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.

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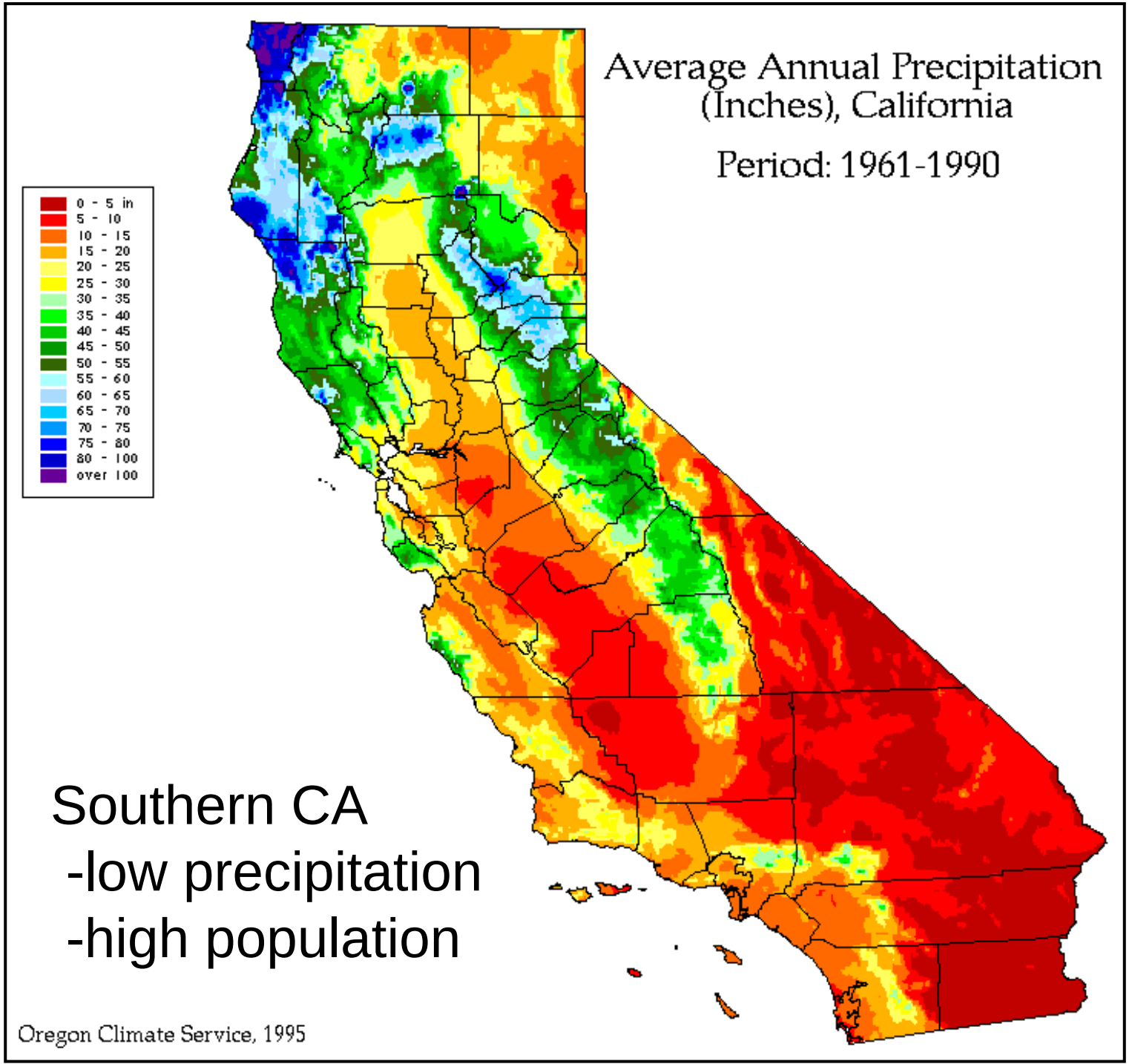
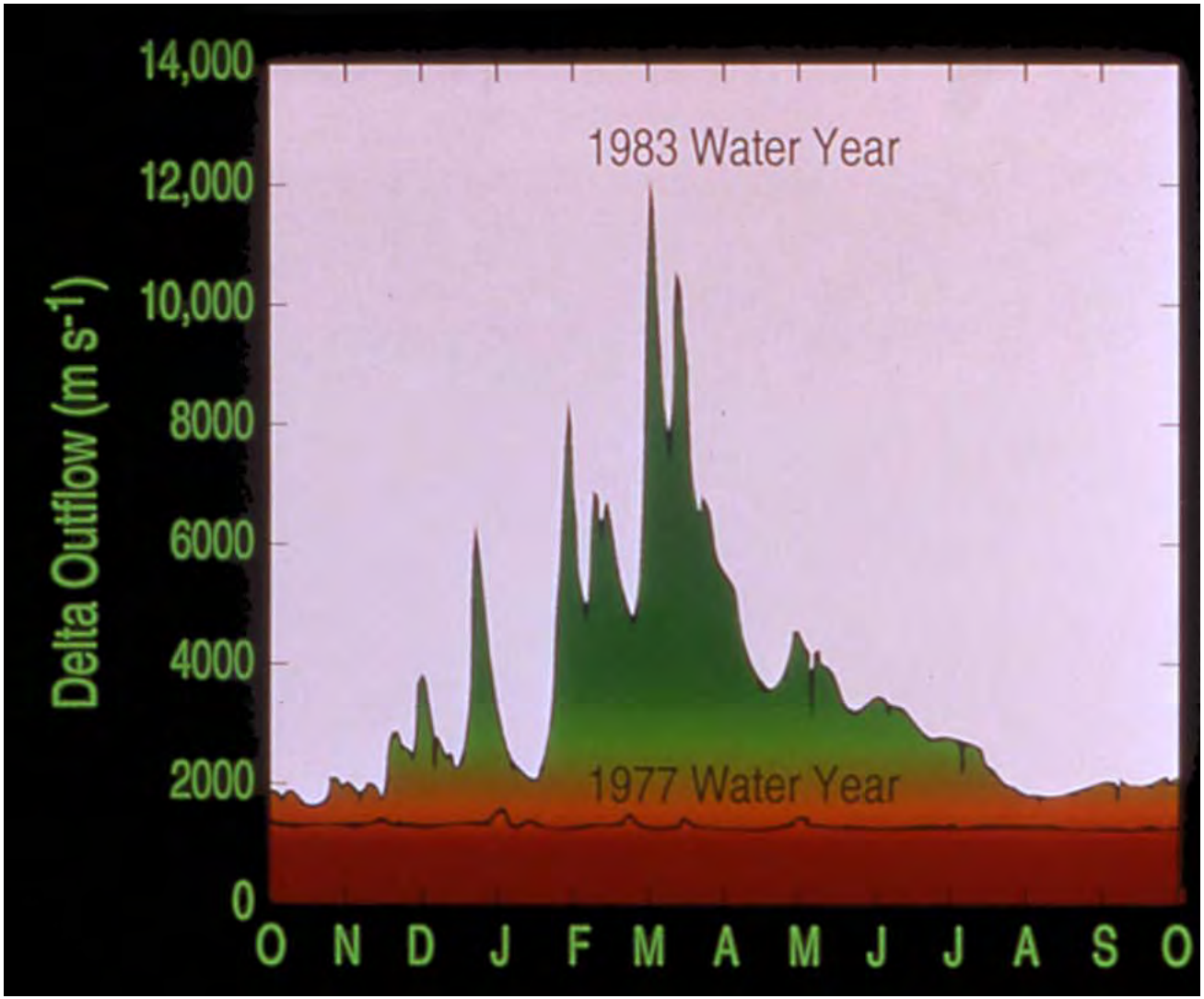
Frances Malamud-Roam, Dept of Geography, U.C. Berkeley

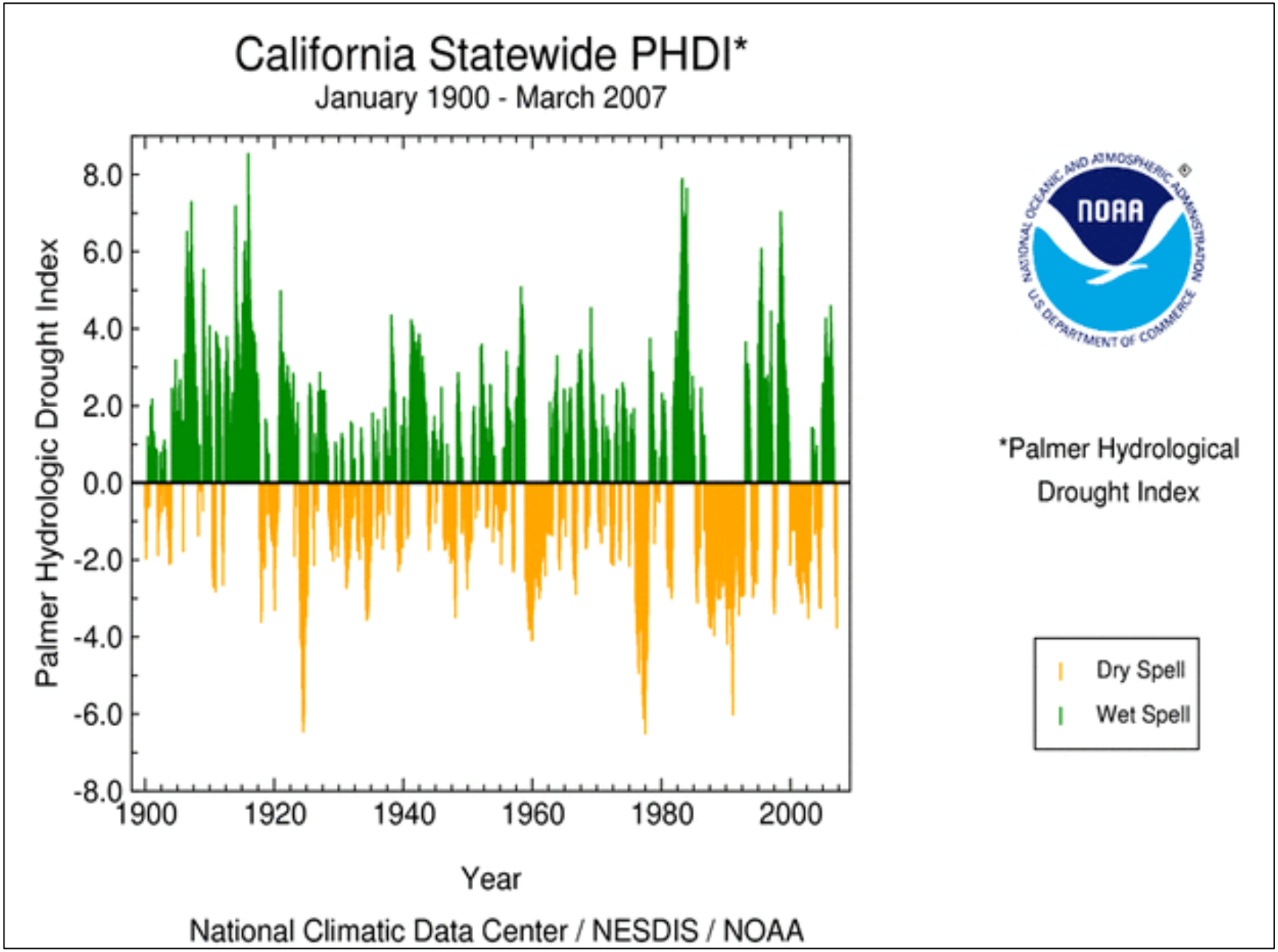
Left: Drought in Lake Oroville, South Fork of Feather River shot 02/03/2009 - Looking West from just in front of the Lumpkin Road Bridge. Note the small amount of water in the riverbed. Right: Flood in Sacramento 1862.


Average Annual Precipitation
(Inches), California
Period: 1961-1990
0 - 5 in
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 35
35 - 40
40 - 45
45 - 50
50 - 55
55 - 60
60 - 65
65 - 70
70 - 75
75 - 80
80 - 100
over 100
Southern CA
-low precipitation
-high population
Oregon Climate Service, 1995

Seasonal and variable year-to-year

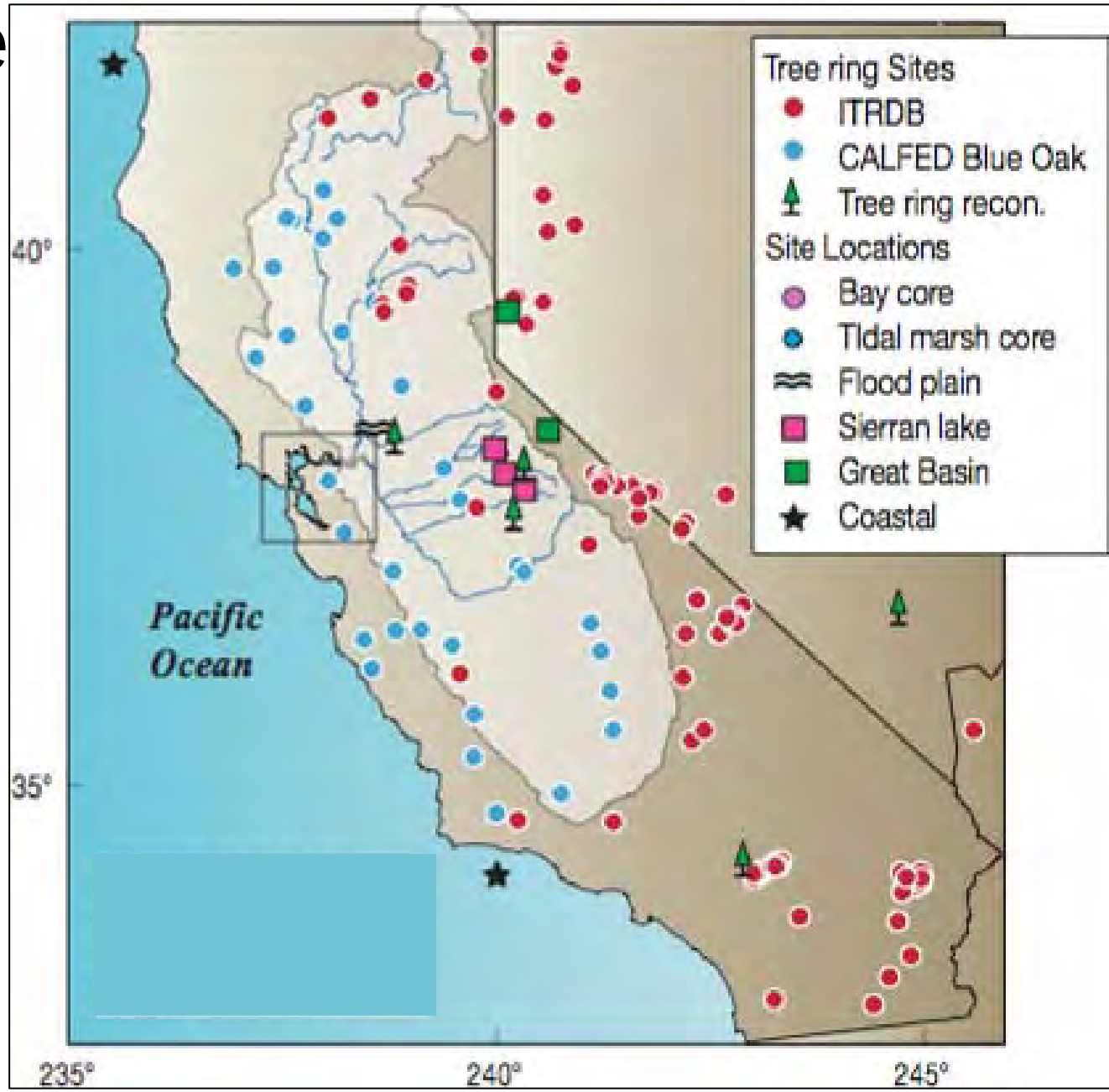


WY 1977
vs. 1983



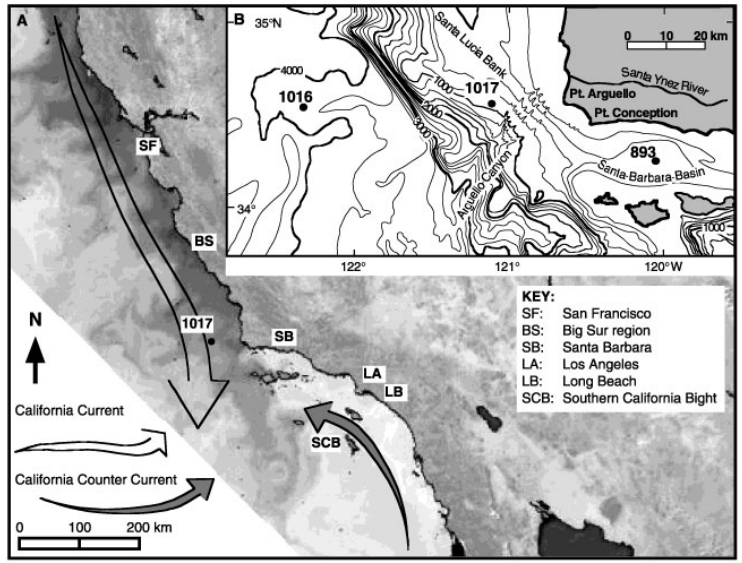
Temporal variability on decadal-scale

Extending the record - paleoclimate research in California



Paleoclimate records from across California

Coastal California: Santa Barbara Basin

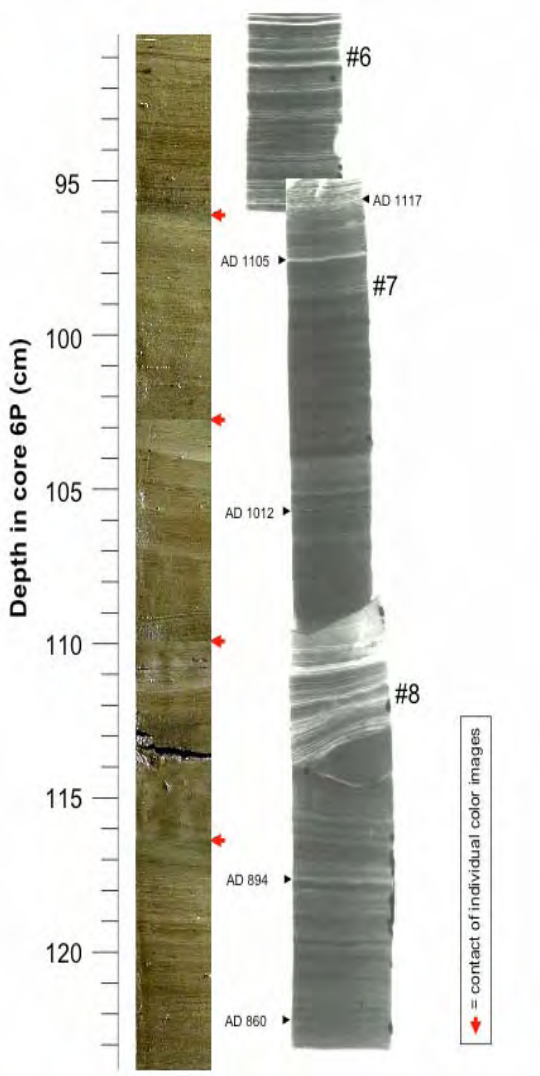


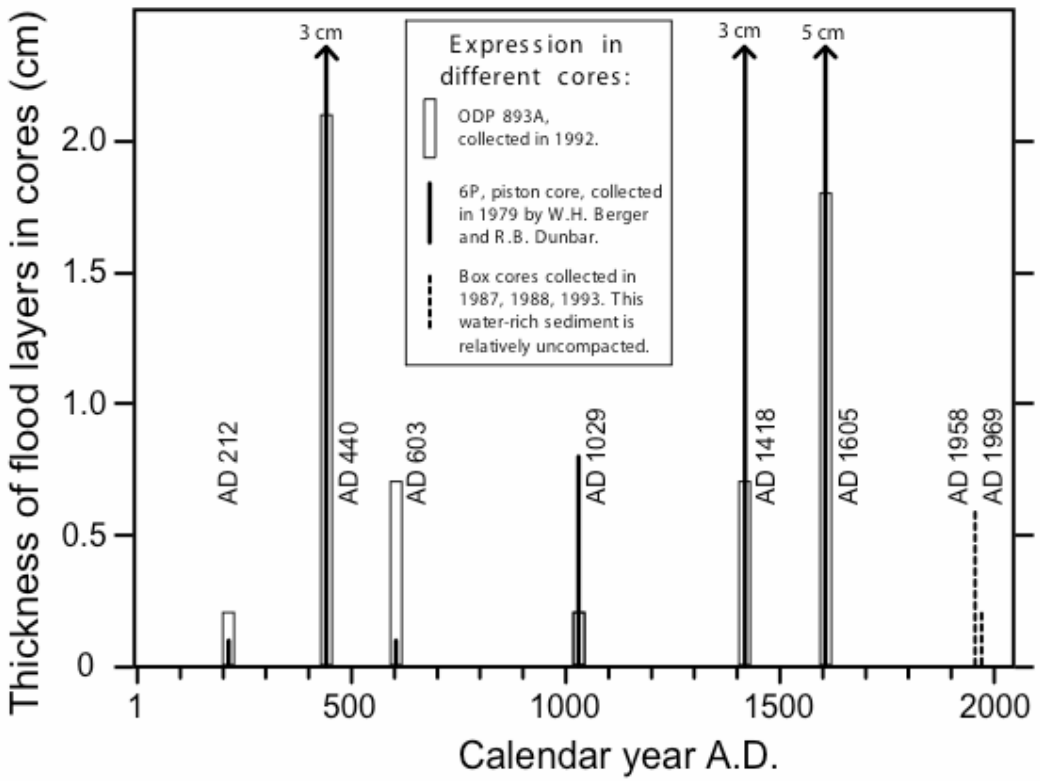
http://www-odp.tamu.edu/publications/167_SR/chap_22/images/01_f01.jpg

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

- sea surface temps
- mixing layer
- floods

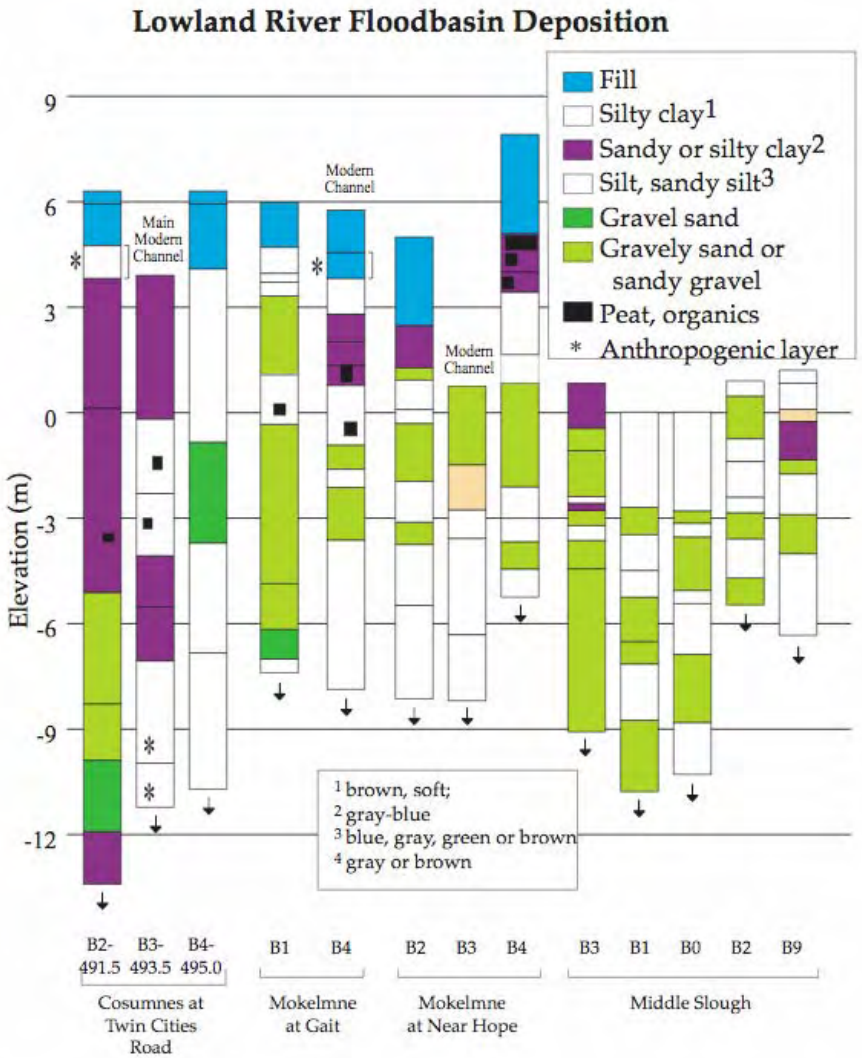
Flood events in Santa Barbara Basin: ~200 year periodicity

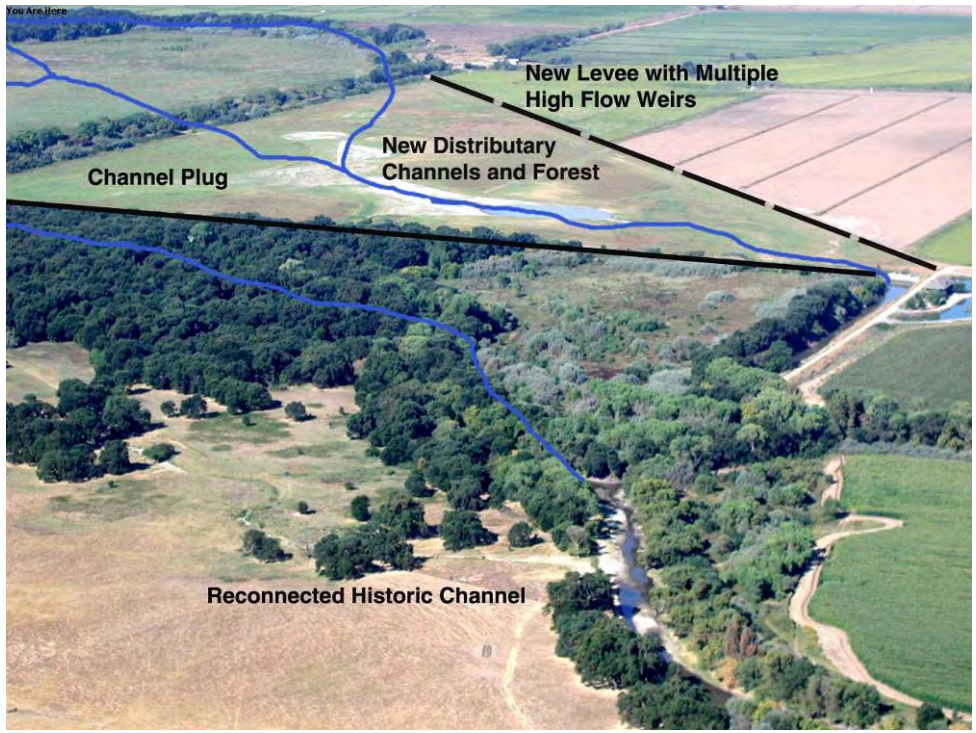




(Schimmelmann et al., 2003)

Central Valley lowland floodplain records

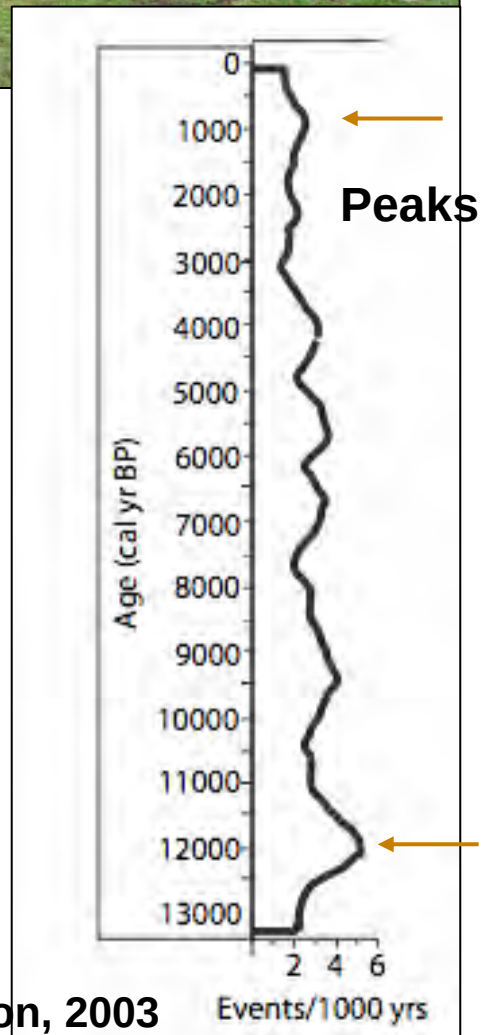




Floods in California's Central Valley

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

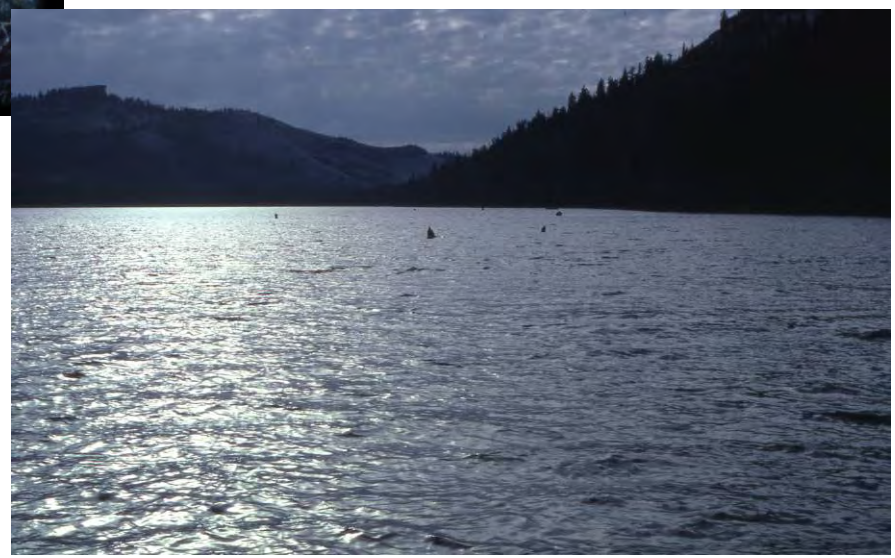
Sierran lake records: e.g., fire frequency



Brunelle and Anderson, 2003

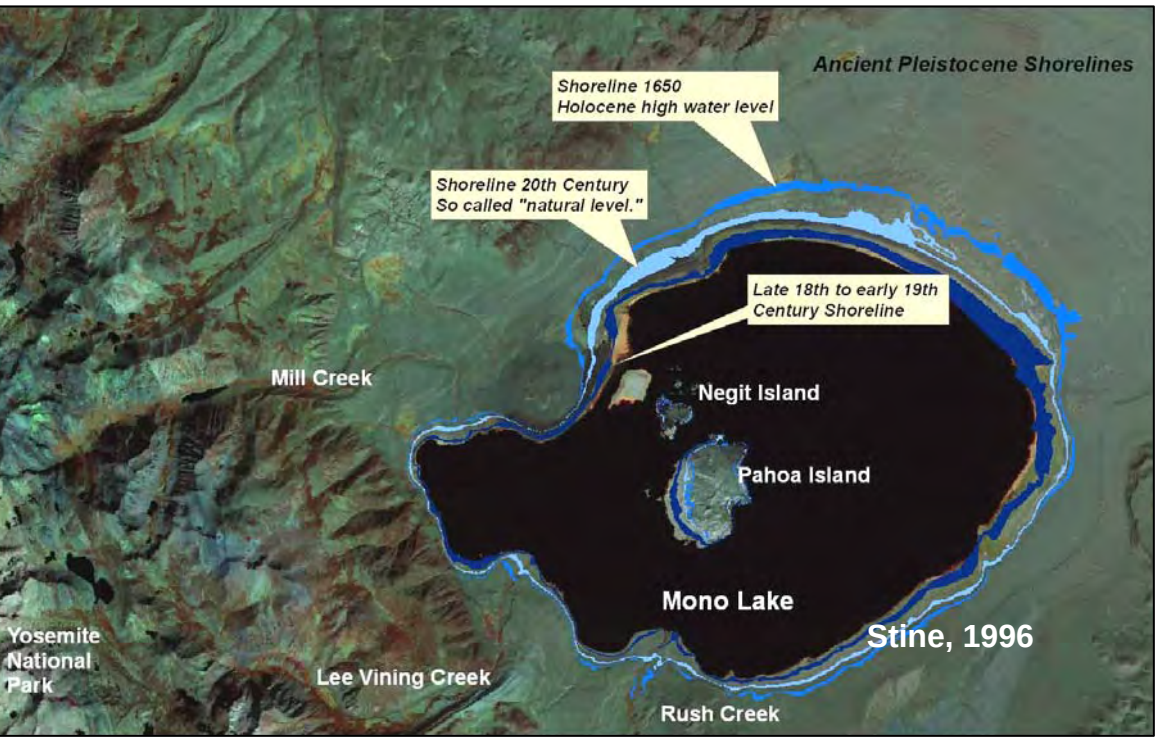
Eastern Sierra Nevada Records:

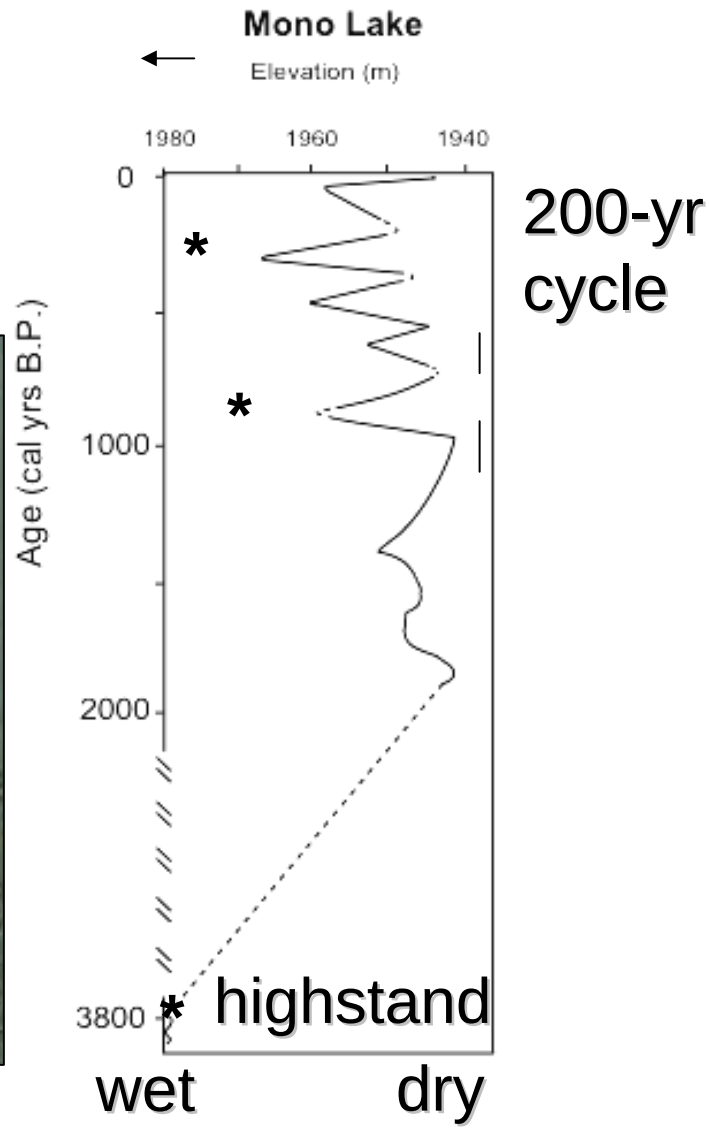
Submerged tree-stumps
-A.D. 900-1100
-A.D. 1200-1350



"Medieval Climate Anomaly"
Stine (Nature, 1994)

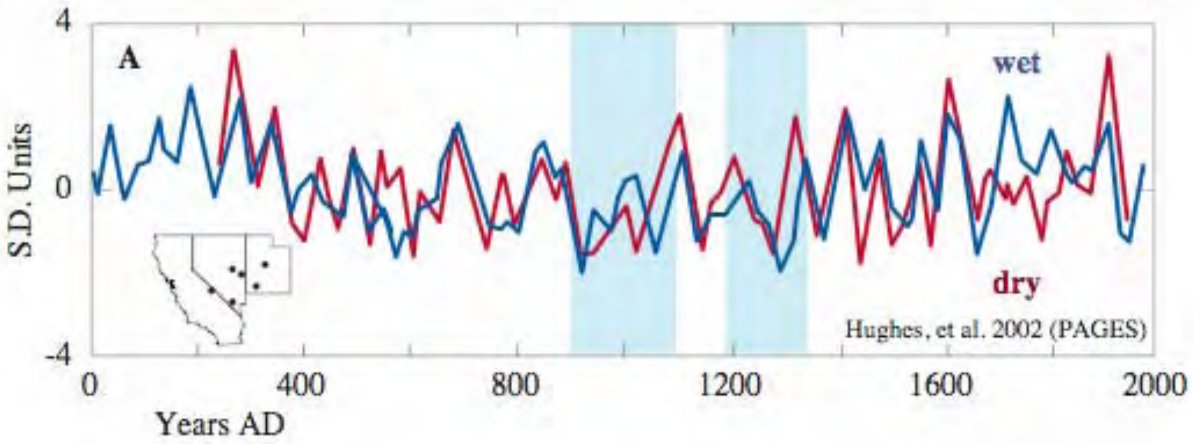
Mono Lake Levels: 3800 yr - present

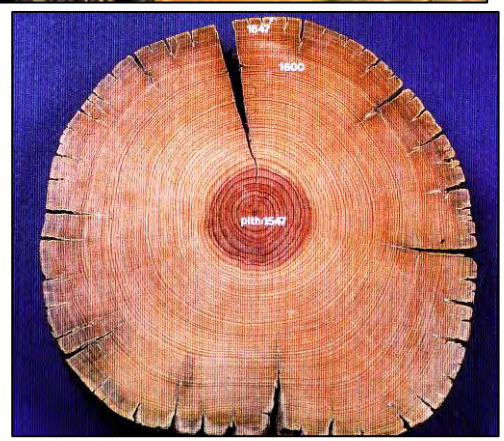




(Stine, 1990)

So. Sierra Nevada Tree-ring records

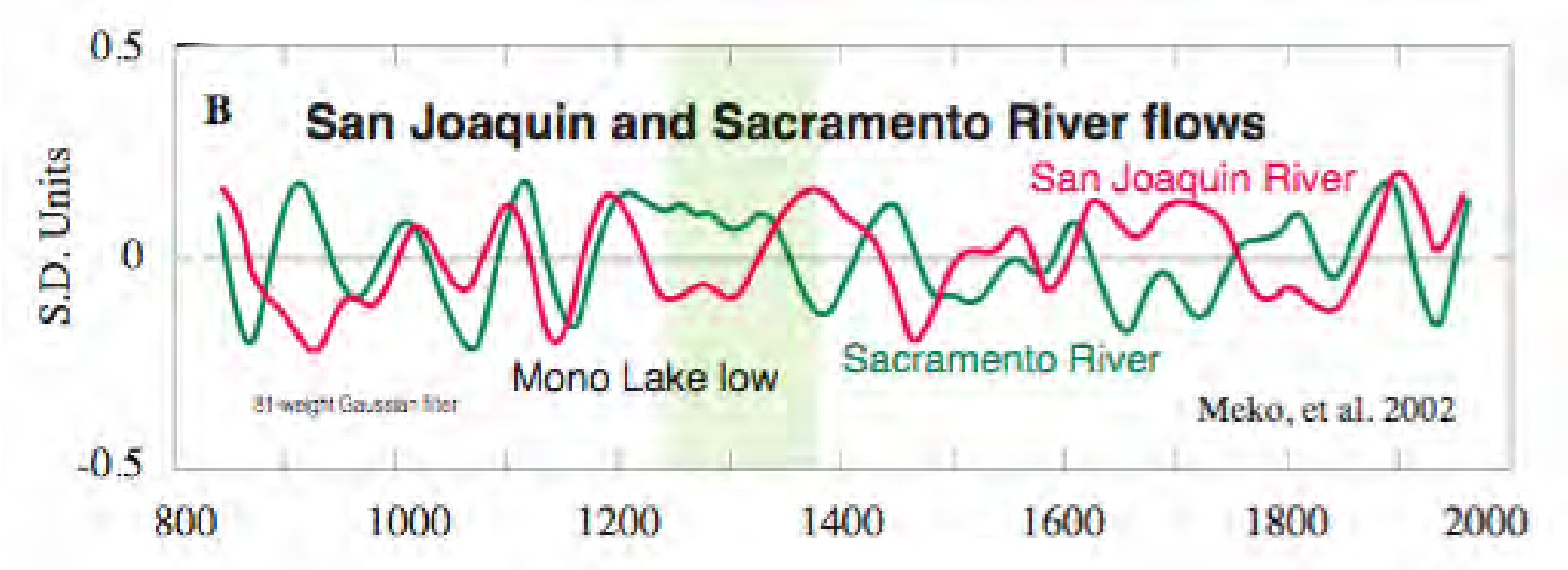




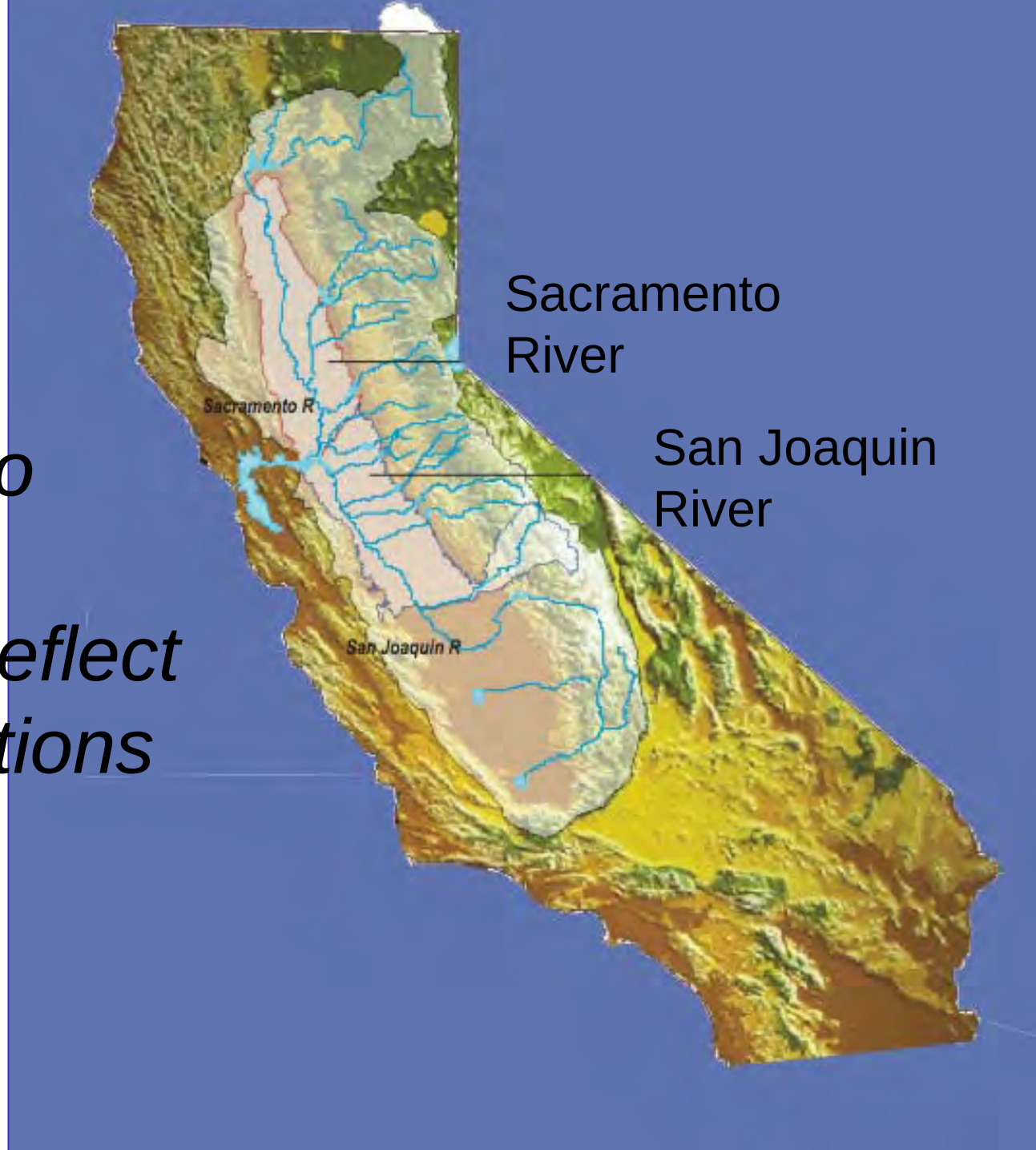
Last 2,000 years

Mono lake droughts highlighted

River reconstructions

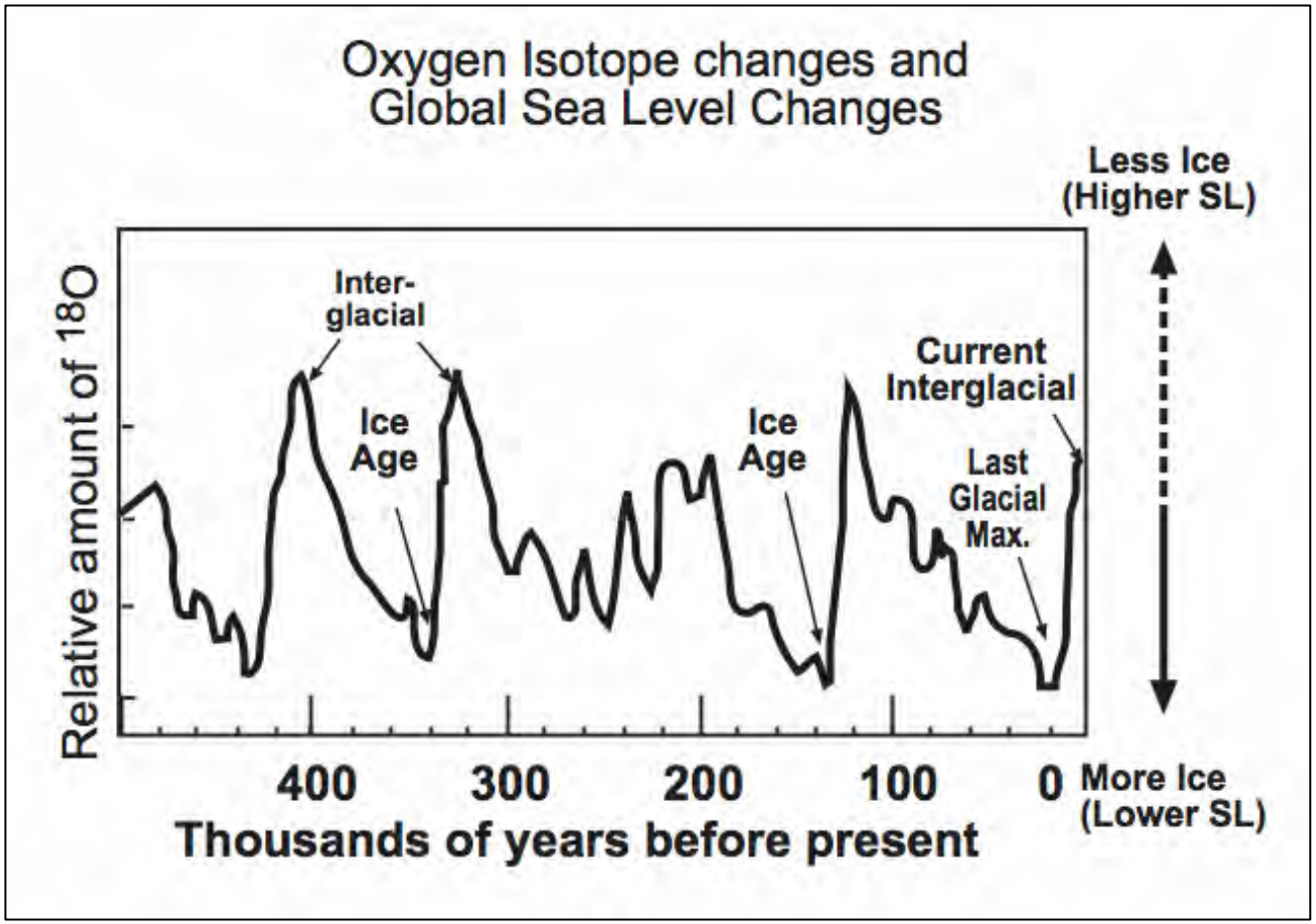


San Francisco Bay estuary ecosystems reflect climate conditions over the watershed



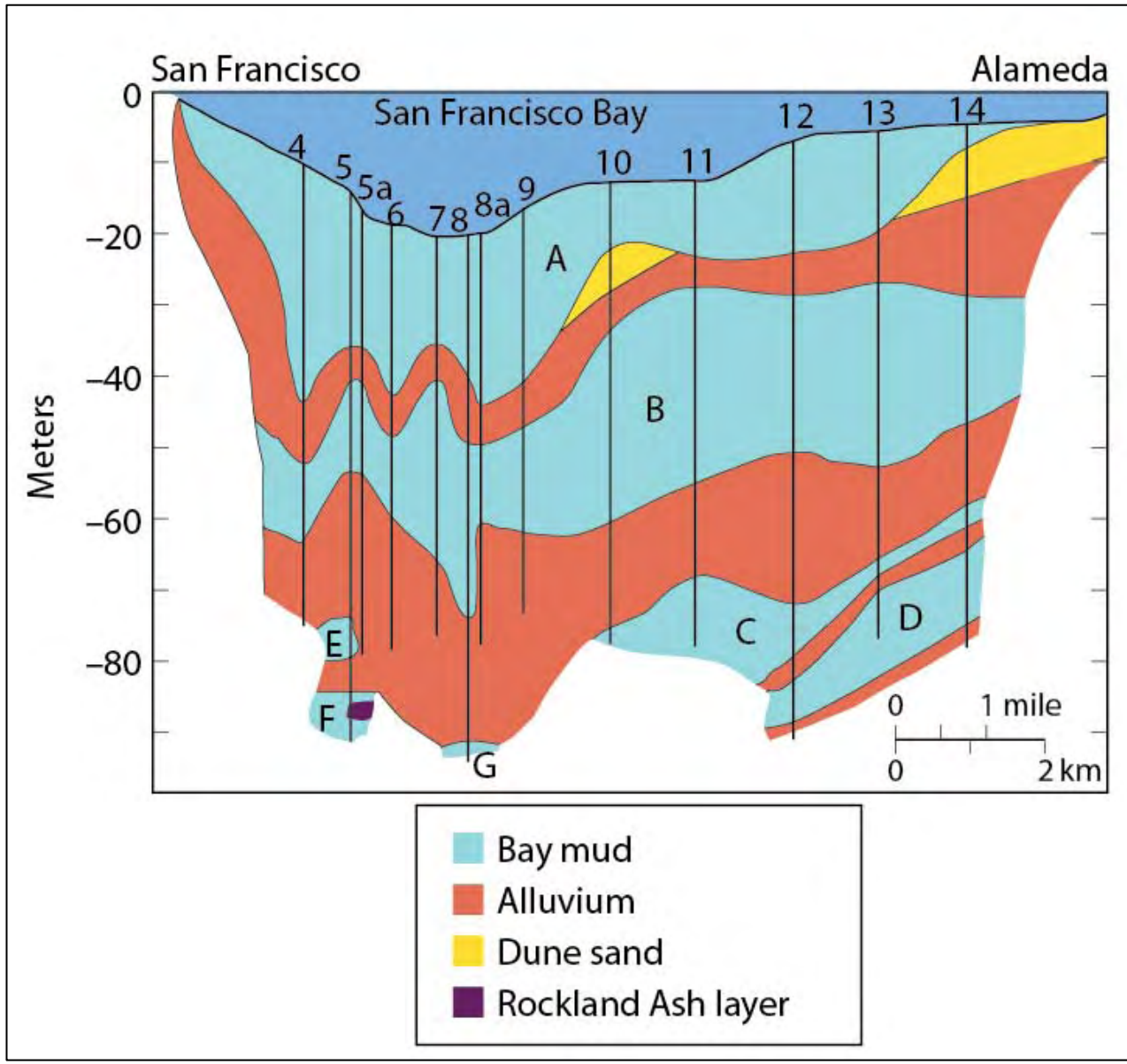
San Francisco Estuary salinity: reflection of climate

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

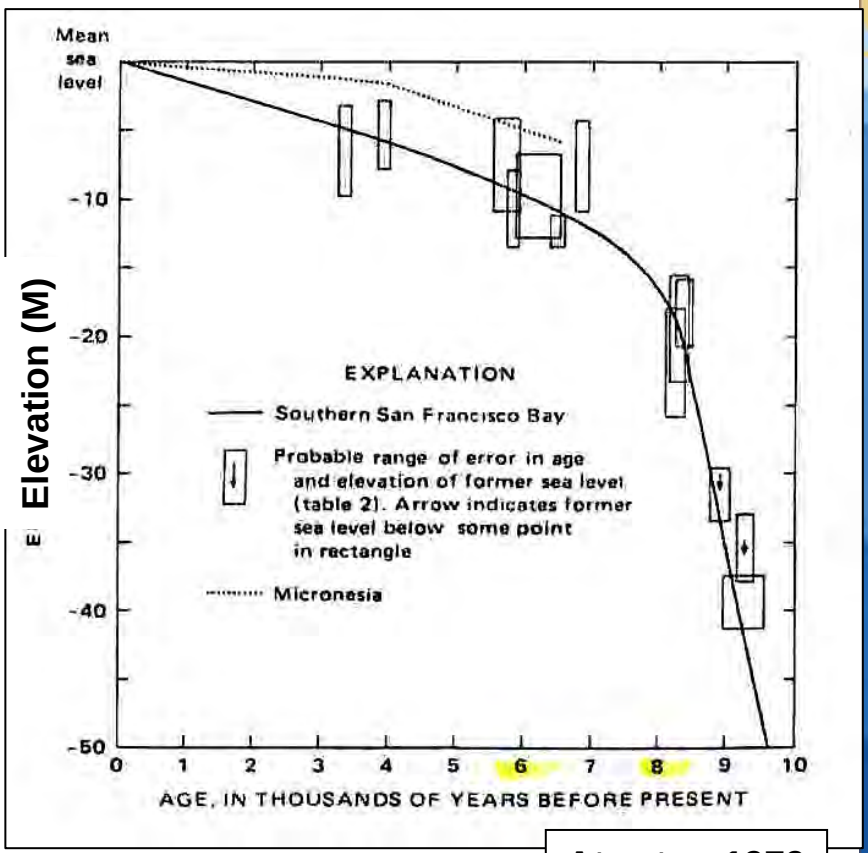


Sloan, 2007

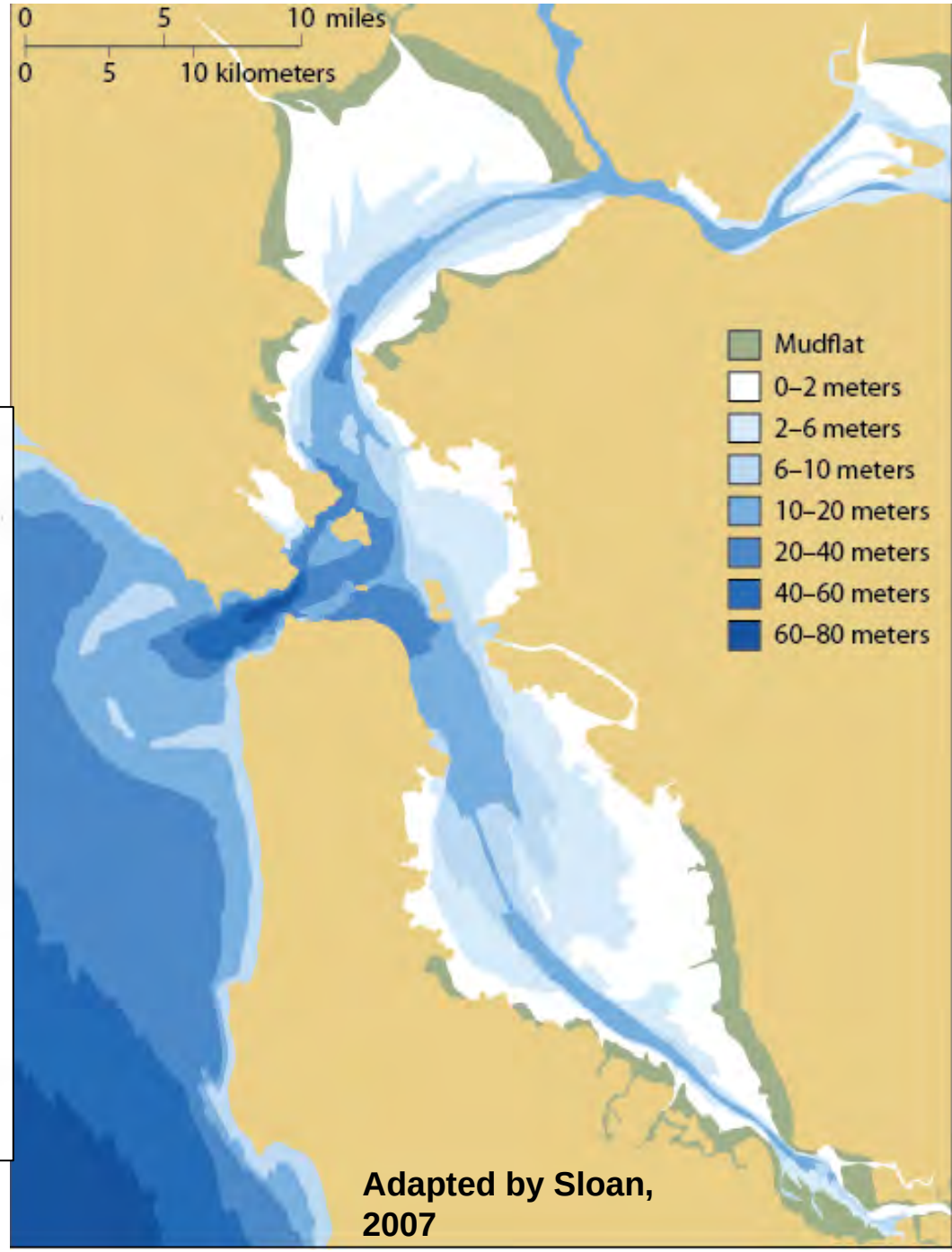
Adapted by Sloan, 2007

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

Sea Level Rise over the Last 10,000 years



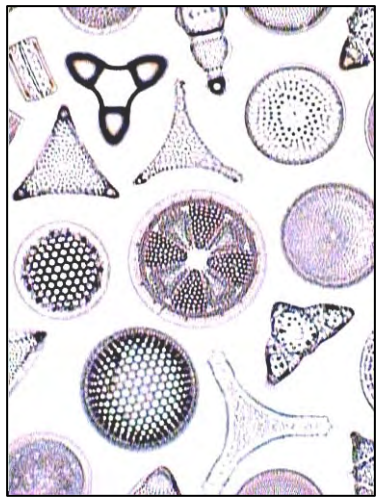
Atwater, 1979

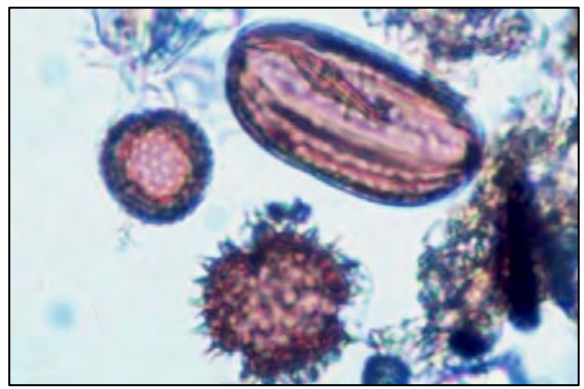


Adapted by Sloan, 2007

Sedimentary records from the Bay

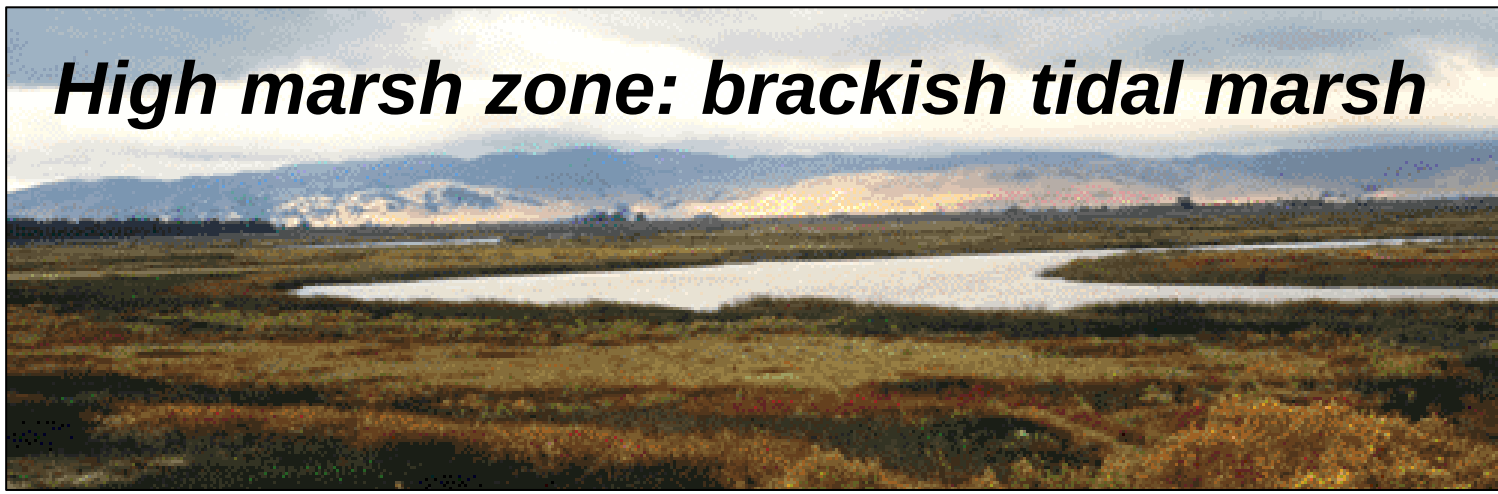
- Stratigraphy
- marine organisms
- Seeds & Macrofossils
- Diatoms
- Pollen
- Chemistry





On the marsh

Slightly fresher



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}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. rhyzomes and sheaths

Plant roots

Coarse sand

Radiocarbon Dates (cal yr BP)

496

826

831

2728

3568

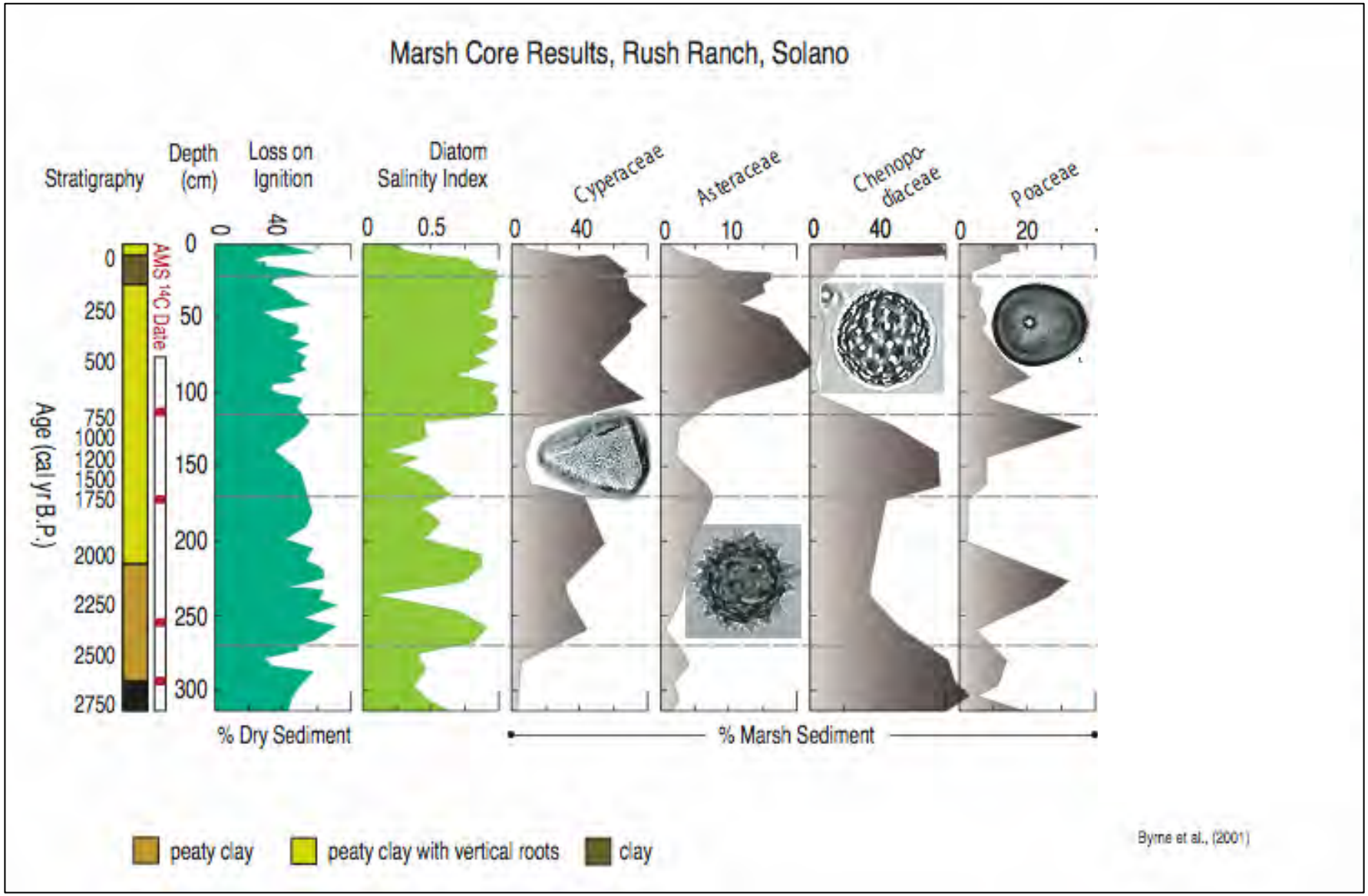
3655

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
Stratigraphy
Depth (cm)
Loss on Ignition
Diatom Salinity Index
Cyperaceae
Asteraceae
Chenopo-diaceae
Poaceae
AMS 14C Date
Age (cal yr B.P.)
% Dry Sediment
% Marsh Sediment
peaty clay
peaty clay with vertical roots
clay
Byrne et al., (2001)

Carbon isotopes

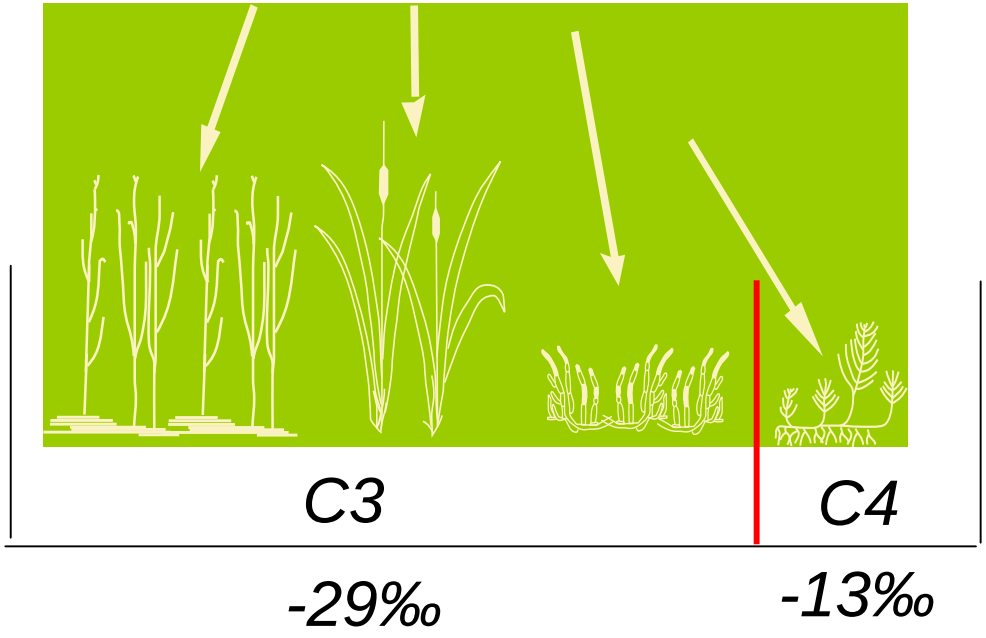
^{12}C: 98.93%

^{13}C: 1.07%

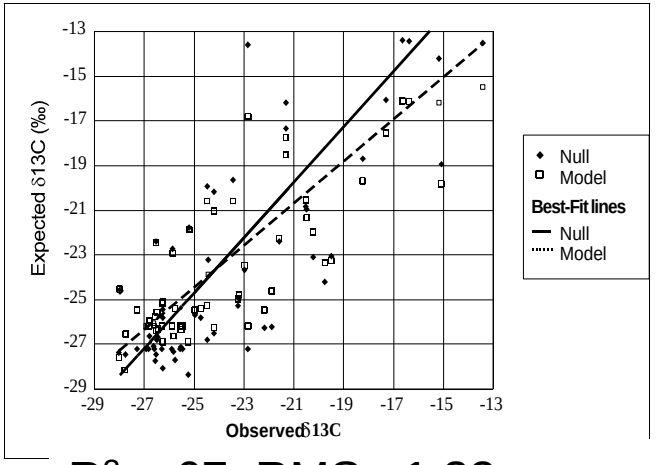
^{14}C: <<.001%

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

CO_2 ~ -8‰



Sedimentary isotopic signature reflects plants



R^2= .67, RMS= 1.33

Differing Plant Environments

=>

Differing Photosynthetic Pathway

C4

C3

(CAM)

=>

Different $\delta^{13}C$ value

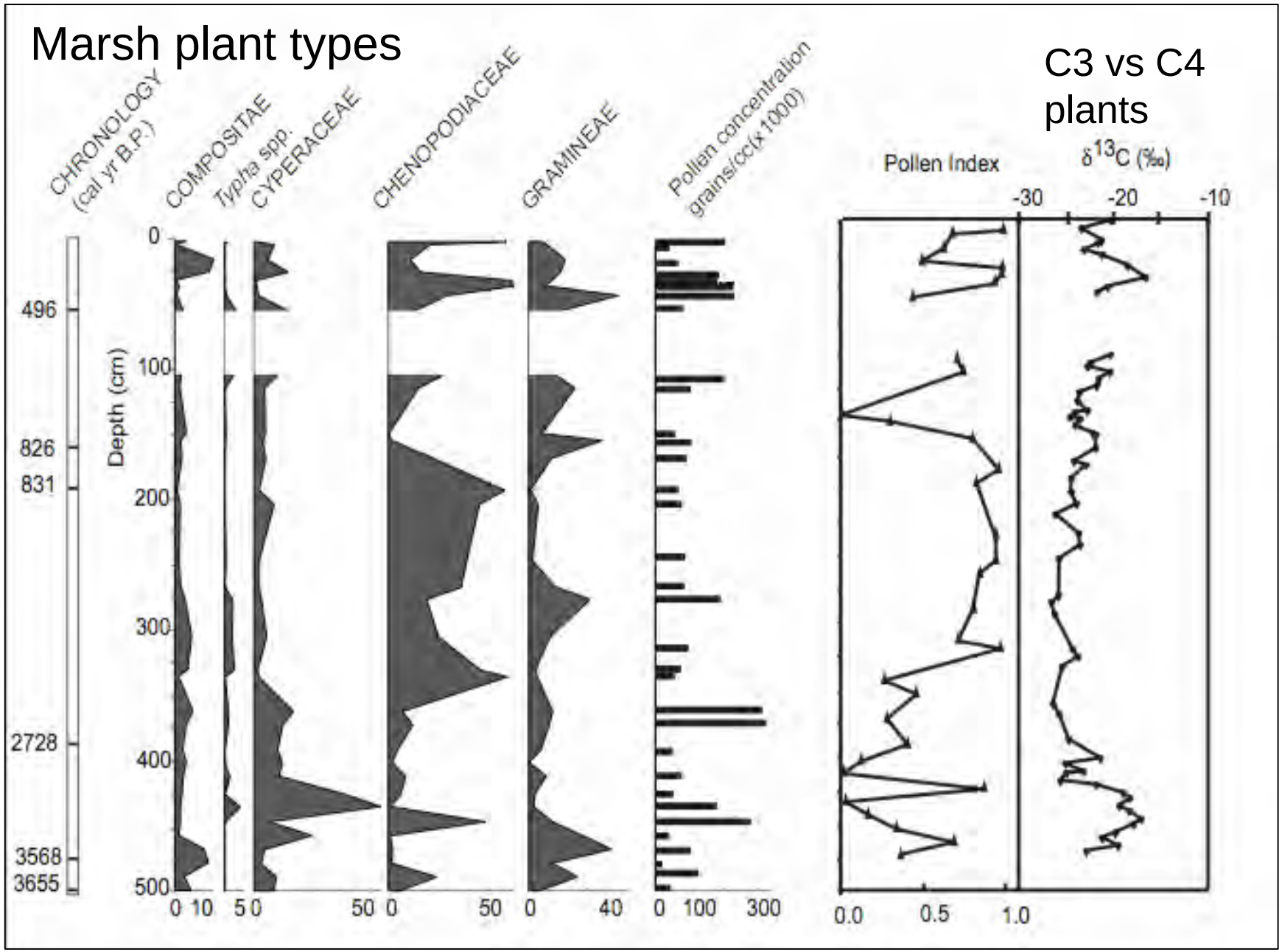
~ -12‰

~ -29‰

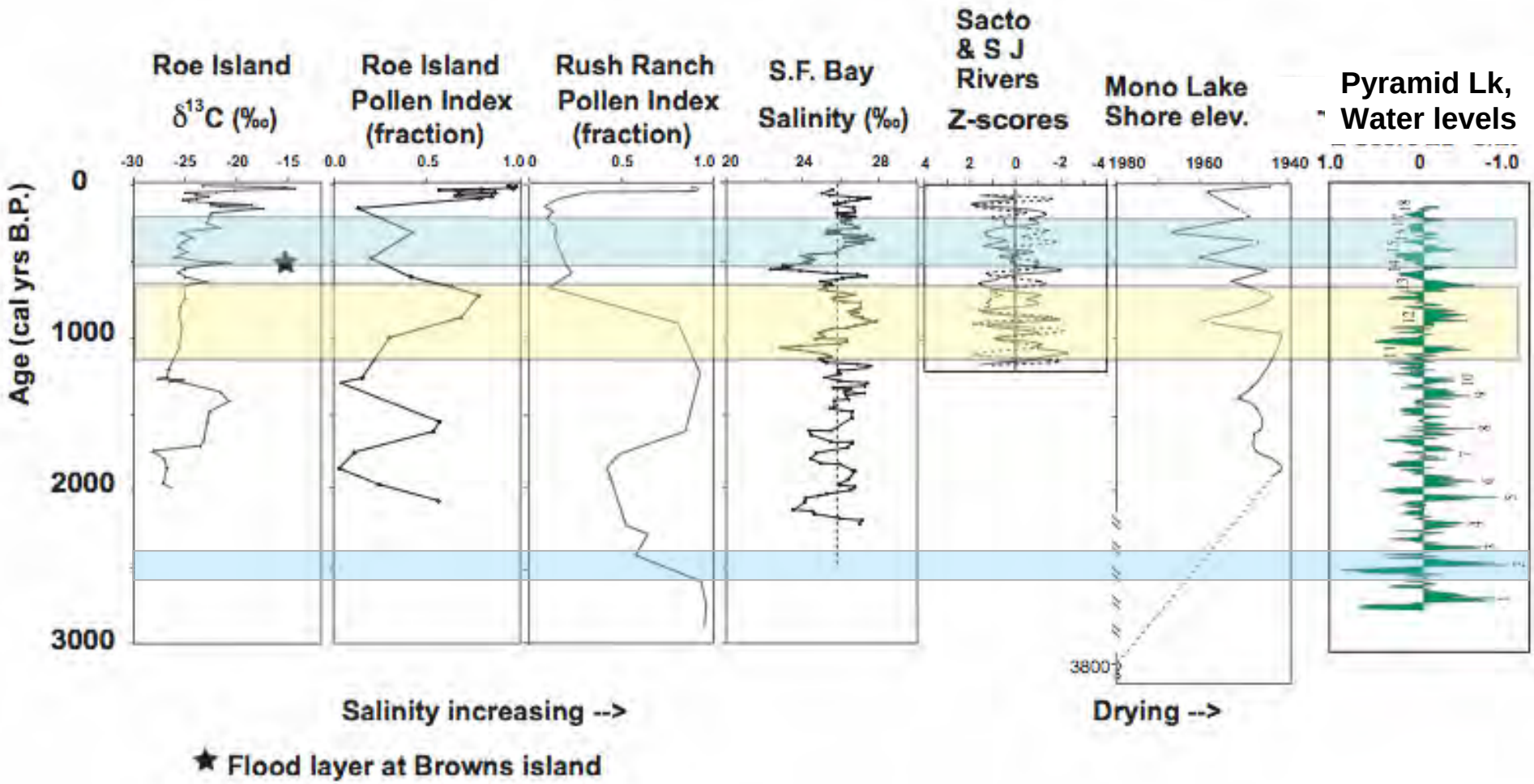
(intermed.)

Isotopic value of plant remains gives clues to past conditions

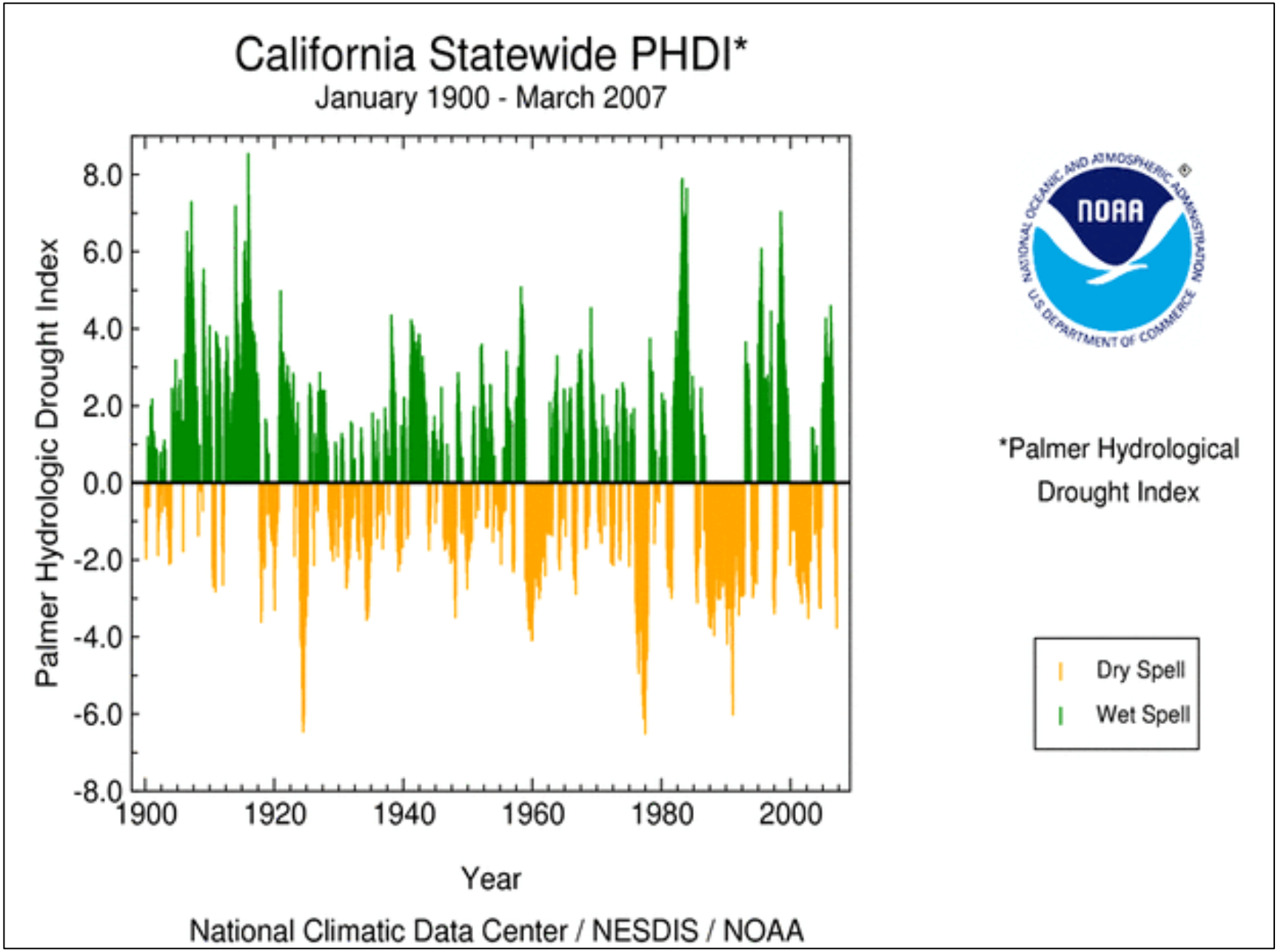
Vegetation history from China Camp core



Records from the Bay and its watershed



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

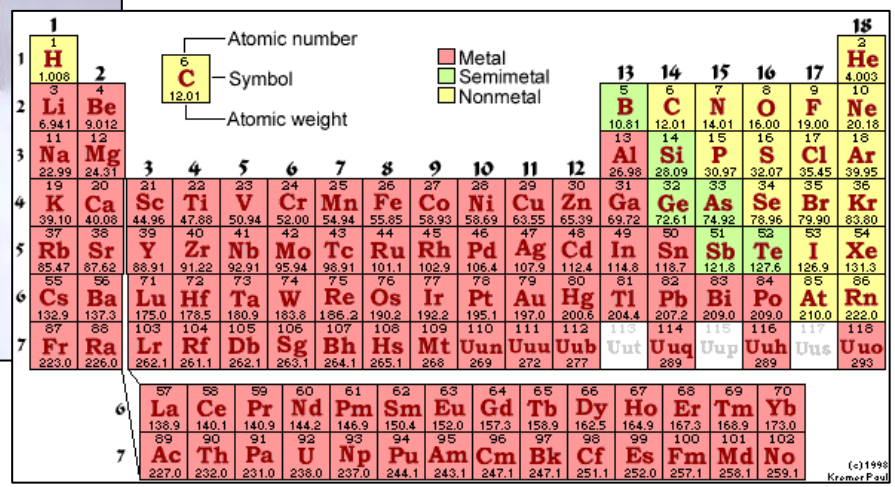


Temporal variability on decadal-scale

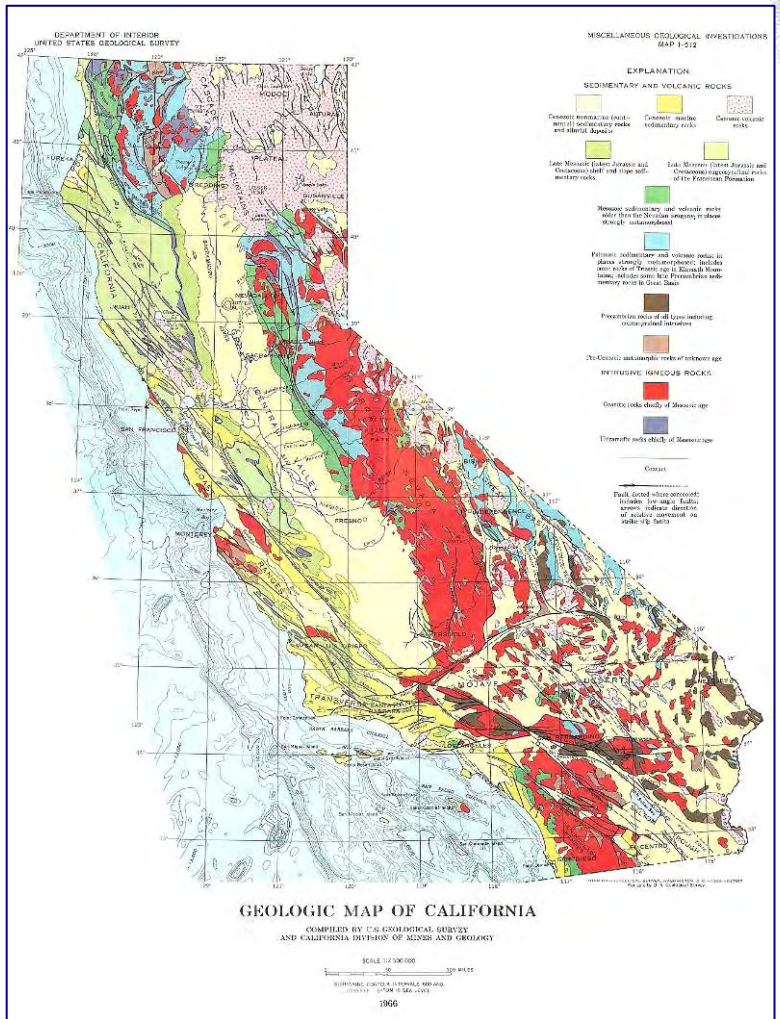
Using elemental concentrations as geochemical fingerprints

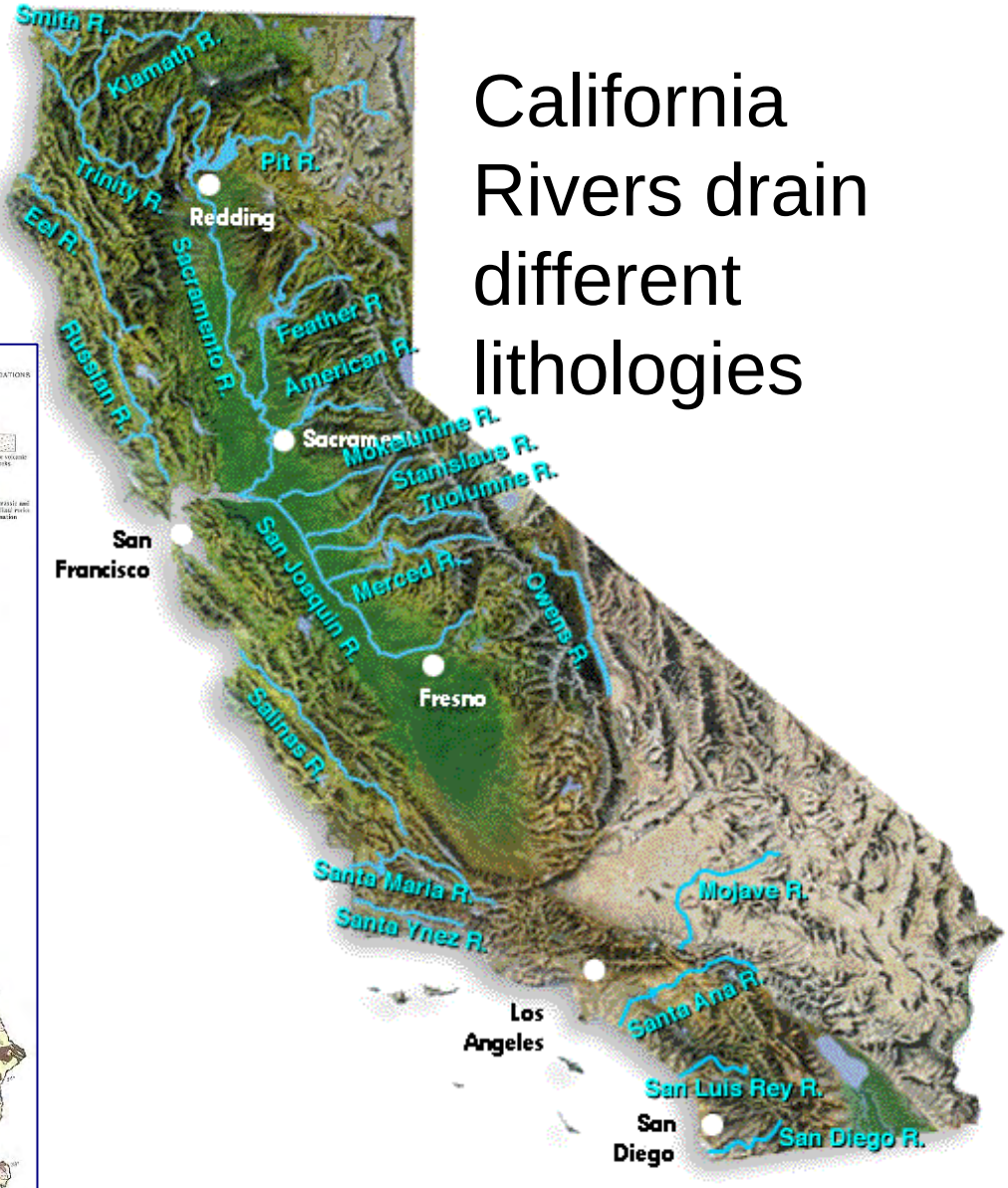
U.C. Davis ICP-MS

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

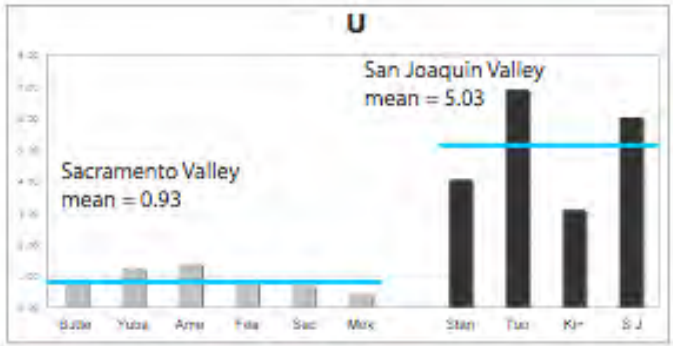


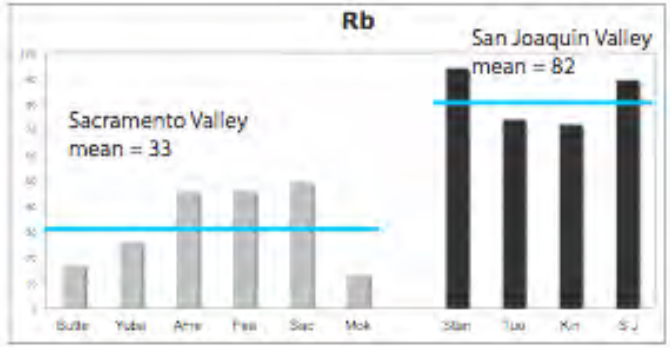
California Geology

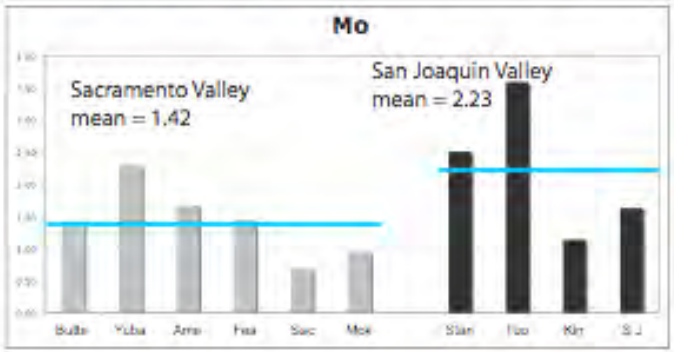


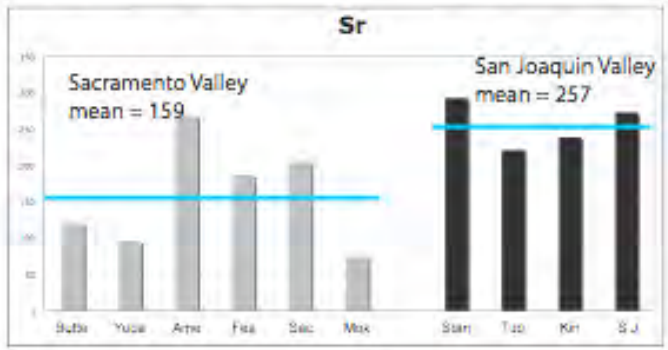


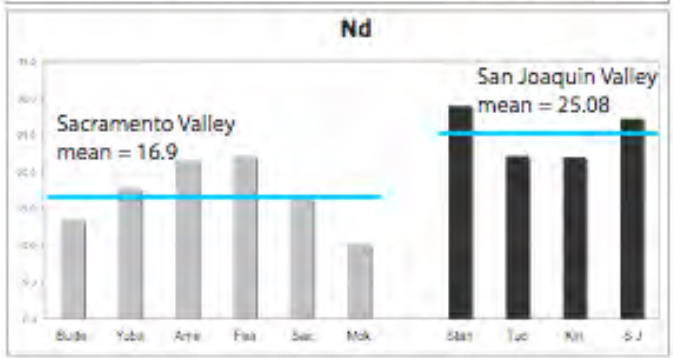
California Rivers drain different lithologies

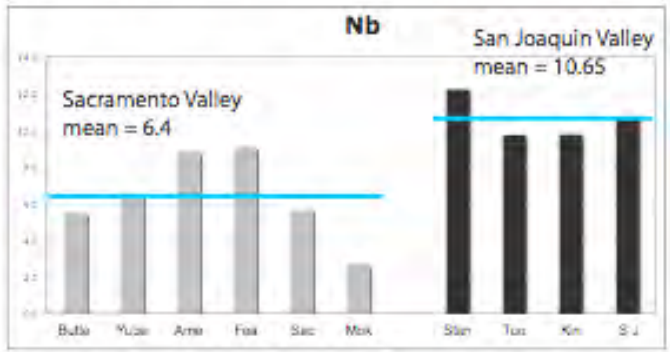

U
San Joaquin Valley
mean = 5.03
Sacramento Valley
mean = 0.93

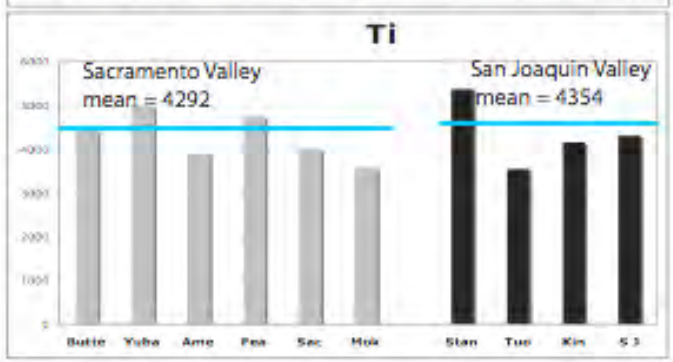

Rb
San Joaquin Valley
mean = 82
Sacramento Valley
mean = 33

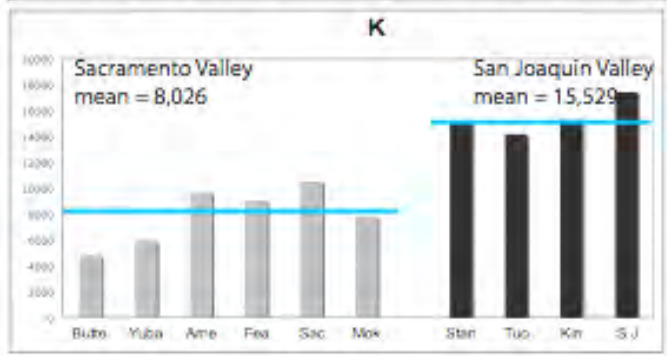

Mo
Sacramento Valley
mean = 1.42
San Joaquin Valley
mean = 2.23


Sr
Sacramento Valley
mean = 159
San Joaquin Valley
mean = 257


Nd
San Joaquin Valley
mean = 25.08
Sacramento Valley
mean = 16.9

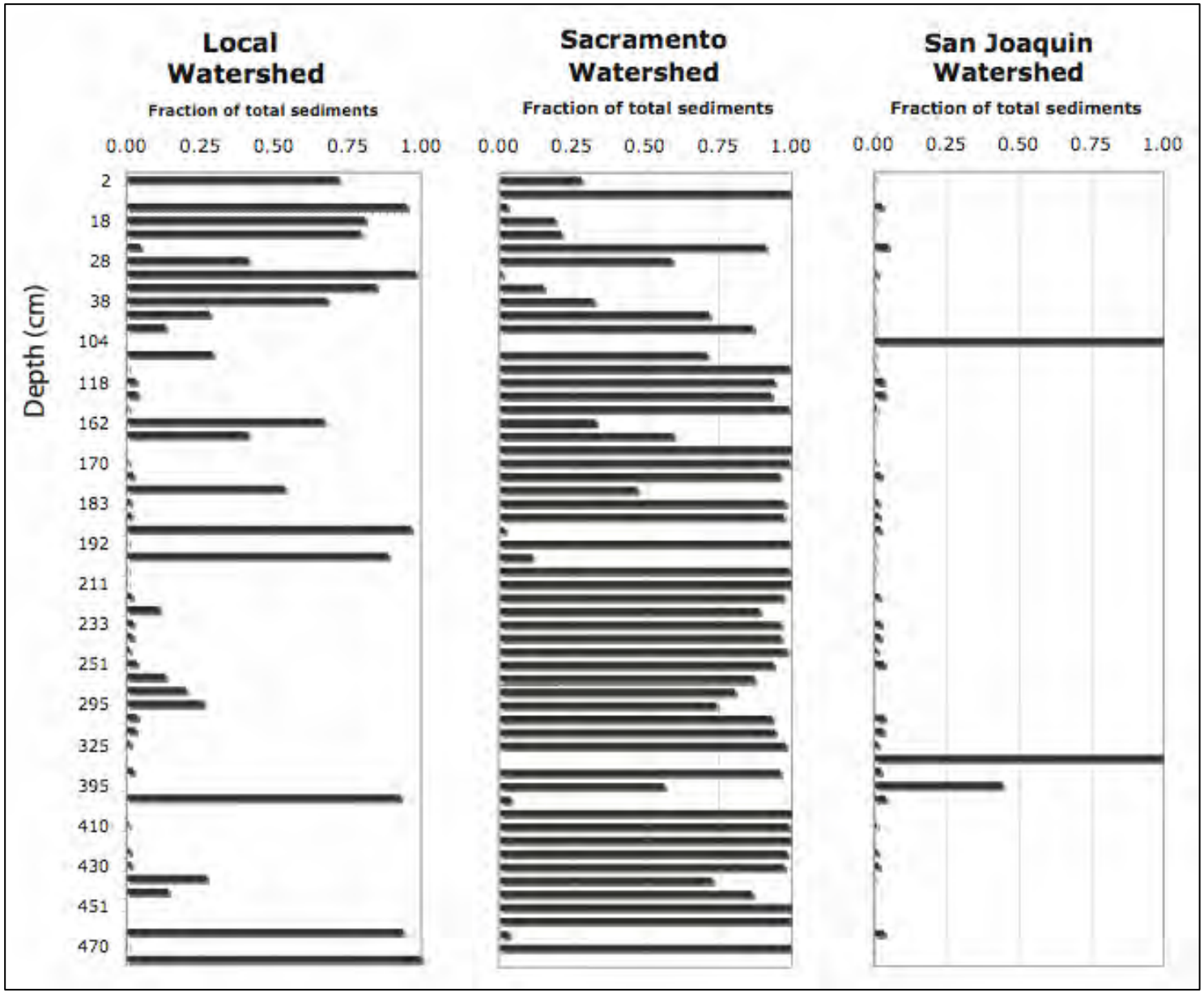

Nb
San Joaquin Valley
mean = 10.65
Sacramento Valley
mean = 6.4


Ti
Sacramento Valley
mean = 4292
San Joaquin Valley
mean = 4354


K
Sacramento Valley
mean = 8,026
San Joaquin Valley
mean = 15,529

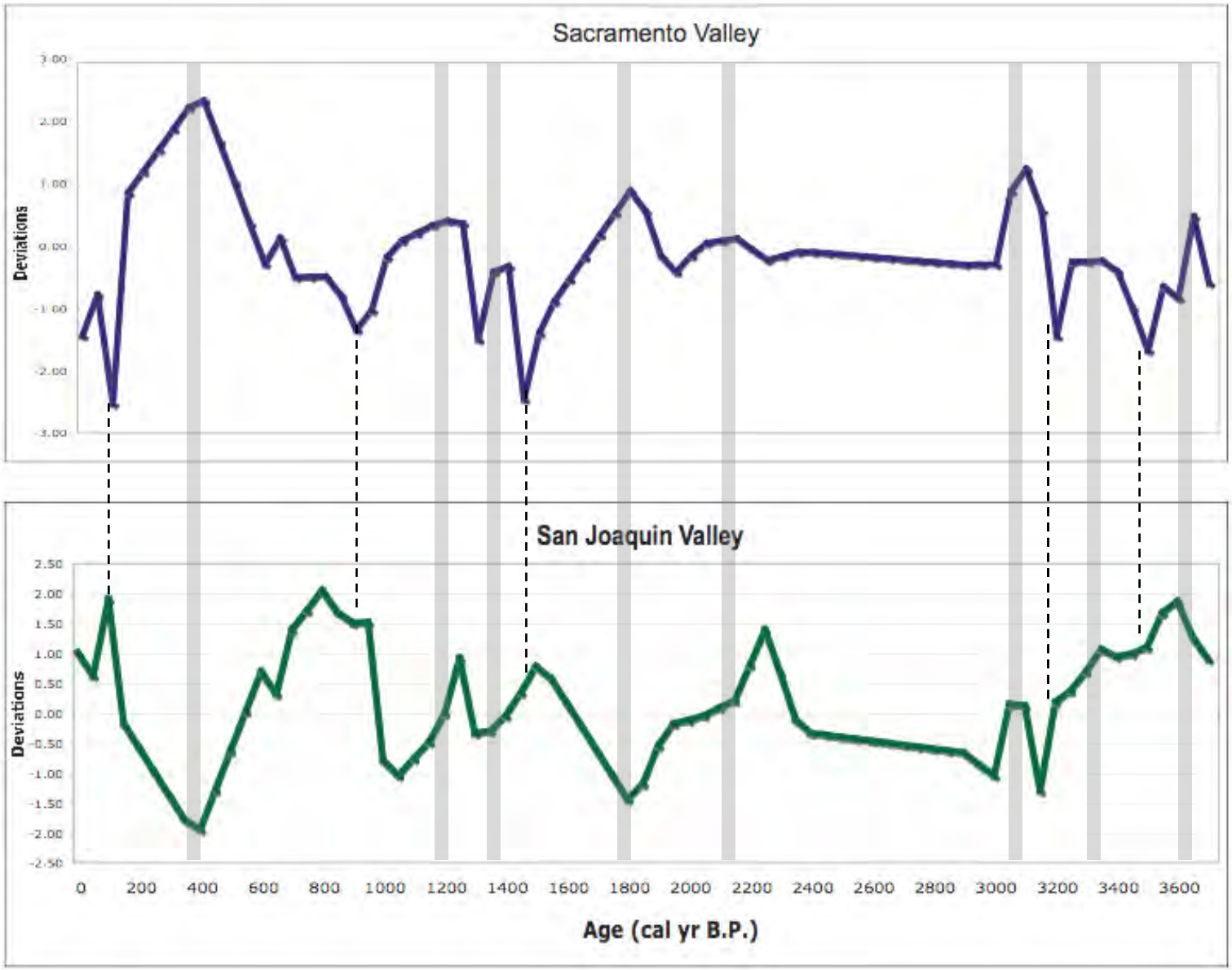
Elemental record of marsh sediments

Proportion of mineral sediments from each source to China Camp marsh



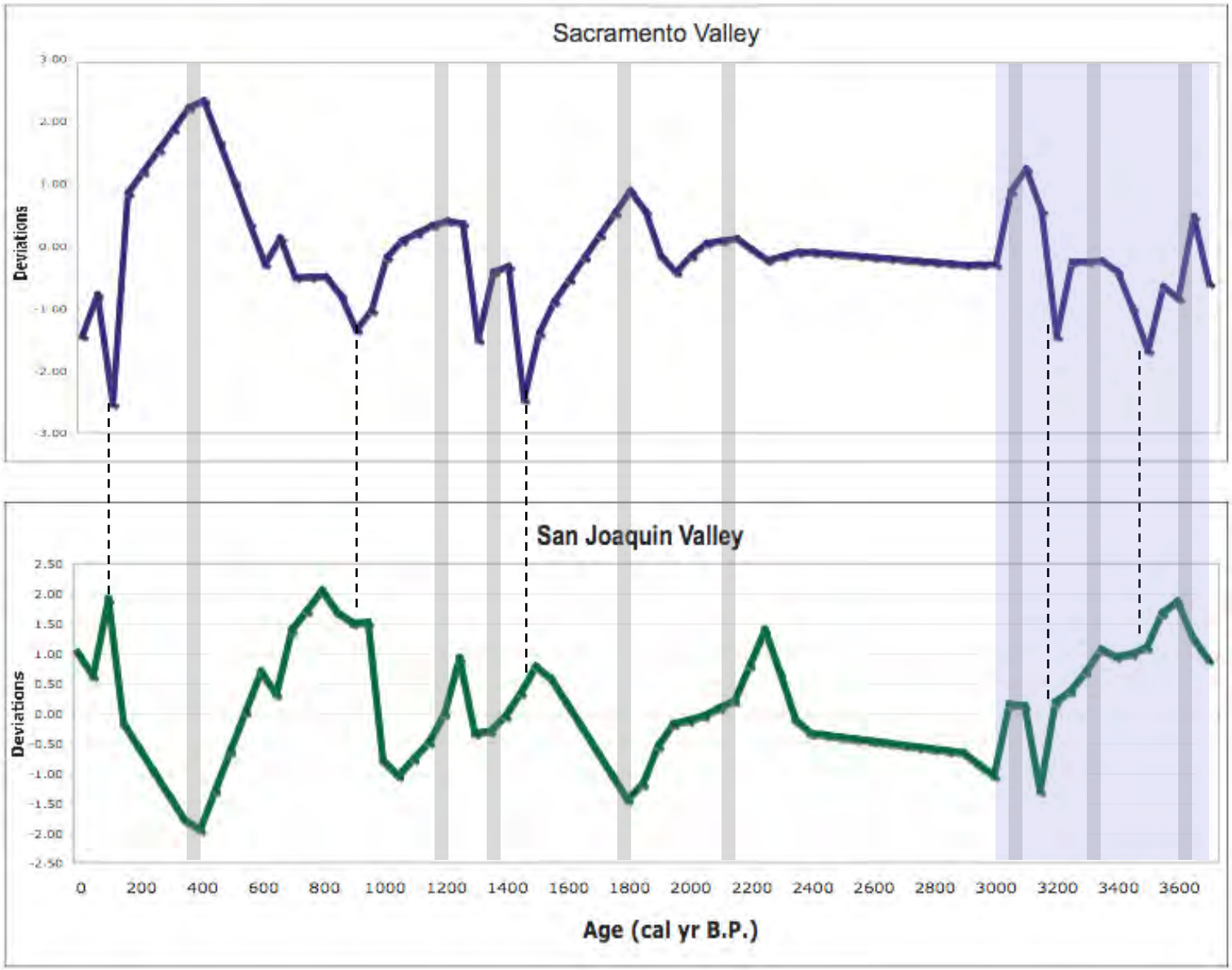
(Malamud-Roam et al. in review)

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



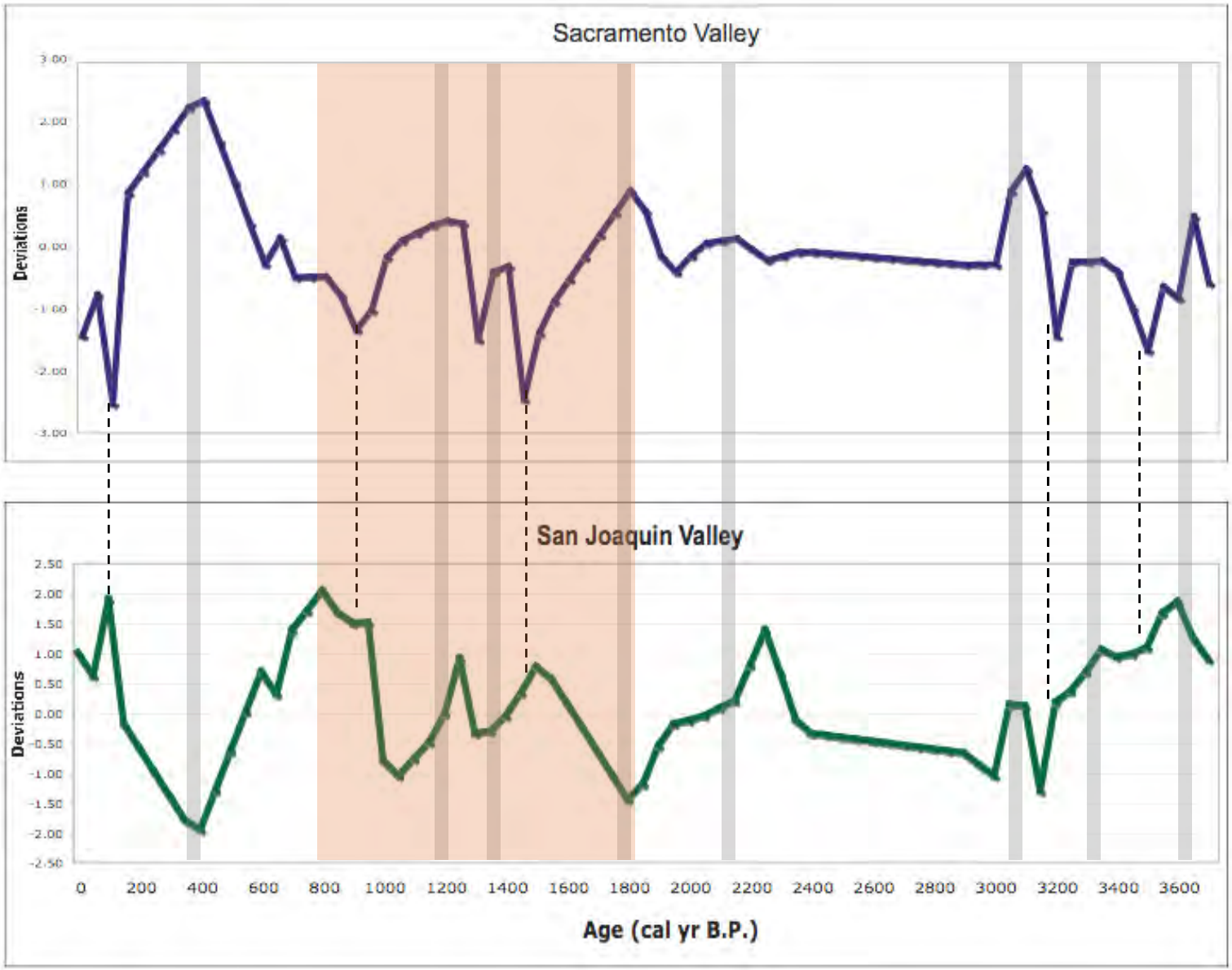
Relatively fresh on the marsh and on other sites in the Bay (e.g., Goman and Wells, 2000)

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

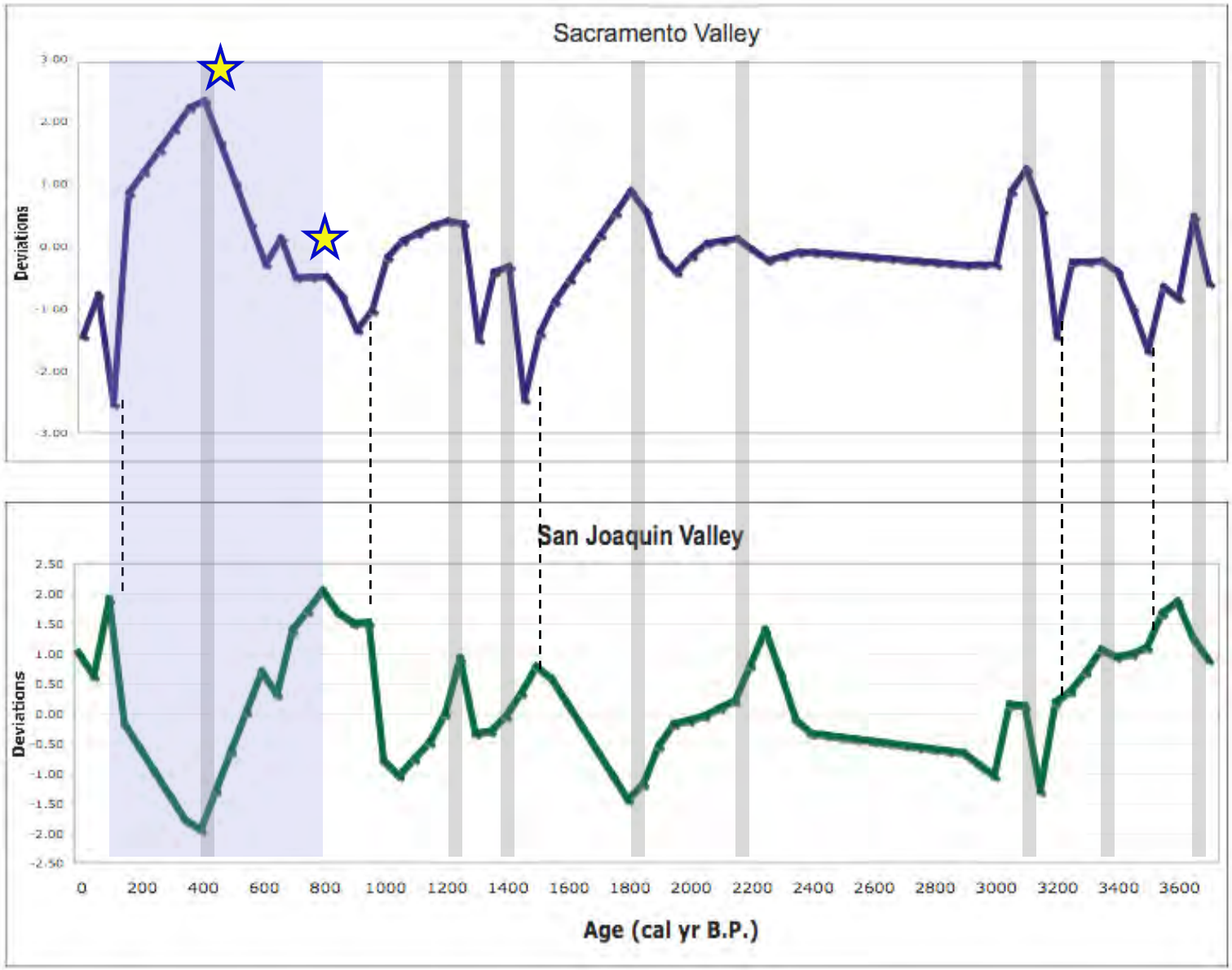


Period of degraded marsh

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



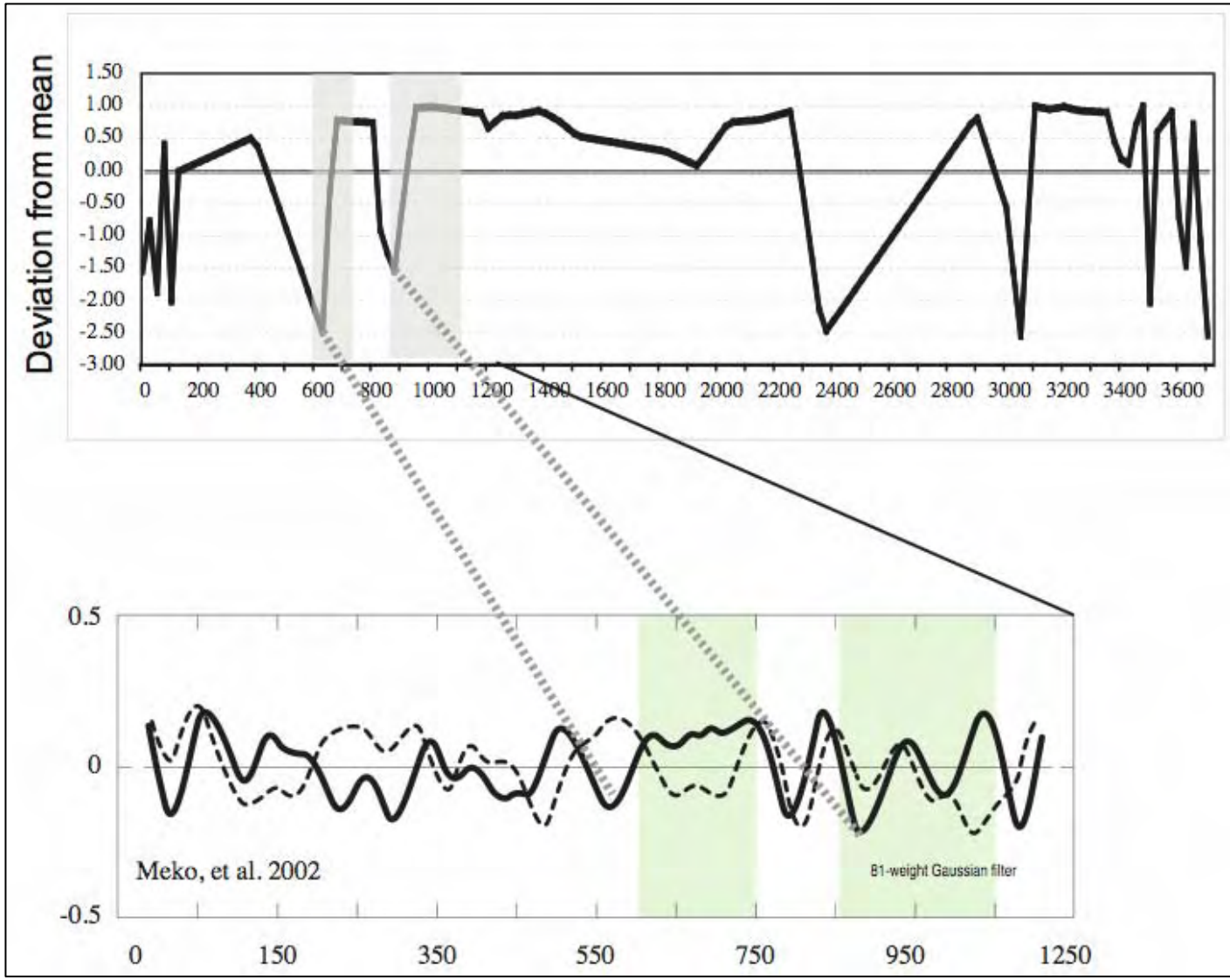
After ca 750 cal yr B.P. conditions freshen (Byrne et al 2001; Starratt 2004)

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

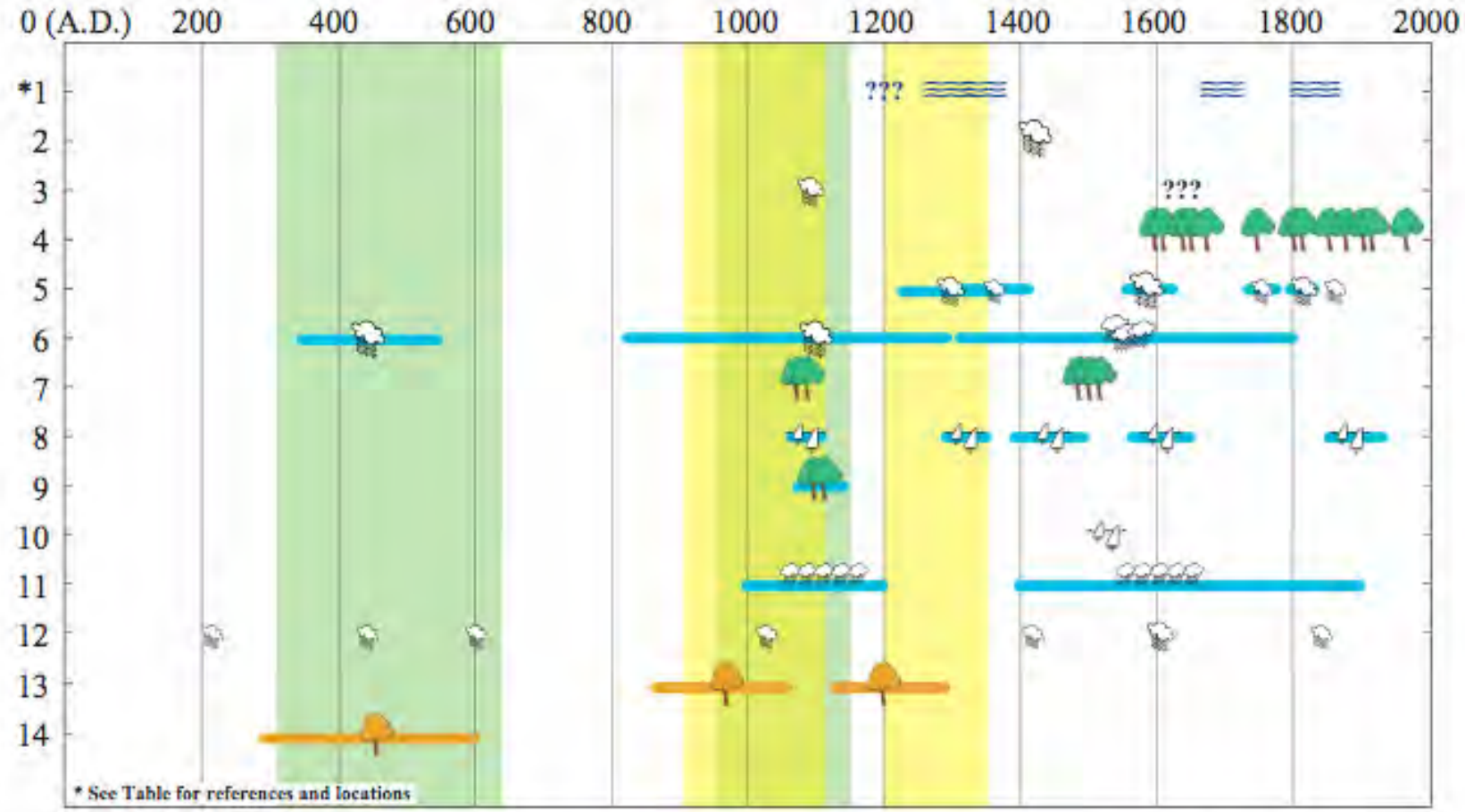
I.D.	Reference	Location	Year	Description
1	Ingram et al. 1996c	San Francisco Bay	1270-1380, 1675-1730, 1800-1860	High inflow
	Ingram et al. 1996c	San Francisco Bay	1200	top of unconformity
2	Goman and Wells, 2000	San Francisco Bay	1420	Browns Is Flood
3	Malamud-Roam, 2002	San Francisco Bay	1090, 1645	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

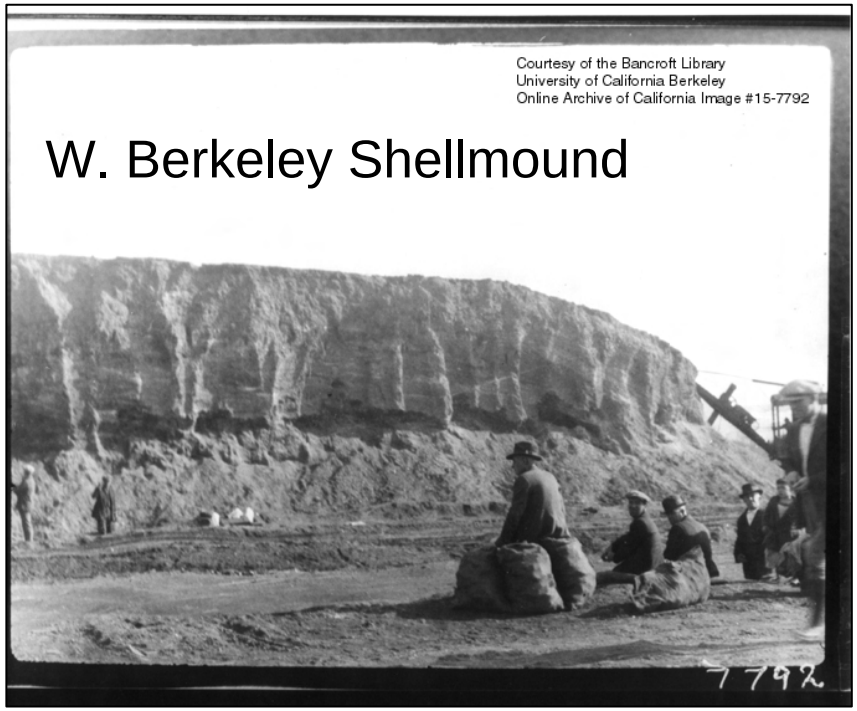


Inferred Wet Periods

- Flood event (size indicates relative magnitude
- Timing unclear
- Period of numerous large floods
- Period of 3 large floods
- Tree ring evidence
- Bay sediments
- Lake deposits
- ??? Unconformity

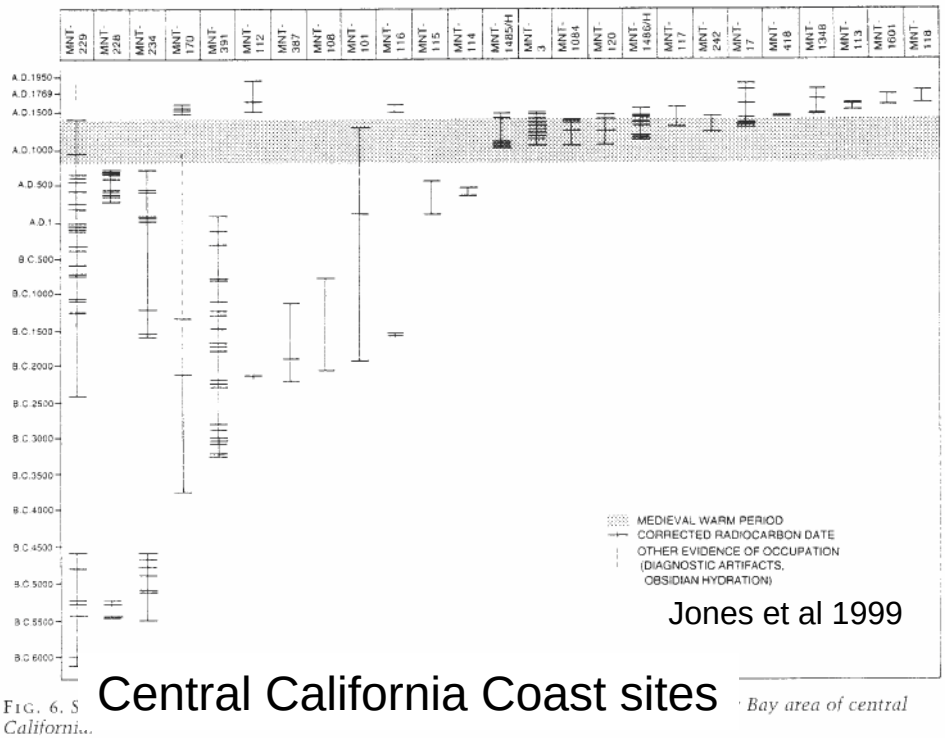
Inferred Dry Periods:

- Bay marsh vegetation
- Mono Lake droughts
- Tree ring evidence



Impacts on human populations

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



Jones et al 1999

Central California Coast sites

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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