

# **Holocene Megadroughts and Megafloods in California's Central Valley**

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## **BIOGRAPHICAL SKETCH**

Frances Malamud-Roam has been a Geographer for over 20 years, with an emphasis on records of environmental change. She received her Master's degree and Ph.D. (2002) from the University of California, Berkeley. Frances has been interested in the intersection of climate and the natural environment, writing her Masters thesis on the origins of agriculture in China focusing on the influence of changing climate patterns. Ms. Malamud-Roam did her Ph.D. research in the San Francisco Bay, examining the organic remains in the sediments from local tidal marshes to reconstruct a long-term environmental history of the San Francisco Bay as a reflection of past climate conditions.

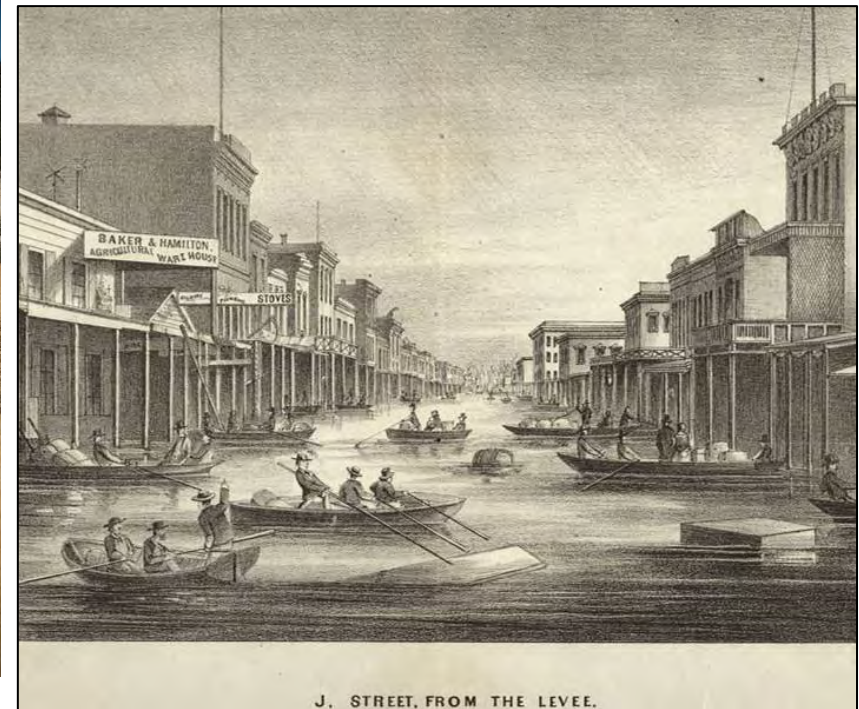
After completing her Ph.D., Ms. Malamud-Roam conducted postdoctoral research that involved analyzing the mineral sediments from the Bay tidal marshes. These mineral sediments are primarily contributed by two main rivers that drain to the Bay Estuary from the northern part of its watershed (the Sacramento river) and the southern part of the watershed (the San Joaquin river). Her research used the mineral sediments as a proxy for reconstructing changes in the relative flows of these two rivers over long timescales. These records elaborate our understanding of changes in precipitation regimes over California as at times in the past the northern and southern parts of the state have experienced similar climate trends and at other times the trends have been at odds.

## **ABSTRACT**

The central valley of California is intimately connected to the Sierran and coastal mountains, where it receives winter and spring runoff and to the San Francisco Bay Estuary, which receives the combined flows of the Sacramento and San Joaquin Rivers. Climate over this broad region is variable over both space and time, with a distinct north-south gradient in total precipitation and pronounced wet and dry seasons. Historic variations in the typical climate conditions have included mild to severe droughts as well as torrential rains accompanied by flooding. An examination of paleoclimate records from throughout California, spanning several thousands of years can provide a greater understanding of the natural range of climate over California's central valley and the potential impacts of global warming on its associated ecosystems than the last century or so of instrumental records has provided.

After a postglacial warming and drying trend in California, conditions grew cooler and, in many places, wetter around 3,800 – 2,000 years ago. These conditions had the effect of lowering salinity in the San Francisco Bay Estuary and altering environmental conditions for local ecosystems. This period was followed by gradual drying throughout the state, a general trend that has been punctuated by recurring periods of prolonged and/or severe drought over the region (megadroughts) and by catastrophic wet periods (megafloods). A number of paleoclimate records from across the state suggest that notably stable conditions have prevailed over the instrumental period, i.e., after ca. A.D. 1850, despite occasional severe, short-term anomalies experienced during this period.

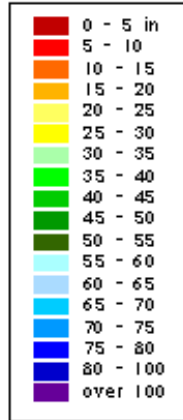
# Holocene Megadroughts and Megafloods in California's Central Valley



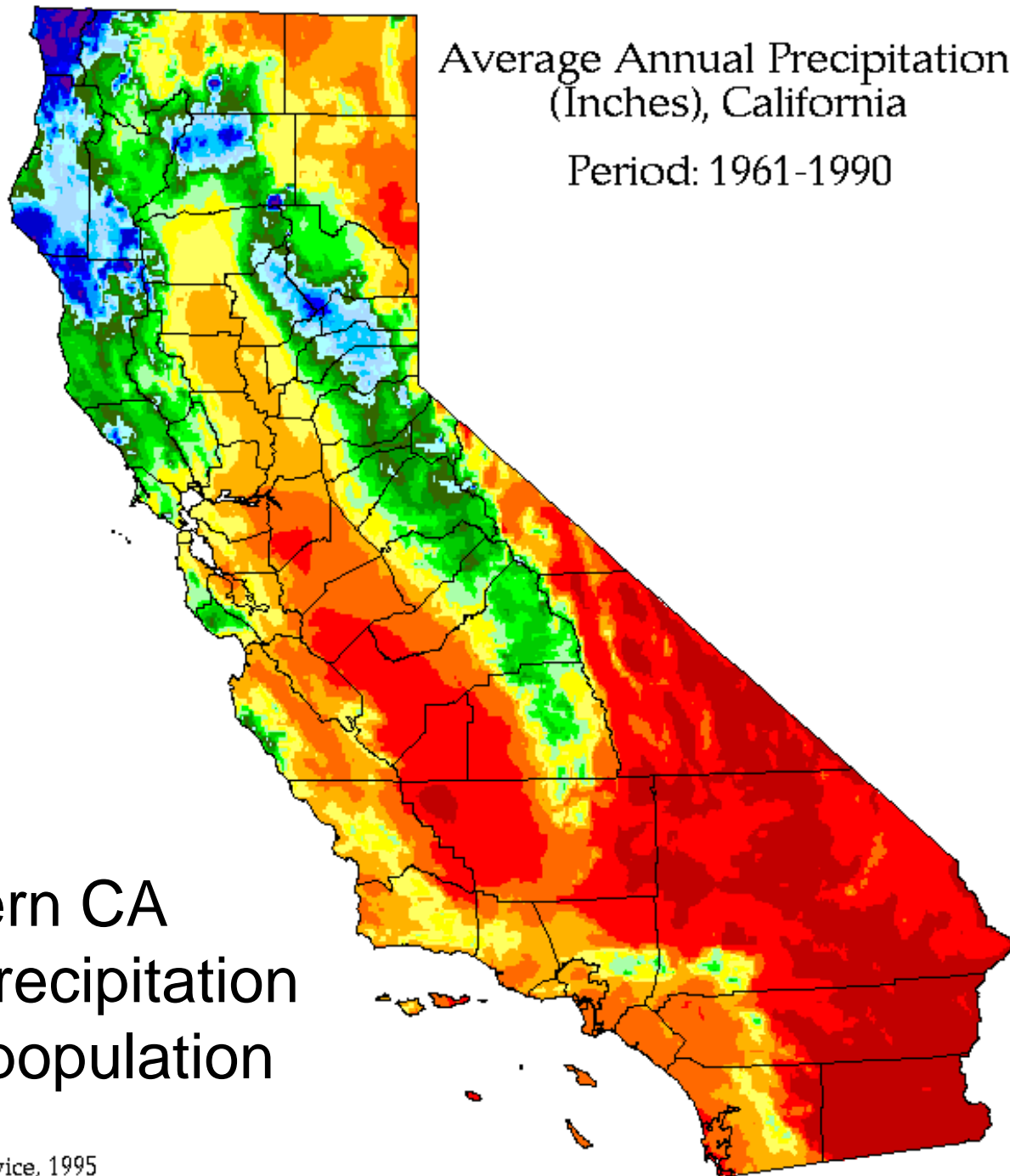
**Frances Malamud-Roam, Dept of Geography, U.C. Berkeley**

Left: Drought in Lake Oroville, South Fork of Feather River shot 02/03/2009 - Looking West from just in front of the Lumpkin Road Bridge. Note the small amount of water in the riverbed. Right: Flood in Sacramento 1862.

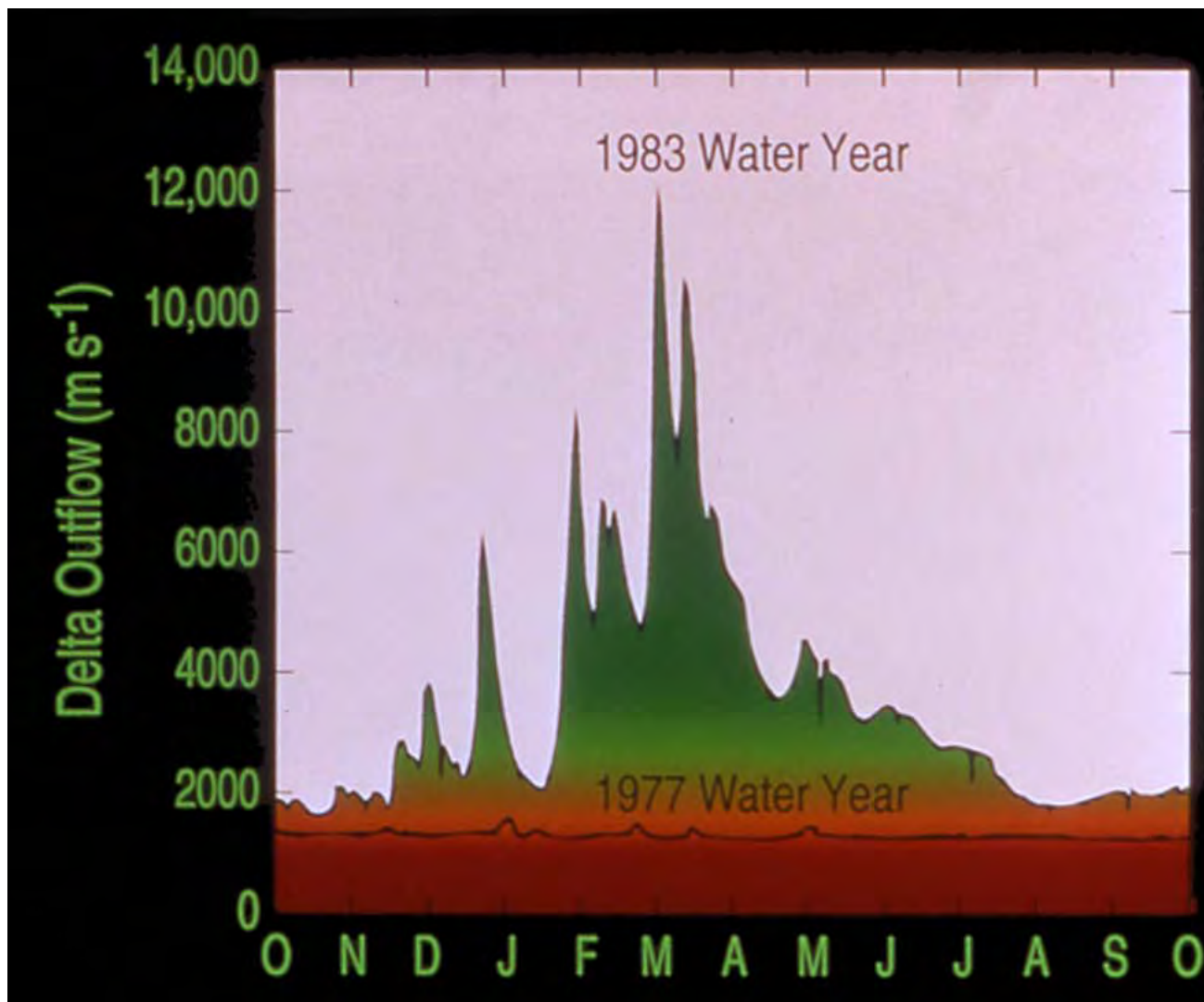
Average Annual Precipitation  
(Inches), California  
Period: 1961-1990



Southern CA  
-low precipitation  
-high population



# Seasonal and variable year-to-year

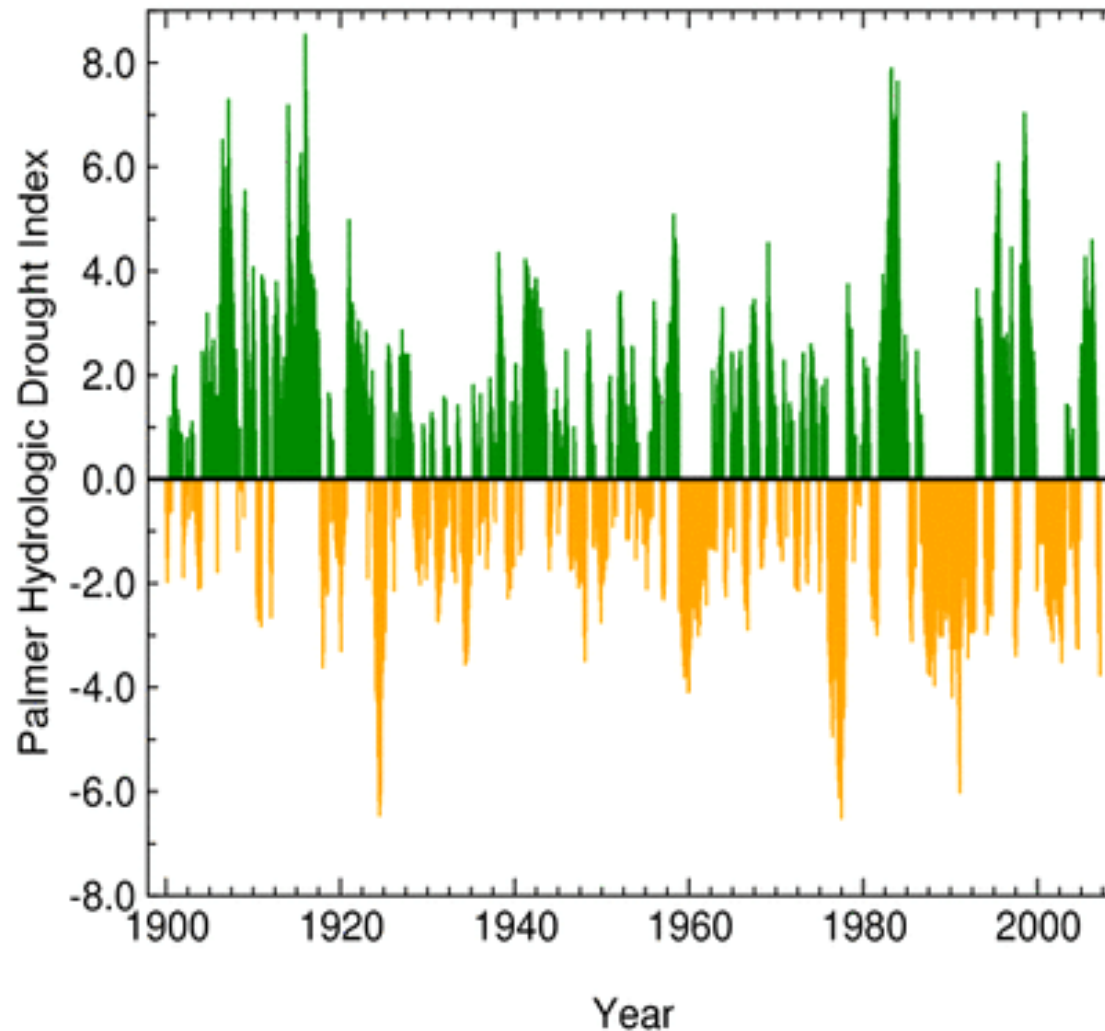


WY 1977  
vs. 1983



# California Statewide PHDI\*

January 1900 - March 2007



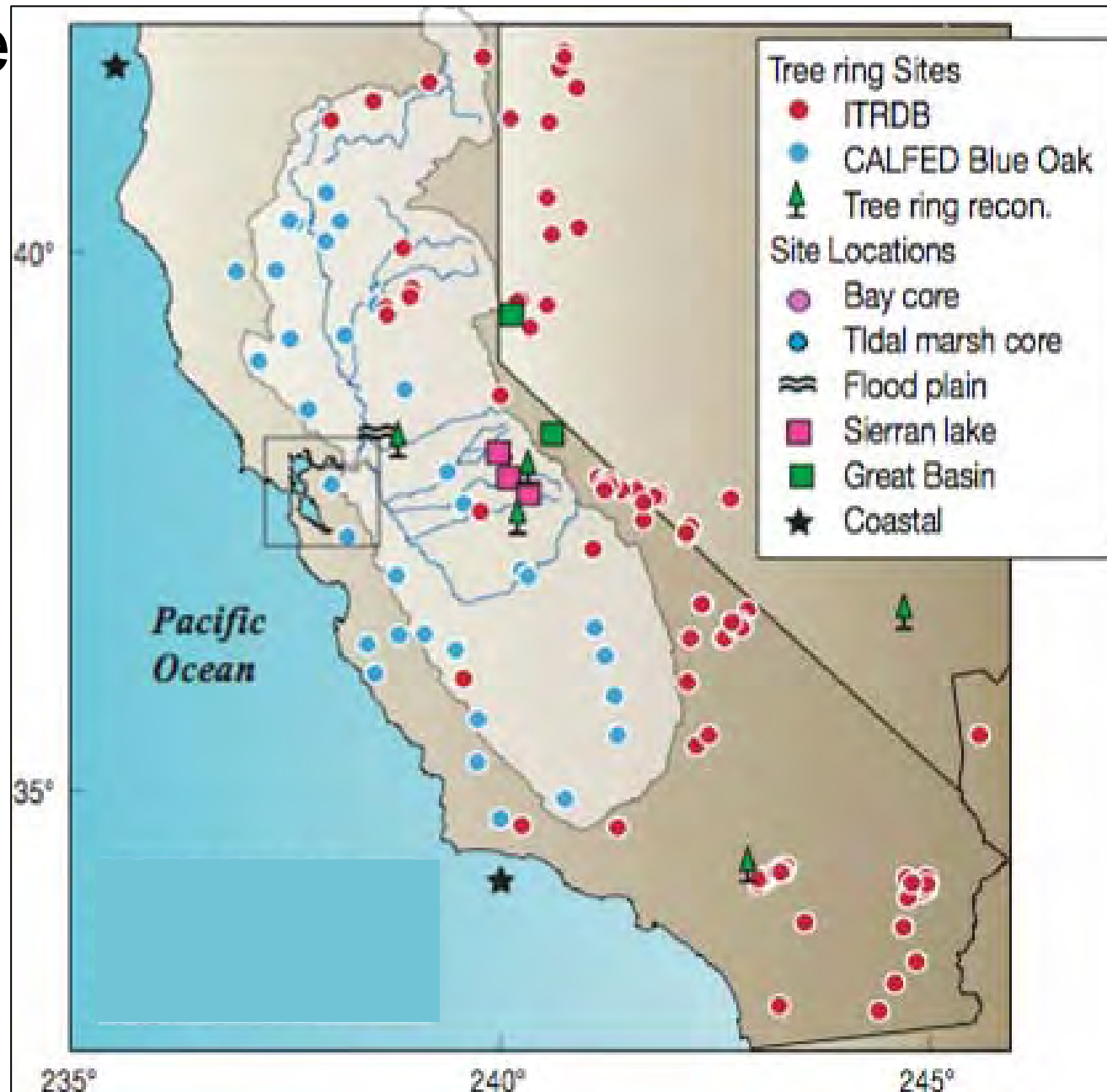
\*Palmer Hydrological  
Drought Index



National Climatic Data Center / NESDIS / NOAA

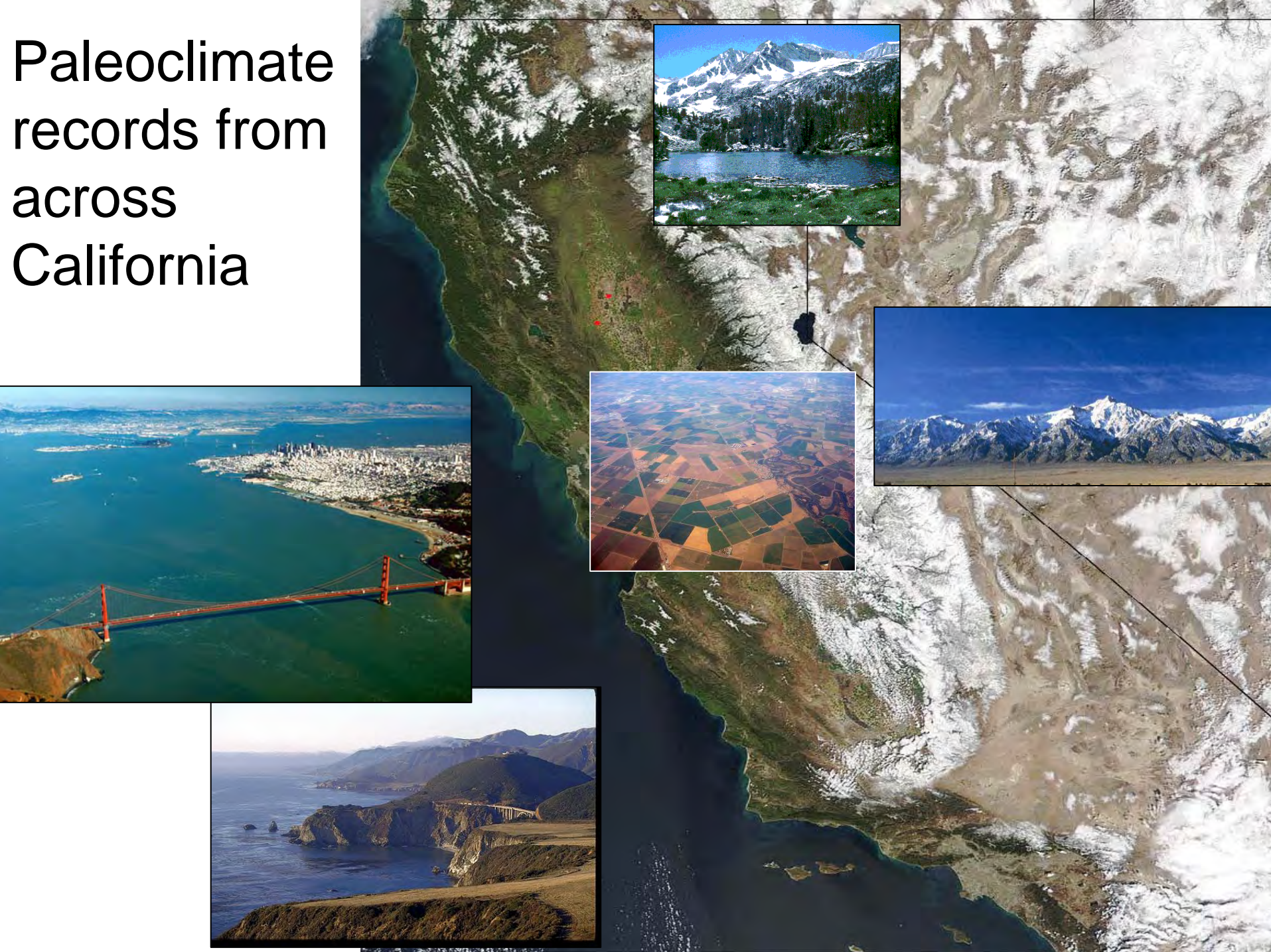
## Temporal variability on decadal-scale

# Extending the record - paleoclimate research in California



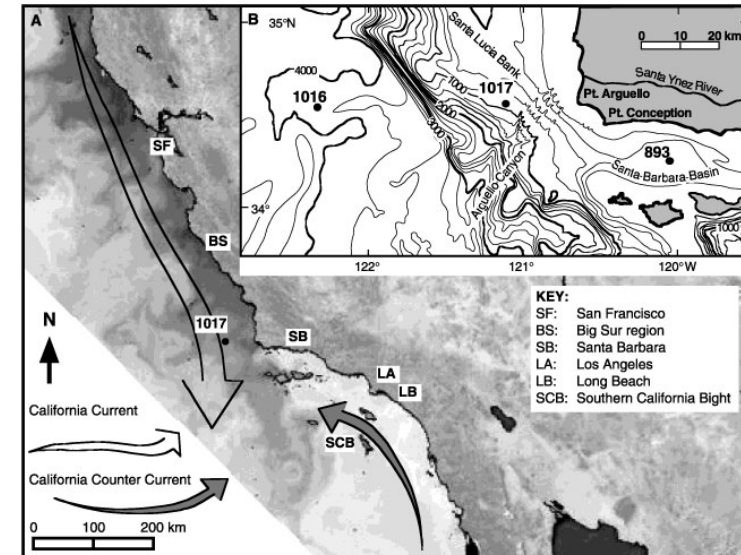


# Paleoclimate records from across California





# Coastal California: Santa Barbara Basin



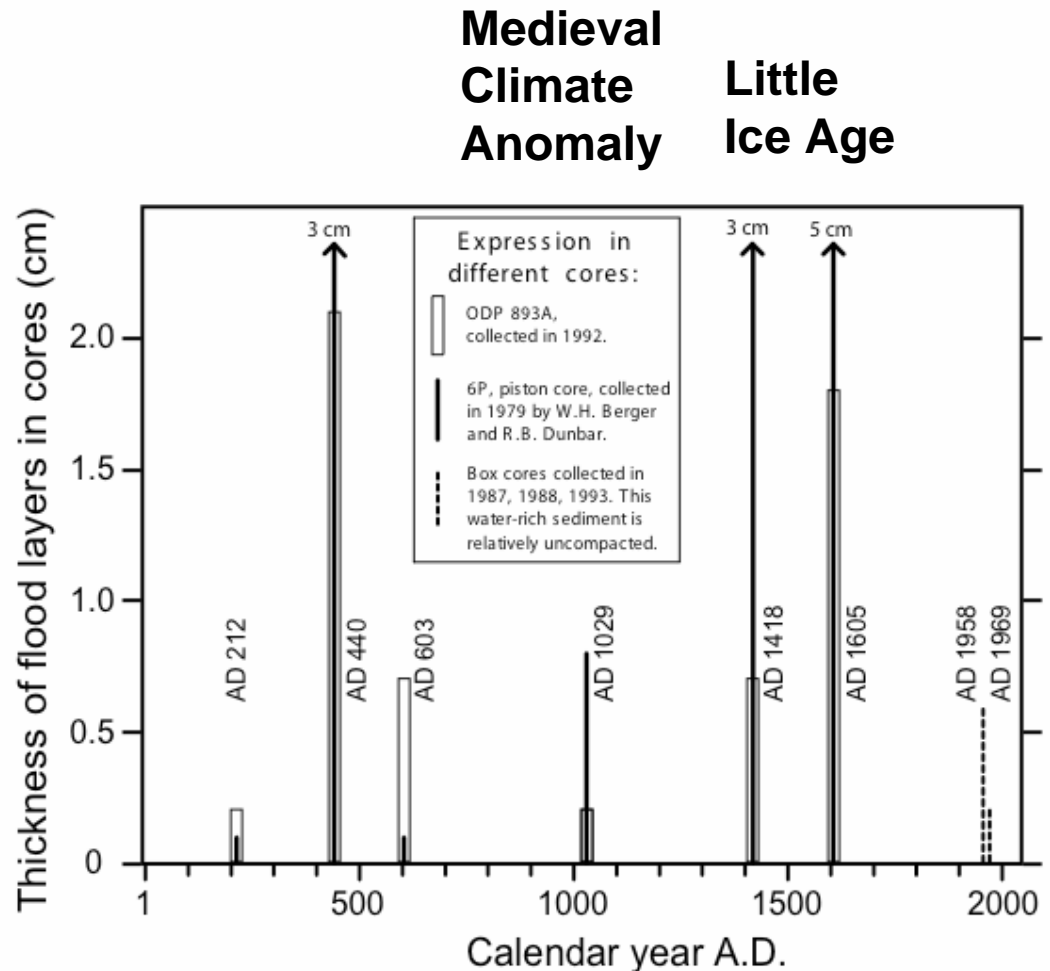
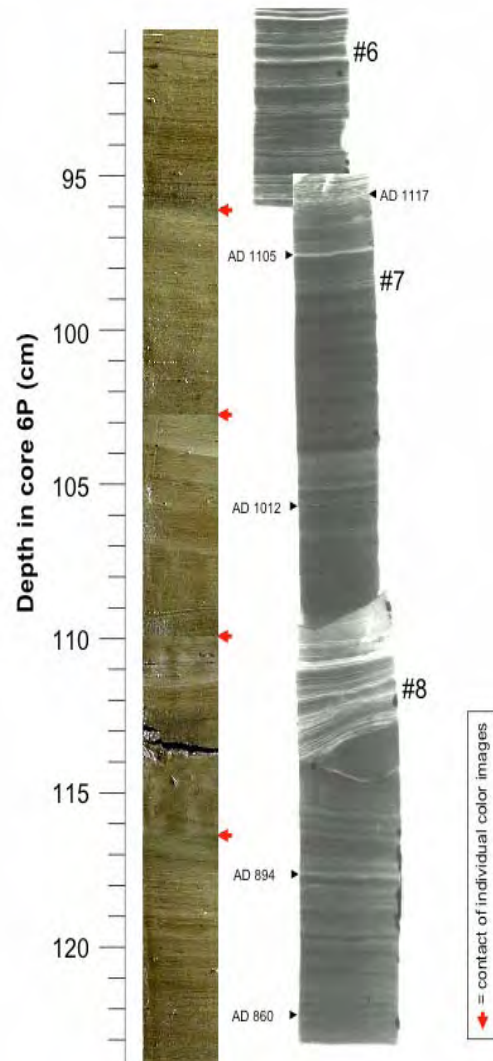
[http://www-odp.tamu.edu/publications/167\\_SR/chap\\_22/images/01\\_f01.jpg](http://www-odp.tamu.edu/publications/167_SR/chap_22/images/01_f01.jpg)

Microfossils and geochemistry of sediments from coastal basins provide histories of:

- sea surface temps
- mixing layer
- floods

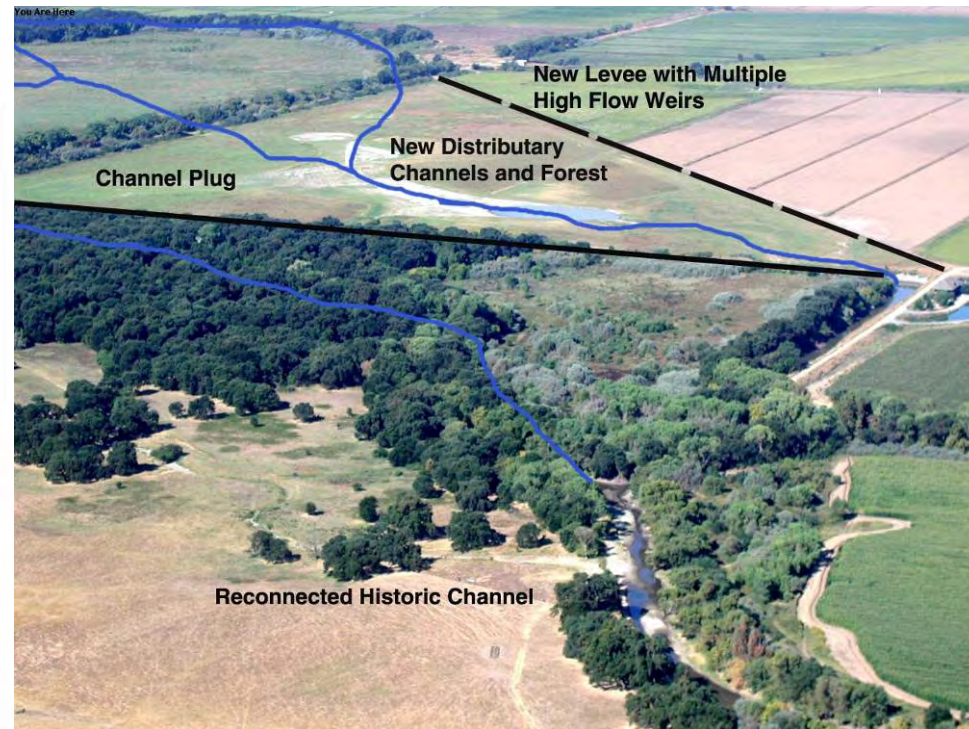
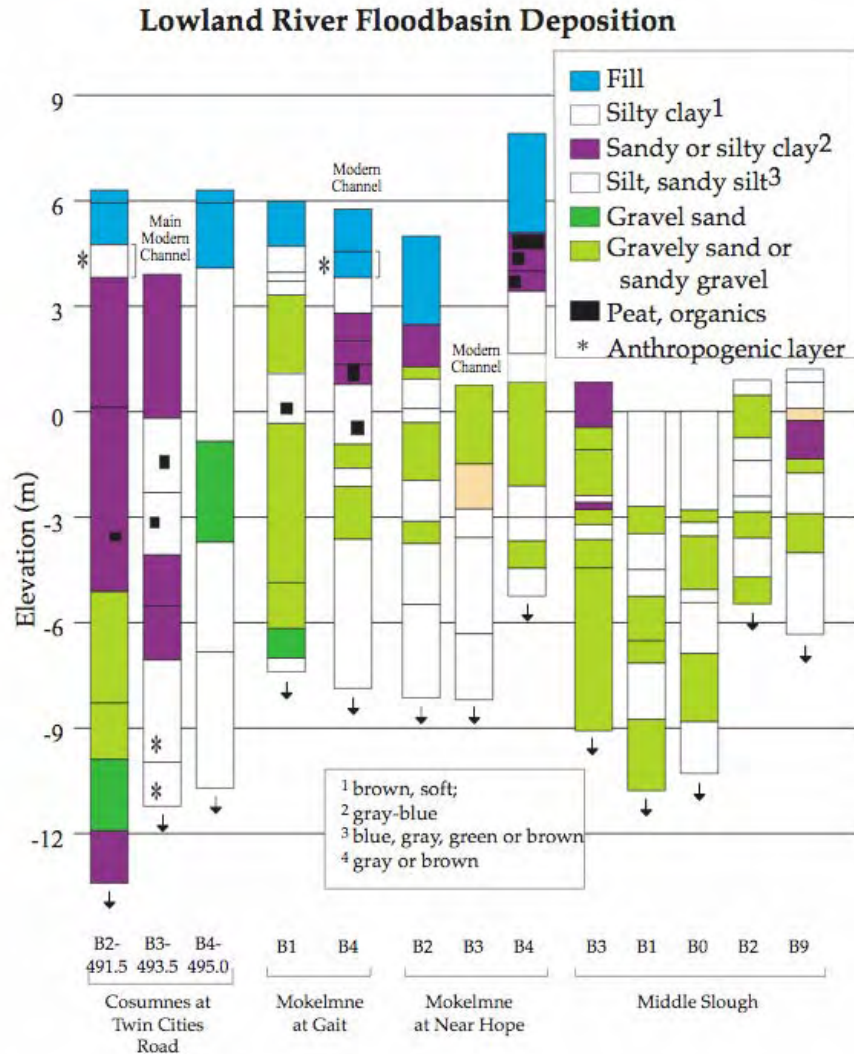


# Flood events in Santa Barbara Basin: ~200 year periodicity



(Schimmelmann et al., 2003)

# Central Valley lowland floodplain records



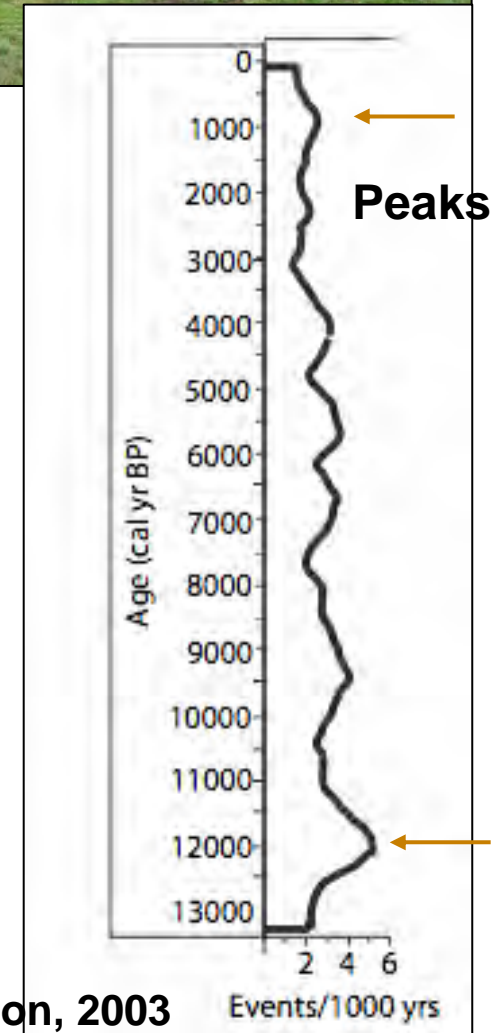
# Floods in California's Central Valley

I.D.	Reference	Location	Year	Description
1	Ingram et al. 1996c	San Francisco Bay	1270-1380, 1675-1730, 1800-1860	High inflow
	Ingram et al. 1996c	San Francisco Bay	1200	top of unconformity
2	Goman and Wells, 2000	San Francisco Bay	1420	Browns Is Flood
3	Malamud-Roam, 2002	San Francisco Bay	1090, 1645	China Camp flood, top of unconformity, Benicia core
4	Earle, 1993	Sacramento River	1597-1613, 1641-1657, 1664-1675, 1725-1735, 1741-1754, 1798-1821, 1854-1869, 1874-1887, 1891-1916, 1962-1973	High flow
5	Sullivan, 1982	Sacramento River	1235-1360 1295-1410 1555-1615 1750-1770 1810-1820 1861	large flood flood largest flood flood large flood Historic flood
6	USBR, 2002	American River	350-550  825-1300 1300-1800	1 flood larger than historic & gage records 1 very large flood 3 floods larger than historic records
7	Graumlich, 1993	So. Sierra	1071-1090, 1478-1527	high precipitation





# ***Sierran lake records: e.g., fire frequency***



Brunelle and Anderson, 2003



# Eastern Sierra Nevada Records:

Submerged tree-stumps

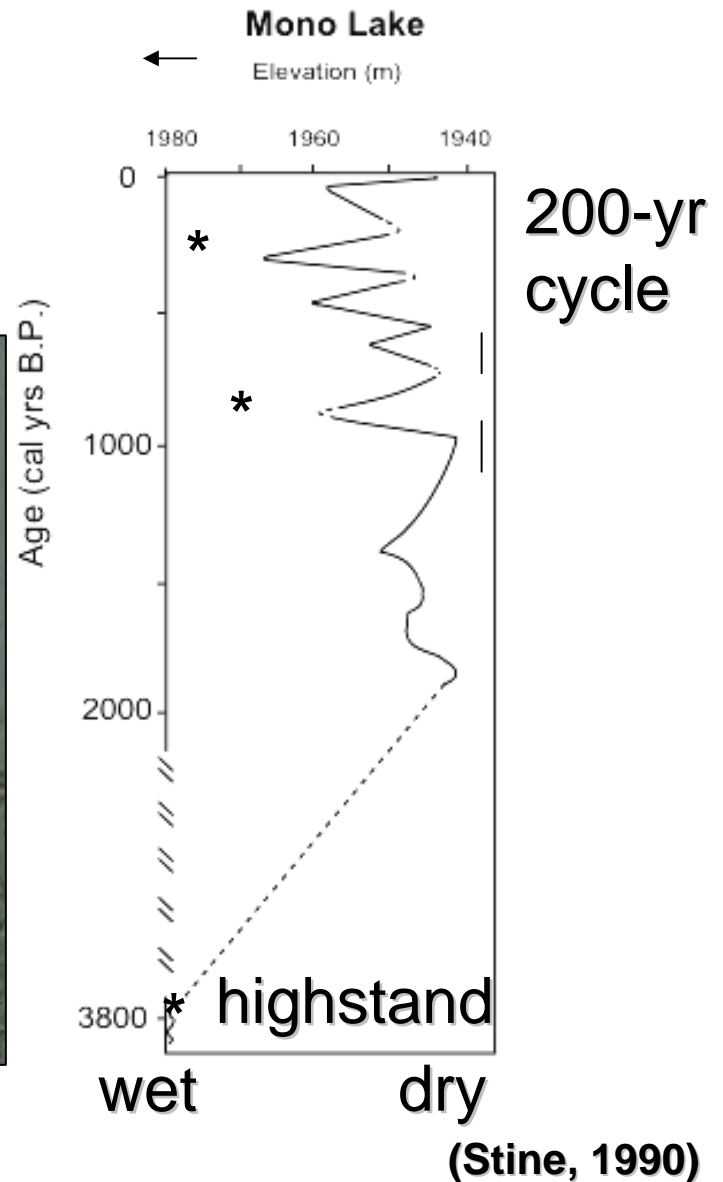
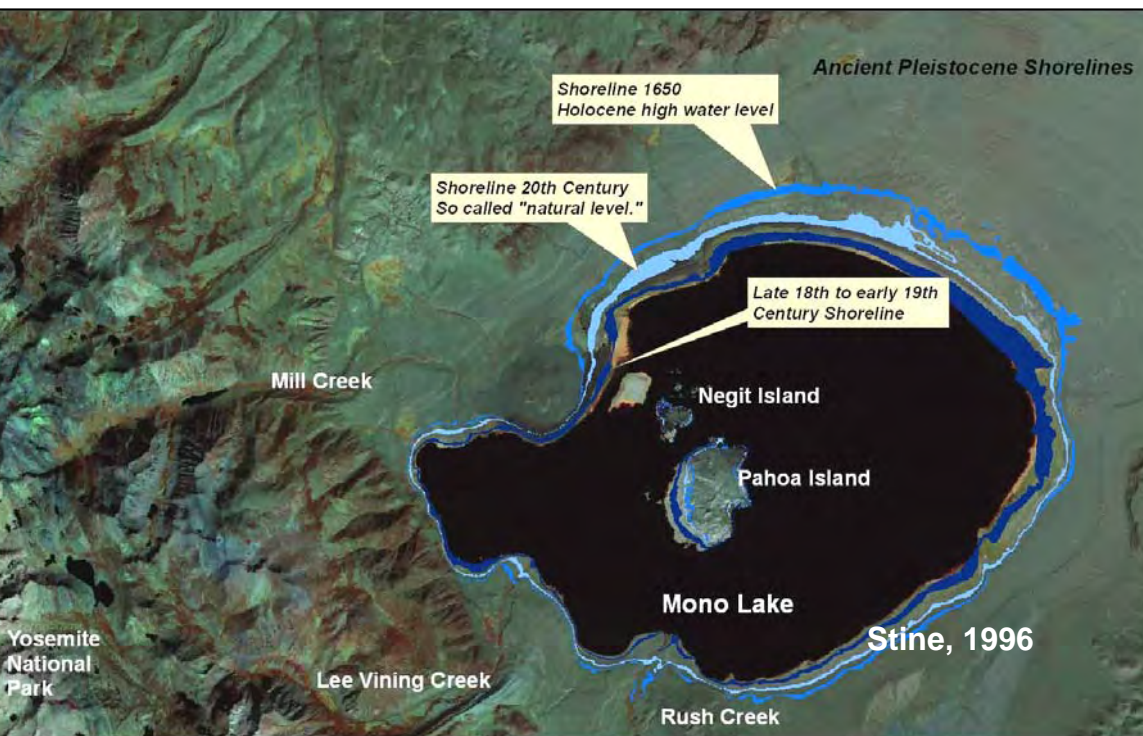
-A.D. 900-1100

-A.D. 1200-1350



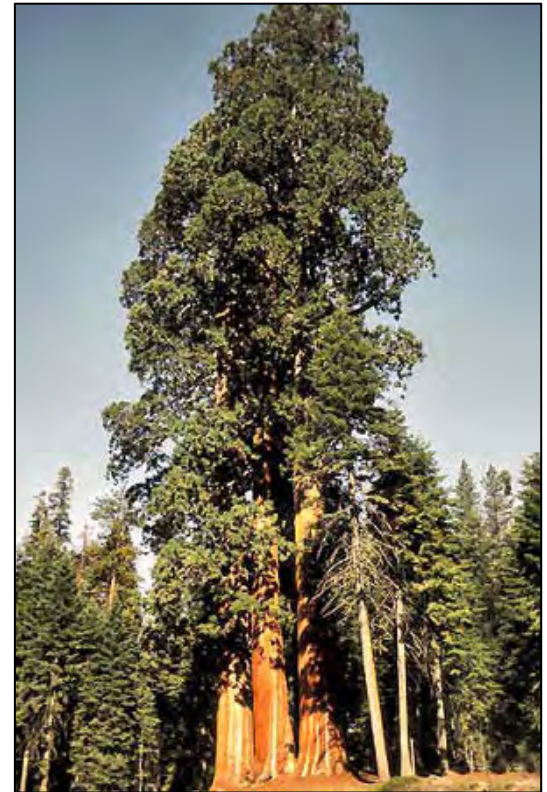
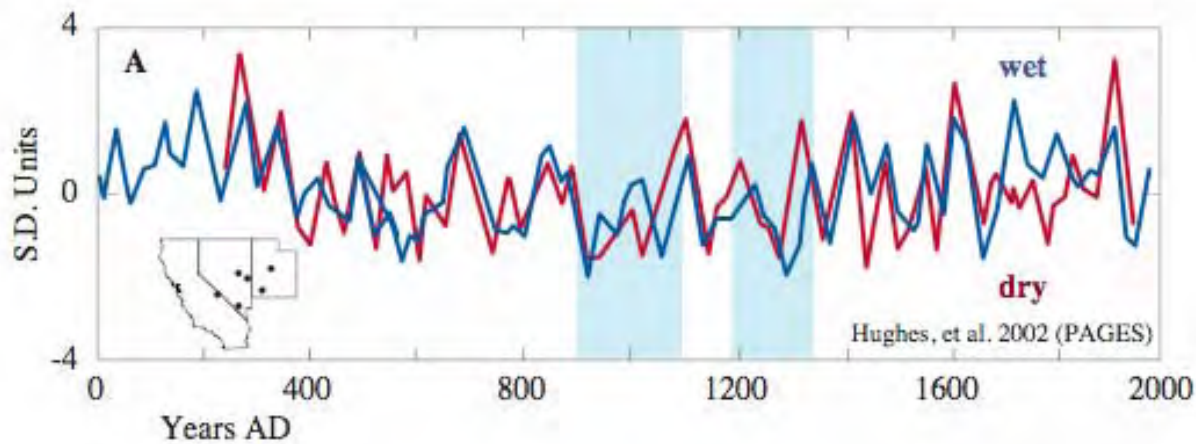
“Medieval Climate Anomaly”  
Stine (Nature, 1994)

# Mono Lake Levels: 3800 yr - present





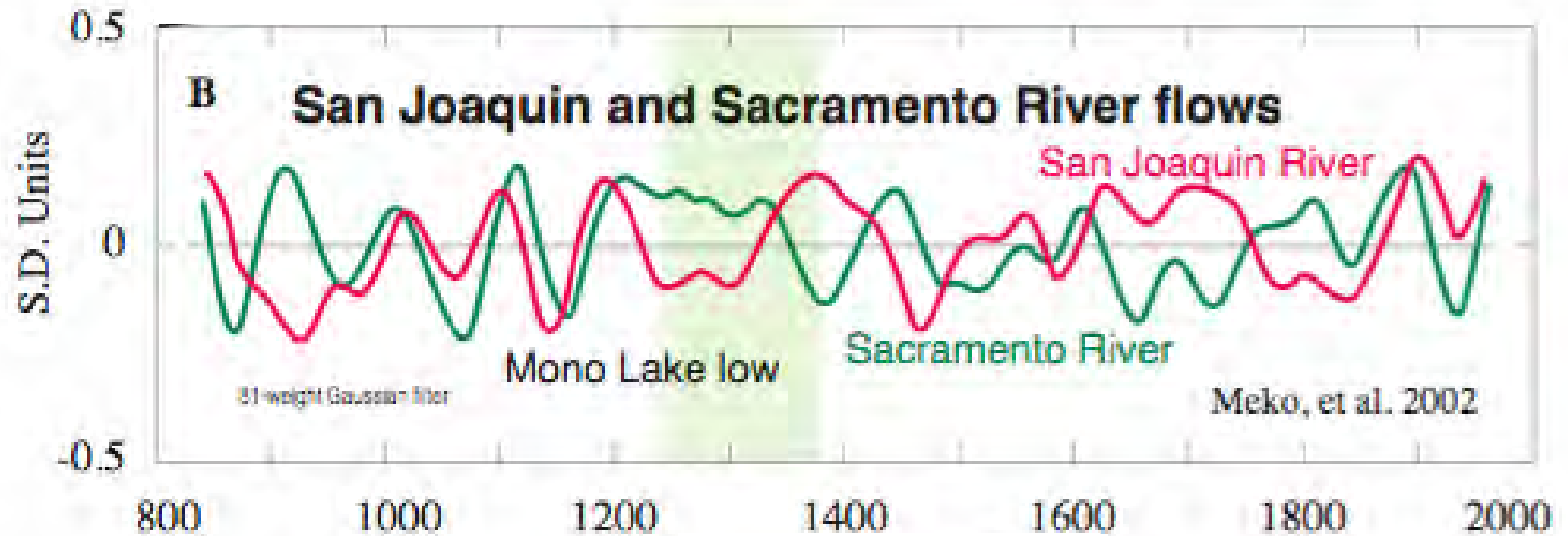
# So. Sierra Nevada Tree-ring records



Last 2,000 years

Mono lake droughts highlighted

# River reconstructions



*San Francisco  
Bay estuary  
ecosystems reflect  
climate conditions  
over the  
watershed*

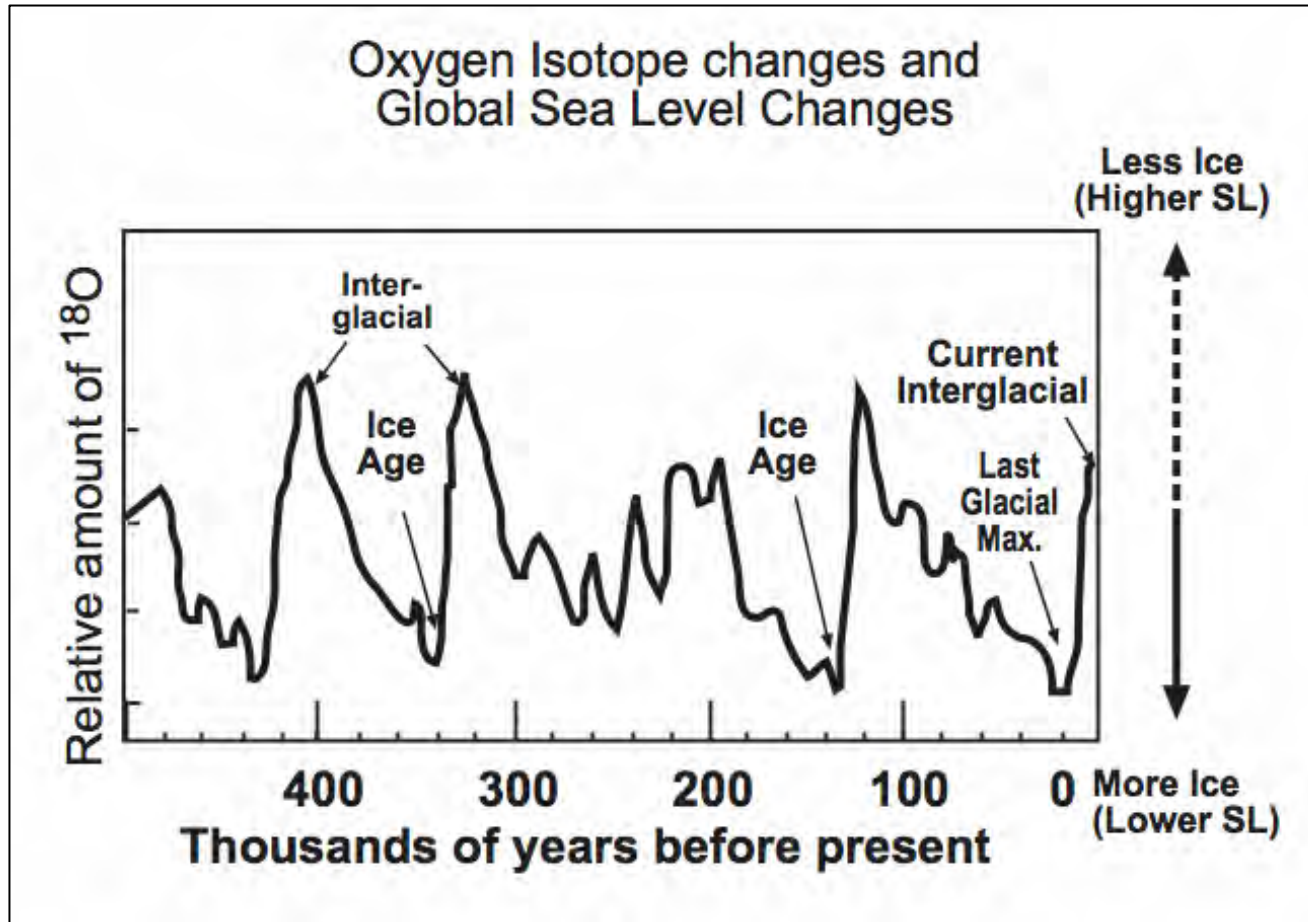




# San Francisco Estuary salinity: reflection of climate

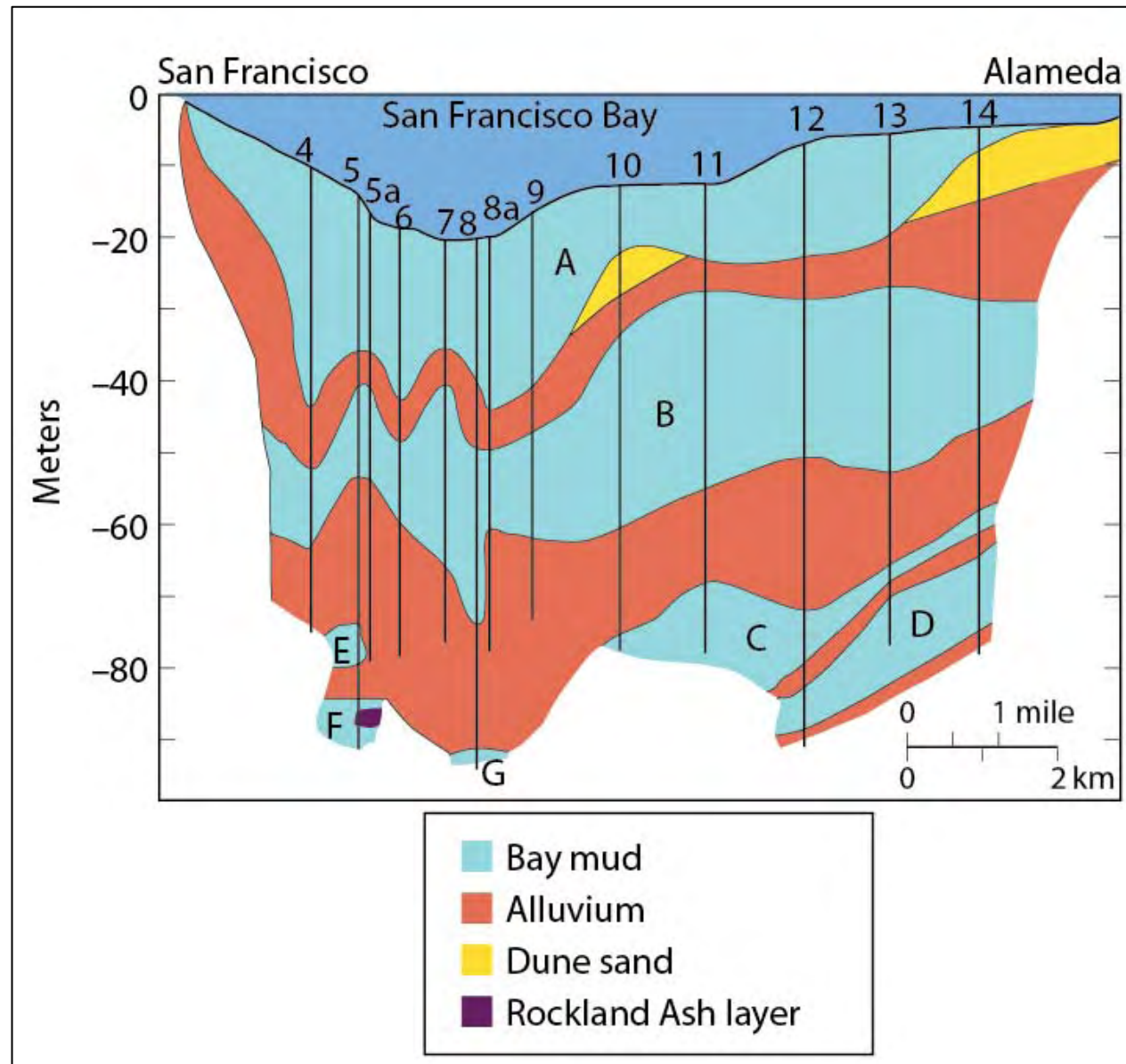


# *A brief history of San Francisco Bay ...*



The estuary is an ephemeral feature appearing and disappearing with the Ice Ages

Previous incarnations of the Bay contained in its sediments



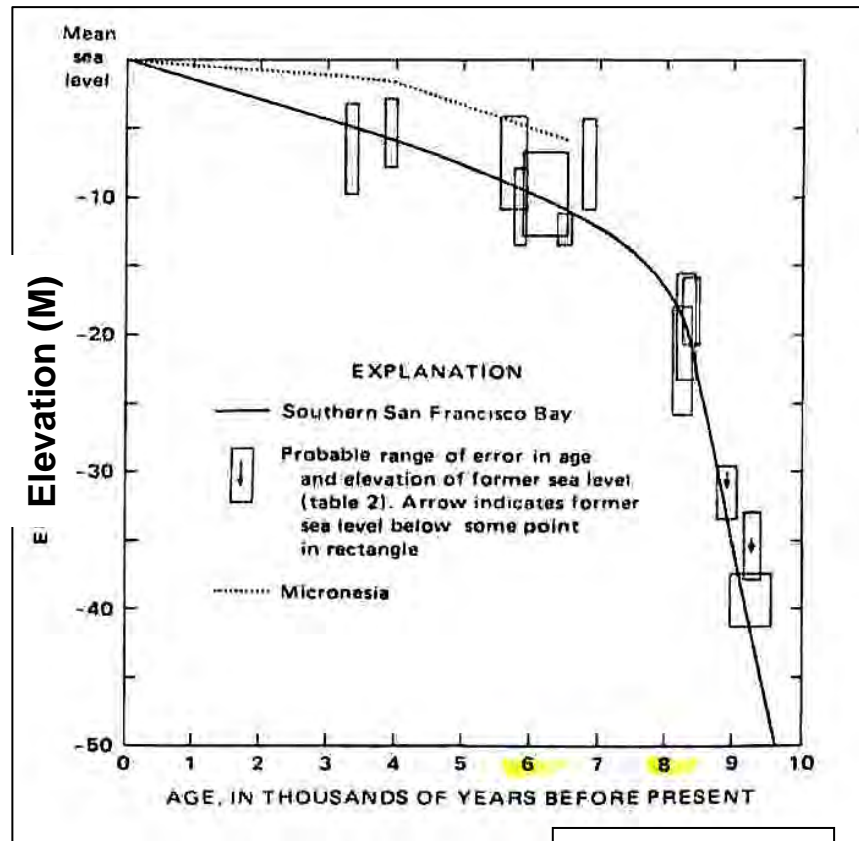




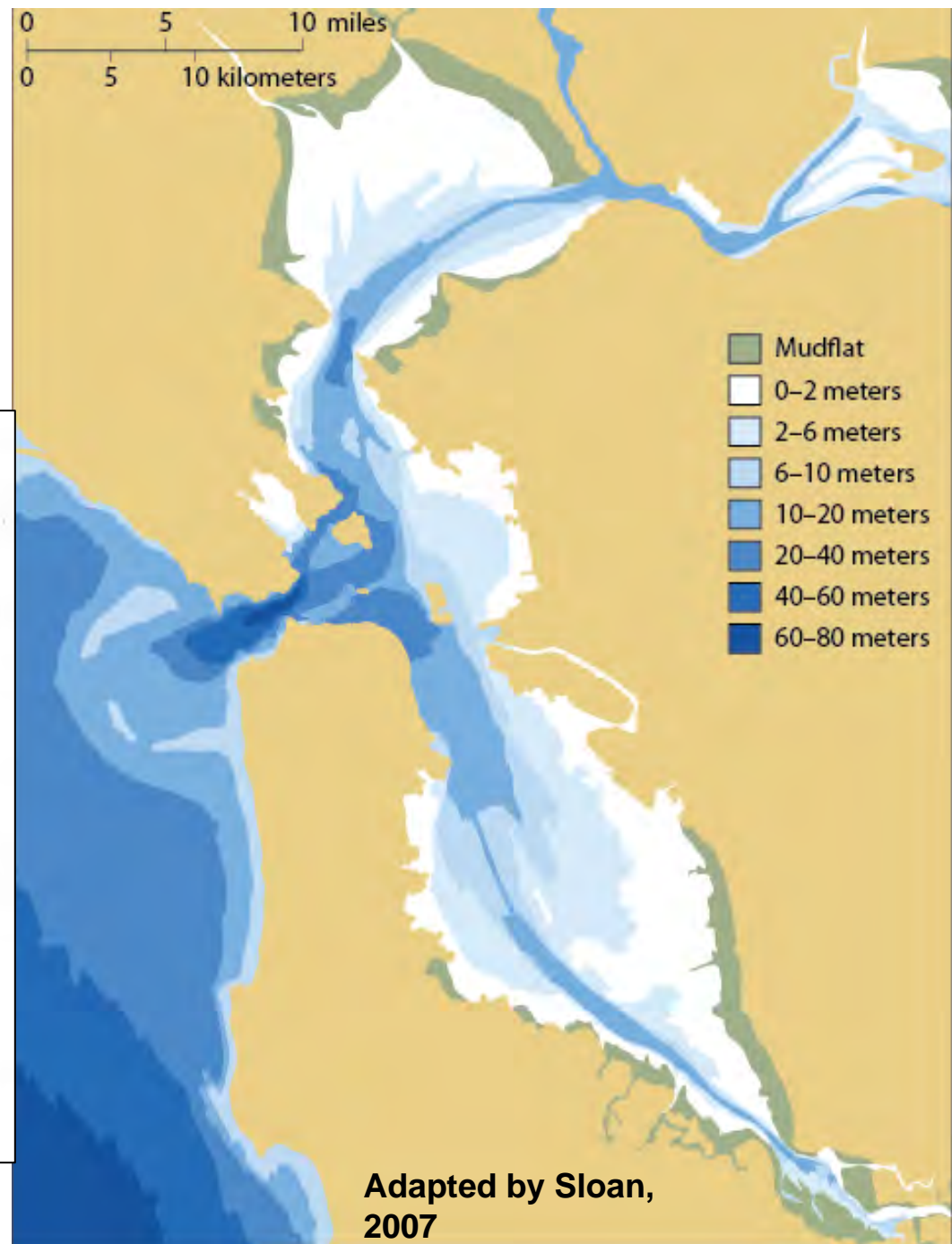
Adapted by Sloan, 2007

Sea level at time of Last Glacial Max:  
120 meters lower; shoreline 19 miles out

# Sea Level Rise over the Last 10,000 years



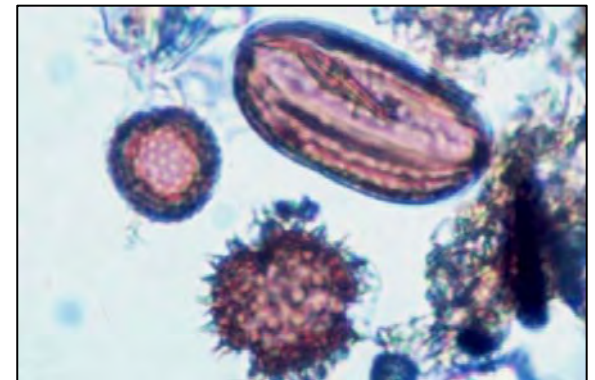
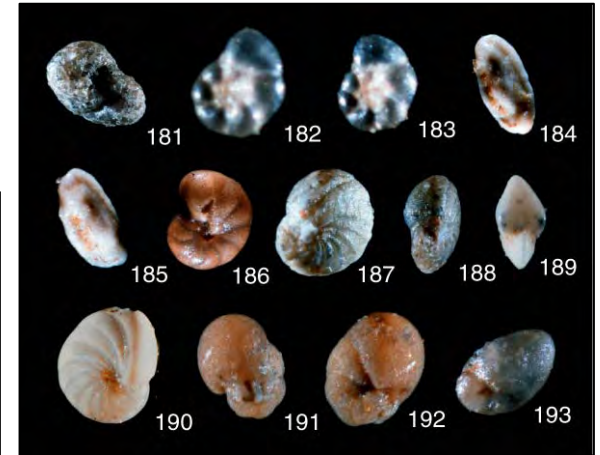
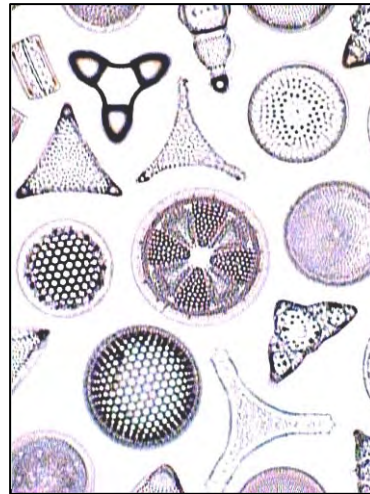
Atwater, 1979



Adapted by Sloan,  
2007

# *Sedimentary records from the Bay*

- Stratigraphy
- marine organisms
- Seeds & Macrofossils
- Diatoms
- Pollen
- Chemistry





# On the marsh

***Low marsh zone:  
brackish tidal marsh***



Slightly  
fresher

***High marsh zone: brackish tidal marsh***



# Plant distributions in the Bay marshes

Brackish to fresh



Higher salinity



# Life in the tidal setting

Aerenchyma



Succulence



Salt excretion

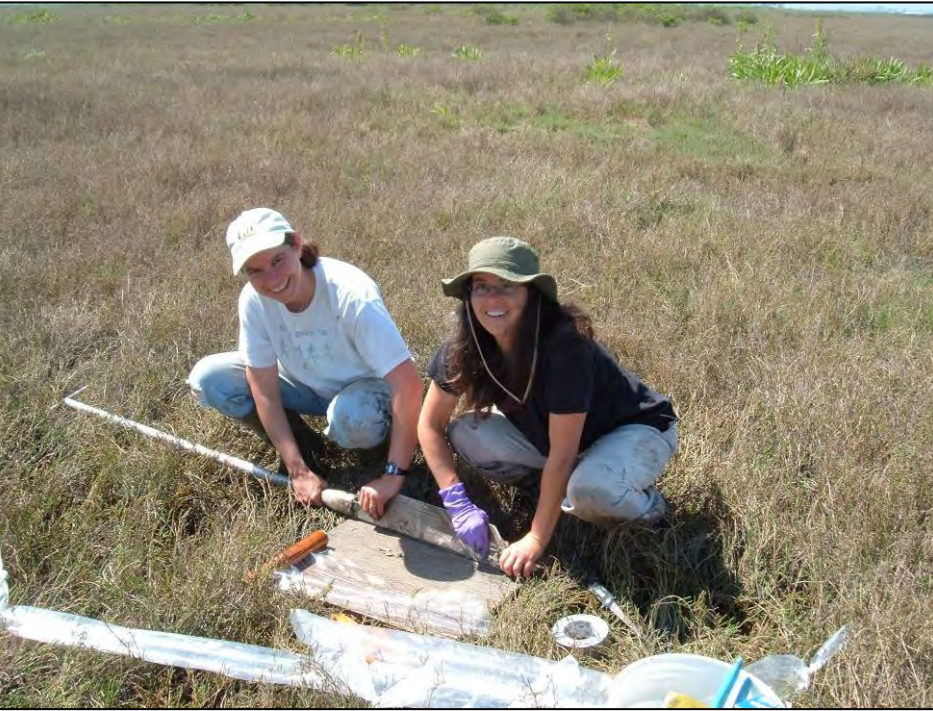


Stresses: inundation and salinity

Adaptations: physical and other



# Sediment cores



*Collecting cores from a tidal salt marsh*








# Core sampling



- Regular intervals
- Seeds for radio-C analysis
- Bulk for  $^{13}\text{C}$  analysis
- Pollen analysis
- Other analyses



# Tidal Marsh Stratigraphy: China Camp

-  Clay-rich Peat
-  Transition to peat
-  Peat
-  Mineral rich estuarine seds (Bay Mud)
-  Plant parts incl. rhizomes and sheaths
-  Plant roots
-  Coarse sand

Radiocarbon Dates (cal yr BP)

496

826

831

2728

3568

3655

Depth  
(cm)

0

25

70

100

150

200

250

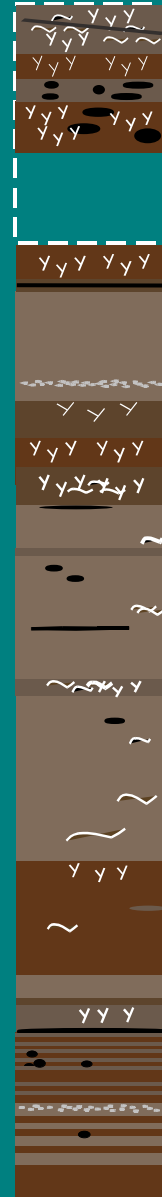
300

350

400

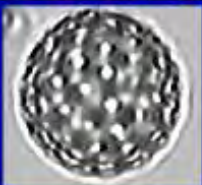
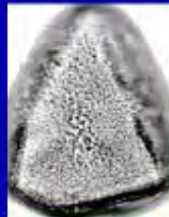
450

475



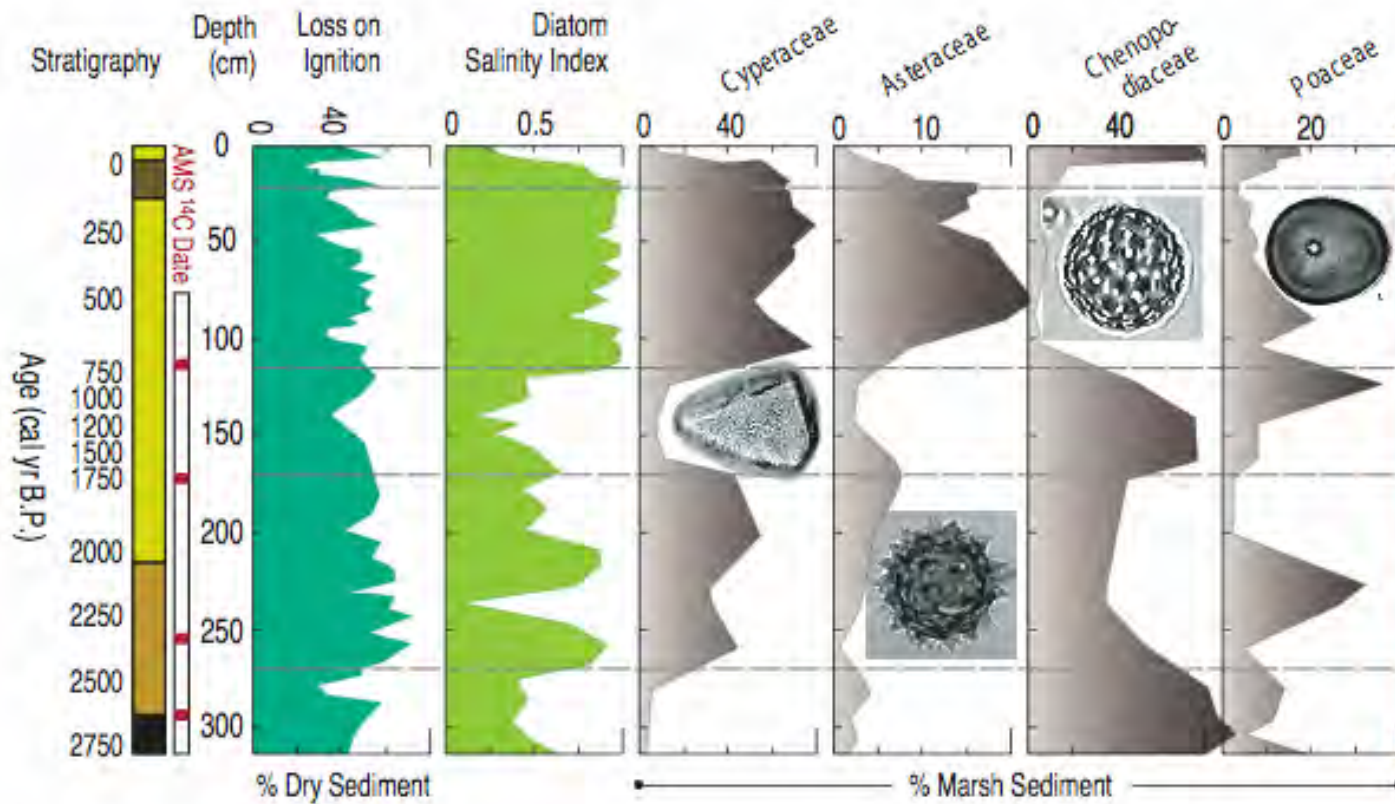


# Pollen Analysis



- Identifiable grains
- Incorporates surrounding area

# Marsh Core Results, Rush Ranch, Solano



peaty clay
  peaty clay with vertical roots
  clay

Byrne et al., (2001)

# Carbon isotopes

**$^{12}\text{C}$ : 98.93%**

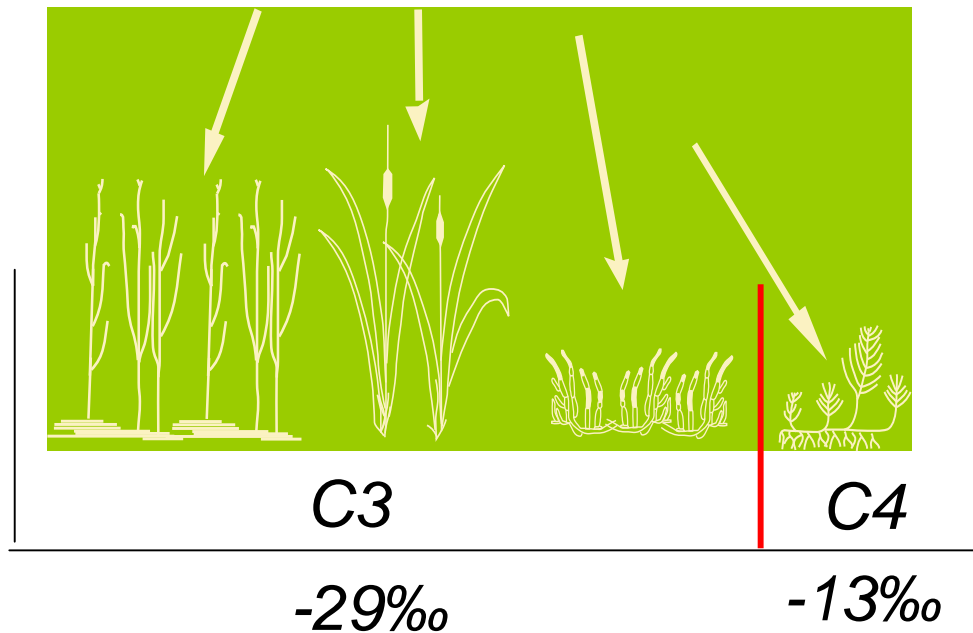
**$^{13}\text{C}$ : 1.07%**

**$^{14}\text{C}$ : <<.001%**

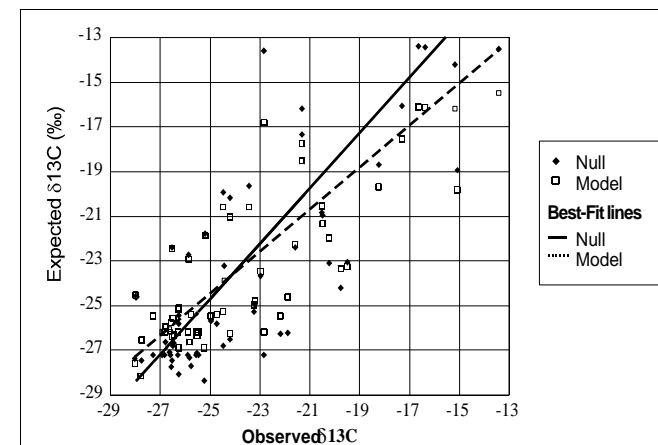


# $^{13}\text{C}/^{12}\text{C}$ Isotope ratio in marshes

$\text{CO}_2 \sim -8\text{‰}$



Sedimentary isotopic signature reflects plants



$R^2 = .67$ ,  $\text{RMS} = 1.33$

Differing Plant  
Environments



=>

Differing  
Photosynthetic  
Pathway

C4

C3

(CAM)

=>

Different  
 $\delta^{13}\text{C}$   
value

~ -12‰

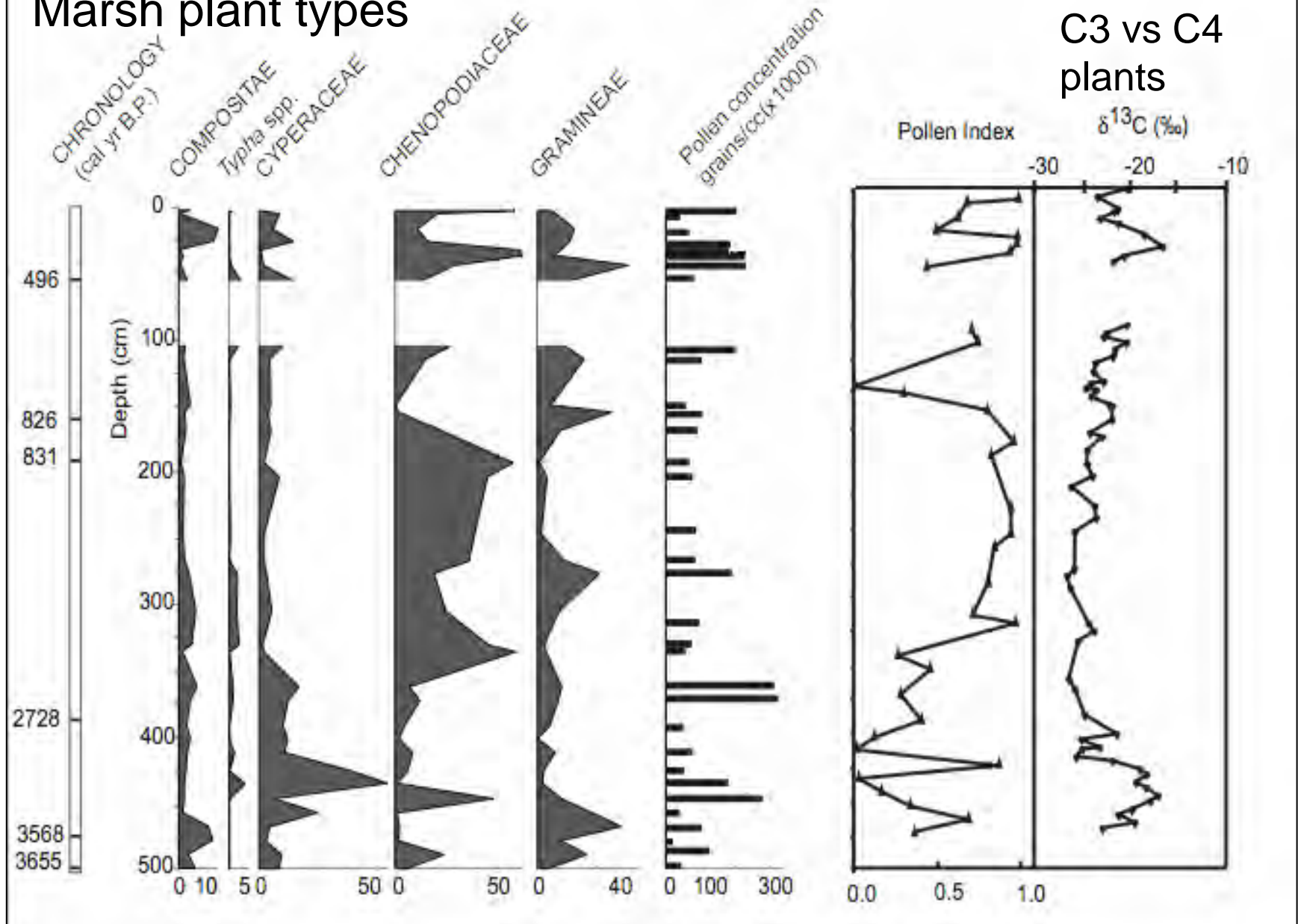
~ -29‰

(intermed.)

Isotopic value of plant remains gives clues  
to past conditions

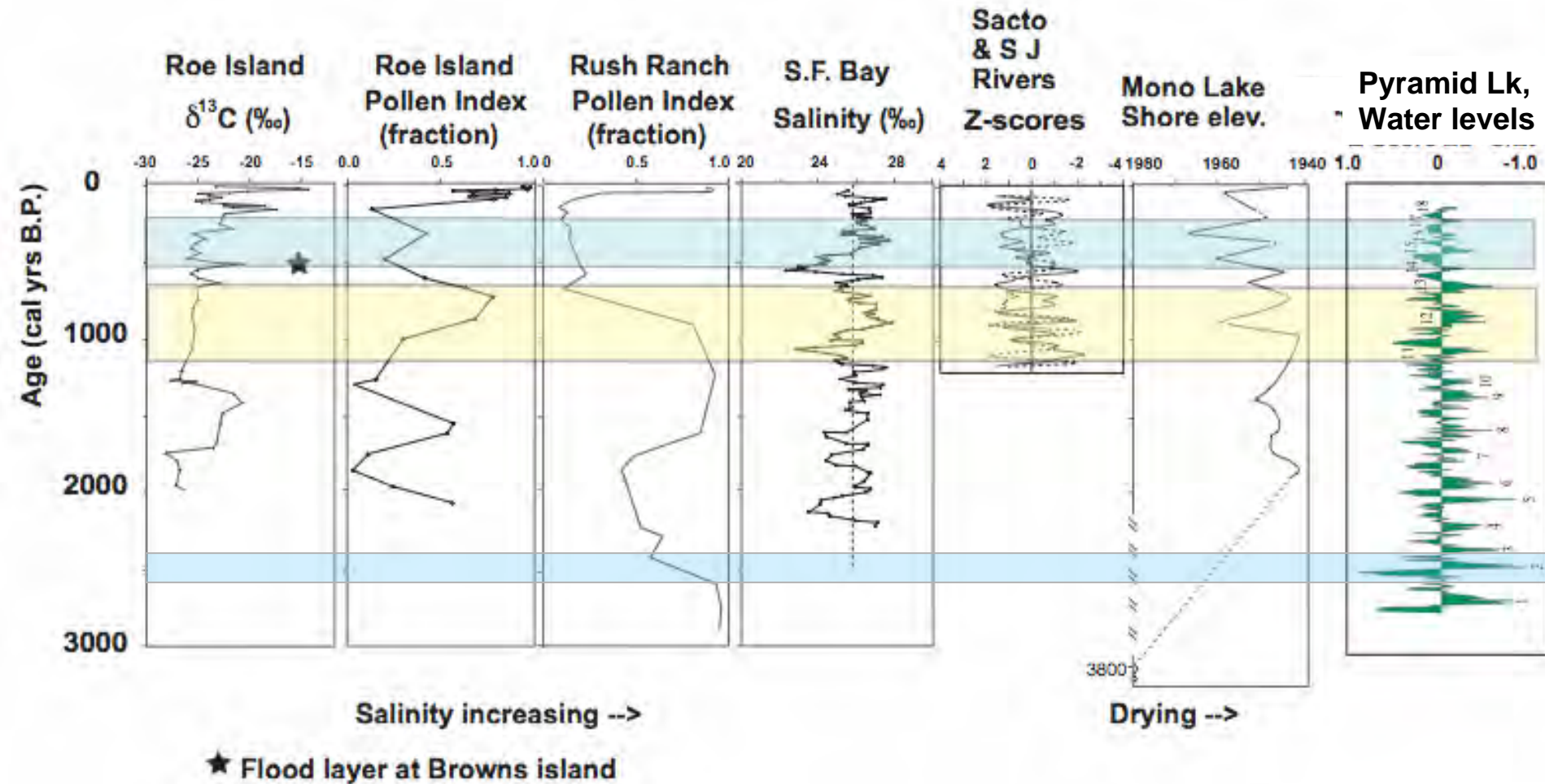
# Vegetation history from China Camp core

## Marsh plant types





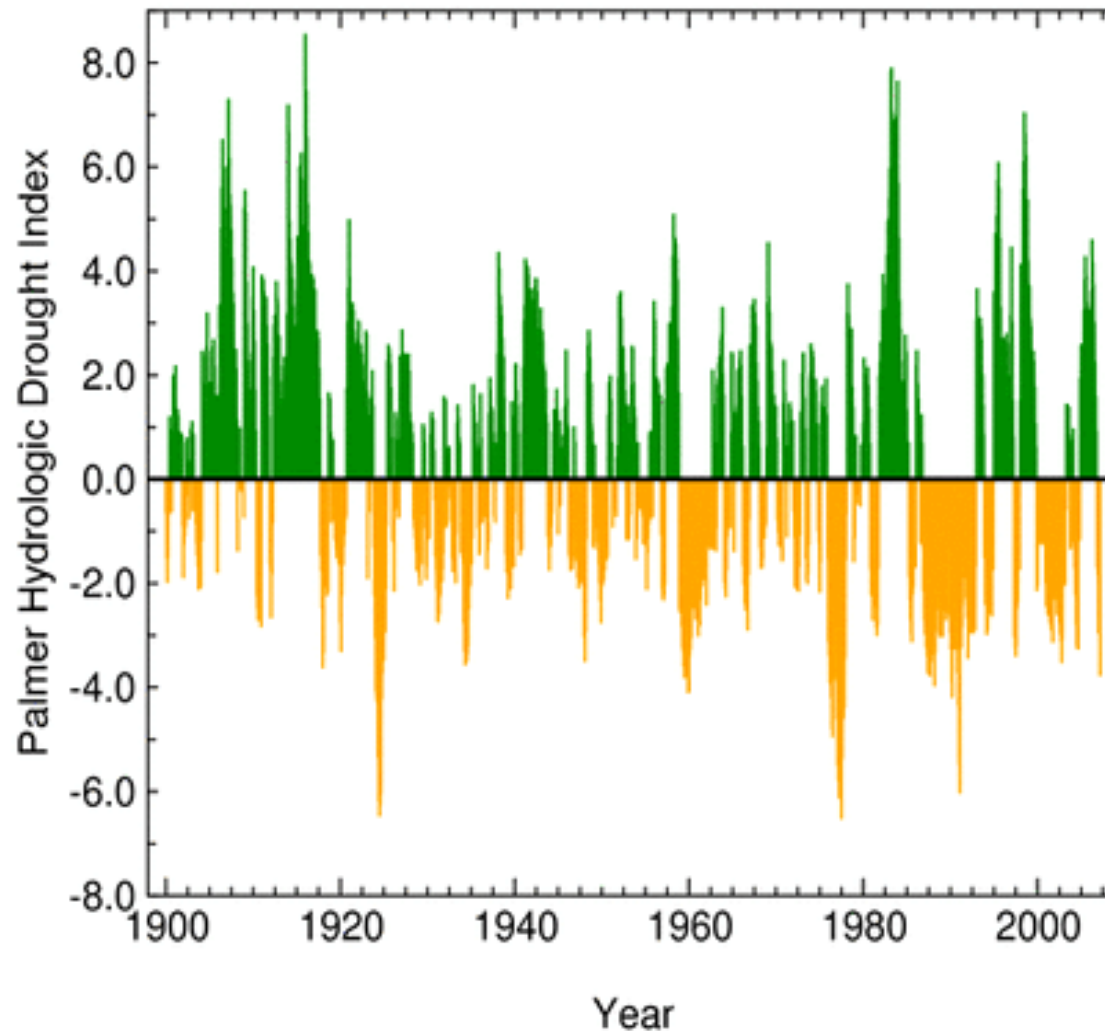
# Records from the Bay and its watershed



Records show similar periodicities of extreme events: 55, 90, 150, 200 yr recurrence

# California Statewide PHDI\*

January 1900 - March 2007



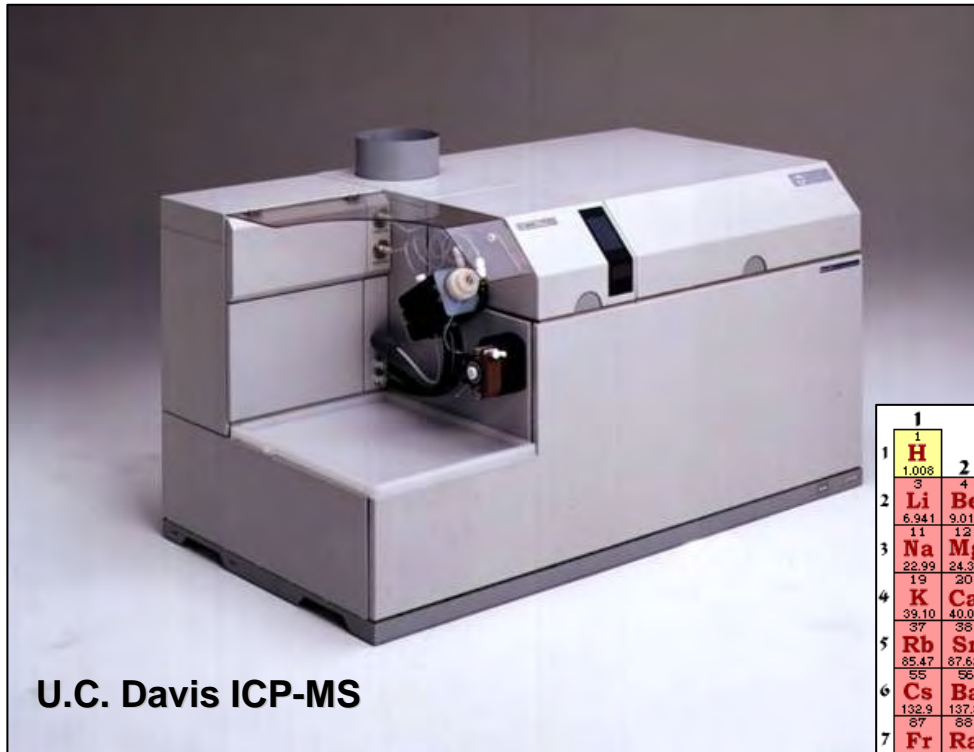
\*Palmer Hydrological  
Drought Index



National Climatic Data Center / NESDIS / NOAA

## Temporal variability on decadal-scale

# Using elemental concentrations as geochemical fingerprints



U.C. Davis ICP-MS

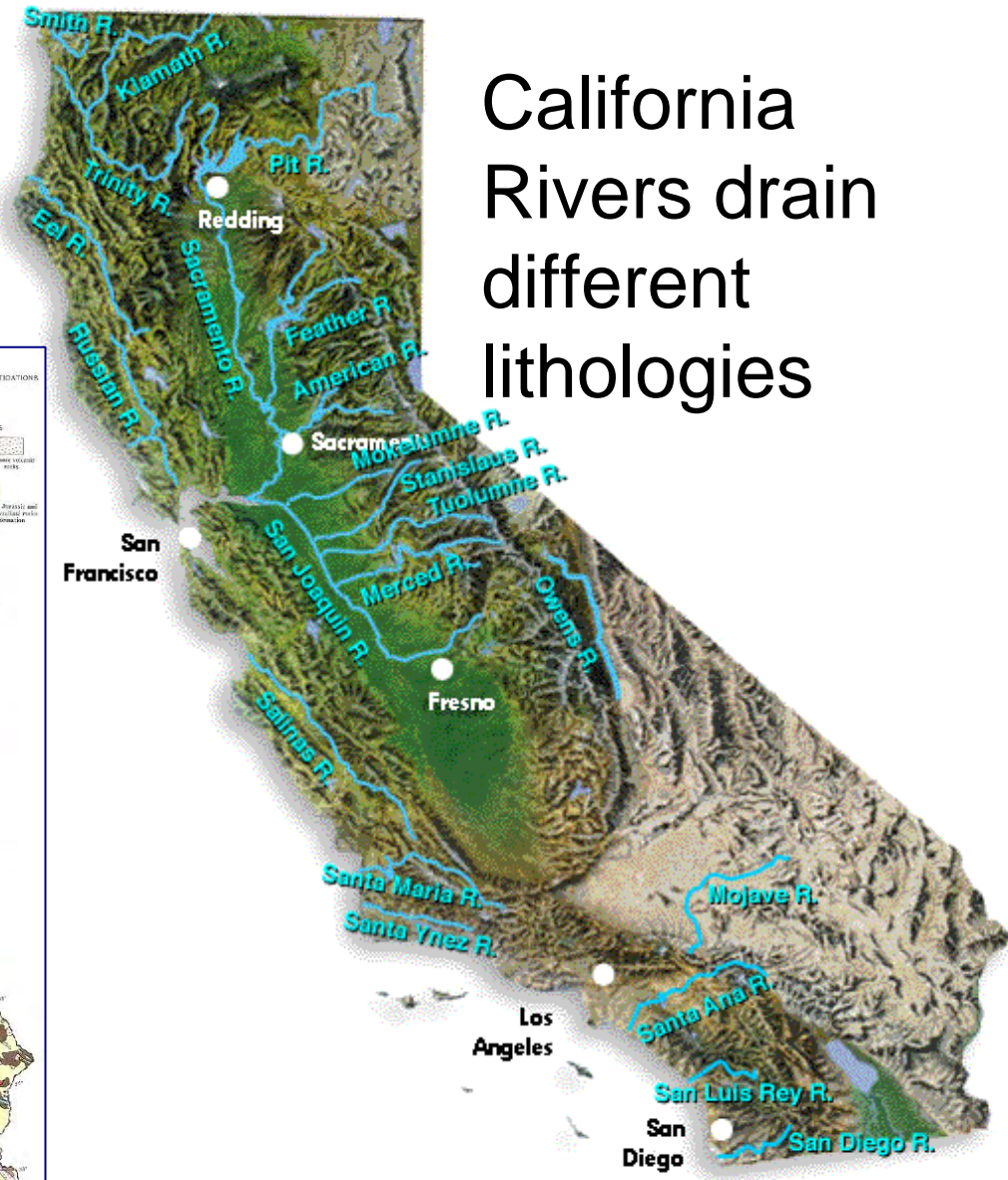
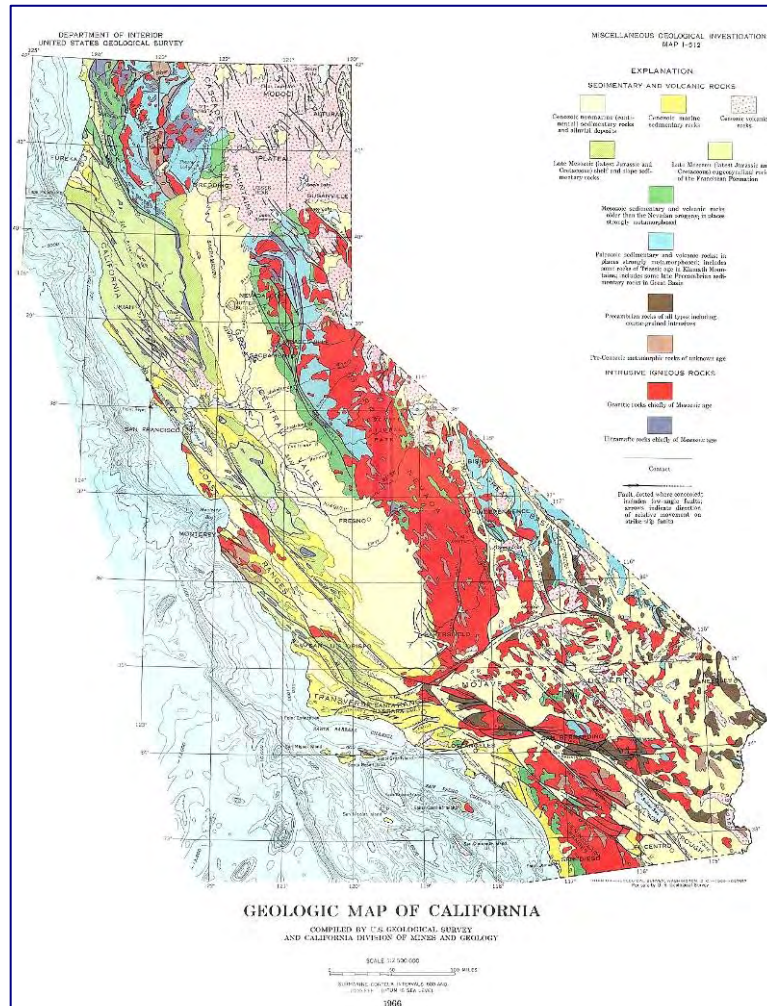
Inductively coupled plasma mass spectrometry (ICP-MS) & optical emissions spectrometry (ICP-OES)

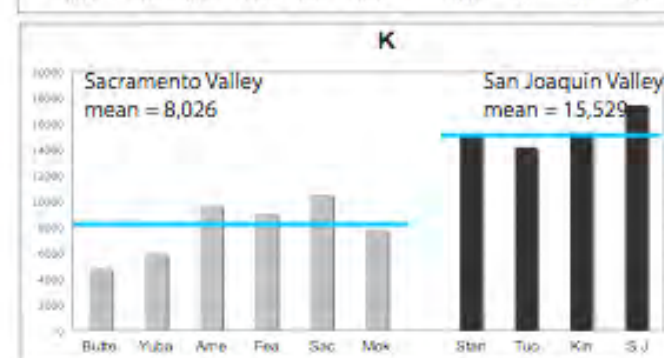
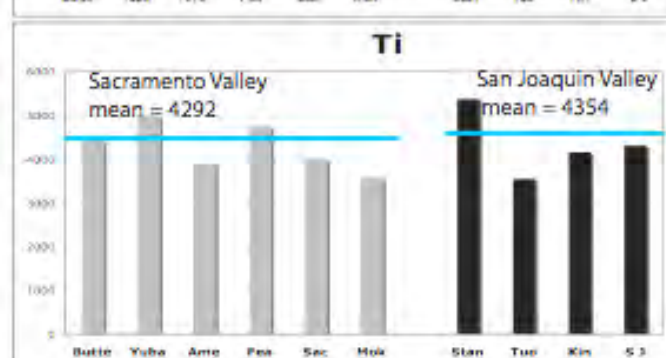
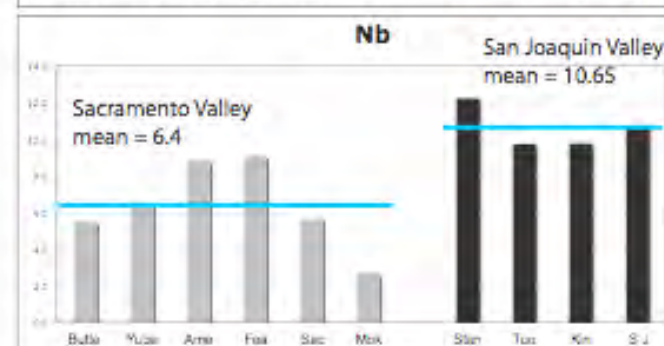
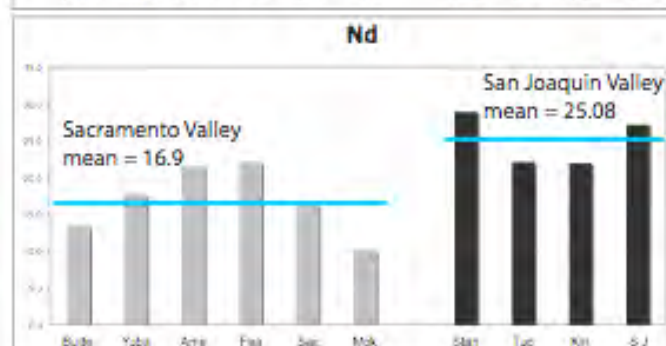
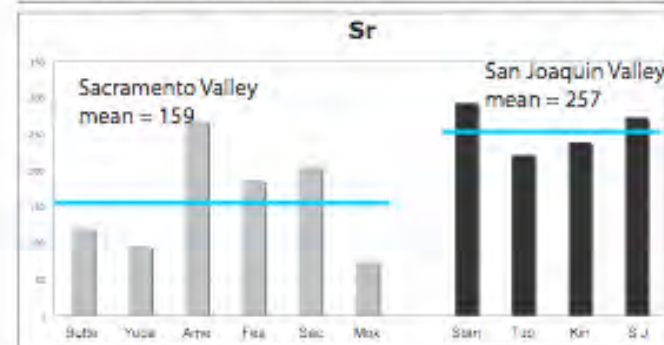
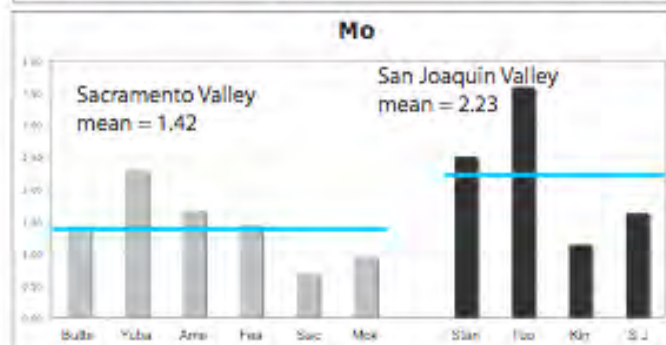
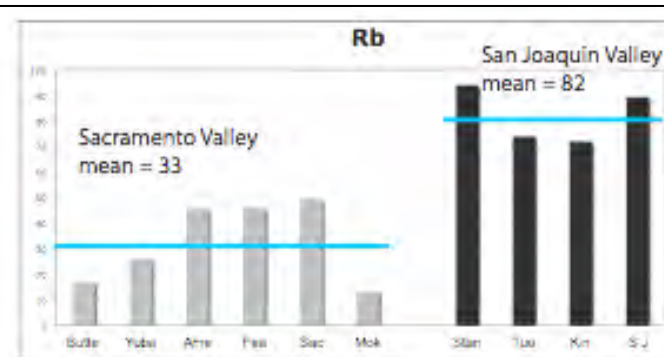
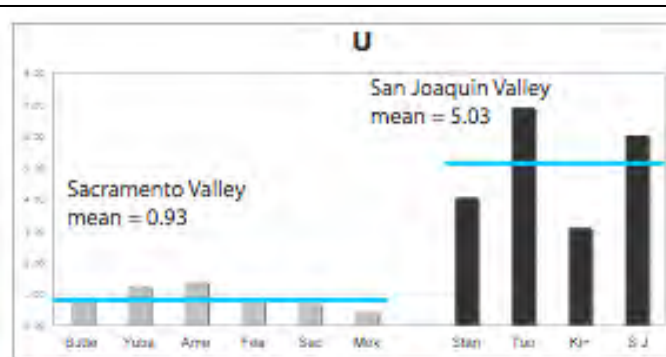
Atomic number																	
Symbol																	
Atomic weight																	
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Semimetal																	
Nonmetal																	
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3	Li	4	Be													10	Ar
5	B	6	C	7	N	8	O	9	F	10	Ne						
11	Na	12	Mg													17	Cl
13	Al	14	Si	15	P	16	S	17	Ar								
19	K	20	Ca	21	Sc	22	Ti	23	V	24	Cr	25	Mn	26	Fe	27	Co
37	Rb	38	Sr	39	Y	40	Zr	41	Nb	42	Mo	43	Tc	44	Ru	45	Rh
55	Cs	56	Ba	57	La	58	Ce	59	Pr	60	Nd	61	Pm	62	Sm	63	Eu
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101	Db	102	Hf	103	Ta	104	W	105	Re	106	Os	107	Ir	108	Pt	109	Au
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461	Uus	462	Uuh	463	Uuo	464	Uus	465	Uuh	466	Uuo	467	Uus	468	Uuh	469	Uuo
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931	Uus	932	Uuh	933	Uuo	934	Uus	935	Uuh	93							



# California Geology

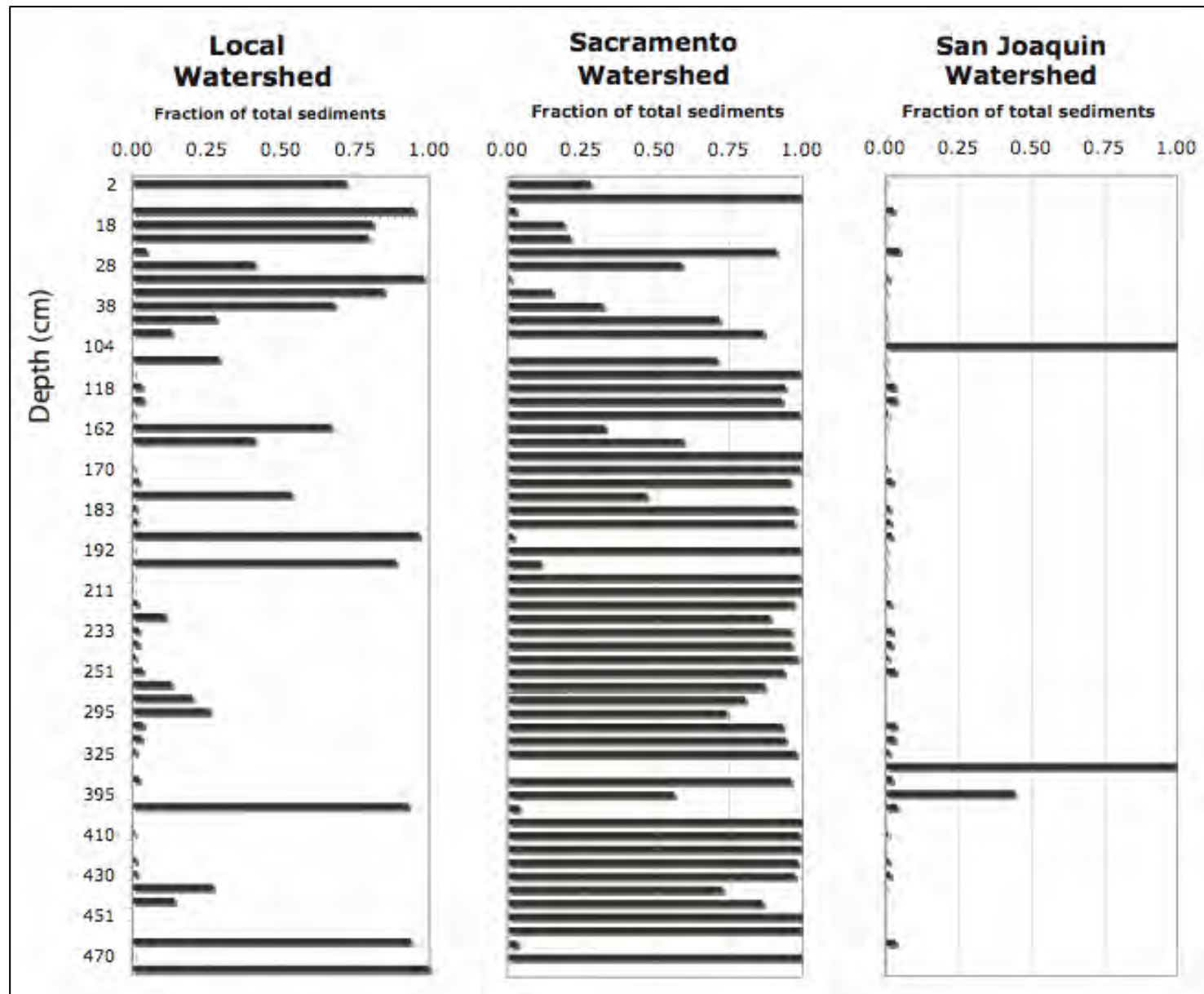
California  
Rivers drain  
different  
lithologies





# Elemental record of marsh sediments

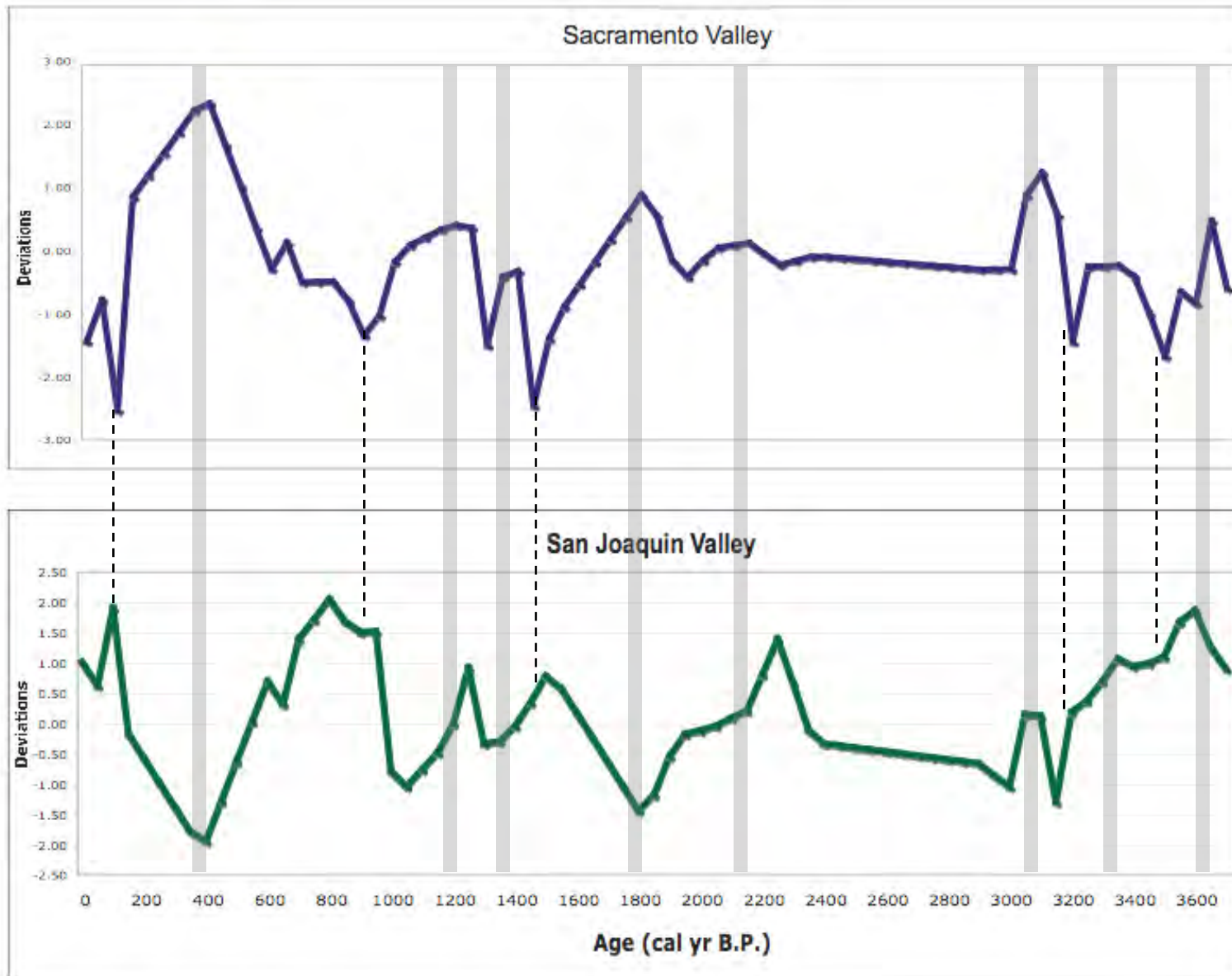
Proportion of mineral sediments from each source to China Camp marsh



(Malamud-Roam et al. in review)

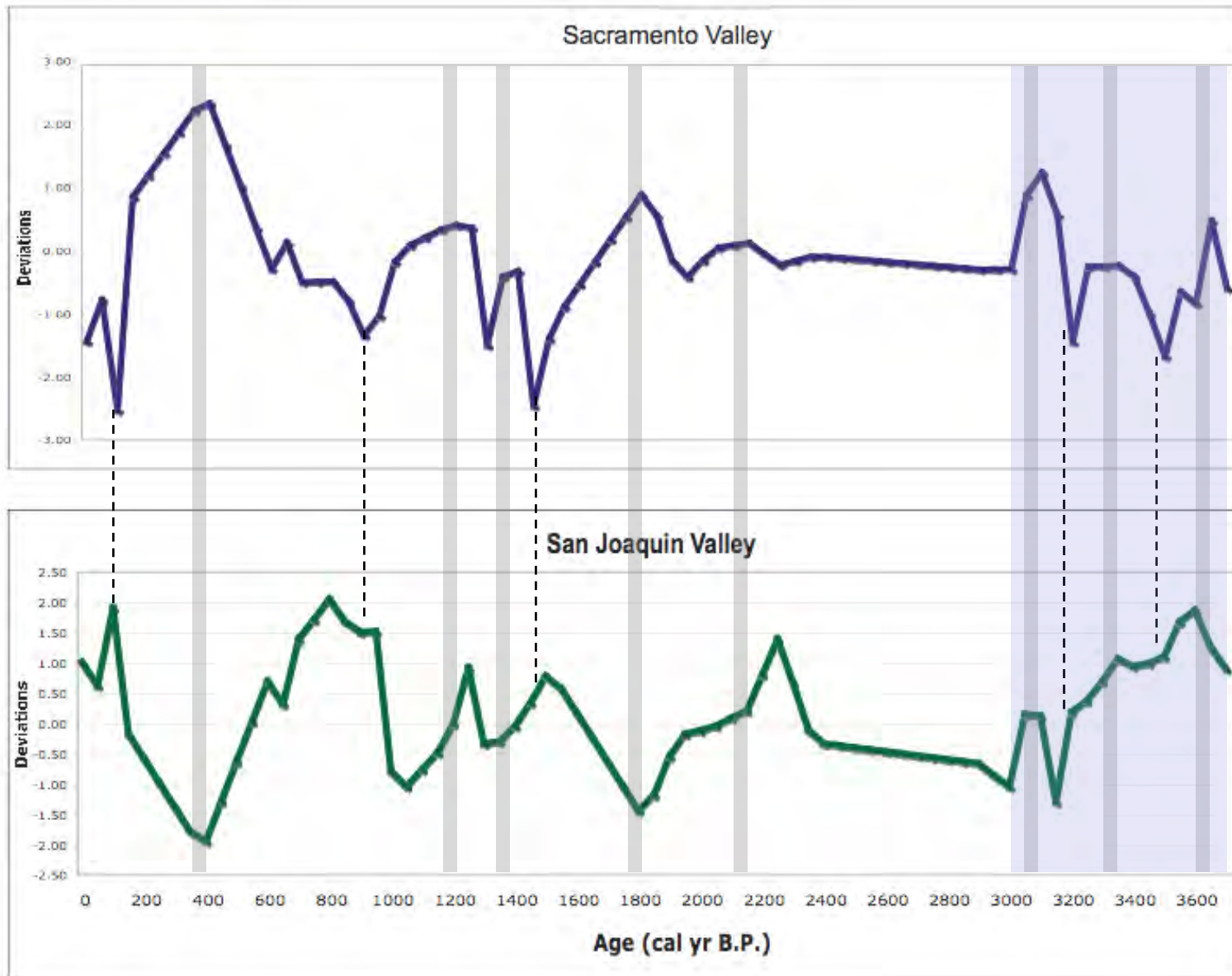


# Results from core analyses: China Camp



*At times in the past the two systems shift in the similar direction, and other times dissimilar*

# Results from core analyses: China Camp



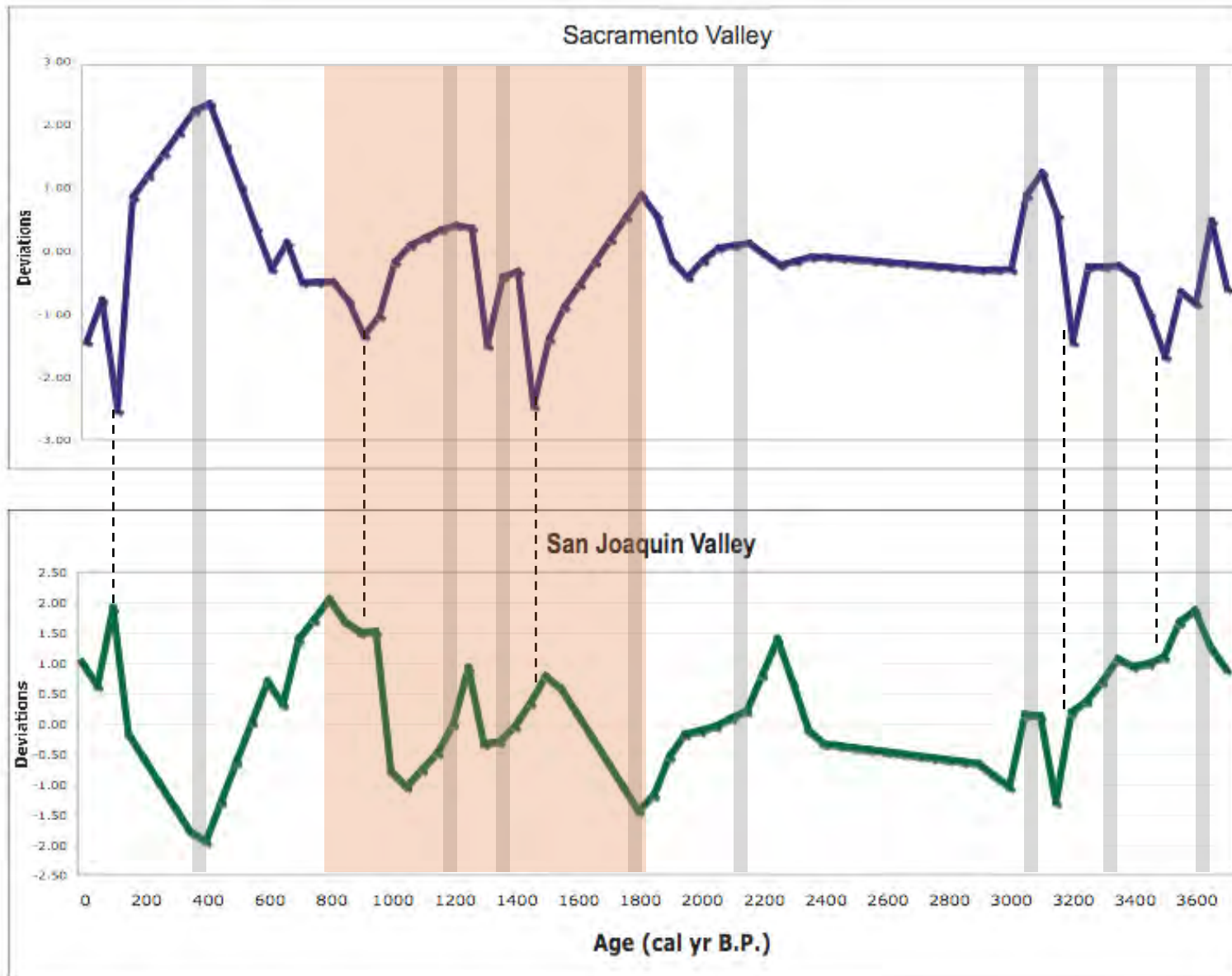
*Relatively fresh  
on the marsh  
and on other  
sites in the Bay  
(e.g., Goman  
and Wells,  
2000)*

*Elsewhere in  
California:*

*Mono lake high  
stand (Stine,  
1990)*

*Pyramid lake  
and Owens  
lakes show  
evidence of  
cool, wet  
(Benson et al.  
2002)*

# Results from core analyses: China Camp



*Period of degraded marsh*

*Other sites in Estuary show shift to more saline conditions (e.g., Byrne et al. 2001; Goman and Wells 2000).*

*Mono lake low stand, later the first MCA drought (Stine, 1990, 1994),*

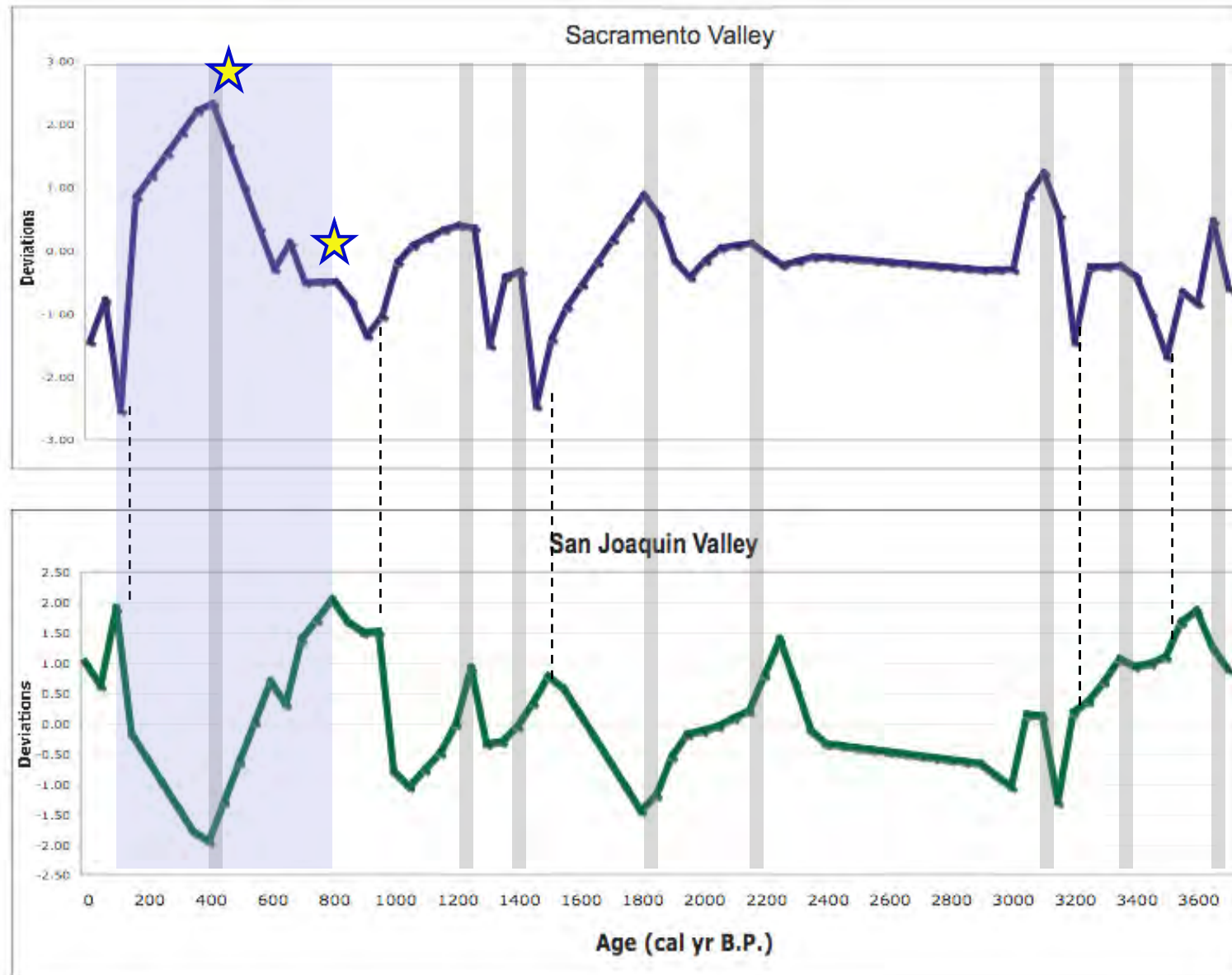


# Results from core analyses: China Camp

*After ca 750 cal yr B.P. conditions freshen (Byrne et al 2001; Starratt 2004)*

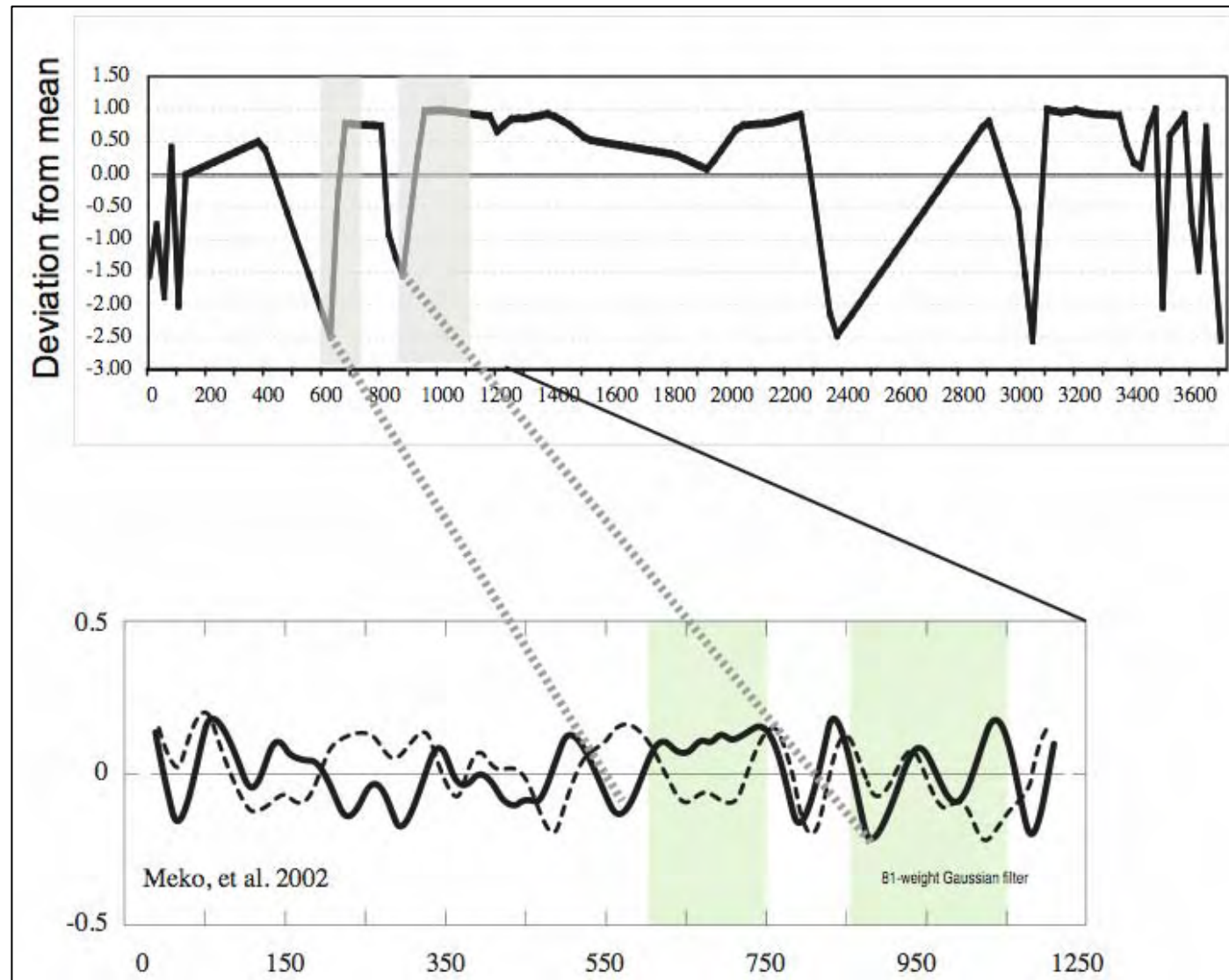
*Evidence of 2 floods between 850 - 450 cal yr B.P. Flood evidence elsewhere (Goman and Wells 2000, Ingram et al. 1996).*

*Flood also in Sacramento Oxbow lake (Sullivan, 1982); Santa Barbara Basin (Schimmelmann 1998, 2003)*



# Sacramento watershed contributions

Sediment  
record  
vs.  
reconstructed  
Sacramento  
(solid line) and  
San Joaquin  
(dashed line)  
flows



Age in cal yr B.P.

(Malamud-Roam et al. in review)

# Flood Events in California

I.D.	Reference	Location	Year	Description
1	Ingram et al. 1996c	San Francisco Bay	1270-1380, 1675-1730, 1800-1860	High inflow
	Ingram et al. 1996c	San Francisco Bay	1200	top of unconformity
2	Goman and Wells, 2000	San Francisco Bay	1420	Browns Is Flood
3	Malamud-Roam, 2002	San Francisco Bay	1090, 1645	China Camp flood, top of unconformity, Benicia core
4	Earle, 1993	Sacramento River	1597-1613, 1641-1657, 1664-1675, 1725-1735, 1741-1754, 1798-1821, 1854-1869, 1874-1887, 1891-1916, 1962-1973	High flow
5	Sullivan, 1982	Sacramento River	1235-1360 1295-1410 1555-1615 1750-1770 1810-1820 1861	large flood flood largest flood flood large flood Historic flood
6	USBR, 2002	American River	350-550  825-1300 1300-1800	1 flood larger than historic & gage records  1 very large flood 3 floods larger than historic records
7	Graumlich, 1993	So. Sierra	1071-1090, 1478-1527	high precipitation
8	Stine, 1990	Mono lake	1084 1270-1345 1400-1485 1575-1650 1857-1919	Post Office High Stand Rush Delta High Stand Danberg Beach H.S. Clover ranch H.S. Historic High Stand
9	Leavitt, 1994	White Mts	1080-1129	Abundant soil moisture
10	Enzel et al. 1989	Mojave Desert	1527	Silver lake deposits
11	Ely et al. 1993	U.S. southwest	1000-1200, 1400-1900	Period of numerous large floods



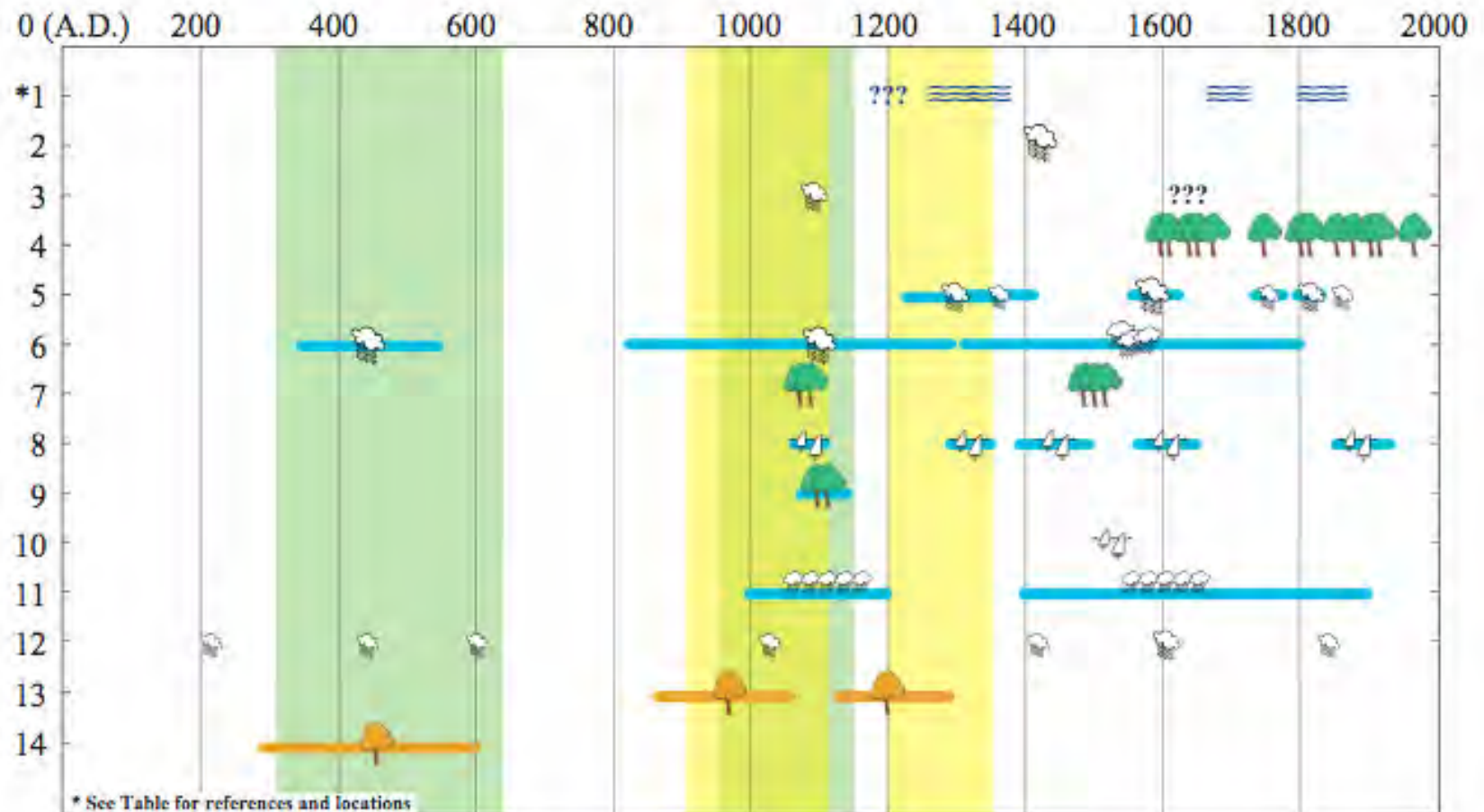


# Comparing the records

Long term trends in Holocene paleoclimate:

- Drier/cooler conditions until around 8000 cal yr B.P.
- Mid-Holocene period of increased warmth and moisture until around 3500 cal yr B.P.
- Conditions becoming cooler after 3500 cal yr B.P. and evidence of increased variability
- Warming/drying again starting 2000 cal yr B.P.

# Extreme Climatic Events in California over the last 2000 years



## Inferred Wet Periods

Flood event  
(size indicates  
relative magnitude)



Period of numerous  
large floods



Period of 3  
large floods

Timing unclear



Tree ring evidence



Bay sediments



Lake deposits



Unconformity

## Inferred Dry Periods:

Bay marsh vegetation

Mono Lake droughts

Tree ring evidence

Courtesy of the Bancroft Library  
University of California Berkeley  
Online Archive of California Image #15-7792

## W. Berkeley Shellmound



Evidence of starvation,  
increased warfare,  
disease all associated  
with this period

# Impacts on human populations

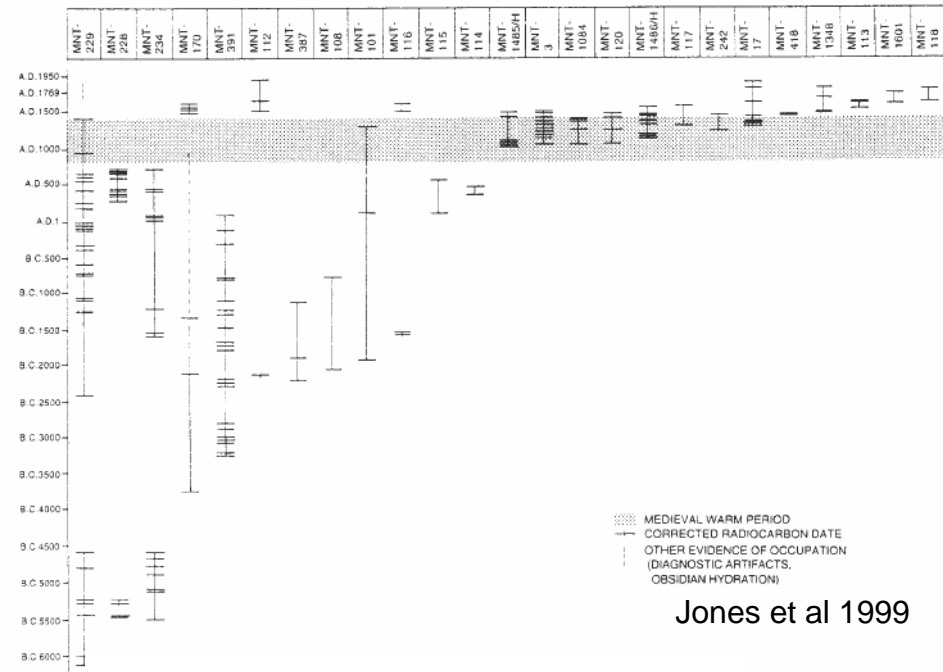


FIG. 6.5 Central California Coast sites Bay area of central California...

Abandoned sites during Medieval period of droughts



# Summary

## The last 3,500+ years

- ca. 3500 cal yr BP: Watershed cooler, wetter, Bay fresher
- MCA in California: AD 900 to 1350 persistent droughts in watershed and Great Basin; higher Bay salinity
- LIA in California: AD 1450 to 1850 Watershed cooler, wetter, Bay fresher
- Higher frequency extreme events

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