Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

Project Information

1. **Proposal Title:**

   Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

2. **Proposal applicants:**

   Braddock Linsley, State University of New York, Albany

3. **Corresponding Contact Person:**

   Braddock Linsley
   The Research Foundation of State University of New York on behalf of University at Albany, State University of New York
   ES 351, Earth and Atmospheric Sciences University at Albany, SUNY 1400 Washington Avenue
   Albany, NY 12222
   518 442-4478
   blinsley@albany.edu

4. **Project Keywords:**

   Climate Change
   Hydrology
   Water Resource Management

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Natural Flow Regimes

8. **Type of applicant:**

   Private non-profit

9. **Location - GIS coordinates:**

Latitude:

Longitude:

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Will use hydrologic tracers preserved in sediments in Walker Lake Nevada to reconstruct century and multi-decadal scael severe droughts in the Sierra Nevada and San Francisco Bay areas over the last 2000 years.

10. **Location - Ecozone:**

    3.1 Keswick Dam to Red Bluff Diversion Dam, 3.2 Red Bluff Diversion Dam to Chico Landing, 3.3 Chico Landing to Colusa, 3.4 Colusa to Verona, 3.5 Verona to Sacramento, 4.1 Clear Creek, 4.2 Cow Creek, 4.3 Bear Creek, 4.4 Battle Creek, 5.1 Upper Cottonwood Creek, 5.2 Lower Cottonwood Creek, 6.1 Stony Creek, 6.2 Elder Creek, 6.3 Thomas Creek, 6.4 Colusa Basin, 7.1 Paynes Creek, 7.2 Antelope Creek, 7.3 Mill Creek, 7.4 Deer Creek, 7.5 Big Chico Creek, 7.6 Butte Creek, 7.7 Butte Sink, 8.1 Feather River, 8.2 Yuba River, 8.3 Bear River and Honcut Creek, 8.4 Sutter Bypass, 9.1 American Basin, 9.2 Lower American River, 10.1 Cache Creek, 10.2 Putah Creek, 10.3 Solano, 10.4 Willow Slough, 12.1 Vernalis to Merced River, 12.2 Merced River to Mendota Pool, 12.3 Mendota Pool to Gravelly Ford, 12.4 Gravelly Ford to Friant Dam, 13.1 Stanislaus River, 13.2 Tuolumne River, 13.3 Merced River, West San Joaquin Basin, 1.1 North Delta, 1.2 East Delta, 1.3 South Delta, 1.4 Central and West Delta, 11.1 Cosumnes River, 11.2 Mokelumne River, 11.3 Calaveras River, 2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.3 Sonoma Creek, 2.4 Petaluma River, 2.5 San Pablo Bay, Code 15: Landscape, Code 16: Inside ERP Geographic Scope, but outside ERP Ecozones

11. **Location - County:**

    Other

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    21

15. **Location:**

California State Senate District Number: N/A

California Assembly District Number: N/A

16. **How many years of funding are you requesting?**

    3

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

    No

    If no, list single overhead rate and total requested funds:

Single Overhead Rate:	49.9% of $138,569
Total Requested Funds:	$214,752

    b) Do you have cost share partners already identified?

    No

    c) Do you have potential cost share partners?

    No

    d) Are you specifically seeking non-federal cost share funds through this solicitation?

    No

    If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

    No

    Have you previously received funding from CALFED for other projects not listed above?

    No

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

    No

    Have you previously received funding from CVPIA for other projects not listed above?

    No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

No

Please list suggested reviewers for your proposal. (optional)

Dr. David Hodell	**University of Florida, Gainesville**	**dhodell@geology.ufl.edu**

21. **Comments:**

Because the laboratory work will be primarily carried out in New York there are not any relevant California Legislative districts.

Environmental Compliance Checklist

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No

   b) Will this project require compliance with NEPA?

      No

   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      Project will use hydrologic tracers preserved in previously collected sediment cores from Walker Lake Nevada to reconstruct century and multi-decadal scale severe droughts in the Sierra Nevada and San Francisco Bay areas over the last 2000 years. Project will mostly involved laboratory analyses and computer modeling and to my knowledge will be outside of CEQA and NEPA jurisdication.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   CEQA Lead Agency: none
   NEPA Lead Agency (or co-lead:) none
   NEPA Co-Lead Agency (if applicable): none

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   XCategorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   -none

   NEPA
   XCategorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   -none

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

Not Applicable

b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land.
Agency Name:

Permission to access state land.
Agency Name:

Permission to access federal land.
Agency Name:

Permission to access private land.
Landowner Name:

6. **Comments.**

Land Use Checklist

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   No

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only

4. **Comments.**

   none

Conflict of Interest Checklist

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Braddock Linsley, State University of New York, Albany

Subcontractor(s):

Are specific subcontractors identified in this proposal? No

Helped with proposal development:

Are there persons who helped with proposal development?

Yes

If yes, please list the name(s) and organization(s):

Dr. Larry Benson USGS, Boulder CO

Dr. Scott Mensing University of Nevada

Dr.Steve Lund University of Southern California

Dr. Michaela Kashgarian Lawrence Livermore National Laboratory

Comments:

None

Budget Summary

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

Federal Funds

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary** ***(per year)***	**Benefits** ***(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
01	Project Research	15 months	42,642	4,603	3,200	200			24,410	75055.0	34,292	109347.00
		0	42642.00	4603.00	3200.00	200.00	0.00	0.00	24410.00	75055.00	34292.00	109347.00

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary** ***(per year)***	**Benefits** ***(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
01	Project Research	15 months	37,816	4,369	2,800	200			12,000	57185.0	28,184	85369.00
		0	37816.00	4369.00	2800.00	200.00	0.00	0.00	12000.00	57185.00	28184.00	85369.00

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary** ***(per year)***	**Benefits** ***(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
01	Project Research	1 month	8,176	1,390	2,800				1,000	13366.0	6,670	20036.00
		0	8176.00	1390.00	2800.00	0.00	0.00	0.00	1000.00	13366.00	6670.00	20036.00

Grand Total=214752.00

Comments.

Budget Justification

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

Direct Labor Hours. Provide estimated hours proposed for each individual.

Dr. Linsley will devote one summer month (in each year of this 3 year project) to the proposed research. He will also devote approximately 0.5 months during the each academic year. Dr. Mensing will devote one summer month in Years 1 and 2. Dr. Lund's postdoctoral associate will devote one summer month in Years 1 and 2. Mr. Yuan will devote 12 months in Years 1 and 2.

Salary. Provide estimated rate of compensation proposed for each individual.

Dr. B.K. Linsley will be the principal investigator (P.I.) and will be responsible for coordinating and completing all aspects of this research. At the University at Albany-SUNY, he will supervise the data generation and interpretation as well as facilitate collaboration with Dr. Mensing (UNR), and Dr. Lund (USC), and Dr. Benson (USGS), who will be assisting in various aspects of the project at no cost to the project (see text). Dr. Linsley is requesting 1 month of summer salary support for each year of this 3 year project ($7,059 Year 1; $7,862 Year 2; $8,176 Year 3). He will spend at least 5% of his time during the academic year on the project. Dr. Scott Mensing (University of Nevada-Reno) will be performing pollen extractions for radiocarbon dating and down-core pollen analyses as part of this project. We request 1 month of summer support for Dr. Mensing in years 1 and 2 ($7,500 each year). Support for an academic year research assistantship and summer salary is requested for Fasong Yuan for years 1 and 2 ($18,000 each year). Mr. Yuan is a Ph.D. candidate in the Department of Earth and Atmospheric Sciences at the University at Albany-SUNY. Tuition is requested for the first year at 18 credit hours per year ($6,333). In the second year Mr. Yuan will have completed all requirements for candidacy and will, therefore, be eligible to register for only 1 research credit per semester with accompanying savings to the budget (Year 2 tuition $704). Fasong Yuan's dissertation research will involve core description and sampling, isotopic analysis of TIC and ostracods, and interpretation of data related to this project. To assist with paleomagnetic and rock magnetic work at the University of Southern California, one month of postdoctoral support is requested for years 1 and 2 ($3,750 each year).

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

Fringe benefits are charged according to The Research Foundation's negotiated indirect cost rate agreement with the Department of Health and Human Services dated 6/14/01. (Dr. Linsley 16.5% years 1 and 2, 17% year 3; Dr. Mensing and Dr. Lund's postdoctoral associate 16.5% years 1 and 2; Mr. Yuan 6.5% years 1 and 2)

Travel. Provide purpose and estimate costs for all non-local travel.

In the first year of the project $2,000 is requested to cover costs associated with travel by a University at Albany graduate student (Fasong Yuan) to the USGS facility in Boulder, Colorado, to analyze core samples by X-ray diffraction to identify carbonate minerals present. In the second and third years of the project $1,600 is requested to cover Dr. Linsley's costs associated with presenting preliminary results at a national scientific meeting (GSA or AGU). These costs include airfare, hotel, per diem, and registration fees. In addition $1200 per year ($3600 total) is requested to cover costs associated with orally presenting results at annual CALFED review meetings in California.

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

$200 is requested in years 1 and 2 for supplies to be used for the analyses described in Other Direct Costs.

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

Dr. Lund (USC) and Dr. Benson (USGS) will be assisting in various aspects of the project at no cost to the project (see text).

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

None

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

In the third year $1,000 has been budgeted to cover page charge costs for publishing the results of this research in the scientific literature.

Other Direct Costs. Provide any other direct costs not already covered.

(1.) Dr. Steve Lund (USC, see attached letter) will direct all needed paleomagnetic and rock magnetic measurements in support of this project. Dr. Lund will carry out a paleomagnetic study of secular variation (PSV) recorded in the 2 longest cores (5.45m and 4.66m) to develop an independent chronology. One month of postdoctoral support is requested for years 1 and 2 to support this important task (see personnel section above). $200 per year is requested for supplies. Year 1: $200 Year 2: $200 (2.) Pollen extraction (12,000 grains each) from 12 samples ($300 each) for AMS radiocarbon (14C) dating. Work to be done by Dr. Scott Mensing at UNR (see attached letter). Year 1: $2,000 Year 2: $1,600 (3.) AMS Radiocarbon analyses of pollen (12 samples) and TOC fraction (12 samples). We prefer to send these very small samples to the Lawrence Livermore AMS Laboratory as they have previous experience working with small pollen samples. Alternatively, the University of Arizona AMS facility can complete the analyses. AMS radiocarbon analyses of pollen or total organic samples cost $400 per analysis. Year 1: $6,400 (16 samples) Year 2: $3,200 (8 samples) (4.) 137Cs and 210Pb dating of collected box cores and core tops for comparison to the historical record: Analyses to be performed by either Dr. Pete Swarzenski at the USGS Coastal Studies Group or Dr. Jack Dibb at the University of New Hampshire. Year 1: $2,000 Year 2: $1,000 (5.) X-ray diffraction identification of dominant carbonate minerals present down core. We will analyze samples at 10-cm intervals, with closer sampling across mineralogic boundaries. This work to be done at the USGS facility in Boulder by University at Albany graduate student Fasong Yuan. We anticipate this will take approximately 1 week. Year 1: $750 (6.) An automated coulometer will be used to analyze %TIC and %TOC of 570 samples from core WLC 001. WLC 002 has already been analyzed. Work to be done in the laboratory of Dr. Peter deMenocal at Lamont Doherty Earth Observatory of Columbia University. 570 total samples at $3.00 each = $1,710 Year 1: $1,710 (7.) Stable isotope analyses of carbonates at SUNY-Albany charged at a rate of $15.00 per sample. To include paired analyses of bulk carbonate and Ostracods where possible, and only bulk carbonate where ostracods are not present. Year 1: 570

TIC samples for d18O and d13C 200 Ostracod samples for d18O and d13C Year 2: 200 TIC samples for d18O and d13C 200 Ostracod samples for d18O and d13C Isotope totals (cost includes 10% replication) Year 1: 770 analyses at $15 each =$11,550 Year 2: 400 analyses at $15 each =$6,000

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

Indirect costs are charged according to The Research Foundation's negotiated indirect cost rate agreement with the Department of Health and Human Services dated 6/14/01. The rate is 49.9% of modified total direct costs (MTDC). University at Albany-SUNY Cost Sharing: The University at Albany supports a half-time (50% per week; 20-30 hours) stable isotope technician (Mr. Steve Howe). Mr. Howe has over 20 years of mass spectrometer operation and maintenance experience and his services will be in direct support of this project.

Executive Summary

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

Executive Summary Drought in the Sierra Nevada dramatically reduces river discharge on both sides of the Sierra crest, including the majority of rivers that feed the San Francisco Bay area. Because of this hydrologic setting, sediments preserved in closed-basin lakes to the east of the Sierra Nevada can be used to reconstruct the past recurrence of droughts in the San Francisco Bay-Delta region, one of the stated objectives of the CALFED San Francisco Bay-San Joaquin Delta Ecosystem Restoration Program. In a sediment record from Pyramid Lake (Nevada), Benson et al., (in press) have documented 18 extreme and persistent droughts over the past 2,800 years by analyzing the oxygen isotopic composition of total inorganic carbon (TIC). However, because the Pyramid Lake basin is hydrologically complex, questions remain regarding the regional extent and timing of these droughts. To develop a better understanding of the regional significance of the Pyramid Lake drought record and other paleo-drought records from the region, we are proposing to develop two high-resolution records of severe droughts from Walker Lake (Nevada) using newly collected sediment cores. Over the past century annual river discharge into both Walker and Pyramid Lakes is highly correlated, thus we expect to observe a similar response to Sierra Nevada droughts in both basins. As part of a preliminary feasibility study (unfunded) we have completed %TIC, and oxygen isotope analyses of the TIC fraction in one of the cores. This record reveals a pattern of repeated and apparently century-scale droughts in the Walker Lake basin. However we have not had the financial resources to develop accurate age models for these cores that would allow us to correlate with other paleo-drought records and evaluate recurrence intervals. Here we are proposing an analytical program that will: (1) Complete analyses of %TIC and oxygen and carbon isotopes of TIC in the second core (WLC-001), analyze bulk carbonate mineralogy, %Organic Carbon (TOC), oxygen isotopes of ostracod shells (where possible), and downcore pollen variations back to ~2,000 yr. B.P. (2) Develop accurate age control using radiocarbon dates of pollen and the TOC fraction. We will also collaborate with Dr. S. Lund (USC) in the analysis of paleomagnetic secular variation to independently date these cores. Based on our preliminary results we expect to generate a well-dated, two-core composite record of hydrologic changes and droughts in Walker Lake that will allow a test of the regional significance of century-scale Sierra Nevada droughts. Accurate documentation of the timing and recurrence interval of droughts in the Sierra Nevada will ultimately assist in the development of a better understanding of regional and global climate conditions responsible for initiating persistent century-scale droughts in the Bay-Delta region.

Proposal

State University of New York, Albany

Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years

Braddock Linsley, State University of New York, Albany

Introduction and Overview

Documentation of past climatic and hydrologic variability in the Bay-Delta watershed is one primary objective of the CALFED San Francisco Bay-San Joaquin Delta Ecosystem Restoration Program. In particular, reconstructing hydrologic conditions in the Bay-Delta watershed during the "epic" medieval droughts of the last 2,000 years is a clearly stated objective (see multi-region priority# 4). Objectives to be addressed include documenting the recurrence interval, severity, and persistence of extreme century and multi-decadal scale droughts in the Bay-Delta region.

Addressing these objectives will require the generation of detailed records of past climatic and hydrologic variability in this region over the last several thousand years. The Sierra Nevada is California's most important catchment with up to 2000mm of precipitation at the crest. This catchment supplies two thirds of the states developed surface water supply and even a higher fraction of the Bay-Delta regions water supply. Because the Bay-Delta watershed is dependent on Sierra precipitation, changes in Sierra rainfall and snowpack will directly impact the hydrologic budget of the Bay-Delta region by reducing discharge in westward flowing rivers that feed the Central Valley and San Francisco Bay areas. Directly to the east of the Sierra Nevada, the hydrologic budget of several closed-basin lakes is also dependent on Sierra Nevada snow-melt into rivers flowing eastward from the Sierra crest (see Figure 1 and Table 1). For example, the r^2-correlation coefficient between annual discharges on the Yuba (western Sierra) and Walker Rivers (eastern Sierra) is 0.86, and between the Yuba and Carson Rivers is 0.91. Because of this setting, droughts in the Sierra Nevada will directly reduce river discharge on both sides of the Sierra Nevada at the same time. Closed basin lake levels in California and Nevada to the east of the Sierra crest whose primary water source is Sierra snowmelt will drop during regional-scale Sierra Nevada droughts. Thus, reconstruction of closed basin lake levels can be used to assess drought frequency and severity in the Bay-Delta region.

The goal of this proposed research is to develop a record of multi-decadal and century-scale lake-level variations from Walker Lake using geochemical tracers in sediments cores spanning the last several thousand years for comparison to other proxy drought records from the region. Walker Lake is a closed basin lake in Nevada that is recharged almost entirely from the Sierra Nevada (for location see Figure 1). This proposed work will allow a more rigorous assessment of drought recurrence intervals and amplitudes in the Sierra Nevada and Bay-Delta regions over the past approximately 2000 years. Based on our preliminary measurements of the oxygen isotopic ($\delta^{18}O$) composition of total inorganic carbon (TIC) in Walker Lake sediments we conclude that multiple century-scale droughts have occurred in this watershed and the Sierra Nevada over the last 2000 years. This is also the conclusion of other researchers working in the region (LaMarche, 1974; Graumlich, 1993; Stine, 1990; 1994; Hughes and Graumlich, 1996; Meko et al., 1999). Most recently, Benson et al., (1999; and in press) have developed a TIC $\delta^{18}O$ record from Pyramid Lake sediments which also indicates that century-scale droughts in Sierra precipitation have occurred repeatedly over the last 2000 years. However, the Pyramid Lake drainage basin is hydrologically complex and this record needs to be replicated in order to test its regional significance. Although our Walker lake record could serve as an excellent means of replicating the Pyramid Lake and other drought records in the region, this $\delta^{18}O$ record remains essentially un-dated (no age control) and should also be replicated. Here we are proposing to analyze a second Walker Lake core for TIC $\delta^{18}O$ and to develop accurate and robust age-models for both cores using radiocarbon dating of pollen and total organic carbon (TOC). In addition, Dr. Steve Lund at USC will analyze paleomagnetic secular variations in these cores with the intent of developing an independent age model (Lund 1996). Our working hypothesis is that droughts recorded by sediments in both Walker and Pyramid Lakes, and by tree ring records in the region are synchronous and are the result of century-scale reductions in Sierra precipitation (mostly snowfall). These droughts would have directly coincided with equal magnitude droughts in the Bay-Delta region. Once the timing and recurrence interval of past severe droughts in the

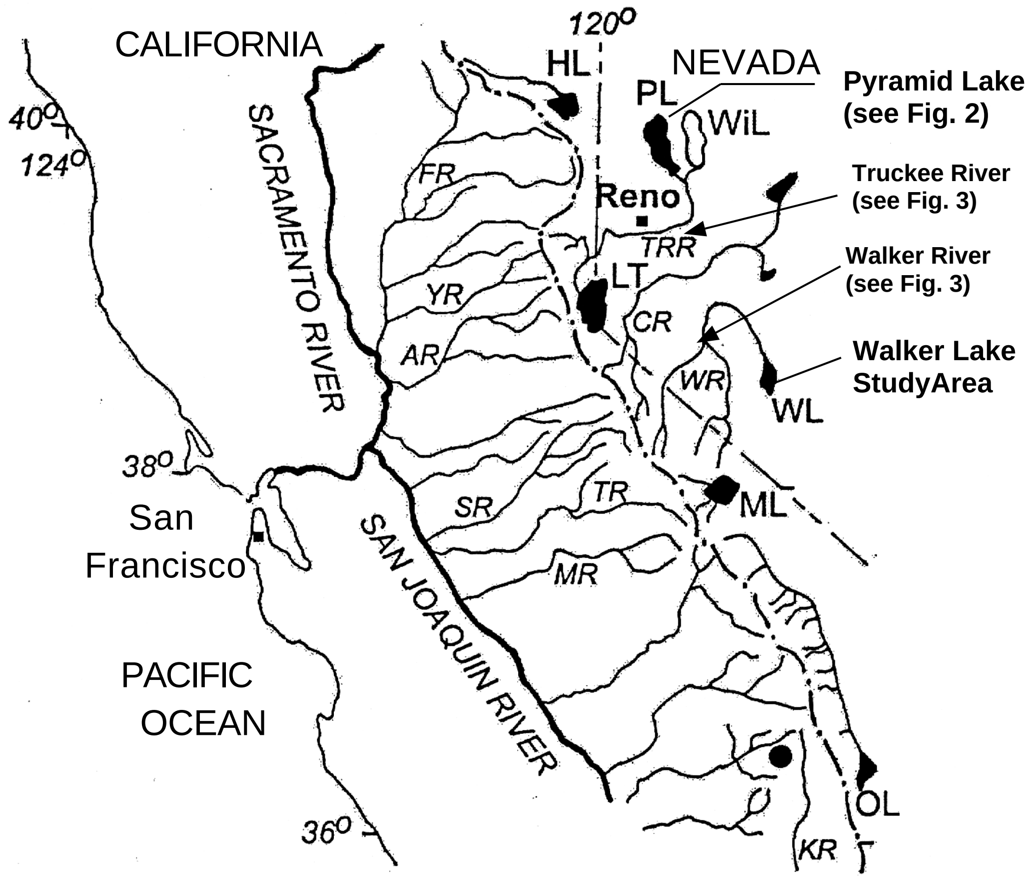


Figure 1; Principal surface-water systems that drain the Sierra Nevada. Dash-dot line indicates location of Sierran crest. Rivers on the western flank include: Feather River (FR), Yuba River (YR), American River (AR), Stanislaus River (SR), Tuolumne River (TR), Merced River (MR), and Kern River (KR). Rivers and lakes on the eastern flank include: **Truckee River (TRR)**,Carson River (CR), **Walker River (WR),** Honey lake (HL), **Pyramid Lake (PL)**,Winnemucca (Dry) Lake (Wil), **Walker Lake (WL**), Mono Lake (ML), Owens Lake (OL), and Lake Tahoe (LT). Note the location of Pyramid Lake and Walker Lake (the study site for this proposed work).

Table 1; Correlation of Selected River Discharge Records. Note that other rivers in this area yield similar correlations

West side of Sierras	(r^2 values)
Yuba (YR) vs American (AR)	0.90
Yuba (YR) vs Stanislaus (SR)	0.91
West vs. East Side of Sierran Divide	
Yuba (YR) vs Carson (CR)	0.91
Yuba (YR) vs **Walker (WR)**	0.86

region is more tightly constrained, we will be in a better position to determine the larger scale climatic conditions responsible. This knowledge would assist in improving the ability to forecast future severe droughts in the Bay-Delta region.

Background: Past Work on Severe Sierra Nevada Droughts

In California and eastern Oregon, published paleoclimatic information from trees and tree rings suggests that numerous multi-decadal and century-scale droughts have occurred over the past ~1000 years (LaMarche, 1974; Graumlich, 1993; Stine, 1990; 1994; Hughes and Graumlich, 1996; Meko et al., 1999). Stine (1994) used evidence from tree-rings in "growth position" tree stumps in several lake basins that are supplied from the Sierra Nevada to document two severe century-scale droughts during the Medieval Warm Period. One lasted from ~900 to ~1100 A.D., and the second from ~1200 to 1350 A.D. These results agree with a Sierra Nevada reconstructed precipitation record from a bristlecone pine tree-ring chronology (Hughes and Graumlich 1996). Graumlich, (1993), Hughes and Graumlich (1996), Hughes and Funkhouser, (1998), and Meko et al., (1999) have also utilized tree-ring growth records from the region to develop annually resolved records of temperature and precipitation variability over the last several thousand years. In the Great Basin, tree-ring data indicate that there was a greater incidence of severe droughts after 400 AD and before ~1500 AD. All records show repeated pronounced century-scale droughts, although discrepancies exist in the reported timing of some droughts. In the southern Sierra, Graumlich (1993) also found that temperatures were on average higher during the time of the Medieval Warm Period (~ 1100 – 1375 A.D.) and colder during the Little Ice Age (~1450 – 1850 A.D.).

Geochemical tracers measured from lake sediment cores also provide a unique source of paleo-drought information that can span longer periods of time. Water levels (and lake chemistry) in lakes usually integrates and monitors climate over a large region. Sediment cores from lakes in this region have previously been used to infer interdecadal to millennial-scale (and longer) changes in the regional hydrologic balance (see Bradbury et al., 1989; Benson et al., 1991; 1996; 1997; Li, 1995; Li et al., 2000; Mensing, 2001). Using trace metals and stable isotope tracers in Owens Lake sediments, Li et al., (2000) have documented an effectively dry climate from 950 to 1220 A.D. followed by a wet climate from ~1220 A.D. to 1480 A.D. This was followed by six wet/dry cycles to the mid-1700s and dry conditions until ~1880. Using bulk carbonate $\delta^{18}O$ in Mono Lake, Li (1995) was able to establish a hydrographical model and reconstruct paleo-lake levels. Li's (1995) work indicates that the moisture deficit in Mono Lake was more pronounced before ~1000 A.D, that lake levels were relatively stable from ~1000 to 700 yrs. B.P., reached a high around 650 yr. B.P., and were variable up to 1940 A.D. It is just before ~1000 AD that many other areas in North America exhibit a pervasive moisture deficit. Droughts are indicated in the diatom-inferred salinity record of Moon Lake, North Dakota (Laird et al, 1996), the median-grain-size record of Pine Lake, Ontario, Canada (Campbell et al, 1998) and oxygen isotopic record from ostracods in Lake Chichancanab, Yucatan Peninsula, Mexico (Hodell et al. 1996; Curtis et al, 1996; Hodell et al., 2001). Even in the San Francisco Bay estuary, the sedimentary sequences showed a major unconformity during this time period (Ingram et al, 1996).

A high-resolution sediment core taken from Pyramid Lake Nevada (see Figure 1) has revealed a record of apparent century and possibly multi-decadal fluctuations in lake level over the last 2800 years (Benson et al., 1999; and in press). Using down core measurements of TIC $\delta^{18}O$, Benson et al. (1999; and in press) interpret fluctuations in TIC $\delta^{18}O$ as documenting 18 extreme and persistent droughts over this time period (see Figure 2). In Pyramid Lake, TIC consists mostly (>90%) of aragonite. Benthic calcitic ostracodes are a minor component of the sediment (Benson, 1994; and L. Benson, per. comm.). Although TIC $\delta^{18}O$ is potentially forced by more than one environmental parameter, Benson et al., (in press) argue that in Pyramid Lake variations in TIC $\delta^{18}O$ is largely driven by changes in the $\delta^{18}O$ of lake water. In Pyramid Lake the aragonite is precipitated during the warm season of each year (July-

Pyramid Lake Drought Record

(modified from Benson et al., 1999;
and Benson et al., in press).

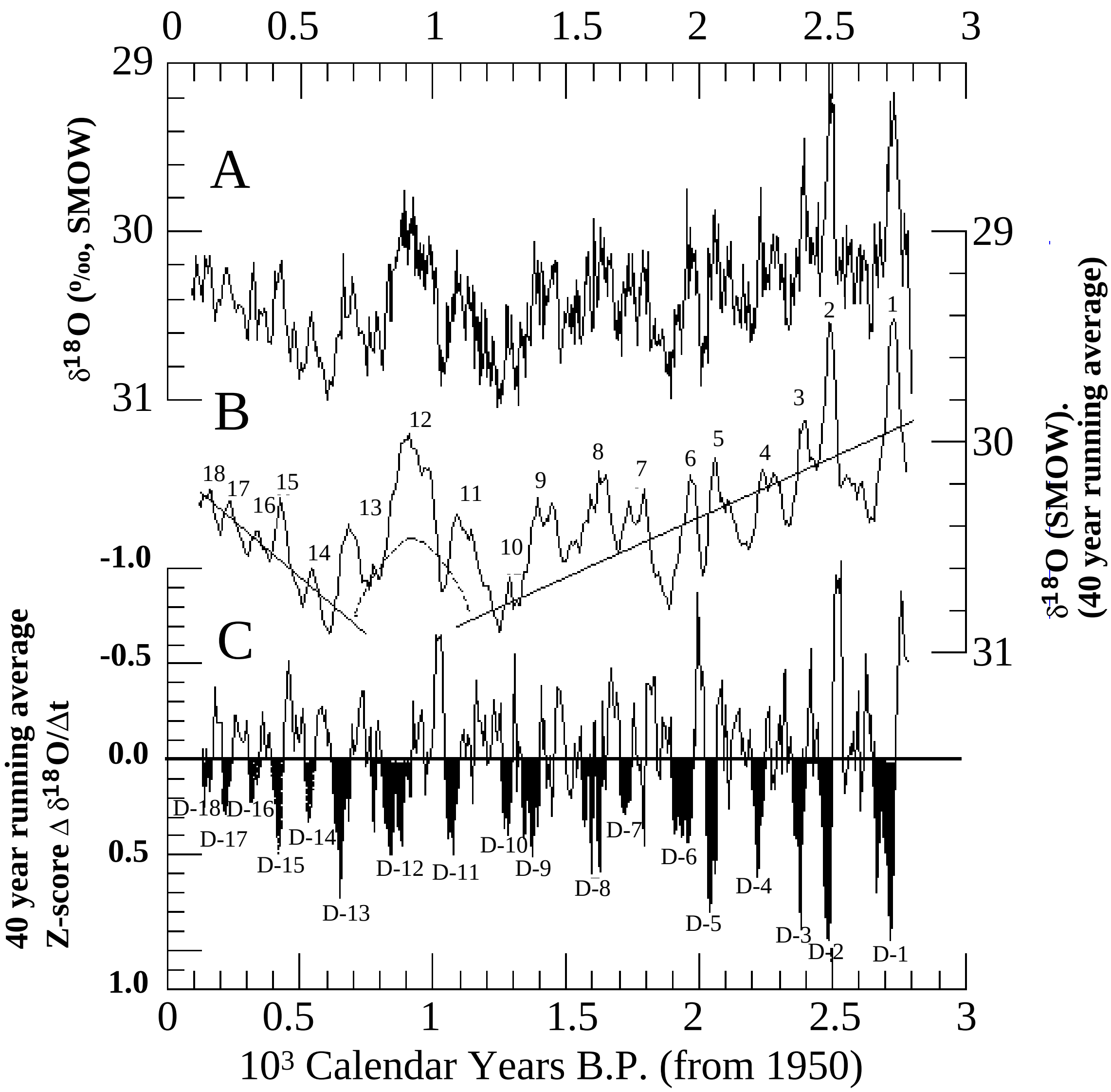


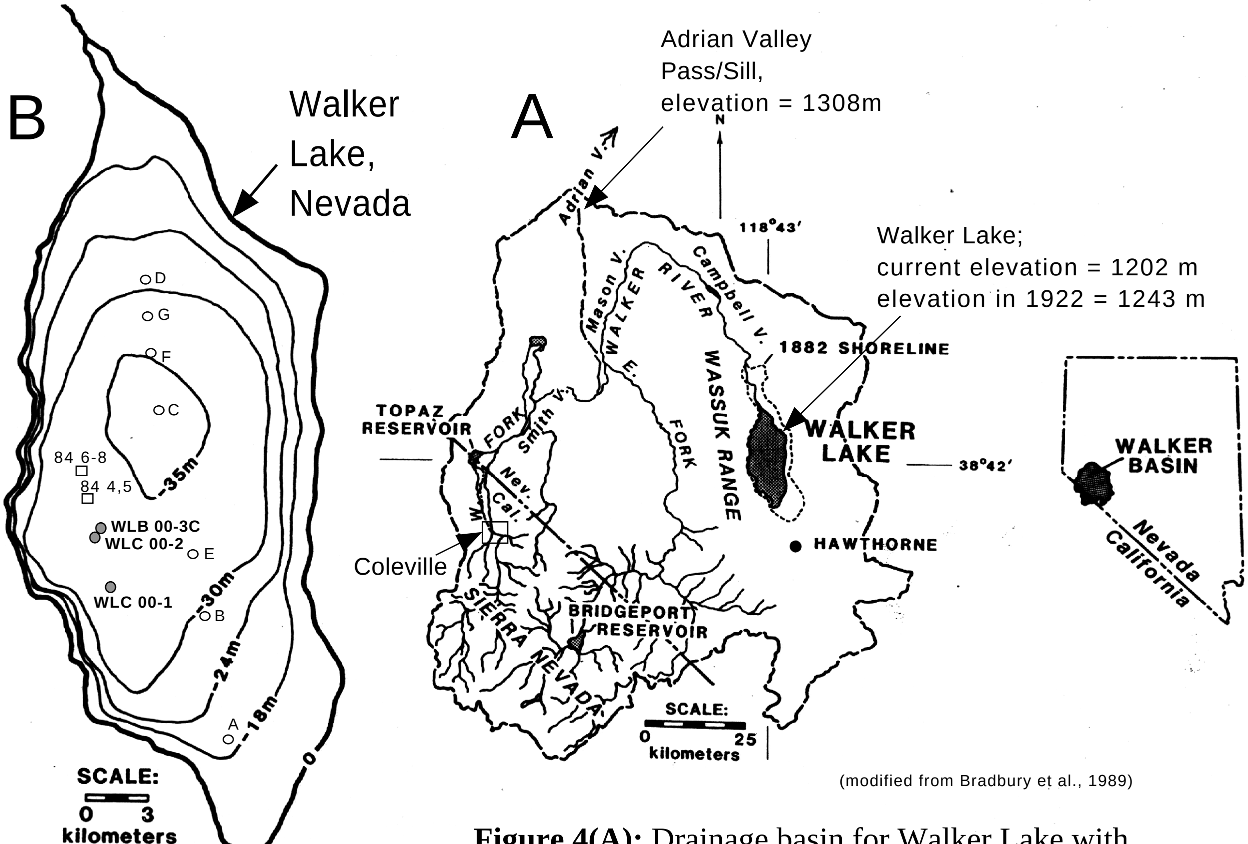
Figure 2; (**A.)** Variations in the oxygen isotopic composition of the total inorganic carbon fraction (TIC $\delta^{18}O$) for Pyramid Lake core PLC97-1 for the period 2800 to 110 years B.P. (modified from Benson et al. ,1999; and Benson et al. ,in review). Each $\delta^{18}O$ measurement was made on samples collected at 1cm intervals and that integrates between 3.5 and 8.5 years, averaging 5.0 years. (**B.)** TIC $\delta^{18}O$ record was fit with a cubic spline, $\delta^{18}O$ values taken from the spline at 8 year intervals, and the record smoothed with a 5 point (~40 year) running average. Oscillations in $\delta^{18}O$ numbered 1 to 18 are considered the result of decadal changes in hydrologic balance. Staight line and dashed arc highlight secular trends in the $\delta^{18}O$ data . (**C.)** Derivative ($\Delta\delta^{18}O/\Delta t$) of normalized, spline-fit $\delta^{18}O$ record. Periods of hydrologic drought (i.e.: rapid positive change in $\delta^{18}O$) have also been numbered. See text for discussion.

September) when water temperatures exceed 22°C and when aragonite saturation is ~10X (Galat and Jacobsen 1985). Thus, Benson et al., (in press) suggest that during the last 2800 years the largest influence on TIC $\delta^{18}O$ will be changes in the $\delta^{18}O$ of lake water which represents a balance between the amount and $\delta^{18}O$ of input water, and the amount and $\delta^{18}O$ of evaporated water. During the late Holocene, Benson et al. (1999; and in press) further suggest that the effects of temporal variations in evaporation on lake $\delta^{18}O$ were much less than temporal variations in the amount and $\delta^{18}O$ of Truckee River discharge into the lake, thus the $\delta^{18}O$ composition of authigenic carbonate in this lake system varied primarily as a function of the amount and $\delta^{18}O$ composition of input water. When interpreting a time-series TIC $\delta^{18}O$ record from the Great Basin lakes, Benson et al. (1999; and in press) argue that the true times of severe droughts are those intervals when the derivative of TIC $\delta^{18}O$ increases with respect to time ($\Delta\delta^{18}O/\Delta t > 0$). This is due to relatively constant evaporation effects on lake $\delta^{18}O$ causing increasing lake $\delta^{18}O$ when inflows are reduced. Times of lake level rise are signaled by $\Delta\delta^{18}O/\Delta t < 0$. <u>It is important to note that TIC $\delta^{18}O$ is not a direct measure of lake level but rather an indicator of the timing and severity of droughts.</u> In Figure 2C, all intervals of interpreted prolonged droughts in the Pyramid Lake basin are number D-1, through D-18. In this reconstruction, intervals between droughts average 150 years, and range from 80 to 230 years. The secular (long-term) trends observed in TIC $\delta^{18}O$ are of unknown origin (see Fig. 2B). It is possible these $\delta^{18}O$ trends are due to water temperature changes. It is also possible they result from long-term changes in snow-pack $\delta^{18}O$, or changes river discharge. Other remaining questions involve the existence, regional extent, and timing of these droughts (see Fig. 2B). Pyramid Lake is hydrologically complex because the lake occasionally spills into adjacent Winnemuca Lake basin (most recently in 1917) and also because Pyramid Lake receives 32% of its input from Lake Tahoe where the residence time of water is ~700 years (Goldman, 1988). It is also possible that some of the higher frequency variability in Pyramid Lake TIC $\delta^{18}O$ is related to decadal-century scale changes in the $\delta^{18}O$ of the snow pack, the timing of snow accumulation, or position of storm tracks (etc). Another potential source of TIC $\delta^{18}O$ variability is diagenetic changes in carbonate mineralogy down-core. The recrystallization of meta-stable aragonite to calcite could potentially induce subtle changes in $\delta^{18}O$ composition, although this does not appear to be the case in this record from Pyramid Lake.

Although all of the above referenced tree ring and sediment tracer studies present an excellent start to understanding the timing, frequency, and duration of severe droughts in the Sierra Nevada, discrepancies exist between the timing and duration of some droughts in these and other western U.S. paleoclimatic records. We argue here that more paleoclimatic records from this important region still need to be generated to allow a detailed spatial and temporal mapping of fluctuations in past hydrologic conditions. We have chosen to first attempt to replicate the lake-level record from Pyramid Lake. One way to test the fidelity and drought interpretation of the Pyramid Lake $\delta^{18}O$ record is to examine the TIC $\delta^{18}O$ record from another Great Basin lake that is also primarily filled with snow-melt fed discharge from the Sierra Nevada. The ideal lake for this purpose is Walker Lake and we are proposing to complete analyses and precise dating of two new cores from Walker Lake. Walker Lake, a closed basin lake with no current outflow, is located 160 km southeast of Pyramid Lake. Under current conditions ~73% of inflow into Walker Lake comes from a single source, the Walker River, and the vast majority of Walker River discharge is from Sierra Nevada snow-melt. Over the past century, the annual discharges of the Truckee and Walker Rivers are highly correlated (r^2=0.74; note Milne, 1987 found r^2=0.76), thus the same climatic forcing should evoke similar responses in hydrologic balance in both basins (see Figure 3).

Study Site: Walker Lake

The Walker River drainage basin occupies about 10,000 square kilometers in the Sierra Nevada of western Nevada and eastern California (Osborne et al., 1982)(Figure 4). Today, Walker Lake has a surface area of about 135 km^2, a lake-surface elevation of 1202 m, and an



Explanation:
A-G, gravity cores, 1975-1976
84-6-8, Livingston core, 1984
84-4,5, Wire line core, 198
***WLC 00-1, Piston core, 2000**
***WLC 00-2, Piston core, 2000**
***WLB-00-3, Box core, 2000**
*= cores to be analyzed
in this study

Figure 4(A); Drainage basin for Walker Lake with the current lake surface area shaded in gray. The location of the Coleville gaging station (used in Figure 3) on the West Fork of the Walker River is outlined. **(B);** Walker Lake bathymetry showing the location of sediment cores used in previous studies and new cores collected in June 2000 to be used in this study.

Comparison of Annual Discharge of the Walker and Truckee Rivers.

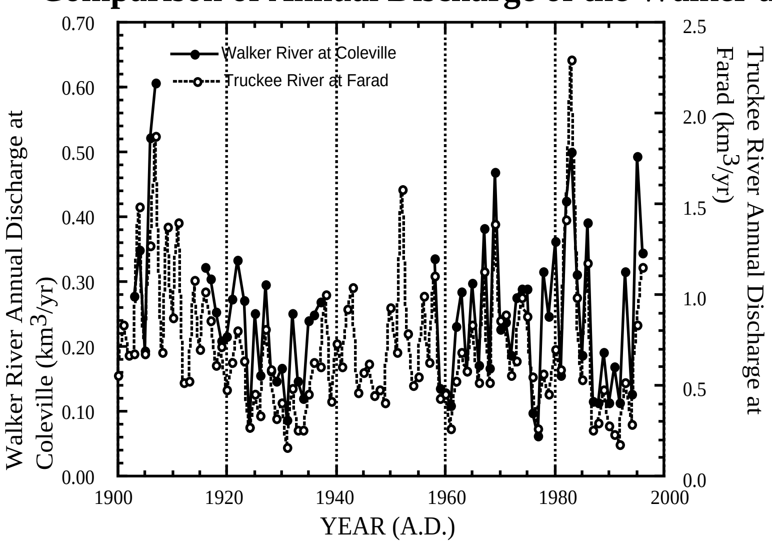


Figure 3 ; Comparison of annual total discharge on the Walker and Truckee Rivers. Total discharge in both rivers is dominated by Sierra Nevada snowmelt. The strong correlation between discharge in both systems (r=0.86; r^2=0.74) and the dependence of Pyramid and Walker Lake volumes on Truckee and Walker River discharge, indicates that similar drought histories should be recorded in the oxygen isotopic composition of the TIC fraction and ostracodes preserved in the sediments of each lake.

average depth of 23m. Today the lake level (elevation) is artificially low due to consumptive use and excessive water withdrawal upstream. Walker Lake has dropped 41m since construction of the Topaz and Bridgeport reservoirs in 1922 and 1923 respectively (see Figure 5A), and due to water diversion and increasing irrigation in the upstream area. This drop translates into a loss of over 70% of the lake's volume and a decrease of lake surface area. Under current conditions, precipitation and discharge make up ~90% of input to Walker Lake with the Walker River being the dominant input at ~73% (see Figure 4B). Walker Lake is a terminal lake with no discharge outlet. The only outflow from this hydrological system is evaporation (1.25m/yr). Streamflow from the Sierra Nevada has averaged 0.40 cubic kilometers per year for the last 55 years (Thomas, 1995). However, the annual discharge to Walker Lake is only about 0.13 km^3 per year due to consumptive use that includes natural evaporation and transpiration and increasingly anthropogenic activities like irrigation (Thomas, 1995). Based on calculations provided by USGS, the water budget of Walker Lake is negative. This means that the lake level will keep dropping if climate and consumptive use remain the same.

Based on measurements of Walker Lake and the Walker River water conducted in 1975-1976 and 1940-1987, respectively, most major chemical components dissolved in river water become concentrated in the lake with the exception of silica which is held at low levels due to diatom productivity, and calcium, most of which precipitates as calcium carbonate. The pH of the lake is 9.4, which is typical of alkaline desert lakes. The major ion concentration of Walker Lake has changed dramatically since 1882 in response to the lake level drop. The direct consequence has been an increase in salinity from 2.5‰ in 1882 (Russell, 1985) to 9.3‰ in 1966 (Rush, 1970) to 13.3‰ in July 1994 (Thomas, 1995). It is estimated that since 1884, 66,000 tons of dissolved solids have been added to Walker Lake annually. This anthropogenic lowering of Walker Lake illustrates how sensitive lake water chemistry is to changes in hydrologic balance. The anthropogenic reduction in lake volume also provides a human-induced "drought" which we can use examine how potential lake-level proxies such as TIC $\delta^{18}O$, ostracod $\delta^{18}O$, % TIC, and sediment type and mineralogy, respond to a known lake level change.

Geographically, the western shoreline of Walker lake is bounded by steep alluvial fans extending from the Wassuk Range, whereas the eastern shoreline is bounded by more gently sloping but extensive alluvial fans flanking the Gillis Range. The Walker River enters the lake on the northern margin and has formed a delta with extensive sand and mud flats. Spencer (1977) analyzed six gravity cores and 1 piston core from the deepest parts of Walker Lake. The deep-lake sediments were found to consist of silt and clay sized material with some sand-sized quartz and feldspar. All core sections (deepest 4.68m) were black and contained free H_2S throughout. This was also true for the recently split box and piston cores collected in June 2000. The presence of H_2S near the sediment-water interface indicates that the oxic/anoxic boundary is near the top of the sediment column and suggests that vertical bioturbation is minimal. Spencer (1977) also determined the predominant carbonate minerals present in Walker Lake by X-ray diffraction (XRD). In the upper 2,000 years of sediment record, weight % $CaCO_3$ is between 10 and 25%. The carbonate mineral that predominates the upper 0.5 to 1.5m of sediment is monohydrocalcite that occurs as small (4μm) crystals (Spencer, 1977; Benson and Spencer, 1983; Benson et al., 1991) and is precipitating today and accumulating at the sediment water interface. High dissolved magnesium concentrations inhibit the formation of other carbonate minerals and allow monohydrocalcite to precipitate. Below this zone calcite is the dominant carbonate mineral and averages ~10 wt %. Monohydrocalcite is not present in Pyramid Lake because Pyramid Lake has a much lower salinity.

Based on analysis of a sediment core collected in 1984, Bradbury et al., (1989) report that Walker Lake has been hydrologically closed (non-spilling) since ~2200 years B.P. Prior to 2200 years B.P. evidence suggests that the Walker River may have diverted down Adrian Pass (elevation = 1308m) into the Carson Sink, causing Walker Lake to desiccate twice (~14,000 to ~5,000 years B.P.; and from ~3,000 to 2200 years B.P.)(Bradbury et al., 1989;

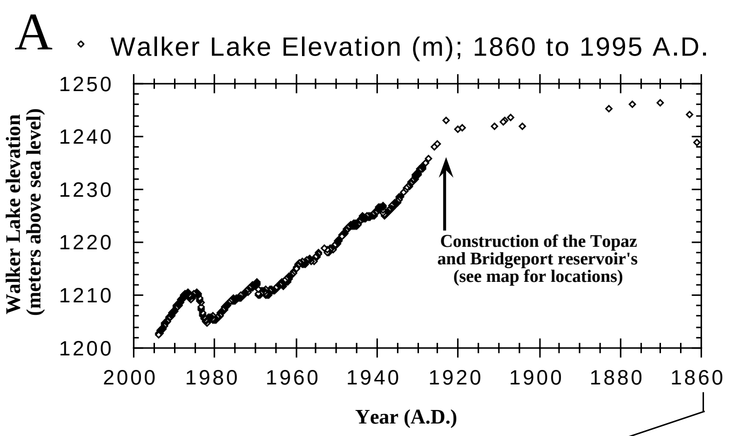
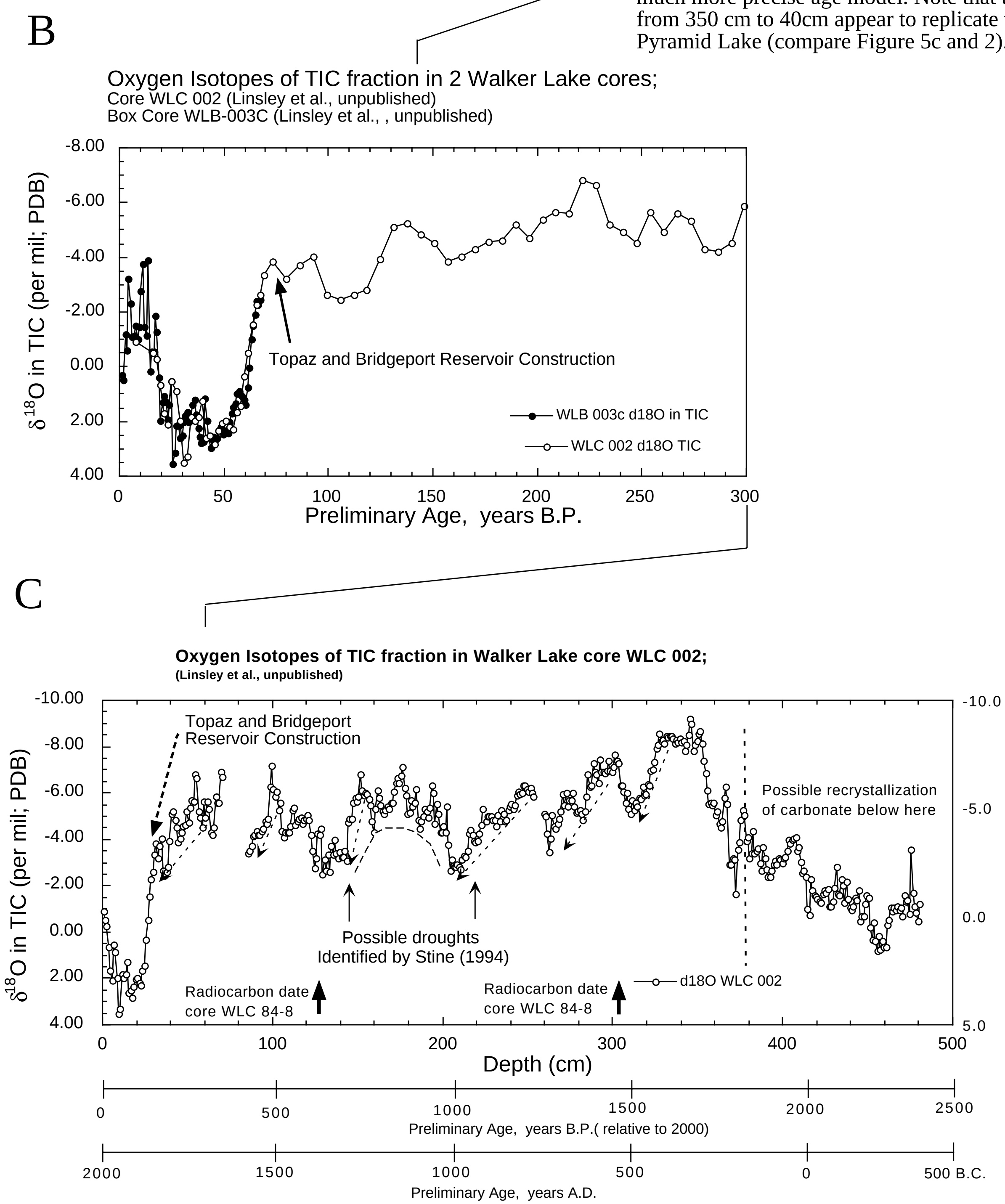


Figure 5, (A); Walker Lake elevation from 1860 to 1995 showing timing of construction of the Topaz and Bridgeport reservoirs. **(B);** Oxygen isotope composition of TIC in 2000 core (WLC 002; Open circles) and box core (WLB-003C) both collected in June 2000 (0-~300 years B.P.). WLB-003C was sampled at 5mm intervals. **(C);** Same data sets as in **B,** but extended back to ~2500 years B. P. <u>Age models shown are very preliminary and are based on the timing of dam construction in 1922/23 and on 2 radiocarbon dates in older Walker Lake core WLC 84-8 and correlation to WLC 002.</u> In panel C, dashed arrows indicate intervals interpreted to be times of prolonged century-scale droughts. Actual timing ofthese droughts must await development of much more precise age model. Note that trends in $\delta^{18}O$ data from 350 cm to 40cm appear to replicate trends observed in Pyramid Lake (compare Figure 5c and 2).



Benson et a., 1991; King, 1993). There is no direct evidence that any other diversions occurred after 2200 years B.P.

Relationship of Sierra Nevada Hydrologic Balance to Regional Climatic Forcing

Over interannual time-scales precipitation in the headwaters of the Walker and Truckee Rivers has been shown to be located at a correlation hinge-point with respect to El Niño Southern Oscillation (ENSO) forcing. A broad region of the US Southwest receives anomalously high winter precipitation during El Niño events whereas the US Northwest generally receives anomalously low winter precipitation (Redmond and Koch, 1991; Cayan, 1996; Cayan et al. 1999). The opposite is true for La Niña events. The Walker River Drainage is located at a nodal point where there is generally a weaker statistical correlation between precipitation and ENSO. Cayan (1996) has also determined that in the western US, anomalous winter precipitation has the strongest influence on total spring snow water equivalent (SWE) measured on April 1st (average time of maximum annual snow accumulation). Anomalous temperature was found to have a weaker correlation to SWE. For the Sierra Nevada, major floods are more likely to occur during La Niña than during El Niño, whereas along the California coast flooding is associated with El Niño events (Cayan et al., 1999). However for Walker and Pyramid Lakes, recent observations reveal that during severe El Niño events the lakes can rise. During the two most recent large El Niño events of 1998 and 1983, Walker Lake level rose 1.3m and 3.7m respectively. For the same two large El Niño events, Pyramid Lake rose 1.6m and 4.1m respectively (USGS news release dated 9/3/98; and see Figure 5a).

Although decadal-interdecadal changes in climate are not as well understood in the western United States, evidence is beginning to show that precipitation variability may be linked to decadal changes in the North Pacific gyre. Over multidecadal time-scales, McCabe and Dettinger, (1999) found correlations between western U.S. precipitation with the Southern Oscillation Index (SOI) and other indices of tropical ENSO processes to be much weaker from 1920 to 1950 than during the most recent three decades. The period from 1925 to ~1940 has also been noted as a time of reduced ENSO variability with weaker atmospheric correlations between the eastern and western tropical Pacific (Trenberth and Shea, 1987; Elliott and Angell, 1988; Cooper and Whysall, 1989; Pan and Oort, 1990; Enfield and Cid, 1991; Allan, 1993; Tudhope et al. 1995; Allan et al. 1996; and Linsley et al. 2000). All observed to varying degrees reduced ENSO-band variability during this time period. This 1925 to ~1940 decadal-scale change in the ENSO system remains unexplained but appears to be related to changes in North Pacific gyre sea surface temperatures (SSTs), and the Pacific Decadal Oscillation (PDO), and loosely related to the North Equatorial Current. The PDO, (which is also referred to as the North Pacific Interdecadal Oscillation or NPO; Gershunov et al, 1999) appears to be a robust, recurring pattern of ocean-atmosphere climate variability identified in the North Pacific (Latif and Barnett, 1994; Minobe, 1997; Mantua et al., 1997; Gershunov et al, 1999) with the phases lasting 2 to 3 decades. A PDO index has been defined based on North Pacific SST (Mantua et al. (1997) such that when it's cooler than average in the central North Pacific and warmer than average in the Gulf of Alaska and along the Pacific coast of North America, the index is positive. These periods tend to correspond with El Niño events. La Niña years correspond with the negative phase of the index when the central North Pacific is warmer than average, and the coastal waters of the NE Pacific are cooler than average. A positive phase of the PDO coincides with the 1925 to 1940 period.

North Pacific gyre SST may also be associated with anomalous western U.S. precipitation. McCabe and Dettinger (1999) found that ENSO teleconnections with precipitation in the western U.S. are strongest when SOI and tropical Nino3 Pacific temperatures are out-of-phase and the PDO is in a negative phase (Mantua et al. (1997). It also appears that ENSO teleconnections are weak when SOI and Nino3 SST are weakly correlated and the PDO index is positive (McCabe and Dettinger, 1999).

Although we are not claiming that this proposed research will establish direct linkages between Sierra Nevada droughts and the PDO or long-term changes in ENSO, the development of a more robust and well dated drought history of the last 2000 years will allow a more accurate quantification of severe and persistent droughts in this region. We will attempt to interpret these drought reconstructions in terms of the current understanding of the climatic systems mentioned above as well as in the context of the other paleo-records in the region.

Approach and Overview of Proposed Work

In June 2000, 2 piston cores and 1 box core were collected from one of the deepest portions of Walker Lake with the assistance of Dr. L. Benson of the USGS (33m water depth: WLC-001, 5.62m; WLC002, 4.87m)(see Figure 4B). These coring sites are near the area of a core collected in 1984 (WLC 84-8) and previously analyzed for lower resolution paleo-work (Bradbury, 1987; Bradbury et al., 1989; Benson et al., 1991). As part of a preliminary feasibility study (unfunded) we have completed %TIC, $\delta^{18}O$, and $\delta^{13}C$ analyses of the TIC fraction at 1 cm resolution in core WLC-002 and at 0.5cm resolution in box core WLB-003. These results reveal a pattern of repeated, an apparently century-scale droughts in the Walker Lake Basin over the last 2000 years (Figure 5 b and c). However we have not had the financial resources to develop accurate age models for these cores. Here we are proposing an analytical program that will:

(1) Complete analyses of %TIC, oxygen and carbon isotopes of TIC in the second core (WLC-001), and analyze bulk carbonate mineralogy, %Organic Carbon (TOC), oxygen isotopes of ostracod shells (where possible), and downcore pollen variations in back to ~2,000 yr. B.P.

(2) Develop accurate age control using radiocarbon dates of pollen (in collaboration with Dr. S. Mensing, UNV) and the TOC fraction. We will also collaborate with Dr. S. Lund (USC) in the analysis of paleomagnetic secular variation to independently date these cores (Lund, 1996). ^{137}Cs and ^{210}Pb will also be analyzed to develop a chronology for the uppermost portions of the box and piston cores and to examine benthic mixing of the sediment for calibration of the upper part of the lake sediment record.

Determination of the recurrence interval of severe droughts in the Sierra Nevada will assist in the effort to understand their climatic origin. To address this goal our final product will be the generation of a multi-decadal resolution, two-core composite %TIC and TIC $\delta^{18}O$ record from Walker Lake spanning at least the last 2,000 years. Pollen variations will also be used to assess vegetation and hydrologic changes in the basin. Based on the preliminary results presented below, we expect these tracers to indicate times of severe drought over this time interval. Comparison with the Pyramid Lake TIC $\delta^{18}O$ record will test for the regional significance of the interdecadal-scale and century-scale droughts identified in each record. Comparison to other paleo-drought indices in the southwest U.S. will ultimately assist with the development of a better understanding of regional climate conditions responsible for initiating persistent, century-scale, Sierra Nevada droughts. A comparable TIC $\delta^{18}O$ record from Walker Lake would also allow us to test the reproducibility of the long term trends in Pyramid Lake $\delta^{18}O$ (Figure 2B). If these $\delta^{18}O$ trends are related to temperature or regional hydrologic balance, they should be at least regional and should be preserved in Walker Lake TIC $\delta^{18}O$. If they are not found in Walker Lake this would support the argument that the TIC $\delta^{18}O$ trends observed in Pyramid Lake are at least in part effected by local hydrologic conditions such as overflow from Lake Tahoe. Our new preliminary TIC $\delta^{18}O$ results (and crude age model) from Walker lake core WLC002 (see Figure 5c) indicate that these Pyramid lake TIC $\delta^{18}O$ trends may be regional in scope and thus related to hydrologic conditions in the Sierra Nevada.

Past Work: Walker Lake Hydrologic History

Several low-resolution and temporally discontinuous studies have previously evaluated past changes in the hydrologic balance of the Walker Lake drainage. Stable isotopic (TIC and ostracodes), geochemical (%TIC, %organic carbon, %calcium carbonate), and palynological measurements of sediment core WLC 84-8 (collected in 1984), suggest that Walker Lake was substantially shallower (desiccated) between ~5300 and 4800 years B.P. and again between ~2700 and 2100 years B.P. (Benson, 1988; Bradbury et al., 1989; Benson et al. 1991). This low resolution record also indicates that the lake level appears to have been relatively high between 4800-2700 years B.P., at 1250 years B.P., and again at ~1700 A.D. A sharp lowering of Pyramid Lake between ~2700 to 2100 years B.P. is not observed in the new TIC $\delta^{18}O$ results of Benson et al., 1999; and in press) (see figure 2), suggesting that the lowering of Walker Lake at this time may be the result of a diversion of the Walker River through Adrian Pass into the Carson Sink (see Fig 4A).

As previously discussed, using tree rings in fossilized tree stumps in growth position, Stine (1994) found that the flow of the Walker River was greatly reduced for two centuries before ~1100 A.D. and for more that 140 years before 1350 A.D. Stine's (1994) results indicate a ~15-30% reduction Walker Lake surface area during these prolonged droughts. Walker Lakes' historical elevation should have been about 1255m or 335km^2 surface area (or a volume of 14.5 km^3). A reduction to 225km^2 results in a volume of ~7.5km^3, or roughly a 50% loss in volume and an elevation of 1230m (It should be noted here that Walker Lake elevation has been lower than this level since 1931). Such a reduction in lake size (14.5 km^3 to 7.5 km^3) or a 15-30% reduction in surface area should have caused measurable increases in salinity and $\delta^{18}O$ of lake water and should be detectable using $\delta^{18}O$ of TIC and ostracodes in Walker Lake sediments.

Feasibility Study and Preliminary Results; Walker Lake

Based on comparison with the core collected in 1984 and due to the similar magnetic susceptibility profiles of new cores WLC 001 and WLC 002 (see Figure 6), we expect that both new piston cores contain continuous high accumulation rate sediment records spanning the last ~2,500 years. For this proposed research we will focus on obtaining high resolution records from both cores spanning the last ~2,000 to 2500 years. We are focusing on this time interval because it spans the Little Ice Age and Medieval Warm Period, and because it overlaps the new results from Pyramid Lake and also because previous work with Walker Lake cores has indicated that recrystallized carbonate exists deeper in the sediment column. In core WLC84-8 two intervals before 2,100 yrs. B.P. (3.8m to 7.4m; and 10.9m to 12.0m) were found to contain calcite that averages about 1 mole % $MgCO_3$. Samples from these low Mg intervals contain large scalenohedral calcite crystals cemented in fine-grained calcite crusts (Benson et al. 1991). These intervals are interpreted to indicate that recrystallization of meta-stable monohydrocalcite has occurred in magnesium-depleted pore water (Hull and Turnbull, 1973).

Preliminary Oxygen Isotopic Results

Our new TIC $\delta^{18}O$ results appear to be consistent with the work of Stine (1994) (see Figure 5C). Although previous very low-resolution analyses of Walker Lake core WLC 84-8 do not indicate Stine's (1994) drought events (Bradbury et al., 1989), our new TIC $\delta^{18}O$ results from core WLC-002 appear to record these droughts as well as a recurring pattern of other severe droughts. It is possible that the low-resolution sampling of WLC 84-8 "missed" these droughts. However, verification of the temporal correlation between Stine's (1994) results and our new TIC $\delta^{18}O$ results awaits the development of detailed age models for these cores such as we are proposing to complete with this proposed work.

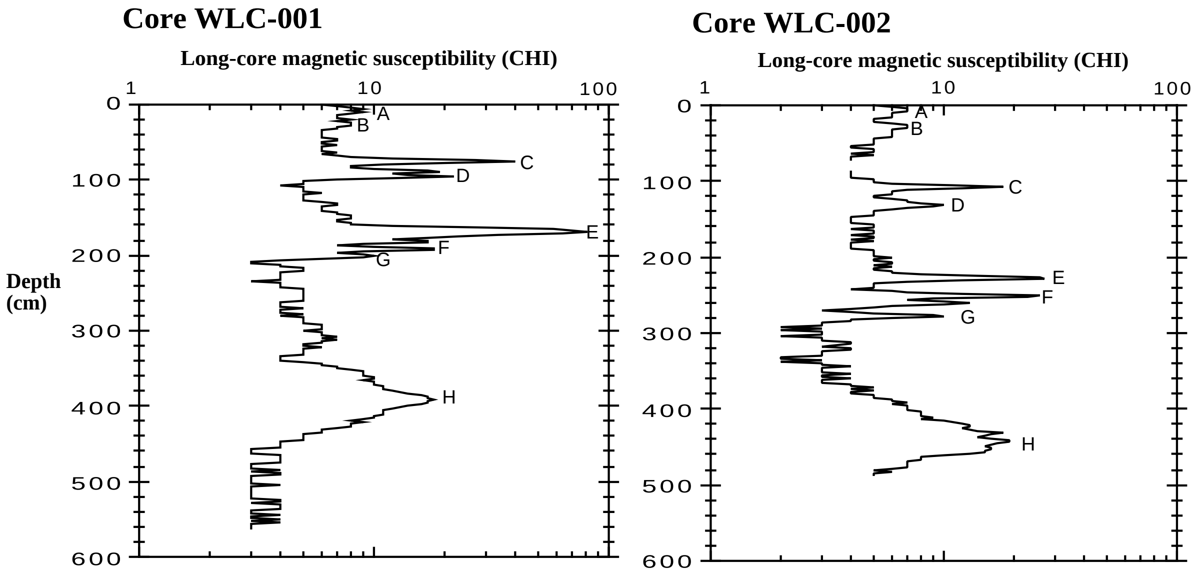


Figure 6: Long-core magnetic susceptibility profiles from cores WLC-001 and WLC-002. Possible tie-points are labeled A to H. The strong similarity of these profiles and inferred sedimentation rates, we suggest indicates that each core contains a continuous, high-resolution, record of sedimentation over the last 2,000 years.

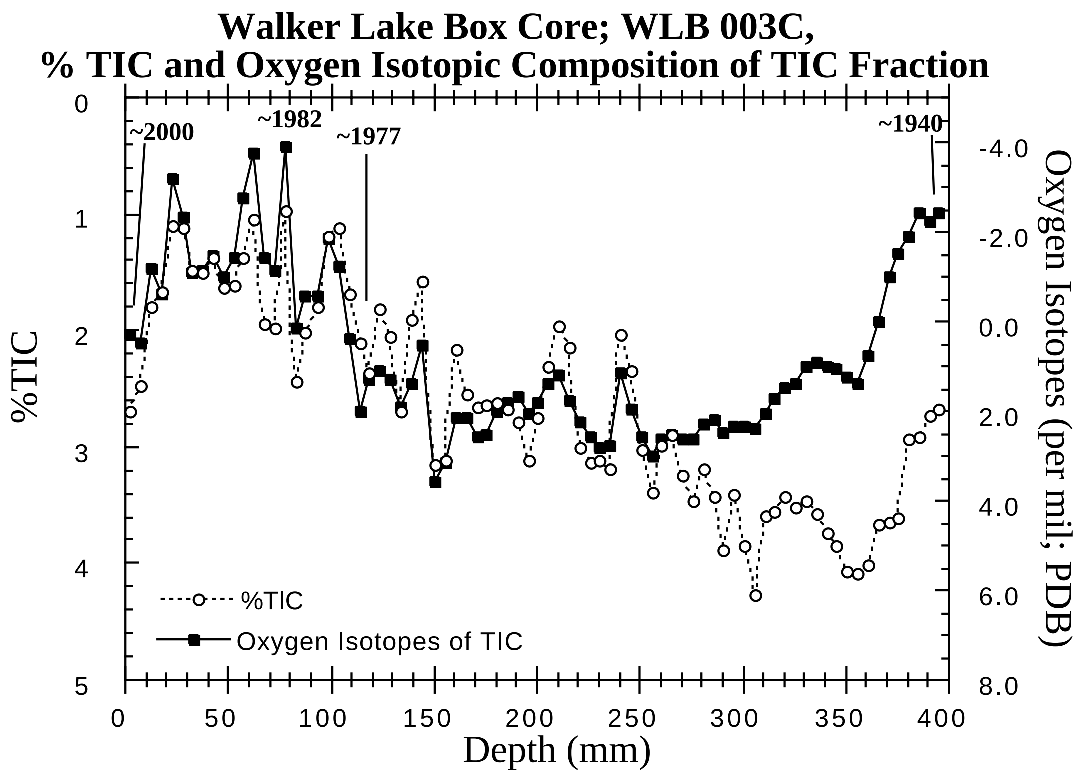


Figure 7: %Total Inorganic Carbon (TIC) and TIC $\delta^{18}O$ for Walker Lake box core WLB-003C. Sampling interval equals 5mm. Preliminary age picks are shown. TIC $\delta^{18}O$ and %TIC are positively correlated with minima in TIC $\delta^{18}O$ and %TIC apparently correlating with peak discharge into the lake (compare with Figure 3). We suggest this indicates that it is the hydrologic balance, and not temperature, that controls the abrupt (interannual) changes in TIC $\delta^{18}O$.

In the U.S. Great Basin Lakes we know that the TIC $\delta^{18}O$ proxy we are proposing to measure as one of our primary tracers is not a direct function of lake size, but is potentially influenced by a number of factors; the $\delta^{18}O$ composition of the water, the temperature of carbonate precipitation, and possible digenetic changes in carbonate mineralogy. Inferring century and interdecadal changes in lake volume from TIC $\delta^{18}O$ is also complicated by the fact that the $\delta^{18}O$ of Walker and Pyramid Lake water can be a function of multiple factors: (1) the $\delta^{18}O$ composition of water input to the lake from precipitation and rivers, (2) the $\delta^{18}O$ of groundwater influx, (3) the evaporation rate and evaporation fractionation factor, (5) the $\delta^{18}O$ of outflow discharge, and (6) the $\delta^{18}O$ of leakage water.

To more quantitatively interpret our TIC $\delta^{18}O$ results from Walker Lake we will modify existing models for water and isotopic balance in closed-basin lake to develop a better understanding of the processes responsible for lake sediment TIC $\delta^{18}O$ (Benson and White, 1994; and Benson and Paillet, in review). This work will form part of the Ph.D. research of Mr. Fasong Yuan at the University at Albany. Previous studies have shown that the water mass balance of a lake system can be described by the following relationship (Phillips et al., 1986; Ricketts and Johnston,1996; among others):

$$dV/dt = Q_{rain} + Q_{river} + Q_{gwi} - Q_{evap} - Q_{outflow} - Q_{leakage}$$

where V=volume, dt = time segment of interest, Q represents the fluxes of the following variables; rain= direct rainfall on lake, river= river inflow, gwi= groundwater inflow, evap= evaporation from lake, outflow = outflow from lake, leakage = groundwater leakage.

For Walker Lake, a closed-basin lake, where river inflow equals ~75% of total inflow (73% of total from Walker River; see table 1), and where groundwater outflows are insignificant due to hydrologic head considerations, and evaporation equals 1.25m/yr (or currently ~1.7×10^8 m^3/yr), the equation can be reduced to:

$$dV/dt = Q_{river} + Q_{gwi} - Q_{evap}$$

$$dV/dt = Q_{river} + Q_{gwi} - 1.25 m/yr$$

Table 2: Walker Lake Water Budget (average after dam construction)

Budget Component	Estimated Quantity (Source: USGS Fact Sheet FS-115-95) (Acre-feet per year)
Inflow	
Walker River	76,000
Local surface water	3,600
Groundwater	11,000
Precipitation (12 cm/yr)	14,000
Total	104,000
Outflow	
Evaporation (1.25m/yr)	137,000
Difference	-33,000

For a closed-basin lake like Walker Lake in which ground-water flux is negligible and surface overflow does not occur, the oxygen isotopic balance can be described as follows (from Benson and White, 1994):

$$d\,(\delta V)/dt = (P\delta_p - E\delta_{evap})\,A + S_i\delta S_i$$

where *t* is time, *V* is lake volume, *P* is the amount of on-lake precipitation, δ_p is the $\delta^{18}O$ value of precipitation, *E* is the amount of evaporation, δ_{evap} is the $\delta^{18}O$ of water leaving the lake surface, A is surface area of the lake, S_i is the input discharge volume, and δS_i is the $\delta^{18}O$ value of discharge into lake. Today in Walker Lake: δS_i = -13 to –14 per mil; S_i = 76,000 acre-ft /year; δ_p = ~-10 per mil; δ_{evap}= -15 per mil (+/- 3 per mil (measured in Pyramid lake at different times in 1988; Benson and White; 1994); and δV= -1.2 to –2.2 per mil. Although some of these parameters may have varied independently in the past, we will attempt to use this relationship to more quantitatively interpret our final results.

This above relationship illustrate that changes in the lake volume–to-area ratio over time, will also change the $\delta^{18}O$ response. A smaller lake would show a larger $\delta^{18}O$ response to changing input $\delta^{18}O$ than a larger lake. An example of this effect can be seen in Figures 5 a+b. The isotopic response to the lake level rise in the 1980s is amplified relative to the size of the lake level rise.

For Pyramid Lake Benson et al., (1999; and in press) argue that variations in TIC $\delta^{18}O$ are largely driven by changes in the $\delta^{18}O$ of lake water because the aragonite is precipitated during the warm season of each year (July-September) when water temperature exceeds 22°C and when aragonite saturation is ~10X (Galat and Jacobsen 1985). Benson et al. (1999; and in press) also suggest that the rate of change in the hydrologic balance (input rate – evaporation rate) is the most important factor that dominated variability in the 2800 year TIC $\delta^{18}O$ record. Because the temperature of carbonate precipitation in lake water is not expected to vary much over the short term, we also argue that variations in the hydrologic balance of Pyramid and Walker Lakes will have the largest influence on TIC $\delta^{18}O$ over the decadal and century time-scales that are the focus of this study. The interpretation of the long term (secular) trends in Pyramid Lake TIC $\delta^{18}O$ (see Figure 2) is unresolved and requires additional research. It is also possible that changes in the $\delta^{18}O$ of winter snow pack and/or input water could have resulted in these $\delta^{18}O$ trends. However, the tentative observation of similar trends in our new $\delta^{18}O$ record from Walker Lake might suggest that the trends are due to regional climatic forcing and are most likely due to changes in hydrologic balance over time.

In Walker Lake, TIC $\delta^{18}O$ has preserved the induced reduction in lake volume that has occurred since the 1920s (Figure 5b+c). TIC $\delta^{18}O$ records an ~7‰ shift associated with this anthropogenic lake lowering. It should be noted that in Pyramid Lake, TIC $\delta^{18}O$ also closely mimics the historical lake volume record (Benson et al., 1999). It is interesting that the amplitude of the TIC $\delta^{18}O$ changes in Walker Lake sediments are 7X those observed in Pyramid Lake where the magnitude of the TIC $\delta^{18}O$ shift due to the anthropogenic lowering of Pyramid Lake since the 1920s is only 1.4‰. This is apparently due to the shallower depth of Walker Lake (36m) vs. Pyramid Lake (109m), which makes Walker Lake more isotopically responsive to changes in the amount inflowing water. Thus with these new cores we may be able to resolve more subtle changes in the hydrologic balance of the region.

<u>Percent Total Inorganic Carbon as a Tracer of Lake Volume</u>

We will also analyze %TIC in both long cores as an additional proxy for lake volume. As mentioned, our preliminary work has also included detailed analyses of %TIC, %organic carbon, $\%CaCO_3$, and TIC $\delta^{18}O$ and $\delta^{13}C$ in a new box core (WLB 003C) on 0.5mm interval samples back to ~1935 A.D. (see Figures 5B and 7). These new results show that %TIC (and $\%CaCO_3$) and TIC $\delta^{18}O$ are positively correlated (Figure 7). % TIC is related to lake volume because as river discharge and lake volume increases, the Ca flux linearly increases with discharge, but the fine silt and silt size fractions suspended in river water and transported to the lake increase exponentially. Therefore lake volume increases are accompanied by decreases in sedimentary %TIC and %$CaCO_3$ (Benson et al., in press; and personal communication.). TIC however is not always homogeneously distributed over the lake bottom thus it may not be as clean a signal as TIC $\delta^{18}O$.

The positive correlation between TIC $\delta^{18}O$ and %TIC in WLB-003C also suggests that the hydrologic balance, and not temperature, controls the abrupt (interannual) changes in $\delta^{18}O$. This is because the inorganic carbonate is precipitated during the warm season of each year, and over this time interval (2000 to 1940 A.D.) the temperature of the warm season has not varied significantly. In Figure 5b, the age model for core WLB-003C is based on assumed sedimentation rates and setting the bottom age to 1935 A.D. Although this age model is very preliminary, the TIC $\delta^{18}O$ in this box core accurately tracks and replicate the lower 1 cm resolution analyses from core WLC-002.

<u>Pollen Analysis</u>

Our third proxy of hydrologic conditions in the Walker Lake basin will be pollen. Dr. Scott Mensing (UNV-Reno) will be analyzing pollen variations at 4 cm intervals to assess vegetation changes in the basin. Previous work has found that the ratio between two low elevation pollen types *Chenopodiaceae* and *Artemisia* is a good proxy for lowered lake levels. Species in the family *Chenopodiaceae* (including *Sarcobatus*, which can be identified to the genus level, and *Atriplex*) commonly grow at low elevation sites in Nevada's basins, and are tolerant of saline soils. When lake levels drop, exposing fresh sediment, plant succession onto the playa surface is dominated by *Chenopodiaceae*. *Artemisia*, (sagebrush) dominates on higher elevation, rocky substrates and prefers more moisture. This taxon tends to increase with increased precipitation. Also, if precipitation increases and the lake rises, the surface area suitable for *Chenopodiaceae* decreases. Thus, the ratio of these two taxa provides a relatively reliable proxy indicator of severe and persistent droughts that affect lake levels over decades to centuries. (Mensing, 2001). The pollen record from these core will be compared to our TIC $\delta^{18}O$ and $\delta^{18}O$ tracers to cross-check our interpretations. Comparisons with the other available proxy records will also be used ($\delta^{18}O$, packrat midden, tree-rings) to assess the regional signal. Dr. Mensing has recently completed down-core pollen analysis on the Pyramid Lake core. It will be particularly informative to compare this Walker lake record with the Pyramid Lake record to see if they are in phase with each other, or record variations at a regional scale.

We find these preliminary results from Walker Lake encouraging and are proposing the following analytical program in order to develop two high resolution paleoclimatic records spanning the last 2,000 years. We will attempt to interpret the results of this study in terms of known climatic forcing in the region as outlined earlier.

Proposed Work and Methods

The working half of the remaining unsampled core WLC-001 will be slab sampled at 1 cm intervals following paleomagnetic cube sampling. A replicate box sub-core will be sampled at twice (2X) this resolution (0.5 cm intervals). Archive core halves will be preserved in refrigerated storage in the lab of B.K. Linsley at the University at Albany.

<u>Chronology Development</u>

Radiocarbon dating (AMS ^{14}C) of total organic carbon and pollen will serve as the primary chronology development tools for these Walker Lake cores. In addition we will employ paleomagnetic secular variations (PSV) and ^{137}Cs to refine the chronology. There is also a volcanic ash horizon that has been identified and dated in seven sediment cores from Walker Lake (Spencer, 1977). Radiocarbon dates on several core sections extrapolated to the ash indicate that it was deposited approximately 1,200 yrs B.P. and serves as a good chronostratigraphic marker (Spencer, 1977). Sedimentation rates from this ash to the sediment -water interface were reported to average 1 to 1.5 mm/year (Spencer, 1977).

Radiocarbon dates on pollen samples may allow us to avoid problems associated with carbon reservoir effect (Regnell 1992; Long et al. 1992; Mensing and Southod, 1999). However, we also are aware of the potential problem where radiocarbon (AMS) dates on pollen may be hundreds of years too old in lake systems which have reworked sediments (Mensing and Southod, 1999). These researchers also found that the pollen dates above an ash layer were about 200 years older than expected. The dates below the ash were in agreement with other radiocarbon dates. They hypothesized that the deposition of ash on the landscape could have acted to armor the landscape to some extent as well as possibly killing some ground cover species. This combination may have contributed to more and faster overland flow, incision, and possibly redeposition of older pollen that was either resident in the soil, or in the near shore environment of the lake. Any lake that fluctuates will have reworked pollen, so a date on pollen will by itself not necessarily give an accurate date. We will pollen date some surface samples (which should give a modern date) and evaluate the degree of pollen reworking. This should give some indication of the error associated with a pollen date. We will also attempt to get a pollen date from just below the Walker Lake ash layer found at ~1200 years B.P. by Spencer (1977).

For samples younger than a few thousand years, the $^{14}C/^{13}C$ ratio is measured with a standard deviation of about 0.5%. This precision yields an uncertainty in radiocarbon age of approximately +/- 40years. Published tree-ring calibration curves are used to determine calendar ages. The uncertainty in the calendar age is generally larger than the uncertainty in radiocarbon age, and depends on the location of the calendar age in the calibration curve.

Here we have proposed to date 12 pollen samples extracted by Dr. Scott Mensing (see attached letter). Extraction of ~ 12,000 grains will be required for each pollen date. We will also AMS radiocarbon date the total organic fraction on 12 samples. Some of these dates will replicate the pollen dates for comparison. We are proposing to have the all radiocarbon samples analyzed at the Lawrence Livermore facility as they have experience with small pollen samples. As a back-up plan, TOC samples could be analyzed at one of the two NSF AMS facilities (Arizona or Woods Hole MA).

Dr. Steve Lund (USC, see attached letter) will conduct needed paleomagnetic measurements in support of this project. Magnetic susceptibility has already been measured (Figure 6). As part of this project, Dr. Lund will carry out a paleomagnetic study of secular variation (PSV) recorded in the sediments as an independent estimate of the chronology. We will use the PSV records to develop an independent chronology to the radiocarbon derived chronology which will assist with our correlation to the Pyramid Lake record. Dr. Lund has significant experience in the coring of lakes and the use of PSV to develop sediment age models (Lund, 1996).

In the box cores, ^{137}Cs and ^{210}Pb will be measured by P. Swarzenski of the USGS Coastal Studies Group or by Dr. Jack Dibb at the University of New Hampshire. With these measurements we should at a minimum be able to identify the ^{137}Cs pulse in 1952. ^{210}Pb will be used to evaluate benthic sediment mixing depths in the box cores.

Carbonate Mineralogy

Variations in major carbonate minerals present down-core will be identified using X-ray diffraction. We will analyze samples at 10-cm intervals, with closer sampling across mineralogic boundaries. This work to be done at the USGS facility in Boulder Colorado by University at Albany graduate student Fasong Yuan.

Total Inorganic Carbon (TIC) and Stable Isotope Analyses

Each remaining core sample will be analyzed for %TIC and % Organic Carbon and for the $\delta^{18}O$ and $\delta^{13}C$ composition of the TIC. TIC analyses will done on a Coulometer in the laboratory of Dr. Peter deMenocal at Lamont Doherty Earth Observatory of Columbia University. Benthic ostracodes will be hand picked and identified from each sample if in high enough abundance. We anticipate utilizing the species *Limnocythere certiotuberosa* which was analyzed from core WLC 84-8. Benthic ostracode $\delta^{18}O$ will serve as a separate tracer to reconstruct variations in the $\delta^{18}O$ of Walker Lake over time.

For isotopic analysis, bulk samples are soaked in 2.6% NaOCL (bleach) for 12 hours to oxidize organic matter, washed in deionized water, and dried at 50°C before analysis. 150µg TIC samples or ~50 to 100µg ostracod samples are then dissolved in 100% H_3PO_4 at 90°C in a Multiprep carbonate inlet system and the resulting CO_2 gas analyzed with a Micromass Optima triple-collecting mass spectrometer at the University at Albany, State University of New York stable isotope facility. Over the past year the average standard deviation of the NBS-19 standards analyzed has been 0.02 ‰ for $\delta^{13}C$ and 0.04‰ for $\delta^{18}O$. For the Walker Lake TIC samples analyzed over the past year average standard deviation of the replicate samples analyzed was 0.041 ‰ for $\delta^{13}C$ and 0.036 ‰ $\delta^{18}O$. Over the course of this project we plan to analyze 1170 samples and replicates for both $\delta^{18}O$ and $\delta^{13}C$. As the laboratory is currently analyzing 35 samples per day, this sample load is well within the sample through-put limits of the facility.

Pollen Analysis Technique

Dr. S. Mensing (UNV) will examine down-core changes in pollen in both new cores to assess changes in plant communities over the last 2,000 years. For the fossil pollen analysis, one cm thick samples will be analyzed every four to five cm down the core (approximately 100 samples total with a 20-25 year sampling interval). Processing will follow standard preparation techniques (Faegri and Iversen, 1985). For each sample, a minimum of 40 terrestrial pollen grains will be identified to produce a set of pollen diagrams for interpretation of vegetation history.

Data Handling and Storage

All data generated as part of this project will be made available to other interested CALFED funded researchers and others working to understand past hydrologic variations in the region. We anticipate that several papers discussing the results of this research will be published in the scientific literature. These papers will contain tables of primary data or have web references for accessing the final data. This project will adhere to all specified data management policies as detailed by the US Global Change Research Program (see: http://www.gcdis.usgcrp.gov/policies/dmwg/). The P.I. will be responsible for ensuring that all data generated by the project will be documented and submitted to the World Data Center for Paleoclimatology at the National Geophysical Data Center in Boulder, CO. Archive halves of cores will be stored at in refrigerated storage at the University at Albany. All unused splits of processed samples will also be archived in the laboratory of Dr. B. K. Linsley.

Performance Measures

Programmatic quarterly reports will be submitted to the CALFED office as well as annual summary reports discussing results to date. Oral presentation of primary results will be made at annual CALFED review meetings. Results of this project will also be presented at several American Geophysical Union (AGU) regular fall or spring scientific meetings. Publication of primary results in the peer-reviewed scientific literature will ultimately serve as the most rigorous performance measure. By the end of this 3 year project we anticipate publishing 2 or 3 papers discussing the results of this work.

Time Line for Proposed Work and Priority of Tasks

Years 1 and 2 of this 3 year project will be focused on data generation and detailed core analysis. The level of anticipated analytical effort is detailed in the budget justification and is only summarized below. The responsible PI is indicated after each task.

Year 1:
- Process samples for radiocarbon dating; (Dr. Mensing and Dr. Linsley)*
- Process samples for stable isotope analyses; (Dr. Linsley)*
- Analyze bulk samples for carbonate mineralogy; (Dr. Linsley)
- Analyze core WLC001 for %TIC and %TOC (Dr. Linsley)
- Begin processes samples for downcore pollen analysis; (Dr. Mensing)
- ^{137}Cs and ^{210}Pb dating of core tops (Dr. Linsley)
- Analysis of Paleomagnetic secular variations (Dr. Lund and Dr. Linsley)*
- Analysis of samples for ostracod content (Dr. Linsley)
- Present results at annual CALFED review meeting; (Dr. Linsley)

Year 2:
- Process samples for radiocarbon dating; (Dr. Mensing and Dr. Linsley)*
- Process samples for stable isotope analyses; (Dr. Linsley)*
- Begin processes samples for downcore pollen analysis; (Dr. Mensing)
- ^{137}Cs and ^{210}Pb dating of core tops (Dr. Linsley)
- Analysis of Paleomagnetic secular variations (Dr. Lund and Dr. Linsley)*
- Analysis of samples for Ostracod content (Dr. Linsley)
- Present results at annual CALFED review meeting; (Dr. Linsley)
- Present results at AGU annual meeting; (Dr. Linsley)

Year 3:
- Publish primary results in scientific peer-reviewed literature (all P.I.'s)
- Present results at annual CALFED review meeting; (Dr. Linsley)
- Present results at AGU annual meeting; (Dr. Linsley)

*Note: In the event that only partial funding is available to support this project, the completion of the isotopic analyses, the radiocarbon dating, and the analysis of paleomagnetic secular variations (for dating) are the aspects of this proposed research that should be given highest priority.

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Braddock K. Linsley

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Education — B.S. (1982); St. Lawrence University, Canton, New York (Geology, w/honors)

M.S. (1984); University of South Carolina, Columbia, South Carolina (Geology)

Ph.D. (1990); University of New Mexico, Albuquerque, New Mexico (Geology)

Postdoctoral Research (1991-1995); Rice University, Houston, Texas

Appointments/Professional Experience

2001-present	Associate Professor, University at Albany-State University of New York
1995- 2001	Assistant Professor, University at Albany-State University of New York
1991 - 1995	Research Associate, Department of Geology and Geophysics, Rice University, Houston, Texas
1991-1992	Hydrogeologist (part-time) at ERM-Southwest Inc, Houston, Texas
1986	Hydrogeologist, Vermont Department of Health, Burlington, VT.

Publications Most Directly Related to High-Resolution Climatic Reconstruction

Evans, M.N., M.A. Cane, D.P. Schrag, A. Kaplan, B. K. Linsley, R. Villalba, and G.M. Wellington, Support for tropically-driven Pacific decadal variability based on paleoproxy evidence, *in press*, **Geophysical Research Letters.**

Garidel-Thoron, T. de., L. Beaufort, B. K. Linsley, and S. Dannenmann, High frequency dyanmics of the East Asian Monsoon during the last 200,000 years, ***Paleoceanography***, *16, no. 5, 491-502, 2001*.

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Other Selected Publications

Guilderson, T. P., D.P. Schrag, E. Goddard, M. Kashgarian, G. M. Wellington, B.K. Linsley, Southwest subtropical Pacific surface water radiocarbon in a high-resolution coral, **Radiocarbon**, vol. 42, 249-256, 2000.

Linsley, B.K.; Messier, R.G., and Dunbar, R.B., Assessing between colony oxygen isotope variability in the coral *Porites lobata* at Clipperton Atoll, **Coral Reefs,** vol. 18 (1**),** 13-27 1999

Linsley, B.K., and R. B. Dunbar, The late Pleistocene history of surface water $\delta^{13}C$ in the Sulu Sea: Possible relationship to Pacific deep water $\delta^{13}C$ changes, **Paleoceanography**., vol 9, no.2, 317-340, 1994.

Dunbar, R.B., Linsley, B.K., and G.M. Wellington, Eastern Pacific corals monitor El Niño/Southern Oscillation, precipitation, and sea surface temperature variability over the past 3 centuries, **in**: Jones, P.D., R.S. Bradley, and J. Jouzel (eds.), Climatic fluctuations and forcing mechanisms of the last 2000 years, Springer-Verlag, Berlin, p. 375-407, 1996.

Anderson, R.Y., Linsley, B.K., and Gardner, J.V., Expression of seasonal and ENSO forcing in climatic variability at lower than ENSO frequencies: Evidence from Pleistocene marine varves off California: *in* Paleoclimates: The record from Lakes, Ocean, and Land, eds. L.V. Benson, and P.A. Meyers, **Palaeogeography, Palaeoclimatology, Palaeoecology,** v.78, 287-300, 1990.

Oceanographic/Paleoclimatic Field Research (1988-2001)

- 1994-2000; -Leader of 4 coral drilling expeditions to Clipperton (1994), Rarotonga and Fiji (1997), Fanning Atoll (1997), and Rarotonga (2000).
- 8/1997: - Deep sea coral collecting off Oahu, Hawaii with Pisces V submersible (NOAA-HURL project with R.B. Dunbar (Stanford University) and R. Grigg (Univ. of Hawaii)
- 3/1992: - CRUISE F2-92 of the R.V. FARNELLA, U.S. Geological Survey, Sedimentologist: Sediment coring and 3.5 khz profiling cruise along the central California margin.
- 6/1990; - CRUISE 125-8 of the R.V. ATLANTIS II, Woods Hole Oceanographic Institution, Scientific staff: Long piston and Box coring was performed in laminated, anoxic marine sediments in the Gulf of California. Sediment traps were also deployed.
- 8/1988 - 1/1989 - ODP LEG 124 of the R.V. JOIDES RESOLUTION, Sedimentologist, Drilled in Sulu and Celebes Seas, western equatorial Pacific Ocean.

Honors, Service, Synergistic Activities, and Past Awards

-Contributor of 4 coral-based time series reconstructions and ODP Site 769 isotopic data to NOAA NGDC paleoclimate database.

-Panel Member (one panel); National Science Foundation Marine Geology and Geophysics Program (1998).

-Invited Speaker, 8 talks on paleoclimatic change given to non-specialists and non-scientists (last 3 years).

-Invited Participant to 8 conferences of interannual to millennial-scale climatic change (last 4 years).

-Book Review: El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation, edited by H.F. Diaz and V. Markgraf, 475 pp, 1992, **Science,** vol. 262, 1283-1284, 1993.

-Teaching Responsibilities; Surficial Applied Hydrogeology (435/535); Sedimentary Geology (335); Environmental Geology (105); Seminar in stable isotope geochemistry.

-Principal Investigator, NSF Grant OCE 9710156, $113,989 , 7/97-6/01, Centennial-Millennial Scale Oscillations in the East Asian Monsoon

-Principal Investigator, NSF Grant ATM-9901649. ($31,764), 1/1/99 to 12/31/00, Climate Records From Corals in the Central and Western Sectors of the Tropical South Pacific.

-Principal Investigator, University at Albany-SUNY Faculty Development Award ($9,700), 12/1/99 to 11/30/00, Stable isotope microanalysis of clam (*V. mercenaria*) shells from archeological shell midden sites near Cape Hatteras: Collaborative project with Dr. Peter deMenocal at Lamont Doherty Earth Observatory.

-Principal Investigator, NSF Grant ATM-9512289; ($144,683), 9/1/95 to 2/28/97. -Project title: " Acquisition of an Isotope Ratio Mass Spectrometer (IRMS) for the University at Albany-SUNY's Environmental Geochemistry - Program." Matching funds provided by The Research Foundation of SUNY.

-Principal Investigator: NSF, Grant SGER ATM 9409368 ($39,123), 4/1/94 to 3/31/95 -Project title: "Collection of Multi-Century Coral Records of Ocean-Atmosphere Variability From Clipperton Atoll."

-Co-Principal Investigator (w/ R. Dunbar): National Institute for Global Environmental Change (NIGEC; Dept. of Energy) Grant, ($118,584), (6/93 to 6/96). -Project title: " Coral based reconstruction of eastern Pacific climate and the Intertropical Convergence Zone over the last 300 years." (total project cost = $242,880)

-Principal Investigator: NSF, Grant ATM-9116780, ($61,848), 3/92 to 3/95.-Project title: "High Frequency Ocean-Climate Variability and Younger Dryas Style Events in the Sulu Sea During the Last 750,000 Years." Reconstructed late Pleistocene millennial-scale oceanographic variability in the Sulu Sea.

- -1992-1994: U.S. Department of Energy Distinguished Global Change Post Doctoral Fellow, at Rice University, ($72,000), Mentor; Dr. Robert B. Dunbar, (8/92 to 8/94). Fellowship Title: "Hermatypic Coral Skeletal $\delta^{18}O$ and Density Bands: Development as Tracers of Oceanographic Conditions in the Eastern Pacific"
- -1989-1990: Principal Investigator, U.S. Science Support Program Grant (JOI-USSSP-NSF, $24,000), in support of post cruise Ocean Drilling Program (ODP) research, University of New Mexico, Albuquerque, NM .

Scientific Collaborators (other than on this proposal) and advisors

Robert B. Dunbar (Stanford University, CA); Postdoctoral advisor while at Rice University)
Roger Y. Anderson (University of New Mexico, NM): Ph.D. advisor
Robert C. Thunell (University of South Carolina, SC): M.S advisor
Gerard M. Wellington (University of Houston, TX)
Luc Beaufort (CEREGE, Aix-en-Provence, France)
Daniel P. Schrag (Harvard University, MA)
Peter B. deMenocal (Lamont Doherty Earth Observatory of Columbia University, NY)
Larry Benson (USGS, Boulder CO)

Professional Research Interests

Paleoclimatology, Stable Isotope and Trace Element Geochemistry, Tropical Climatology, Paleolimnology, Global Change Research, Hydrogeology

Professional Affiliations

American Geophysical Union, Geological Society of America, Sigma Xi

September 28, 2001

Dr. Brad Linsley
Department of Earth and Atmospheric Sciences
State University of New York-Albany
Albany, NY 12222

Dear Brad:

I would be pleased to help you in your proposed study of a new Holocene lacustrine sediment sequence from Walker Lake, Nevada. The main goals of the proposed work are to develop a highly resolved isotopic record (bulk carbonate and ostracodes) spanning the last 2000 years or so. This record will be useful for many reasons, one of which is to replicate the new Pyramid Lake record which Larry Benson and I have been working on for the last two years.

I will conduct all needed paleomagnetic and rock magnetic measurements in support of this project. I have already measured long-core magnetic susceptibility on the cores as we collected them. I will make a suite of rock magnetic measurements on discrete samples to better assess the sediment record of local environmental variability. I will also carry out a paleomagnetic study of secular variation recorded in the sediments as an independent estimate of chronology. I have had great success, in the last few years, comparing paleomagnetic age estimates with radiocarbon age estimates to assess radiocarbon reservoir effects or potentially anomalous individual dates. I have found that almost all lakes in the western USA, which I have studied, have significant radiocarbon reservoir effects, some of which are time dependent. The paleomagnetic results will provide one mechanism for evaluating such possible systematic errors and developing a high-resolution chronology for the lake sediments.

I look forward to our collaboration in this project.

Sincerely,

Steve P. Lund
Professor of Geophysics
University of Southern California

Sept. 18, 2001

Director
CALFED program

Dear Director,

I am writing in support of Brad Linsley's application for analysis of Walker Lake Nevada entitled "Utilizing Tracers in Walker Lake Sediments to Reconstruct the Timing of Severe Droughts in the Sierra Nevada and Bay-Delta Area Over the Last 2000 Years". I will be assisting in this research by isolating quantities of pollen from lake sediments for AMS radiocarbon dating. I am confident that this is feasible for Walker Lake based on my prior experience of obtaining pollen radiocarbon dates from Pyramid Lake as well as Sierran Lakes and marine sediments (see Mensing, S. A. and Southon, J. R. (1999) A simple method to separate pollen for AMS radiocarbon dating and its application to lacustrine and marine sediments, *Radiocarbon* 41, 1-8). Pollen dates have also been obtained by others from sediments in nearby Mono Lake (Long et al., 1992 v. 34, *Radiocarbon*). I have worked closely with colleagues at Lawrence Livermore Laboratory who have worked out procedures for consistently obtaining reliable dates from extremely small samples (typically 25 – 70 μg of carbon).

I have cold storage available at the University of Nevada, Reno for storing samples and a pollen lab where all of the pollen extraction will be performed. I see no problem being able to complete the work under the budget and timing proposed by Dr. Linsley.

Sincerely,

Scott Mensing
Associate Professor
Department of Geography
University of Nevada
Reno, NV 89557