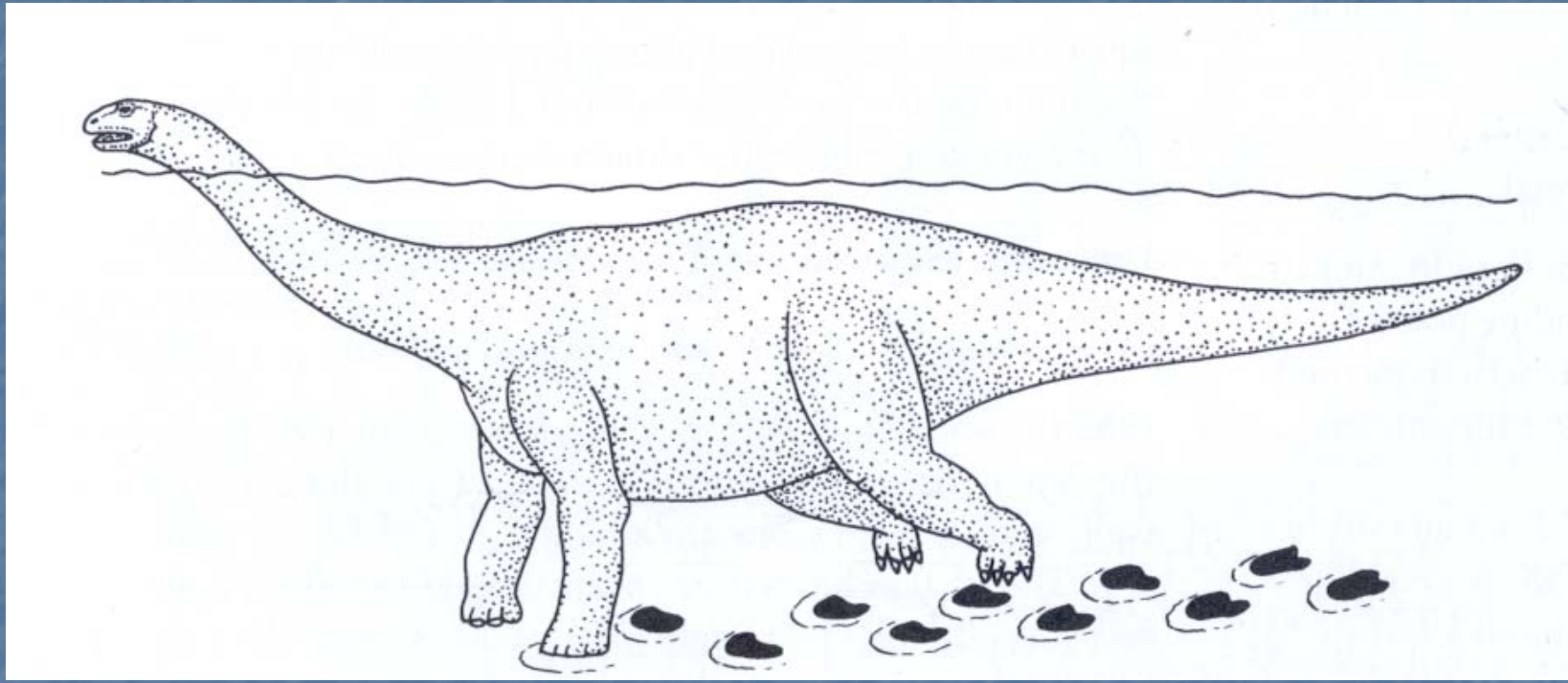
Sea Level and Climate Variability: Diatom Records from Coastal Marshes

Scott W. Starratt
U.S. Geological Survey

USGS

Sea Level Rise . . .



. . . It Has Happened Before

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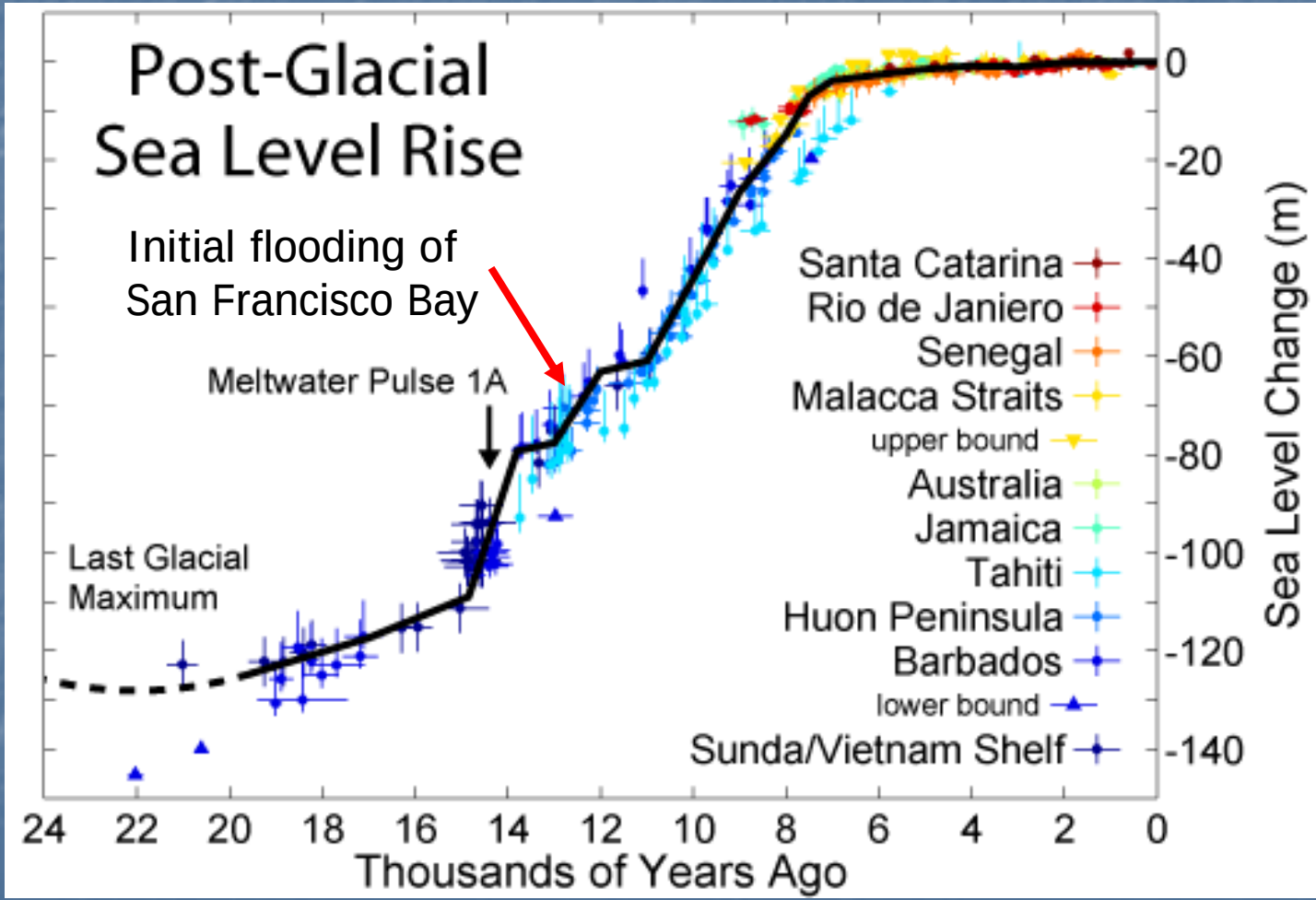
Sea level rise since the Last Glacial Maximum has been about 120 m



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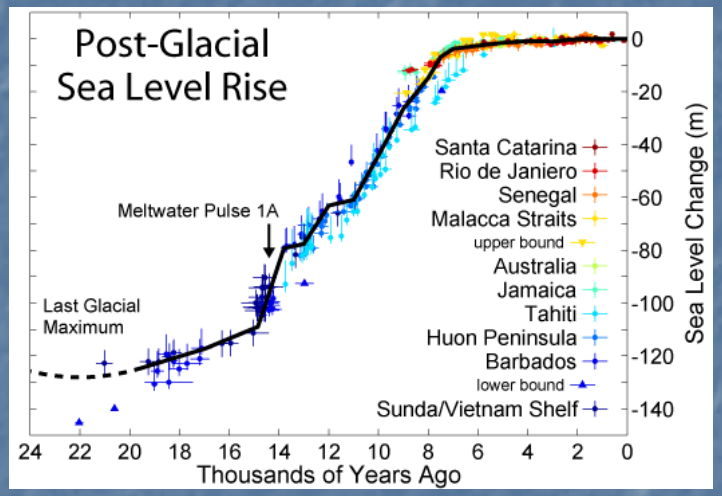
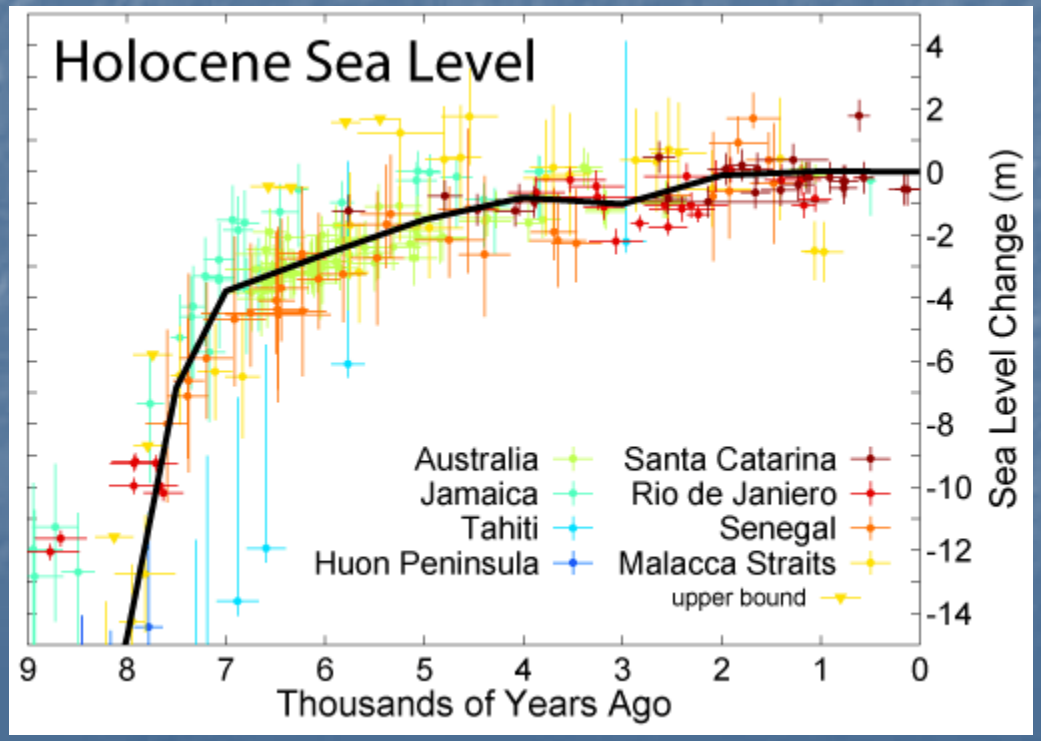
About 7,000 years ago the rate of rise slowed due to a decrease in meltwater input



Atwater estimated the rate of sea level rise to be nearly 2 cm/year in the early Holocene

Over the past 5,000 years, the rate sea level rise has been less than half the rate of the early Holocene



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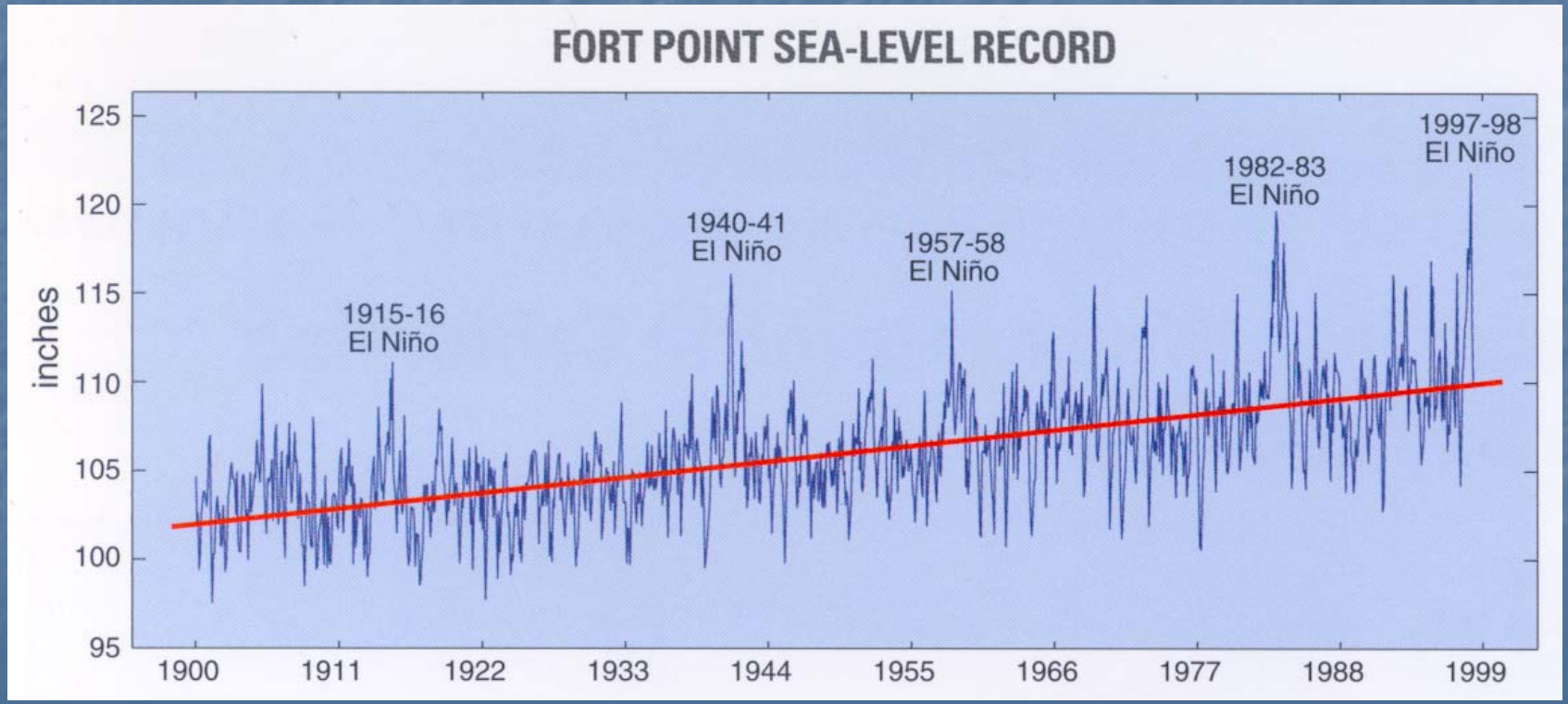
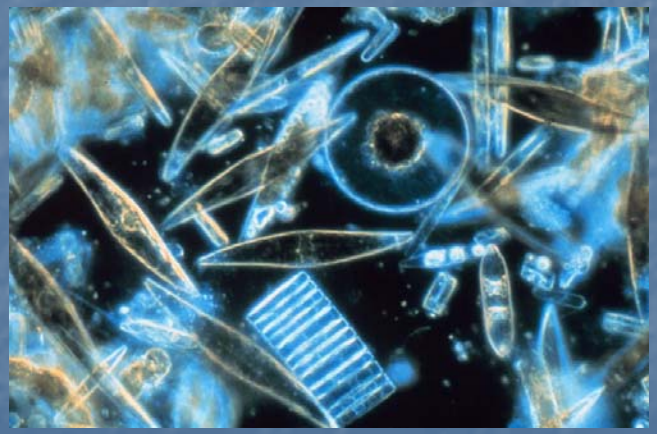
Sea level has risen about 0.04 to 0.08 inches (0.10 to 0.20 cm) per year since 1900



USGS

WHY DIATOMS?

- Live anywhere there is sufficient light and water
- Secrete shells of amorphous silica (SiO_2)
- Not susceptible to solution in the low pH environments typical of marshes
- High diversity (more than 600 species and varieties in San Francisco Bay)
- Ecological specificity
- Problems
  - Transportation
  - Bioturbation
  - High diversity and ecological specificity



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WHY MARSHES?

- Stability of environment for long-term studies
- Less susceptible to physical and biological reworking
- Accessibility
- Problems
  - Regional comparability

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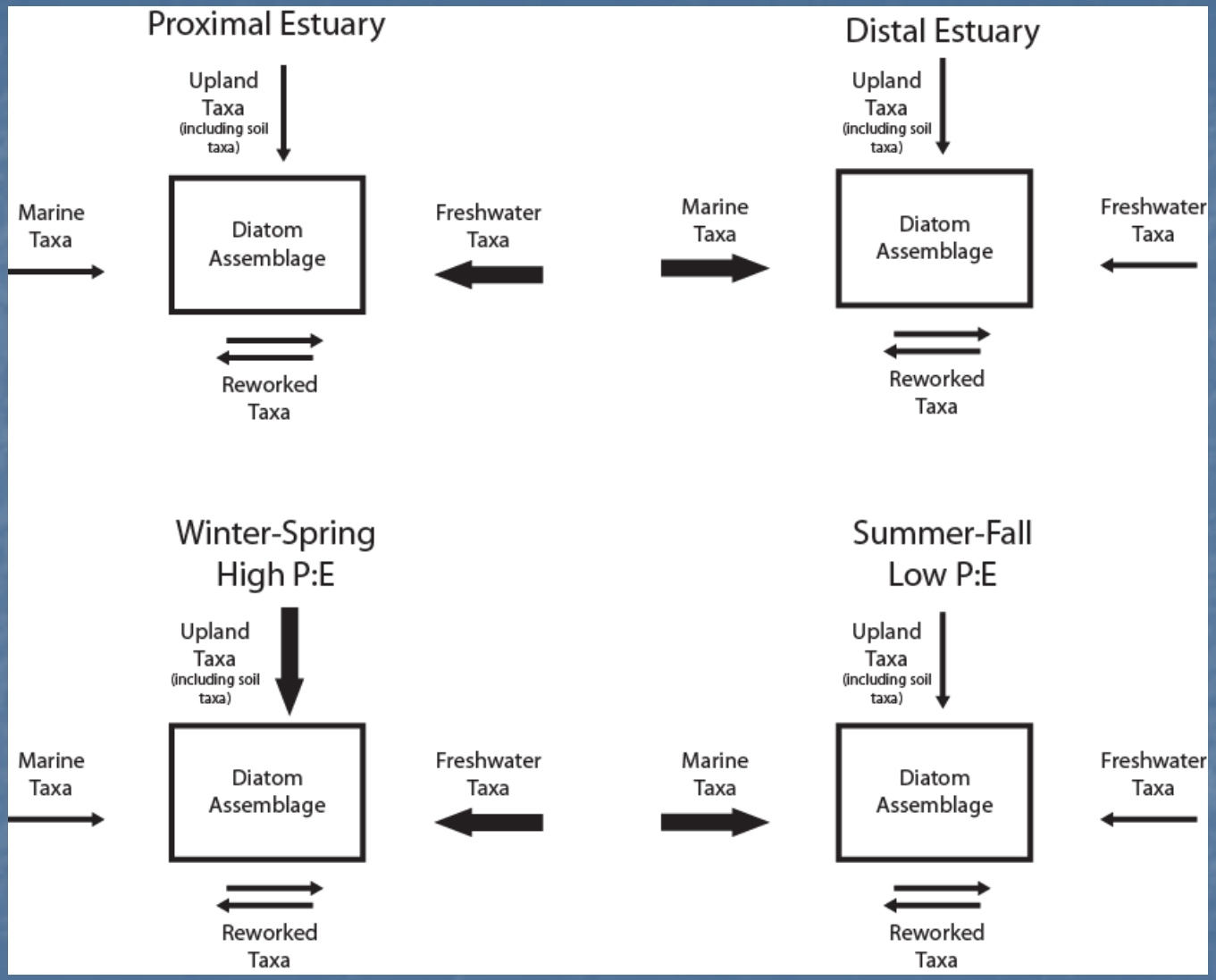
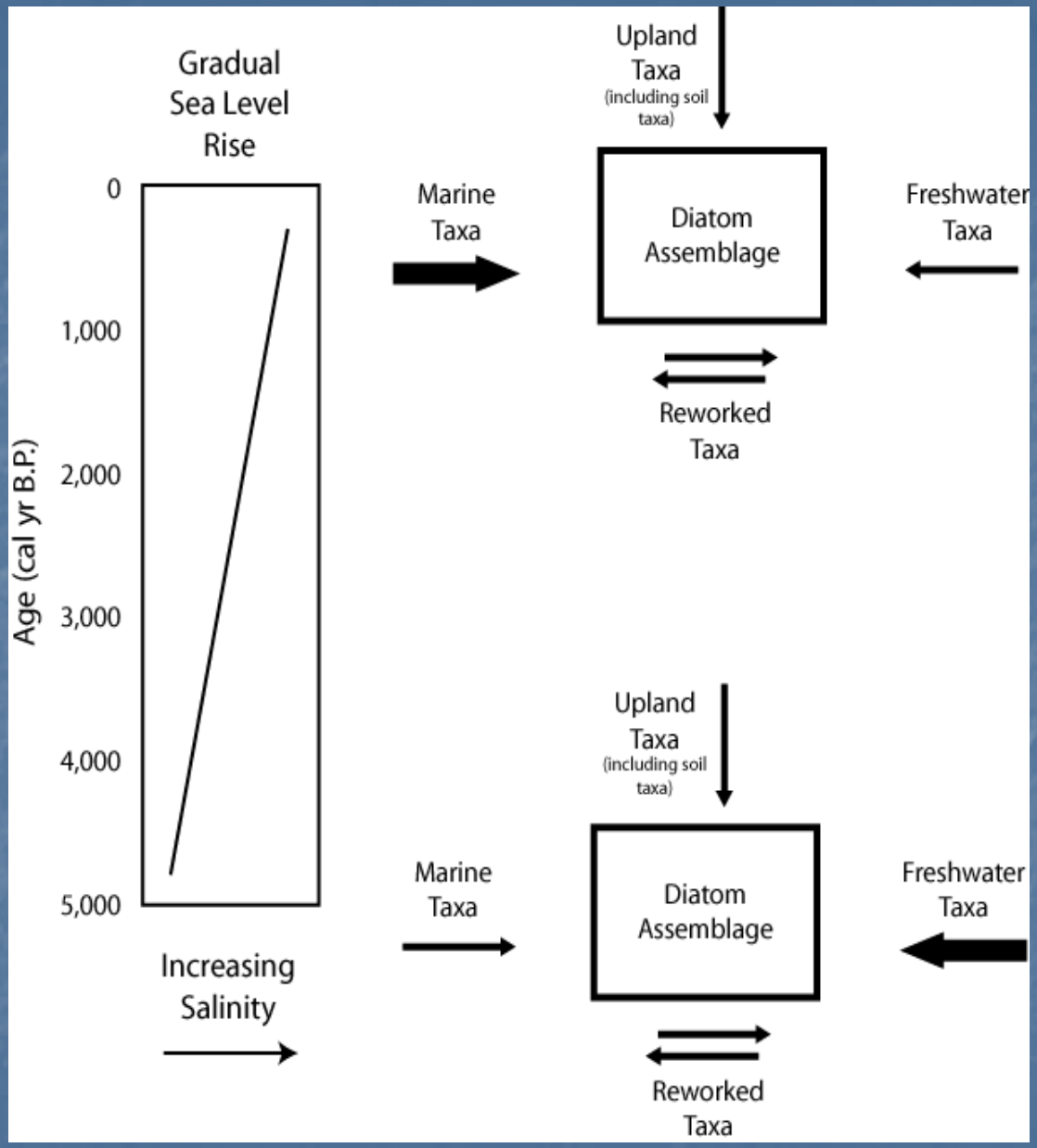
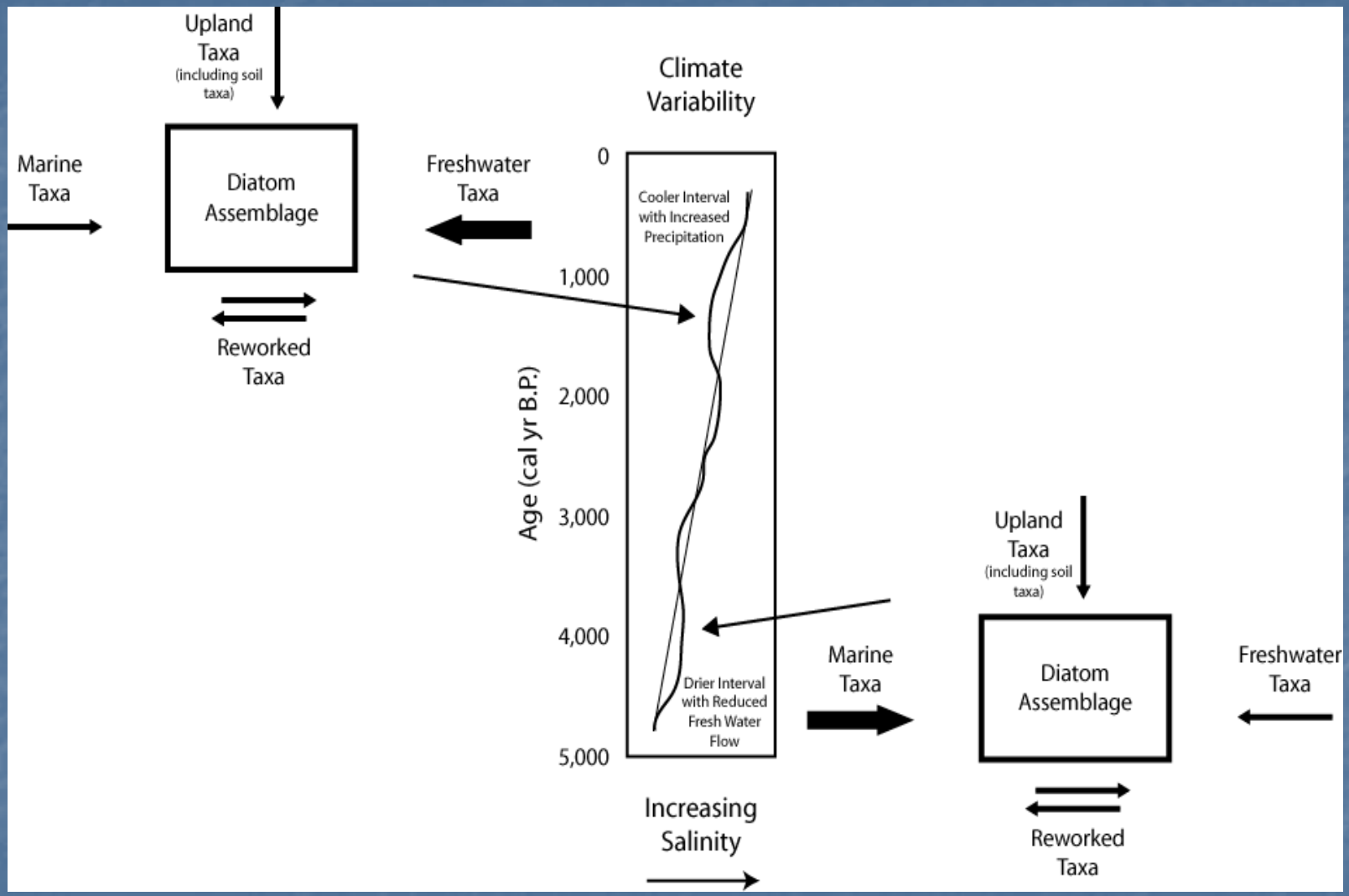

Proximal Estuary
Upland Taxa (including soil taxa)
Marine Taxa
Diatom Assemblage
Freshwater Taxa
Reworked Taxa
Distal Estuary
Upland Taxa (including soil taxa)
Marine Taxa
Diatom Assemblage
Freshwater Taxa
Reworked Taxa
Winter-Spring High P:E
Upland Taxa (including soil taxa)
Marine Taxa
Diatom Assemblage
Freshwater Taxa
Reworked Taxa
Summer-Fall Low P:E
Upland Taxa (including soil taxa)
Marine Taxa
Diatom Assemblage
Freshwater Taxa
Reworked Taxa

USGS


Gradual
Sea Level
Rise
0
1,000
2,000
3,000
4,000
5,000
Age (cal yr B.P.)
Increasing
Salinity
Marine
Taxa
Upland
Taxa
(including soil
taxa)
Diatom
Assemblage
Freshwater
Taxa
Reworked
Taxa
Marine
Taxa
Upland
Taxa
(including soil
taxa)
Diatom
Assemblage
Freshwater
Taxa
Reworked
Taxa

USGS


Upland Taxa (including soil taxa)
Marine Taxa
Diatom Assemblage
Reworked Taxa
Freshwater Taxa
Climate Variability
0
1,000
2,000
3,000
4,000
5,000
Age (cal yr B.P.)
Cooler Interval with Increased Precipitation
Drier Interval with Reduced Fresh Water Flow
Increasing Salinity
Marine Taxa
Upland Taxa (including soil taxa)
Diatom Assemblage
Freshwater Taxa
Reworked Taxa

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San Francisco Bay, California

- Laws (1988) generated Q-mode cluster and R-mode principle components analysis
- Recognized six assemblages
  - Identified assemblages in northern, central, and southern parts of San Francisco Bay
  - Separate marsh assemblages
- Assemblages used to identify Sangamon (~125,000 years ago) deposits and fault offsets

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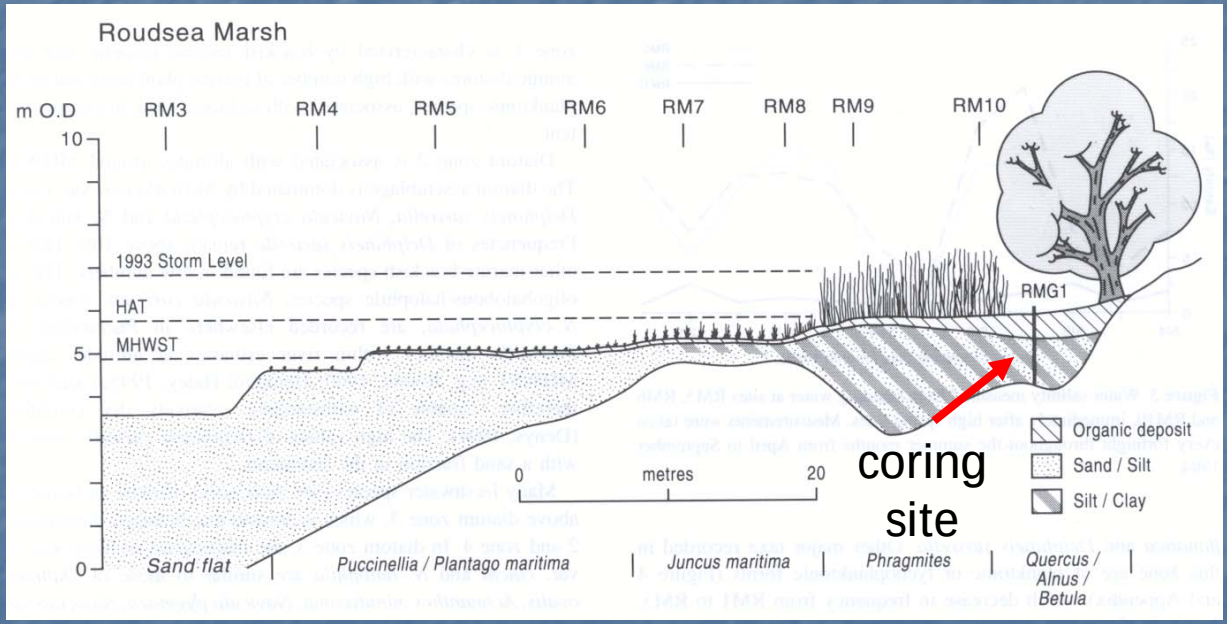
Sea Level Reconstruction

- Quantitative
  - Use modern floras at specific elevations in the tidal cycle
  - Follow the history of specific horizons
    - highest astronomical tide
    - mean high water of spring tides
- Qualitative
  - Identify transgressive and regressive markers
  - Often in conjunction with other fossil groups

- Quantitative Sea Level Studies
  - Select a marsh transect from the intertidal zone to a point above marine influence
  - Evaluate physical, chemical, and biological characteristics



MHWST - mean high water of spring tides

HAT – highest astronomical tide

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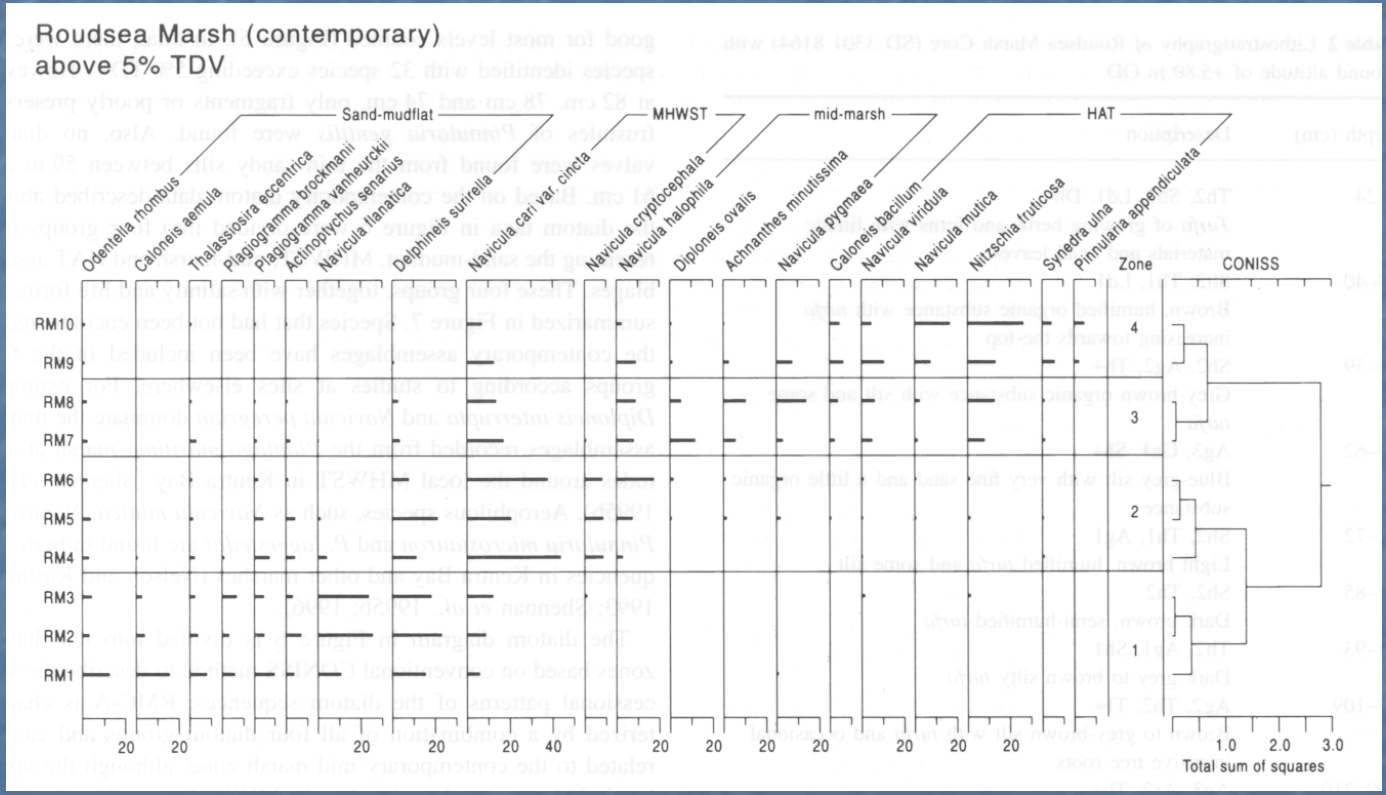
- Quantitative Sea Level Studies
  - Evaluate the modern diatom flora relative to known water levels



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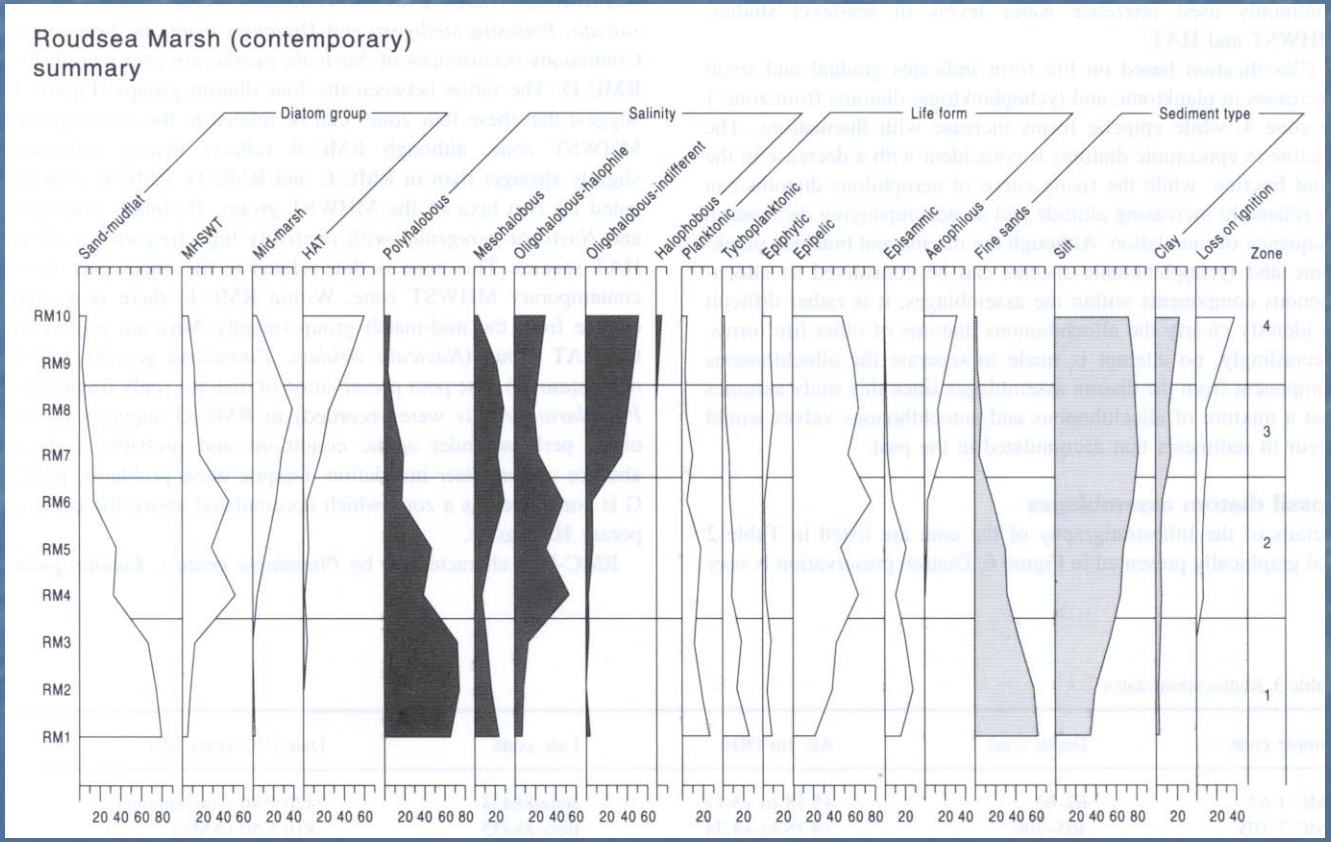
- Quantitative Sea Level Studies
  - Evaluate the modern diatom flora relative to known environmental preferences



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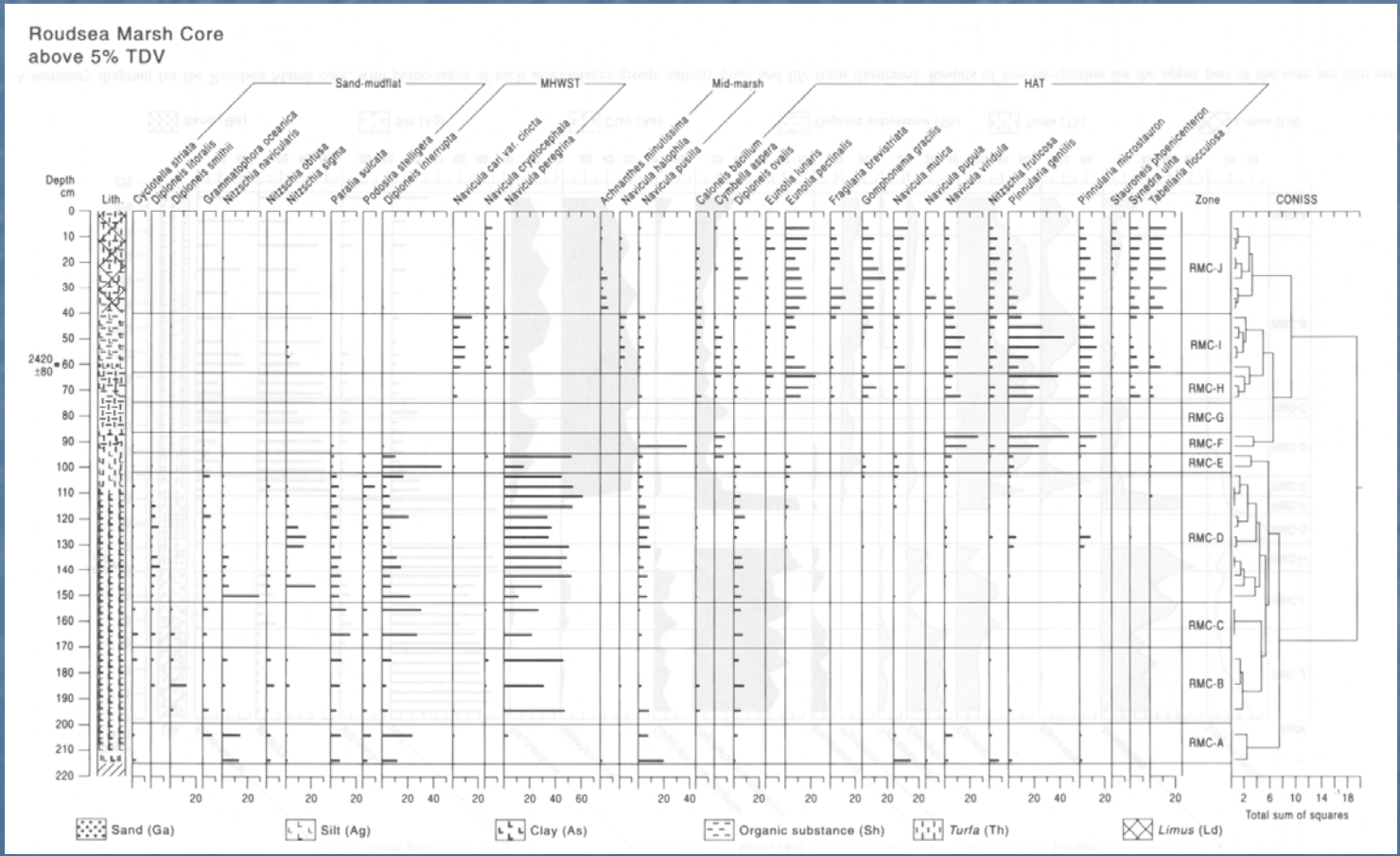
- Quantitative Sea Level Studies
  - Evaluate the diatom floras in one or more sediment cores



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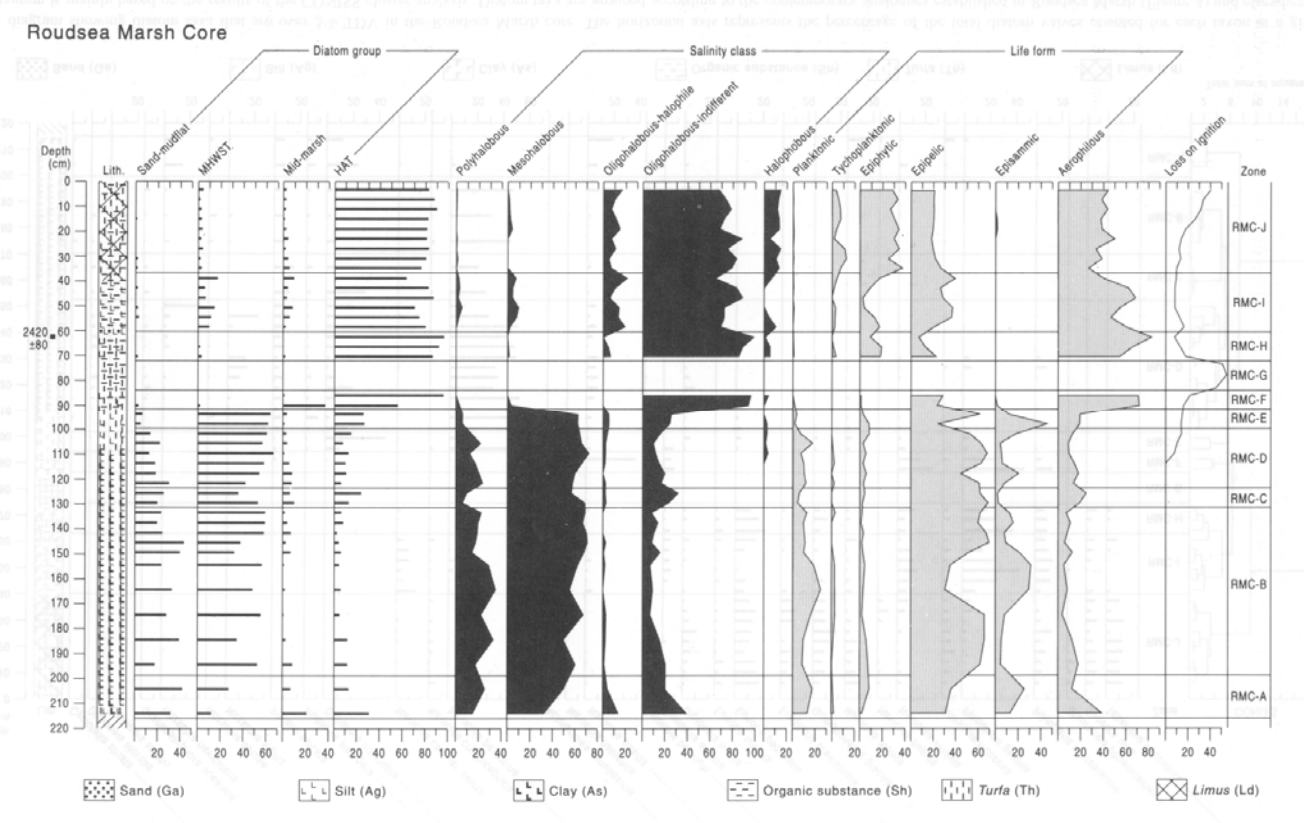
- Quantitative Sea Level Studies
  - Use the fossil assemblages and ancillary data to identify paleoenvironments



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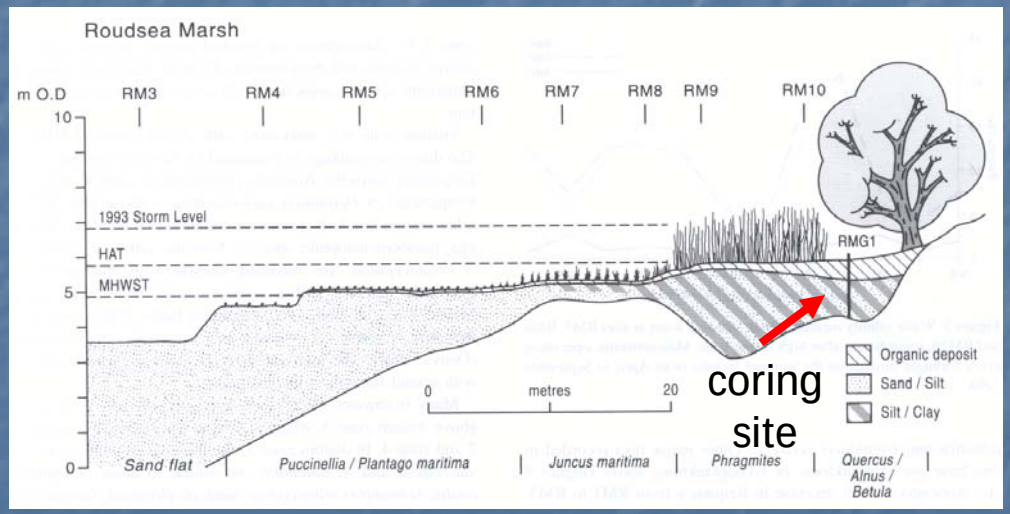
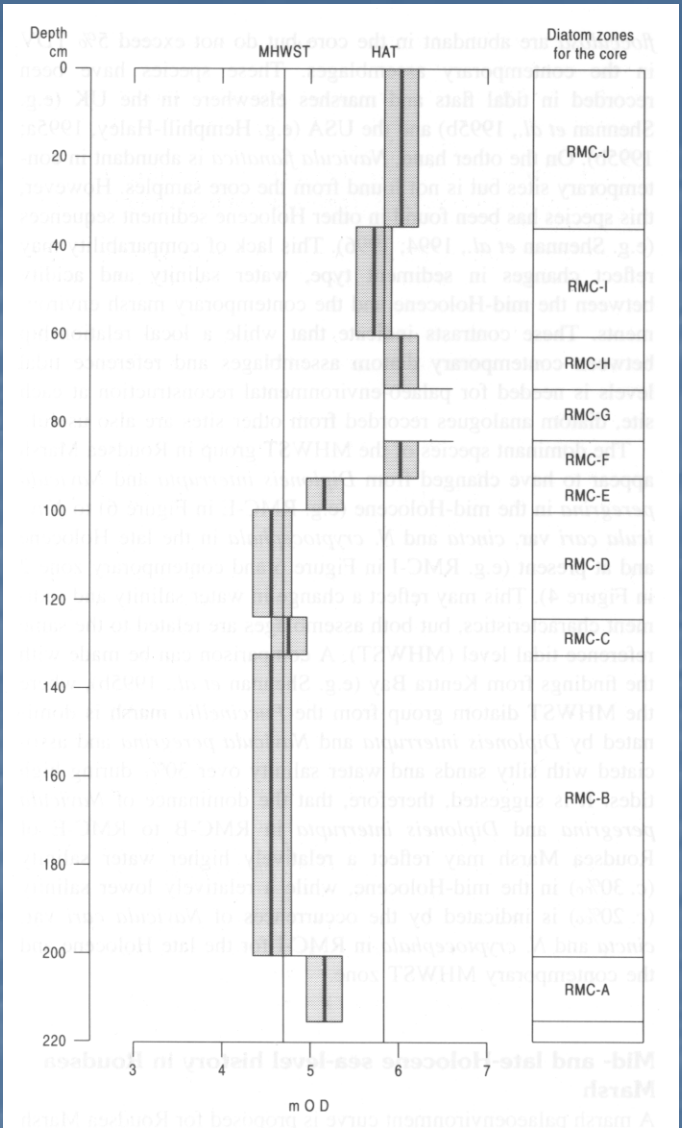
- Quantitative Sea Level Studies
  - Use those paleoenvironments to compare changes at the coring site





Climatic Influence on Regional Fresh Water Variability

- Regional climatic variations affect amount of fresh water flowing into San Francisco Bay
- Modern assemblages calibrated to modern salinity conditions
- Secondary calibration to other parameters including tree-ring and strontium isotope records

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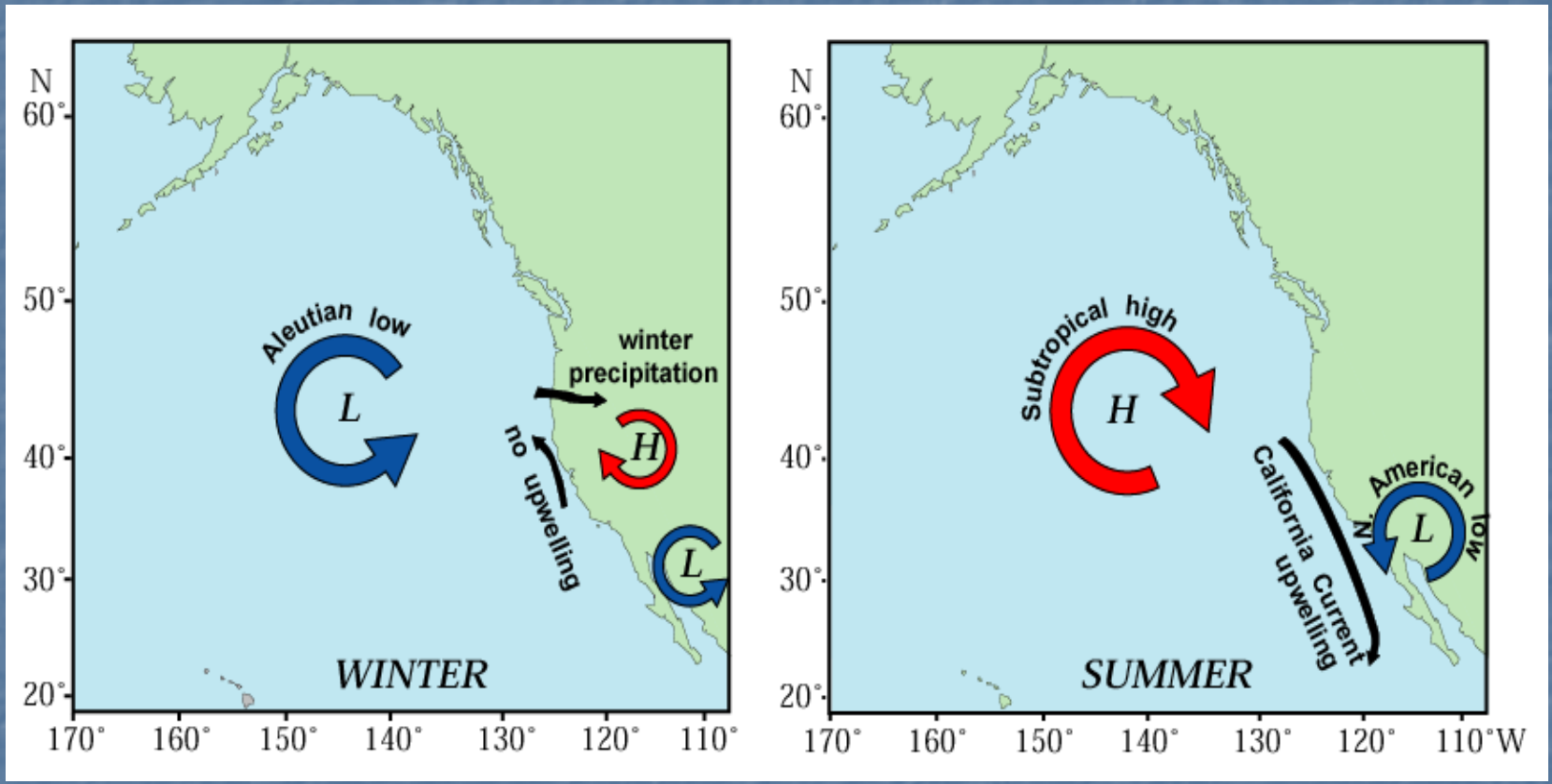
CLIMATE CONTROLS



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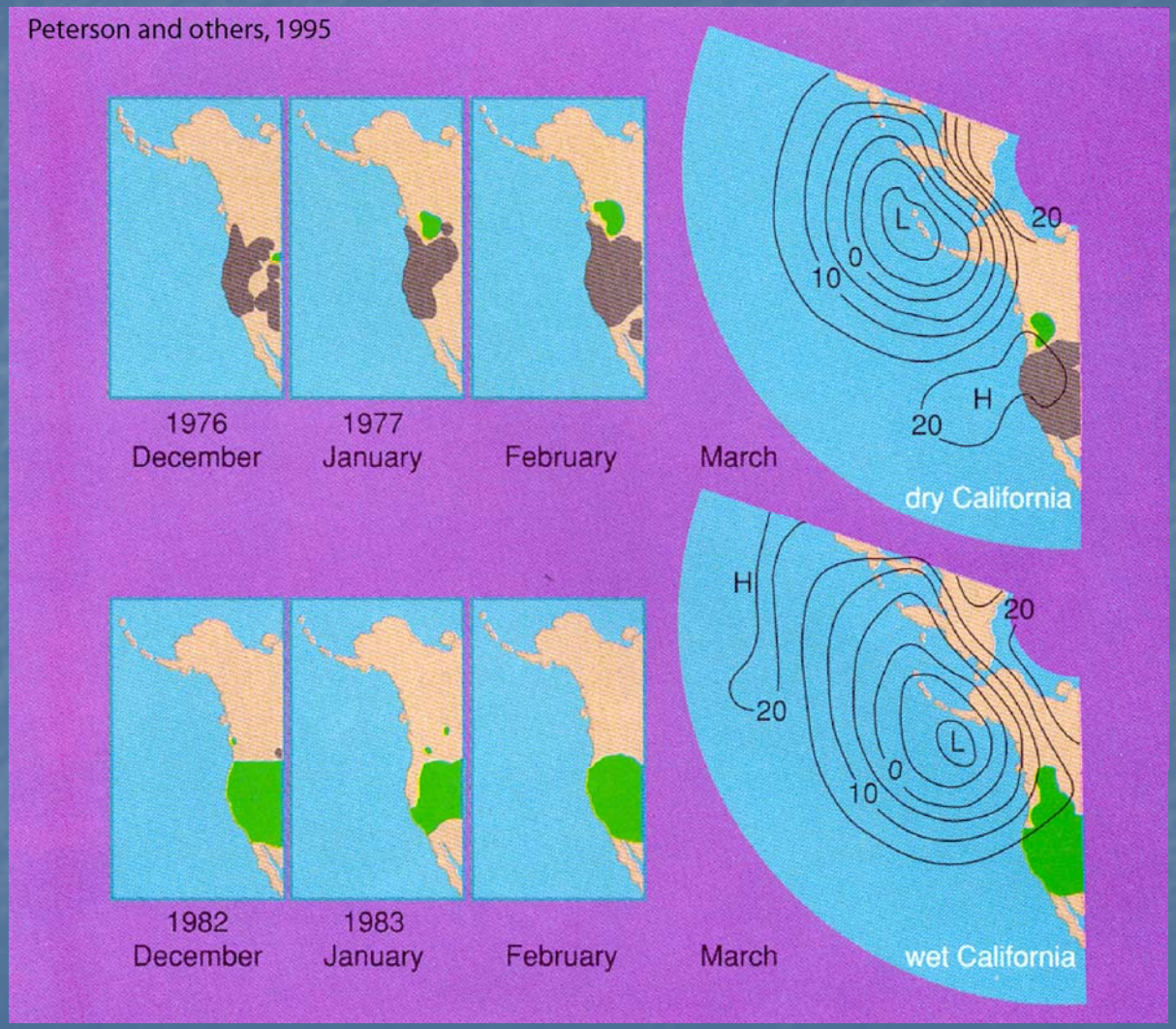
CLIMATE CONTROLS



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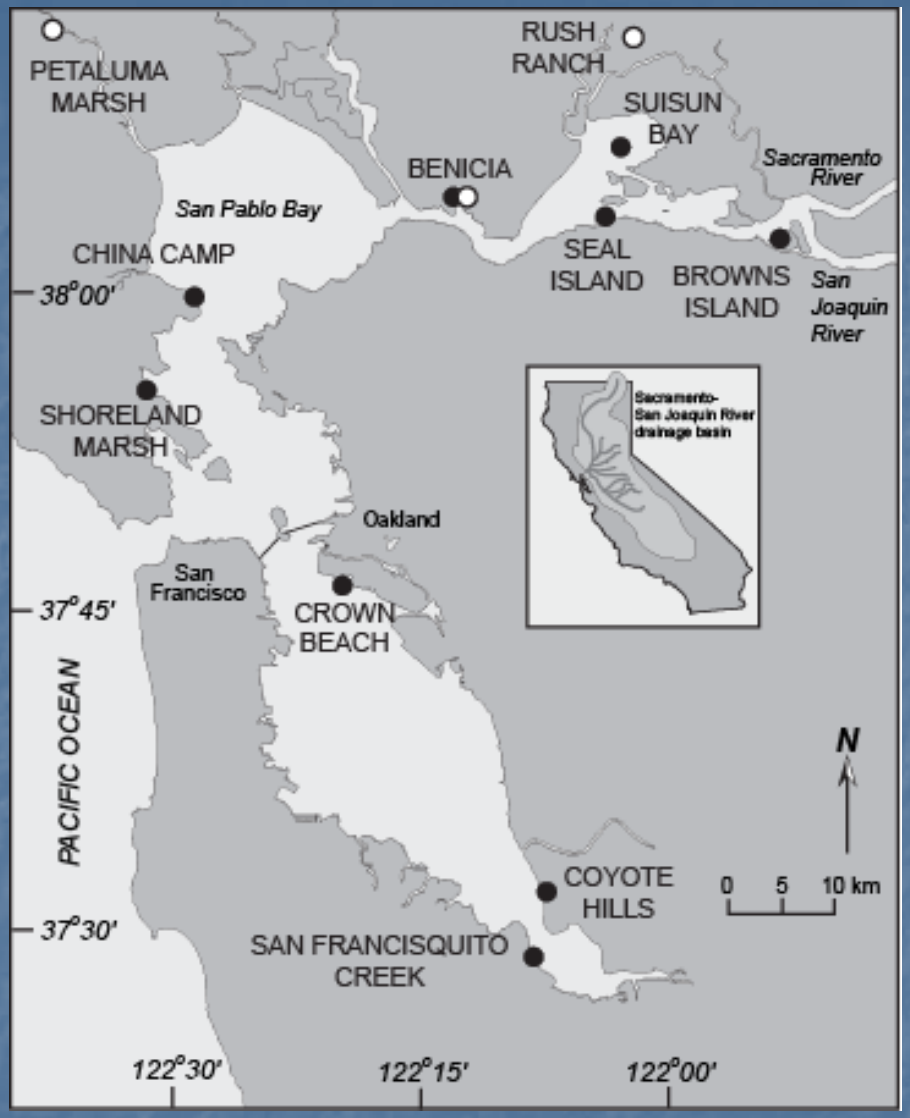

Located between normal marine and freshwater environment

Some of the last remaining areas of original tidal marsh

40% of the precipitation that falls in California and 90% of the freshwater entering San Francisco Bay flows through the Sacramento-San Joaquin River Delta

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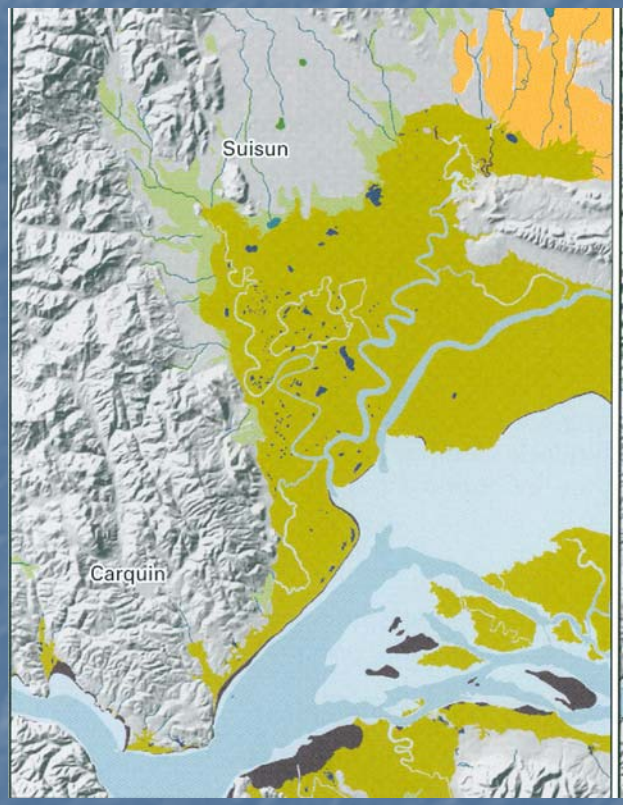
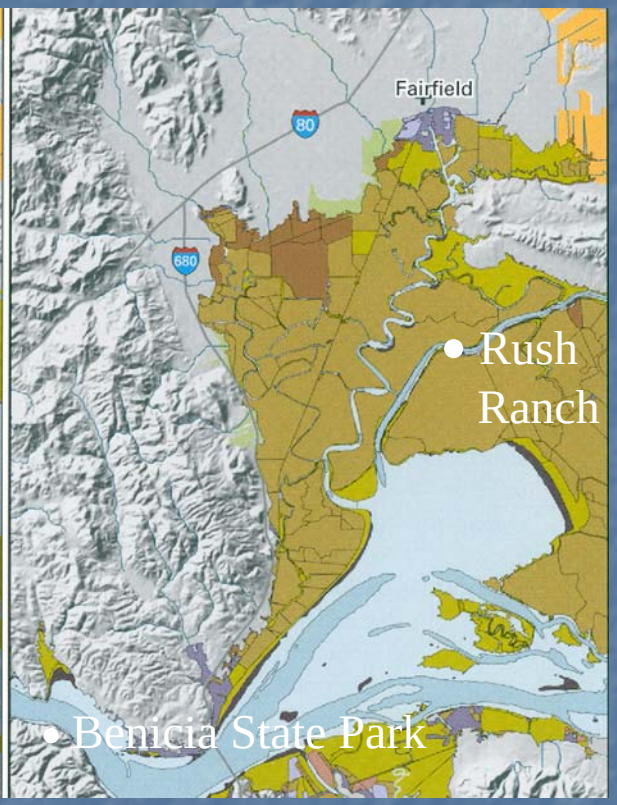
THE STUDY SITES: PAST

Db	Deep Bay/Channel
Sb	Shallow Bay/Channel
Tf	Tidal Flat
Tm	Tidal Marsh
Tp	Tidal Marsh Pan
Lg	Lagoon
Bc	Beach/Dune
Ag	Agricultural Bayland
Dw	Diked Wetland
Sp	Salt Pond
St	Storage or Treatment Pond
Uf	Undeveloped Bay Fill
Df	Developed Bay Fill
Pr	Perennial Pond
Rw	Riparian Forest/Willow Grove
Mg	Moist Grassland
Gr	Grassland/Vernal Pool Complex





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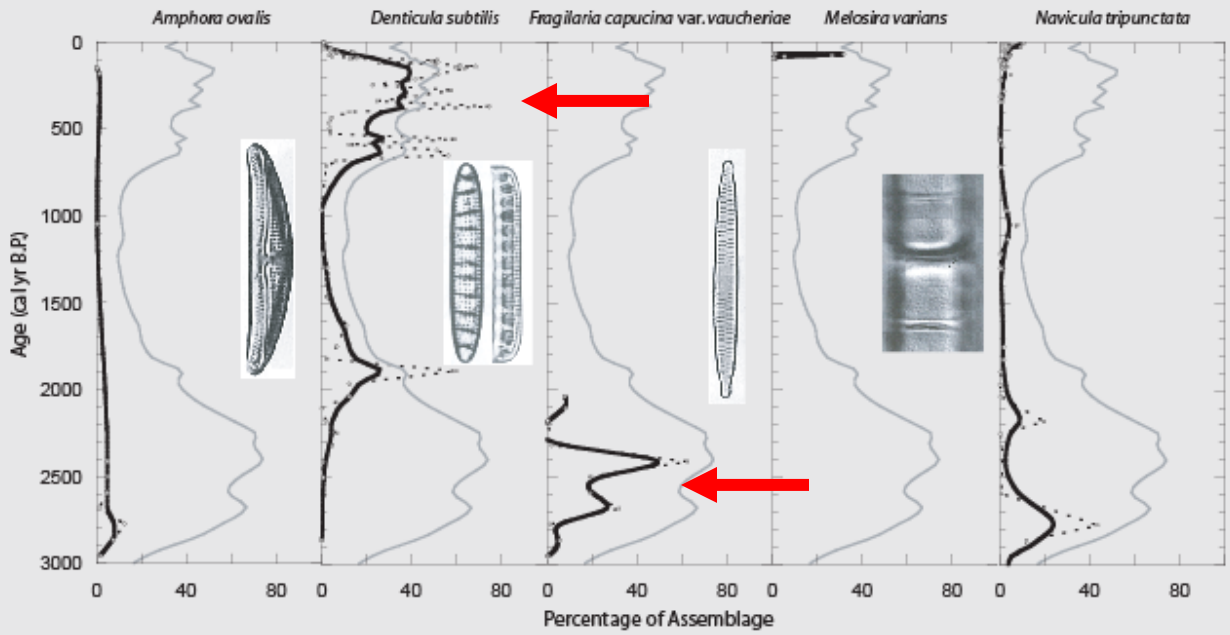
Significant Salinity Controlled Diatom Species at Rush Ranch



Temporal variation of selected taxa preferring fresh water. Gray line is the smoothed curve for the freshwater assemblage.

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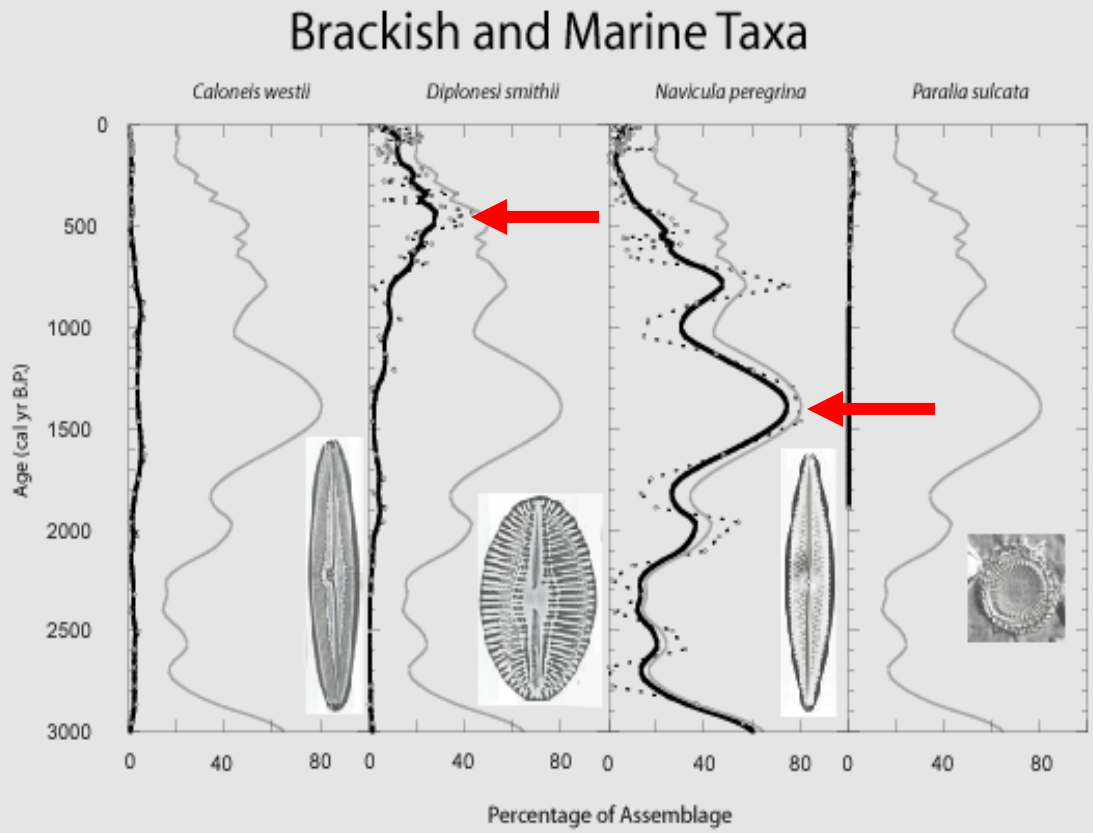
Significant Salinity Controlled Diatom Species at Rush Ranch



Temporal variation of selected taxa preferring brackish water and normal marine salinity. Gray line is the smoothed curve for the brackish and marine assemblage.

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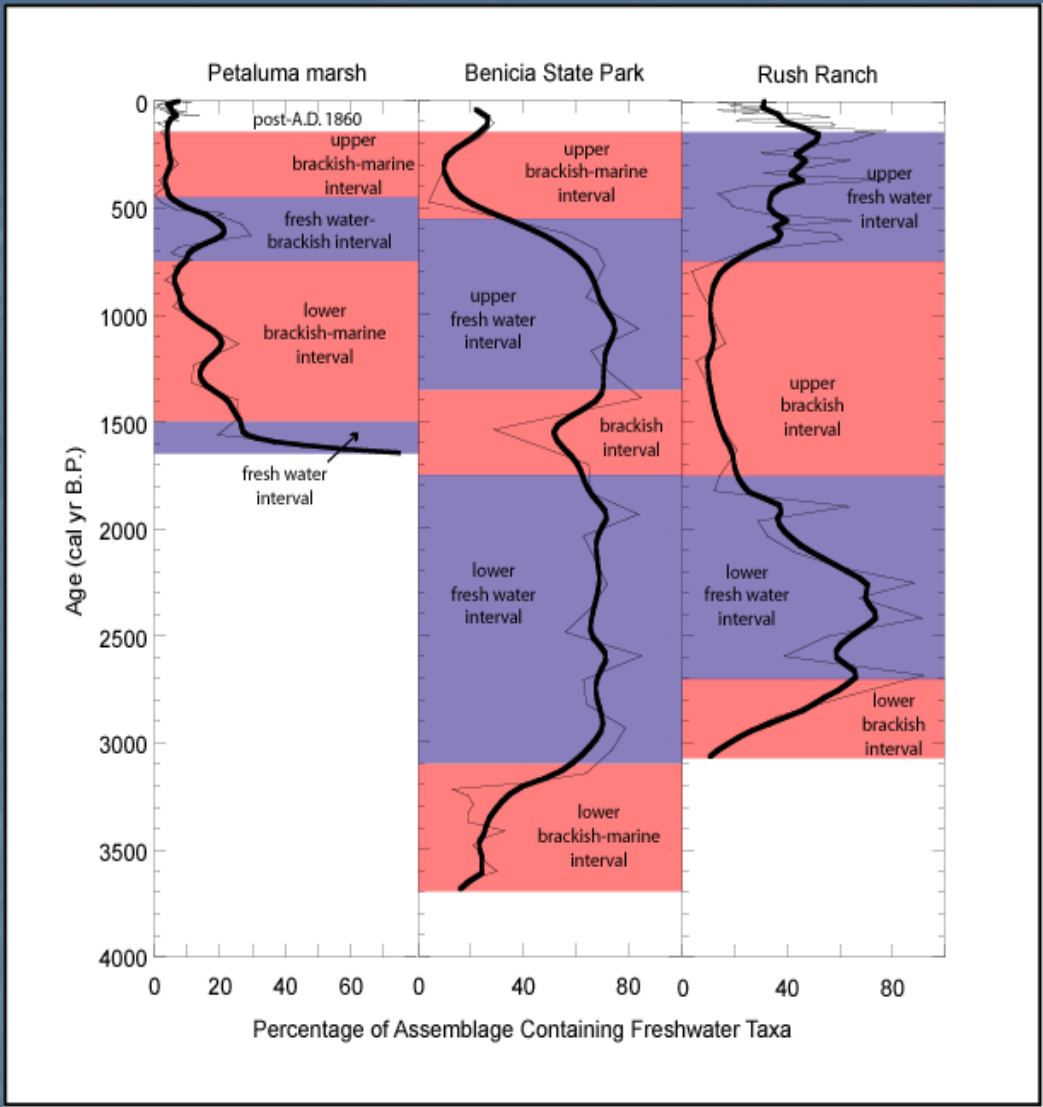
Complicated Record Due to Multiple Factors Controlling Salinity

Petaluma marsh – largely controlled by local precipitation conditions

Benicia State Park – controlled by flow of Sacramento River

Rush Ranch – most sensitive to rapid shifts in fresh water flow

General patterns are consistent between sites but timing varies



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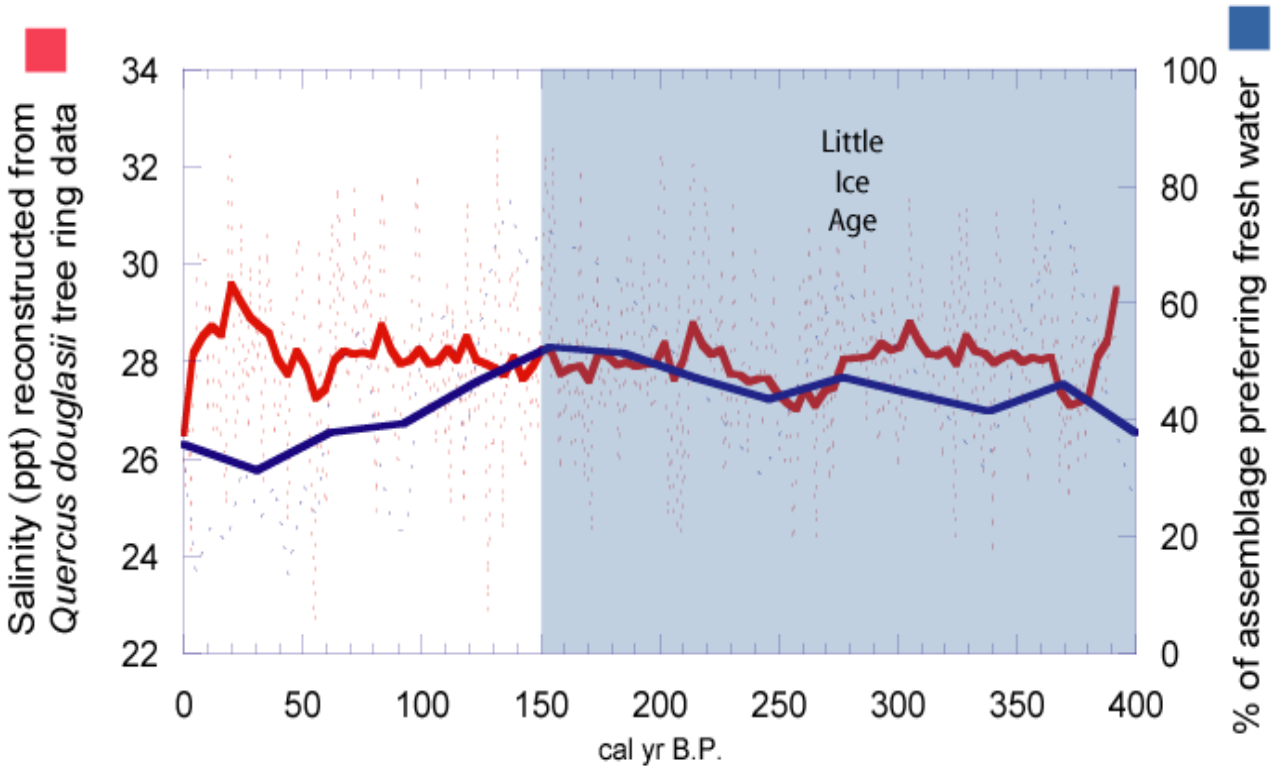
Tree Ring (Blue Oak)-Derived Precipitation Record



Salinity record reconstructed from blue oak (*Quercus douglasii*) tree-ring data from the central valley (red line; Stahle and others, 2001; blue line is the smoothed curve for the freshwater assemblage).

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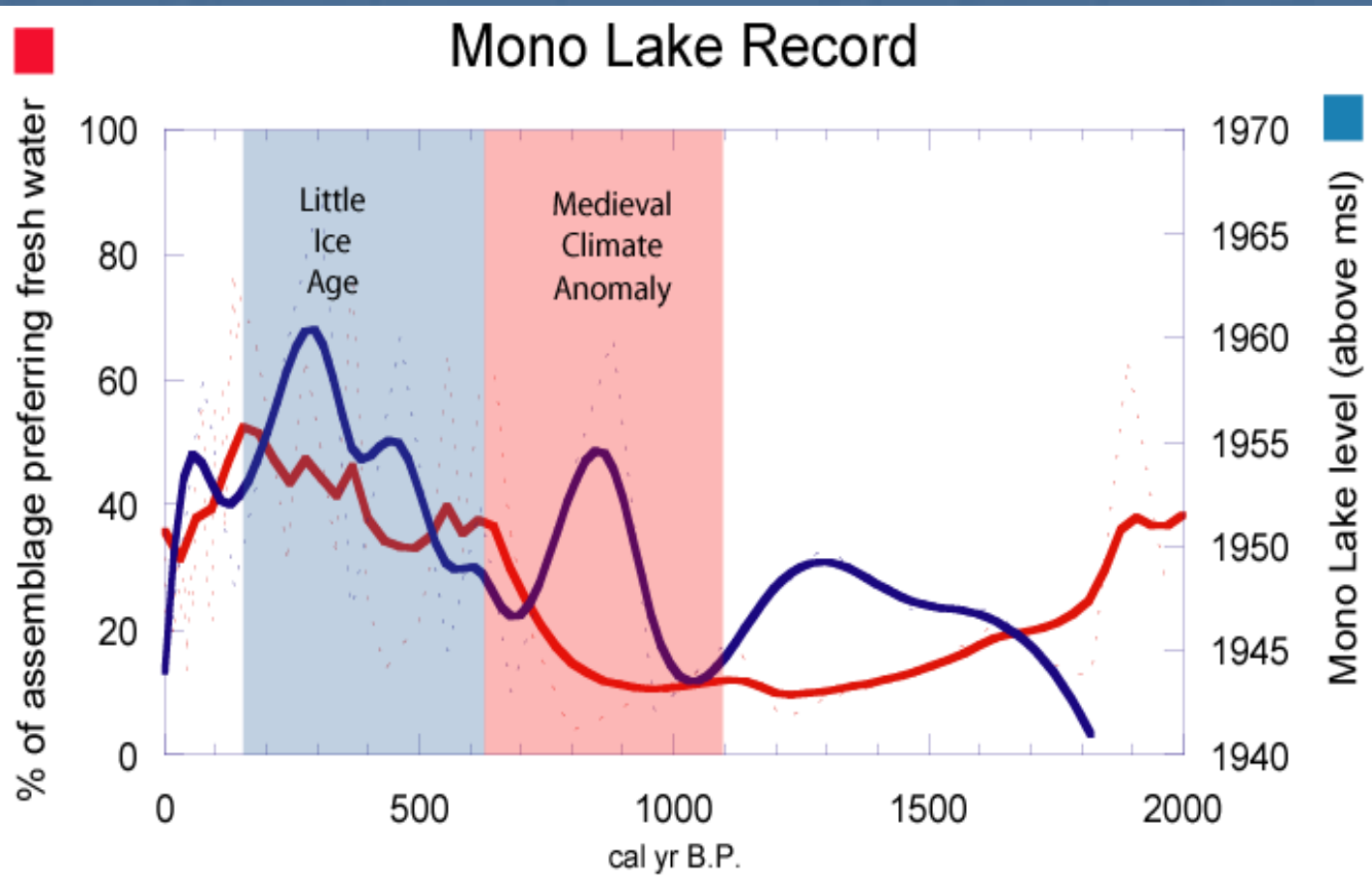

Mono Lake, California record of reconstructed lake levels (blue line; Stine, 1990, red line is the smoothed curve for the freshwater assemblage).

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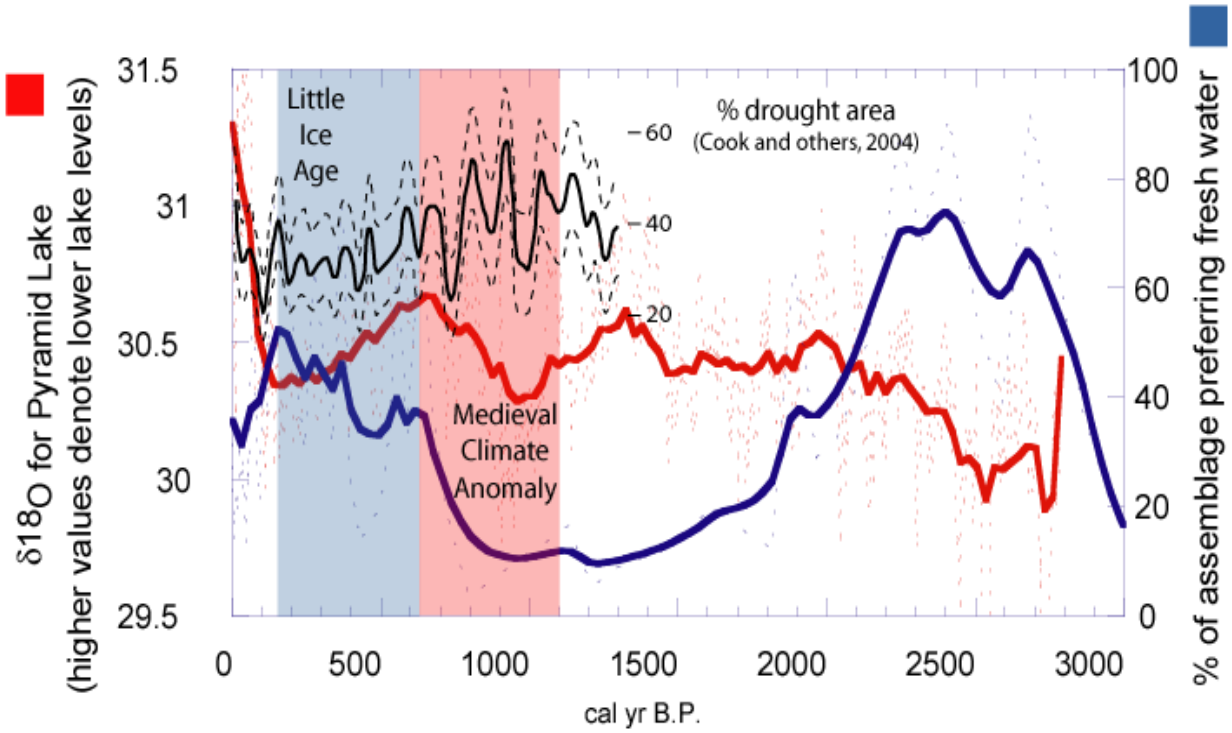
Pyramid Lake Record



δ^{18} O data for Pyramid Lake, NV (red line; Benson and others, 2002, blue line is the smoothed curve for the freshwater assemblage). Higher δ^{18} O values indicate lower lake level due to both decreased freshwater inflow and increased evaporation.

CONCLUSION

- Climate records can be obtained from marsh ecosystems using diatoms,

  BUT . . .

  - Detailed knowledge of the modern ecological controls is necessary
  - High diversity requires detailed taxonomic analysis

FUTURE RESEARCH

- Calibration studies at sites throughout San Francisco Bay and the Sacramento Delta
- Additional down core studies
- Method can be applied to salt marsh restoration projects

Pacific Climate Workshop (PACLIM)

"Marine-Terrestrial Connections – Seasonal Variability to Millennial Records"

April 19-22, 2009 (Sunday-Wednesday)
Asilomar Conference Grounds
Pacific Grove, California

Abstract and Registration Deadline February 15

sstarrat@usgs.gov

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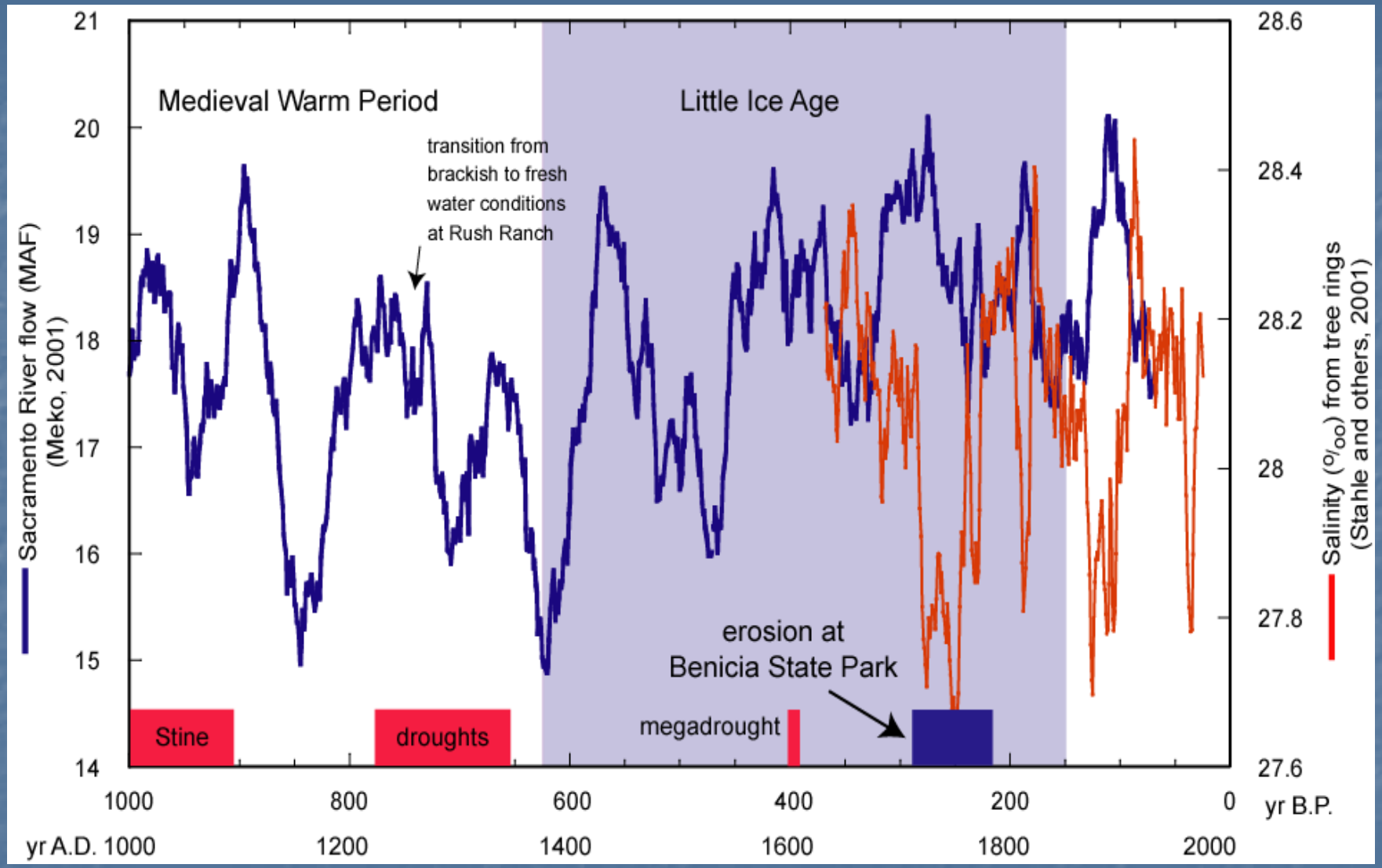

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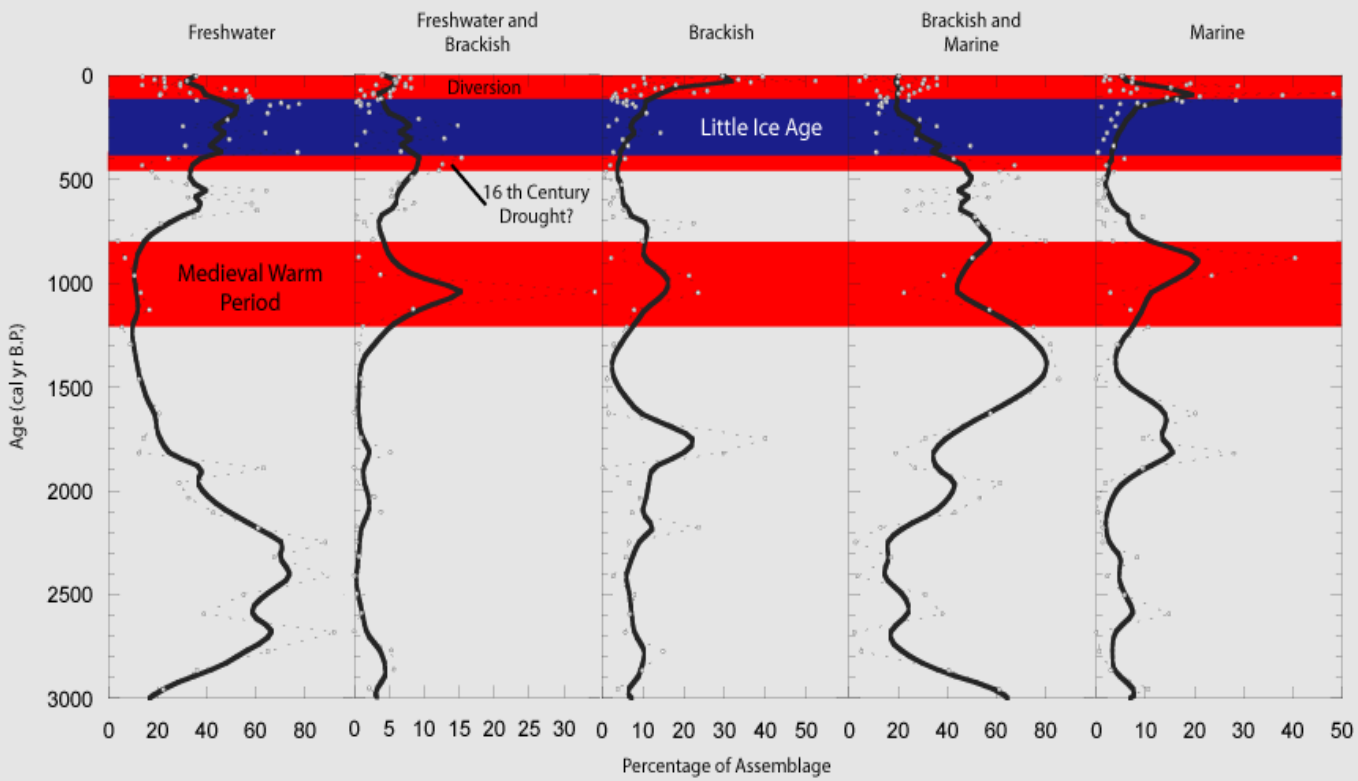

Temporal variation of the five diatom assemblages found at Rush Ranch. Black line represents curve fit using Stineman function (+10% data range). Shaded areas represent historically documented climatic intervals Medieval Warm Period, 16th century megadrought?, Little Ice Age, modern interval of diversion).

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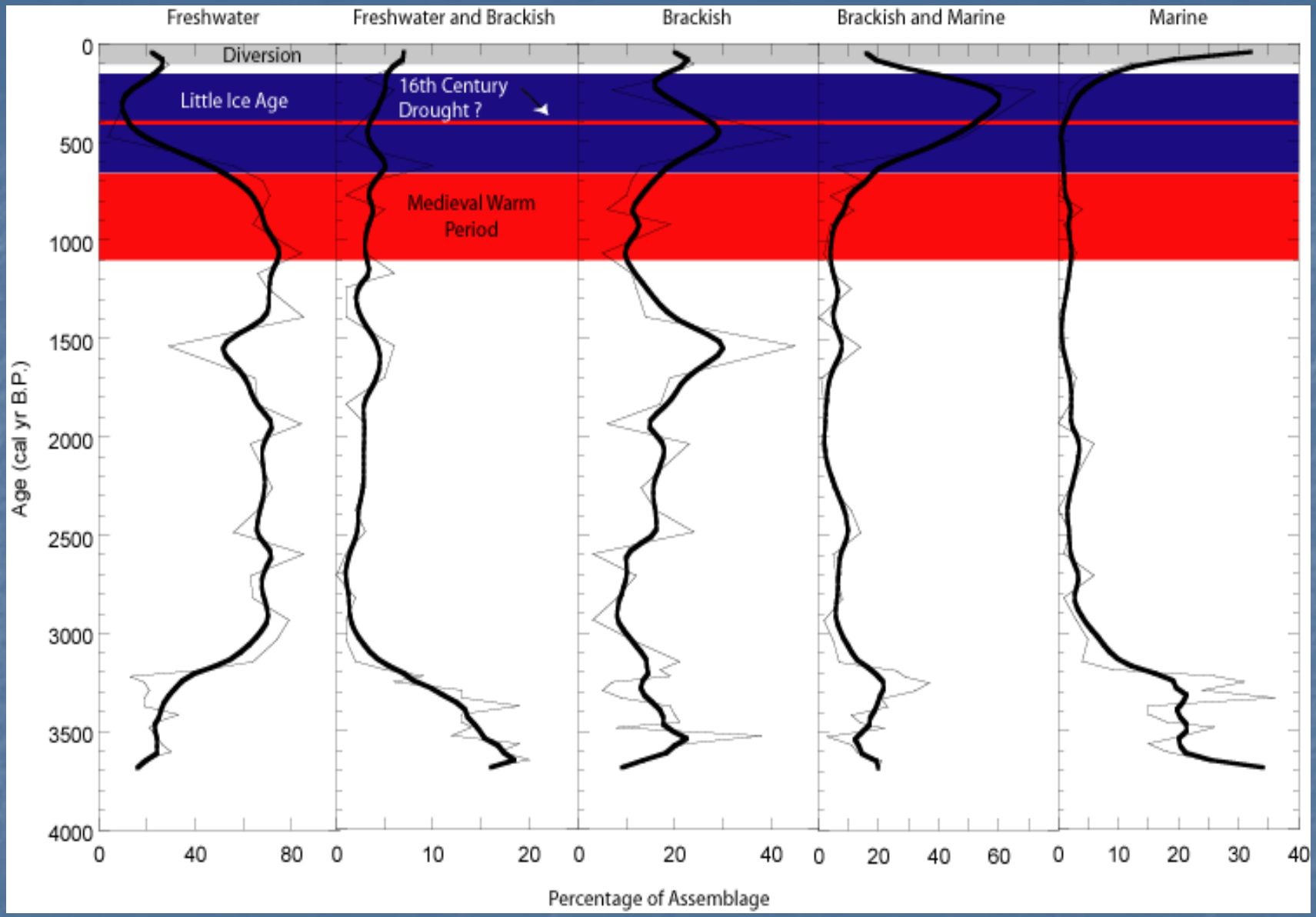

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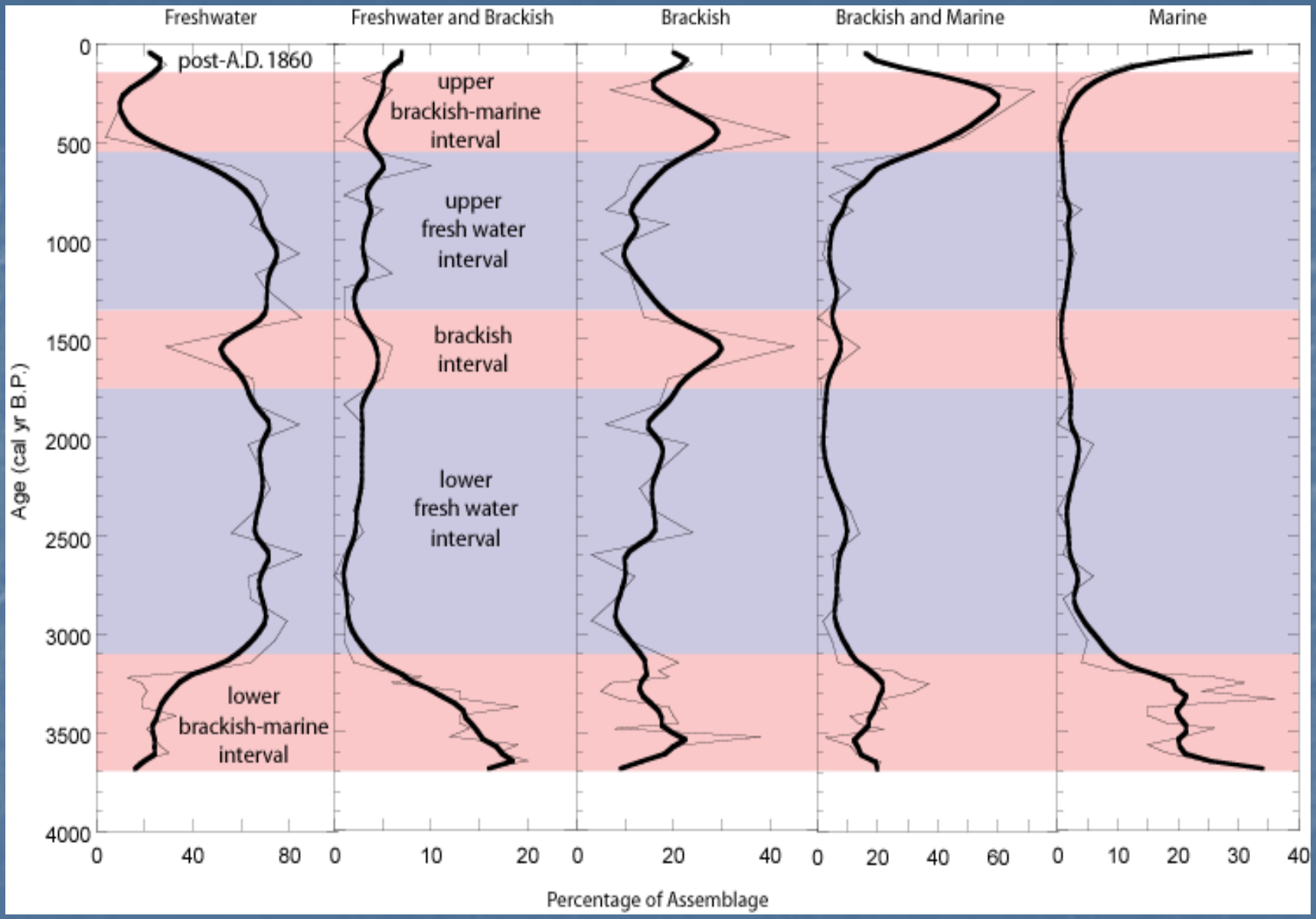

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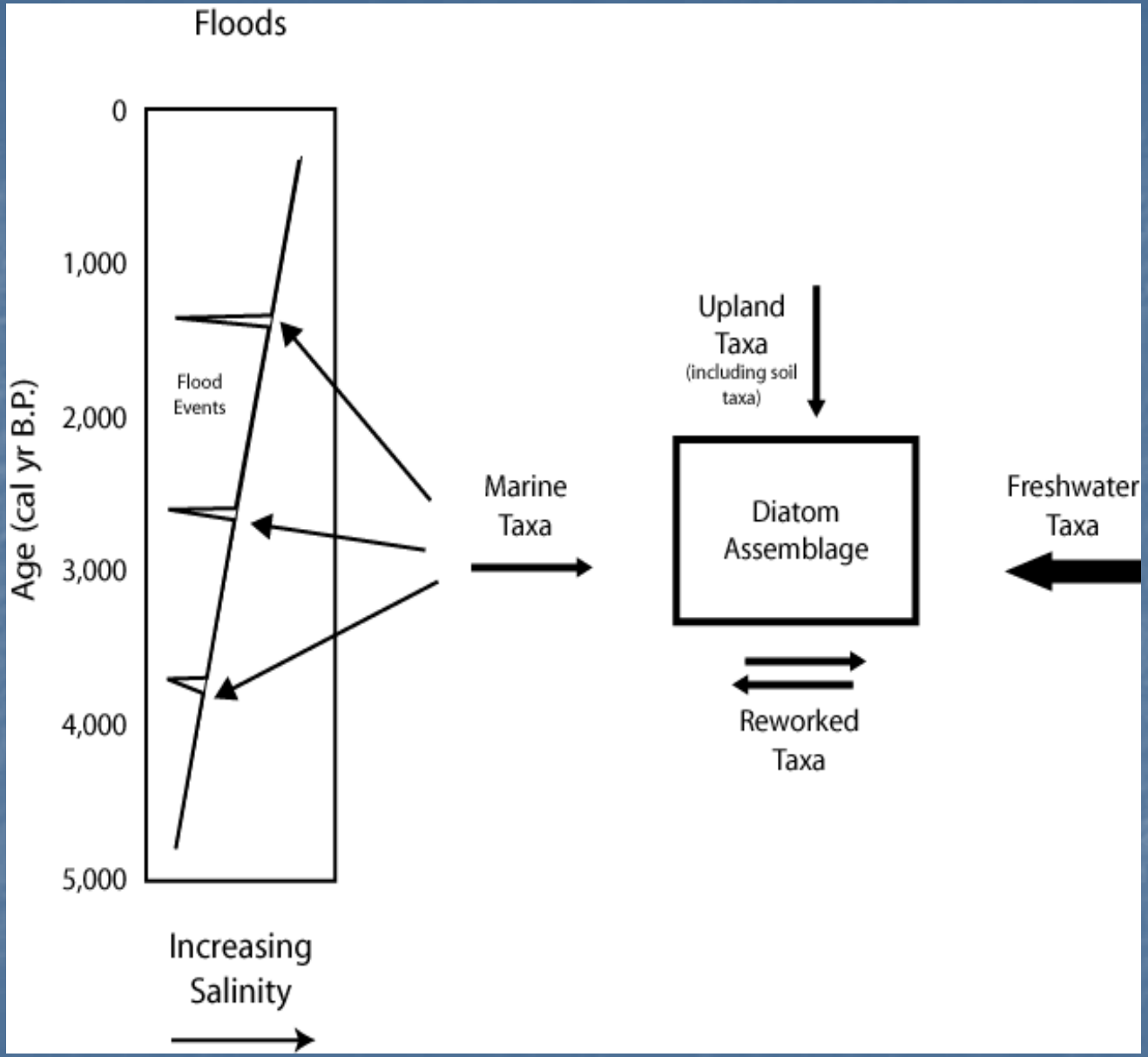
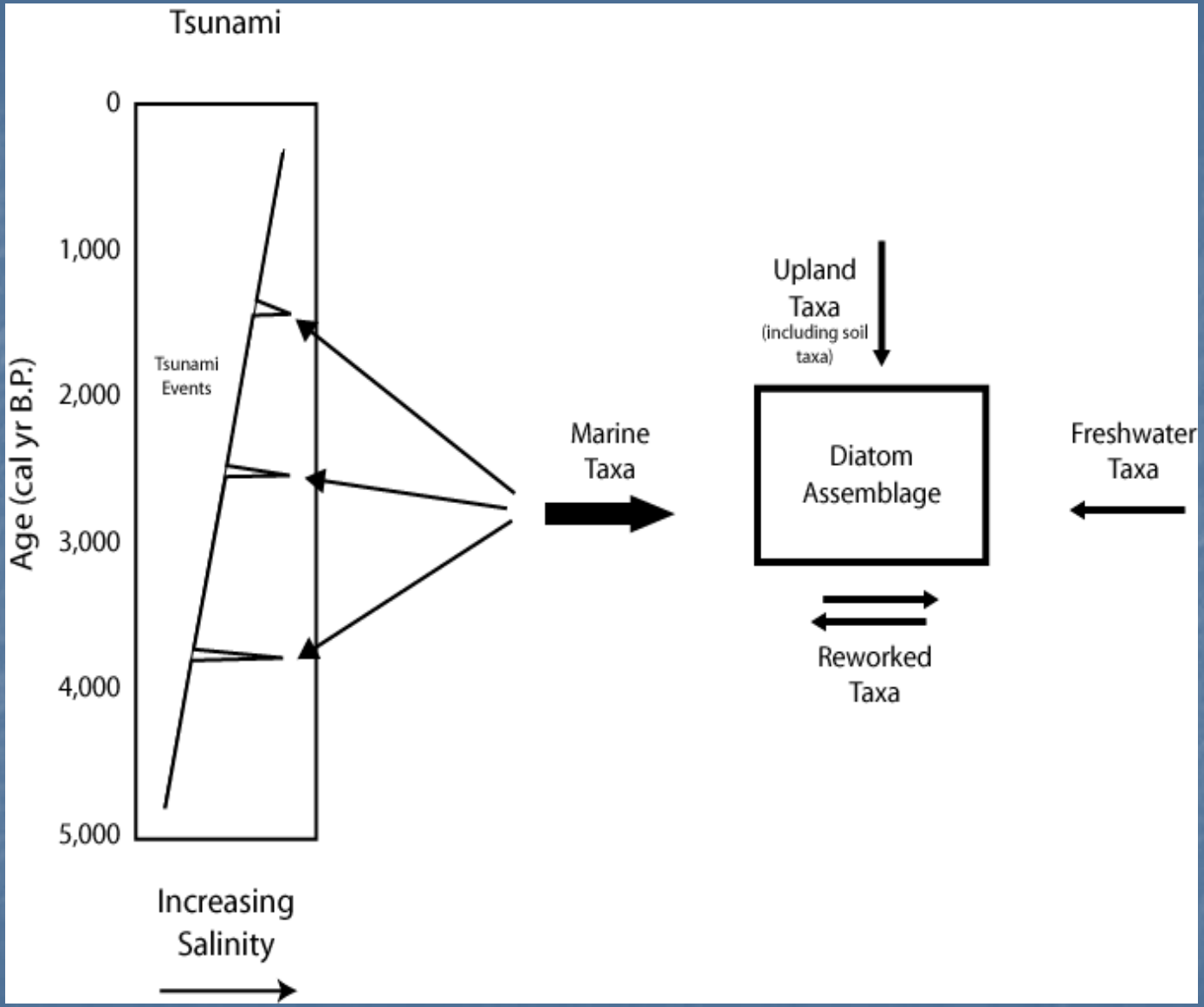
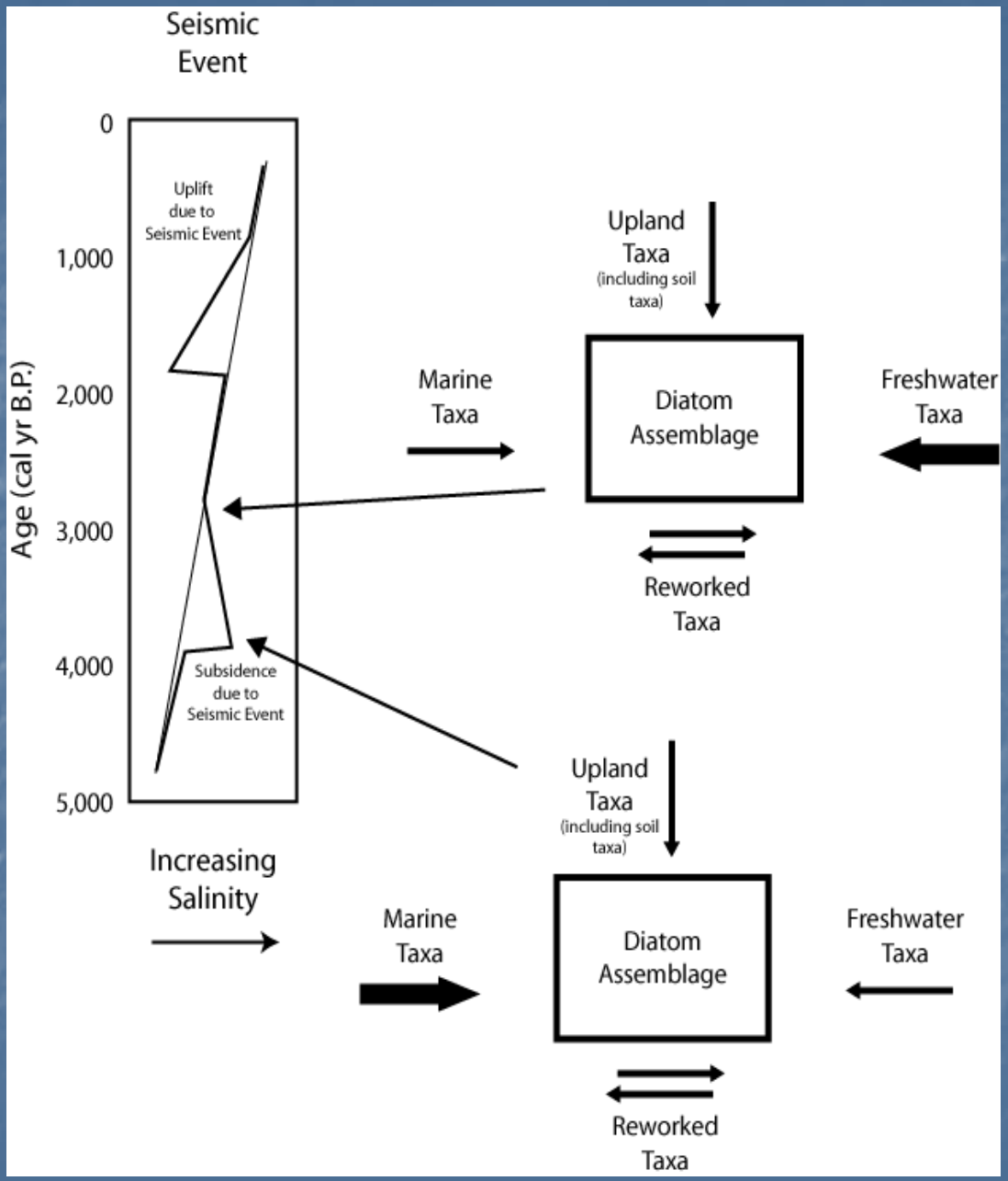

Floods
0
1,000
2,000
3,000
4,000
5,000
Age (cal yr B.P.)
Flood Events
Increasing Salinity
Marine Taxa
Upland Taxa
(including soil taxa)
Diatom Assemblage
Freshwater Taxa
Reworked Taxa


Tsunami
0
1,000
2,000
3,000
4,000
5,000
Age (cal yr B.P.)
Tsunami Events
Increasing Salinity
Marine Taxa
Upland Taxa
(including soil taxa)
Diatom Assemblage
Freshwater Taxa
Reworked Taxa



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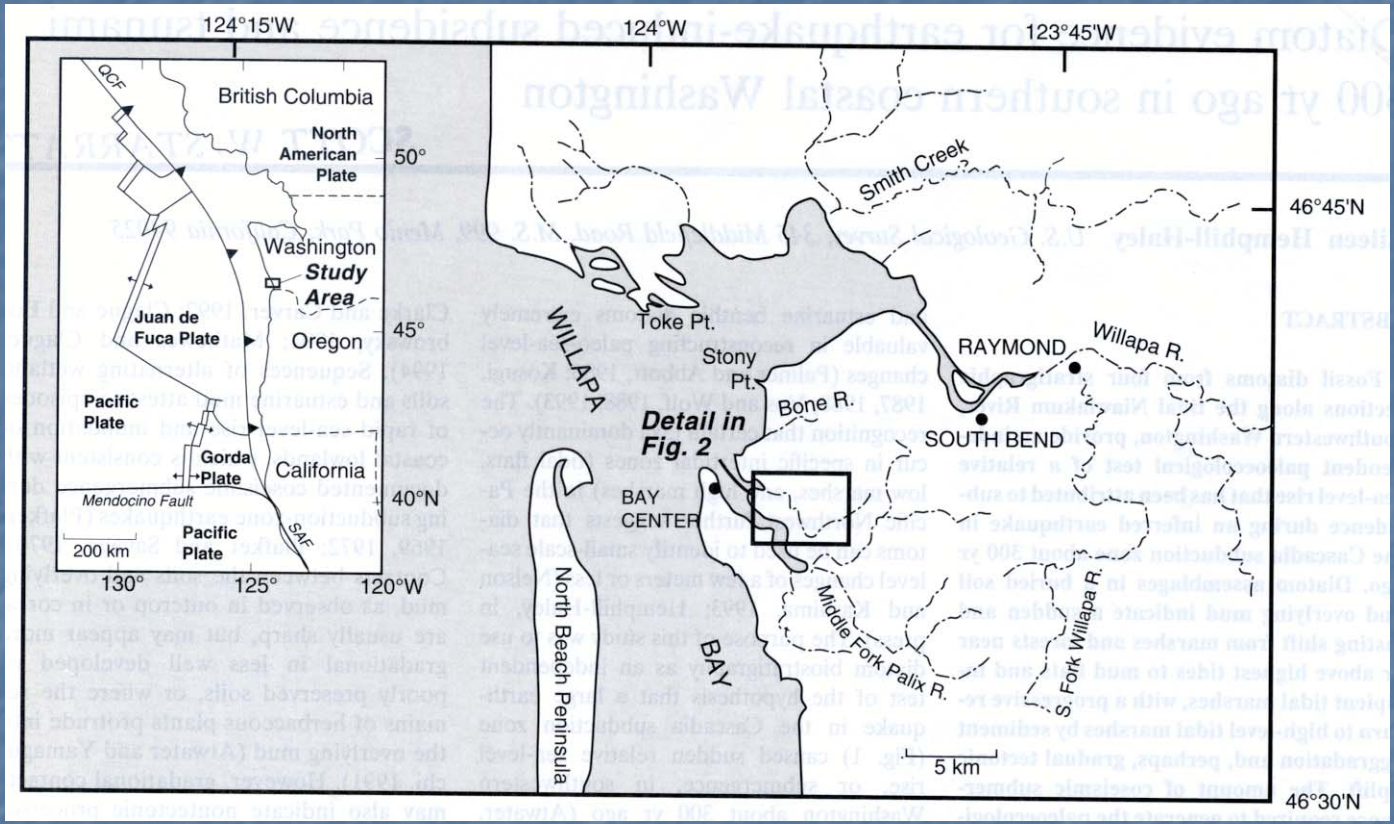
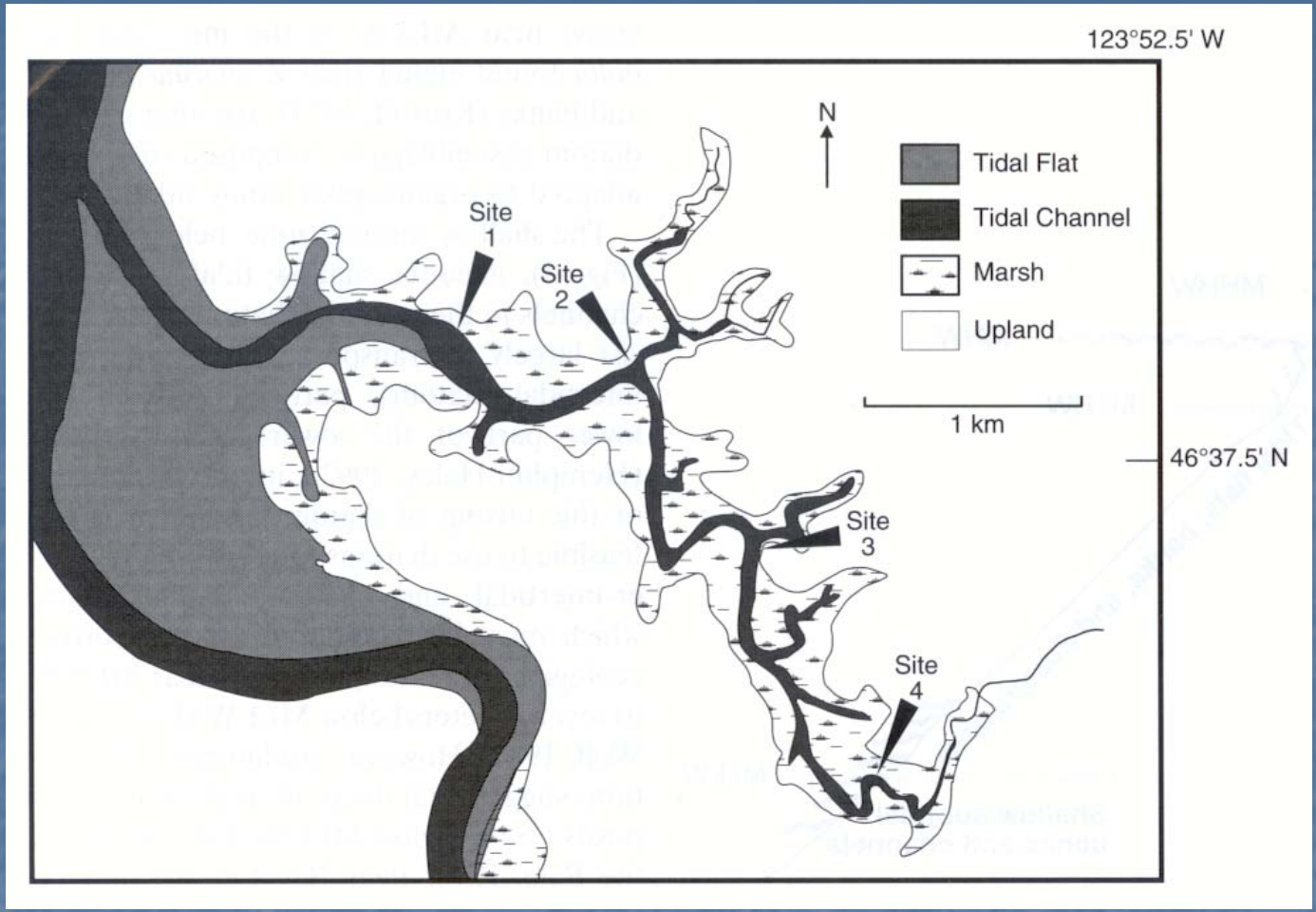
Thames Estuary, England

- Juggins (1992) used weighted-averaging to create a salinity transfer function
- Applications for seasonal variability and decadal temperature trends
- Evaluate Pleistocene sea level trends through changes in the diatom assemblages

Earthquakes and Tsunamis

- Hemphill-Haley (1992, 1995a, 1995b)
  - History of tsunami events in coastal Washington
  - Transects from intertidal zone to high marsh environments.
  - Diatom assemblages characterized and marsh, intertidal, and upland assemblages using principle components analysis


124°15'W
124°W
123°45'W
46°45'N
46°30'N
British Columbia
North American Plate
50°
Washington
Study Area
Juan de Fuca Plate
Oregon
45°
Pacific Plate
Gorda Plate
California
40°N
Mendocino Fault
200 km
Pacific Plate
QCF
SAF
130°
125°
120°W
Smith Creek
Toke Pt.
Stony Pt.
WILLAPA
BAY
Bone R.
Detail in Fig. 2
RAYMOND
Willapa R.
SOUTH BEND
BAY CENTER
North Beach Peninsula
Middle Fork Palix R.
S. Fork Willapa R.
5 km



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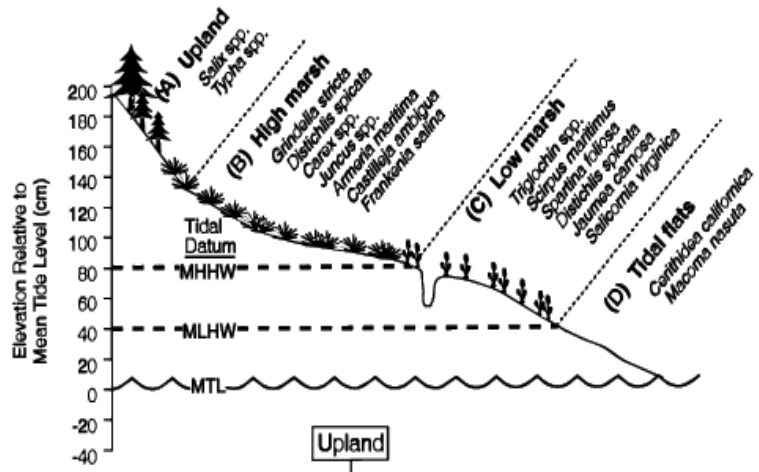


Upland

only rare transported diatoms and freshwater species, in many cases barren

Intertidal marshes

High marsh

Cosmioneis pusilla
Denticula subtilis
Navicula tenelloides
Nitzschia brevissima
N. pusilla
N. terrestris
Pinnularia lagerstedtii
Tryblionella aerophila

High or low marsh

Caloneis bacillum
Diploneis pseudovalis
Frustulia vulgaris
Luticola mutica
Navicula cincta
Nitzschia commutata
N. fasciculata
Tryblionella debilis

Low marsh

Caloneis westii
Diploneis interrupta
D. smitthii* var. *rhombica
Frustulia linkei
Gyrosigma eximium
Mastogloia exigua
Navicula cryptotenella
Nitzschia bilobata
N. scapelliformis
Rhopalodia musculus
Scoliopleura tumida
Tryblionella navicularis

Intertidal flats and shallow subtidal channels

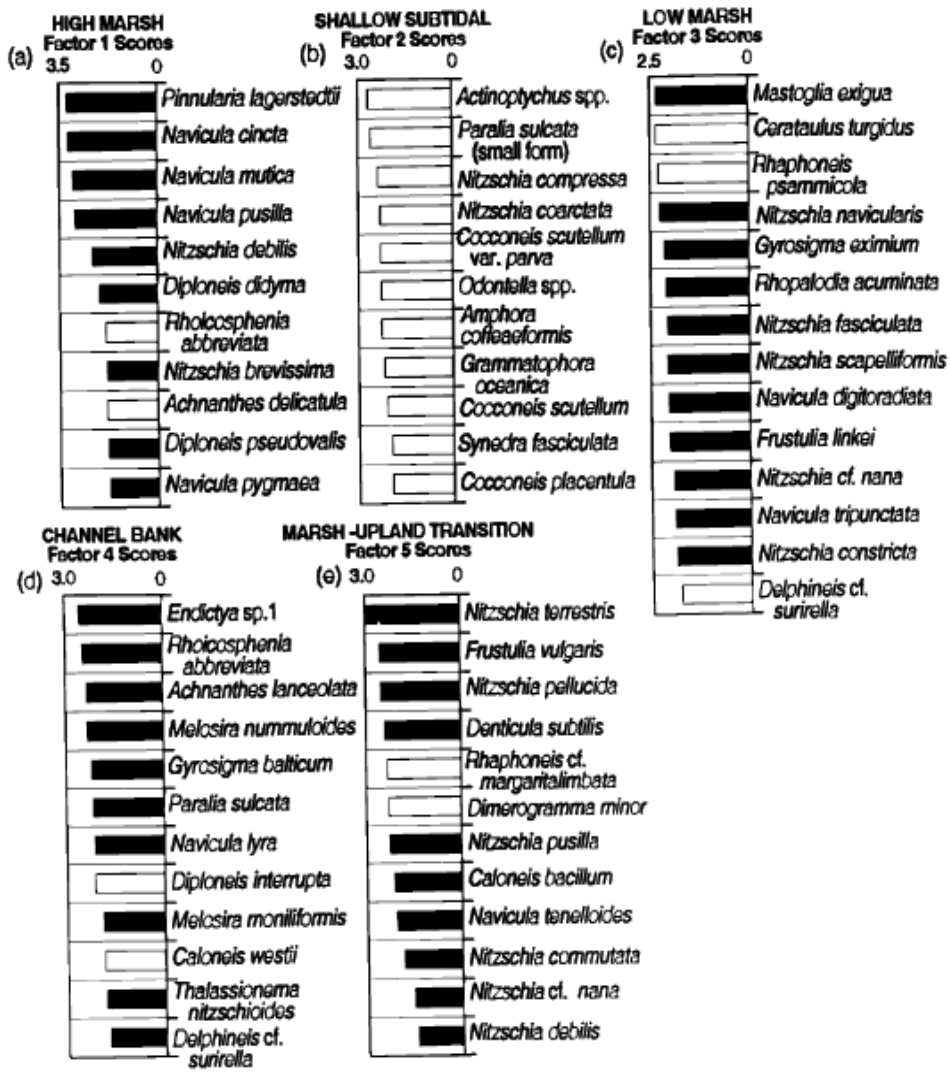
Mud

Bacillaria paradoxa
Camplyodiscus echinois
Catenula adhaerens
Cerataulus turgidus
Cocconeis scutellum* var. *parva
Gyrosigma balticum
Melosira nummuloides
Navicula digitoradiata
Navicula tripunctata
Nitzchia sigma
N. socialis
Odontella aurita
Opephora parva
Rhaphoneis amphicoros
R. psammicola
Synedra fasciculata
Plagiogramma staurophorum
Trachyneis aspera
Tryblionella acuminata
T. coarctata
T. punctata

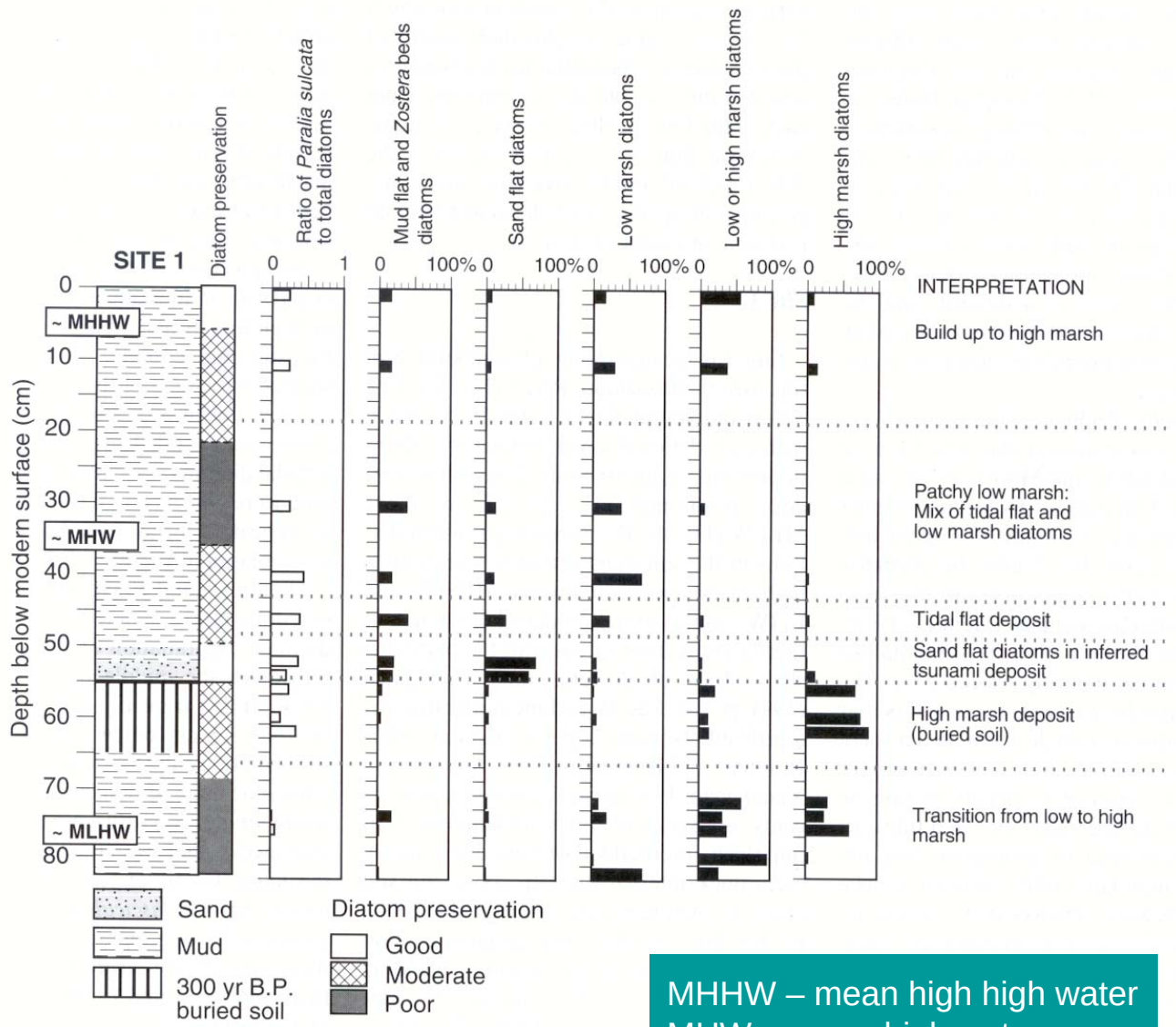
Sand

Achnanthes delicatula
Amphora proteus
A. ventricosa
Cocconeis diminuta
C. peltoides
Dimeregramma minor
Fallacia cryptolyra
Lyrolla lyra
Navicula cancellata
Petroneis granulata
P. marina
Trachyneis australis

USGS



USGS
science for a changing world



MHHW – mean high high water
MHW – mean high water
MLHW – mean low high water

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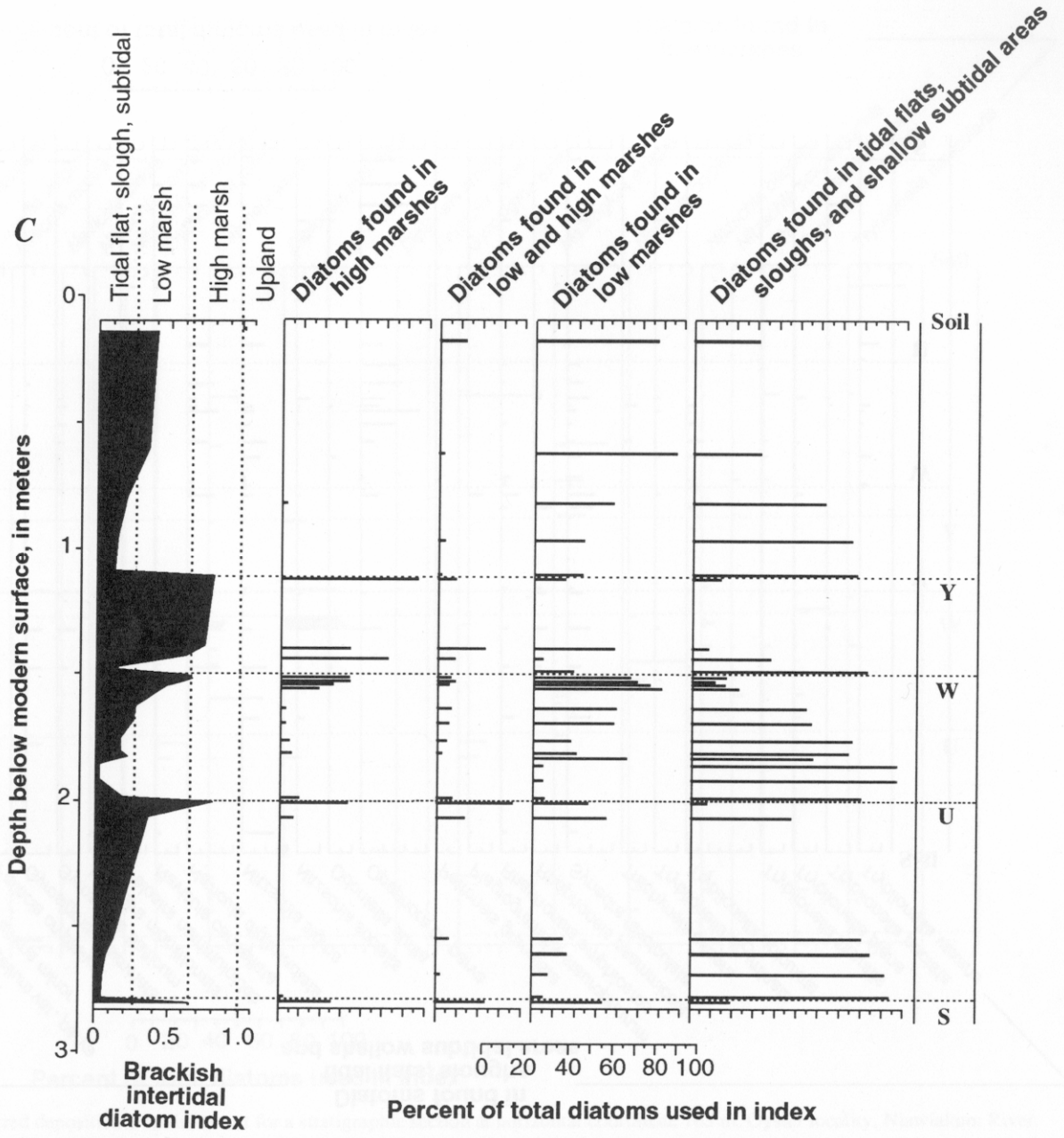
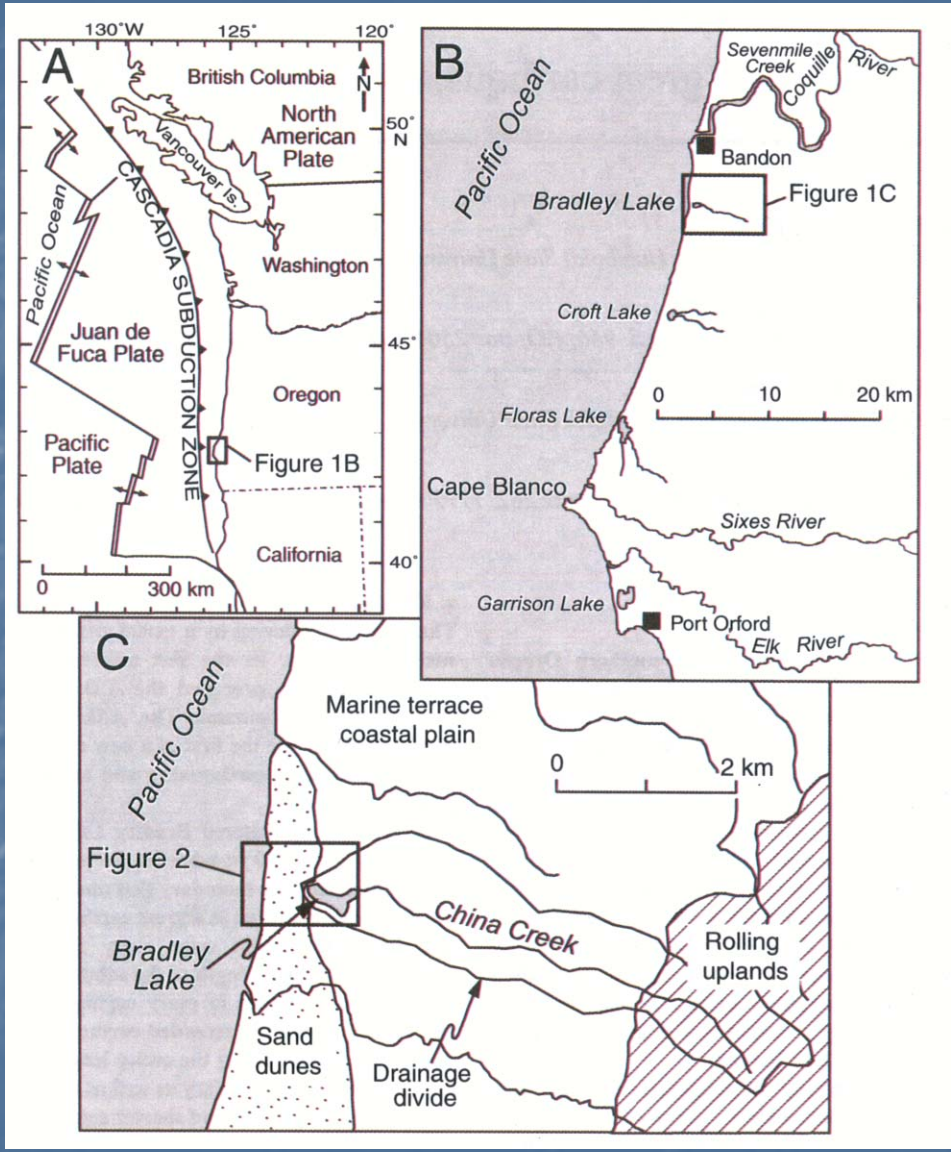


Brackish intertidal diatom index simplifies presentation of changes in sea level



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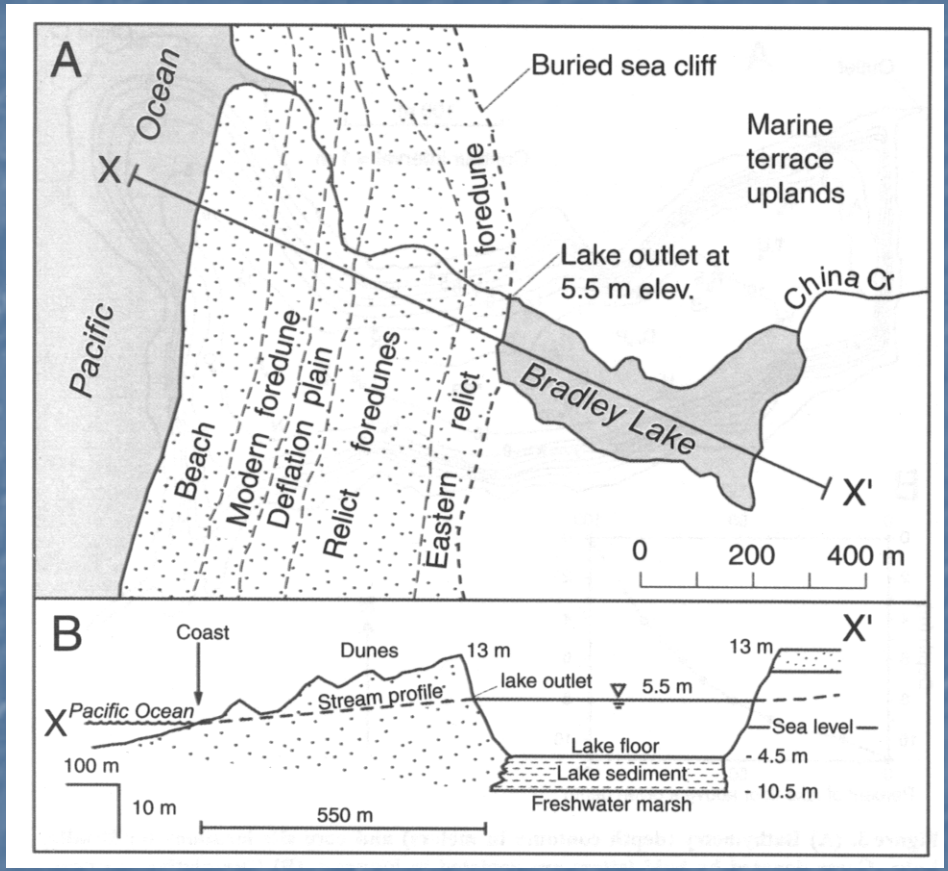
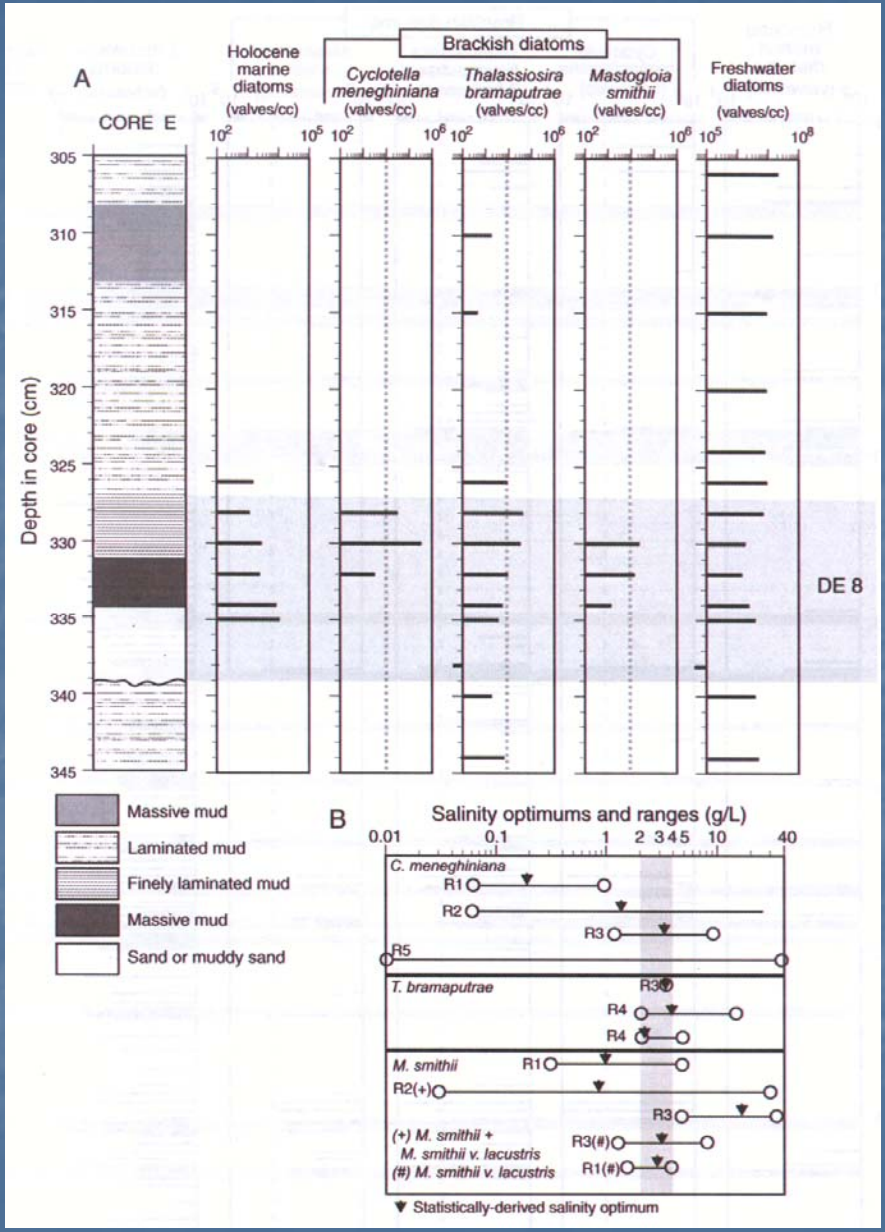
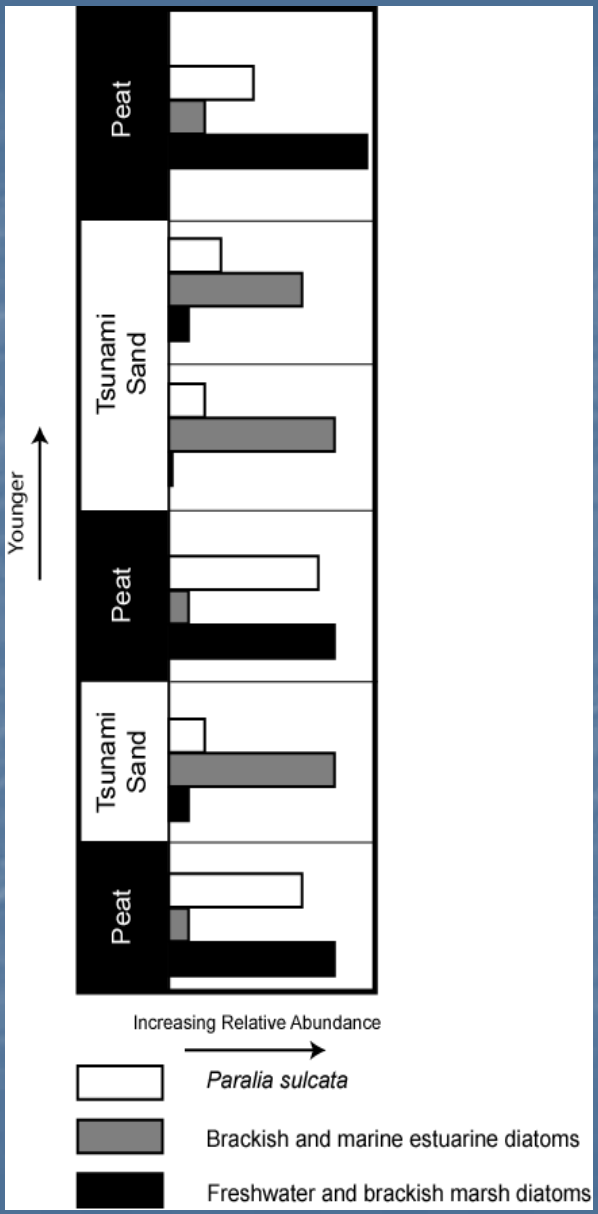

A
Pacific Ocean
X
Buried sea cliff
Marine terrace uplands
Lake outlet at 5.5 m elev.
China Cr
Bradley Lake
X'
Beach
Modern foredune
Deflation plain
Relict foredunes
Eastern relict foredune
0
200
400 m
B
Coast
Dunes
13 m
13 m
X'
X
Pacific Ocean
Stream profile
lake outlet
5.5 m
Sea level
Lake floor
- 4.5 m
Lake sediment
- 10.5 m
Freshwater marsh
100 m
10 m
550 m



USGS
science for a changing world



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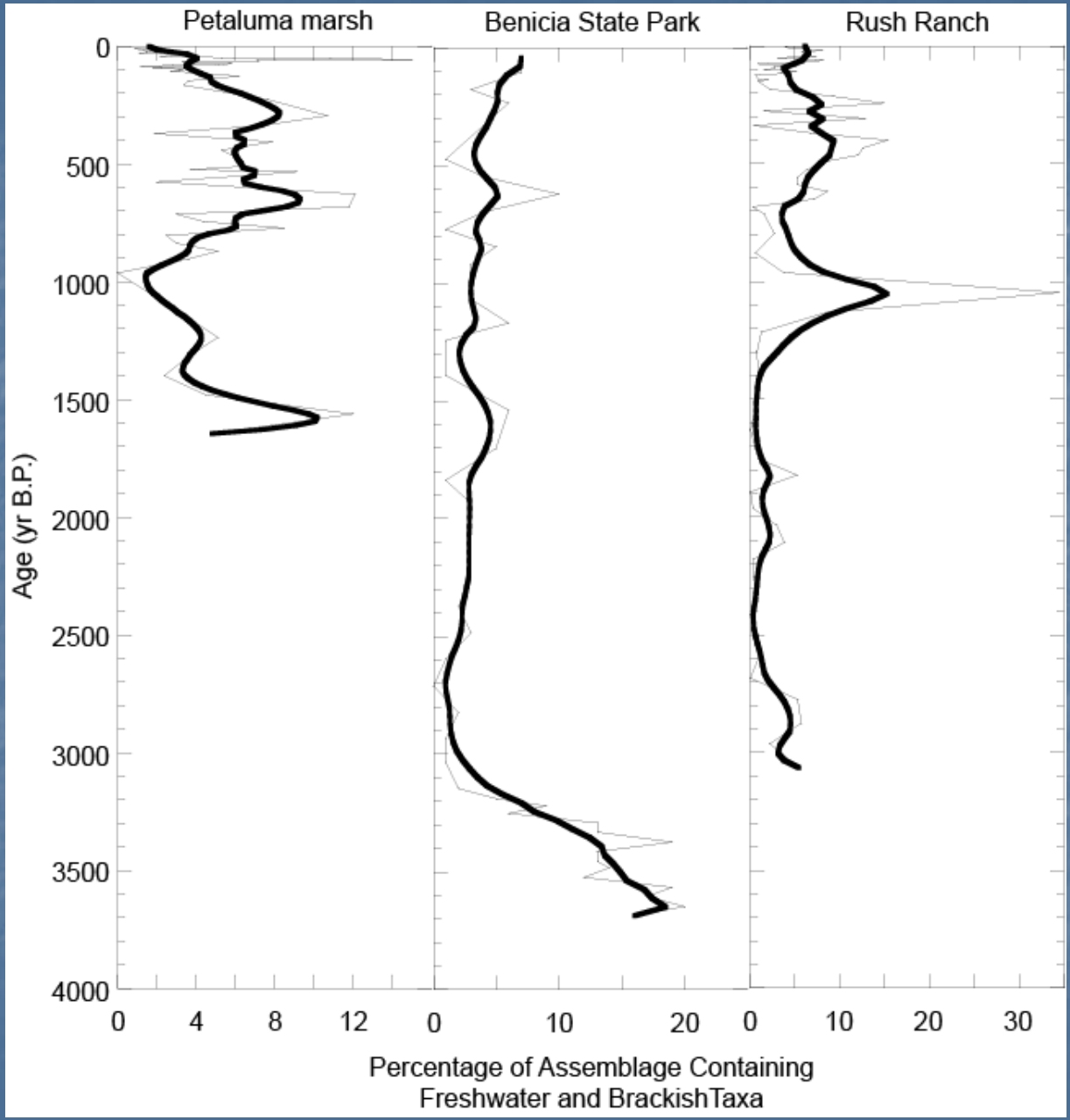
EXAMPLES

- Calibration sets
- Sea level reconstructions on a passive margin
- Evidence of earthquakes and tsunamis on an active margin
- Climate-controlled variations in freshwater flow



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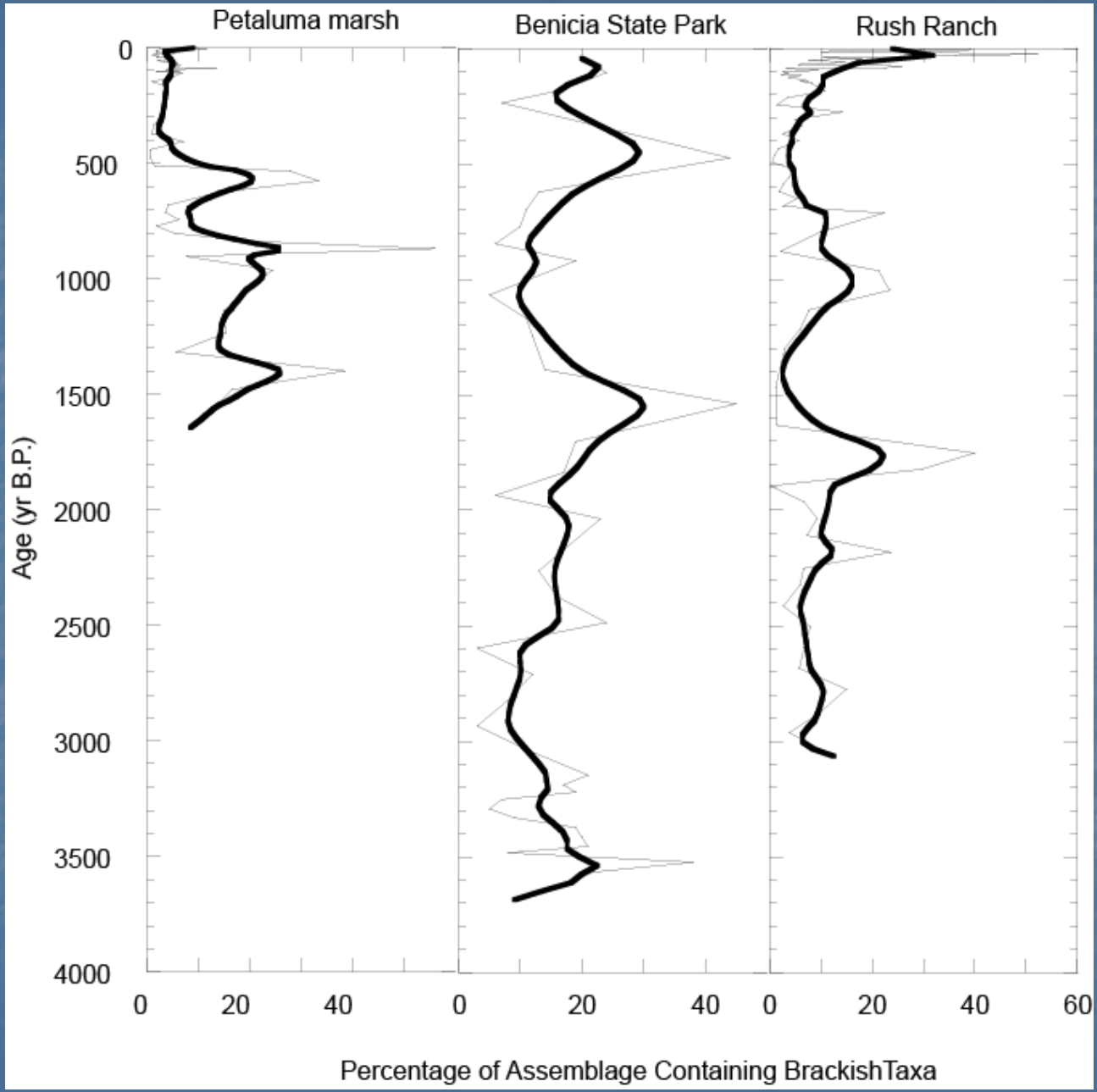

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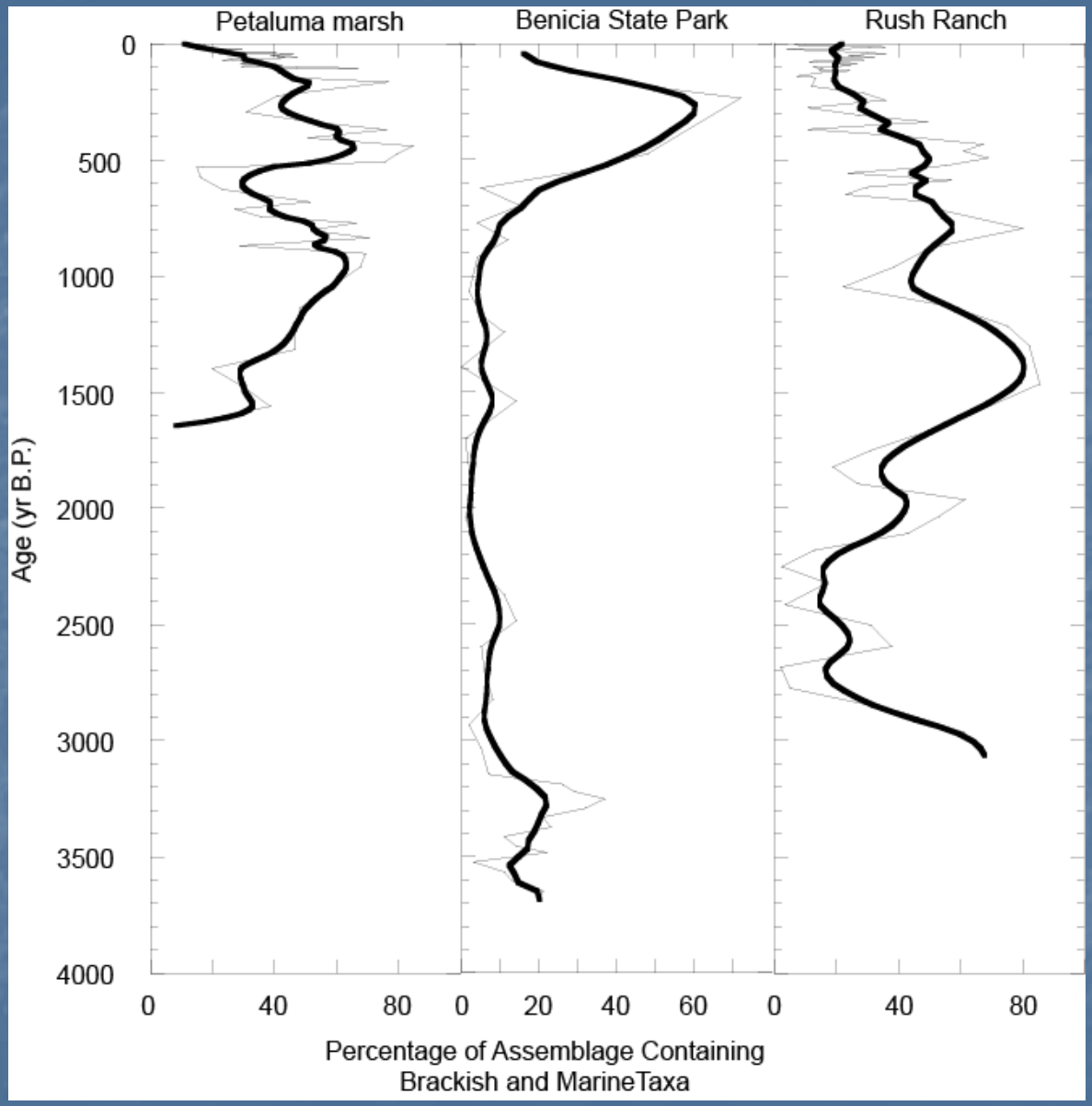

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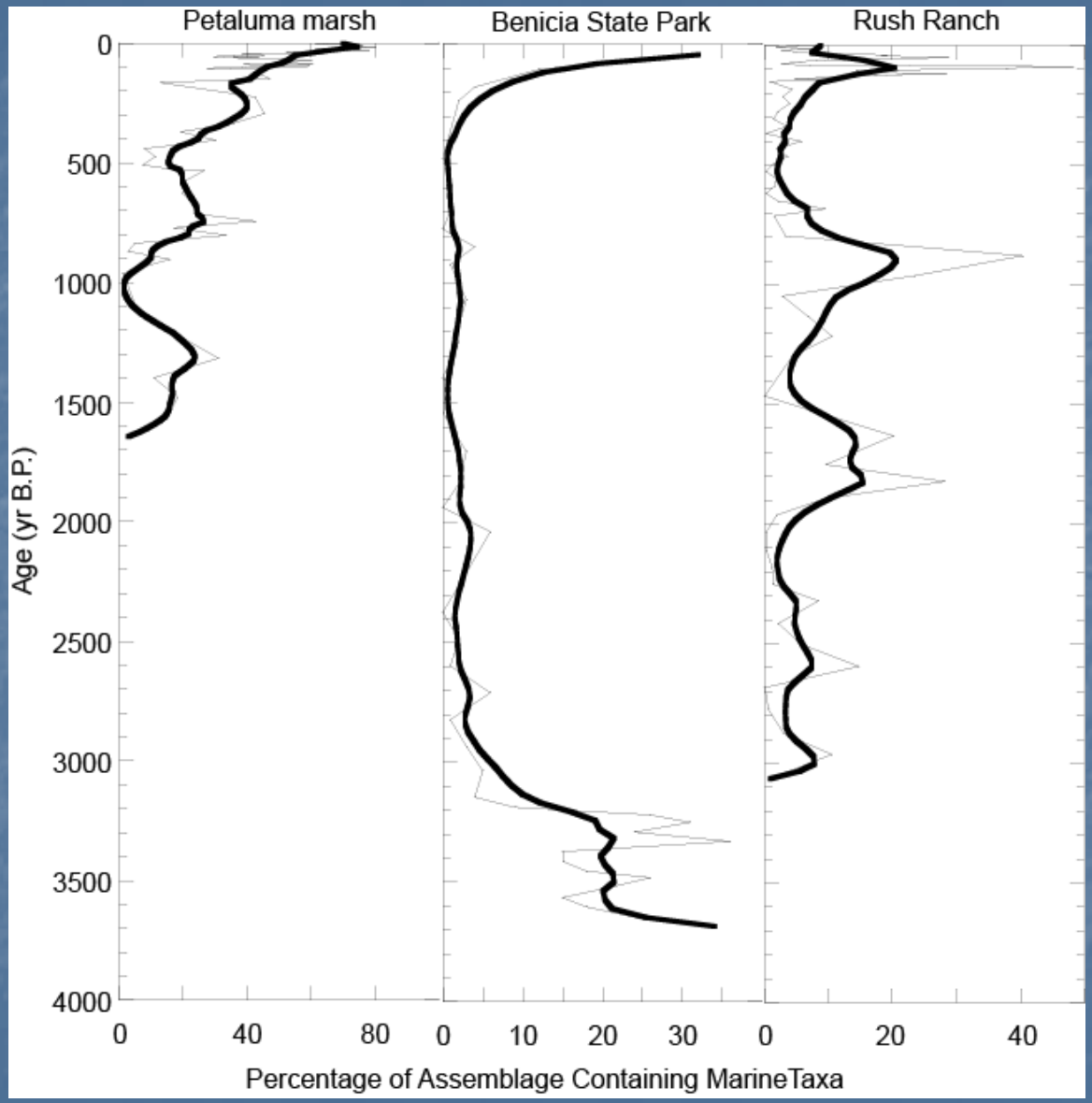

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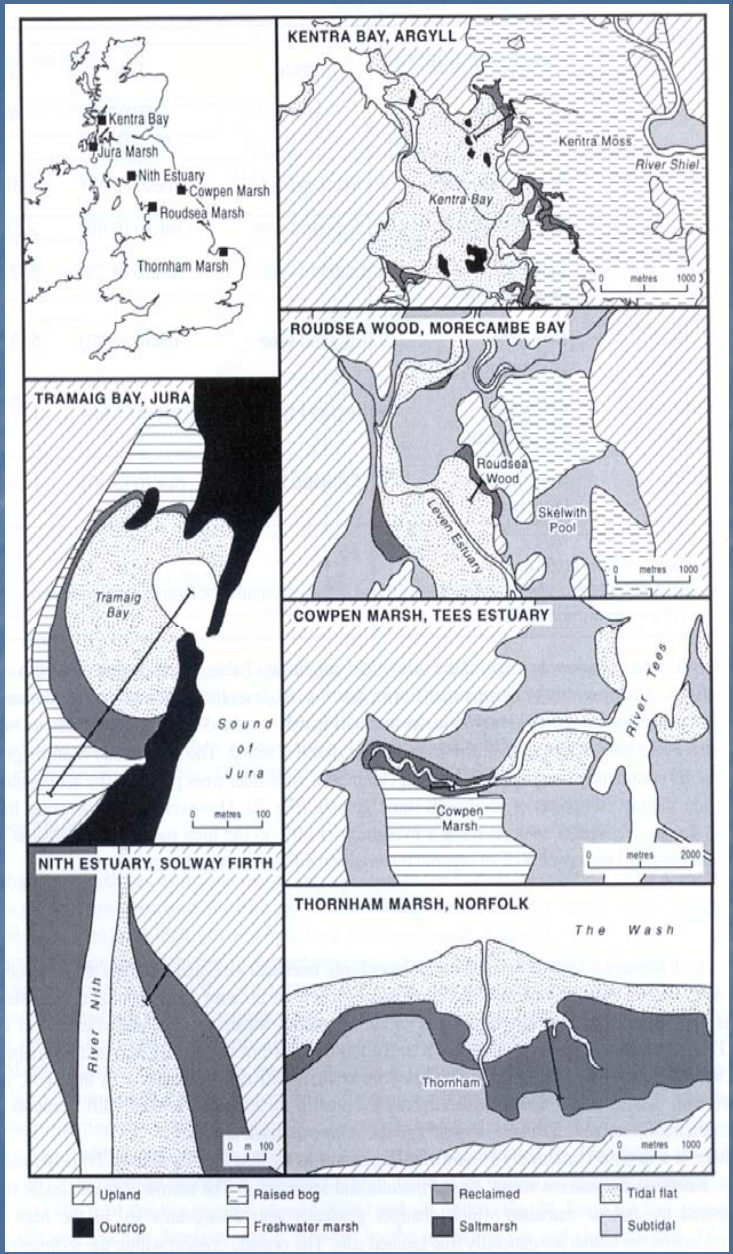
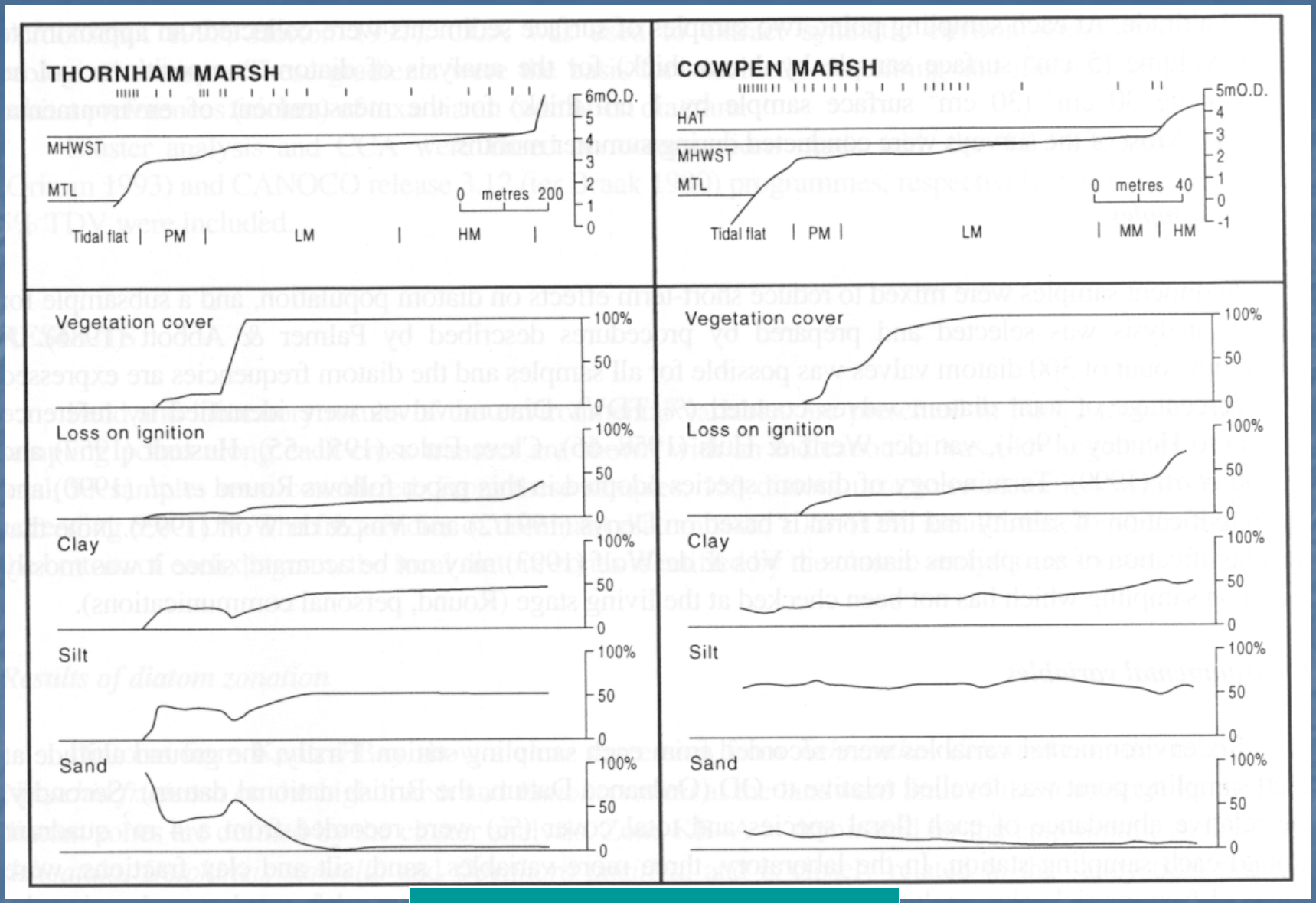
ENVIRONMENTAL PARAMETERS IN MARSHES AND ESTUARIES

- Well understood
  - Salinity
  - Temperature
  - pH
- Poorly understood
  - Major nutrients (N, P, Si)
  - Minor nutrients (Fe, Cu, Mg, *etc.*)
  - Turbidity
  - Sediment type
  - Exposure
  - Oxygen levels

USGS


Kentra Bay
Jura Marsh
Nith Estuary
Cowpen Marsh
Roudsea Marsh
Thornham Marsh
KENTRA BAY, ARGYLL
Kentra Moss
River Shiel
Kentra Bay
0 metres 1000
ROUDSEA WOOD, MORECAMBE BAY
Roudsea Wood
Leven Estuary
Skelwith Pool
0 metres 1000
TRAMAIG BAY, JURA
Tramaig Bay
Sound of Jura
0 metres 100
COWPEN MARSH, TEES ESTUARY
River Tees
Cowpen Marsh
0 metres 2000
NITH ESTUARY, SOLWAY FIRTH
River Nith
0 m 100
THORNHAM MARSH, NORFOLK
The Wash
Thornham
0 metres 1000
Upland
Raised bog
Reclaimed
Tidal flat
Outcrop
Freshwater marsh
Saltmarsh
Subtidal

USGS

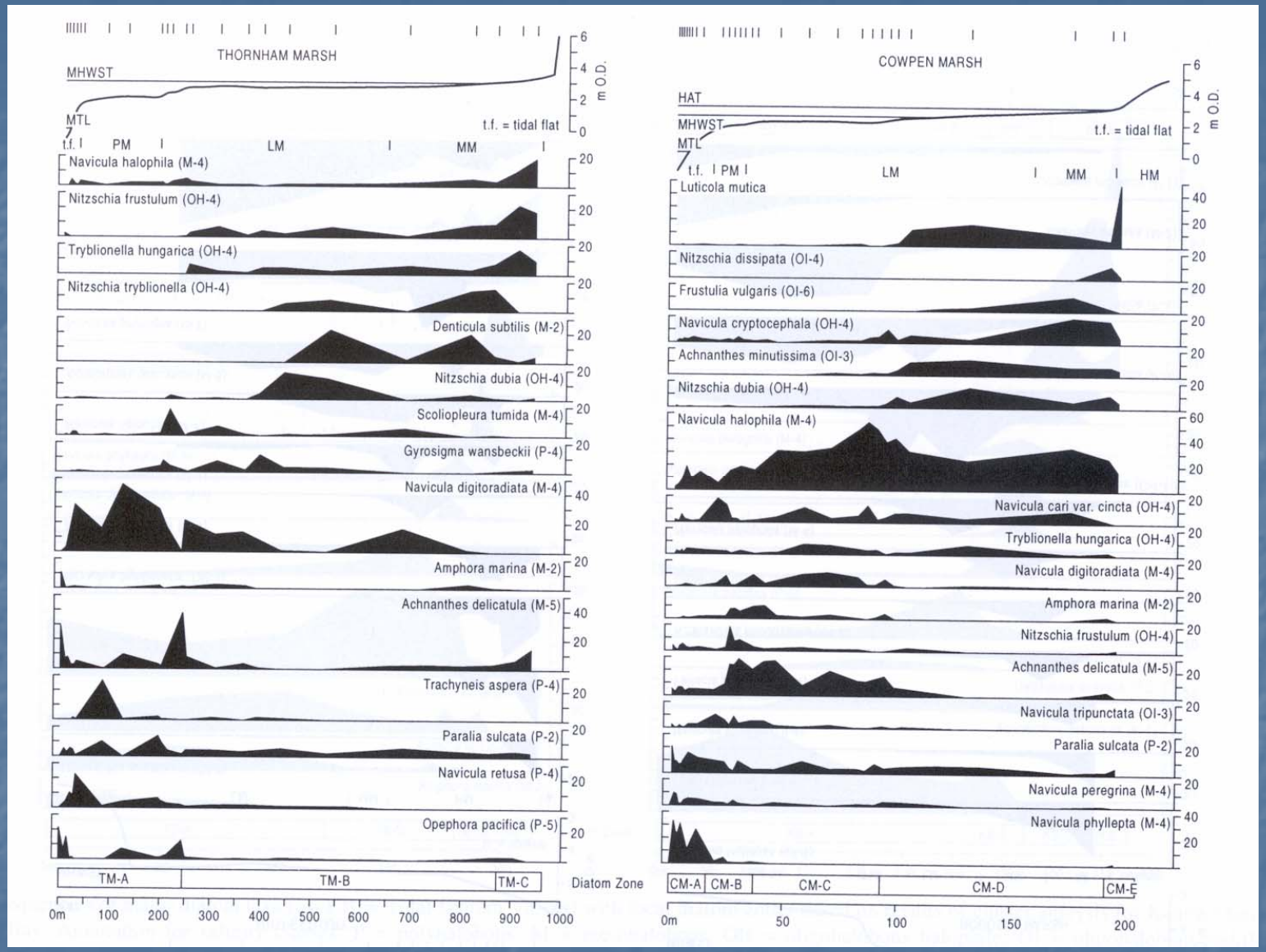


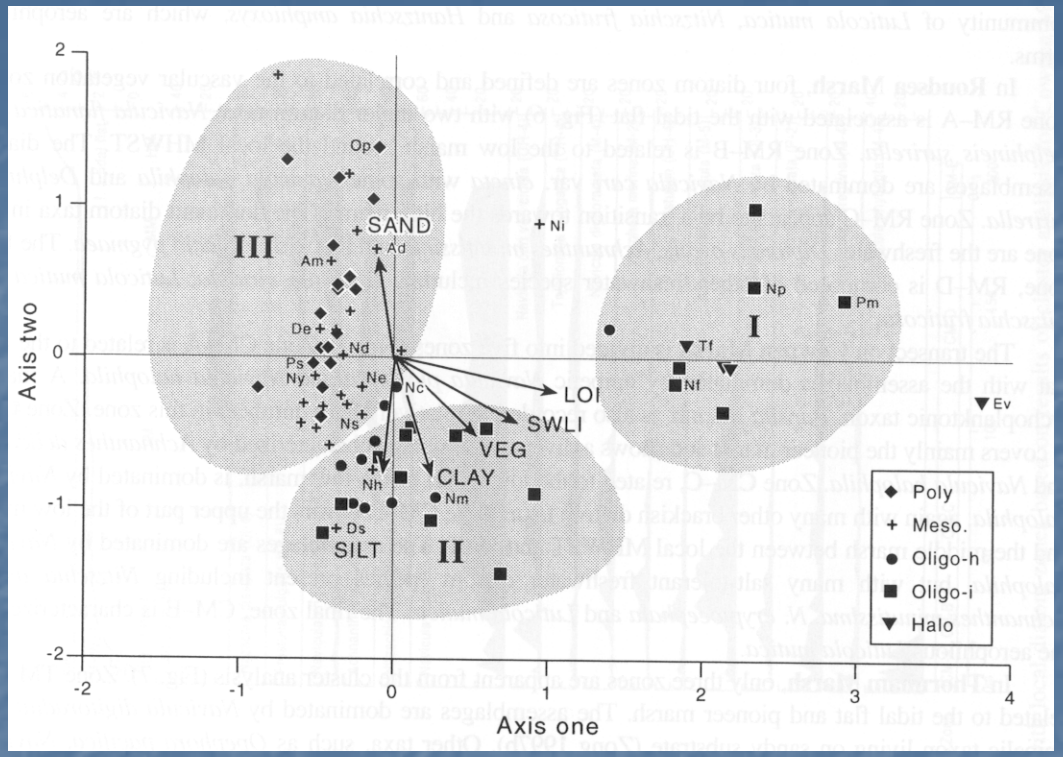
MHWST - mean high water of spring tides

MTL – mean tide level

HAT – highest astronomical tide

USGS


THORNHAM MARSH
MHWST
MTL
t.f. = tidal flat
m O.D.
t.f. PM LM MM
Navicula halophila (M-4)
Nitzschia frustulum (OH-4)
Tryblionella hungarica (OH-4)
Nitzschia tryblionella (OH-4)
Denticula subtilis (M-2)
Nitzschia dubia (OH-4)
Scoliopleura tumida (M-4)
Gyrosigma wansbeckii (P-4)
Navicula digitoradiata (M-4)
Amphora marina (M-2)
Achnanthes delicatula (M-5)
Trachyneis aspera (P-4)
Paralia sulcata (P-2)
Navicula retusa (P-4)
Opephora pacifica (P-5)
TM-A
TM-B
TM-C
Diatom Zone
0m 100 200 300 400 500 600 700 800 900 1000
COWPEN MARSH
HAT
MHWST
MTL
t.f. = tidal flat
m O.D.
t.f. PM LM MM HM
Luticola mutica
Nitzschia dissipata (OI-4)
Frustulia vulgaris (OI-6)
Navicula cryptocephala (OH-4)
Achnanthes minutissima (OI-3)
Nitzschia dubia (OH-4)
Navicula halophila (M-4)
Navicula cari var. cincta (OH-4)
Tryblionella hungarica (OH-4)
Navicula digitoradiata (M-4)
Amphora marina (M-2)
Nitzschia frustulum (OH-4)
Achnanthes delicatula (M-5)
Navicula tripunctata (OI-3)
Paralia sulcata (P-2)
Navicula peregrina (M-4)
Navicula phyllepta (M-4)
CM-A
CM-B
CM-C
CM-D
CM-E
0m 50 100 150 200

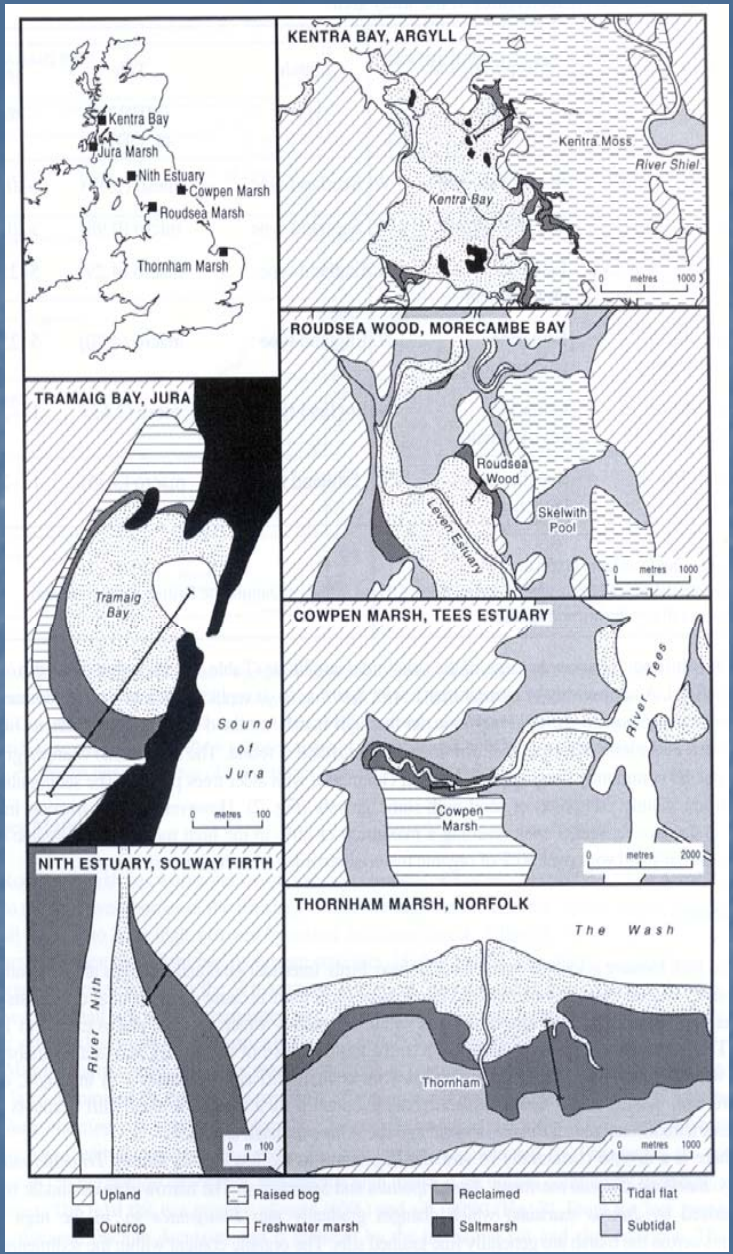


Canonical Correspondence Analysis identifies about 12.9% of the variance

I – High Marsh – dense vegetation, high organic content, short and low duration of tidal influence, oligohalobous indifferent and halophobous

II – Middle and low marsh – dense vegetation, low organic content, longer duration of tidal influence, oligohalobous indifferent, oligohalobous halophilous, and mesohalobous

III – tidal flat – sparse vegetation, inorganic substrate, polyhalobous and mesohalobous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Jura Marsh
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0 metres 1000
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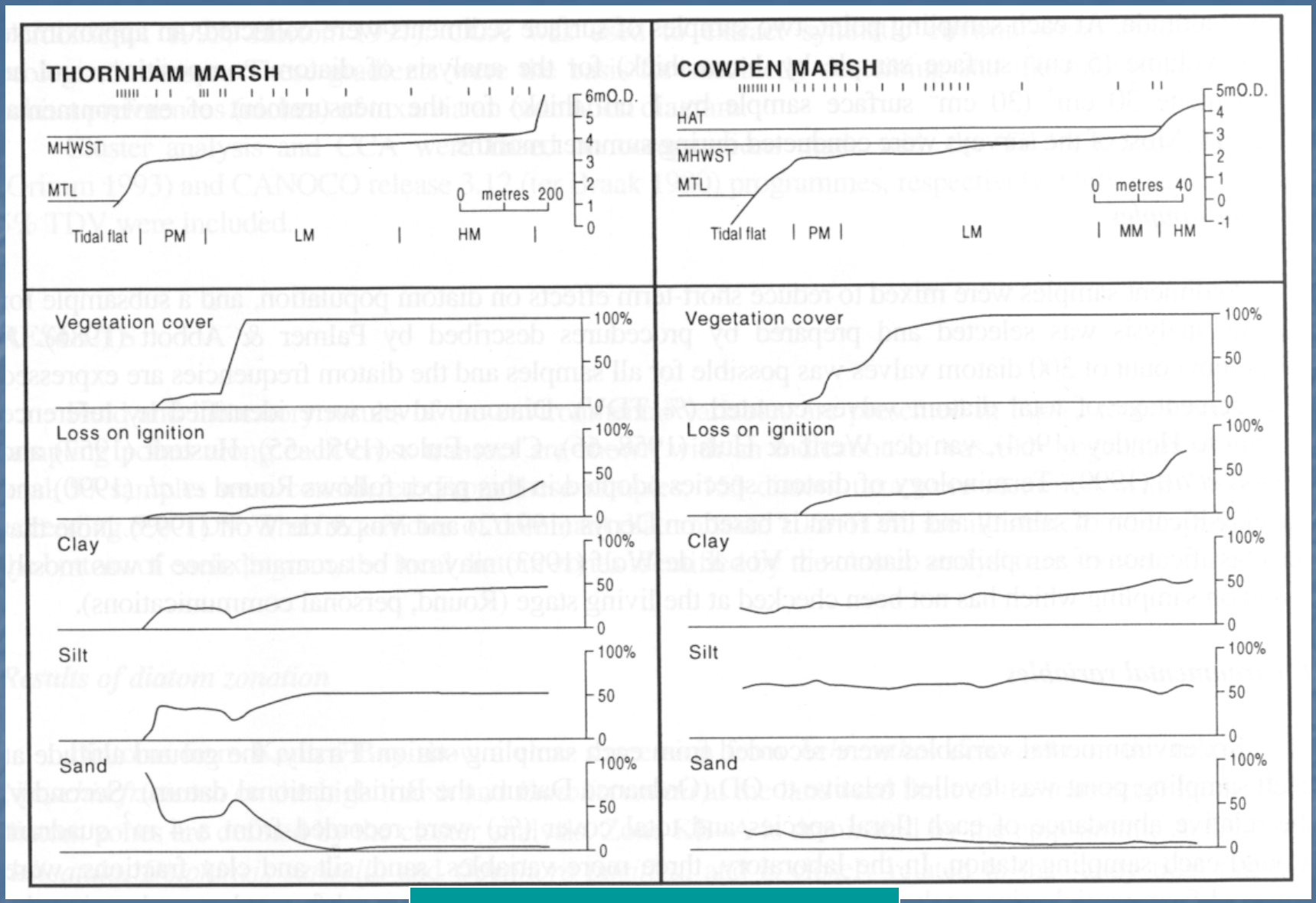
USGS



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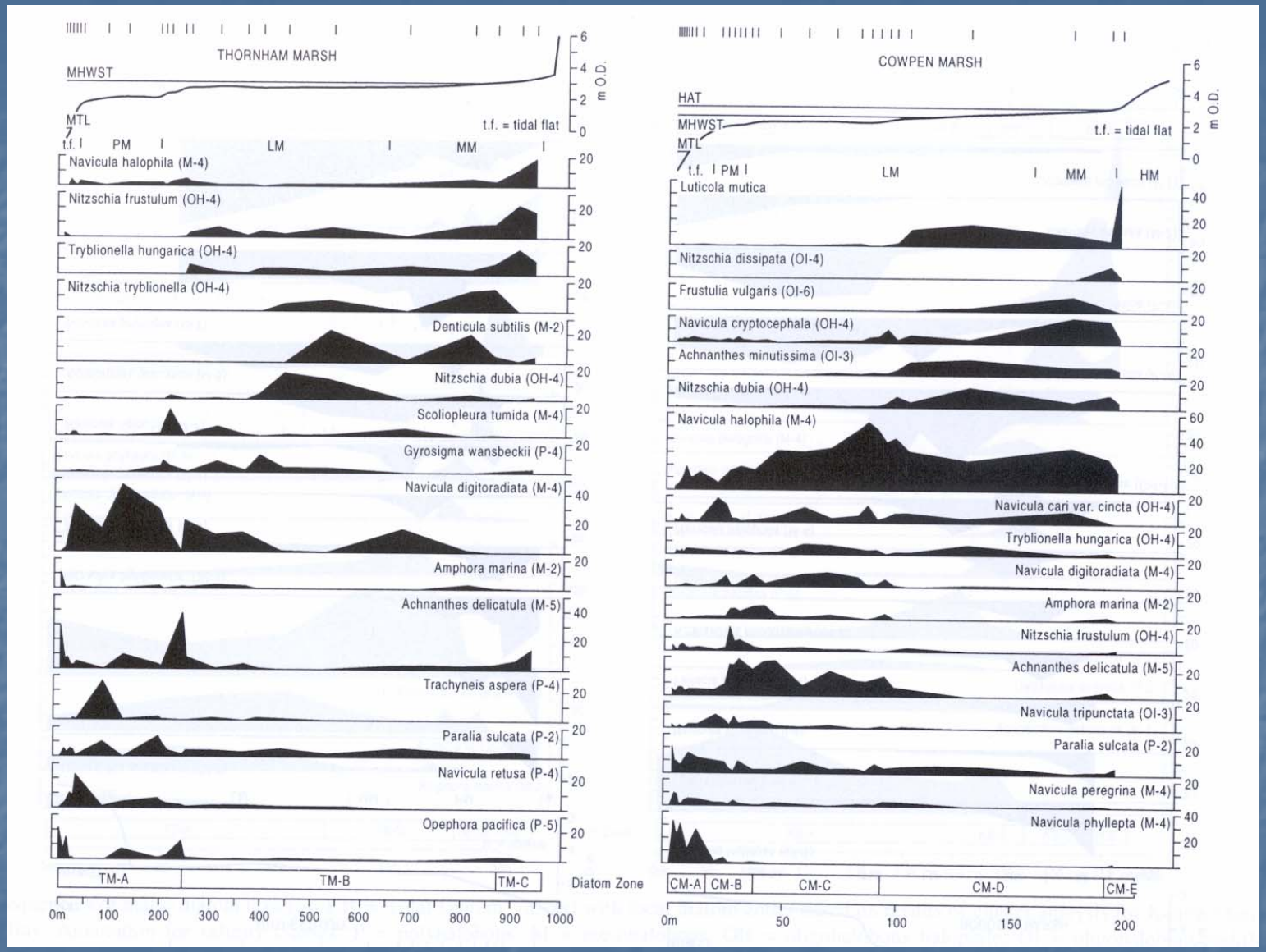
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Tryblionella hungarica (OH-4)
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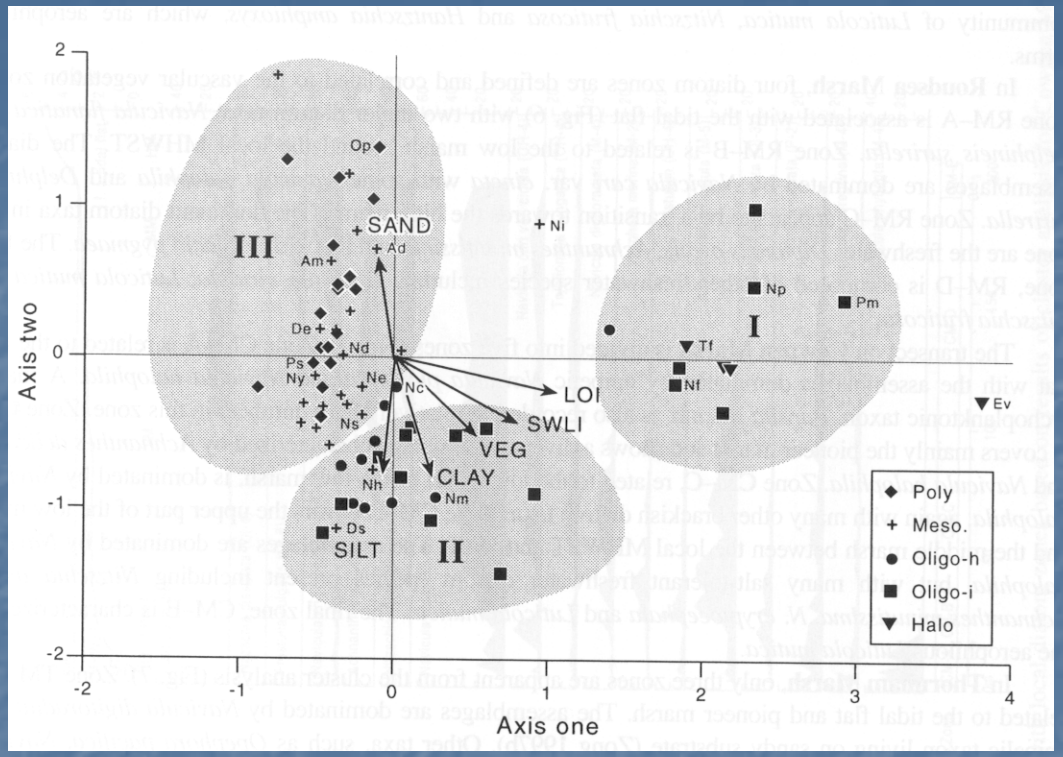
Paralia sulcata (P-2)
Navicula peregrina (M-4)
Navicula phyllepta (M-4)
CM-A
CM-B
CM-C
CM-D
CM-E
0m 50 100 150 200



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Calibration Sets

- Advances have been made with the increasing availability of statistical packages such as CANOCO and PRIMER-E
- Not often applied to estuaries due to high seasonal variability

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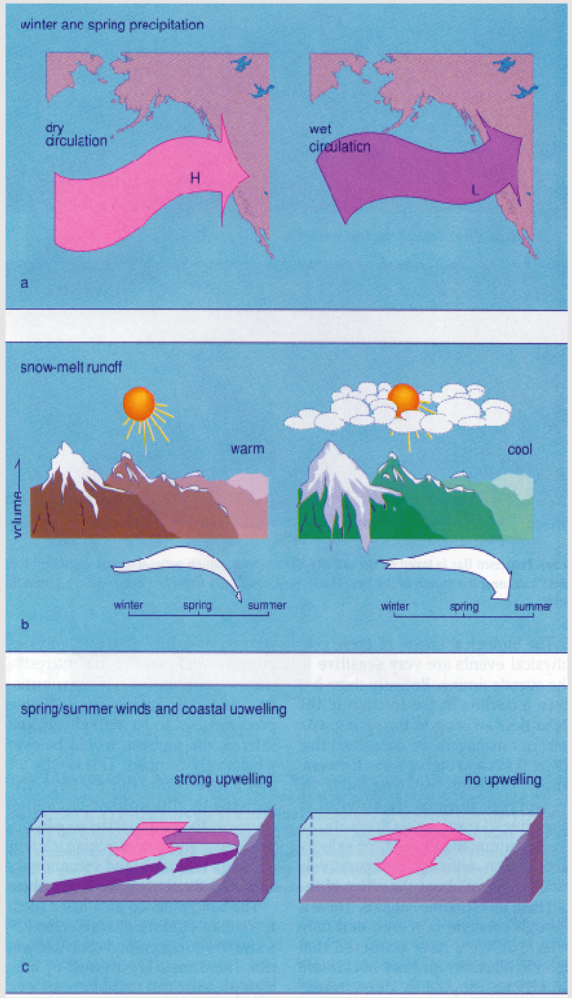
CLIMATE-DRIVEN SALINITY CONTROLS

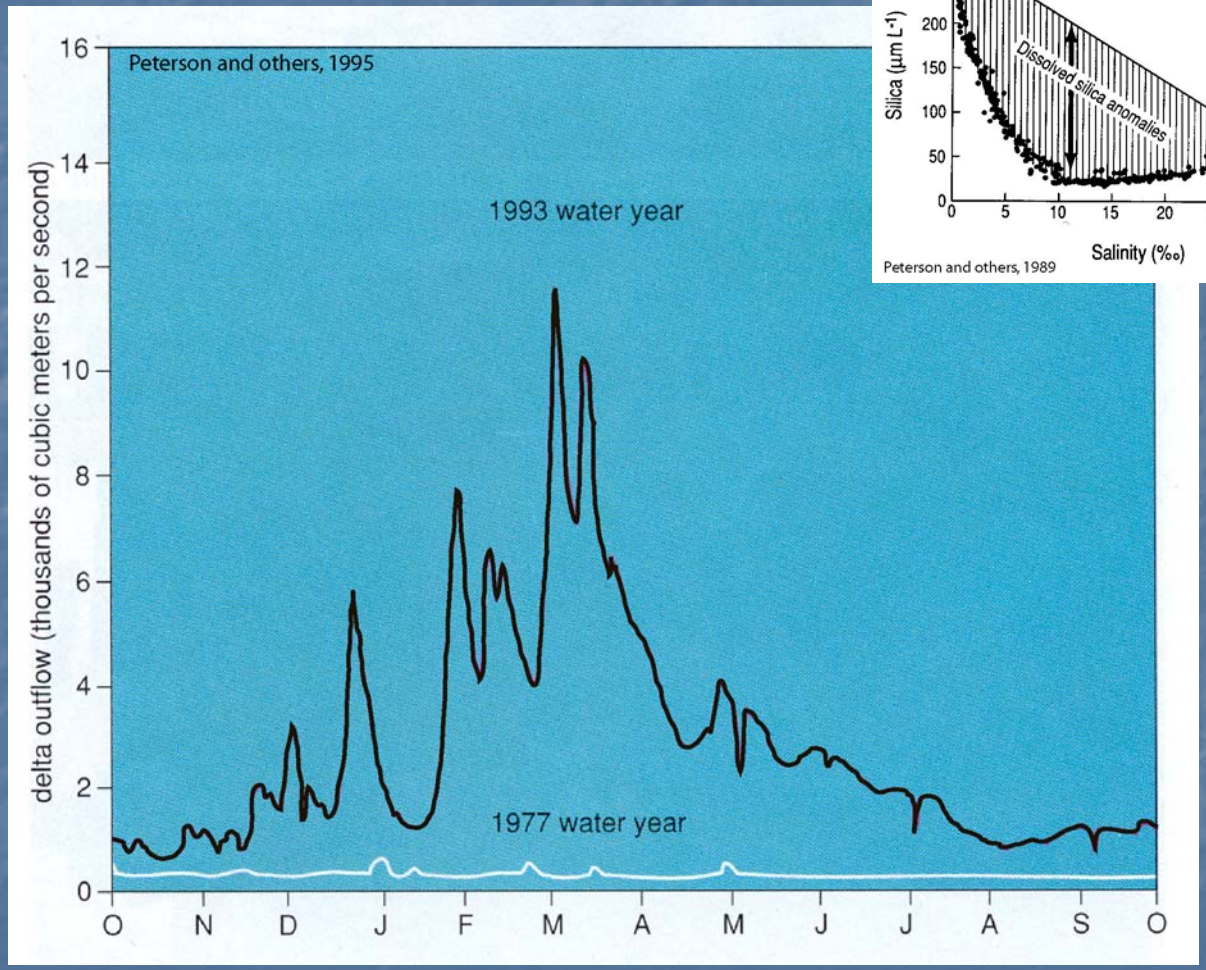


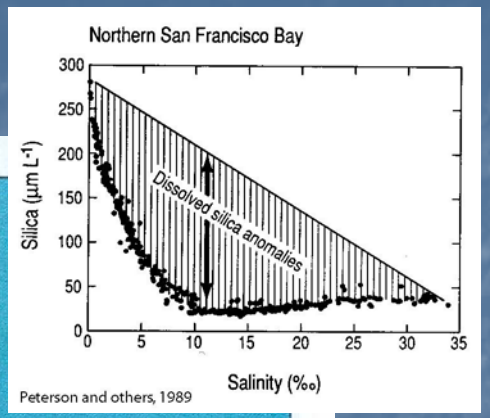
-- Position of high and low pressure systems controls precipitation and upwelling

-- Cloudiness of spring and ealry summer controls timing of snowmelt

USGS

WATER FLOW





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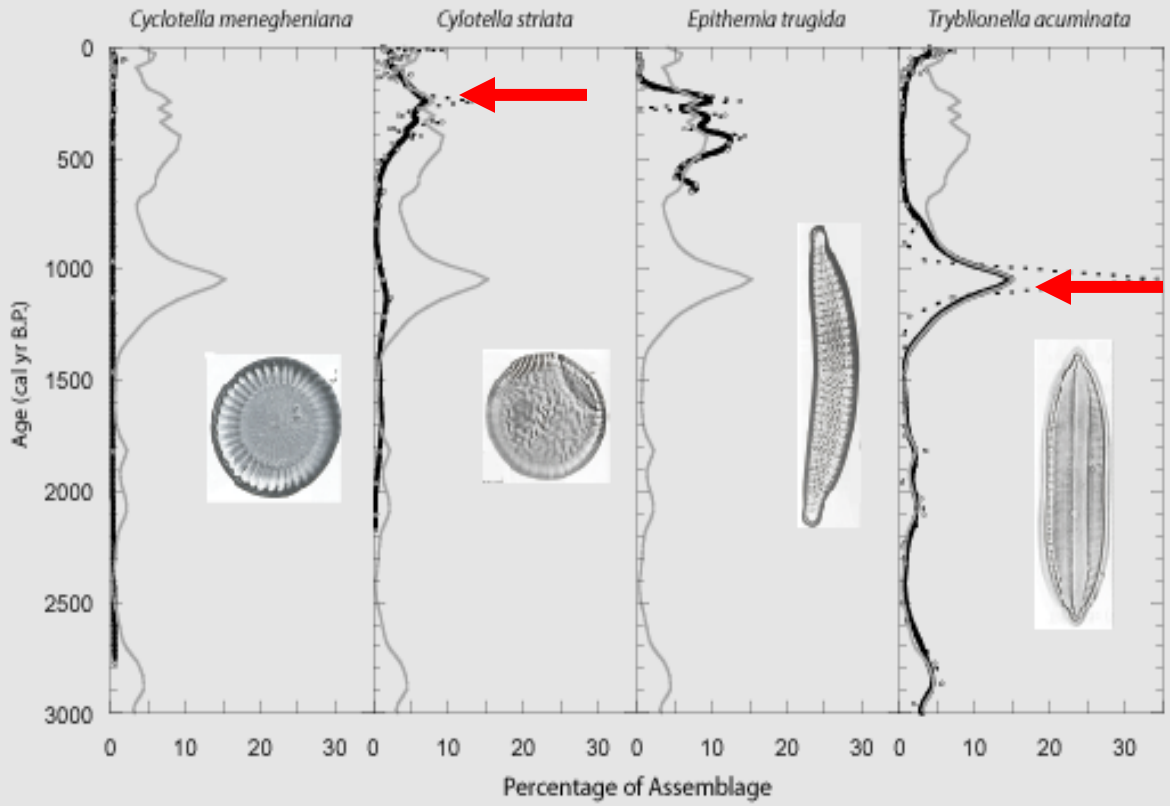
Freshwater and Brackish Taxa



Temporal variation of selected taxa preferring fresh and brackish water. Gray line is the smoothed curve for the freshwater and brackish assemblage.

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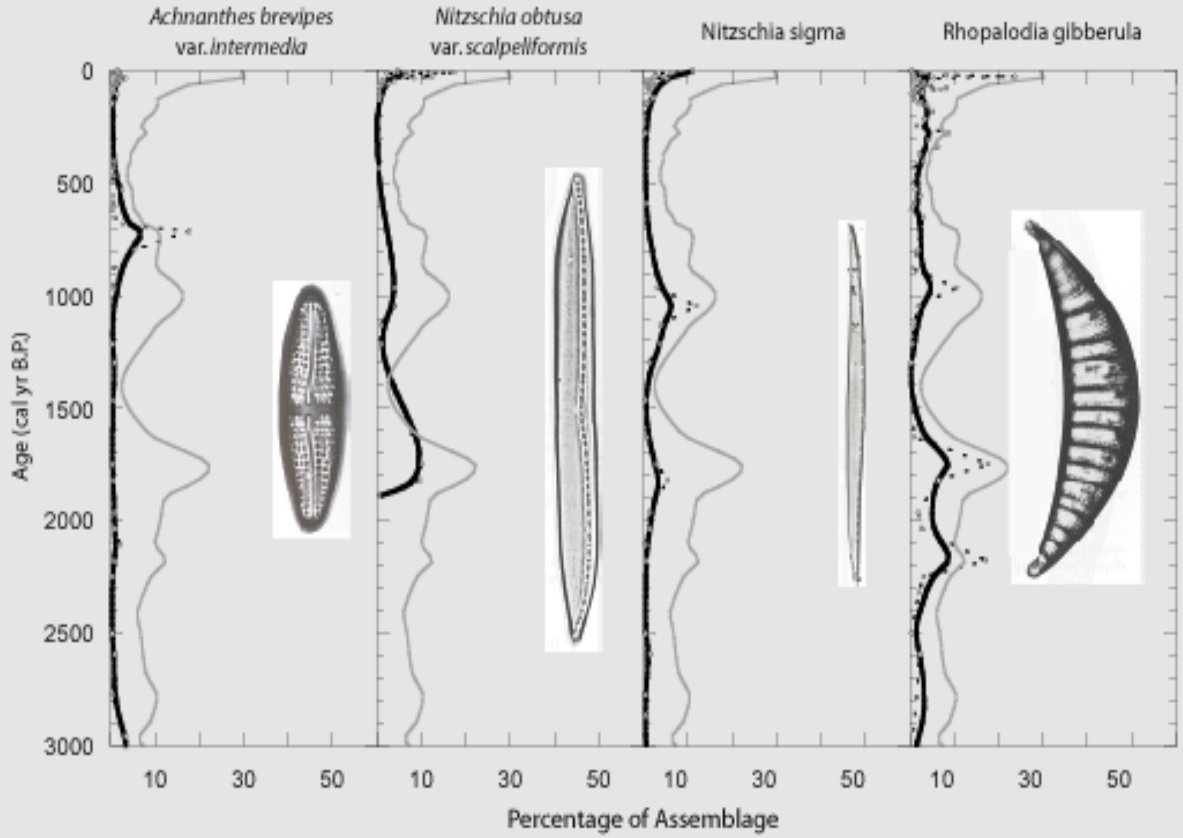
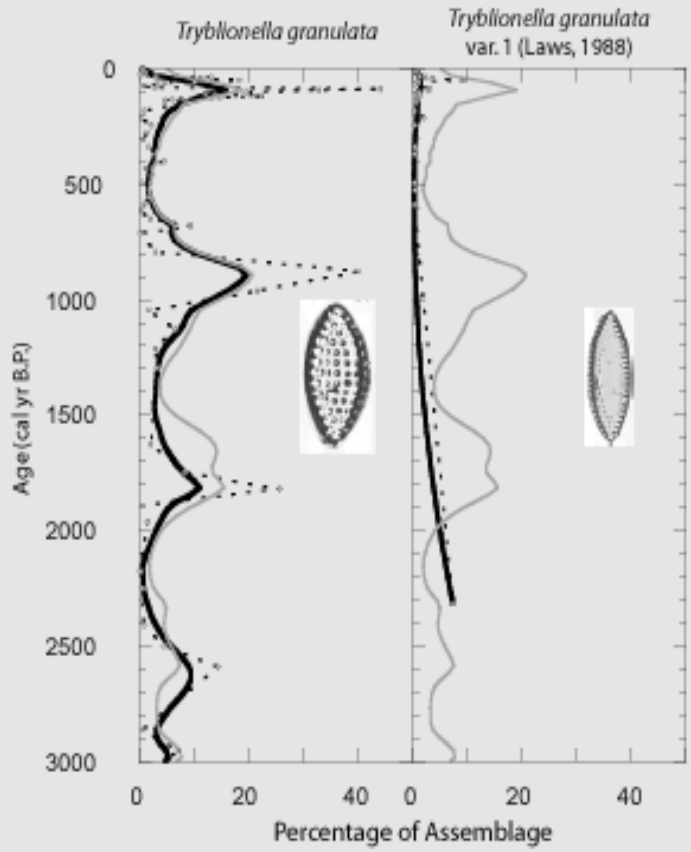
Brackish Taxa



Temporal variation of selected taxa preferring brackish water. Gray line is the smoothed curve for the brackish assemblage.

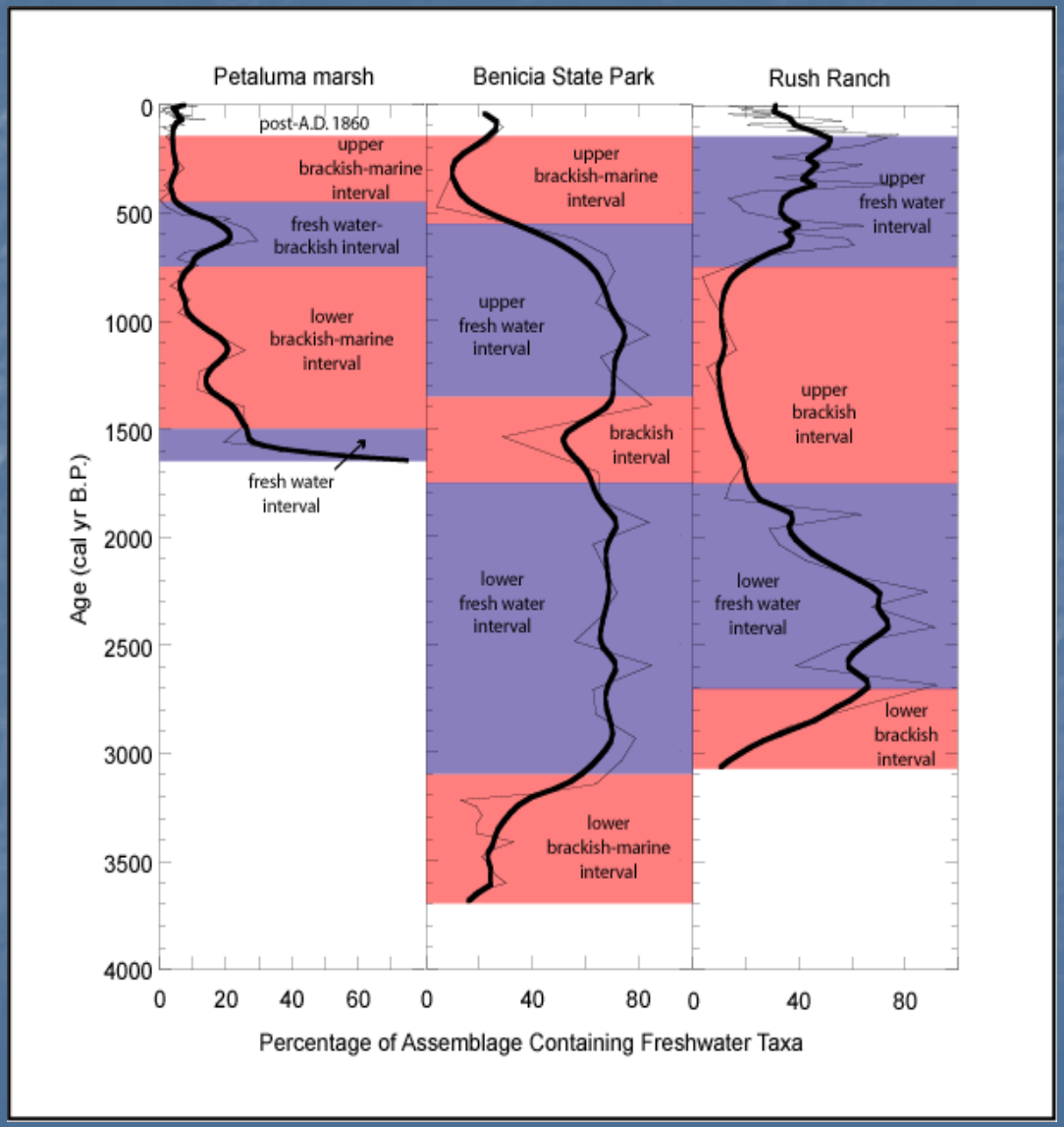
USGS

Marine Taxa

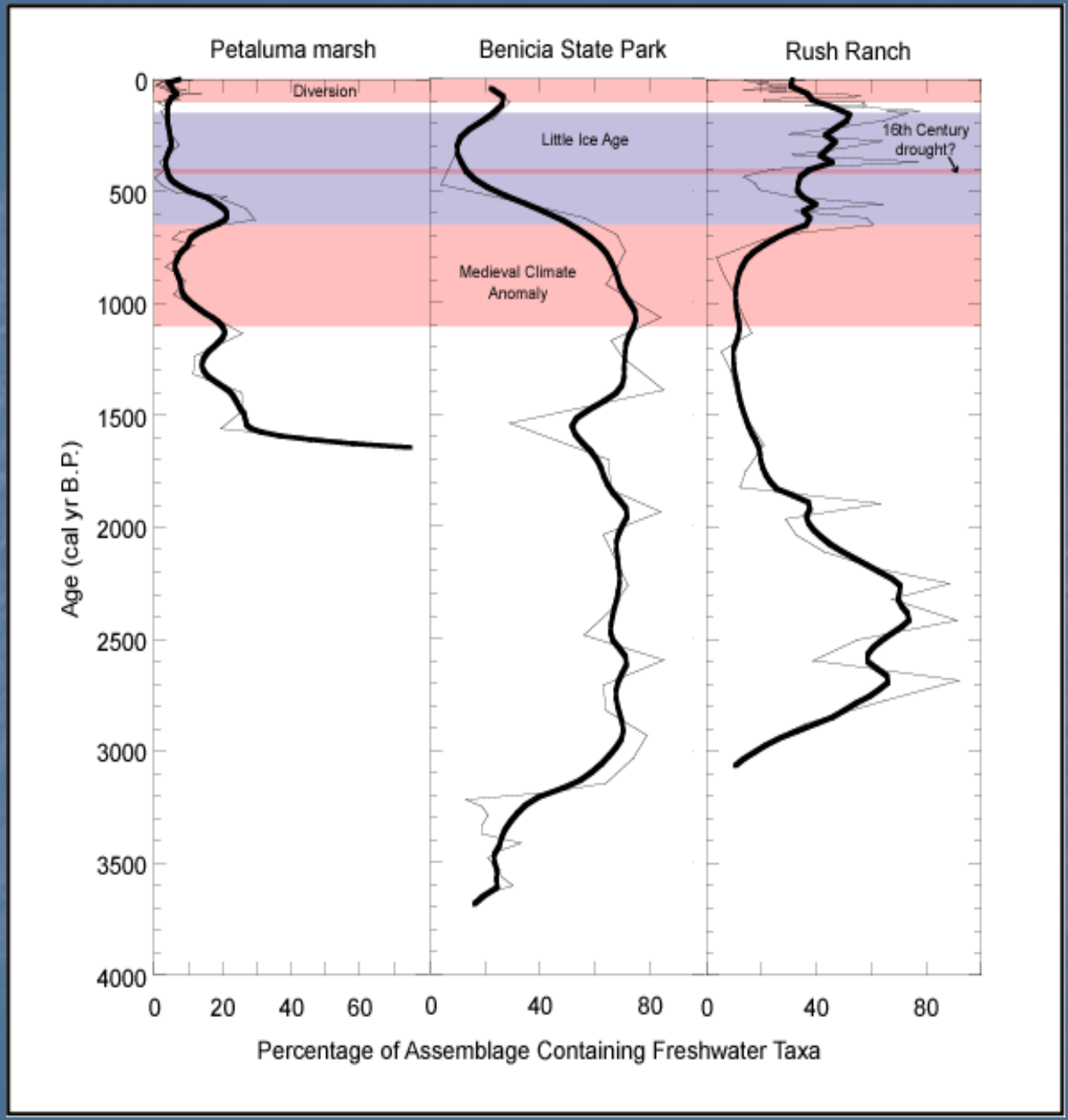


Temporal variation of selected taxa preferring normal marine salinity. Gray line is the smoothed curve for the marine assemblage.

ABUNDANCE OF FRESHWATER TAXA

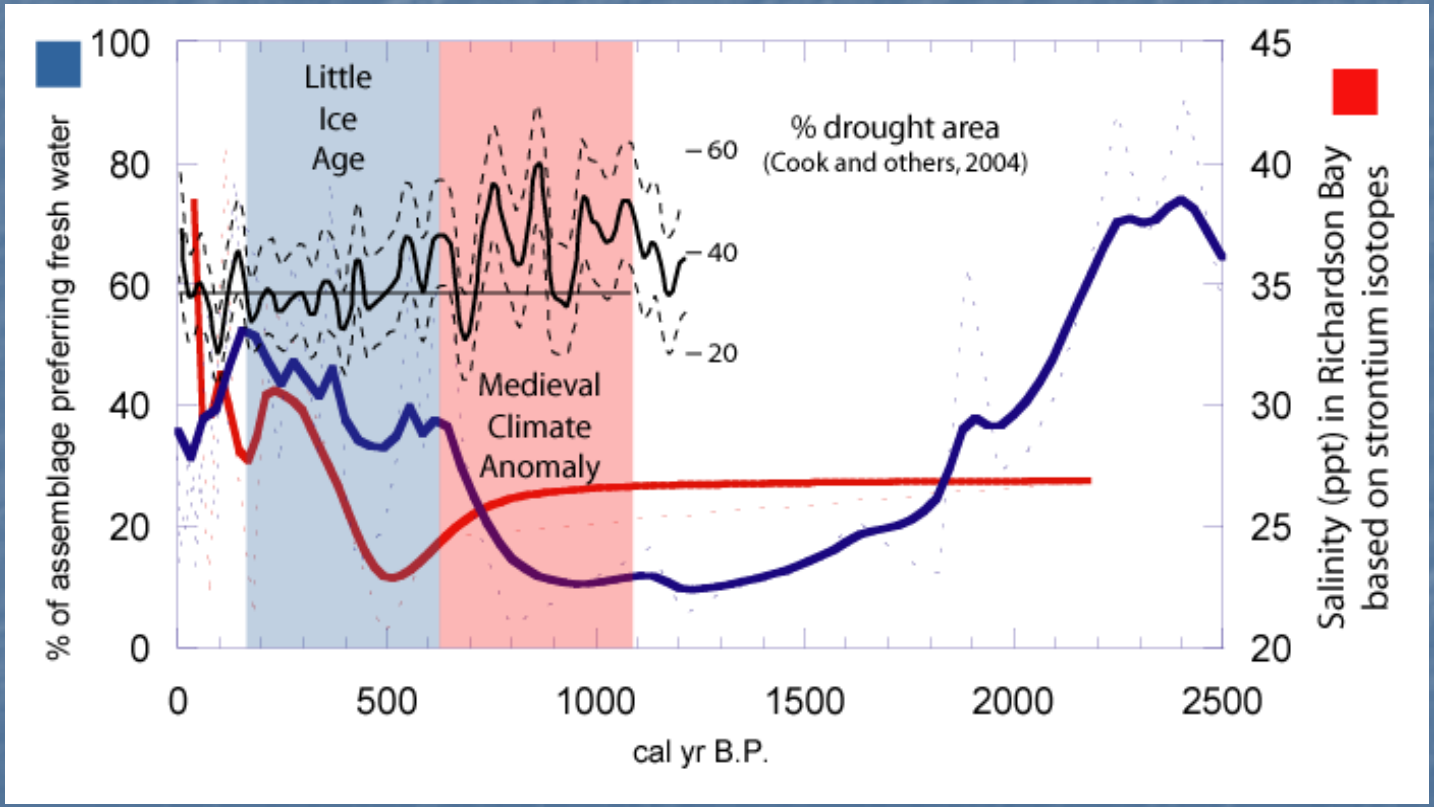


USGS


Petaluma marsh
Benicia State Park
Rush Ranch
Diversion
Little Ice Age
16th Century drought?
Medieval Climate Anomaly
Age (cal yr B.P.)
0
500
1000
1500
2000
2500
3000
3500
4000
0
20
40
60
0
40
80
0
40
80
Percentage of Assemblage Containing Freshwater Taxa

USGS

Strontium Isotope-Derived Salinity Record



USGS