Biogeography Specialty Group
2003 Graduate Student Research Grant Competition

Cover Sheet

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The proposed study is for: doctoral dissertation

Anticipated date of graduation: August 2003

Title of project: Eastern Colorado Paleoenvironment: A Multi-proxy Approach Using Low Elevation Sites

Amount requested: $700.00

I am a student member of the AAG and the Biogeography Specialty Group

Signature of Applicant: submitted electronically

Date: January 10, 2003

Proof of student eligibility:
I certify that the applicant is currently a graduate student under my supervision and that the proposed project is part of her/his dissertation research.

Name of Advisor: Dr. Don Sullivan Signature: submitted electronically

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Introduction

The purpose of the present proposal is to fund initial analysis and radiocarbon dating of samples from sediment cores that will be used to obtain paleoenvironmental information germane to addressing questions of environmental change during the late Holocene. These cores will come from both high elevation data sources, which are relatively common in the Front Range of Colorado, and more importantly, from much more rare low elevation data sources. Dating and analysis of the continuous sedimentary records from low elevation sources is the most urgent task, and promises to provide information critical for addressing the research questions found below.

Previous paleoenvironmental investigations in the Front Range of Colorado have for the most part involved high elevation data sources, and has focused on obtaining long records documenting the timing of major climatic episodes such as the late Pleistocene deglaciation and the timing and duration of the Younger Dryas episode, with documentation of lesser magnitude temperature and moisture changes of the Holocene given somewhat perfunctory attention. This is due to several factors. The primary research interests of many investigators is focused on the nature and magnitude of climate change associated with the Pleistocene/Holocene boundary, and as such the climate changes of the late Holocene are seen as relatively minor, comparatively speaking, and therefore not nearly as interesting.

Sediment cores from lakes and fens are continuous records and have the potential to provide high resolution data. However, most of the previous investigations using sediment cores on the Front Range used sampling intervals of 5 to 10 cm for sediment and pollen analysis, which did not take full advantage of the information available in these records (Doerner 1994; Maher 1972; Pennak 1963; Short 1985). Depending on sedimentations rates, a 5 to 10 cm sample interval represents data points that are separated by 200 to 600 years. These sampling intervals may not have sufficient resolution to ascertain many of the short-term climatic deviations that information from other regions suggests are characteristic of the late Holocene (Laird et al. 1996). Part of my dissertation research is focused on obtaining high resolution paleoenvironmental data for the late Holocene.

My first research question is “What is the nature of environmental change over the last 3000 years, and can previously undocumented high and low frequency climatic events be discerned using high resolution sampling intervals on continuous sediment records? The last 3000 years in eastern Colorado were an interesting time, environmentally. Unfortunately for investigators interested in paleoenvironment, little data based on continuous records is available. The majority of paleoenvironmental information for the last 3000 years pertaining to low elevations in Colorado is from discontinuous sources, and much of these data suggest that conditions were much more dynamic than implied by high elevation data sources. Dated eolian deposits on the plains of eastern Colorado indicate that there were periods of sufficient aridity to reactivate dune activity and actively transport sand (Forman and Maat 1990; Forman et al. 1992; Gilmore 1991; Madole 1995; McFaul et al. 1995). , and these episodes of aridity became more common after A.D. 1000 (Tate and Gilmore 1999).

This is counter to the information available for higher elevations. In most investigations of Front Range paleoenvironment, discussion of late Holocene environments is limited to short general statements suggesting that for the last 1500 to 3000 years temperature, moisture and vegetation have been essentially modern in character (Doerner 1994; Elias, 1983, 1985; Maher 1972; Pennak 1963; Short 1985). This seeming contradiction between high and low elevation sources deserves investigation.

Which leads directly to my second research question: “Are paleoclimatic events equally discernable in low and high altitude sediment and pollen sources, and are low elevation data sources as useful as high elevation sources?” The utility of high elevation sources for providing millennial scale paleoenvironmental data has been demonstrated. One advantage that high elevation sources have over low elevation sources is that it is not difficult to find a lake or fen that is close to modern treeline, which can potentially produce a sensitive pollen record documenting the vertical movement of treeline in response to changes in temperature and moisture. Although low elevations data sources may in fact prove to be less sensitive to climatic changes as represented in the pollen record, they have an advantage over high elevation data sources in that the information they do provide will be more directly representative of low elevation conditions, and will not necessarily be subject to the same level of interpretation and projection required to extrapolate information from high altitude sources into low elevation environments.

Description of the Proposed Research

In order to determine the timing and nature of short-term climatic deviations, the sediment from several lakes will be sampled. These data should provide the high resolution, time transgressive paleoenvironmental data necessary to address the research questions, and will consist of fossil pollen, percent organic carbon and sediment bulk density, all of which fluctuate as local vegetation and lake environment changes in response to changing environment.

As proxy measures of past environment, organic carbon and bulk density offer complimentary information on temperature and available moisture respectively, especially in the sediments of low elevation lakes where temperature is not as much a limiting factor of vegetation growth as it is at high elevation (Yang 1989). The method for deriving organic carbon and bulk density data is relatively quick and easy and allows for the preliminary identification of periods of paleoclimatic change, which in turn allows greater focus of resources (pollen analysis and radiocarbon dates) on portions of the core that will provide the most important information.

Methods

At this time, three lakes have been identified as data sources. Lake Edith, situated in the glaciated headwaters of Clear Creek at an elevation of 3080 m and Mud Lake, situated at 2550 m in the Boulder Creek drainage will provide high and medium elevation data sources. Palmer Lake is situated at an elevation of 2200 m in the headwaters of Monument Creek on the drainage divide between the Arkansas and Platte River basins. Palmer Lake is possibly the lowest elevation natural lake in eastern Colorado, and has the potential to provide an interesting record.

Preliminary results of organic carbon and bulk density analysis of a 36 cm sediment core from Mud Lake sampled at one centimeter intervals suggest that even relatively short sediment cores from shallow, low elevation lakes of recent origin do contain proxy information pertaining to fluctuations in late Holocene paleoenvironment. These results are comparable to results obtained from analysis of a core from the same lake (Pennak 1963). Pennak sampled his core at 10 centimeter intervals and aggregated six centimeters of the core for each sample, and needless to say, this does not qualify as a high resolution method. However, using radiocarbon dates from Pennak's work allows for the determination of sedimentation rates for the lake. Lake sedimentation rates indicated by these cores range between .006 to .042 cm/yr, and a sampling interval of 0.5 cm would still document episodes of between 12 and 82 years in length for both cores.

A multi-proxy approach like that described above is preferred for the proposed paleoenvironmental research. A multi-proxy approach has the advantage of providing both complimentary and comparative information. As mentioned above, bulk density and organic carbon determinations provide information on moisture and temperature, respectively. Pollen analysis provides both temperature and moisture data, as vegetation is sensitive to both temperature and moisture changes, but at lower elevation is probably most sensitive to changes in moisture. Bulk density, organic carbon and pollen all act as independent checks on the veracity of the paleoenvironmental information derived from sediment cores.

The preliminary results have demonstrated that the cores from these lakes are likely to contain paleoenvironmental information. In order for this information to be placed in a meaningful temporal context, critical sections of cores from each data source need to be dated. This will require at least two radiocarbon ages per core to determine sedimentation rates, and additional dates in order to bracket core sections that exhibit evidence of significant environmental change. Cores from each of the three data sites that have so far been identified will require a minimum of two dates apiece, at a minimum cost of approximately $595 per accelerator mass spectrometry (AMS) date. The $700 grant award would pay for part of two dates on the Palmer Lake core. These preliminary results would allow for a more convincing case to be made to other granting agencies such as the NSF dissertation fund for funding for the additional dates required to complete the research.

Significance of the Proposed Research

The proposed research is significant for several reasons. The methods will provide continuous high resolution paleoenvironmental data for the late Holocene in Colorado, a time period for which little high resolution data exists. It will also provide paleoenvironmental data for the lower elevations of the foothills and plains, geographic regions for which there is little available paleoenvironmental data due to the paucity of data sources. The proposed research will also provide comparable data sets for high and low elevation sources, which will allow comparison of the nature and magnitude of responses associated with different environments to the same climatic episodes, and will test the usefulness of low elevation data sources for providing paleoenvironmental data. Low elevation sources for continuous paleoenvironmental data are rare, and also subject to accelerating anthropogenic impacts that will eventually result in the disappearance of these sites. The proposed research provides a unique opportunity to obtain potentially valuable data regarding low elevation paleoenvironmental change from endangered resources.

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Budget Justification

At least two accelerator mass spectrometry (AMS) dates will be required to place the sedimentary sequence from each of the three lakes into a temporal context and determine sedimentation rates, with additional dates as necessary to bracket portions of the core that exhibit evidence of environmental change. Beta Analytic charges $595 per AMS date, however, it is possible that discounts may be available that lower the price to $415. The minimum cost for the project using the discount rate 6 dates @ $415 per AMS date, for a total of $2490.00. I am requesting funding of $700 from the Biogeography Specialty Group

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Education

2003 Ph.D. Geography, University of Denver. Expected graduation August 2003. Dissertation: *Prehistoric Cultural Ecology and Population Dynamics in the Central Plains: Adaptive Responses to Climate Change.*

1991 M.A. Anthropology. University of Colorado, Boulder. Thesis title: *Bayou Gulch: Geoarchaeology of a Multicomponent Site in Central Colorado.*

1981 B.A. Anthropology. Colorado College, Colorado Springs, Colorado.

Honors and Awards

Colorado Graduate Fellowship from the University of Denver (2000)
Van Riper Scholarship from the University of Colorado Museum (1985).

Publications (peer reviewed)

Colorado Prehistory: A Context for the Platte River Basin (1999). Kevin P. Gilmore, Marcia J. Tate, Mark L. Chenault, Bonnie J. Clark, Terry McBride, and Margaret Wood. University of Utah Press, Salt Lake City.

Papers Presented at Professional Conferences

"Changes in Attitude, Changes in Longitude: Prehistoric Culture Change and Population Increase on the Plains Woodland Periphery." Paper scheduled for presentation at the 99th Annual AAG meeting (2003).

"Postcards from the Edge: The Plains Woodland as Viewed from the Western Periphery". Invited symposium paper scheduled for presentation at the meeting of the Society for American Archaeology, Milwaukee (2003).

"These Boots Were Made For Walking: Moccasin Production, Gender and the Late Prehistoric Hide Working Sequence on the High Plains of Colorado". Scheduled for presentation, Fifth World Archaeology Congress, Washington D.C. (2003).

"Prehistoric Population Dynamics in Eastern Colorado: The Last 2500 Years" (2002). SAA meeting, Denver.

"Paleodemography of Prehistoric Hunter-gatherers in Eastern Colorado" (2002). AAG meeting, Los Angeles.

"Perishable Artifacts and Corn from Franktown Cave (5DA272), Colorado: Paleoclimatic Implications and Late Prehistoric Cultural Adaptations in the Western High Plains" (2001). SAA meeting, New Orleans.

"Geography of the Ancients: Late Prehistoric Population Dynamics in Eastern Colorado" (2001). Colorado Council of Professional Archaeologists, La Junta.

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"The Use of Geotechnical Bridge Foundation Reports in an Archaeological Context: Holocene Alluvial Stratigraphy in Colorado" (1991). Association of Transportation Archaeologists Workshop, Society for American Archaeology, New Orleans.

"Implications for Paleoclimatic Reconstruction and Site Formation Processes based on Eolian Geochronology at the Bayou Gulch Site, Colorado" (1991). Paper presented at the 56th Annual Meeting of the Society for American Archaeology, New Orleans.

Question 1. How would you write a grant proposal for your doctoral research? What rationale would you give for the research, and how would you explain why this research is needed?

Prehistoric Population Dynamics, Culture Change and Paleoenvironment: A Multi-proxy Approach Using Low Elevation Data Sources

By Kevin Gilmore

Introduction

The relationship between prehistoric population dynamics, culture change and environment is a topic that is of great interest to archaeologists and environmental scientists. Although cultural systems are dynamic and adaptive, there are many examples of prehistoric population decline and culture change that coincides with climatic deterioration, which suggests that cultural responses involving economic change may be insufficient to maintain population levels. Although it invokes the specter of environmental determinism, it is arguable that climatic deterioration should not be overlooked as a proximate cause of prehistoric population decline, migration and culture change around the world (Brenner et al. 2001; Gill 2000; Jones et al. 1999; Weiss and Bradley 2001). More recently, questions have been raised concerning the patterns of prehistoric population growth, decline and movement in eastern Colorado, and what influence (if any) environment and climate change had on population dynamics.

Population Background

Archaeologists working in eastern Colorado have recognized a pattern in which Early Ceramic Period (AD 150-1150, 1850-800 BP) radiocarbon dates dramatically increase in number over the previous Late Archaic Period (1000 BC–AD 150, 3000-1850 BP) and then decrease dramatically over the course of the subsequent Middle Ceramic Period (AD 1150-1540, 800-400 BP). This pattern has been the topic of much speculation, and archaeologists have cautiously suggested that this increase in radiocarbon ages is related to an increase in prehistoric population, although this conclusion has never been systematically investigated, and these conclusions have always been qualified by discussion of alternative sources for the observed pattern such as changes in settlement pattern, changes in technology and subsistence, and geomorphological explanations that may have lead to greater visibility or preservation of Early Ceramic sites compared to other periods.

However, this pattern is not limited to eastern Colorado. In addition to the compiled radiocarbon data from eastern Colorado (Gilmore et al. 1999; Zier and Kalasz 1999), examination of both relative and absolute temporal data from the upper Colorado River Basin (Reed and Metcalf 1999), the Lower Colorado River basin (Lipe et al. 1999), the Rio Grande River basin (Martorano et al. 1999), and Wyoming (Frison 1991), reveals a region-wide pattern that suggests that the distribution of radiocarbon ages through time can be used with some caution as a proxy for prehistoric population trends, which in turn can be used to examine questions of prehistoric population geography and its relationship to paleoenvironment in the Platte and Arkansas river basins of eastern Colorado. It is our contention that the patterns of proxy population increase and decrease may be in response to changes in climate that resulted in in greater or lesser environmental productivity.

The distribution through time of radiocarbon ages from the various regions of Colorado and Wyoming all follow a similar pattern, and the geometry of the respective distribution curves is remarkably similar between the different areas. The number of radiocarbon ages in areas for which a large number of radiocarbon ages are available (The Platte, Arkansas and Northern Colorado river basins) and Wyoming significantly increase at approximately 2200 BP, and peaks between 1300 and 1000 BP. The peaks in the radiocarbon frequency curves for the Platte River Basin (Figure 1) occurs between 1300 and 1200 B.P., the peak in the Arkansas curve occurs between 1100 and 1000 BP (Figure 2). The 200 year offset in peak population between the Platte and Arkansas basins may indicate that hypothesized climatic deterioration in the Platte basin preceded that in the Arkansas basin, and that one possible adaptive response of a portion of the population of the Platte basin was migration into the Arkansas basin.

There are also interesting suggestions of a shift in population from higher to lower elevation through time in the Platte basin. Examination of the frequency of radiocarbon ages by sub-region based on elevation (Figure 3) provides detail that is glossed over by the regional frequency curve. Proxy population in the Mountains sub-region (>2320 m) peaks between 1600 and 1200 B.P., in the Hogbacks/Foothills sub-region (1830-2320 m) between 1300 and 1200 B.P., and on the Plains (<1830 m) between 900 and 800 B.P. Evidence from above tree line in the Colorado Front Range which forms the headwaters of the Platte River, suggests that population in the mountains increases during periods of aridity on the Plains, and conversely population in the mountains decreases during periods of increased snowfall and persistence of snow cover, both of which represent a dominance of upslope conditions (Benedict 1999). The dominance of upslope conditions would also result in greater moisture on the Plains. Although there are complementary short-term fluctuations in proxy population between the three sub-regions representing both upslope and downslope movement, the long-term trend during the Late Prehistoric reflects a progressive shift of population from the Mountains and Hogbacks/Foothills regions down onto the Plains as conditions became warmer and moister during the Neo-Atlantic climatic episode. The Plains experienced historically high population right at the end of the Early Ceramic period, ca. 900-800 B.P.

The purpose of the present proposal is to fund initial analysis and radiocarbon dating of samples from sediment cores that will be used to obtain paleoenvironmental information germane to addressing questions of prehistoric population dynamics in the Platte and Arkansas basins. These cores will come from both high elevation data sources, which are relatively common in the Front Range of Colorado, and more importantly, from much more rare low elevation data sources. Dating and analysis of the continuous sedimentary records from low elevation sources is the most urgent task, and promises to provide information critical for addressing the research questions.

Paleoenvironmental Background

Previous paleoenvironmental investigations in the Front Range of Colorado have for the most part involved high elevation data sources, and has focused on the obtaining long records documenting the timing of major climatic episodes such as the late Pleistocene deglaciation and the timing and duration of the Younger Dryas episode, with documentation of lesser magnitude temperature and moisture changes of the Holocene given somewhat perfunctory attention. This is due to several factors. The primary research interests of many investigators is focused on the nature and magnitude of climate change associated with the Pleistocene/Holocene boundary, and as such the climate changes of the middle and late Holocene are seen as relatively minor, comparatively speaking, and therefore not nearly as interesting. Another factor is that many studies rely on discontinuous records such as fossil insects (Elias 1983, 1985, 1995: Elias and Toolin 1990) or eolian stratigraphy (Forman et al. 1992; Gilmore 1991; McFaul et al. 1995;

Madole 1995), which although useful, do not provide information at a level of resolution that can be used to address questions of short term environmental change.

Sediment cores from lakes and fens are continuous records and have the potential to provide high resolution data. However, most of the investigations using sediment cores on the Front Range did not take full advantage of the available record by using a 5 to 10 cm sample interval for analysis, which represents data points that are separated by 200 to 600 years, depending on sedimentation rates (Doerner 1994; Maher 1972; Pennak 1963; Short 1985). These sampling intervals may not have sufficient resolution to ascertain many of the short-term climatic deviations that information from other regions suggests are characteristic of the middle to late Holocene (Laird et al. 1996). Needless to say, this level of resolution may be sufficient to satisfy the research needs of investigators interested in determining long-range climatic trends on a century scale of resolution, but it is insufficient to effectively document shorter climatic deviations that could potentially have great effect on human population dynamics and culture change of the sort discussed above. In fact, in most investigations of Front Range paleoenvironment, discussion of the last 3000-4000 years is limited to short general statements suggesting that conditions for the last 1500 to 3000 years, temperature, moisture and vegetation have been essentially modern in character (Doerner 1994; Elias, 1983, 1985; Maher 1972; Pennak 1963; Short 1985).

Major Research Topics

What is the nature of environmental change over the last 3000 years, and can previously undocumented high and low frequency climatic events be discerned using high resolution sampling intervals on continuous sediment records? The last 3000 years in eastern Colorado were an interesting time. As discussed above, it was a period in which prehistoric population grew precipitously and then decreased just as quickly, and it was also a period in which many social, technological and economic innovations occurred, such as the introduction of the bow and arrow and ceramics, increased intensification of natural resources and eventually the adoption of limited agriculture, and group size may have increased, and mobility decreased. Unfortunately for archaeologists interested in paleoenvironment, little data based on continuous records is available. The majority of paleoenvironmental information from low elevations that is available for the last 3000 years in Colorado is from discontinuous sources and suggests that conditions were much more dynamic than is suggested by statements that modern vegetation had been established by 3000 to 1500 years ago. Dated eolian deposits in eastern Colorado indicate that there were periods of sufficient aridity to reactivate dune activity and actively transport sand (Forman et al. 1992; Gilmore 1991; McFaul et al. 1995; Madole 1995). This is especially true after A.D. 1000 (Tate and Gilmore 1999). Elsewhere in western North America there is evidence of extended droughts in the ninth and thirteenth centuries that caused wide-spread population movement, population decrease, and regional abandonment beginning in the ninth century and lasting until the thirteenth century (Jones et al. 1999).

Is there correlation between paleoenvironmental episodes, demographic events and prehistoric culture change in eastern Colorado? The period of population growth in eastern Colorado begins just prior to the start of the Early Ceramic Period, which is defined archaeologically by the appearance of ceramics and the bow and arrow. Coincident with population growth during the Early Ceramic period, there is an apparent intensification of the use of wild resources and toward the end of the period corn appears in the archaeological record. Many theories seeking to explain how the change from hunting-gathering to food production occurred are a variation on a theme, explaining origins and subsequent intensification as a response (at least in part) to population pressure (Binford 1968; Boserup 1965; Cohen 1977), or population "packing" within environmentally or socially circumscribed areas (Binford 1983). Other theories explain the initial domestication of plants or the adoption of domesticates from elsewhere as an outgrowth of individual motivations toward the acquisition of social prestige within the context of increasing social complexity (Hayden 1992), or as a hedge against possible fluctuations in the availability of wild food staples (Minnis 1985; Will 1992). Minnis points out that in the Southwest the initial introduction of domesticated plants was "a monumental nonevent with little immediate impact on native human populations" and cultigens were integrated into a hunting-gathering economy for a thousand years before having an effect on the economy or the sociocultural structure of society (1985:310).

Population packing is a possible explanation for the adoption of agriculture in eastern Colorado. Although the transition between the Early and Middle ceramic periods occurs during a period when population in the Platte Basin as a whole is apparently decreasing rapidly from a peak in the middle of the Early Ceramic period, between 1300-1200 B.P., A.D. 650-1000 (Figure 1), examination of the distribution of radiocarbon ages by elevational sub-region suggests that the transition between the Early and the Middle Ceramic periods took place right around the peak of population on the plains in the Platte basin. Compared to the Early Ceramic, the number of identified Middle Ceramic components drops precipitously, and the frequency of radiocarbon ages from this period also drops, both of which suggest a rapid decrease in population (Gilmore 1999:7). Some investigators view the switch from hunting-gathering to the adoption of agricultural systems as representing a quantum increase in the amount of energy devoted to subsistence activities, and that this increase in energy expenditure would only have occurred in situations of population disequilibrium within the natural environment which would result in resource stress (Binford 1983). Could this indicate disequalibrium in the Platte basin associated with climatic deterioration?

Are paleoclimatic events equally discernable in low and high altitude data sources? Are low elevation data sources as useful as high elevation sources? The utility of high elevation sources of continuous paleoenvironmental data has been demonstrated, and many of these records extend well into the late Pleistocene. Potential high elevation sources are relatively common, due to geology and water availability in the mountains, among other factors. One advantage that high elevation sources have over low elevation sources is that it is not difficult to find a lake or fen that is close to modern treeline, which can potentially produce a sensitive pollen record documenting the vertical movement of treeline in response to changes in temperature and moisture. This begs the question; can low elevation data sources supply the same sort of sensitivity to environmental change? Although low elevations data sources may in fact prove to be less sensitive to climatic changes as represented in the pollen record, they have an advantage over high elevation data sources in that the information they do provide will be more directly representative of low elevation conditions, and will not necessarily be subject to the same level of interpretation and projection required to extrapolate information from high altitude sources into low elevation environments.

Although few radiocarbon ages are available for the Late Prehistoric Stage in the in the Rio Grande basin, the number of sites (n=222) cross dated to the relatively short Late Prehistoric Stage (AD 500-1600) is equal to the number of sites cross-dated to the entire Archaic Stage (5500 BC-AD 500) (Martorano et al. 1999). This concentration of components within the relatively short Late Prehistoric Stage (1100 years) compared to the much greater dispersion of the same number of components during a much longer Archaic Stage (6000 years) suggests an increase similar to that observed in the other Colorado context areas and Wyoming.

Methods

The source of most continuous, time transgressive paleoenvironmental data has been sediment cores from lakes and fens. Multiple proxy methods for deriving paleoenvironmental data from lake cores exist, including both biotic and abiotic methods. Biotic methods include pollen analysis, diatom analysis, and analysis of fossil insects and determination of organic carbon content. Abiotic methods include bulk density and particle size distribution of sediments and varves in glaciated areas.

The properties of lacustrine and fen sediments have been demonstrated to be sensitive to environmental changes, and therefore especially useful as proxies for past climate change. Two properties of sediments that have been demonstrated as sensitive to climate change are the percentage of organic carbon and sediment bulk density.

Changes in the percentage of organic carbon in lacustrine sediments represent changes in the productivity of biomass in the lake, which is in turn related to changes in temperature. Increasing organic carbon in lake sediments have been shown to reflect increases in temperature (Yang 1988), with decreases in organic carbon representing decrease in temperature and lake production or greater inorganic sediment influx (Mayle et al. 1997). Although it has been argued that most of the organic matter in lake sediments originates in soils within the drainage basin and is therefore is not representative of lake production (Mackereth 1966 cited in Drummond 1999), recent research suggests that the majority of organic matter in temperate lakes is autochthonous, and does represent lake production (Gorham et al. 1974; Dean and Gorham 1998, cited in Drummond 1999).

Changes in the bulk density of lake sediments can either represent changes in the rate of inorganic sediment influx or a decrease in the production of organic carbon, or both of these processes. As a general rule, bulk density is often inversely proportional to organic carbon in sediments, and often accompanies an increase in sedimentation rate. Sediments can enter lake basins in several ways. Sediments can be transported into lakes by surface streams, by overland flow or by mass wasting events affecting hillslopes surrounding the basin, or as fine textured sediments transported by eolian action. As a mechanism for transporting sediment into a lake, mass wasting events can introduce significant amounts of sediment into a lake, but the signature of these events in the sediment record should be easily identified by the nature of the sediments, which should reflect the high intensity-low frequency character of these events.

Increase in sedimentation rate and increase in bulk density of lacustrine sediments is a function of sediment availability for both fluvial and eolian transport, which should be related to vegetation cover. Eolian activity is associated with both cold-arid and warm-arid conditions (Forman and Maat 1990). At high elevations and latitudes, increased eolian transport should correlate with episodes of increased aridity and cold temperatures, and at low elevations increased eolian transport should be associated with episodes of increased aridity and possibly higher temperatures. Similarly, increased fluvial transport of sediments should be a function of vegetation cover on hillslopes of the drainage basin. Denuded hillslopes would have the dual function of making more sediment available for transport as well as increasing both runoff and discharge associated with storm episodes, which would serve to increase the competency of streams in the watershed. At any elevation then, increased bulk density in lacustrine sediments should be associated with periods of increased aridity, regardless of whether the source of the sediment is from fluvial or eolian processes. Determining the source of sediments would depend on the physical characteristics of particles, the particle size distribution and how well sorted the sediments are.

As proxy measures of past environment, organic carbon and bulk density offer complimentary information on temperature and available moisture respectively, especially in the sediments of low elevation lakes where temperature is not as much a limiting factor of vegetation growth as it is at high elevation.

The method for deriving organic carbon and bulk density data from sediment samples is relatively quick and easy and allows for the preliminary identification of periods of paleoclimatic change, which in turn allows greater focus of resources on portions of the core that are more likely to provide useful information. This allows for a more efficient use of both time (represented by time intensive techniques like pollen analysis) and money (AMS dates) by focusing on periods of environmental change.

Description of the Proposed Research

In order to determine the timing and nature of short-term climatic deviations that may have influenced cultural change and population dynamics, the sediment from several lakes will be sampled. The acquisition of high resolution, time transgressive paleoenvironmental data will provide a critical component to the study of climate and its influence on prehistoric peoples. These data will come from sediment cores from both high and low elevation lakes and fens, and consist of fossil pollen, percent organic carbon and sediment bulk density, all of which fluctuate as local vegetation and lake environment changes in response to changing environment. Ideally, a series of data sources describing both a north-south transect between the Platte basin and the Arkansas basin would provide evidence of the timing of the hypothesized north to south transgression of the boundary between westerly and monsoonal flow that is thought to have occurred at the transition between the Neo-Atlantic and Pacific climatic episodes (ca. A.D. 1150-1200 A.D.). These data sources should also provide evidence of the length and severity of any climatic deviations coincident with the Medieval Climatic Anomaly (A.D. 800-1350) reported for Western North America (Jones et al. 1999). A comparison of high and low elevation data points could also provide evidence of how climatic deviations are expressed at different elevations as well as provide environmental context for the apparent population shift from the mountains to the Plains that occurred between A.D. 600 and 1025.

At this time, three lakes have been identified as potential data sources. All three of the lakes are situated in the Platte basin. Lake Edith, situated in the headwaters of Clear Creek at an elevation of xxxx m and Mud Lake, situated at 2550 m in the Boulder Creek drainage will provide high and medium elevation data sources. Palmer Lake is situated at an elevation of 2200 m in the headwaters of Monument Creek at the drainage divide between the Arkansas and Platte River basins. Palmer Lake is possibly the lowest elevation lake in eastern Colorado, and has the potential to provide an interesting record.

Methods

Preliminary results of organic carbon and bulk density analysis of a 36 cm sediment core from Mud Lake sampled at one centimeter intervals suggest that even relatively short sediment cores from shallow, low elevation lakes of recent origin do contain proxy information pertaining to fluctuations in late Holocene paleoenvironment (Figure 4). The organic carbon curve correlates generally to the gross pattern of the percent organic carbon of an 86 cm core recovered by Pennak from the same lake, called "Muskee Lake" in his original article (1963). Penetration of both cores ended at a coarse textured inorganic sediment. Pennak sampled his core at 10 centimeter intervals and aggregated six centimeters of the core for each sample. Needless to say, this does not qualify as a high resolution method by any stretch of the imagination. However, because the general trends between our core and Pennak's core are similar, we will assume that both cores represent the same period of time with different rates of deposition, which allows for the use of Pennak's radiocarbon dates for making general statements about sedimentation rates and the nature of environment during the past 4300 years, based on Pennak's basal radiocarbon age (Figure 5).

Sedimentation rates in Pennak's core ranged between .042 cm/yr in the lower part of the core to .014 cm/yr in the upper part of the core, which translates into 24-71 years per cm. Based on the radiocarbon ages that Pennak (1963) acquired for the core he collected, estimated sedimentation rates in the recent core of Mud Lake range between .020 and .006 cm/yr, which translates to between 50 and 166 years per cm. Low sedimentation rates would necessitate decreased sample intervals to recover high resolution data. A sampling interval of .5 cm would still document episodes of between 25 and 82 years in length for the shorter core, and 12 to 35 years in the longer core. (Here is where we insert the preliminary results from the cores from Palmer Lake, Lake Edith, and a low elevation lake or fen in the Arkansas basin to be named later.)

A multi-proxy approach like that described above is preferred for the proposed paleoenvironmental research. A multi-proxy approach has the advantage of providing both complimentary and comparative information. As mentioned above, bulk density and organic carbon determinations provide information on moisture and temperature, respectively. Pollen can detect both temperature and moisture changes, but at lower elevation is probably most sensitive to changes in moisture. Bulk density, organic carbon and pollen all act as independent checks on the veracity of the paleoenvironmental information derived from sediment cores.

The preliminary results have demonstrated that the cores from these lakes contain paleoenvironmental information. In order for this information to be placed in a meaningful temporal context, critical sections of cores from each data source need to be dated. This will require x number of dates to accomplish these goals. In support of the proposed research , we are asking NSF for X amount of money ($$ per date) for the xx number of AMS dates required to complete the research.

Significance of the Proposed Research

The research proposed here is significant for several important reasons. The methods will provide continuous high resolution paleoenvironmental data for the middle to late Holocene, a time period for which little high resolution data exists. It will also provide paleoenvironmental data for a geographic region for which there is little available paleoenvironmental data, let alson continuous high resolution records. The proposed research will provide the environmental context within which questions of prehistoric population dynamics and culture change can be addressed. It will also provide comparable data sets for high and low elevation sources, which will allow comparison of the type and magnitude of responses associated with different environments to the same climatic episodes, and will test the usefulness of low elevation data sources for providing paleoenvironmental data. Low elevation sources for continuous paleoenvironmental data are rare, and the proposed research provides a unique opportunity to obtain potentially valuable data regarding low elevation paleoenvironmental change.

Potential low elevation data sources are rare compared to potential high elevation sources. This is due to several factors. The first concerns the differences in geology and geomorphology between the glaciated igneous rocks at higher elevations of the Rocky Mountains and the non-glaciated foothills and plains regions that are mostly underlain by sedimentary bedrock or unconsolidated Quaternary deposits. The second reason is the lower precipitation at lower elevations in a semi-arid climate. Finally, due to proximity to area of high human population density, there is a high probability that the rare, permanent water sources associated with low elevation lakes and fens have already been developed, have dried up due to lowered water tables, or otherwise modified through human action during the last 140 years of Euroamerican occupation, thus destroying the associated sedimentary record. All of these factors contribute to the urgency of sampling these unique sources of paleoenvironmental data before they disappear.

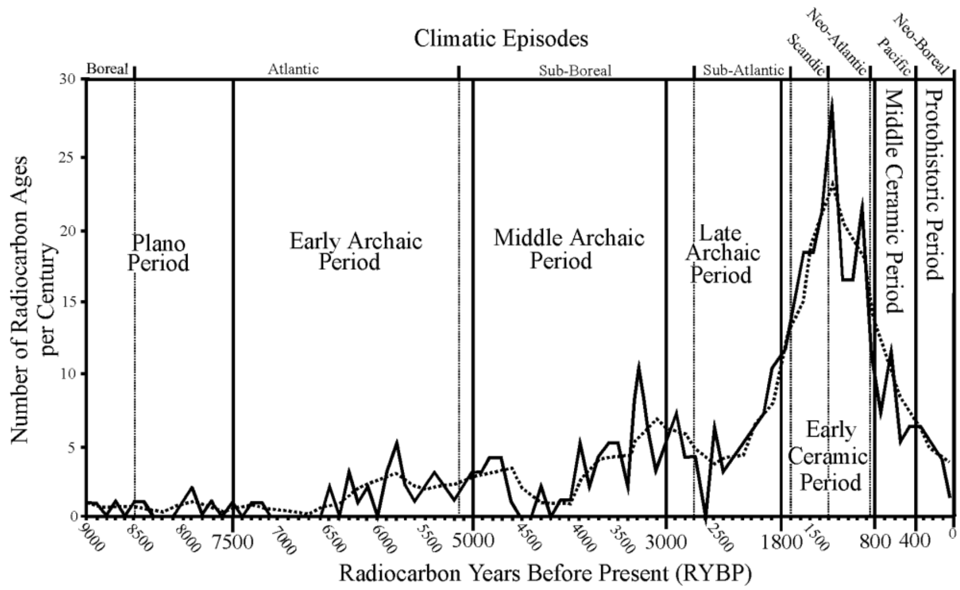


Figure 1. Distribution of radiocarbon ages in the Platte River Basin with cultural periods and climatic episodes. Adapted from Gilmore et al. (1999), Figure 1-2.

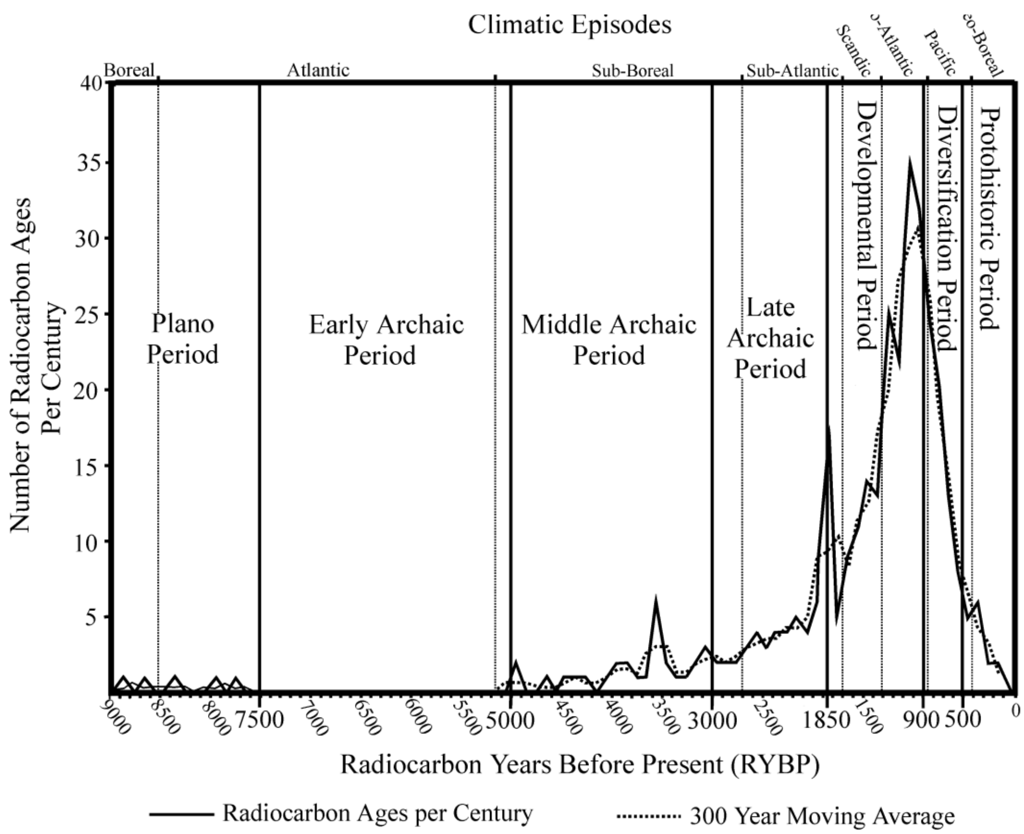


Figure 2. Distribution of prehistoric radiocarbon ages in the Arkansas River Basin with cultural periods and climatic episodes. Graph of data in Zier and Kalasz (1999), Appendix A.

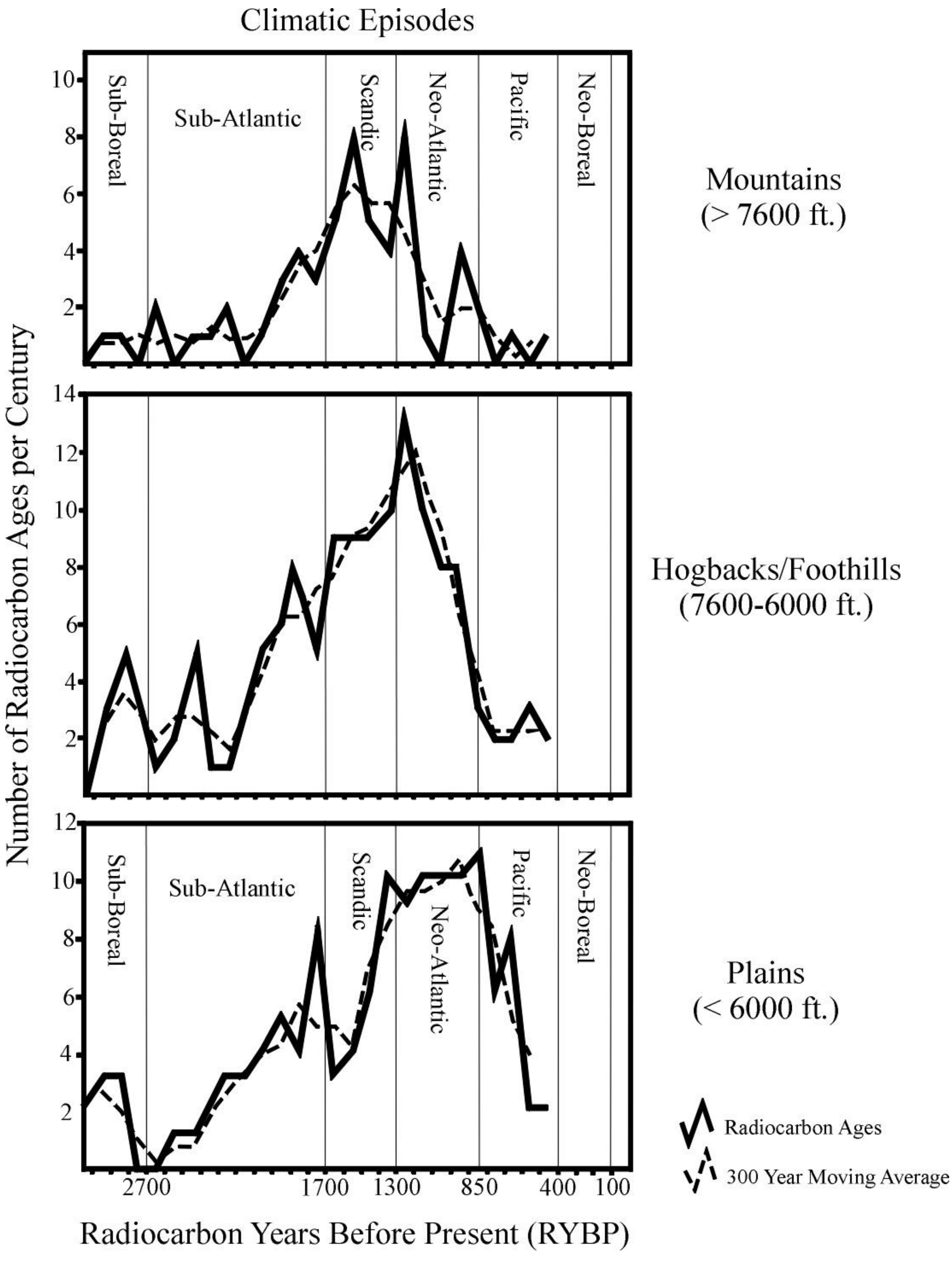


Figure 3. Frequency of radiocarbon ages per century by elevational sub-region in the Platte River Basin of Colorado, with paleoclimatic episodes shown.

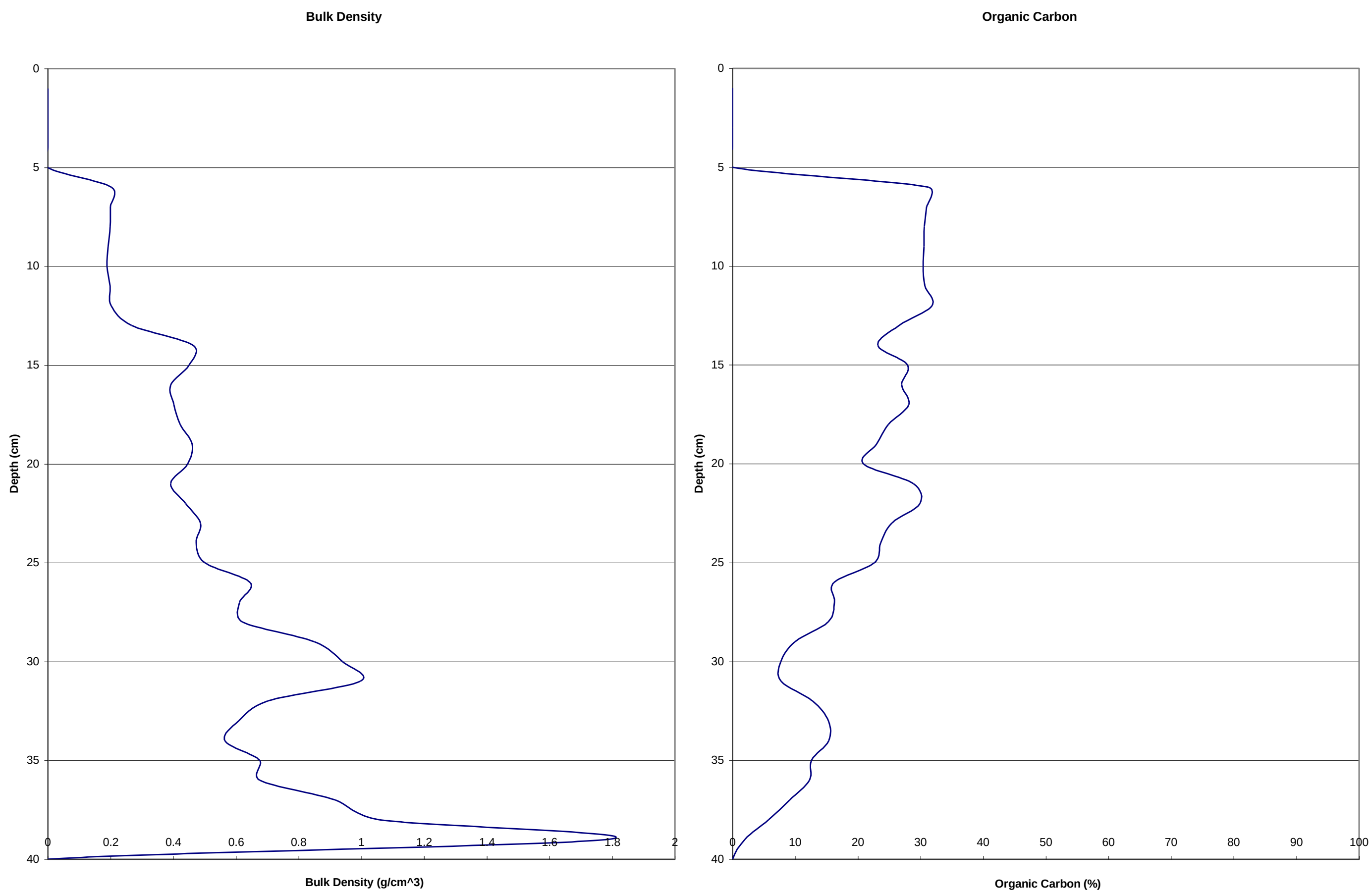


Figure 4. Side by side comparison of the bulk density and organic carbon values for the recent sediment core from Mud Lake. The upper 5 cm was soft and somewhat deformed, and therefore the flattening of the curve at this point is thought to reflect mixing and homogenization of the strata. The peak in bulk density centered on 30 cm is not completely reflected in the organic carbon curve, which may indicate a period of increased aridity and eolian activity.

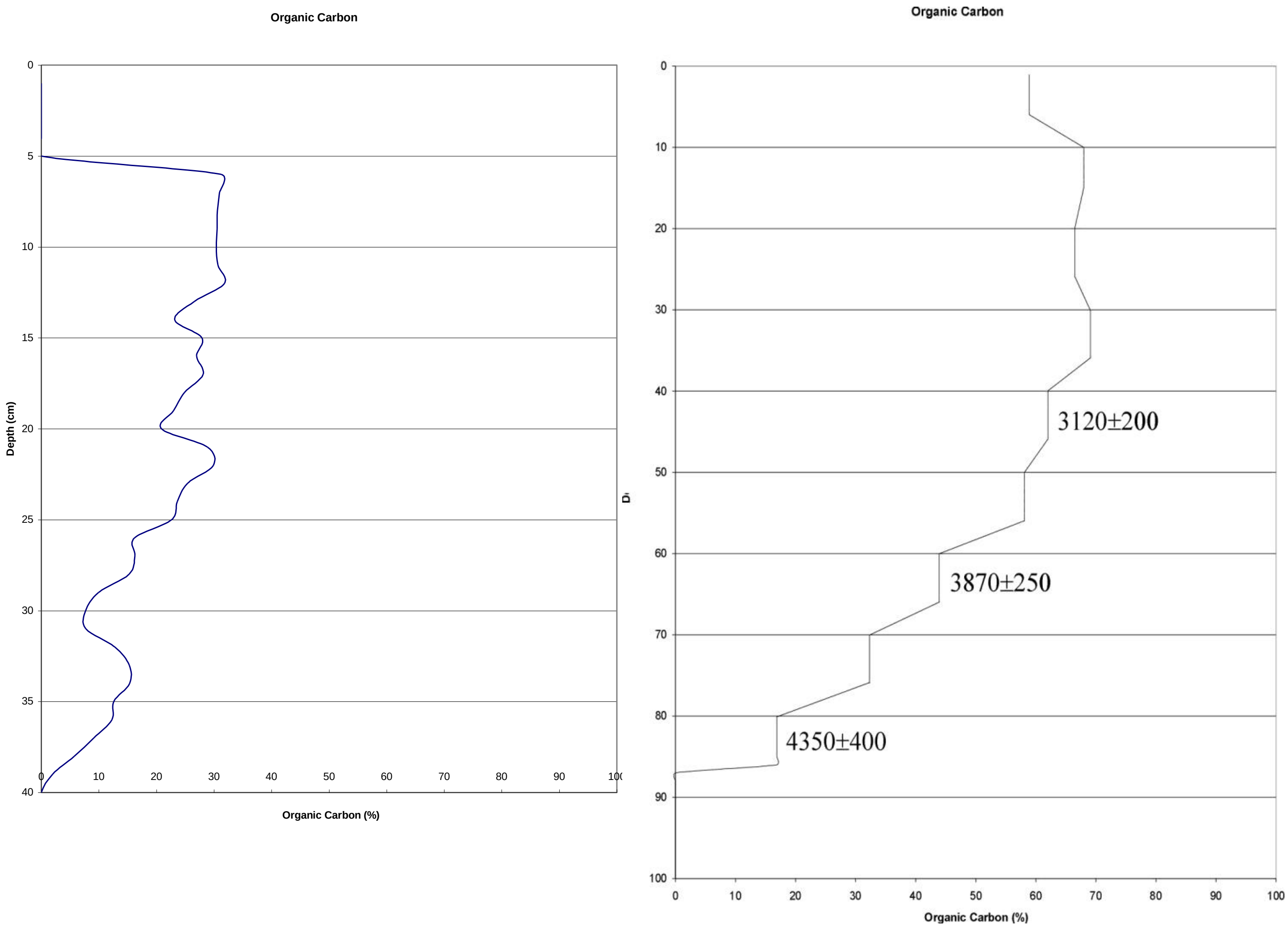
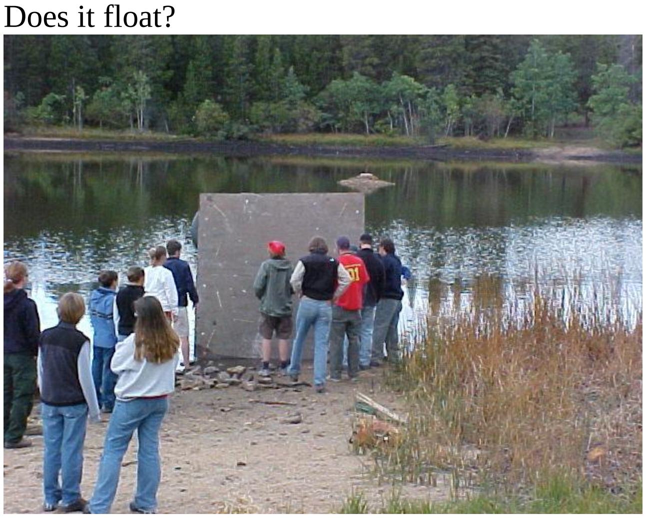


Figure 5. Side by side comparison of the 1 cm sample interval organic carbon determinations from the recent Mud Lake core (left) to the graphed results of the 10 cm interval, 6 cm sample aggregate organic carbon determinations from the "Muskee Lake" (Mud Lake) core of Pennak (1963, right), with radiocarbon dates from the original report. The general trends in the data suggest that both cores were measuring the same period of time in parts of the lake in which the sedimentation rate was much lower in the area where the recent core was located. The Y axis of the graph of Pennak's data has been shortened to allow comparison.

Mud Lake coring project 9/12/02 by Univ. of Den.
Platform building

Still building

Does it float?



Moving to coring location

Taking the core sample