallowest drive, drive 7. The majority of the core is fine-grained ranging from silt to very fine sand and was unusually homogenous through the whole 6 m of the core studied herein. Drive 10 is composed of mostly light brownish gray very fine sand with an exception from 0-19 cm (13.6-13.8 mbgs), where the core consists of fine sand. The color of the core is variegated with brownish yellow oxidation stains throughout the drive. Drive 9 of brownish gray fine sand that is massive throughout the section. Small specks of iron oxides approximately ≤ 0.5 cm in length are distributed throughout the drive. The specks found throughout the drive were oxidized. Drive 8 consists of fine sand to very fine sand and fluctuated slightly in color from light brownish gray to grayish brown. The drive was mostly massive with the exception of 77-80 cm (~11.3 mbgs) that contained carbonate nodules that were also observed under a microscope. Above it, drive 7 is characterized by light yellow gray, very fine massive sand throughout the entire drive.

4.2 Sediment Analyses

Silt and very fine sands dominate throughout the entire core, with two pulses of very fine sands at 10.7 and 13.7 mbgs (Figure 4A). The sediments are predominantly silt from the core bottom to 13.7 mbgs and then are followed by a sudden pulse of very fine sand until 13.5 mbgs (Figure 4B). It then returns to being predominantly silt until another pulse of very fine sand at 10.4-11 mbgs and then reverts to silt until the top of core drive 7 (Figure 4B). The coarse fraction of the grain-size distribution fluctuates from silt to very fine sand with the exception of a pulse of fine sand at 13.7 mbgs (Figure 4C).

TIC, TOC, and N values are low throughout the core with values less than 0.5 % (Figures 4F, 4G, and 4H). An exception to this can be seen at 14.5 mbgs and 15.1 mbgs, where %TC > 1. Consequently, TIC and TOC and C/N values are higher at those intervals. C/N ratios are mostly low as well, with most ratios less than 10 (Figure 4I).

4.3 Magnetic Susceptibility

Magnetic susceptibility results for core drives 7-10 are characterized by low κ (<0.001) and χ ($\leq$3E-4) values with slight variability (Figure 4D and 4E). Most κ values stay within the range of 4E-4 and 6E-4, with the exception of three peaks with values of ~ 1E-3 at depths 10.3 mbgs, 11.3 mbgs, and 11.8 mbgs. Values of χ stay within 1E-4 and 2E-4 with the exception of three peaks with values $\geq$ 3E-4 corresponding to the same depths as the κ value exceptions.

4.4 Proxy comparisons with other TL05-4A records

Two other studies have been completed on the Tulare Lake TL05-4A core by Blunt (2013) and Van Grinsven (2015). Blunt (2013) compared the clay content for core drives TL05-4A drives 1-3 to sea surface temperatures (SST) in the Pacific ocean and discovered that Tulare

Lake clay % followed SST. Blunt (2013) then concluded that Tulare Lake level seems to be driven by NE Pacific SST's during the late Pleistocene and Holocene, where increasing clay % corresponded with an increase in SST's. Van Grinsven (2015) studied core drives 4-6 of TL05-4A and used geochemical analyses to reconstruct Tulare Lake level. Van Grinsven (2015) noticed that the clay % of the oldest part of the record showed a drop in lake-level that may have been connected to D-O event 2 (~ 23-26 ka). The lake-level then decreased during the Tioga Glaciation(~ 15-28 ka). Tulare Lake clay % increased during the late Tioga Glaciation as a result of runoff from melting glaciers and water from the Kings River. Both studies used clay % as a proxy for lake-level and these records conformed with those of similar studies from the region (e.g., figure 5 of Blunt et al., 2015 and figure 8 of Kirby et al., 2015), thus we presume that Tulare Lake will behave the same way back into the Pleistocene; that is clay % will be reflective of lake level and sea surface temperatures.

4.5 Age Control

A hypothesis based on an age-depth model as well as some "wiggle-matching" to the GICC05 core down to 9 mbgs (TL05-4A core drives 4-6) was produced in an earlier study by Van Grinsven (2015). This hypothesis presumes that Tulare Lake was affected by global climate changes and as a result the lithology at Tulare Lake should reflect these events. It is perhaps no surprise then, that a rough comparison between the clay % for TL05-4A-7-10 and the $\delta^{18}O$ record of the GICC05 core revealed a similarity in morphology of the time series between both cores (see Figure 6). Those fluctuations of clay % for core drives 7-10 resemble the typical square-wave shape of D-O oscillations. This new correlation model comparing the bottommost part of the TL04 core suggests a sedimentation rate that is significantly different from that based on the Van Grinsven (2015) radiocarbon constrained age model extrapolated to the base of the

TL05-4A core. The former results in a decreased sedimentation rate below 9 m instead of an unusually rapid sedimentation rate of 4.9 cm/yr as suggested by the Van Grinsven (2015) age model. As a result, the new comparison between the GICC05 core and Tulare Lake clay % implies an older age for the bottom 6 m of the TL05-4A core, extending the record back to 35,000 cal yr BP instead of the suggested 27,500 cal yr BP by Van Grinsven (2015). This accounts for changes in sedimentation rate and thus 6 m of core is no longer condensed into 3,000 yrs and spans a much more reasonable time frame of 9,500 yrs.

5. Discussion and Conclusion

The purpose of this study is to test the hypothesis that Tulare Lake sediment may be affected by D-O events. The following section will summarize and interpret the data for this study, state why clay % can be used as a lake-level proxy, discuss why it's reasonable to correlate the data with GICC05, and propose a hypothesis that may test that preferred model.

Silt and very fine sand were the dominant grain size throughout the TL05-4A core suggesting a lacustrine dominated environment. After establishing an age range for the core from the extrapolation of the Van Grinsven's (2015) chronology (Refer to section 4.5), the clay % record resembles the repetitive saw tooth climatic pattern that is typical of D-O events. Previous studies have demonstrated that Tulare lake level fluctuates as a result of stream discharge from the Sierra Nevada Mountains as evidenced by clay % during the Holocene (Blunt and Negrini, 2015). Tulare Lake level from Blunt (2013) varies similarly to other Tulare Lake studies conducted by Davis (1999) and Negrini et al. (2006) suggesting that clay % does truly follow lake level change in Tulare Lake during this time period. Thus, it is reasonable to infer from these previous studies, that clay % can be used as a proxy for Tulare Lake level and regional precipitation for the remainder of the drives in core TL05-4A. Blunt (2013) also compared the clay content for core drives TL05-4A-1-3 to alkenone sea surface temperatures (SST) and *C. Bulloides* Mg/Ca SST off marine core ODP 1017 (Figure 7). Blunt (2013) concluded that an increase in clay content corresponded with an increase in SST's. Therefore, Tulare Lake level and Sierran runoff was being driven by NE Pacific SST's during the late Pleistocene and Holocene.

During what would be stadial climate conditions of a D-O event, Tulare Lake clay % drops suggesting that the amount of runoff it is receiving from the Sierra's has diminished and as a result lake level is lower. As expected, clay % increases rapidly during possible interstadials, suggesting that the amount of runoff has increased resulting in a deeper Tulare Lake. Very low TOC, N, CN, and TIC values present throughout the core TL05-4A-7-10 further suggest that Tulare lake was unproductive, sterile, and fresh (Cohen, 2003) as a result of glacial stream run off from the Sierra Nevada during this time period as seen by Blunt & Negrini (2015) for the time interval from ~19-15 ka.

In the northern Atlantic region D-O events are transitions back and forth from cold dry stadial conditions (low $\delta^{18}O$ values) to mild wet interstadial (high $\delta^{18}O$ values) conditions (Van Meerbeeck et al., 2009). Various Northern Hemisphere terrestrial (e.g. Zic et al., 2002; Benson et al., 2003; Kirby et al., 2006) and ocean proxy records (e.g. Hendy and Kennett 1999) show the presence of these millennial scale cycles adding additional support to the possibility of Tulare Lake being affected by these climate change signals. These events were once thought to be the result of changes in thermohaline circulation coupled with warming and cooling in the North Atlantic (Cohen, 2003). Recent studies have argued that this explanation does not work because there is no mechanism for the forcing causing changes in thermohaline circulation at this timescale (Petersen et al., 2013). Instead, these latest studies propose that changes in ice shelf and sea ice dynamics in the North Atlantic resulted in the cyclical nature of D-O events (Li et al., 2010). A "teleconnection" in temperature changes between the North Atlantic and the North Pacific may increase the amount of precipitation on Tulare Lake (Benson et al., 1997; Zic et al., 2002; Benson et al., 2003). If this is the case, it would be reasonable to correlate clay % to the GICC05 as they both should be influenced by hemisphere-wide climate events. The extrapolated ages from the GICC05 and clay % comparisons for this study suggest an age range of 25,000-35,000 cal yr BP for TL05-4A-7-10. This hypothesis is testable. If the age range is accurate, the core can be revisited and sampled to analyze for the presence of the 34 Ka Mono Lake Excursion. Declination, inclination, and paleomagnetic intensity features associated with the MLE correspond with a peak in ^{36}Cl values in the Greenland ice core between D-O 6 and 7 (Wagner et al., 2000; Zic et al., 2002) and propagate upwards in time after D-O 5 (Negrini et al., 2014). The predicted location of the MLE in the core is shown in Figure 6. The boundaries corresponding to a depth range of ~ 14.9-13.0 mbgs in the TL05-4 core.

Figures

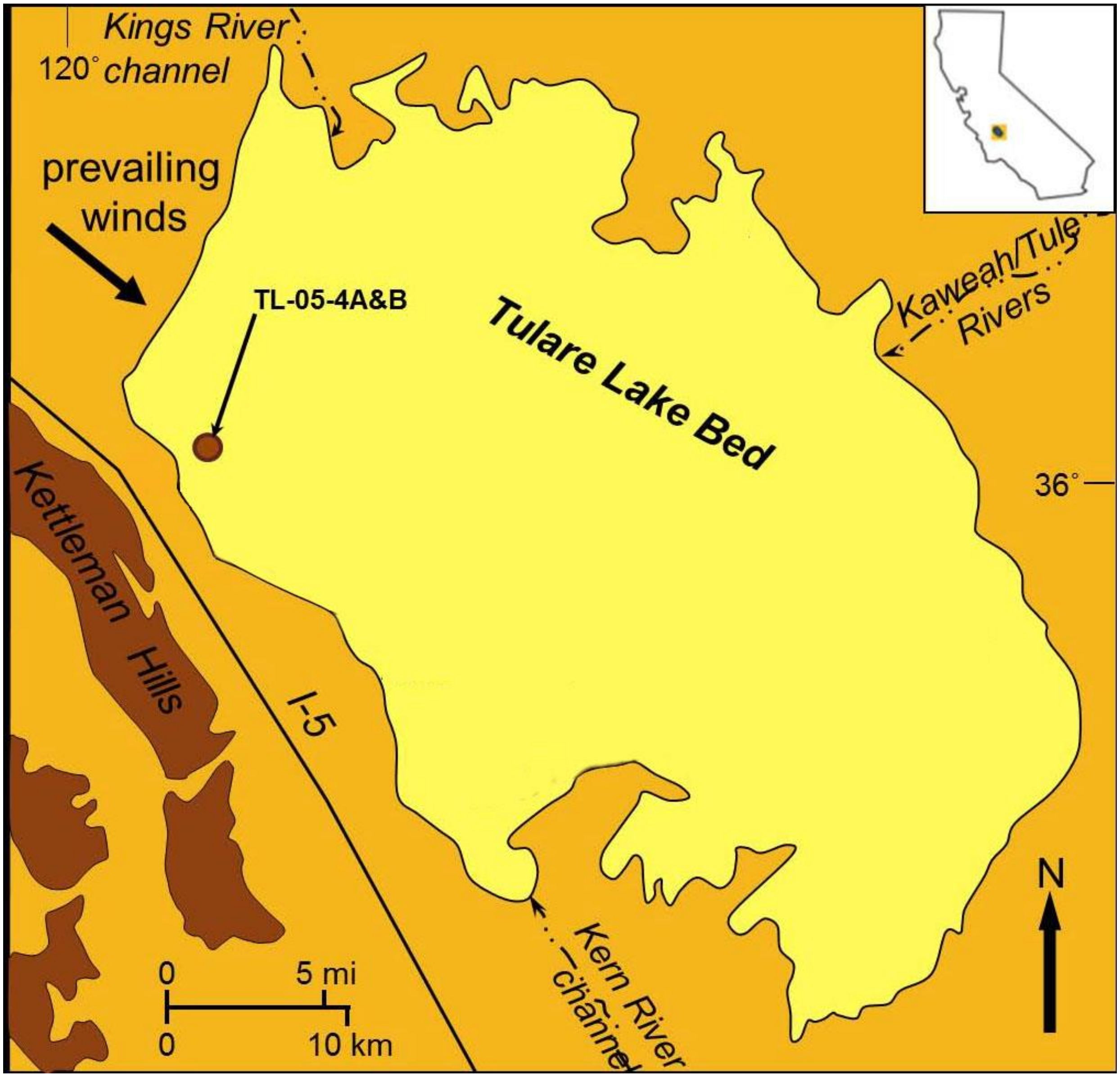

Figure 1. Location map of Tulare Lake showing location of sampled cores. Modified from Negrini et al. (2006).

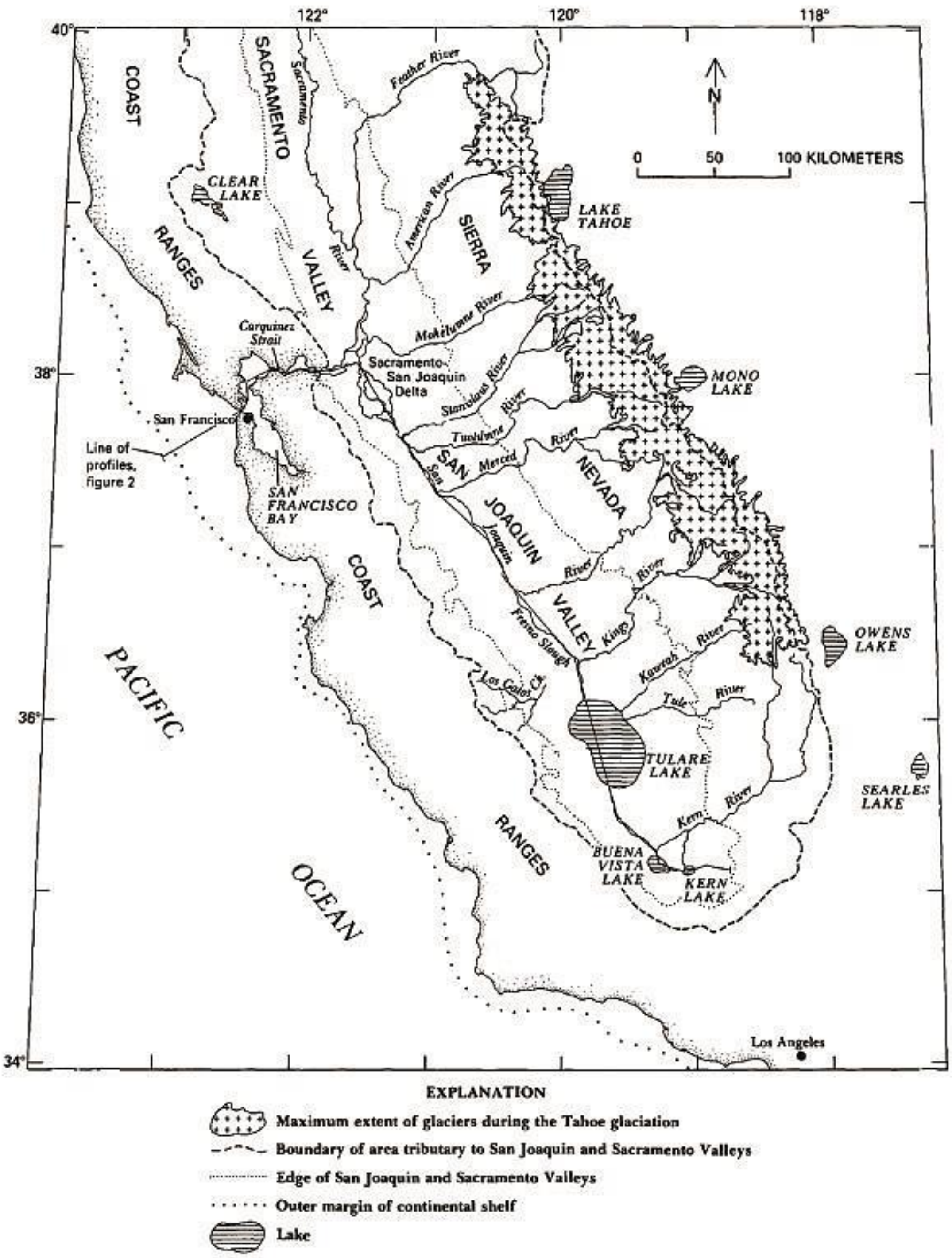

Figure 2. Map of the San Joaquin valley and the maximum extent of glaciers during the Tahoe glaciation. The streams that enter Tulare Lake are the Kaweah, Tule, and Kern. The Kings River did not flow into Tulare Lake before the Tioga glaciation. Modified from Atwater et al. (1986).

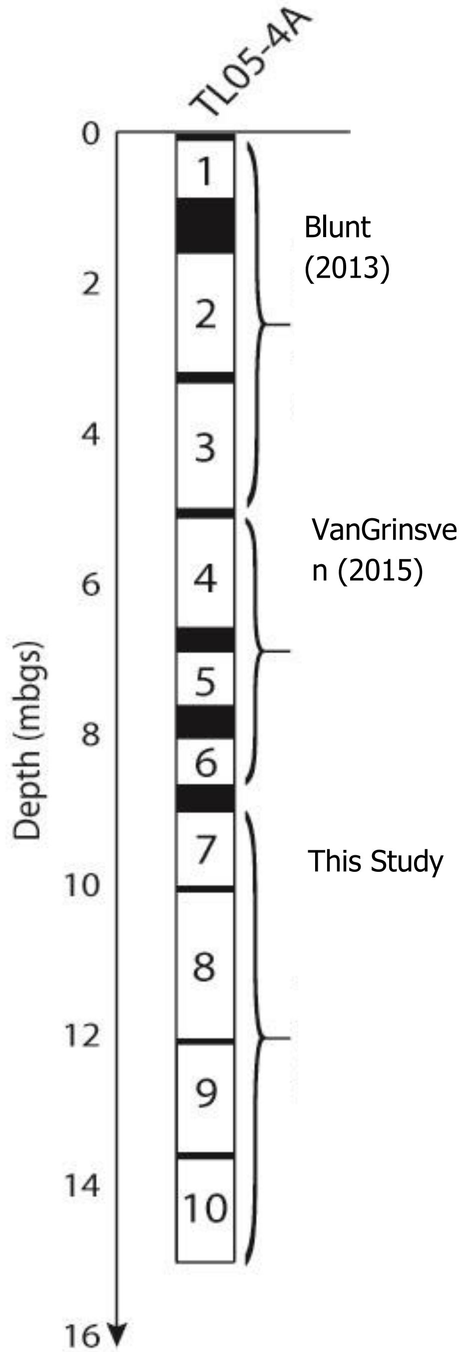

Figure 3. Core illustration showing relative core depth and core drives for core TL05-4A and the extent of this study and previous work. This study includes core drives 7-10 of TL05-4A. Studies completed by Blunt (2013) include drives 1-3 and Van Grinsven (2015) includes drives 4-6.

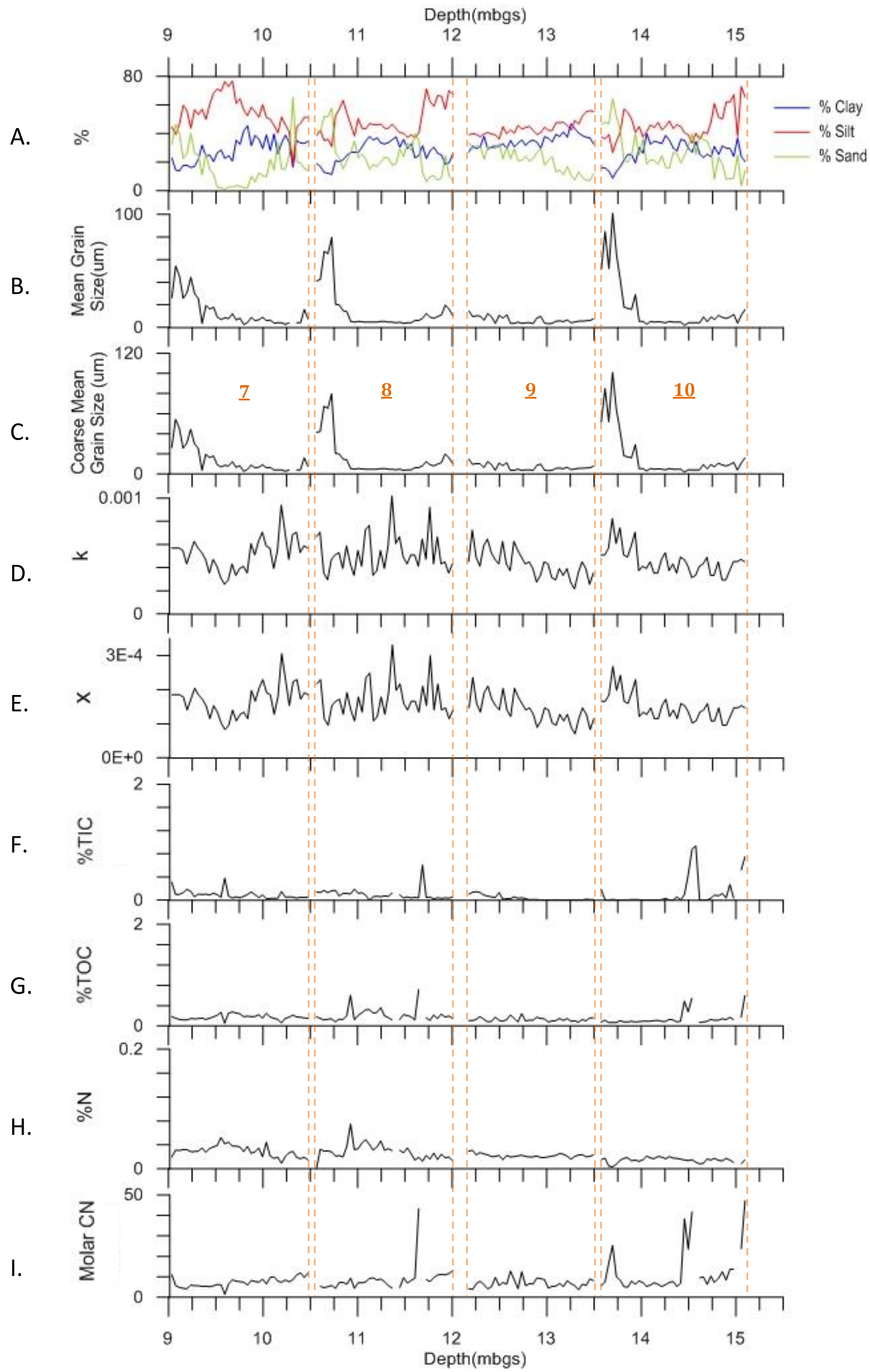

Figure 4.Geochemical and geophysical Proxy data for TL05-4A-7-10 plotted versus depth (mbgs). Drive boundaries (7-10) marked by dashed line. A) Clay, silt, and sand %; B) Mean grain size in micrometers; C) Coarse fraction mean grain size in micrometers; D) Magnetic susceptibility, (cgs); E) Magnetic susceptibility, (gm^{-1}); F) Total inorganic carbon (weight %); G) Total organic carbon (weight %); H) Nitrogen (weight %); I) Molar CN ratio values >10 correspond to terrestrial material; values <10 correspond to aquatic material (Meyers et al., 1999).

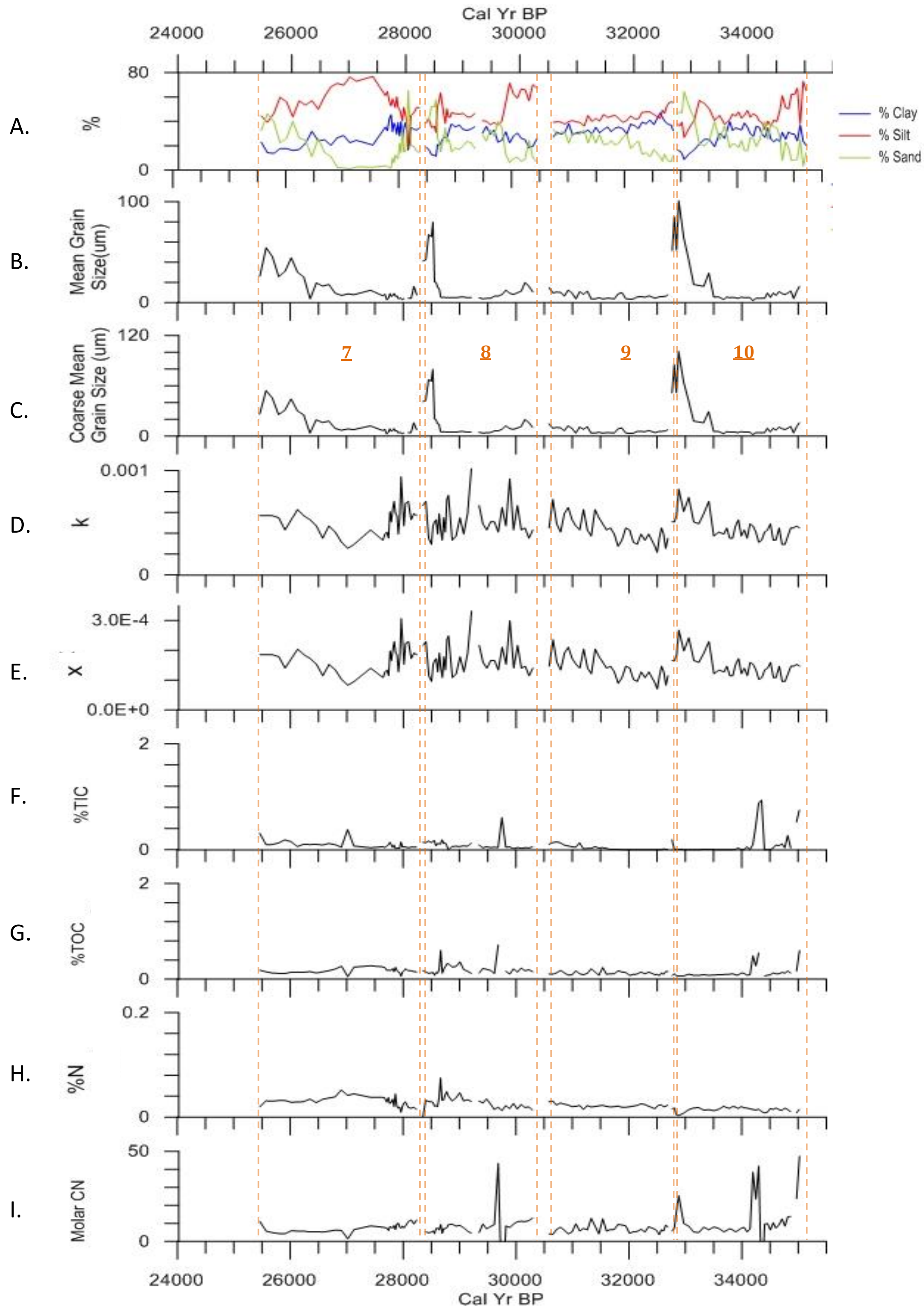

Figure 5. Geochemical and geophysical Proxy data for TL05-4A-7-10 plotted versus cal yr BP. Drive boundaries (7-10) marked by dashed line. A) Clay, silt, and sand %; B) Mean grain size in micrometers; C) Coarse fraction mean grain size in micrometers; D) Magnetic susceptibility, (cgs); E) Magnetic susceptibility, (gm^{-1}); F) Total inorganic carbon (weight %); G) Total organic carbon (weight %); H) Nitrogen (weight %); I) Molar CN ratio values>10 correspond to terrestrial material; values <10 correspond to aquatic material (Meyers et al., 1999).

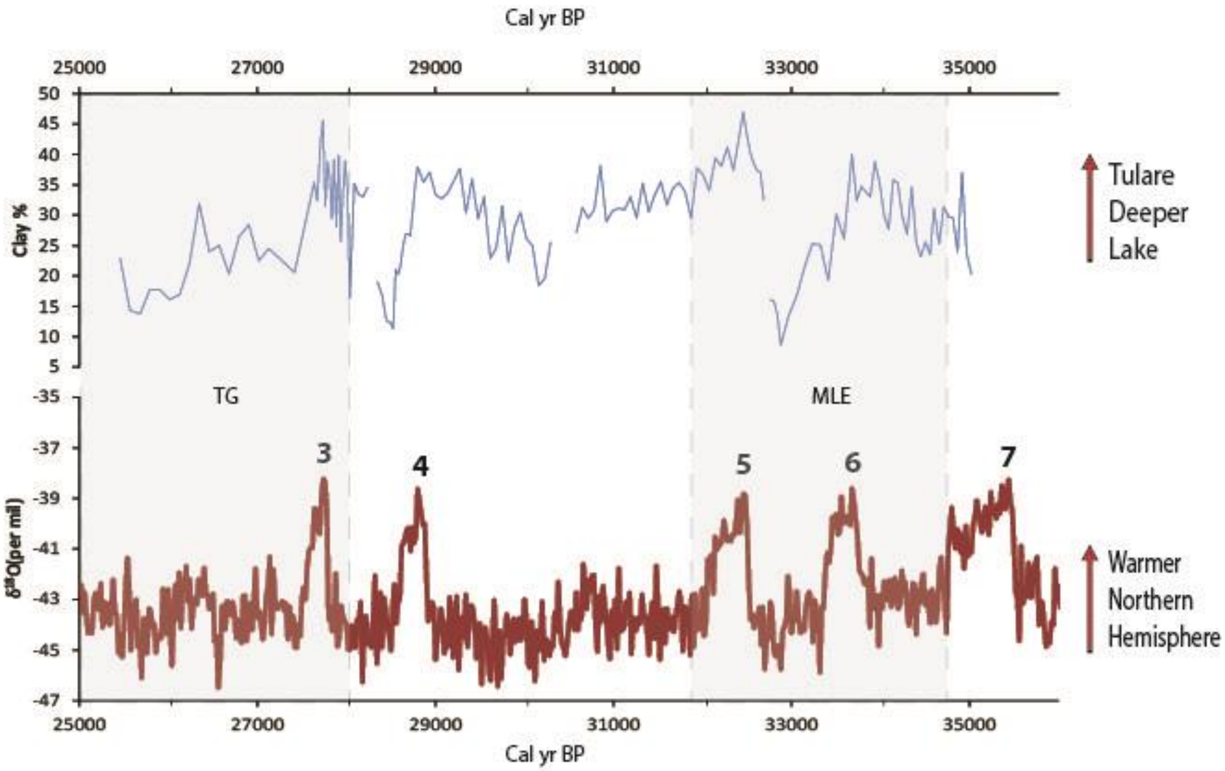

Figure 6 .Plot shows Tulare lake clay % compared to the position of the intensity recorded in the GICC05 ice core between IS #6&7(Wagner et al., 2000) as well as the age of the full vector component record Mono Lake Excursion (MLE) from ~32-35 ka (Negrini et al., 2014), D-O events 3-7(See Appendix Table 1.1 for a list of approximate D-0 ages), and the Tioga Glaciation (TG).

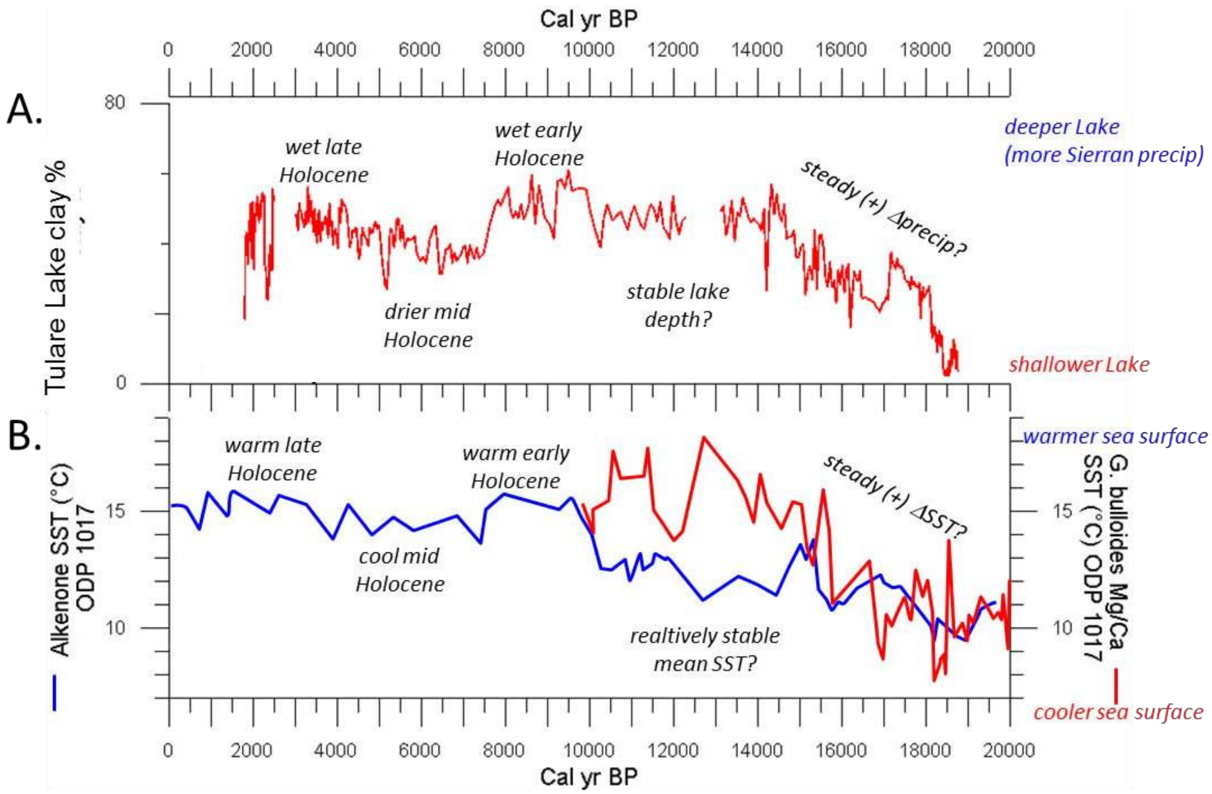

Figure 7.Clay content (A.) compared to Alkenone SST based off ODP 1017E (Seki et al. 2002) in blue and G. bulloides Mg/Ca SST based off ODP 1017(Pak et al. 2012). Tulare lake level seems to be driven by northeast Pacific SSTs during the late Pleistocene and Holocene. Figure from Blunt (2013)

Appendix

Event	Approximate Age (ka)
Sierra Nevada Glaciation	
Tioga Glaciation	15-28
Marine Isotope Stage(MIS)	
MIS 2	10-29
MIS 3	29-59
MIS 4	59-80
Dansgaard Oeschger Events(D-O)	
D-O 2	23-26
D-O 3	27-28
D-O 4	28.5-32
D-O 5	32-33
D-O 6	33.5-34.5
D-O 7	35-37

Table 1.1 Table of approximate ages for glacial millennial climate events mentioned. Modified from Cronin (2009).

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