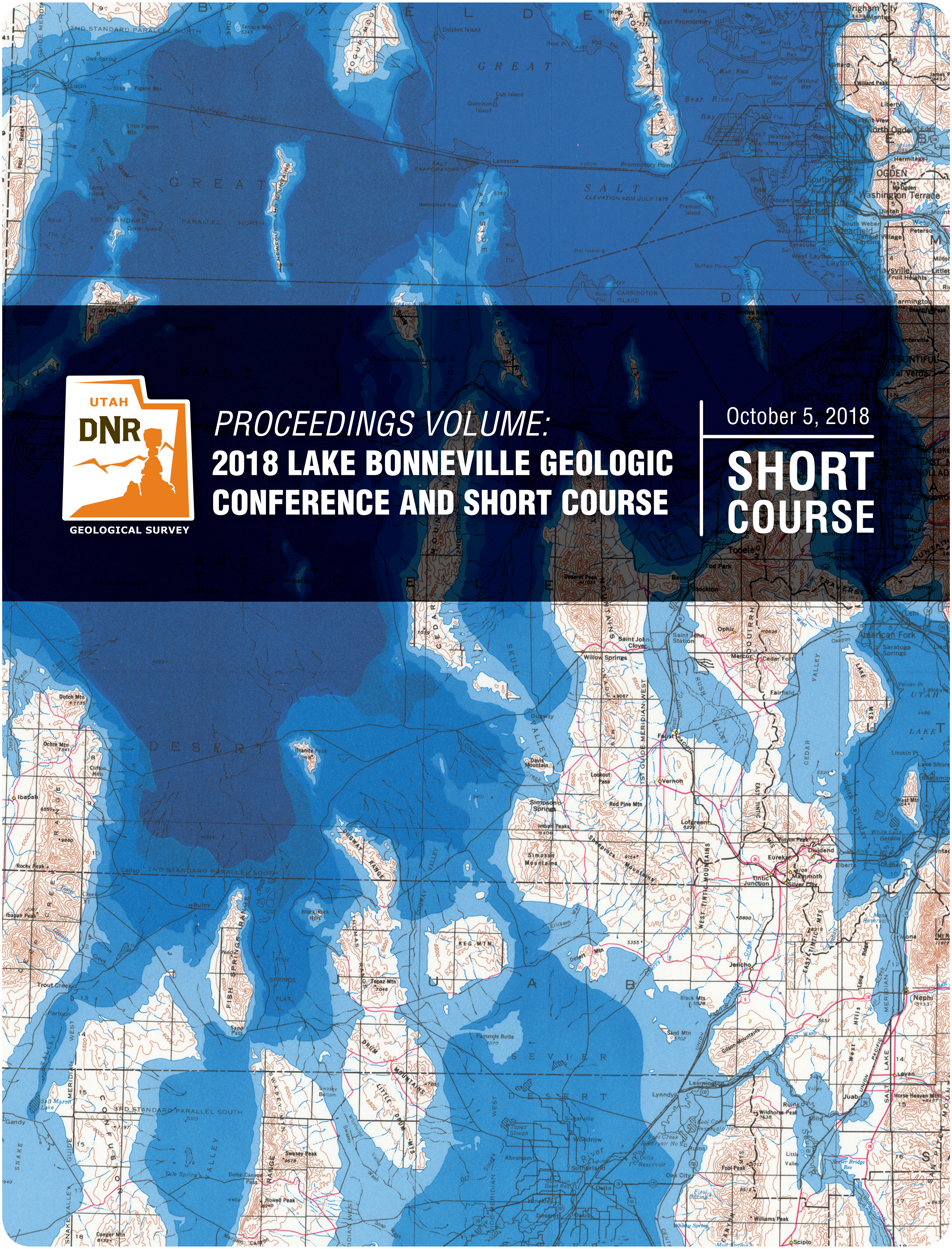


![UTAH DNR GEOLOGICAL SURVEY]

PROCEEDINGS VOLUME:

2018 LAKE BONNEVILLE GEOLOGIC CONFERENCE AND SHORT COURSE

October 5, 2018

SHORT COURSE

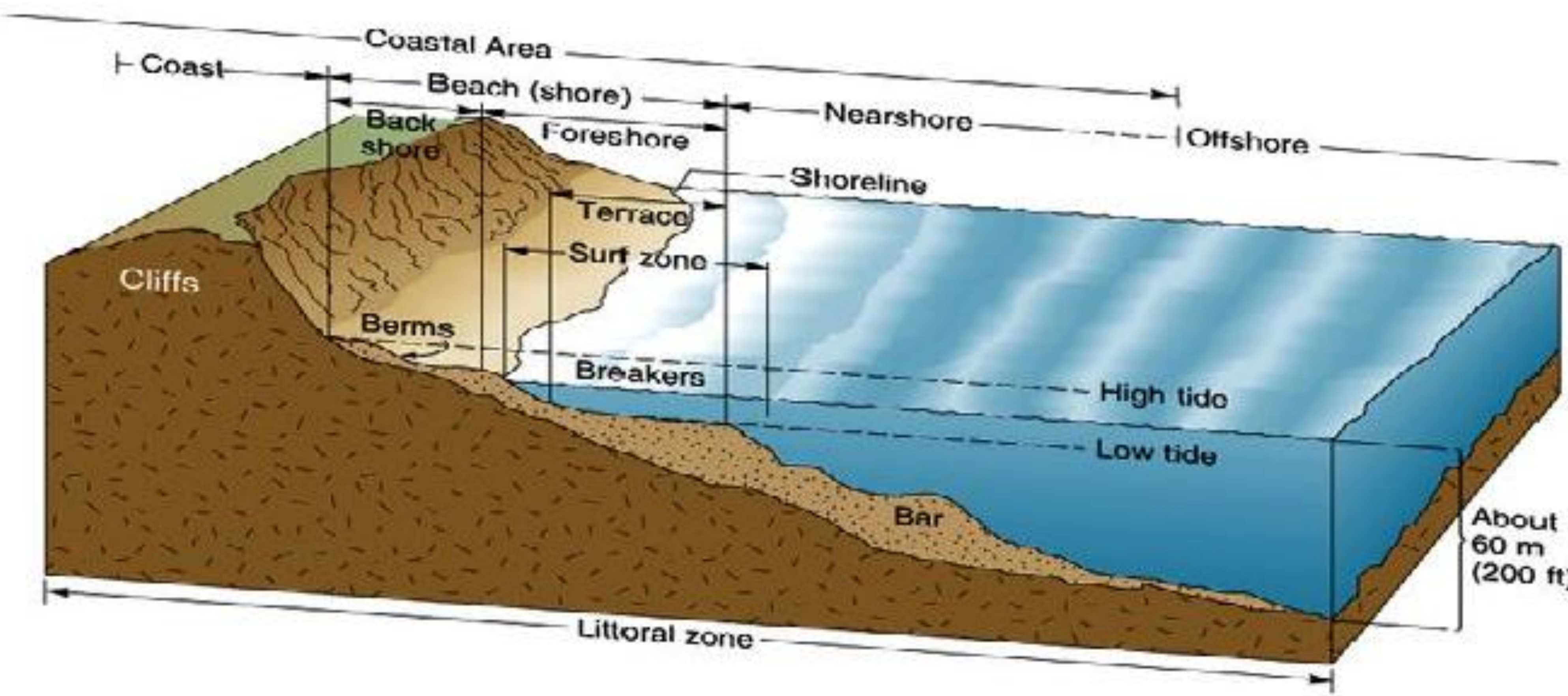
Commonly Used Terms and Updated Lake Bonneville Stratigraphy

Jack Oviatt
Kansas State University
(retired)

some commonly used terms

shoreline
wave zone
offshore
barrier
bar
spit
longshore drift
delta
underflow fan
embankment
wave-cut notch
cut-and-built terrace

erosional shoreline
constructional (depositional) shoreline
abrasion platform
constructional (depositional) platform
marl: stratigraphic unit or lithological description
Wentworth scale:
gravel (pebble, cobble, boulder)
sand (coarse, medium, fine)
mud (silt and clay, usually with some sand)
shoreline tufa
spring tufa



https://en.wikipedia.org/wiki/Littoral_zone

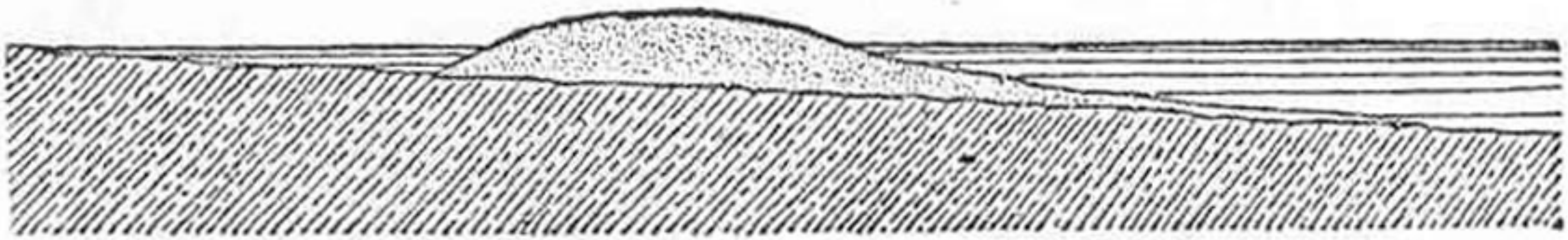


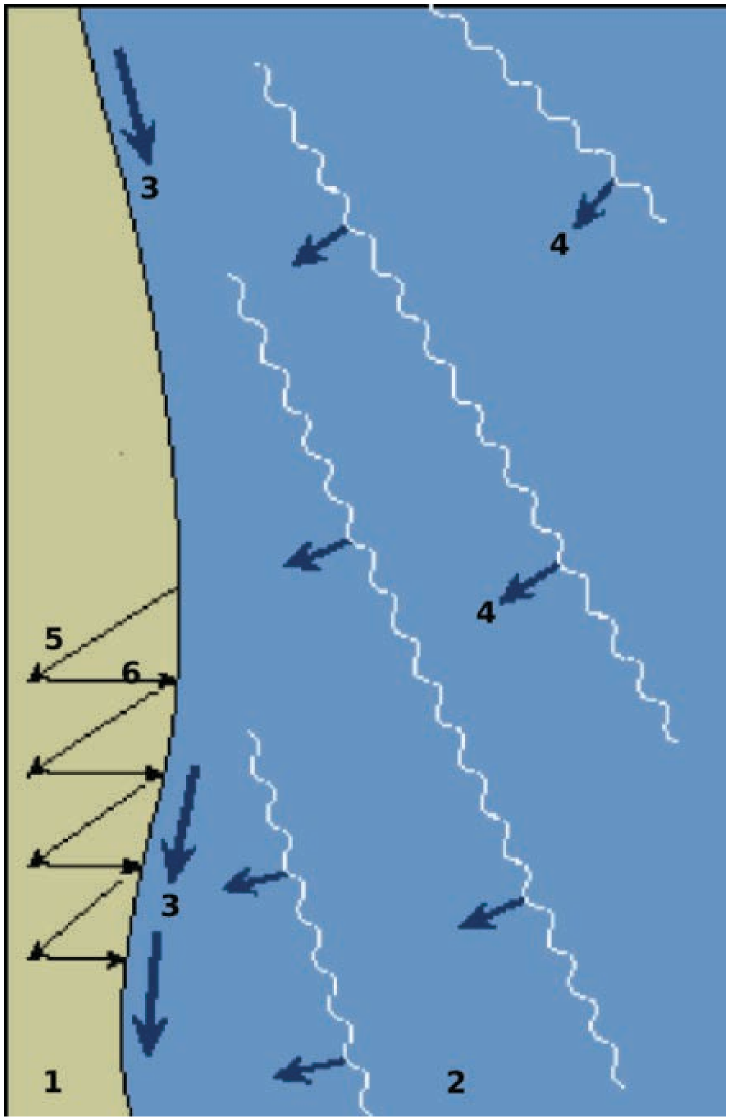
FIG. 6.—Section of a Barrier.

Gilbert (1890)

spit

Gilbert (1890)

https://en.wikipedia.org/wiki/Spit_(landform)



longshore current; longshore drift

https://en.wikipedia.org/wiki/Longshore_drift

embankment

https://en.wikipedia.org/wiki/Embankment_(transportation)

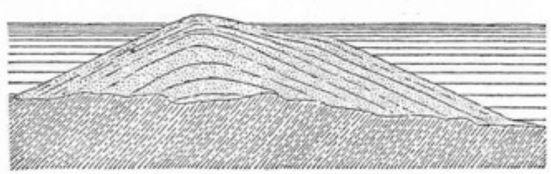


FIG. 7.—Section of a Linear Embankment.

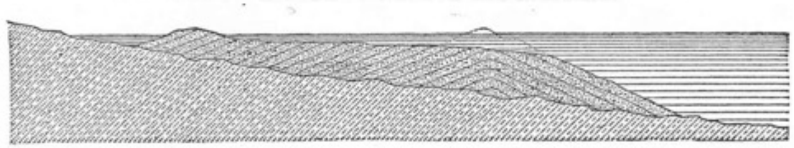
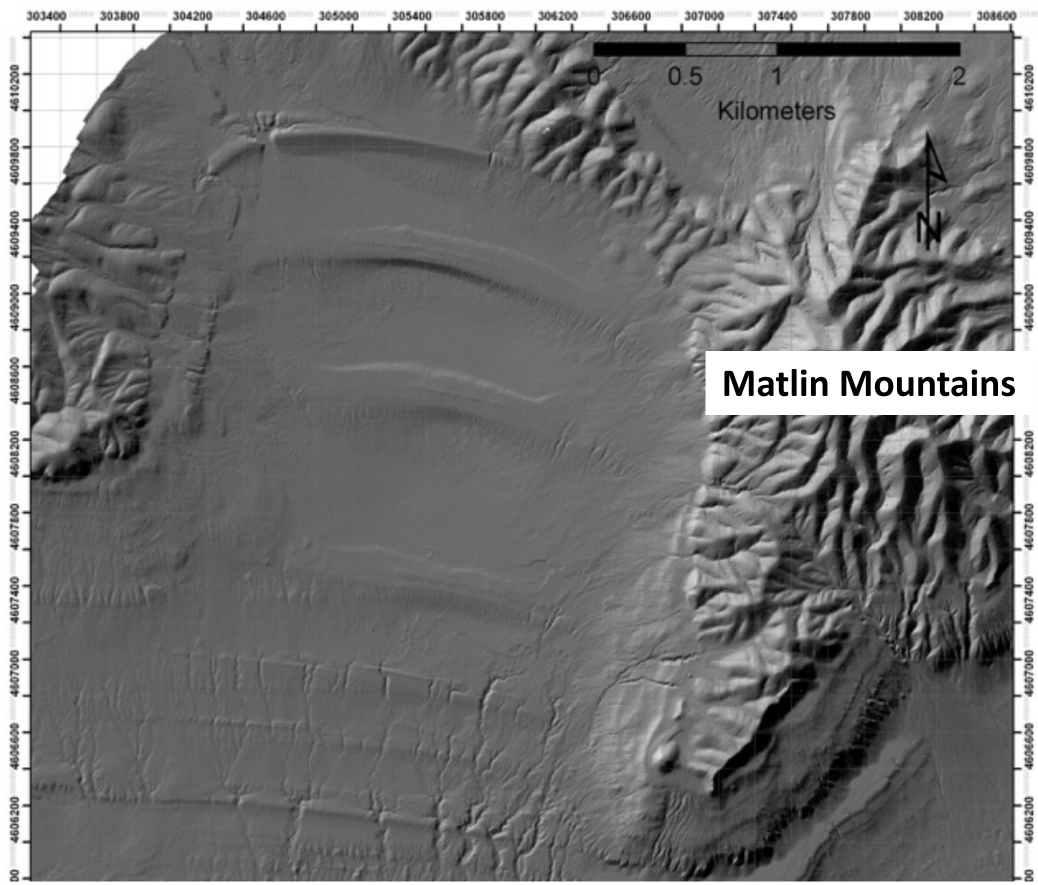


FIG. 12.—Section of a Linear Embankment retreating landward. The dotted line shows the original position of the crest.

Gilbert (1890)



lidar image from Paul Jewell


Grass Valley, NV
2603 m
Google Earth

wave-cut notch (erosional shoreline)

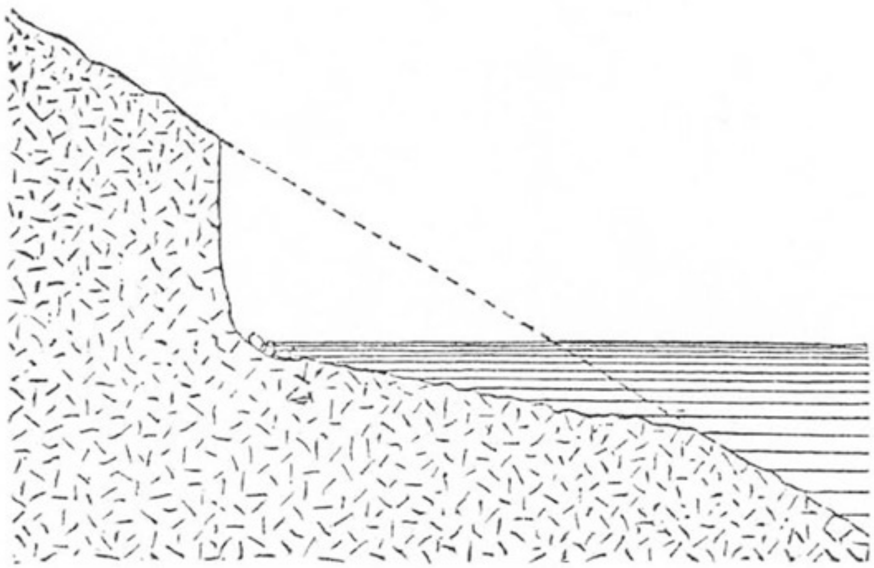


FIG. 3.—Section of a Sea Cliff and Cut-Terrace in Hard Material.

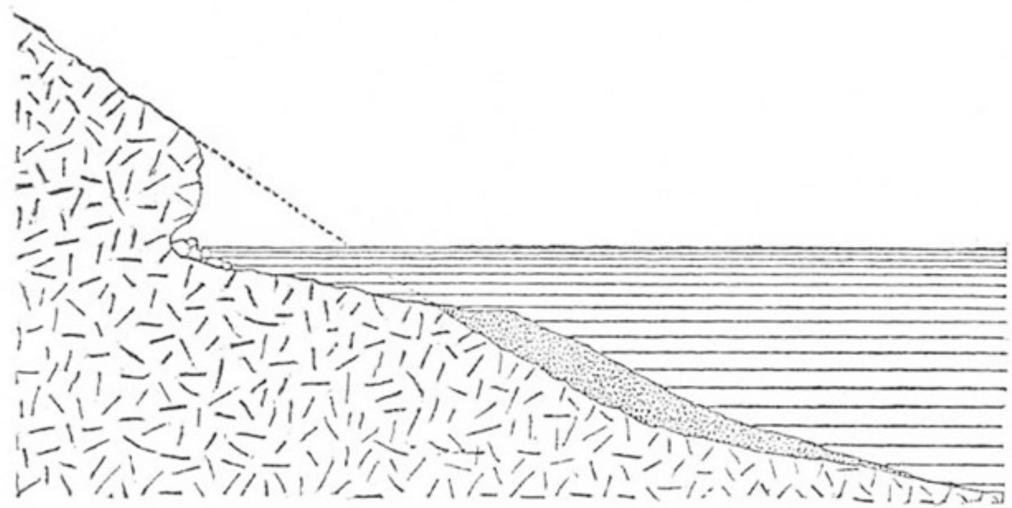
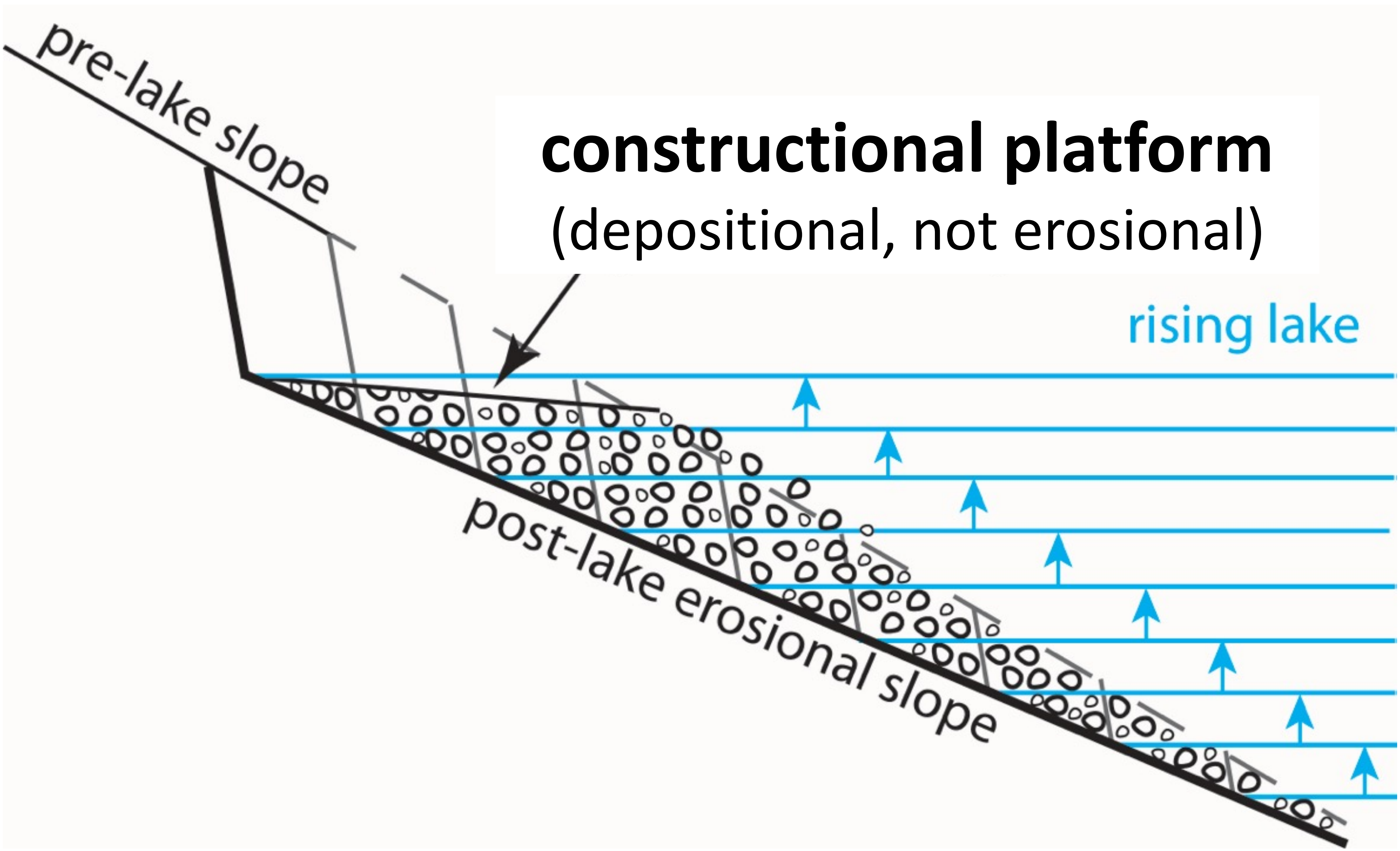


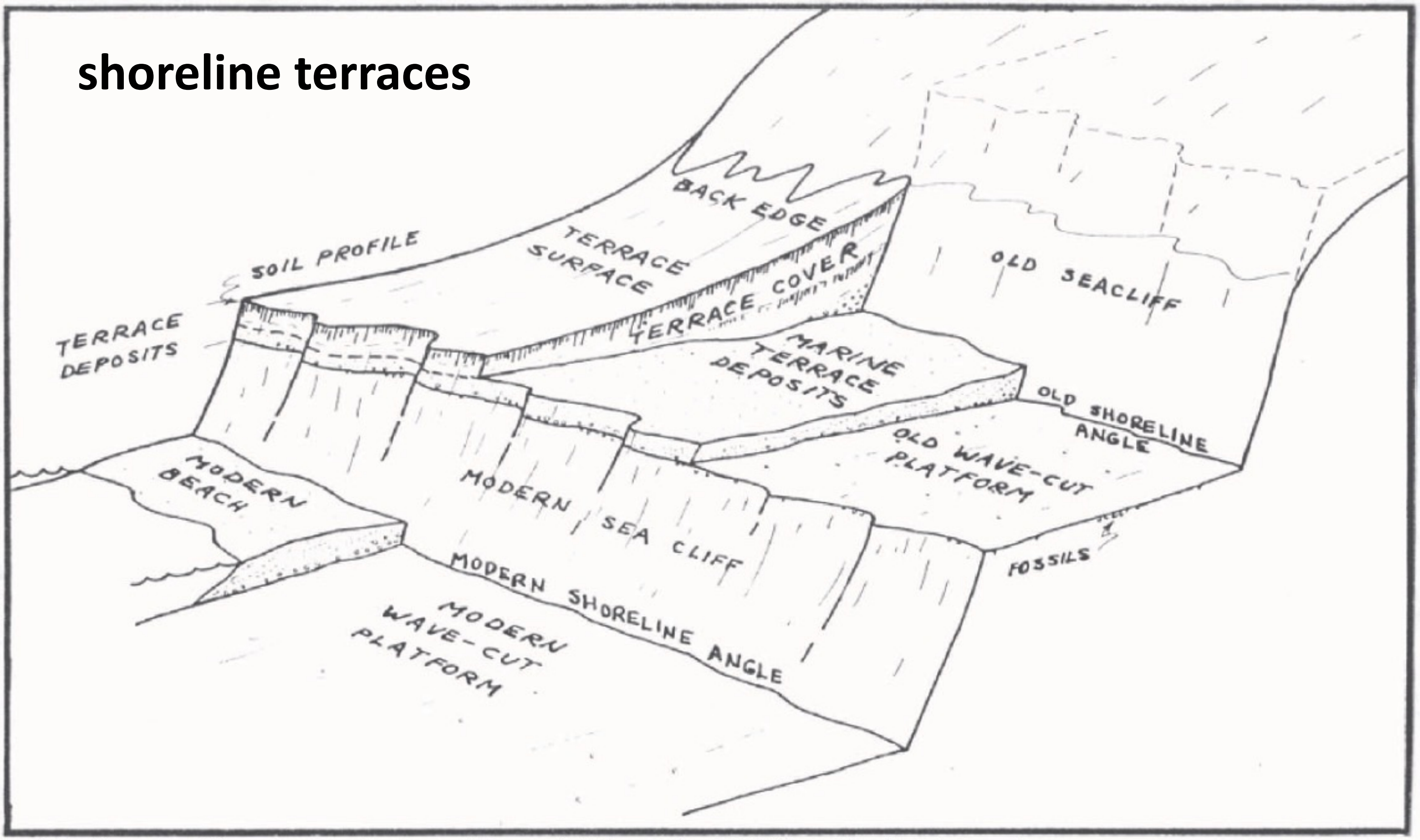
FIG. 5.—Section of a Cut-and-Built Terrace.

Gilbert (1890)

abrasion platform (erosional)

http://thebritishgeographer.weebly.com/coasts-of-erosion-and-coasts-of-deposition.html


pre-lake slope
constructional platform
(depositional, not erosional)
rising lake
post-lake erosional slope



http://www.mobileranger.com/santacruz/the-cool-staircase-shaped-hills-north-of-santa-cruz/

marl

stratigraphic: “The White Marl, a fine calcareous clay or argillaceous marl, light gray or cream-colored on fresh exposer, nearly white on weathered surface.” Gilbert (1890, p. 190)

lithologic: “. . . [a] loose, earthy [deposit] consisting chiefly of an intimate mixture of clay and calcium carbonate, formed under marine or esp. freshwater conditions; specif. an earthy substance containing 35-65% clay and 65-35% carbonate . . .” (Bates and Jackson, 1987)

Wentworth grain-size scale

cobbles and boulders	>64 mm
pebbles	2 - 64 mm
sand	0.0625 - 2 mm
silt	0.004 - 0.0625 mm
clay	<0.004 mm

water classification

category	total dissolved solids (mg/l or g/m^3)
fresh	**0-1000**
brackish	**1000-10,000**
saline	**10,000-100,000**
brine (hypersaline)	**>100,000**

Freeze and Cherry, 1979

tufa, microbialites


Provo shoreline tufa

microbialite or tufa-mound at Lakeside
(not associated with a shoreline, probably spring discharge)

microbialites in sediments of Great Salt Lake

Utah Geological Survey – Lake Bonneville Geologic Conference and Short Course

October 5 session –
Field identification – Shorelines.

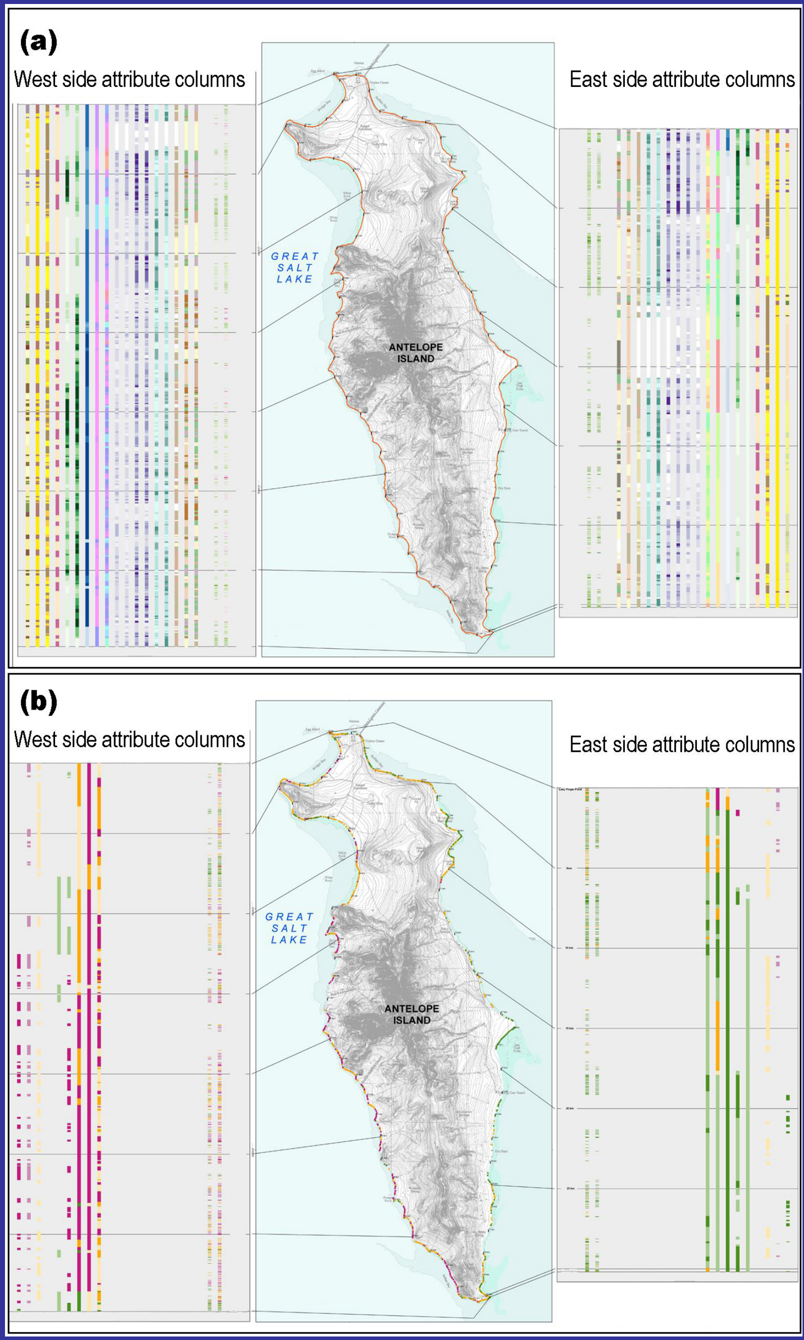
Field methods and data analysis used 1987 – 2006

Identification and characterization of highstand shorelines of Great Salt Lake,

Genevieve Atwood

What we saw.
What worked.
What didn't work.

Some images.
Some thoughts.



GOALS of the field work

Re: Coastal hazards

Contribute to the understanding of the dynamics of shallow, closed-basin lakes, specifically GSL.

Unique opportunity

Document evidence of the 1980s highstand of Great Salt Lake.

Criteria: collect what we wished had been documented for the 1870s highstand.

What we saw:

Anthropogenic debris

Floated (flotsam) =
automobile tires, railroad ties, telephone poles, lumber, and plastics.

Entrained =
bowling balls, marbles, asphalt, concrete, and pottery.

Organic debris: from brine fly pupae cases to tree trunks.

Locally derived: windrows of sagebrush twigs and disintegrated organic matter.
Driftwood: tree limbs tree trunks carried across the lake from mainland sources.

Wave-deposited terrigenous debris.
Erosional scarps.

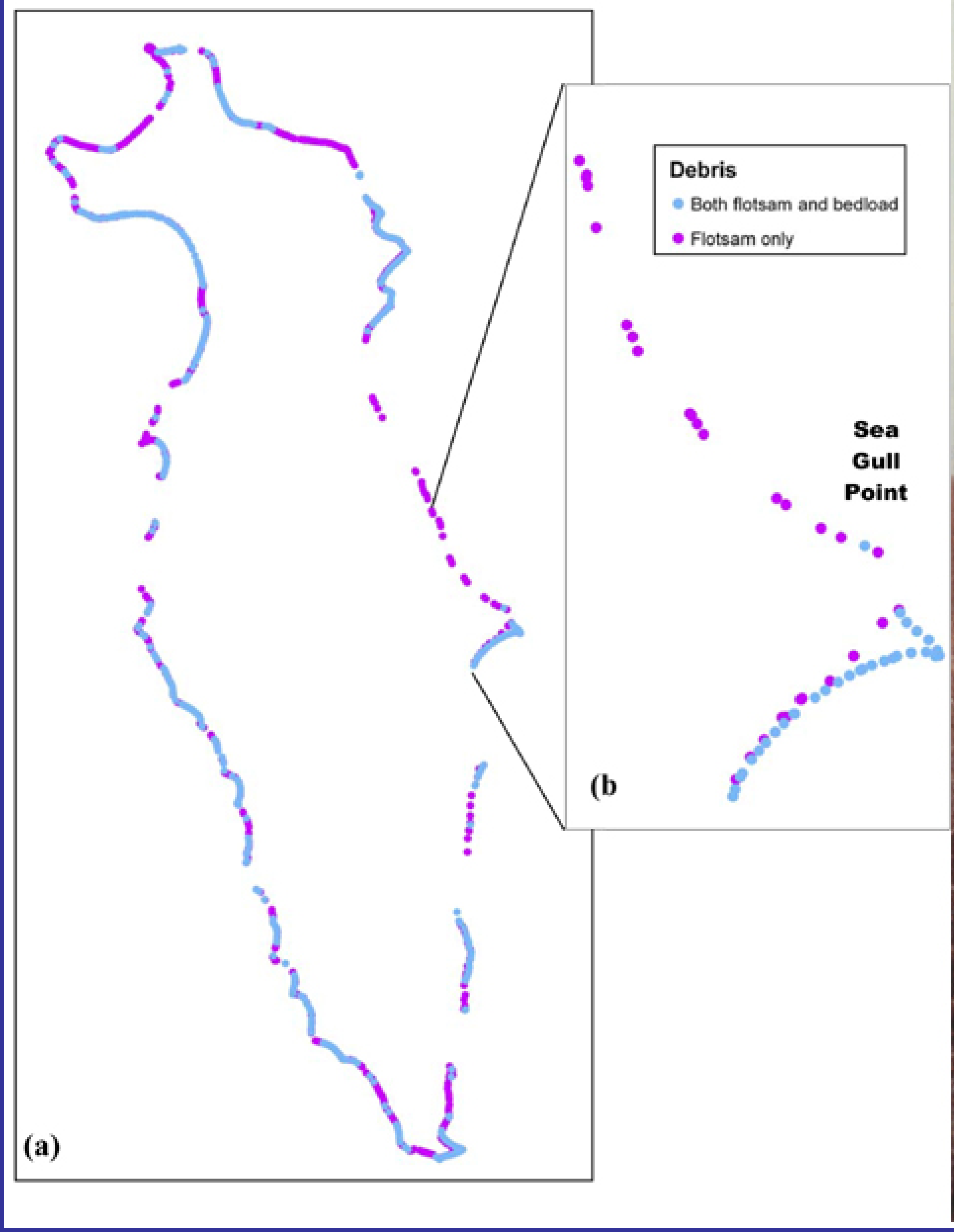
PRESERVATION:
From 1986 – 1989, floated organic material was nearly CONTINUOUS around Antelope Island marking the highstand. One could walk on fine organic debris virtually uninterrupted, with total confidence of highstand.

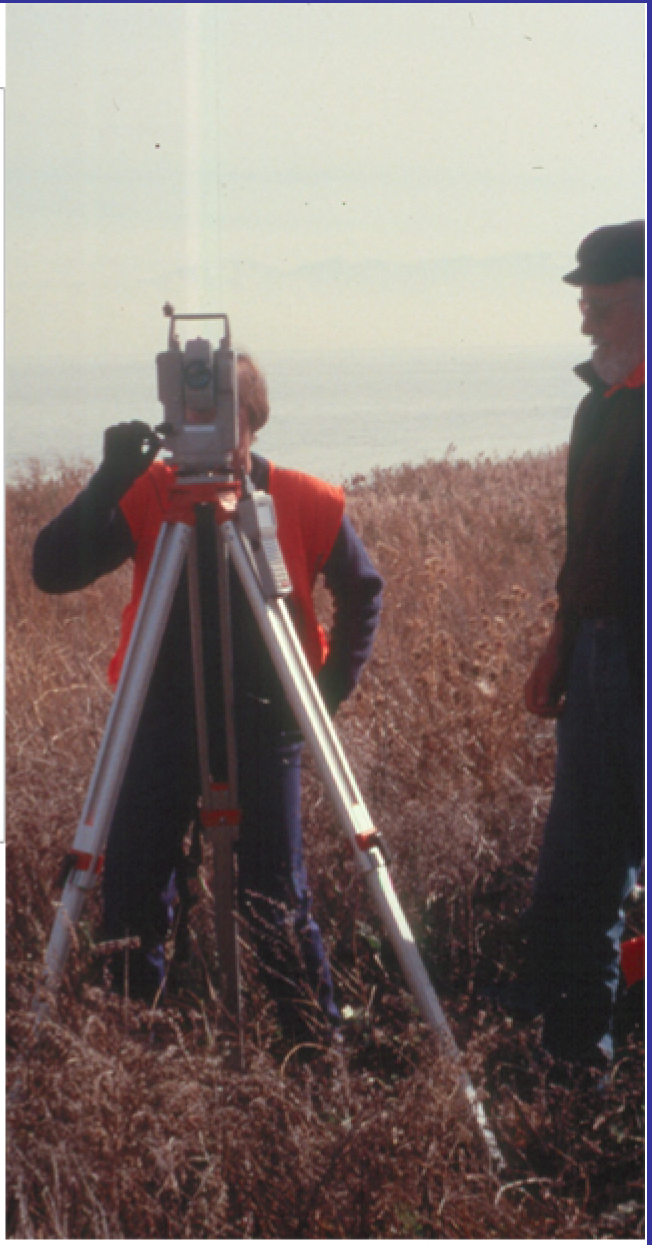
After 10 years…. The continuous fine organic debris was lost.

Fire. Erosion. Burial. Boy scouts.

Three types of debris:
Terrigenous (sand and gravels mostly), Anthropogenic, Organic

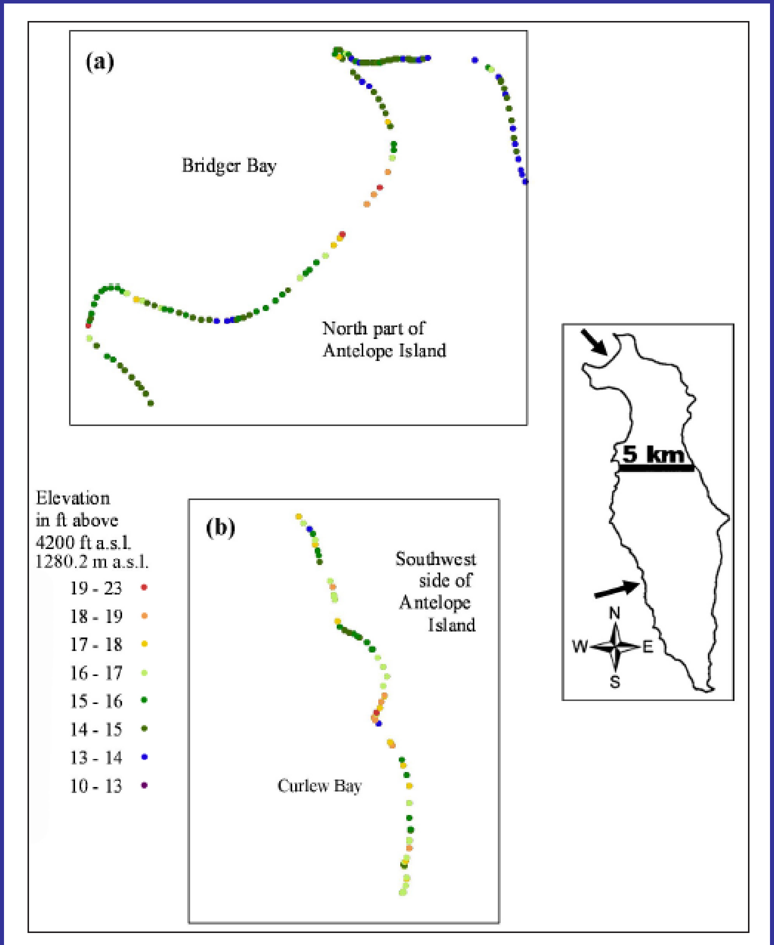
Elevation survey – 1228 locations





The monitored elevation of GSL in both 1986 and 1987 was approximately 4212 ft a.s.l. (1283.7 m a.s.l.). The elevation of shoreline evidence of that highstand was rarely at that elevation. Why?

No wind, no waves, no work !



We had to distinguish the concept of SHORELINE used by the Corps of Engineers and others
From
SHORELINE used by geomorphologists studying paleoshorelines of the Great Basin.

"Shoreline" meaning the hypothetical still-water interface of water and land.
Versus
"Shoreline" meaning physical evidence left by wave processes.

Comments about survey markers.

Wish for a dog that could smell brass.

Wonder whether road graders get extra points when they take out a survey marker. (Image on right.)

Be grateful for GPS.

Carry control.

Datums matter.
Be careful and compulsive.

Pre-LIDAR. We used the lake as datum.

The still-water elevation of GSL is monitored.
But.. check that the GSL really is… still !!
Redundant field-day monitoring. (Image on right.)
On a calm day, seiche can change local level.

Shoreline evidence of GSL is not at still-water elevation of the lake.

We surveyed the elevation of shoreline evidence approximately every 50 m although 13 (erosional) stretches were spaced >0 .5 km.

Research Question:
“Superelevation” = difference from still-water elevation of lake level.
Is the variation from still-water elevation systematic?
What association can be made to explain patterns?

Antelope Island data set – for UofU dissertation.
All georeferenced into GIS
Technique = linear referencing

"**Linear referencing** is a method of storing distance and temporal data that adds a new dimension to line features." ESRI.

1228 surveyed locations on inundation expressions of the 1986/87 shoreline on Antelope Island

667 shoreline stretches characterized for 15 attributes

305 shoreline stretches characterized for geomorphic attributes such as fetch and aspect

208 shoreline stretches characterized with geologic attributes such as bedrock versus surficial materials

94 shoreline stretches characterized for their planform shape, such as convex or concave

Great Salt Lake data set – also for UofU dissertation.

5 relationships of Antelope Island research tested

10 shore regions

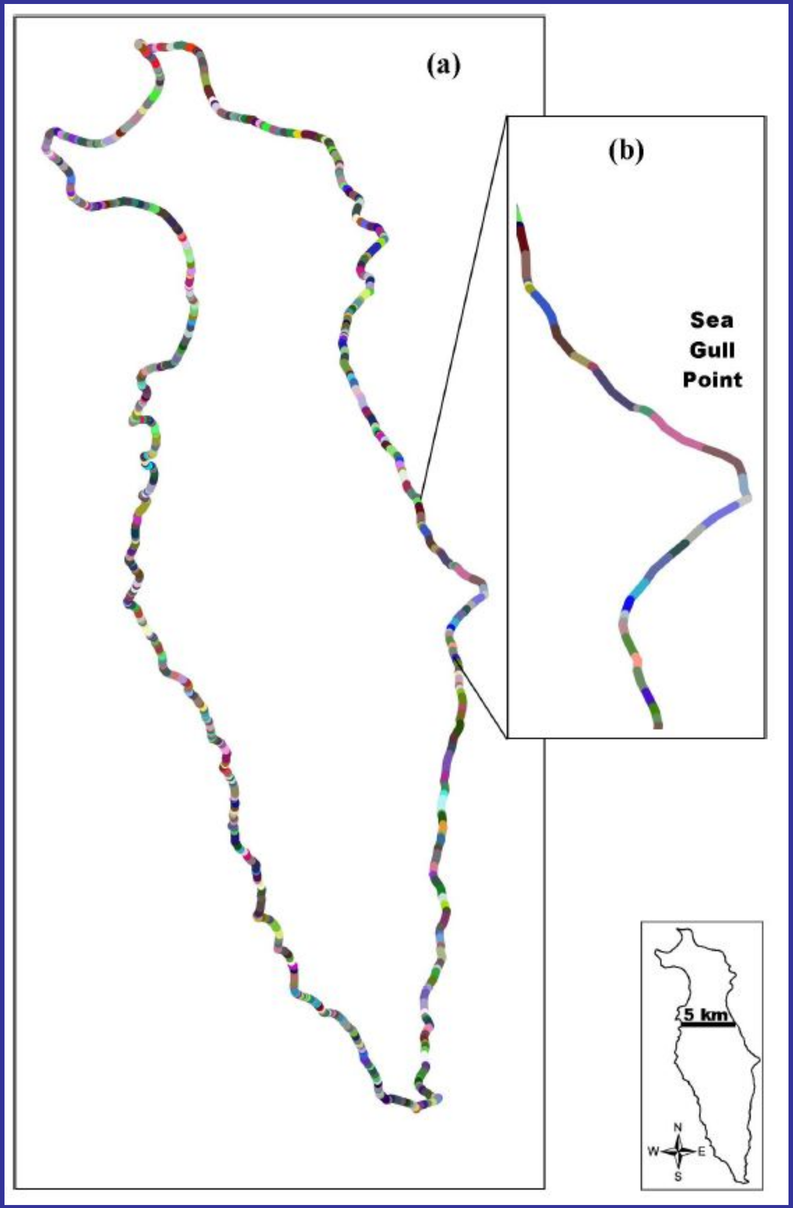
20 contrasting coastal conditions

608 surveyed locations

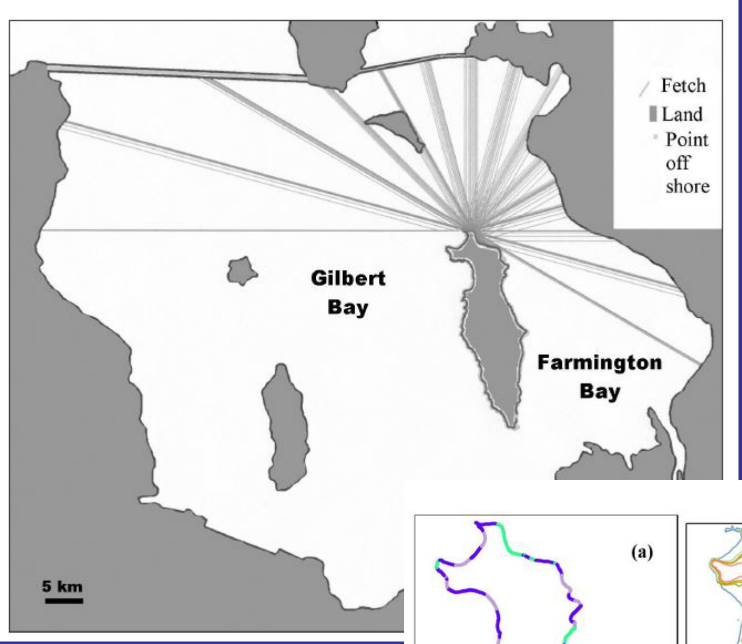
667 shoreline stretches characterized for 15 attributes

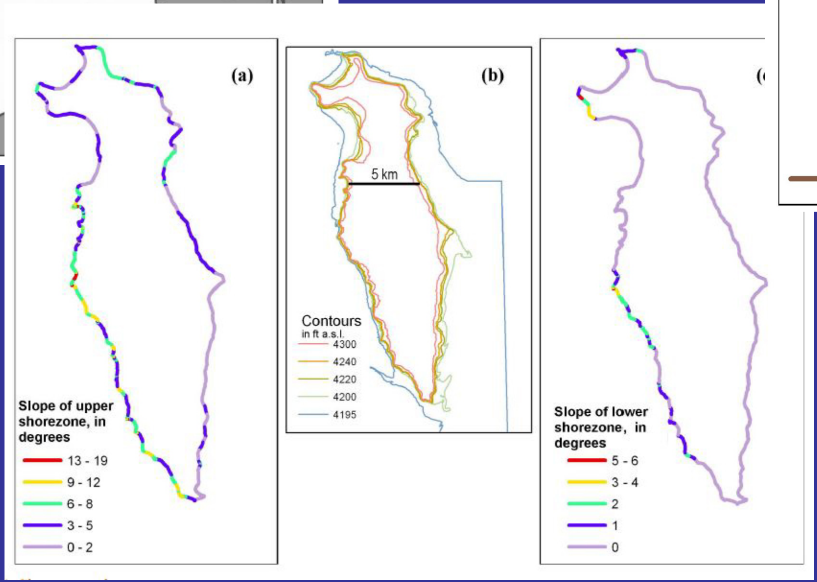
· Abundance of locally-derived vegetative debris,
· Abundance of lumber,
· Abundance of large, natural driftwood,
· Abundance of non-wood, anthropogenic materials, such as plastic or rubber,
· Abundance of sand,
· Abundance of gravel,
· Size of largest particle moved by shore processes of 1986/87,
· Substrate, i.e., terrigenous materials underlying shore materials,
· Beach materials exposed along the 1986/87 shorezone, and
· Shorezone type (erosional, depositional, or both erosional and depositional).

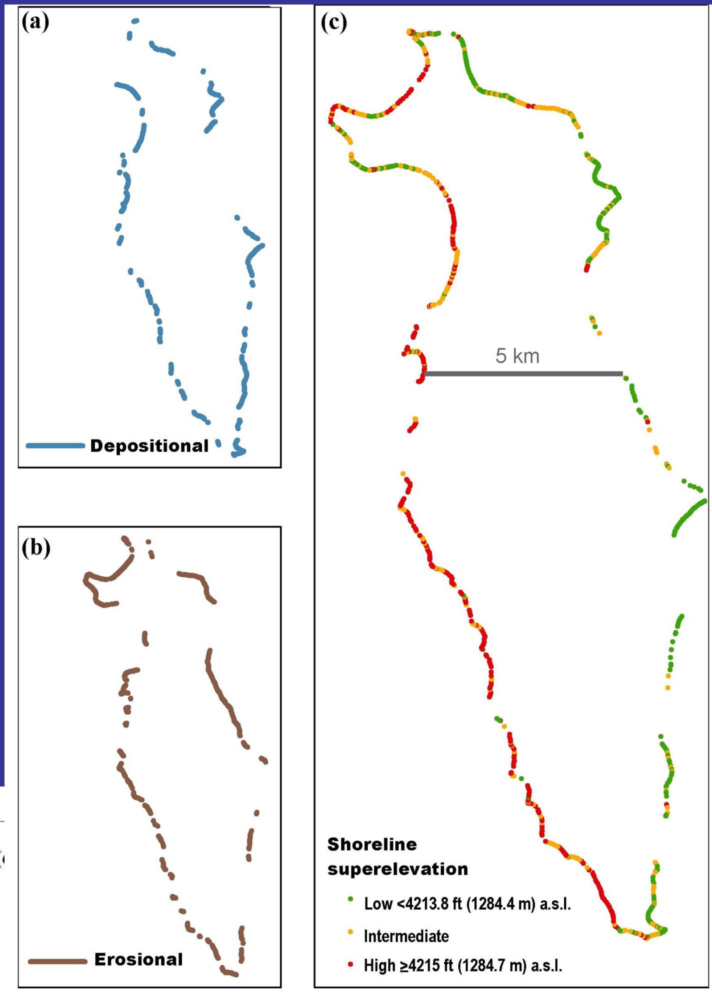
Classifications of abundance of materials (above) were based on visual assessment of amount of materials present, not percentages of materials of the shore.



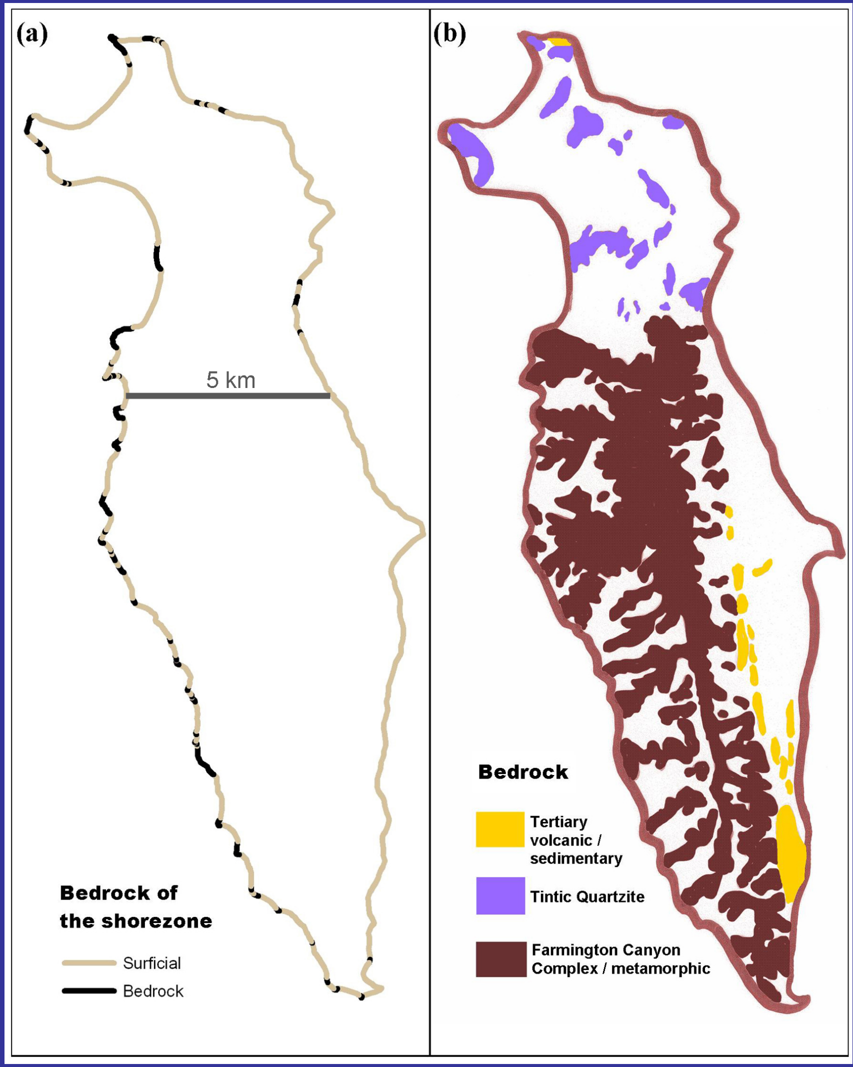
305 shoreline stretches characterized for geomorphic attributes such as fetch, aspect, shorezone slope.





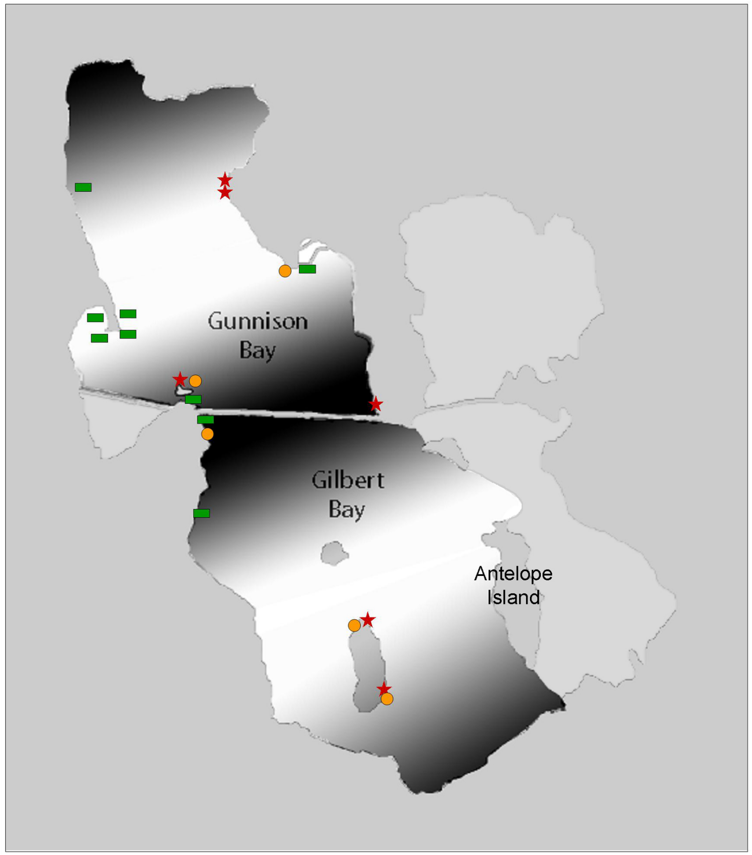


208 shoreline stretches characterized with geologic attributes such as bedrock versus surficial materials



Great Salt Lake data set:

5 relationships of Antelope Island research tested
10 shore regions
20 contrasting coastal conditions
608 surveyed locations



Shores classified as generally ★high, ●intermediate, and ▬low shoreline superelevation.

Antelope Island research data set

What worked: LINEAR REFERENCING in GIS.

Diverse data sets can be referenced to a common “shoreline.”

POINT DATA

1228 locations surveyed for elevation of shoreline evidence.

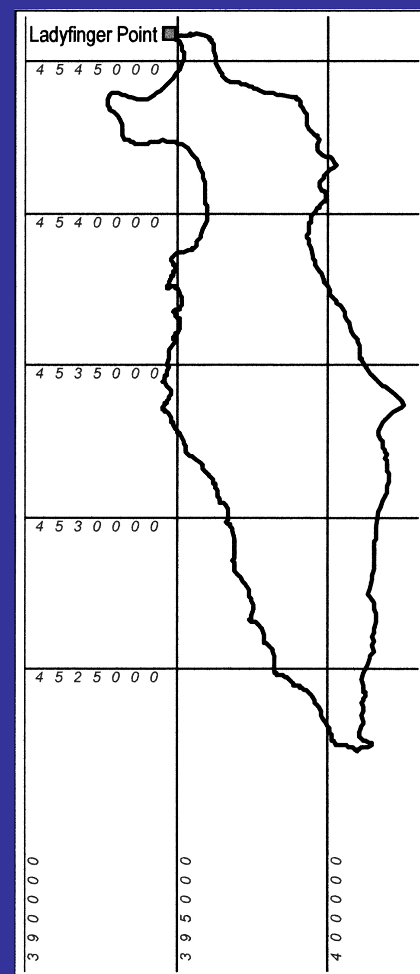
THREE SETS of LINE DATA

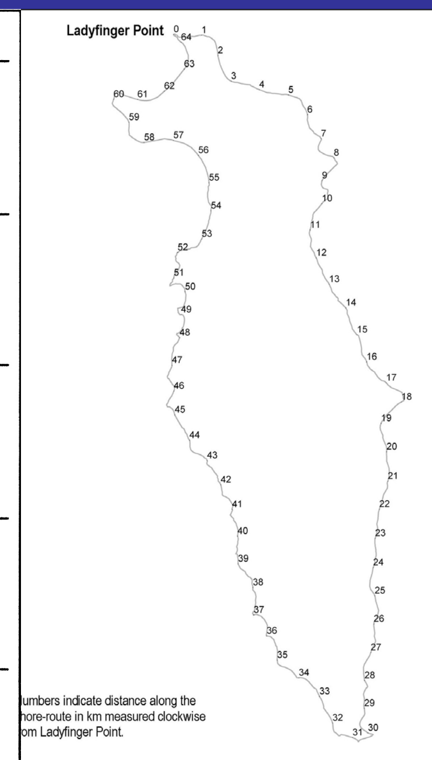
667 shoreline stretches characterized for the 15 attributes.

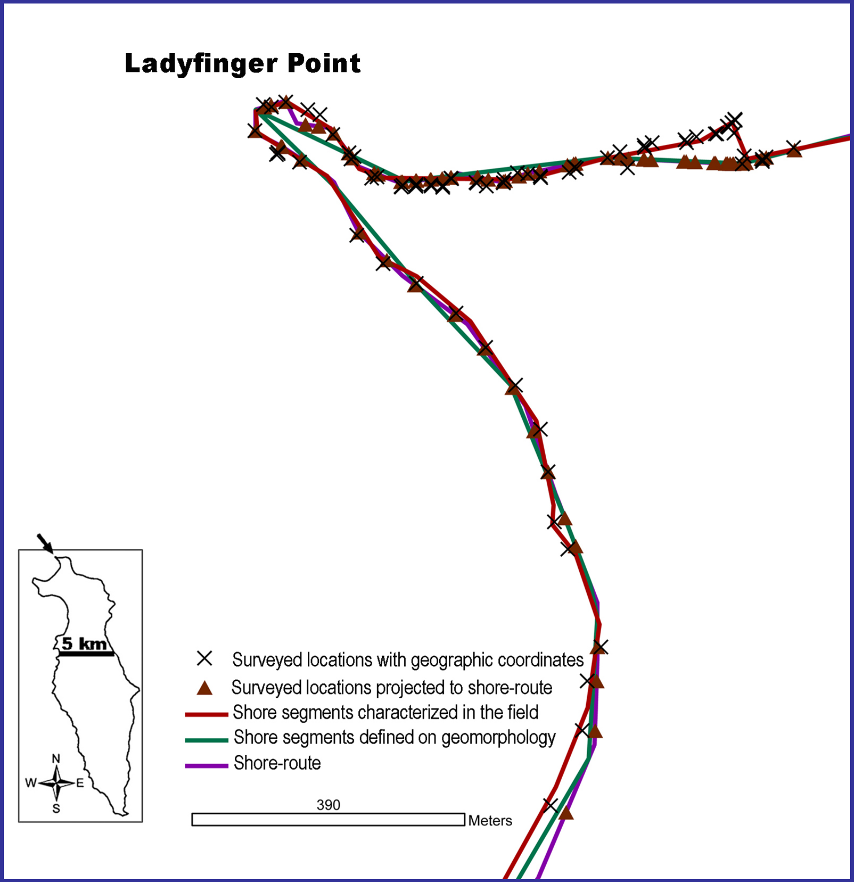
305 shoreline stretches characterized for geomorphic attributes such as fetch and aspect from maps.

94 shoreline stretches characterized for their planform shape, such as convex or concave.

POLYGON DATA 208 shoreline stretches characterized with geologic attributes such as bedrock versus surficial materials.





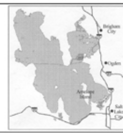


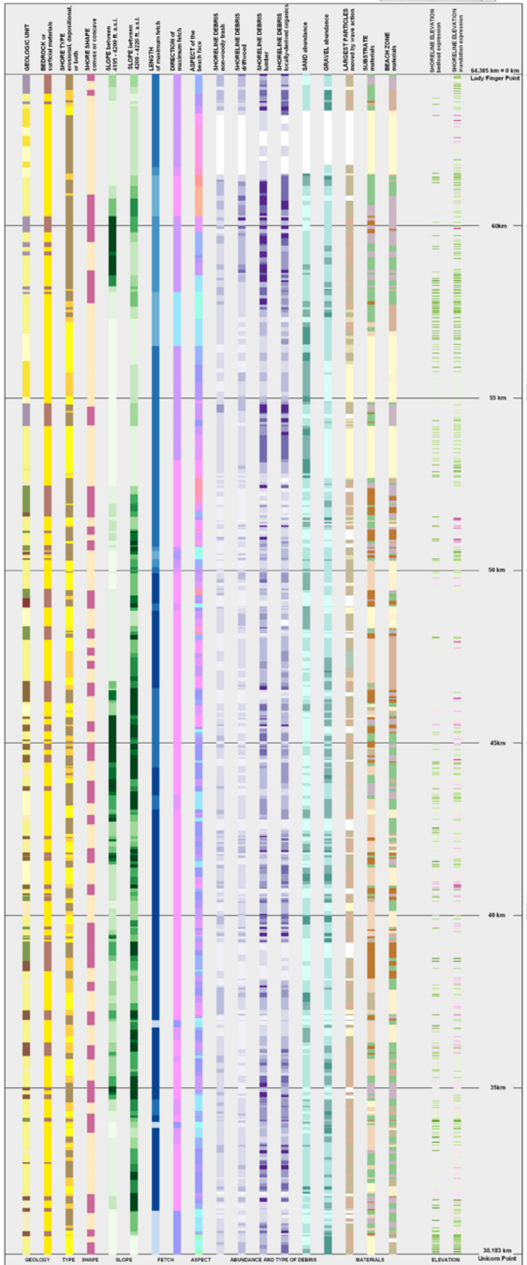
The attribute sets (point, line and polygonal) were projected to the “shore route” so differences in shoreline elevation could be analyzed with respect to diverse attributes.

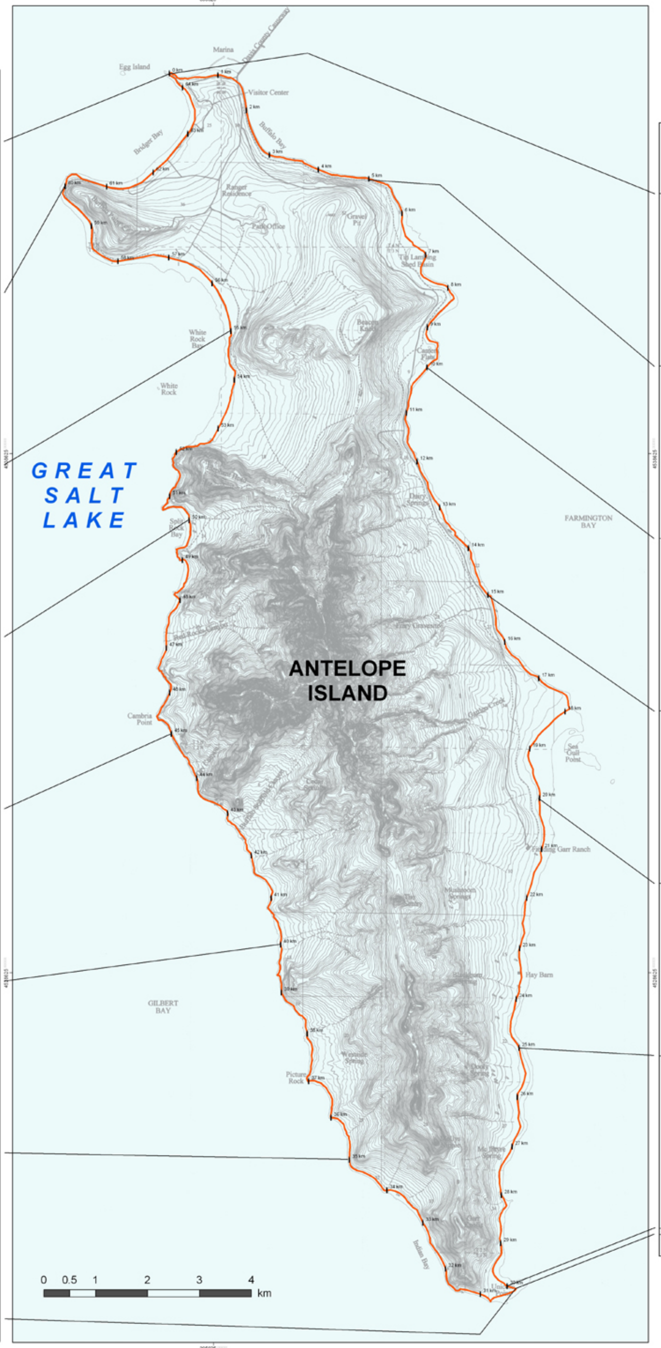
(Atwood, G., 2003, Columnar display of multiple attributes of linear features using ArcGIS, *in* 2003 ESRI International User Conference: Redlands, Calif., ESRI Press, Proceedings of the twenty –third annual ESRI user conference.
Atwood, G., and Cova, T.J., 2000, Using GIS and linear referencing to analyze the 1980s shorelines of Great Salt Lake, Utah, USA, in 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Boulder, Colo., NOAA National Geophysical Data Center.)

Columnar Display of Twenty Characteristics of the 1986-87 Highstand Shoreline of Great Salt Lake on Antelope Island.
Plate 1: Data display

Genevieve Atwood, genevieve.atwood@geog.utah.edu
(unpublished doctoral research in progress)







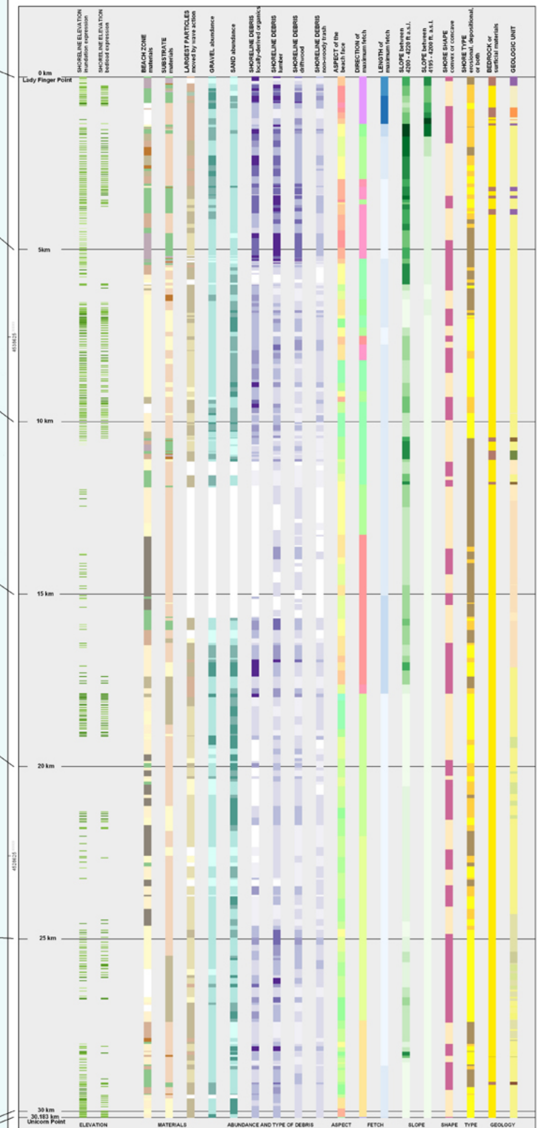
EXPLANATION:

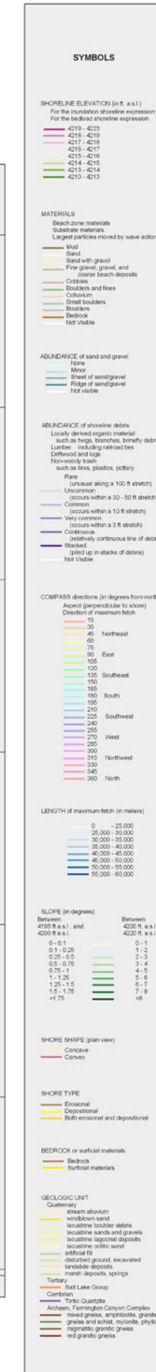
Plate 1, Columnar Display of Twenty Characteristics of the 1986-87 Highstand Shoreline of Great Salt Lake on Antelope Island, is a hard-copy plot of a map created using ESRI ArcGIS ArcView 8.2 software. Each column shows variability of one shoreline characteristic, referred to in GIS terminology as an attribute. Diverse data types are displayed. Quantitative data include shoreline elevation and length of maximum fetch. Ordinal data include relative abundance of shoreline debris types. Nominal data include shore shape and shore type. Colors depict attribute values. Antelope Island is elongated north - south. The order of columns for the east side of the island mirrors that of the west side of the island.

Spatial location of attribute data is keyed to distance referenced along a shore route. The shore route is displayed in red on the map of Antelope Island. Positions along the shore route have linear referenced location measured in kilometers, clockwise, from Lady Finger Point, and geographic location referenced to UTM zone 12N, North American Datum 1927. Grid lines associate data in columns with position along the shore route.

Plate 1 can be viewed hard-copy or interactively using ESRI GIS software. With GIS software, columns of data can be turned off and on. Color schemes can be altered to enhance visualization of attribute values.

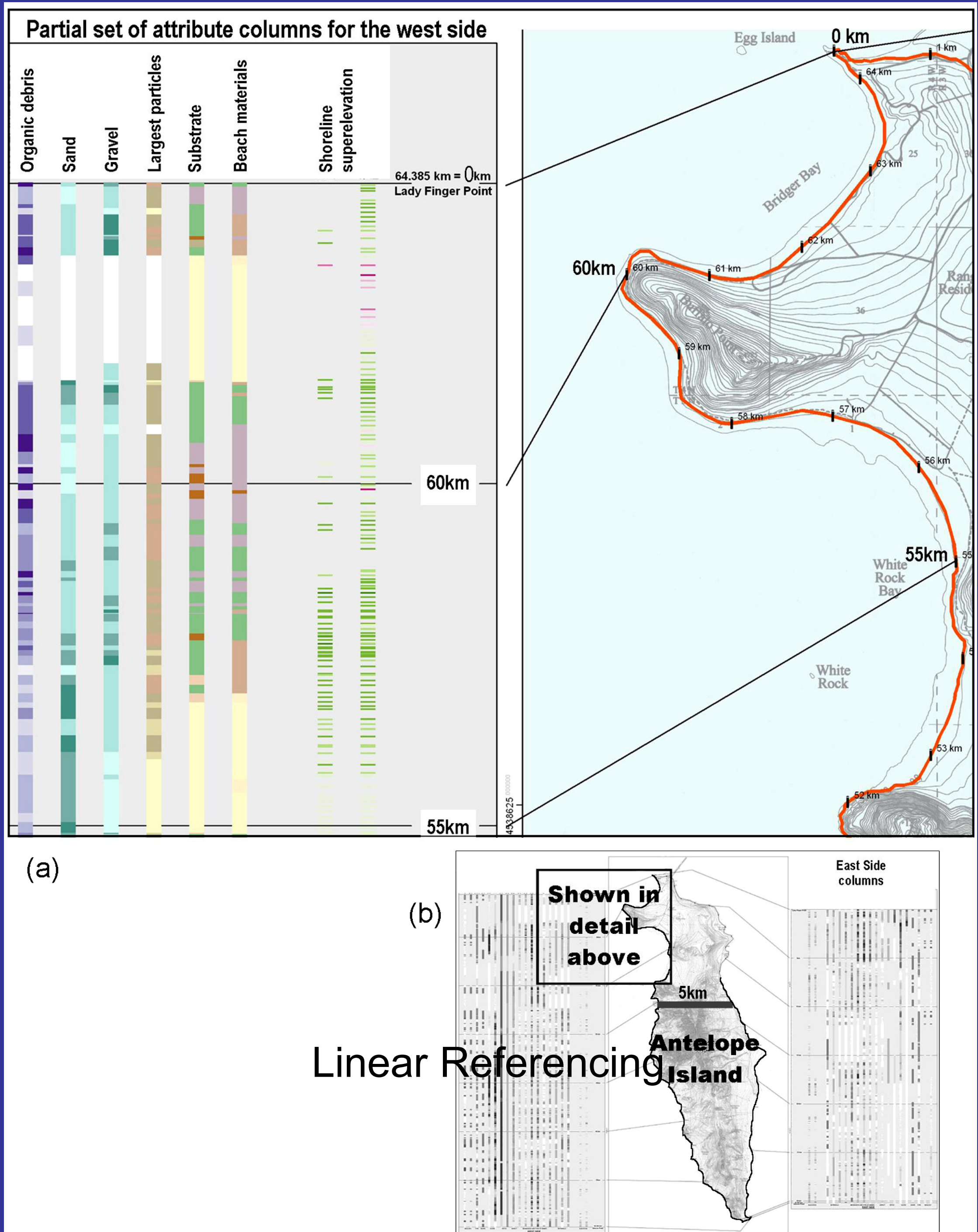
Plate 1 displays a complete research dataset. Subsets of attributes and data can be created interactively to explore relationships. Plate 2 is a hard-copy example of a GIS-generated interpretive display that highlights correlations between shoreline superelevation (shoreline elevation above the undisturbed, stillwater lake level) and shorezone characteristics such as aspect, length of maximum fetch, slope, and spatial location.





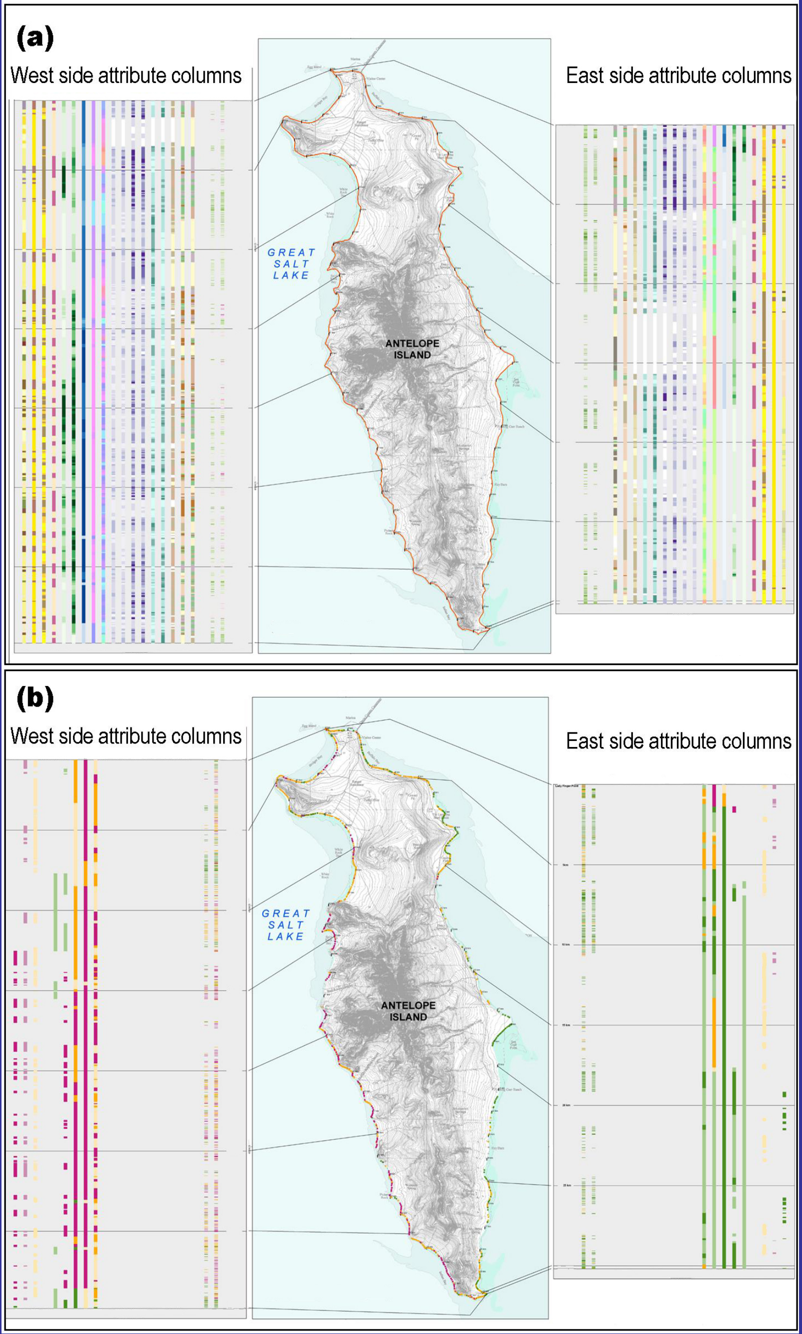
SOURCES:

Base and index maps adapted from Utah State Parks and Recreation, 2001, Antelope Island State Park 2001, 1:48,000.
Color ramps adapted from ESRI ArcGIS style manager and ColorBrewer web site of Cindy Brewer, Pennsylvania State University.
Shoreline elevations were surveyed in 1998.
Shoreline characteristics were surveyed in 1998 including: materials of the beach zone; substrate; largest particles moved by wave action; abundance of shoreline debris types, and shore type.
Fetch was derived from USGS, 1998, State of Utah: Shaded Relief Map, 1:500,000.
Aspect, slope, and shore shape were derived from USGS 7.5 minute topographic quadrangle maps, 1:24,000.
Geology was derived from Doelling, H.H., et al., 1990, Geologic Map of Antelope Island, Davis County, Utah, Map 127, Utah Geological Survey, 1:24,000.
Software used to digitize, store, analyze, and manage data included: Cartalinx and IDRISI of Clark University Labs, Worchester, MA; ArcView, ArcInfo, and ArcGIS of Environmental Systems Research Institute, Redlands, CA; and S-Plus of Insightful Corporation, Seattle, WA.



Associations are easy to present but their meaning is a challenge.

GIS provides tools to highlight relationships. (next slide).



The upper display shows all attributes. The columns closest to the island are elevation data.

The lower display classifies the elevation data in quantiles (higher elevations in reds and oranges and lower elevations in greens and yellows).

Note how the elevation of shoreline evidence of the 1980s highstand is clearly lower (greens) on the east side of the island and higher (reds and oranges) on the west side.

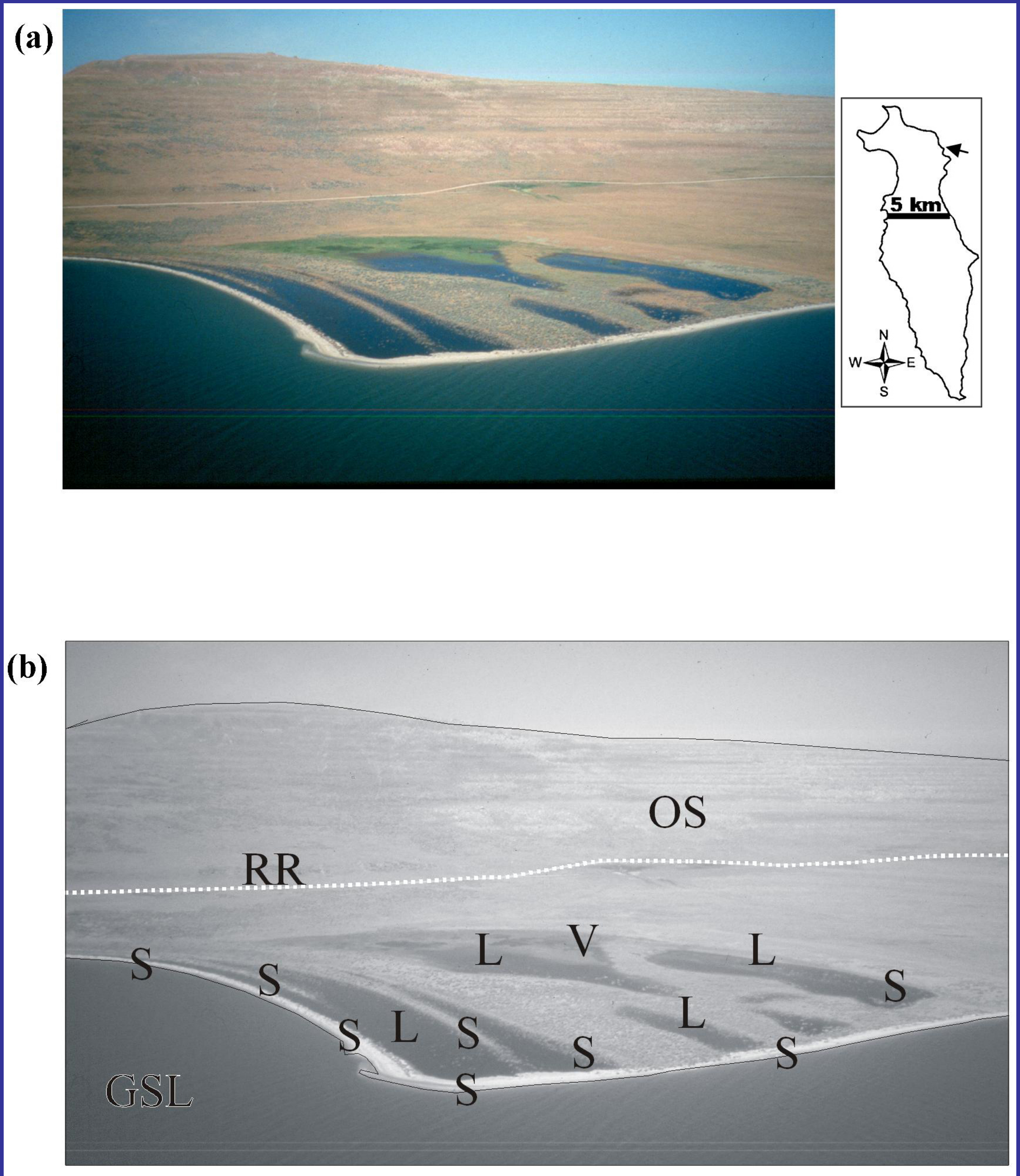
Attributes portrayed as quantiles showed associations. For example, quantile classes of “slope immediately off shore” had patterns similar to patterns of shoreline superelevation.

TIPS to mappers:
Try to view evidence from different perspectives

Satellite
From the air
On the ground

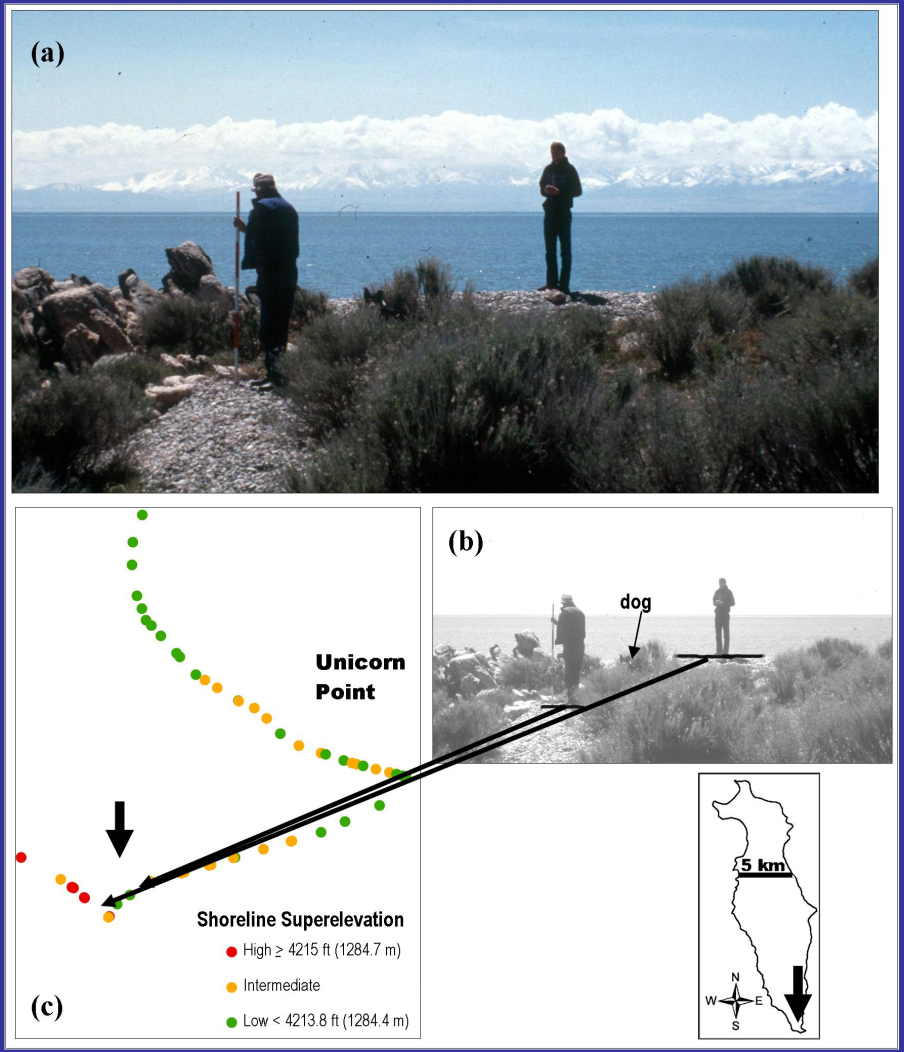
FROM the AIR.
Still-water elevation of GSL and shorezone features of the highstand. Image taken (Atwood) from helicopter survey within a week of June 3, 1986 highstand.

S = Shoreline evidence
L = Lagoon
V = Vegetation change
RR = Ranch Road
OS = Older shorelines



ON THE GROUND.

The 1980s highstand left unequivocal evidence. It contained anthropogenic trash. We were not lost stratigraphically. Without this evidence, the two shoreline expressions (right) of the 1980s highstand might have been mapped as shorelines of different ages rather than the same highstand event but expressions of contrasting wave energy.

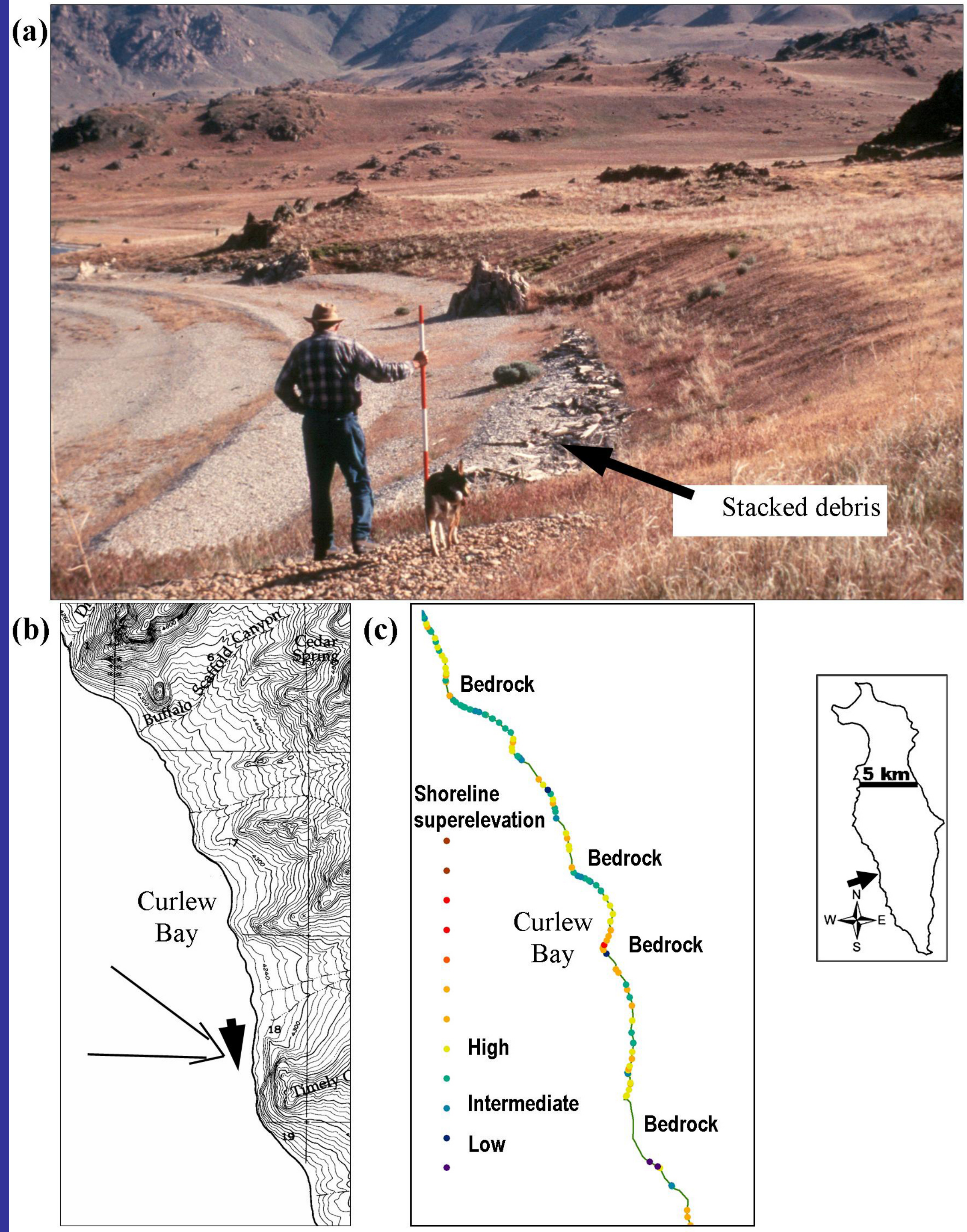


It helps to see the processes in action… in real time.

Antelope Island's cobble beaches are erosional remnants of the swash zone. Still-water elevation is at the base of the cobble beach. Waves run up the shore and carry away fines abrading cobbles. This is a low-energy beach. Buffalo Bay, 1998.

Stacked debris indicated transport direction.

But stacked debris is ephemeral.

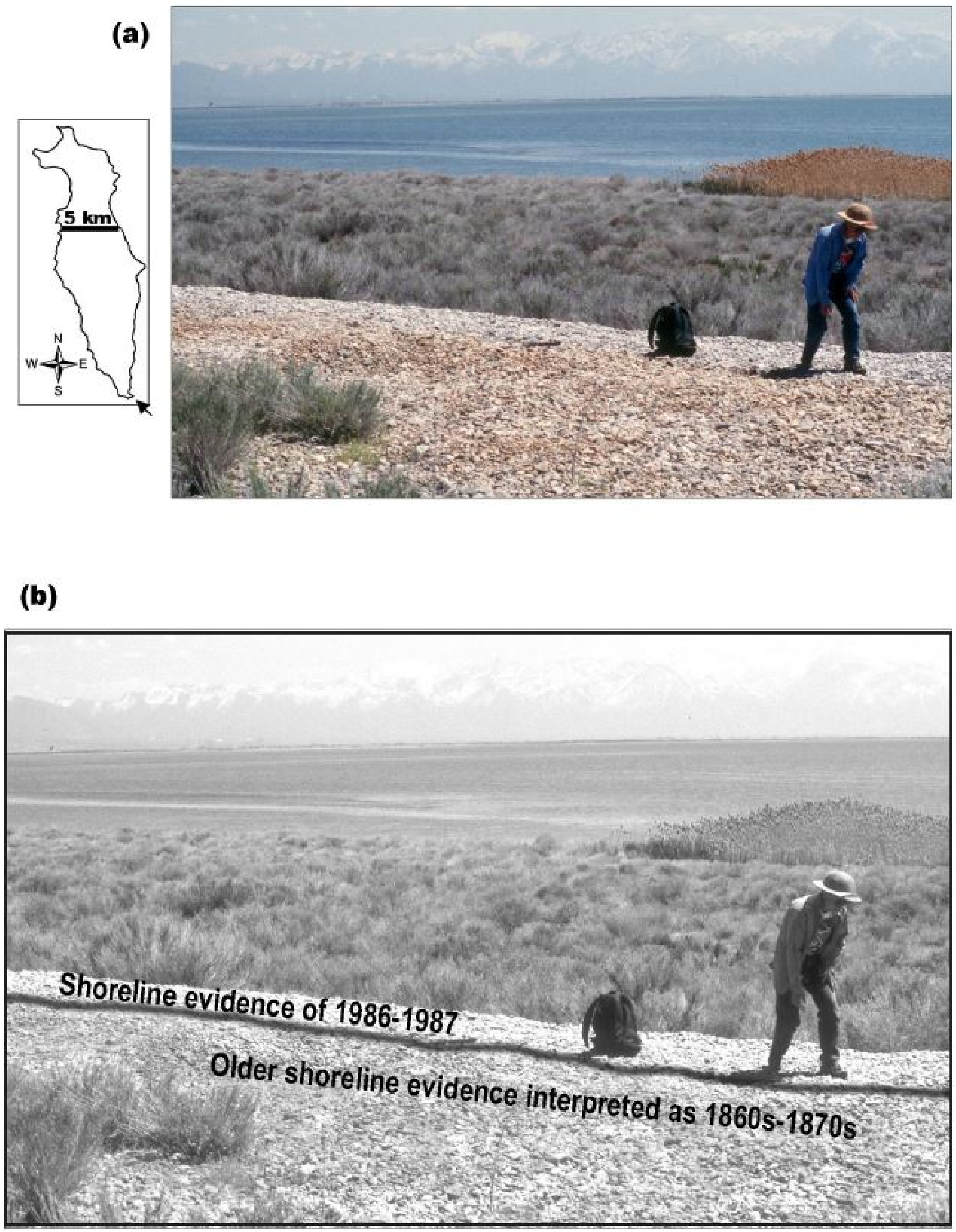


The problem of reworked terrigenous materials.

We distinguished only one patch of 1860s highstand debris. Note change in patina. Patina is ephemeral.

Two highstands to the same elevation will not be distinguished.

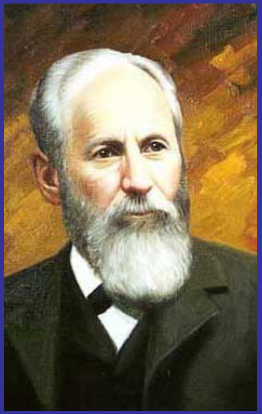
Succeeding higher highstands rework prior ones eliminating evidence of the earlier highstand.



Highly recommended:

Have colleagues,
Have a buddy.

And always check out what GK had to say on the subject.



This talk summarizes field methods and the GIS analysis of my University of Utah doctoral research published in Miscellaneous Publication 06-9, Utah Geological Survey.

Committee members: Katrina Moser (chair), Marjorie Chan, Tom Cova, Paul Jewell, Harvey Miller; and former committee members: Don Currey (deceased), Roger McCoy.

Field colleague: Don R. Mabey.
Field assistance: Roy Adams, Katie Andrews, Amanda Atwood, Tim Edgar, Alisa Felton, Holly Godsey, Art Hantla and family, Paul Jewell, Matthew Mabey, Linda Martinez, Mark Milligan, Ann Neville, Vicki Pedone, Pamela Poulsen, Jack Oviatt, Janet Roemmel, Vicky Solomon, and Catherine Spruance.

Technical assistance: Mark Finco, Matthew Mabey, and Tamara Wambeam for GIS assistance, and Julia Reid for assistance with SPlus statistical software.

Logistical support: Antelope Island State Park; Utah Geological and Mineral Survey; Lee Brown and Dan Tuttle of US Magnesium; Jim Huizingh and Nathan Tuttle of Morton Salt; Eric Beaumont and Tom Burton of Great Salt Lake Minerals; the Bleazard brothers of Stansbury Island; and Bill Hopkins of Deseret Land and Livestock.

Readers of earlier drafts: Roy Adams, Lehi F. Hintze, Don R. Mabey, Charles G. (Jack) Oviatt, and Dorothy A. Sack.

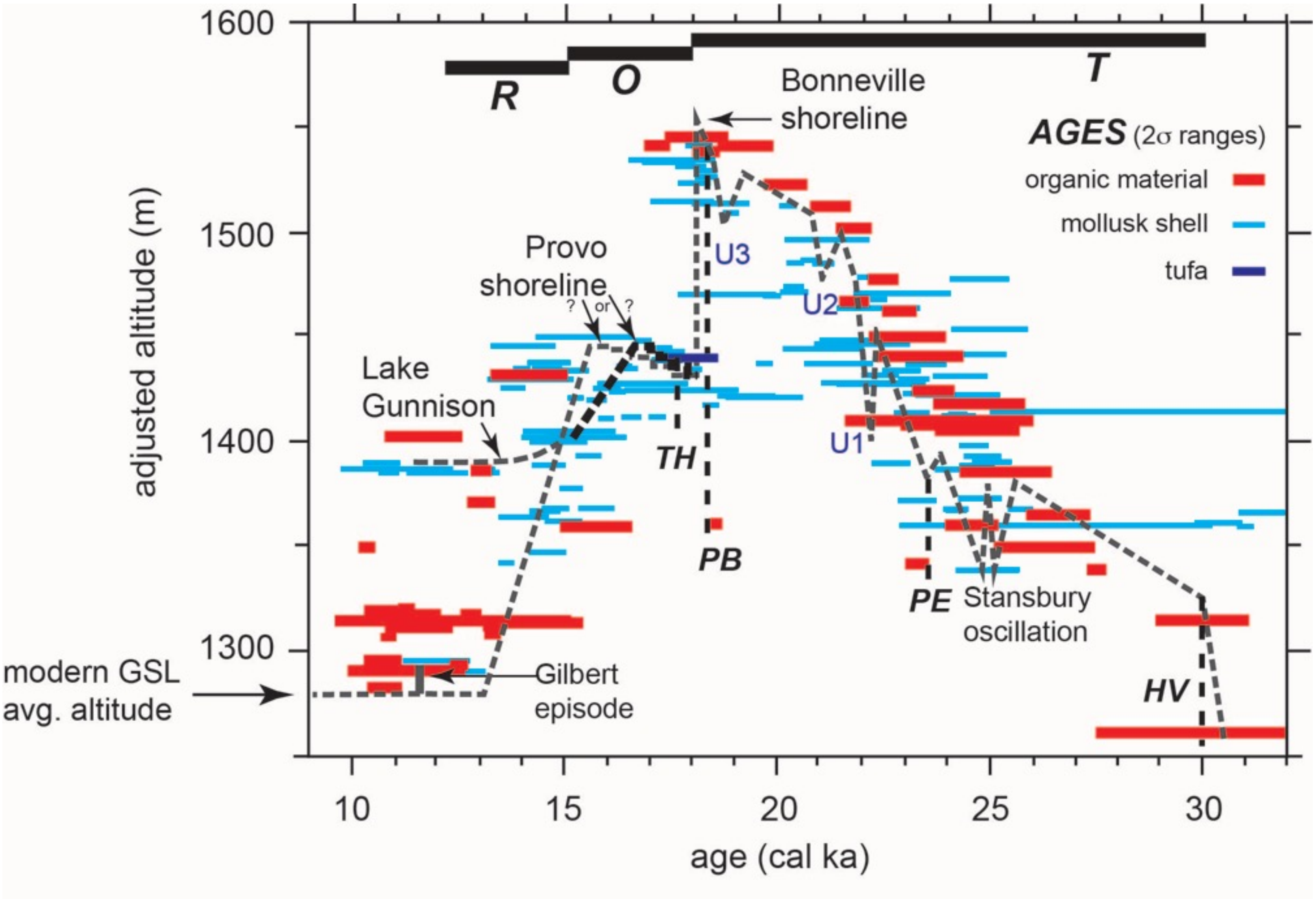
Funding and in-kind support: USGS data grant for satellite imagery; NSF grant to Chan and Currey, NSF grant DEB-9817777.

Stratigraphy, Marker Beds, and Age Dating

Jack Oviatt
Kansas State University
(retired)

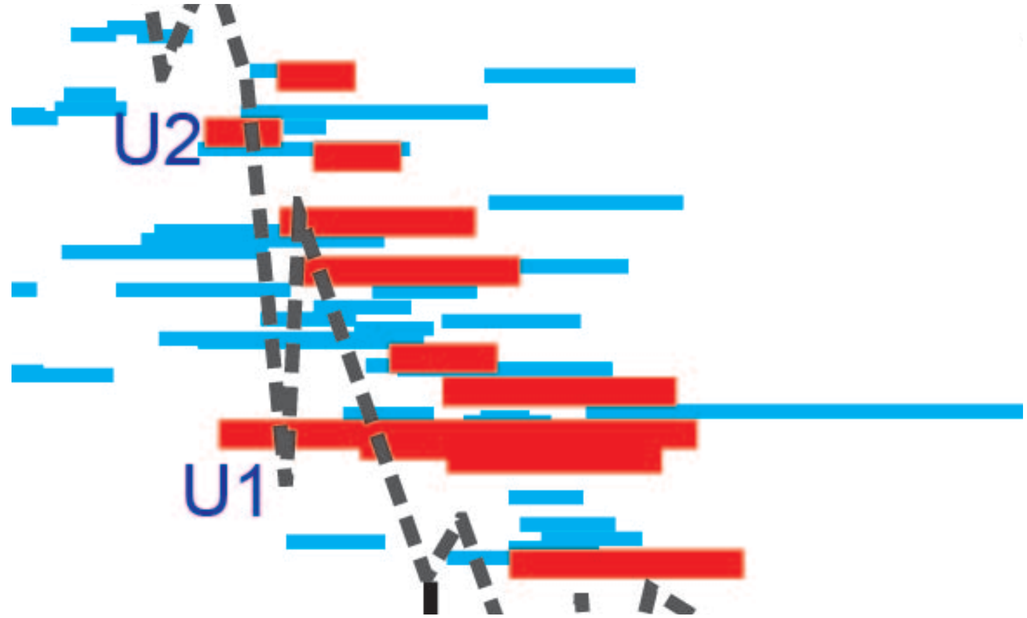
Lake Bonneville chronology

- hundreds of radiocarbon ages reviewed
- used: ages with known stratigraphic and/or geomorphic context; ages of reliable materials; ages in shoreline settings
- not used: ages in cores; most tufa ages; infinite ages


1600
1500
1400
1300
adjusted altitude (m)
R
O
T
Bonneville shoreline
AGES (2σ ranges)
organic material
mollusk shell
tufa
U3
U2
U1
Provo shoreline
? or ?
Lake Gunnison
TH
PB
PE
Stansbury oscillation
HV
modern GSL avg. altitude
Gilbert episode
10
15
20
25
30
age (cal ka)

Oviatt, 2015

Radiocarbon ages of wood or charcoal have fewer potential problems than radiocarbon ages of gastropod shells (or any carbonate materials).



Therefore, shell ages that are older than wood ages at the same elevation have to be incorrect; but they might indicate radiocarbon reservoirs in the water.

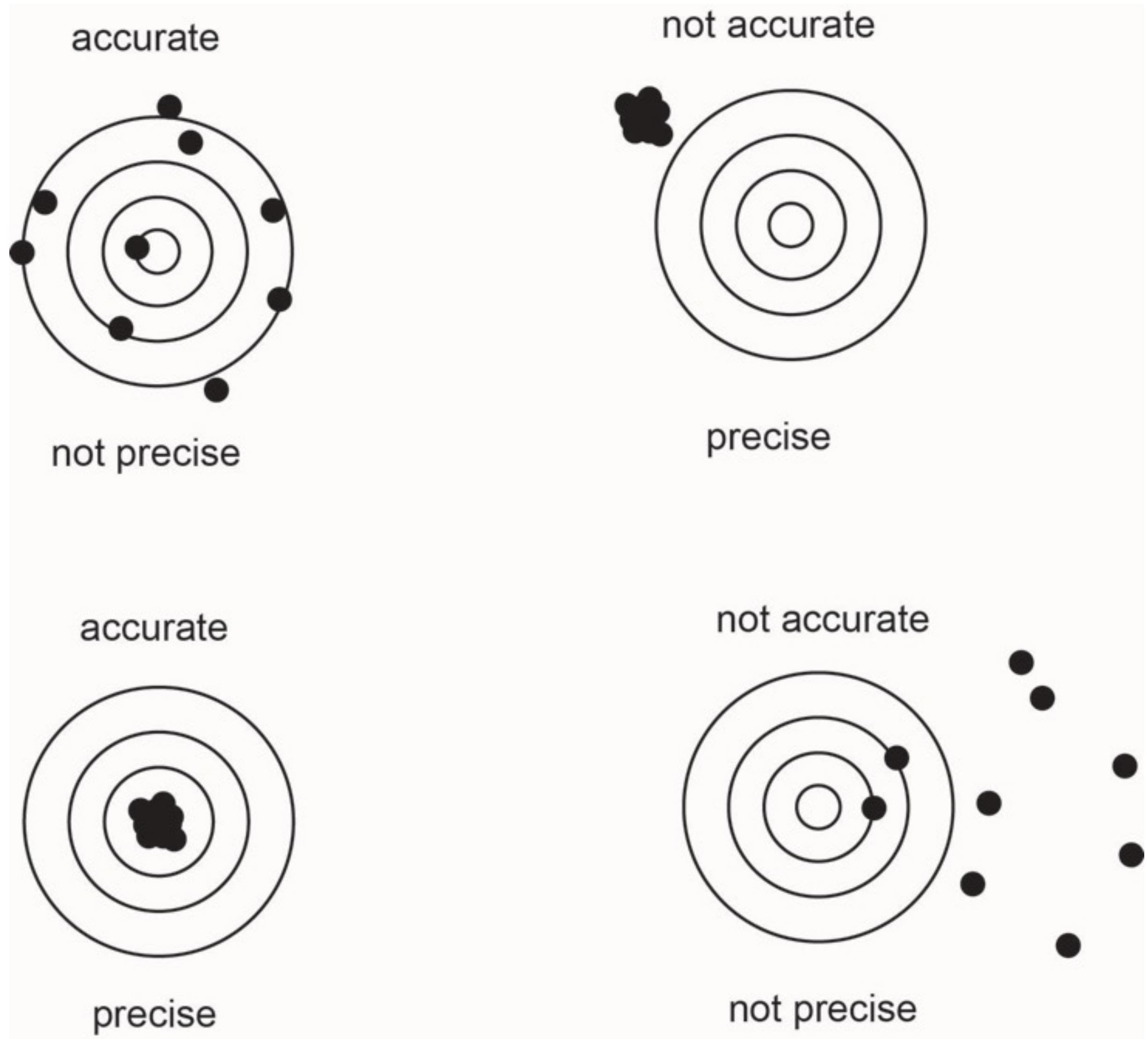
Bonneville barrier south of Kanosh

Oviatt (1991a); Oviatt, unpublished

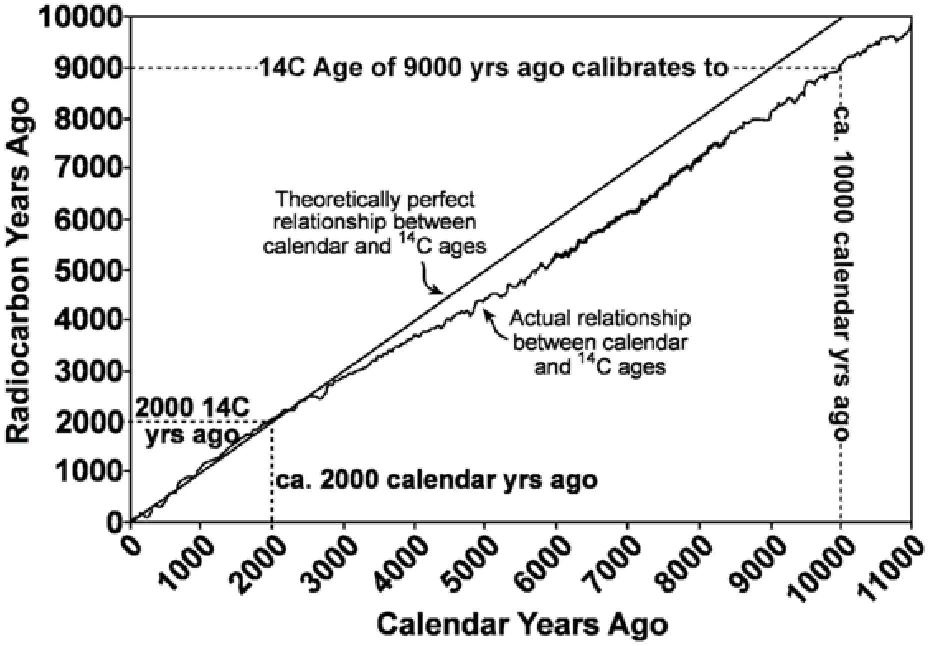
radiocarbon ages:

- 14,130 ± 100 charcoal mixed with soil and sediment
- 14,650 ± 190 charcoal mixed with soil and sediment
- 15,250 ± 160 charcoal
- 15,320 ± 140 charcoal
- 15,900 ± 290 charcoal
- 19,840 ± 400 charcoal
- >27,150 mollusk shells

accuracy and precision

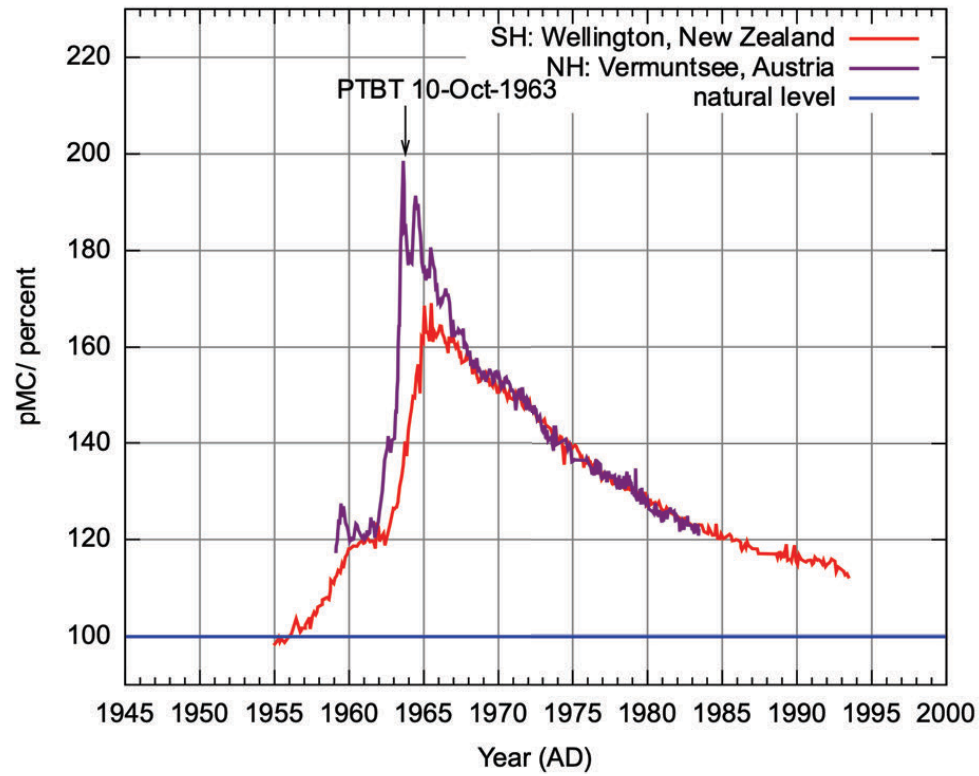


radiocarbon calibration



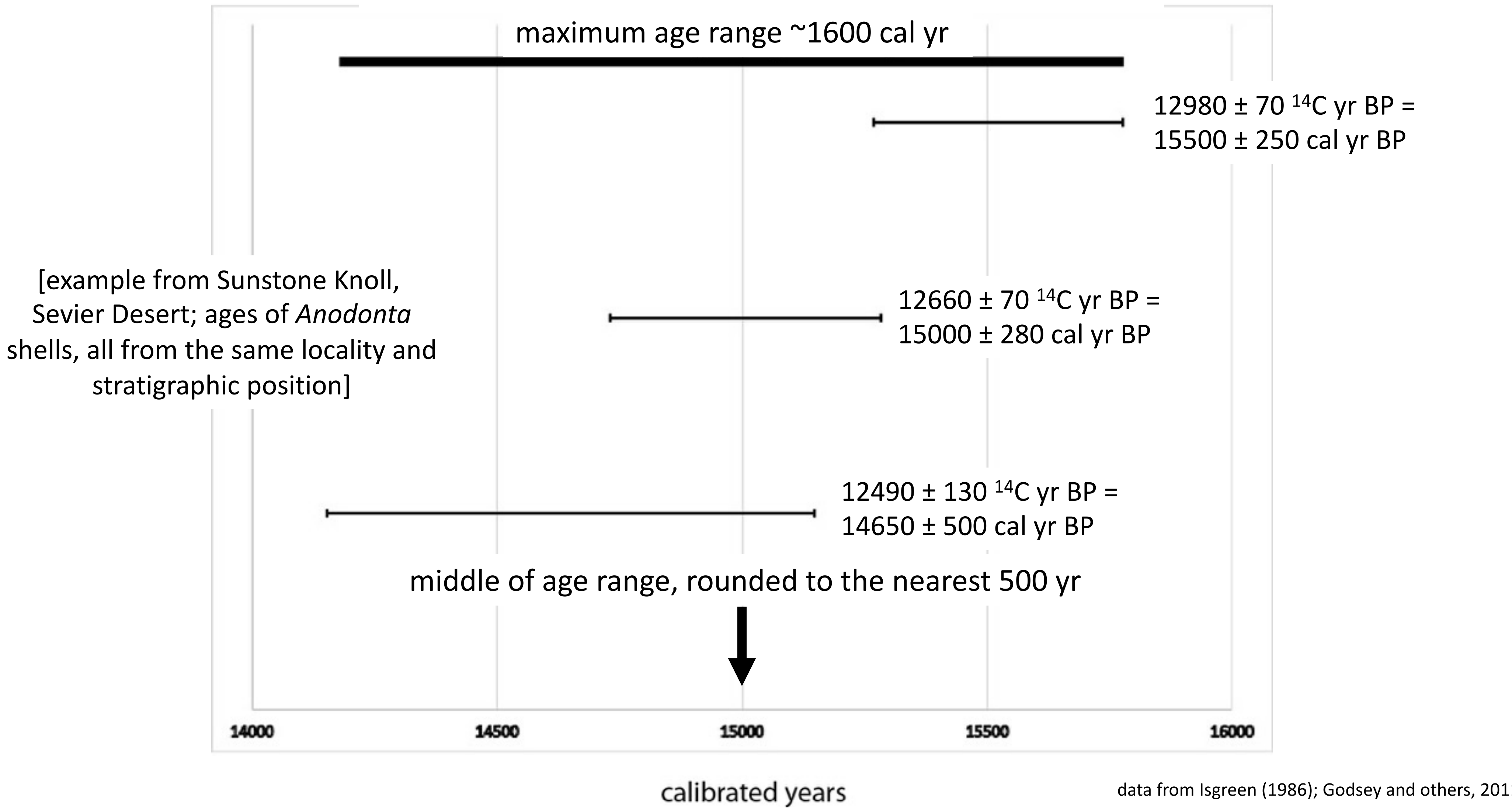
https://www.researchgate.net/figure/Radiocarbon-calibration-curve-the-straight-line-shows-what-a-perfect-relationship_fig2_255483709

atmospheric radiocarbon



https://en.wikipedia.org/wiki/Partial_Nuclear_Test_Ban_Treaty

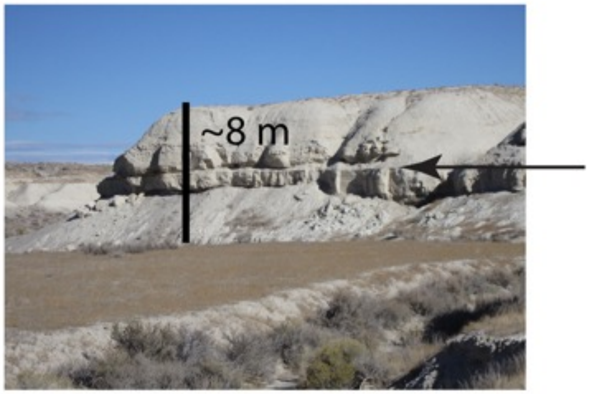
rounding of radiocarbon ages



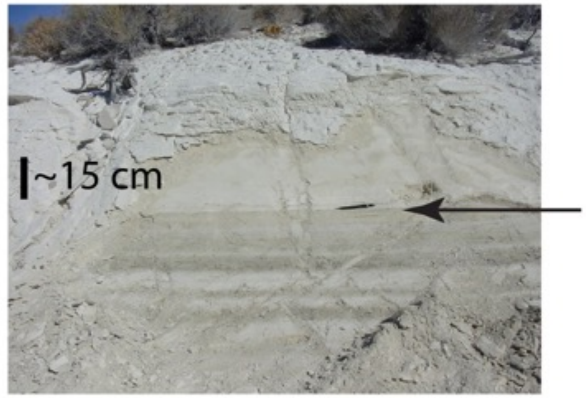
data from Isgreen (1986); Godsey and others, 2011

Bonneville flood

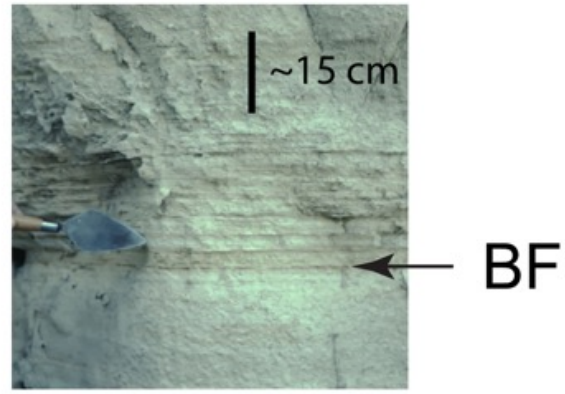
near Deep Creek, western Utah



NW of Sevier Lake

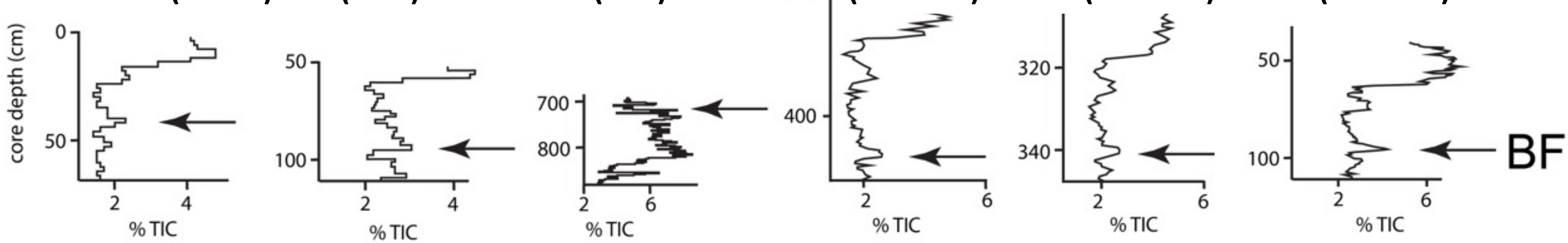


Old River Bed



outcrops

Newfoundland Mtns. (NFM5) **Fingerpoint (DIW)** **Sevier Lake (RK8)** **Great Salt Lake (GSL96-3)** **Great Salt Lake (GSL96-4)** **Great Salt Lake (GSL96-6)**



TIC in cores

Oviatt (1987); Thompson and others (2016); unpublished


Old River Bed
two-year-old for scale
BF

Hansel Valley Wash

Bonneville flood

near Deep Creek, western Utah

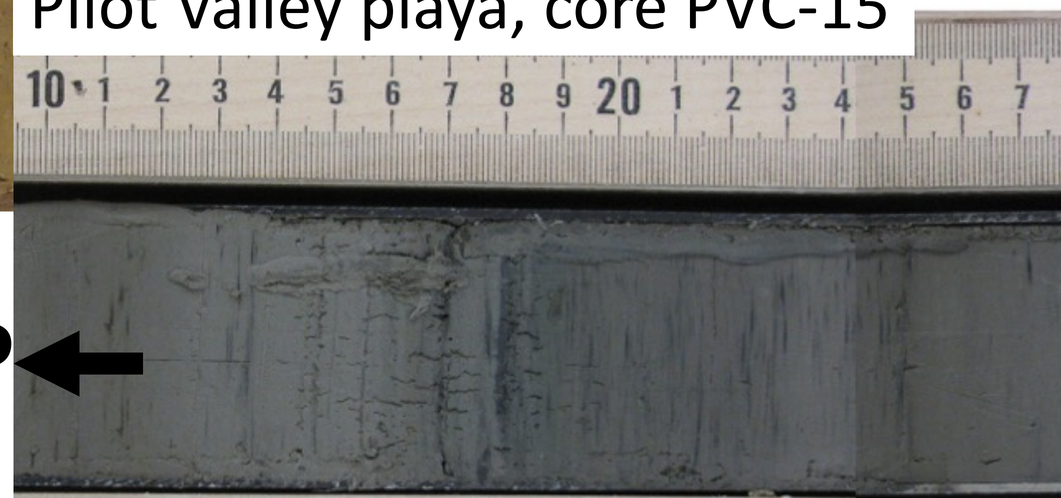
Bonneville flood in cores

Blue Lake

UP

BF

Pilot Valley playa, core PVC-15



UP

BF

photos from David Rhode and Kevin Ray

Deciphering Paleo-winds: The Promise and Pitfalls of Lake Bonneville

Paul Jewell
Department of Geology andGeophysics
University of Utah

Lake Bonneville Short Course
October 5, 2018

Lake Bonneville as a record of the Pleistocene climate of the Great Basin?

What we do know:

- **The Great Basin was colder during the Pleistocene**
- **The hydrologic balance was more positive (P > E) than today**

What we don't know:

- The general nature of the atmospheric circulation
- ***The influence of the continental ice sheet***
- ***The nature of the shift in climate regimes (when? gradual or rapid?)***

Paleoclimate variables:

- Temperature

Paleoclimate variables:

- Temperature

- Precipitation

Paleoclimate variables:

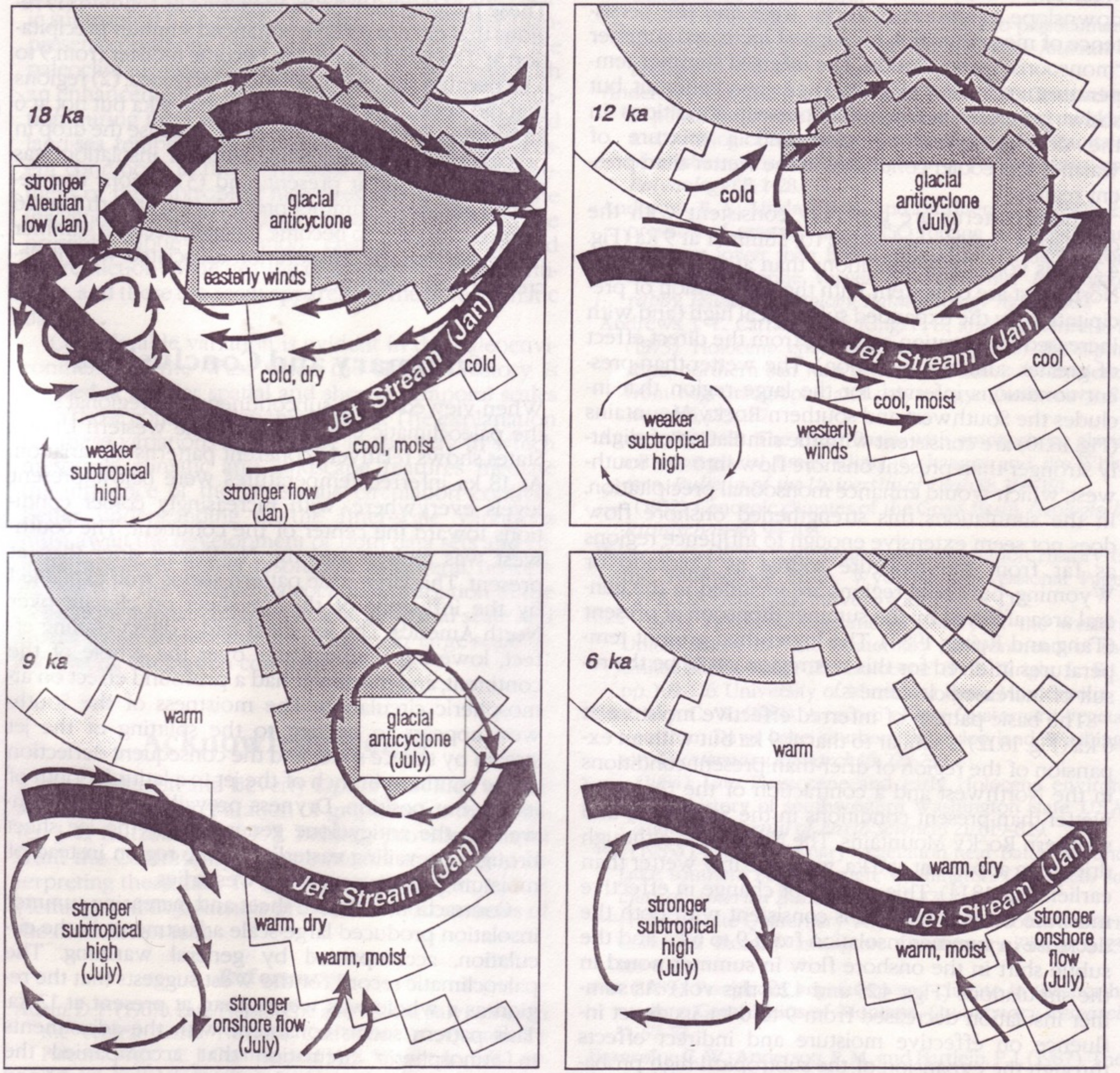
- Temperature

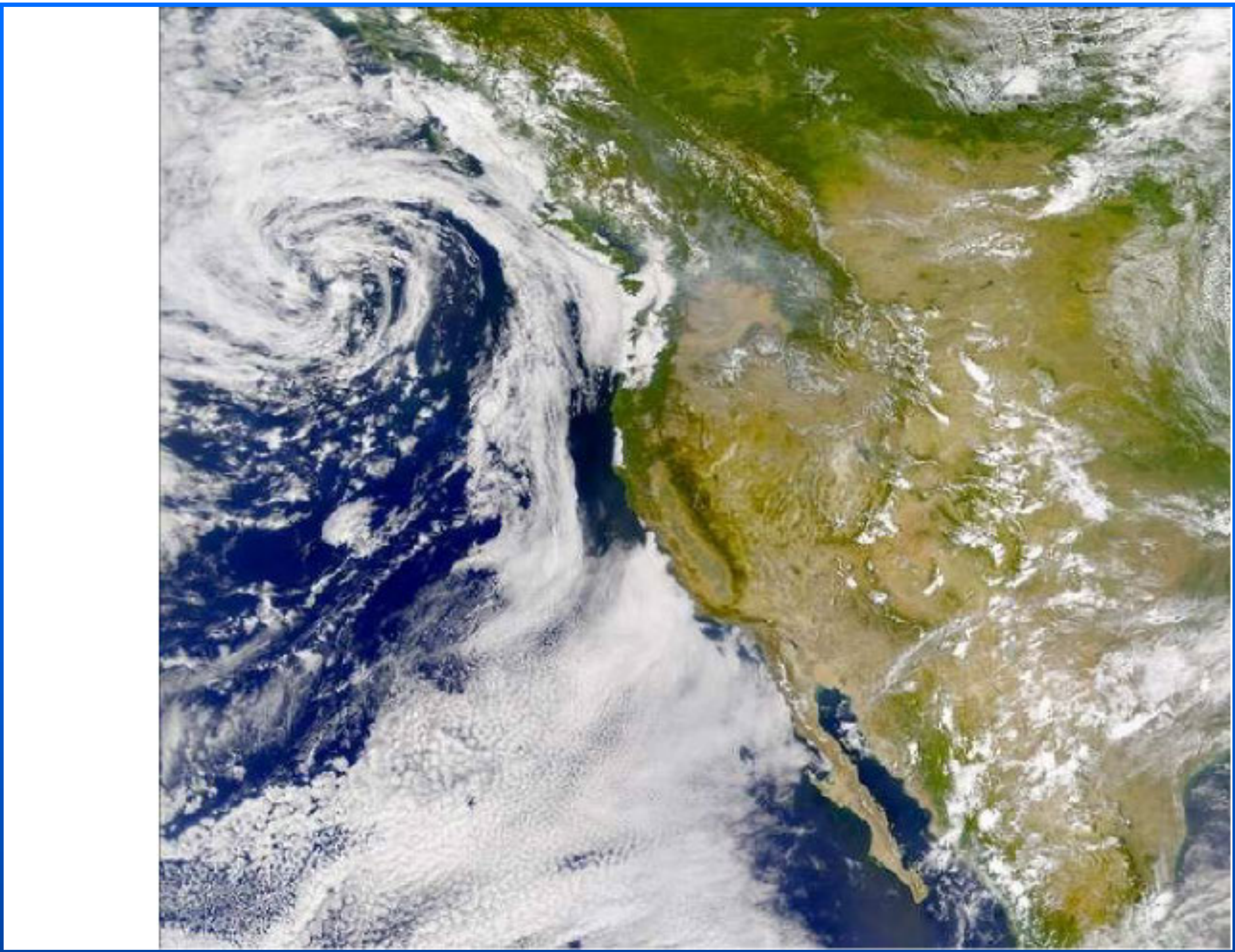
- Precipitation

- Wind speed, direction?

Significance of understanding paleowinds

- Transport of aeolian material (including toxic materials)
- Formation of common geomorphic features (spits, shorelines, tombolos)
- Validating climate models and evaluating the differences between modern and ancient climate
- Intellectually challenging (very few proxies)


18 ka
stronger Aleutian low (Jan)
glacial anticyclone
easterly winds
Jet Stream (Jan)
cold
cold, dry
weaker subtropical high
cool, moist
stronger flow (Jan)
12 ka
cold
glacial anticyclone (July)
Jet Stream (Jan)
cool
cool, moist
weaker subtropical high
westerly winds
9 ka
warm
glacial anticyclone (July)
Jet Stream (Jan)
stronger subtropical high (July)
warm, dry
warm, moist
stronger onshore flow (July)
6 ka
warm
warm, dry
Jet Stream (Jan)
stronger subtropical high (July)
warm, moist
stronger onshore flow (July)



“Extra-tropical cyclones”: these do most of the geomorphic work

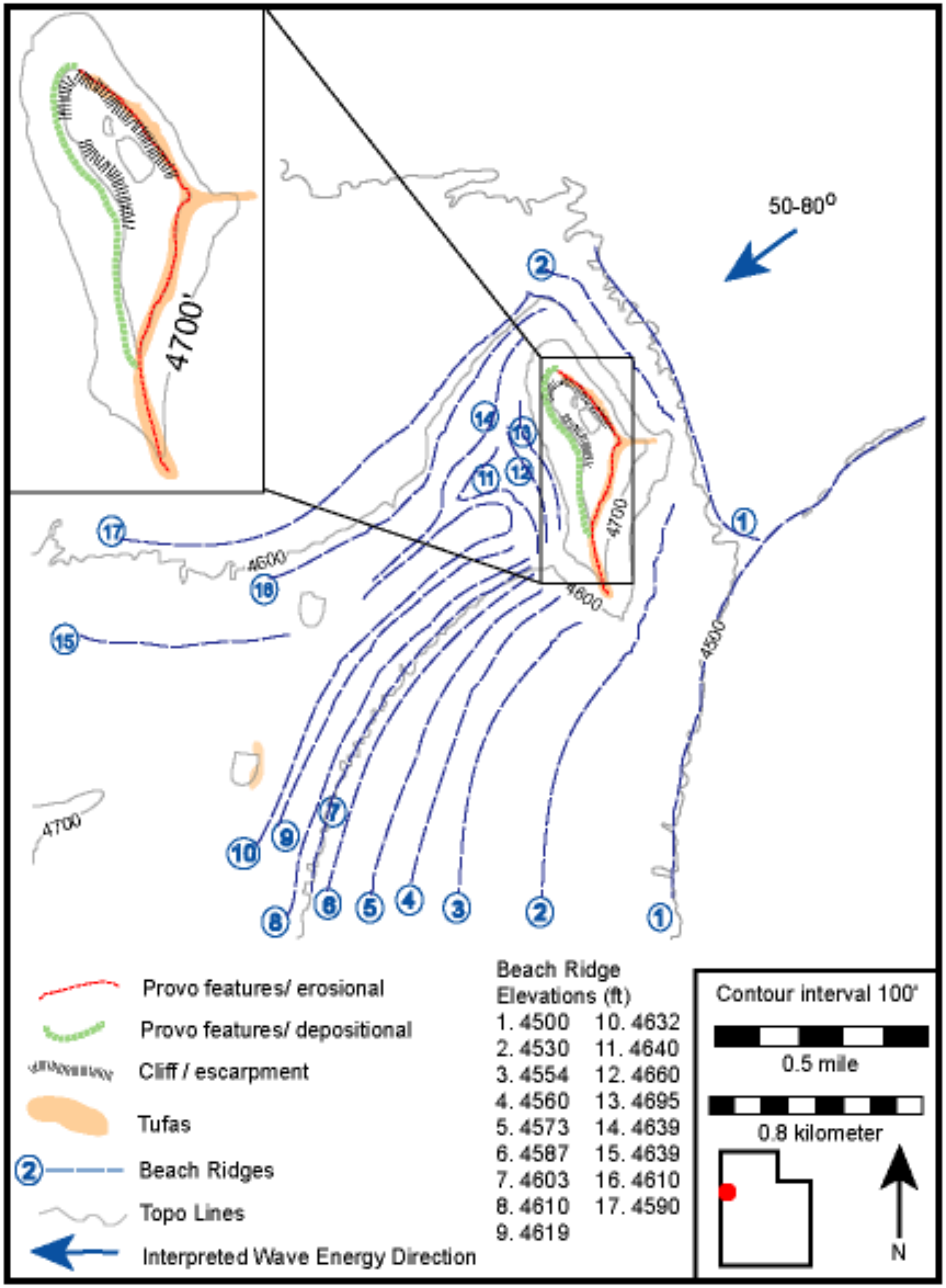
Existing paleowind proxies

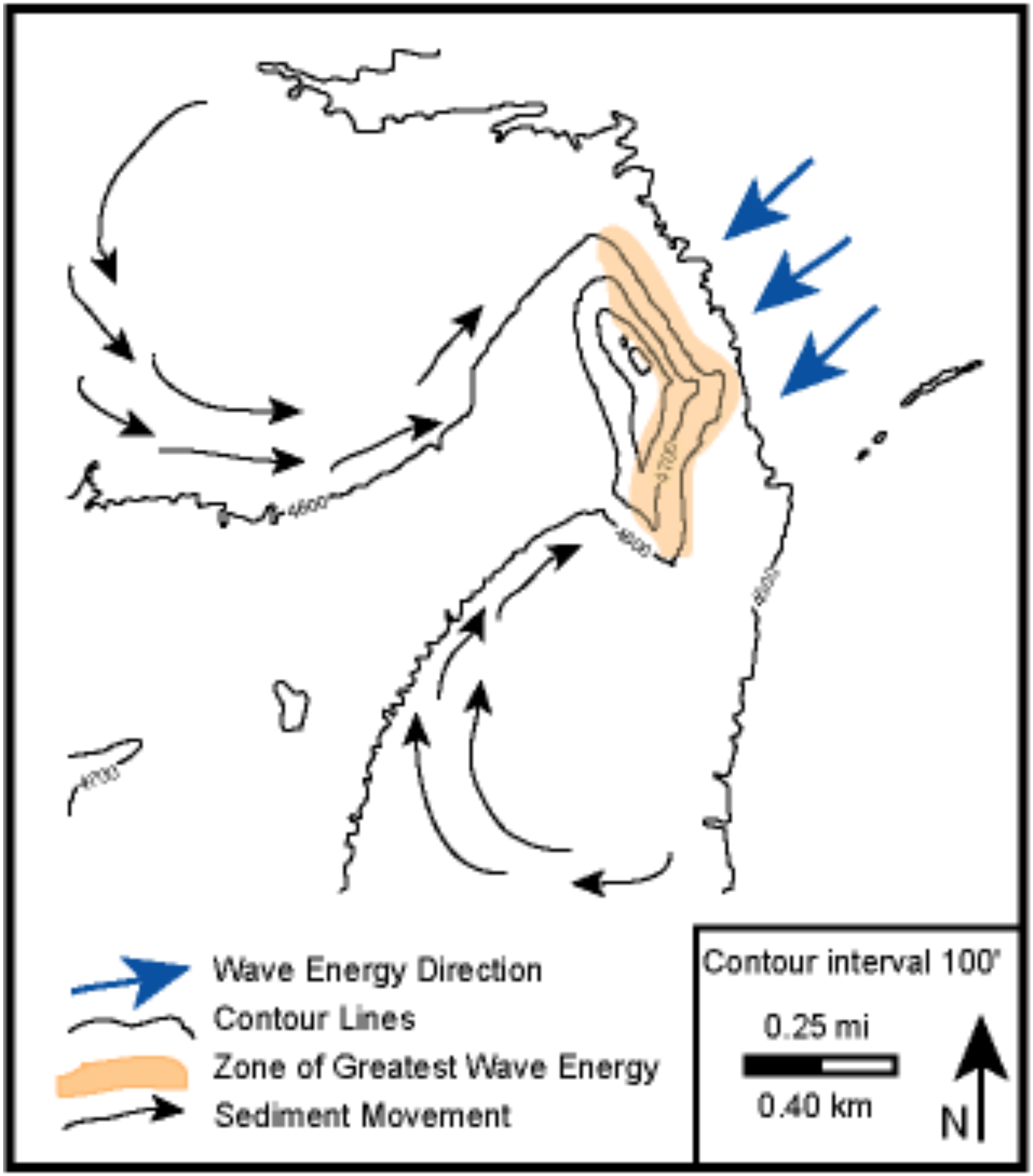
Proxy	Disadvantage
Loess/sand dunes	The result of relatively strong winds (> 6 m/s)
Fallen trees	Strong winds necessary to knock down trees

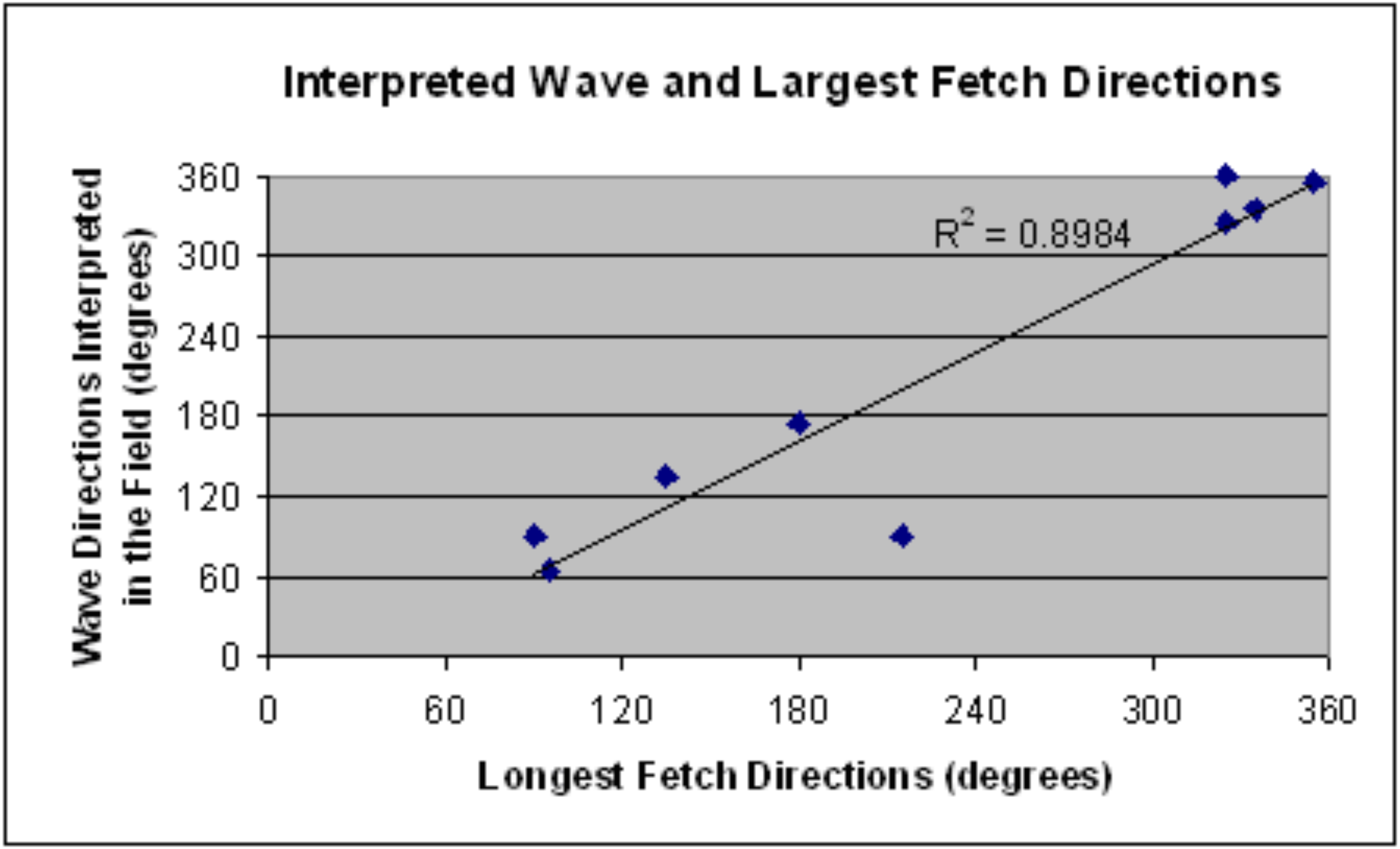
Most continental paleowind proxies have limited spatial distribution: might there be something better?

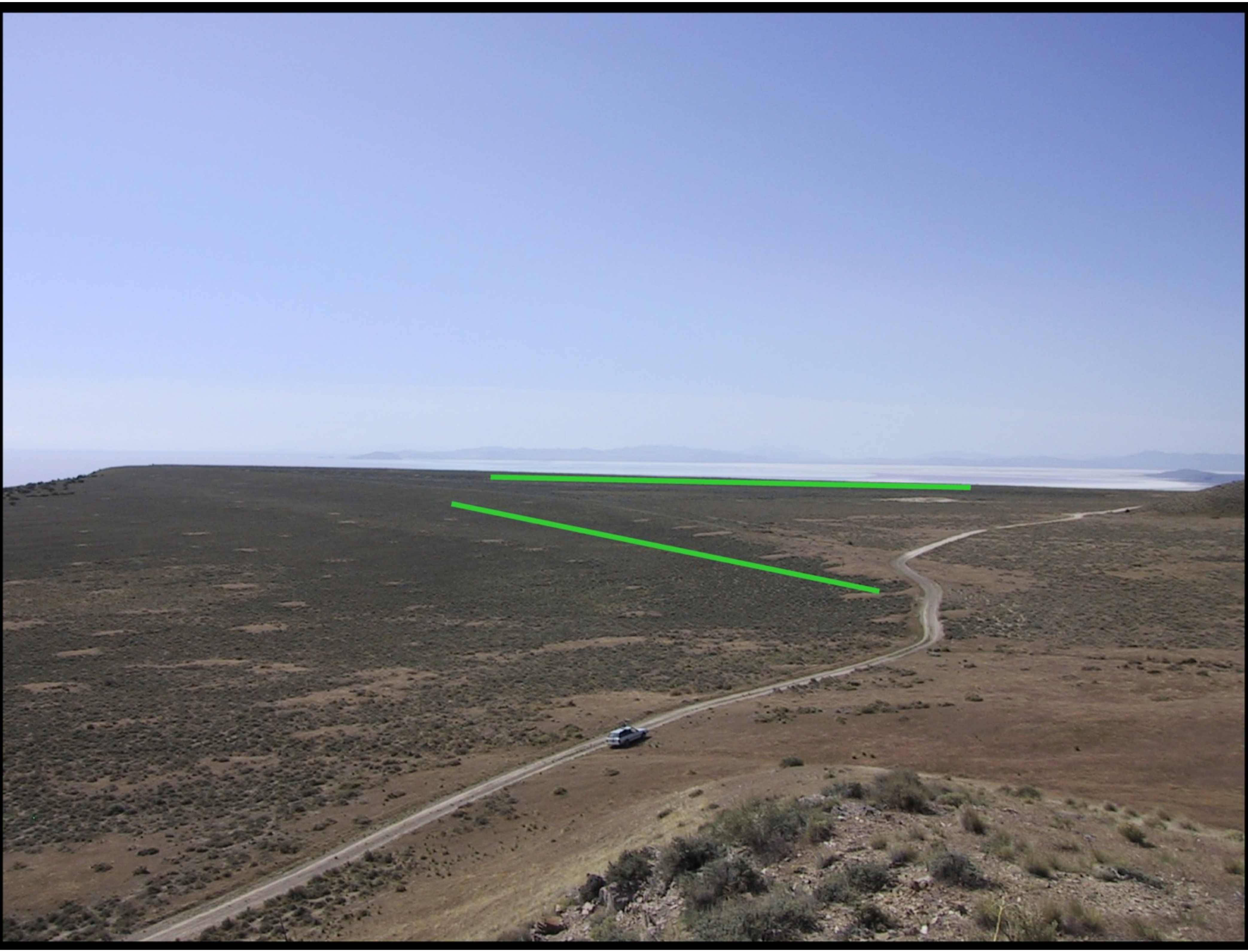
Three mechanisms to precipitate tufa:

1. Water agitation (waves)
2. Photosynthesis (algae)
3. Rising temperature

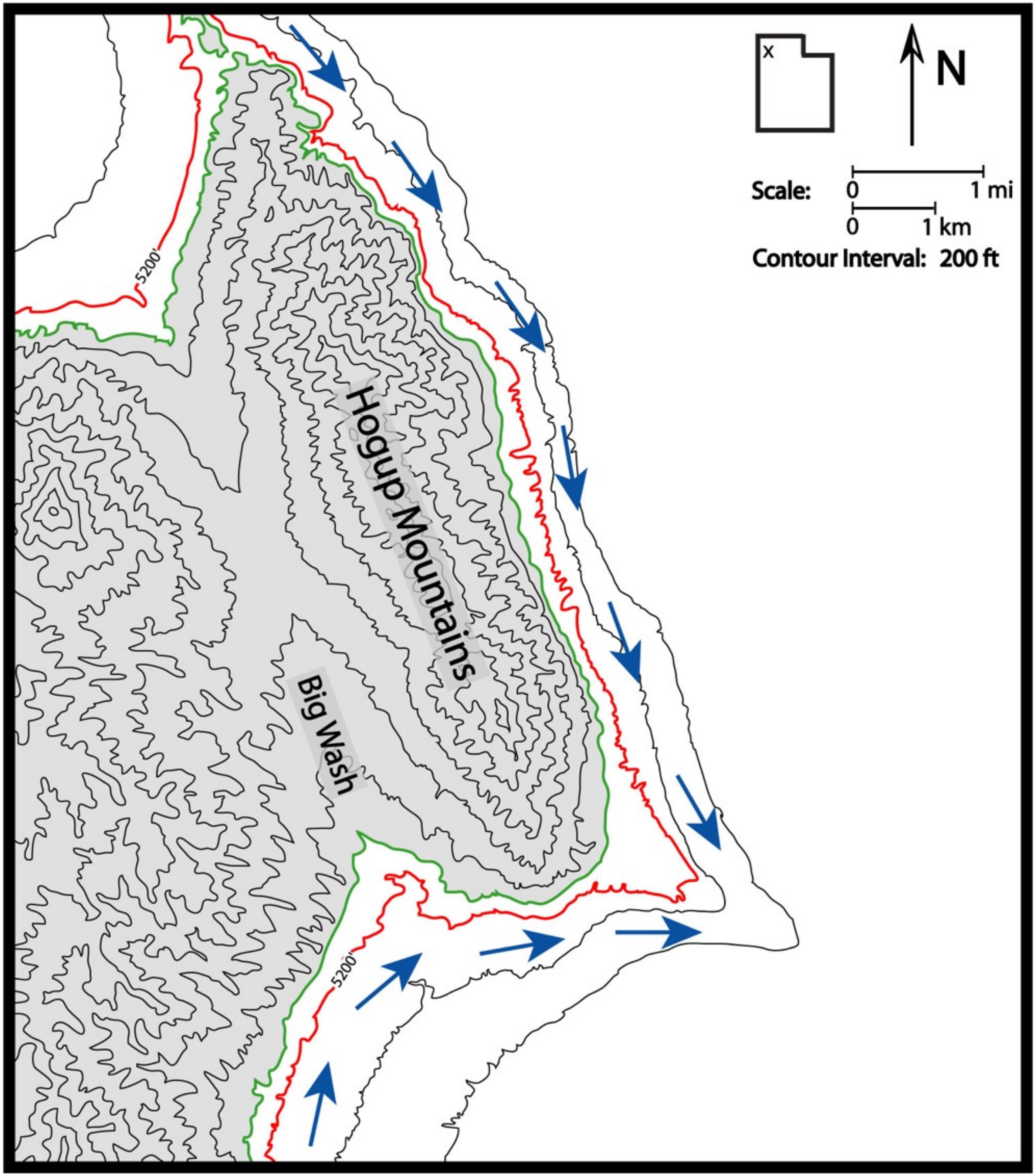

4700'
50-80°
4600
4500
4700
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Provo features/ erosional
Provo features/ depositional
Cliff / escarpment
Tufas
Beach Ridges
Topo Lines
Interpreted Wave Energy Direction
Beach Ridge Elevations (ft)
1. 4500
2. 4530
3. 4554
4. 4560
5. 4573
6. 4587
7. 4603
8. 4610
9. 4619
10. 4632
11. 4640
12. 4660
13. 4695
14. 4639
15. 4639
16. 4610
17. 4590
Contour interval 100'
0.5 mile
0.8 kilometer
N

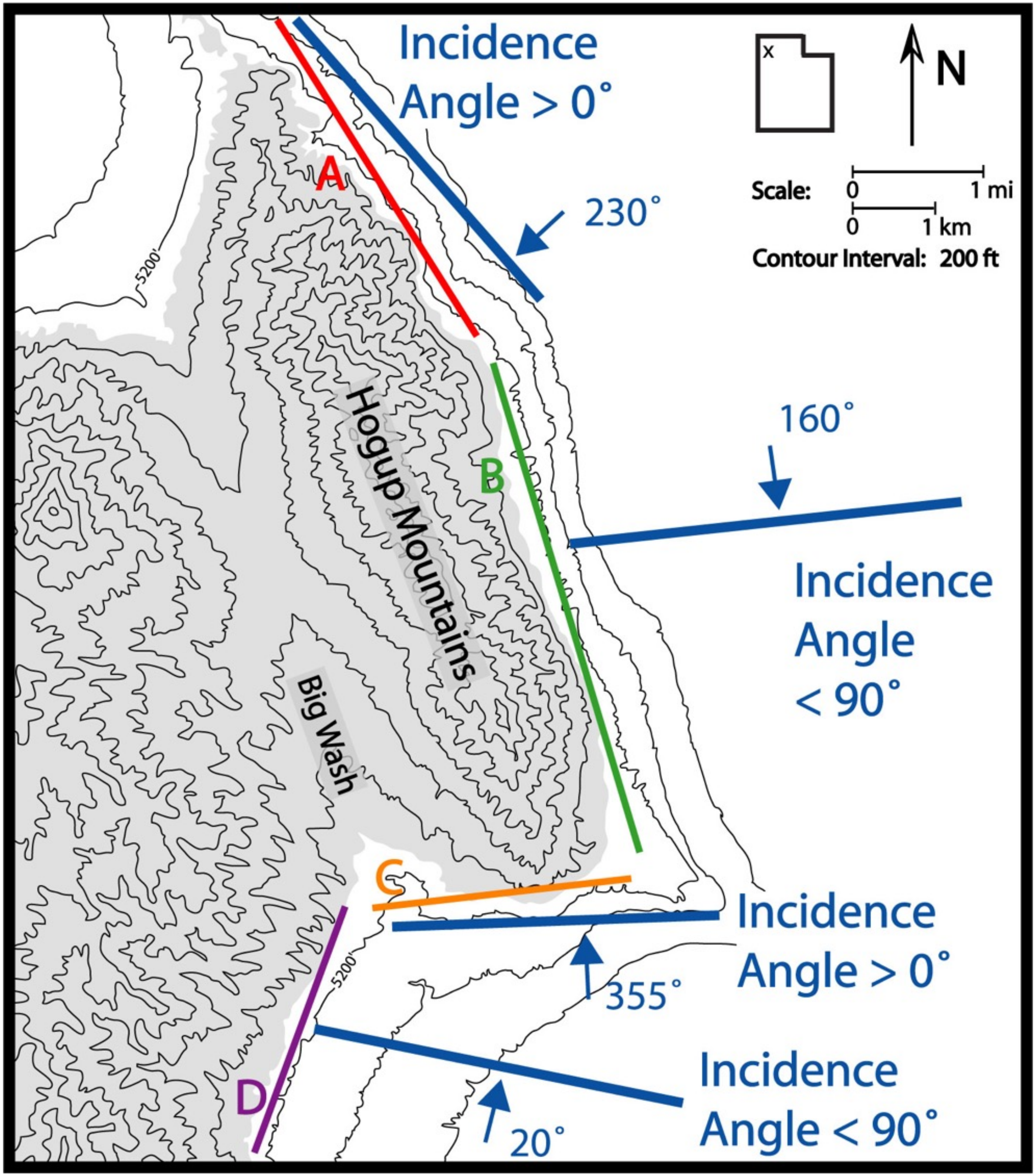

Wave Energy Direction
Contour Lines
Zone of Greatest Wave Energy
Sediment Movement
Contour interval 100'
0.25 mi
0.40 km
N


Interpreted Wave and Largest Fetch Directions
Wave Directions Interpreted in the Field (degrees)
Longest Fetch Directions (degrees)
$R^2 = 0.8984$
0
60
120
180
240
300
360

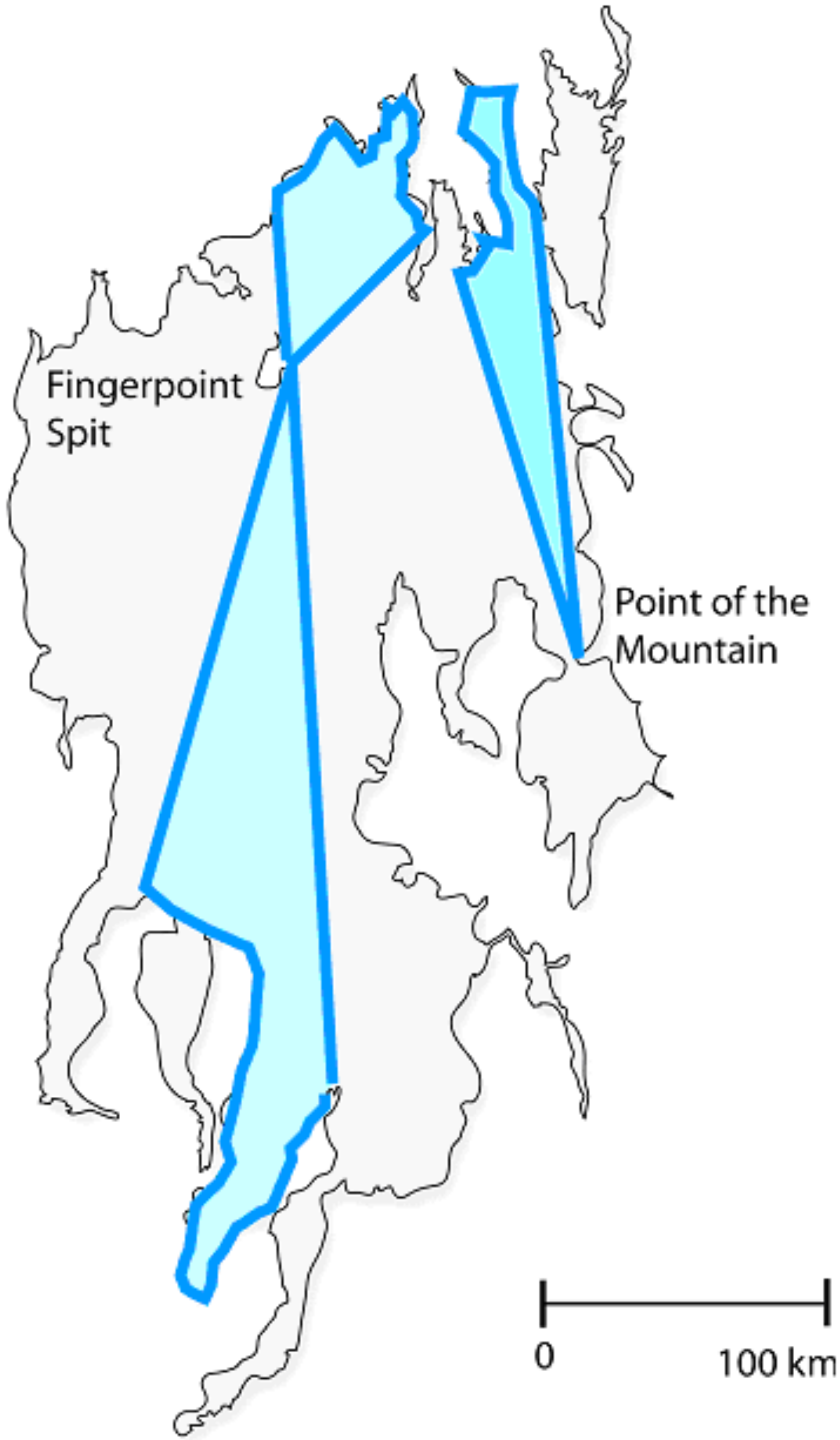



1 km


N
Scale: 0 1 mi
0 1 km
Contour Interval: 200 ft
5200'
Hogup Mountains
Big Wash
5200'

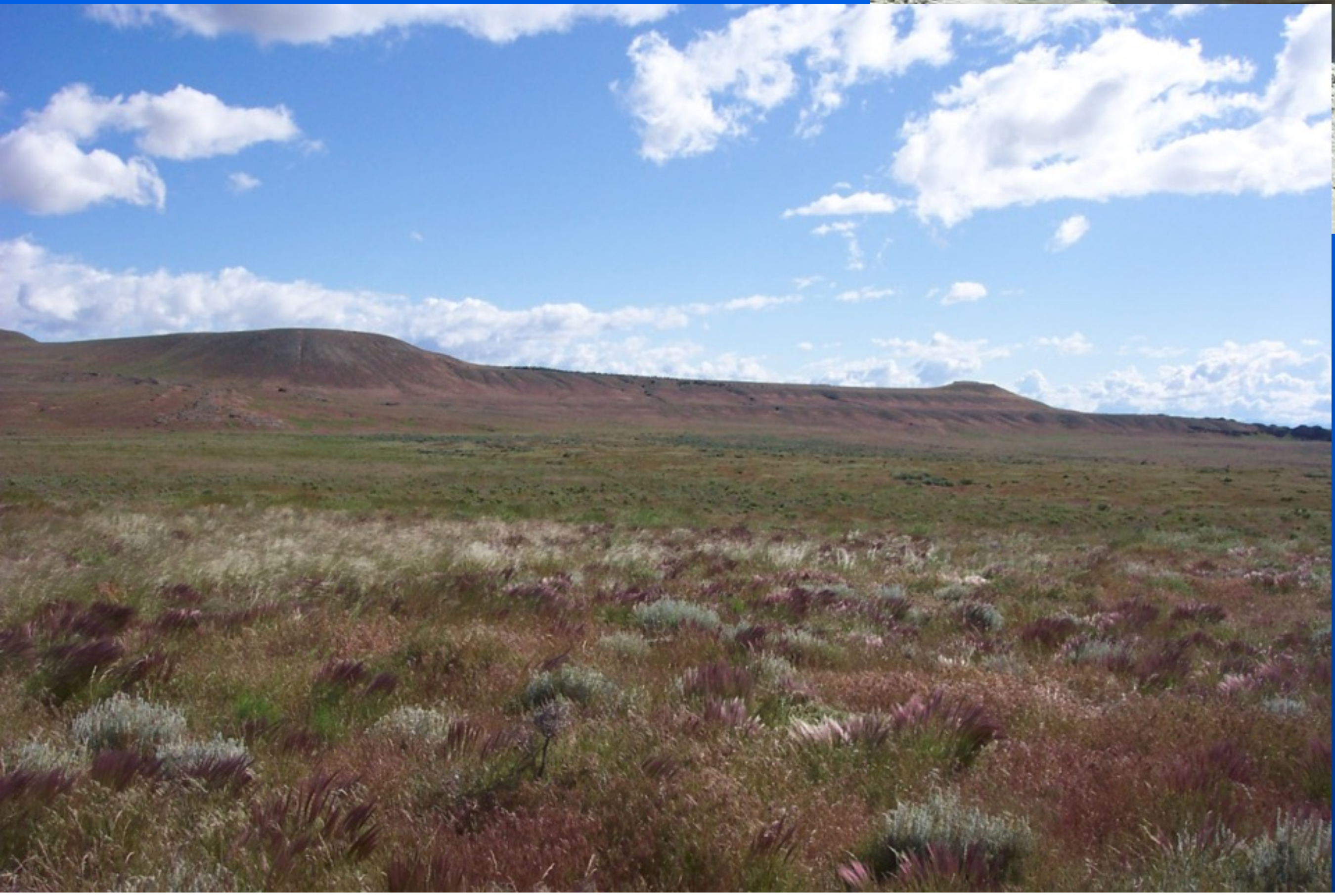

Incidence
Angle > 0°
N
Scale:
0
1 mi
0
1 km
Contour Interval: 200 ft
A
230°
5200'
Hogup Mountains
B
160°
Incidence
Angle
< 90°
Big Wash
C
D
5200'
Incidence
Angle > 0°
355°
Incidence
Angle < 90°
20°

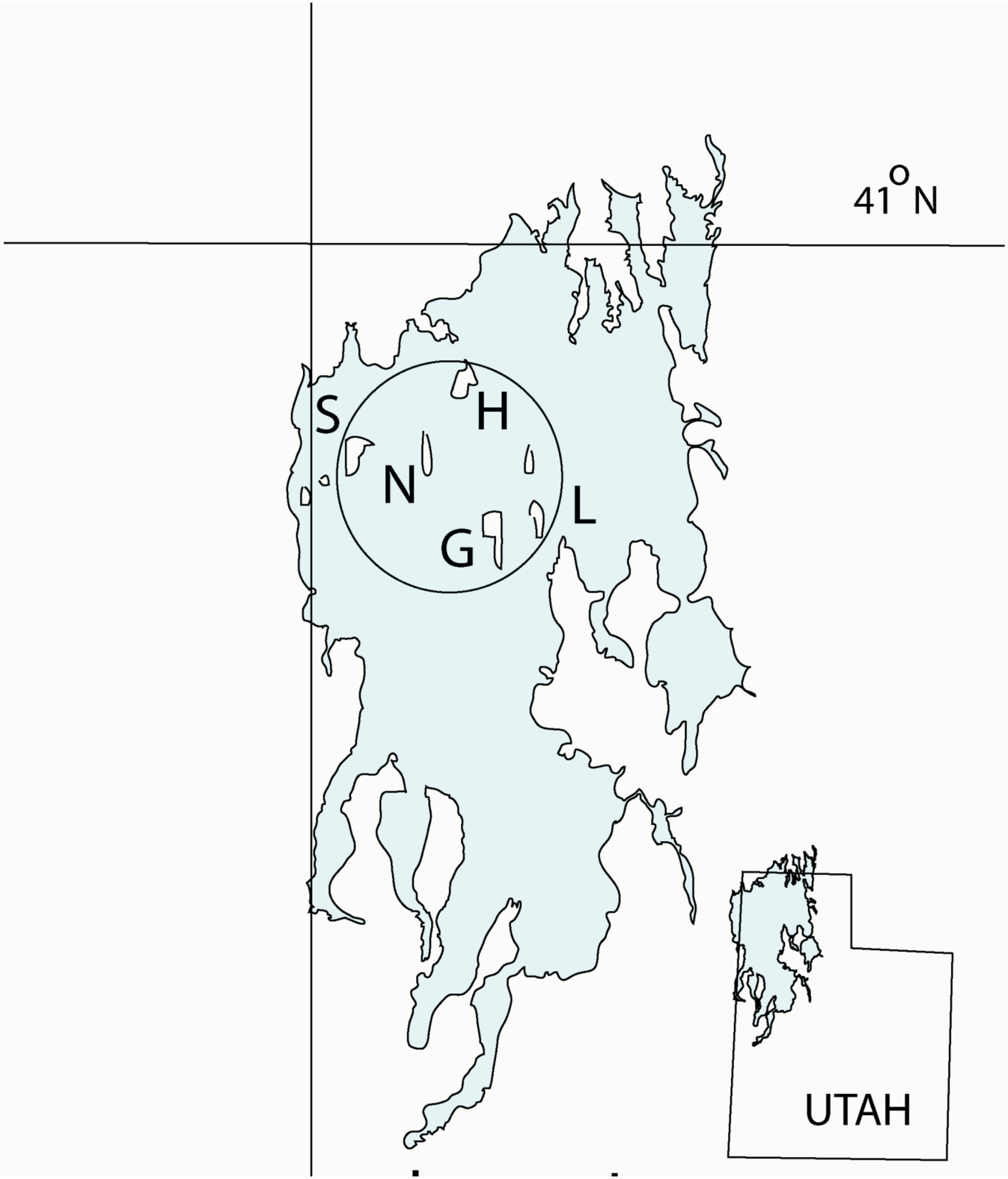
Direction of wave trains

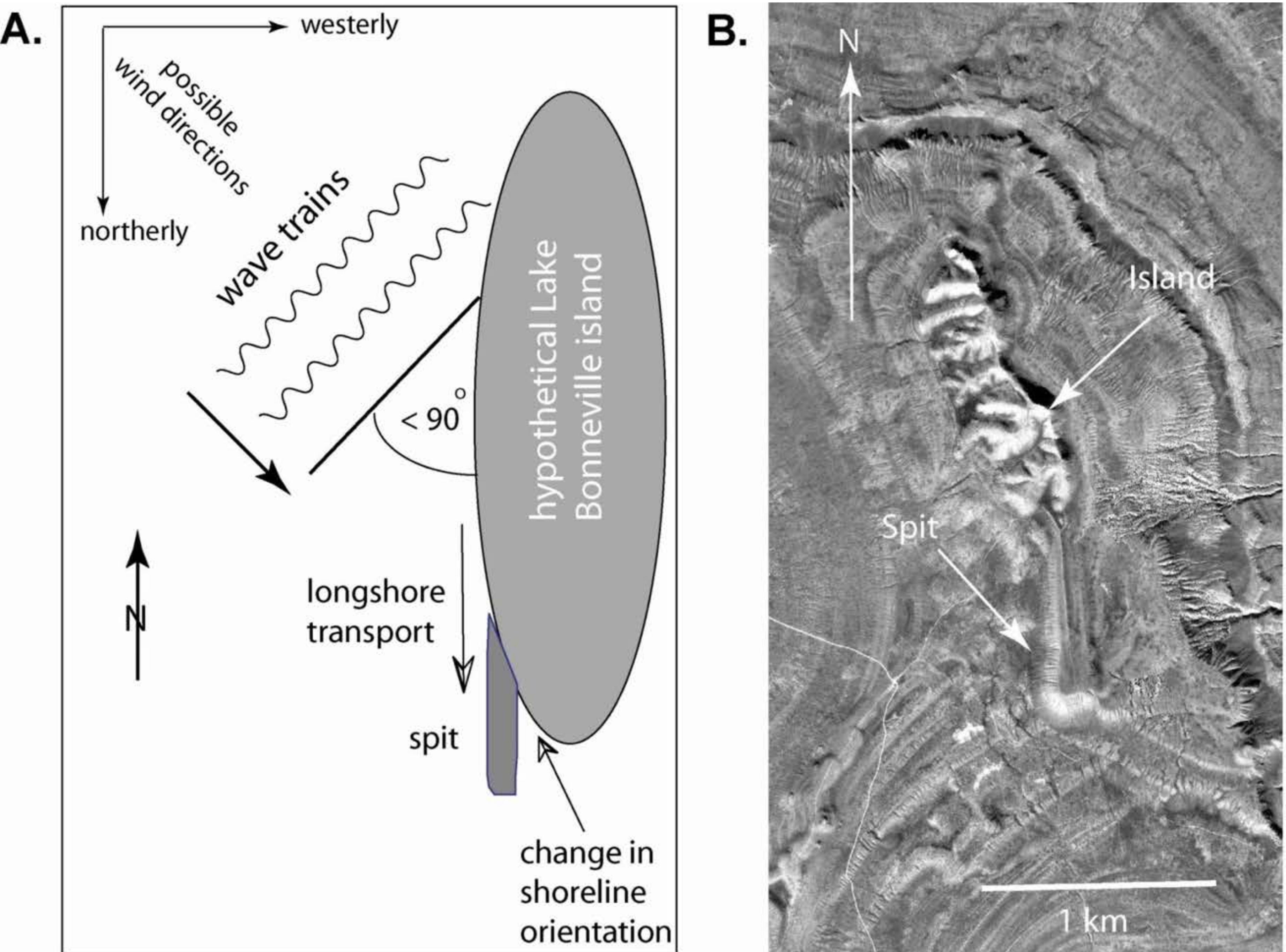


“Most Lake Bonneville spits are oriented to the south”

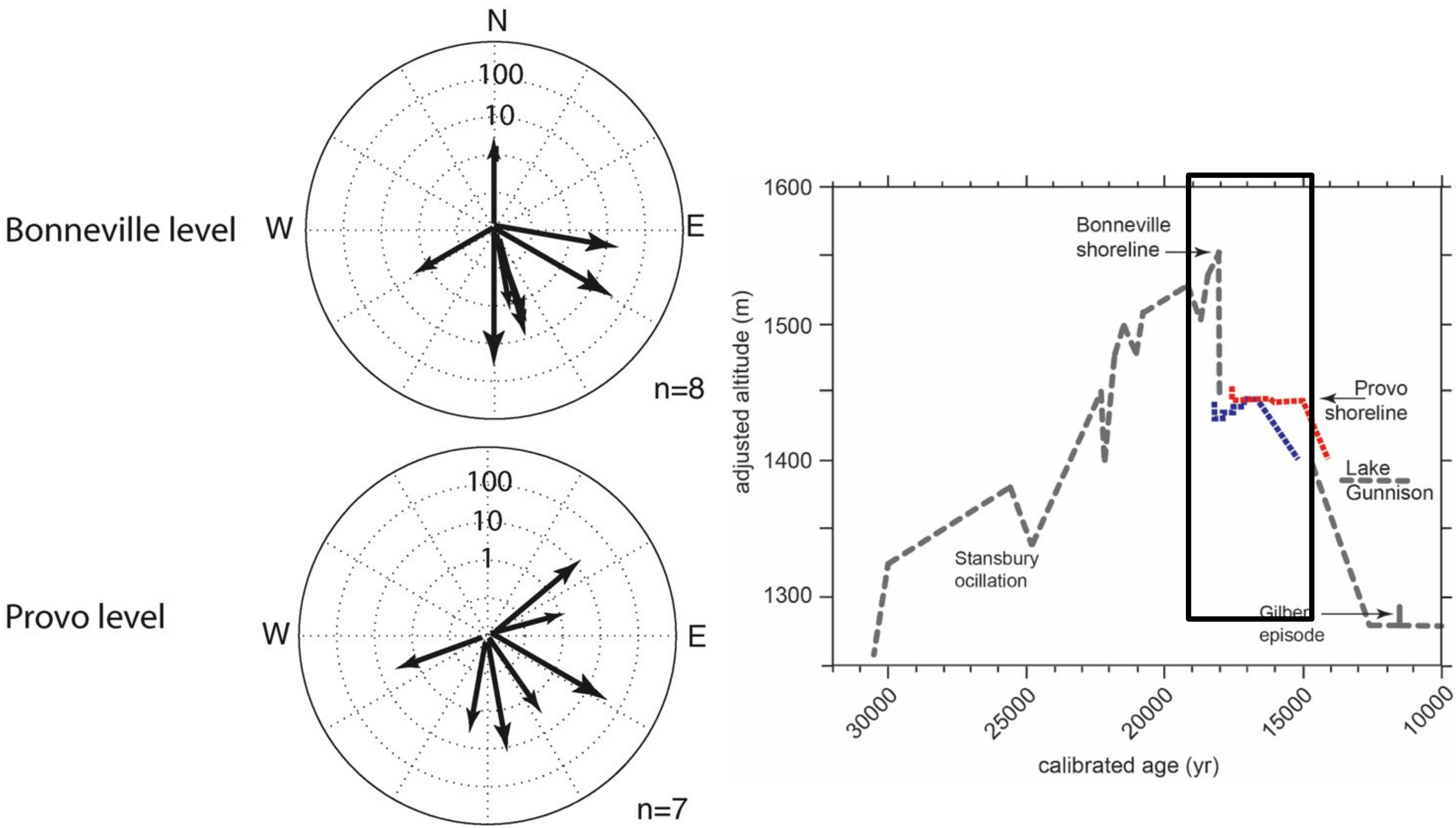
- Don Currey

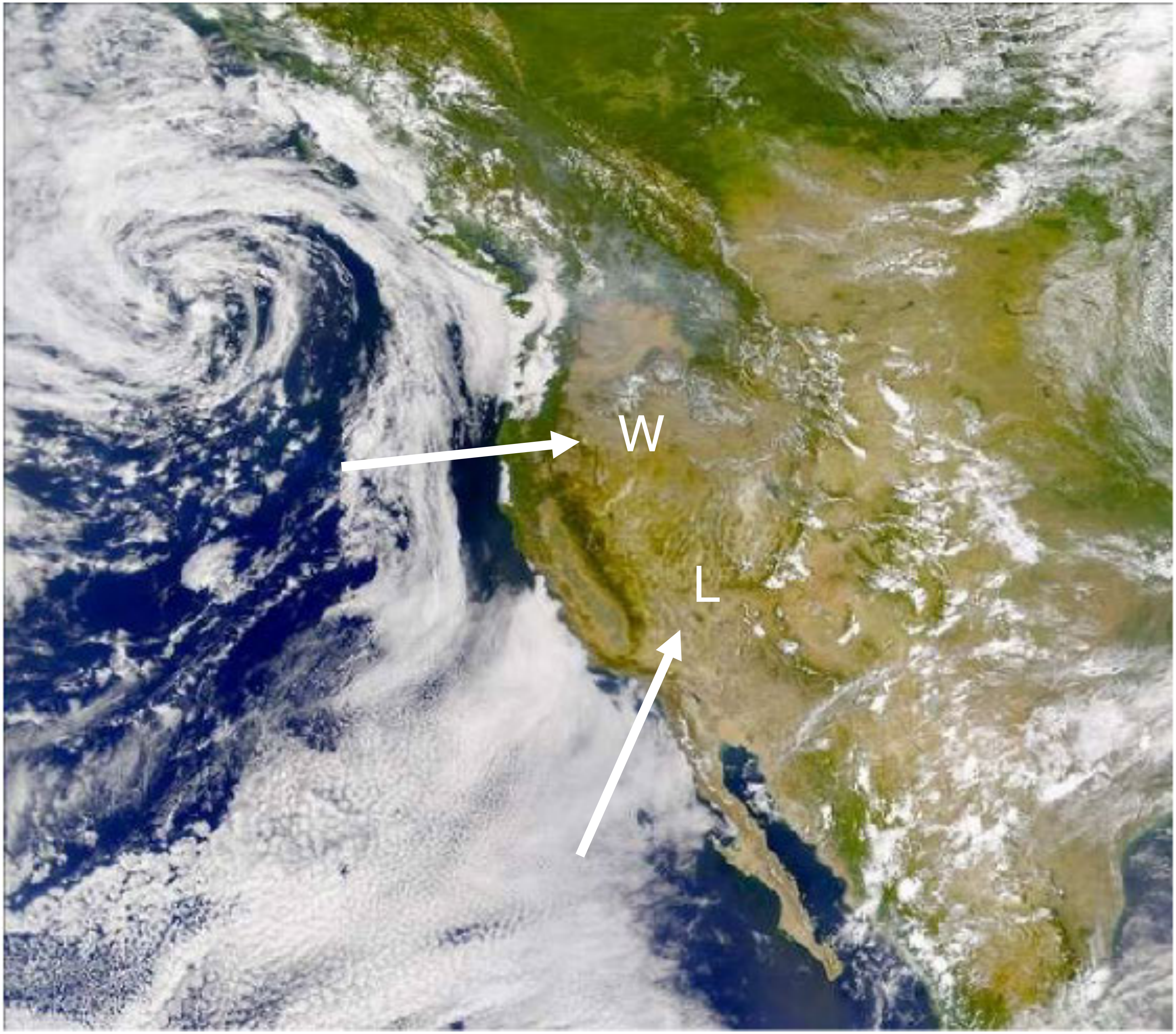


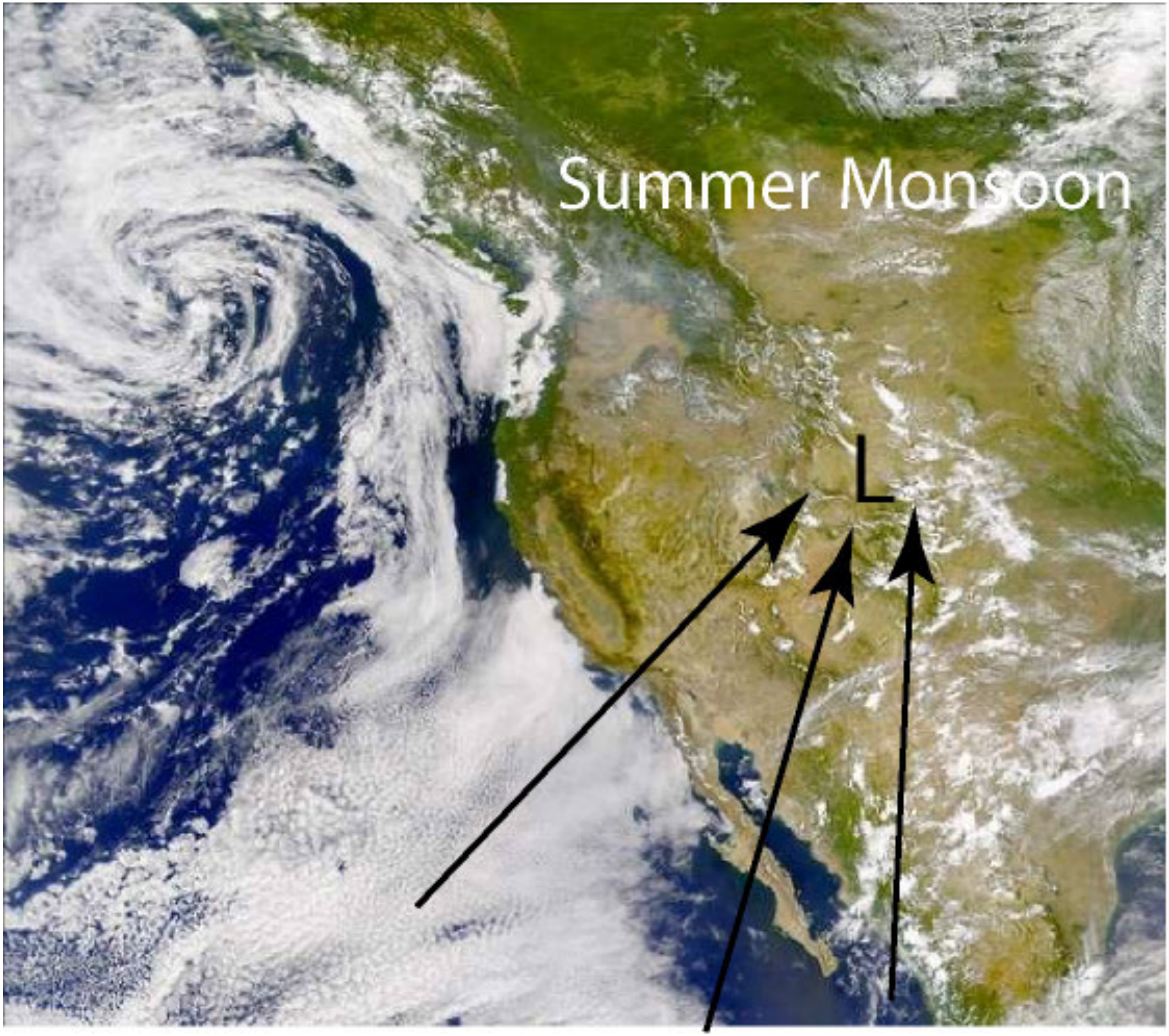

41°N
S
H
N
L
G
UTAH

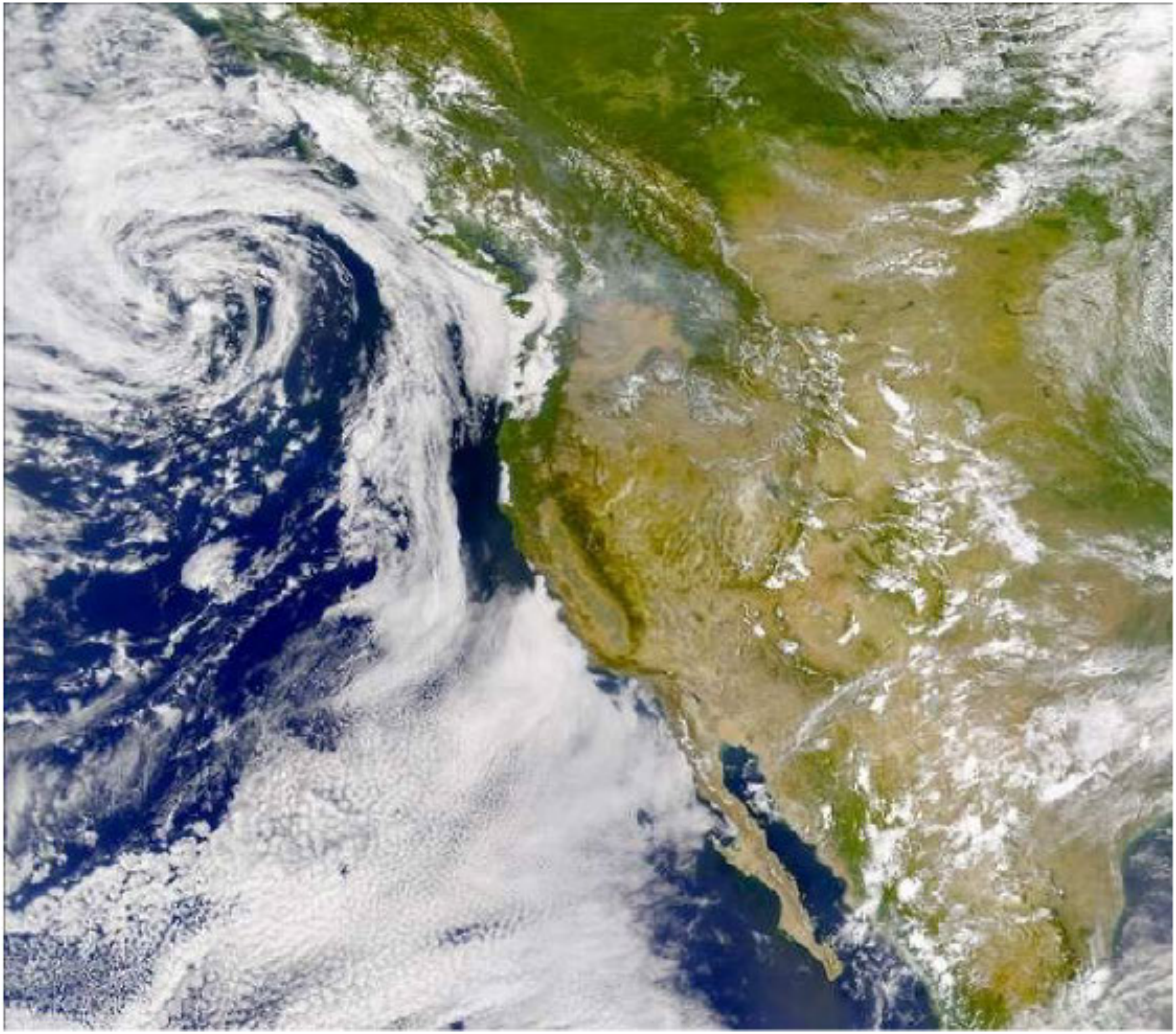


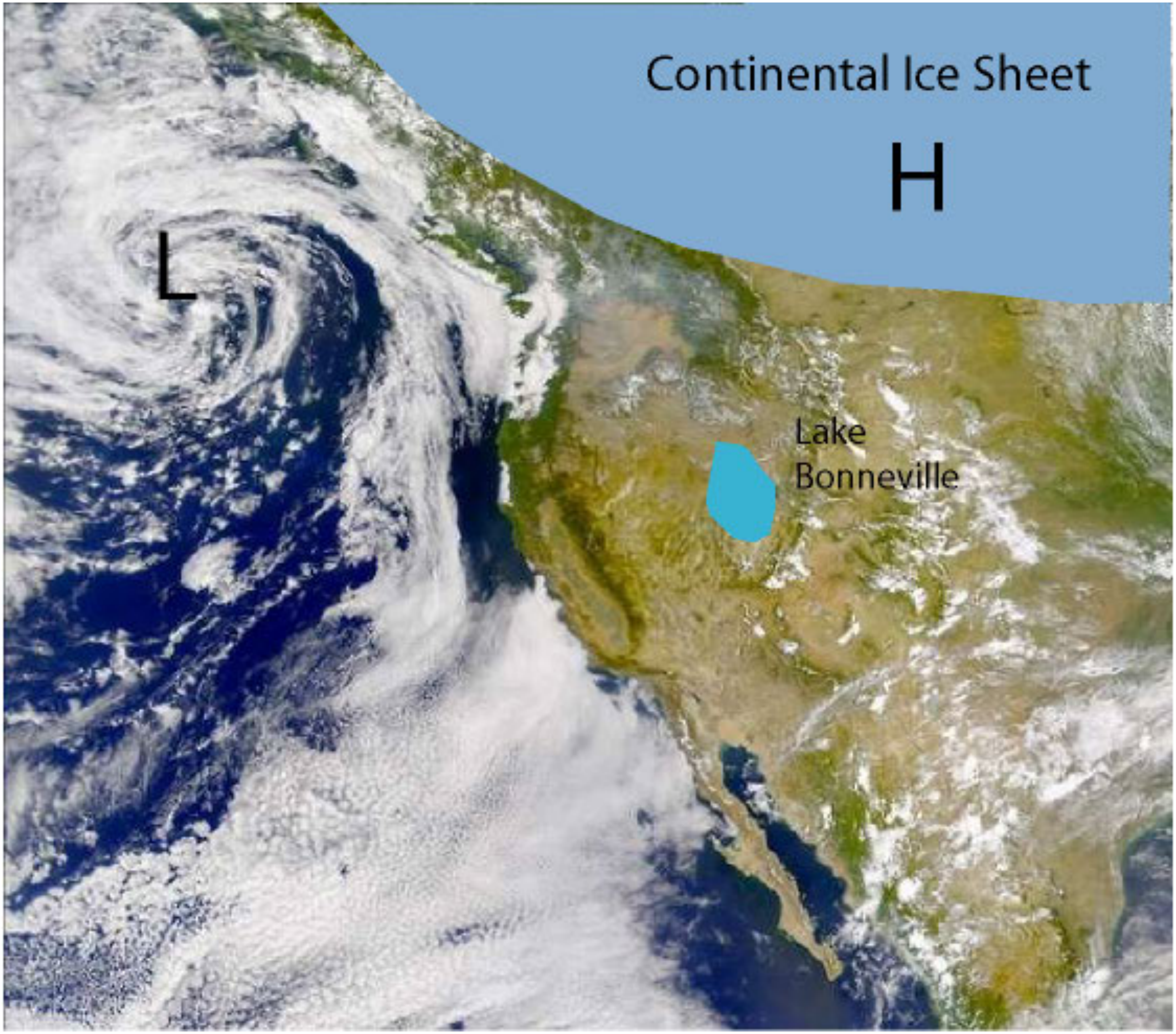
Most geomorphic work in aquatic environments is accomplished by large storm events

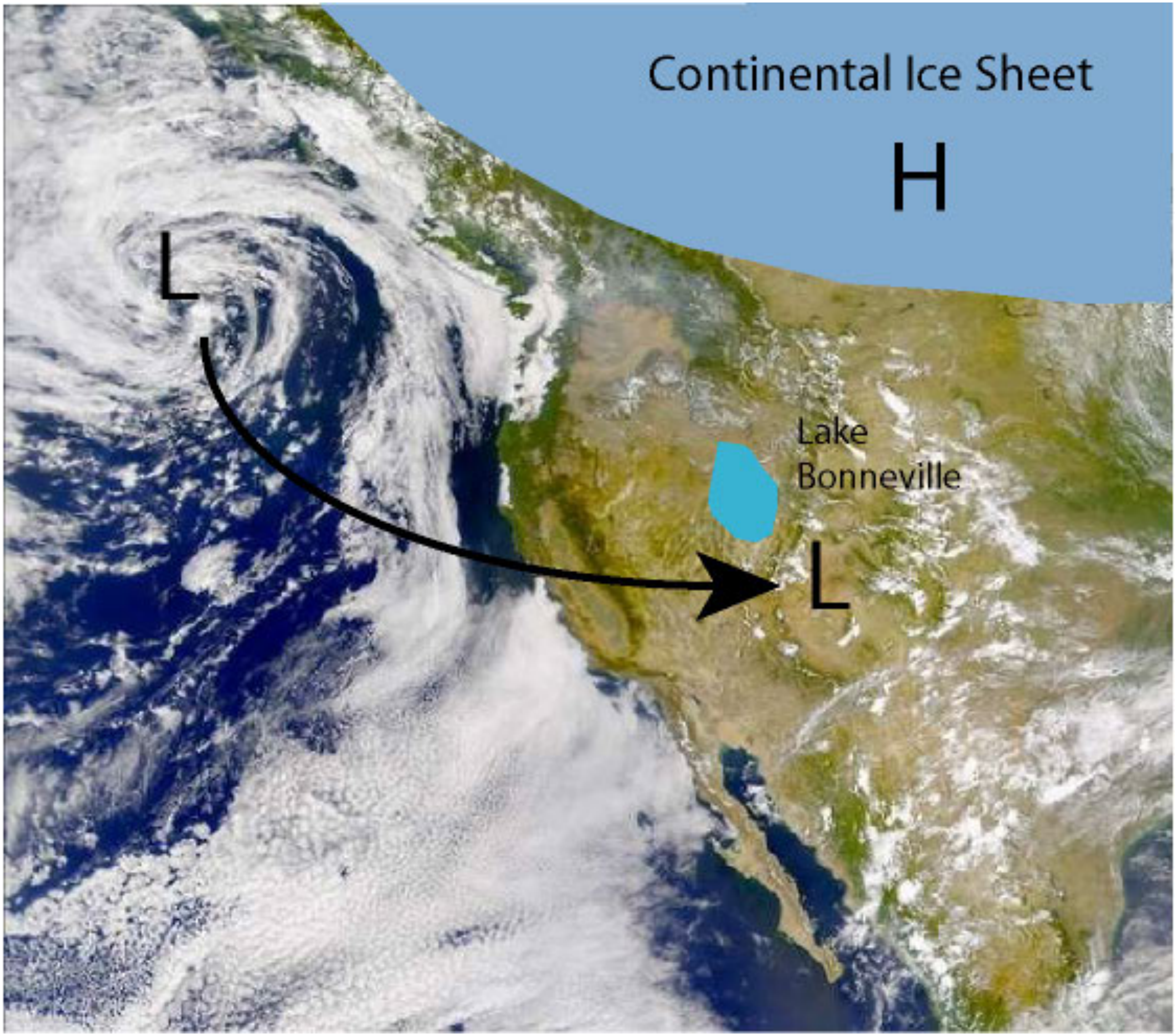

Bonneville level
N
W
E
100
10
n=8
Provo level
W
E
100
10
1
n=7
1600
1500
1400
1300
adjusted altitude (m)
Bonneville shoreline
Provo shoreline
Lake Gunnison
Stansbury ocillation
Gilbert episode
30000
25000
20000
15000
10000
calibrated age (yr)


W
L

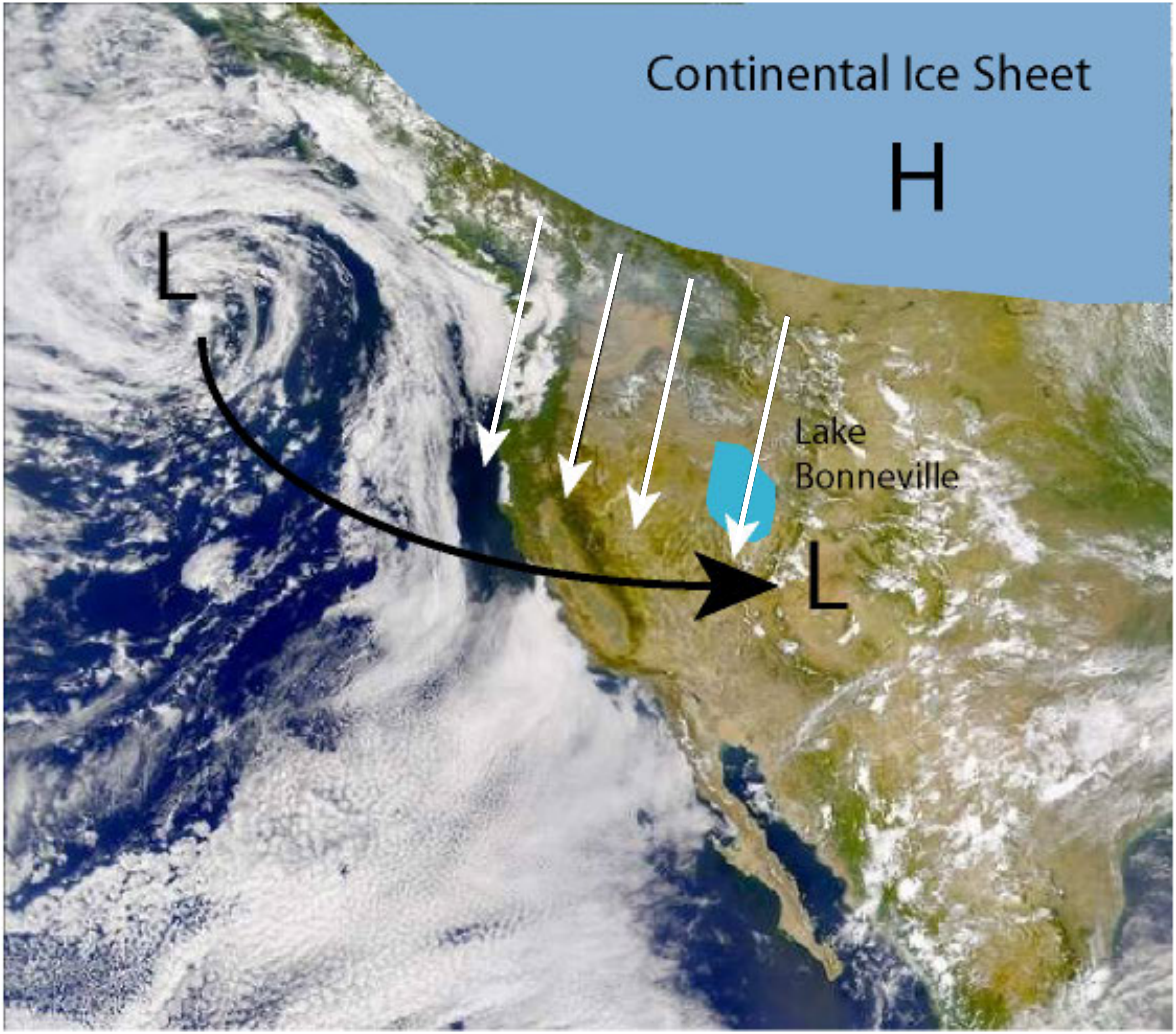

Summer Monsoon
L



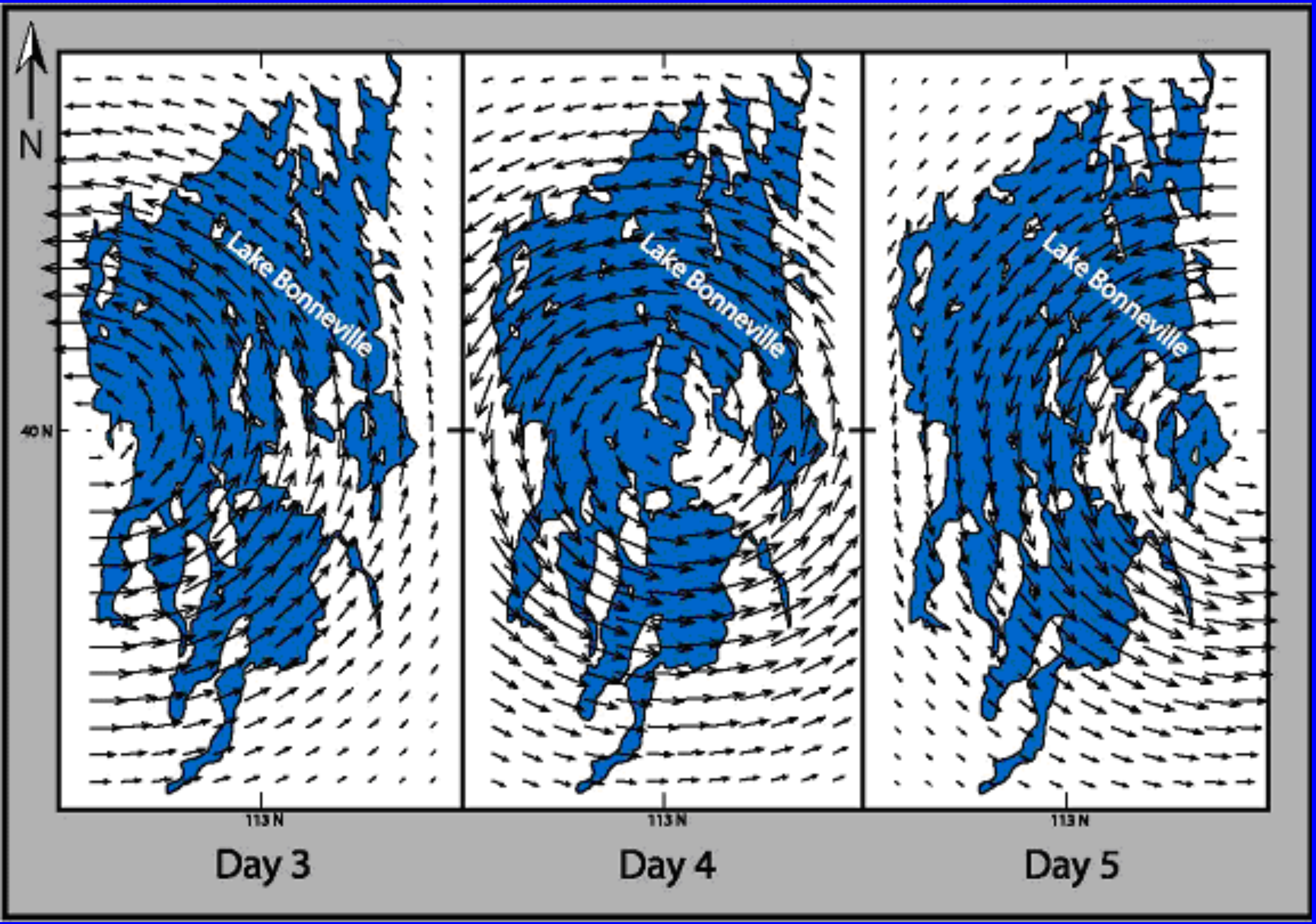

Continental Ice Sheet
H
L
Lake
Bonneville



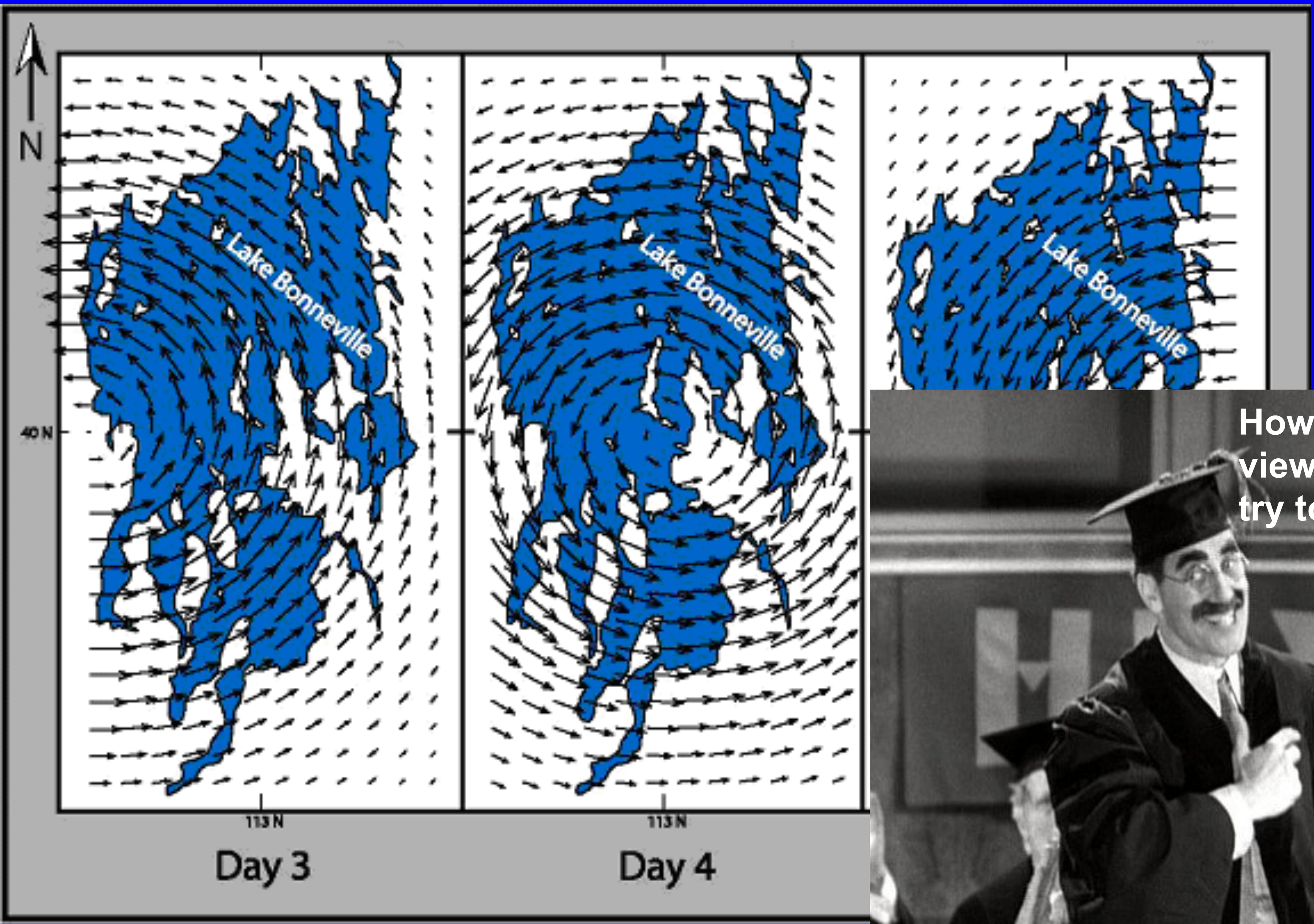
Continental Ice Sheet
H
L
Lake
Bonneville
L

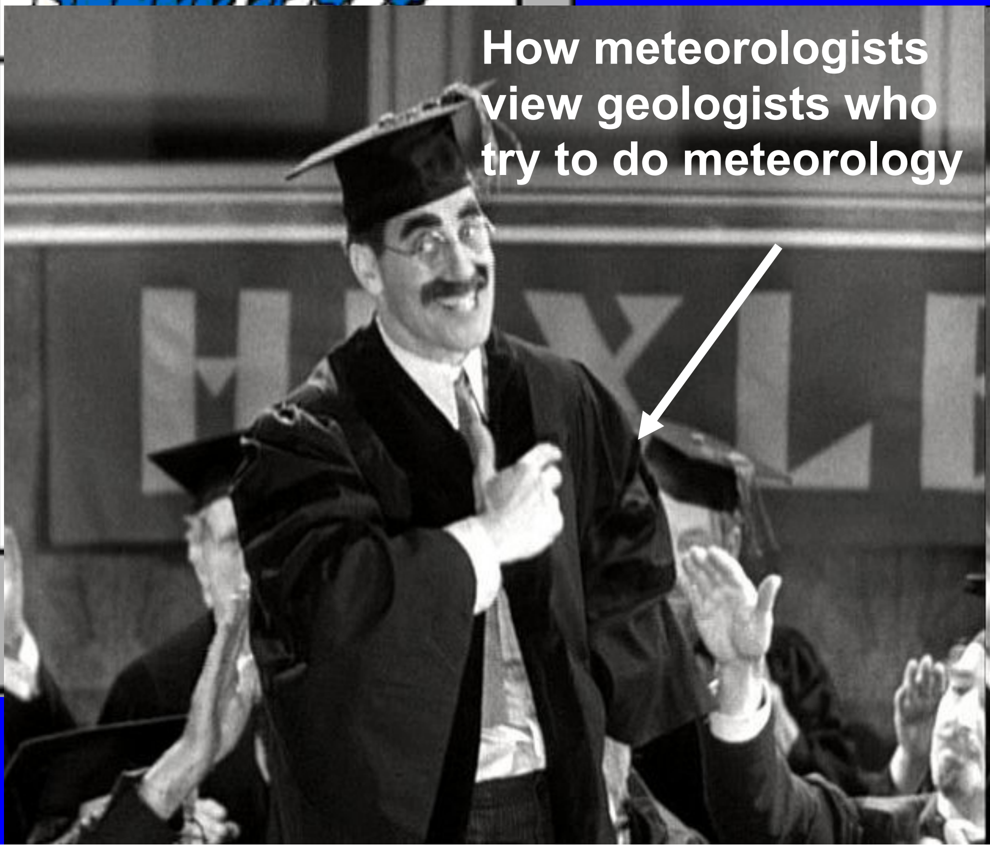

Continental Ice Sheet
H
L
Lake Bonneville
L

A geologist's simplistic view of an extratropical cyclone over Lake Bonneville



A geologist's simplistic view of an extratropical cyclone over Lake Bonneville

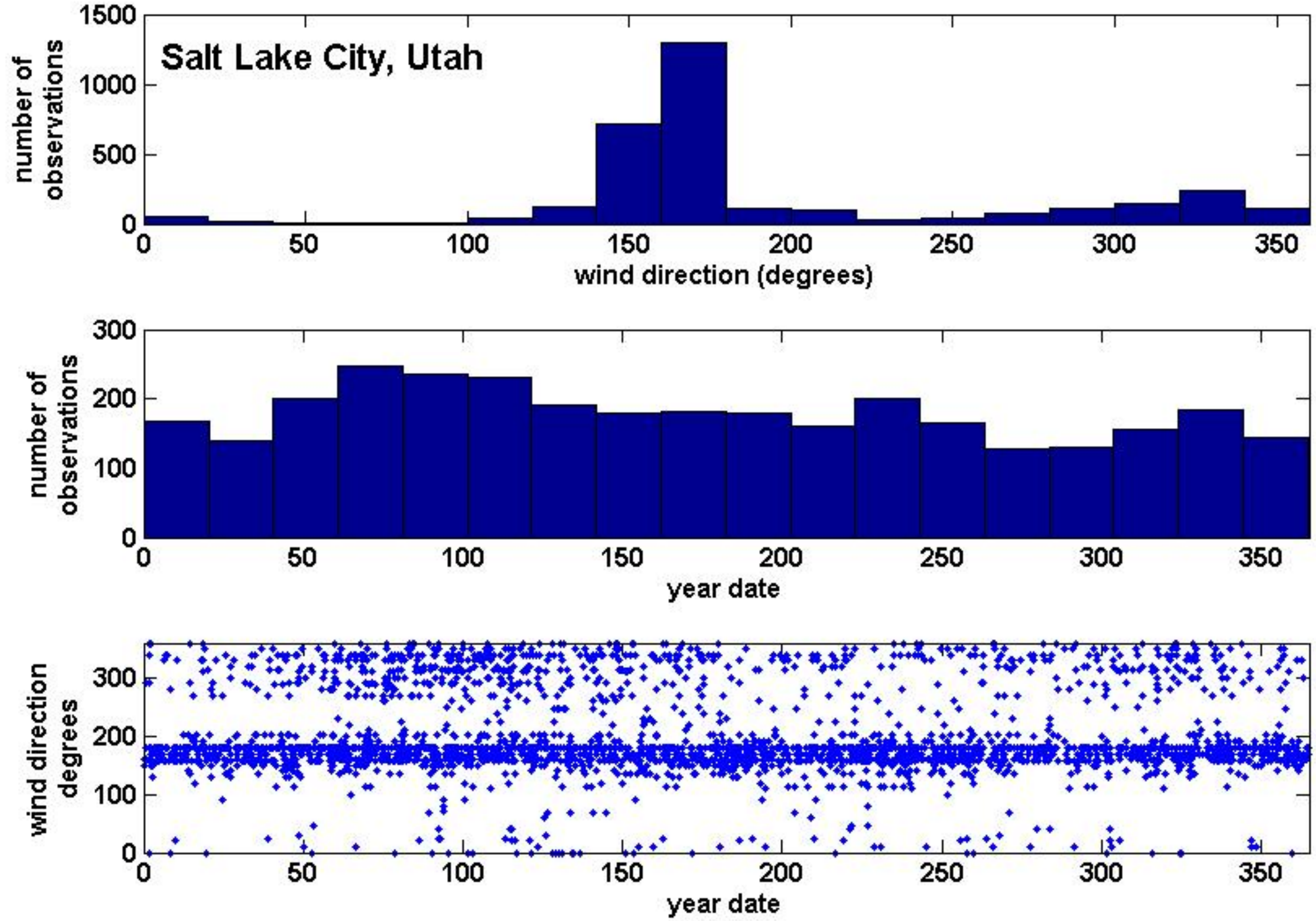




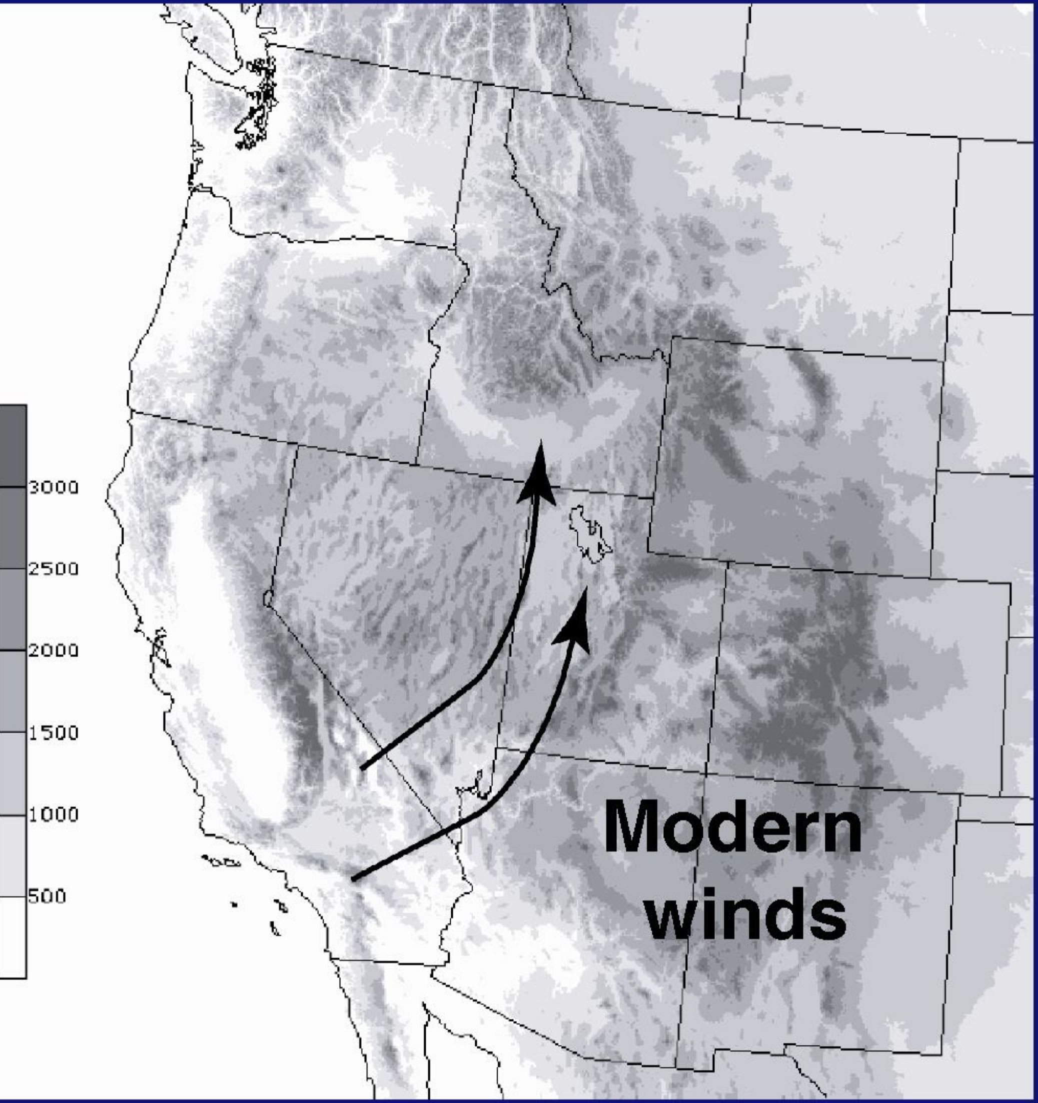
So the humble geologist begins his quest to understand modern surface winds in the Great Basin …

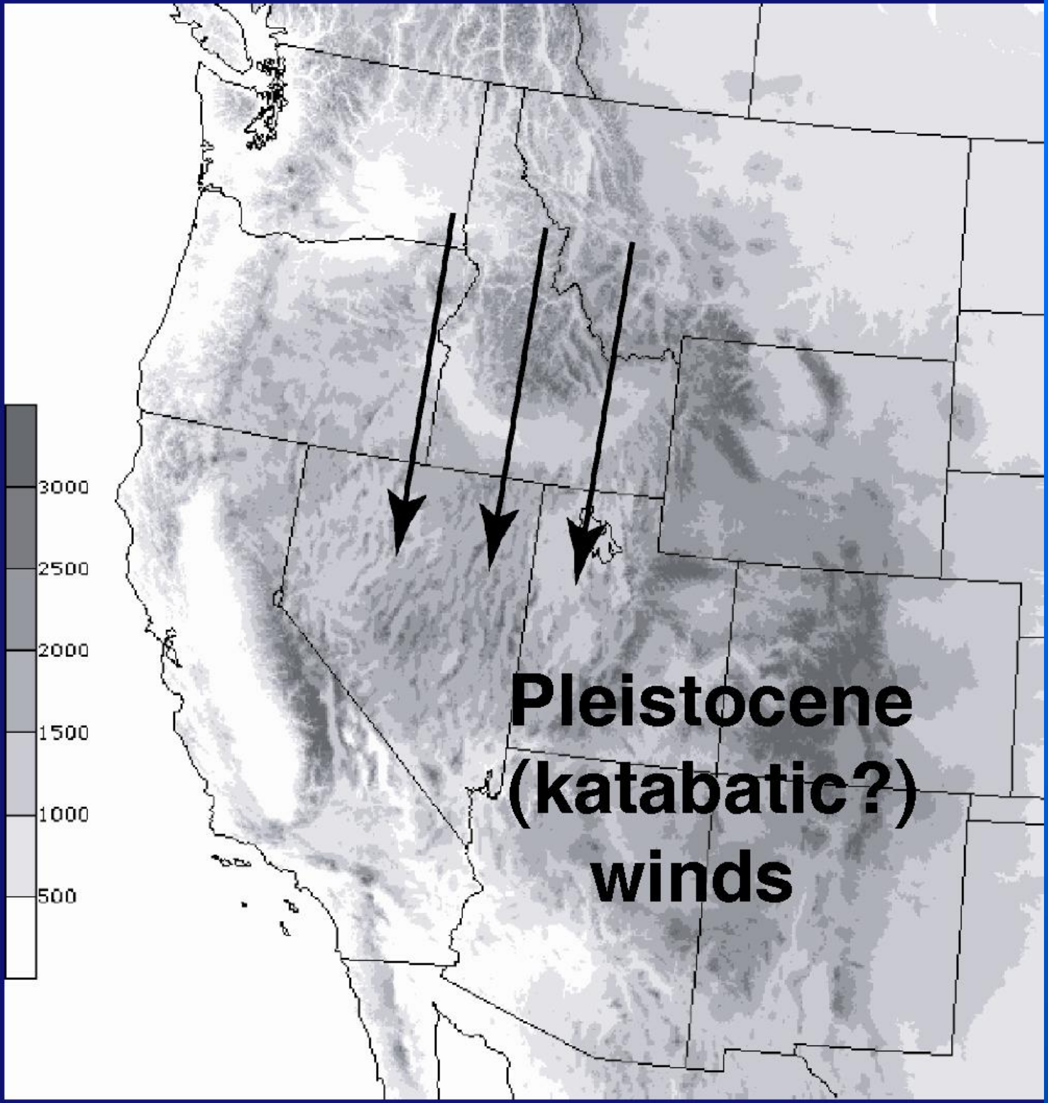
Procedure:

- Hourly wind records from 1946 – 2001 (up to ~ $5x10^5$ per station) examined for various Great Basin localities
- 24-hour moving average filter to find periods of extended high winds (i.e., storm events)
- Beaufort Wind Scale: during10 m/s winds "large waves form; white foam crests everywhere …". ***These winds move sediment and cause longshore drift.***



Salt Lake City, Utah
number of observations
wind direction (degrees)
number of observations
year date
wind direction degrees
year date





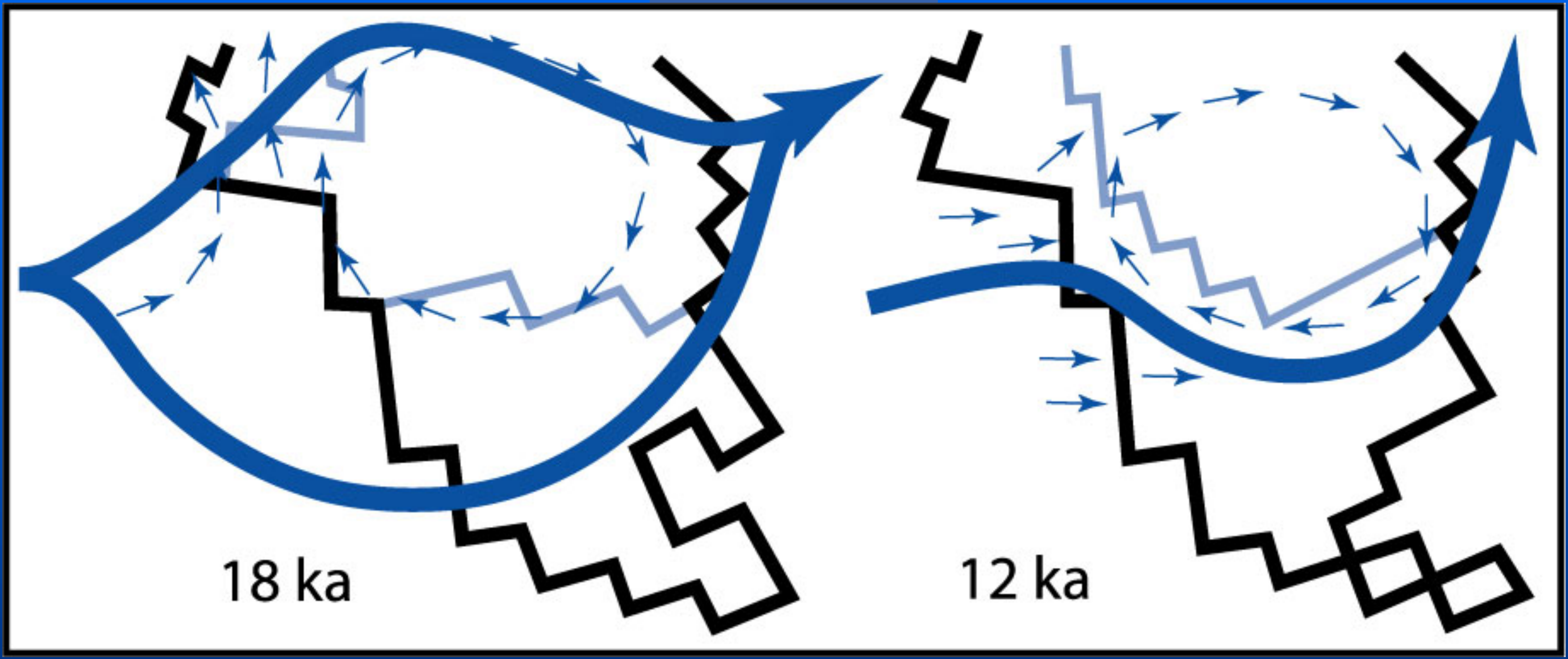
When did the switch happen? Why did it happen?

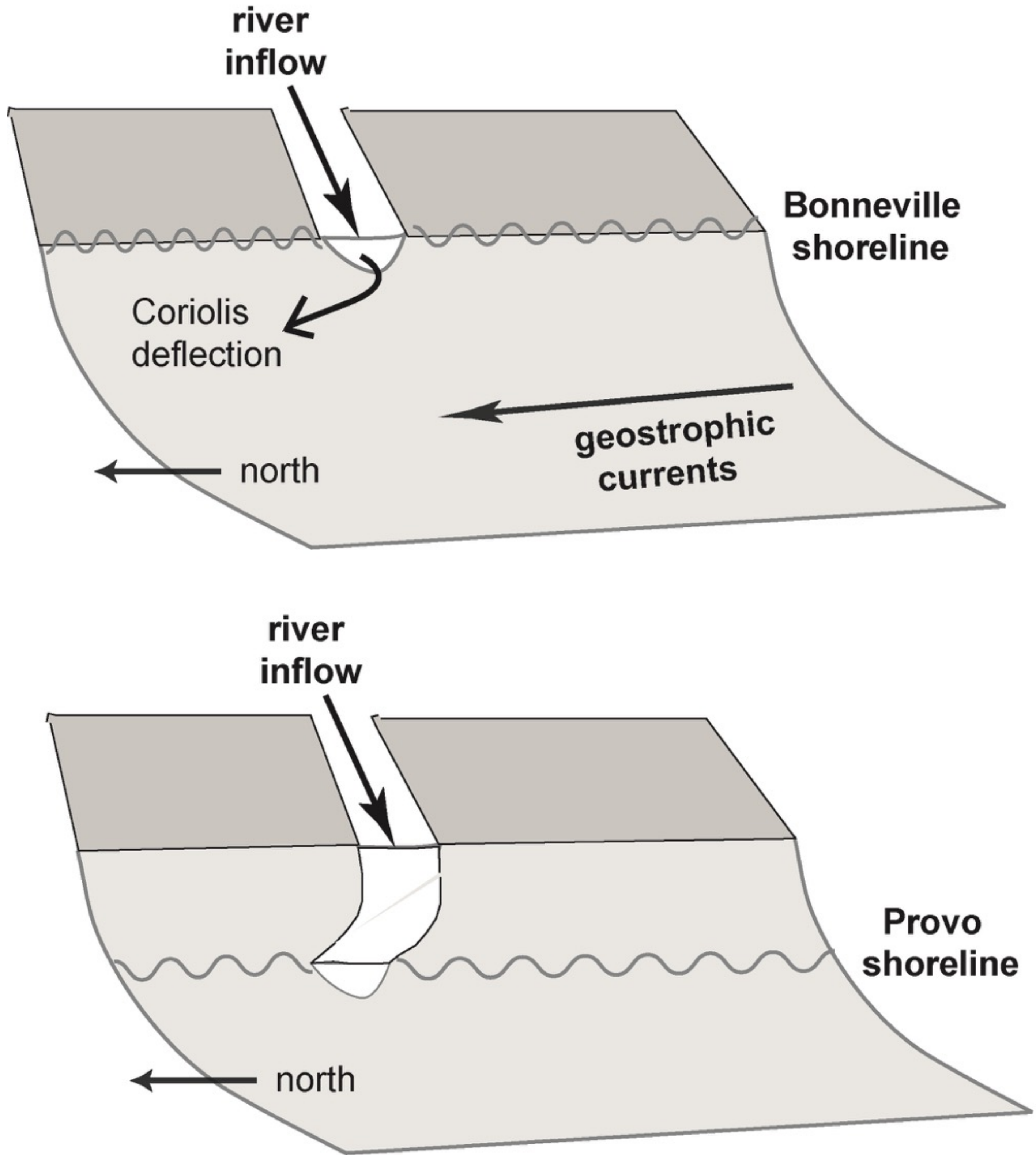
“Pleistocene strong wind paradox”

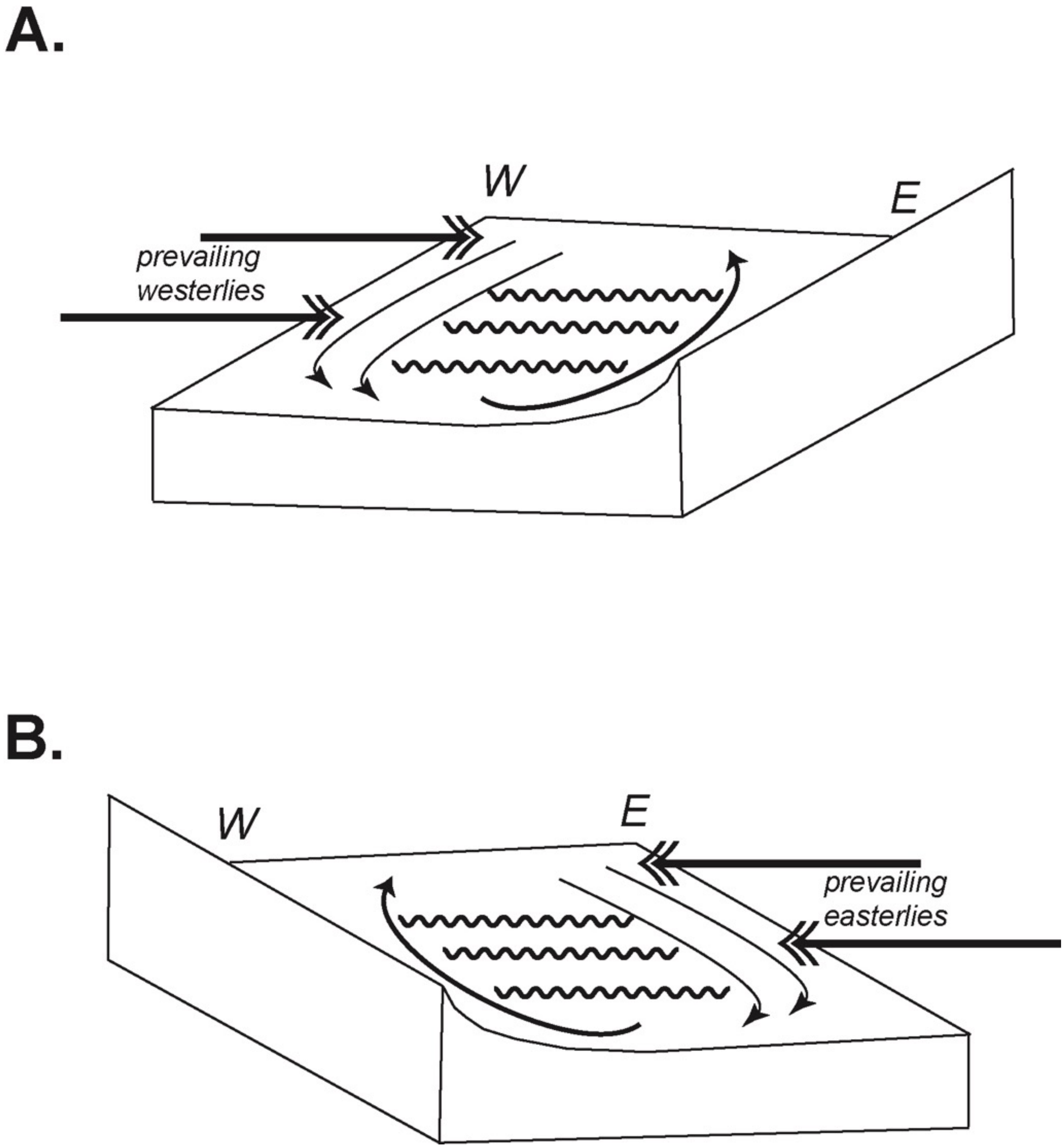
A North America Continental Anti-Megamonsoon?

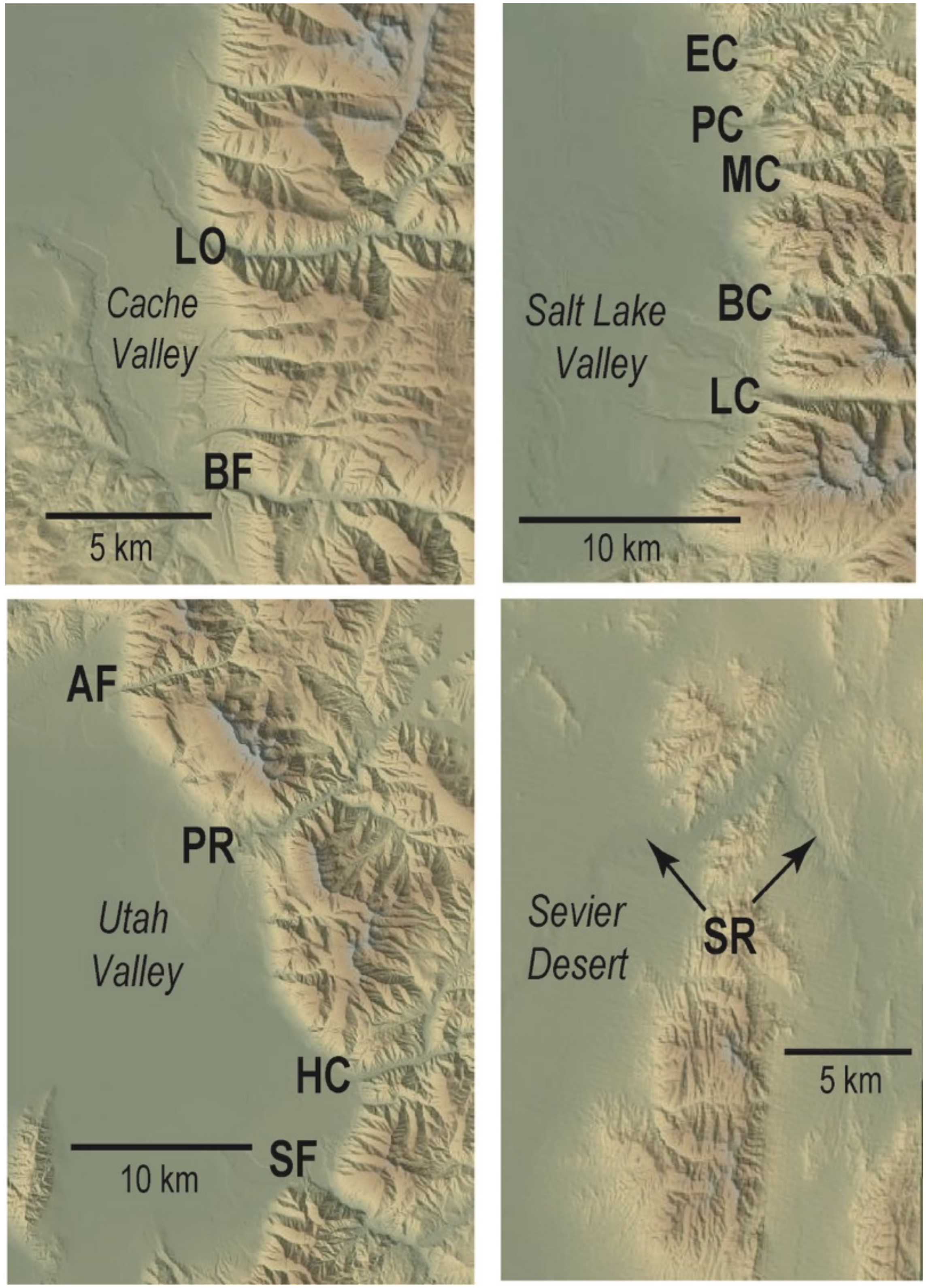
- High pressure over the continental ice sheet would be quasi-permanent and intense
- Extra-tropical cyclones would be relatively common leading to strong, unidirectional winds (“katabatic” winds) over Lake Bonneville capable of producing southward directed spits
- If so, then the track of the Pleistocene jet stream was **south** of Lake Bonneville (an important constraint on paleoclimate reconstructions and GCMs)

Jet stream placement and atmospheric circulation over North America during the Pleistocene (as seen by an atmospheric GCM)

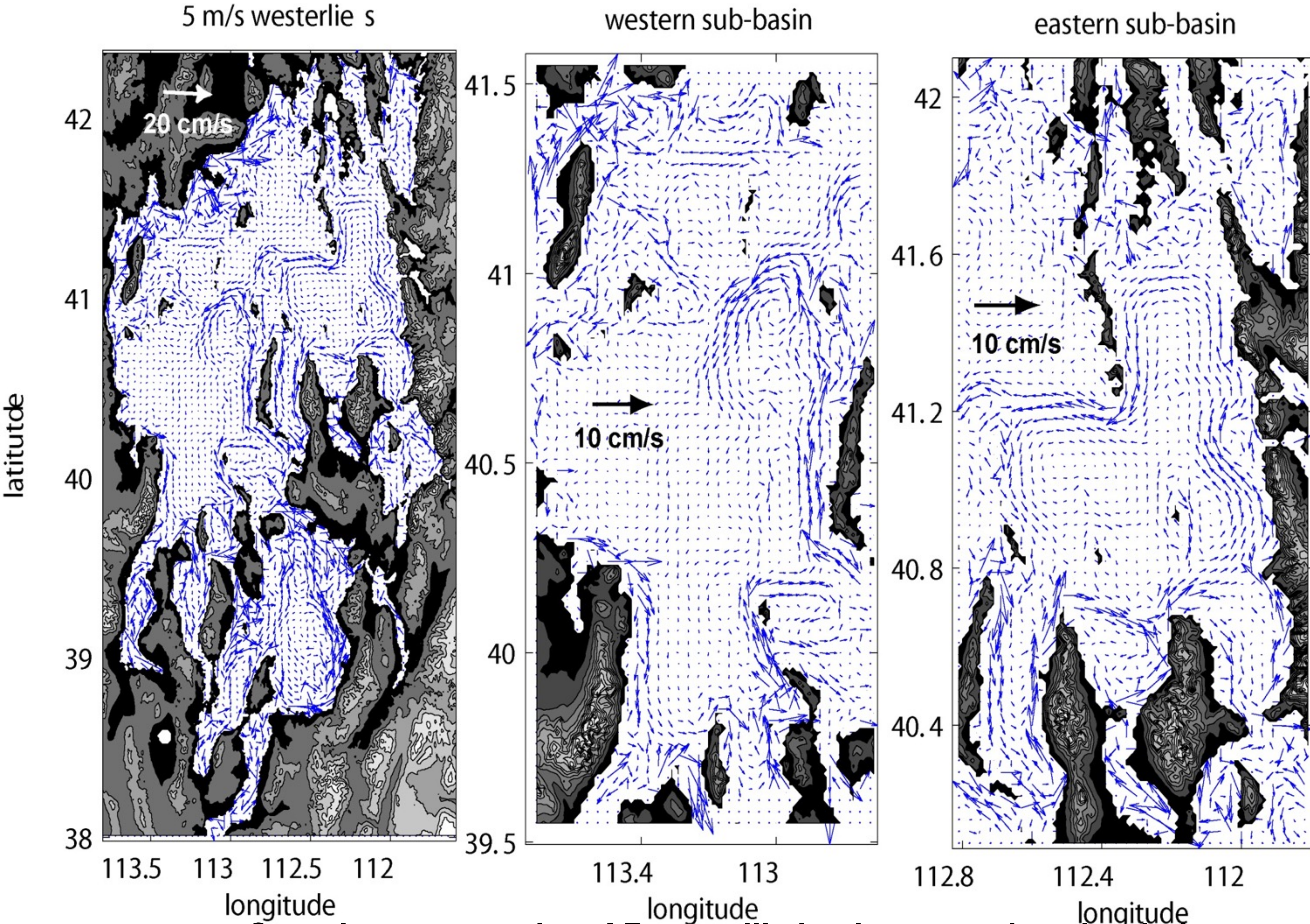



river
inflow
Bonneville
shoreline
Coriolis
deflection
geostrophic
currents
north
river
inflow
Provo
shoreline
north

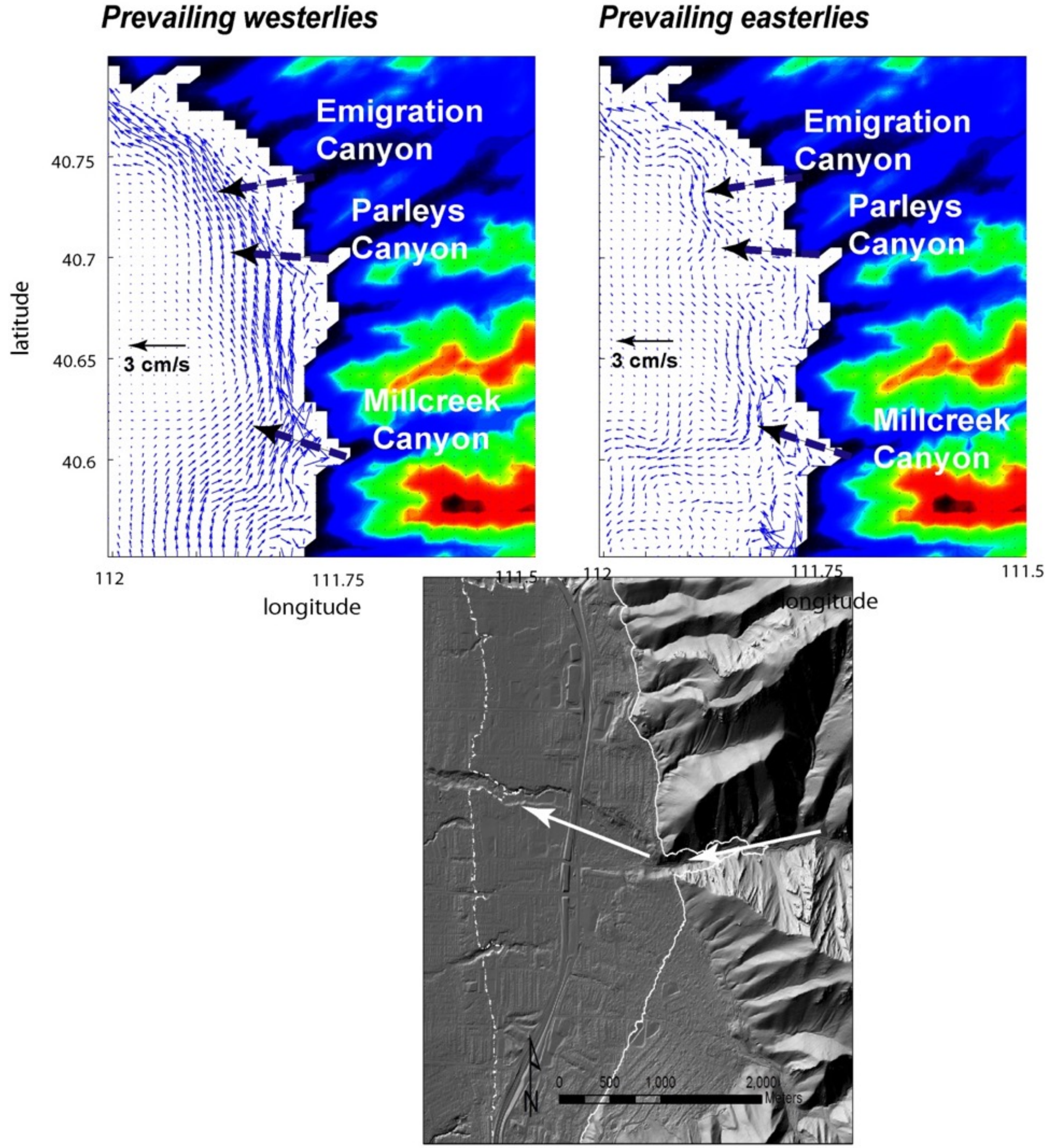

A.
W
E
prevailing
westerlies
B.
W
E
prevailing
easterlies

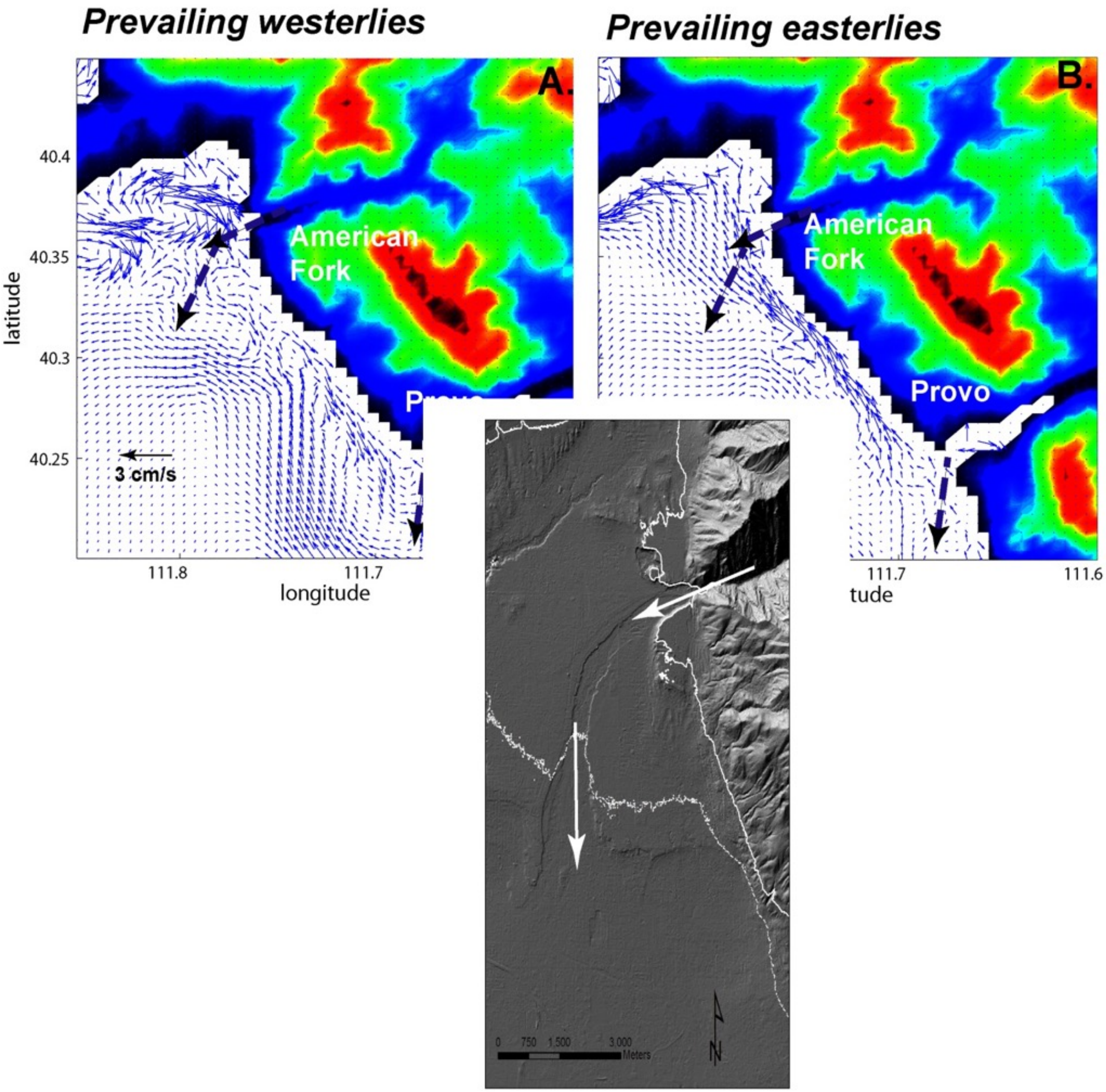


LO
Cache Valley
BF
5 km
EC
PC
MC
Salt Lake Valley
BC
LC
10 km
AF
PR
Utah Valley
HC
SF
10 km
Sevier Desert
SR
5 km



Complex topography of Bonneville basin = complex circulation


Prevailing westerlies
Prevailing easterlies
Emigration Canyon
Parleys Canyon
Millcreek Canyon
Emigration Canyon
Parleys Canyon
Millcreek Canyon
3 cm/s
3 cm/s
latitude
40.75
40.7
40.65
40.6
112
111.75
111.5
112
111.75
111.5
longitude
longitude
0
500
1,000
2,000
Meters
N



Prevailing westerlies
Prevailing easterlies
A.
B.
American Fork
Provo
40.4
40.35
40.3
40.25
latitude
3 cm/s
111.8
111.7
longitude
111.7
111.6
tude
0 750 1,500 3,000 Meters
N

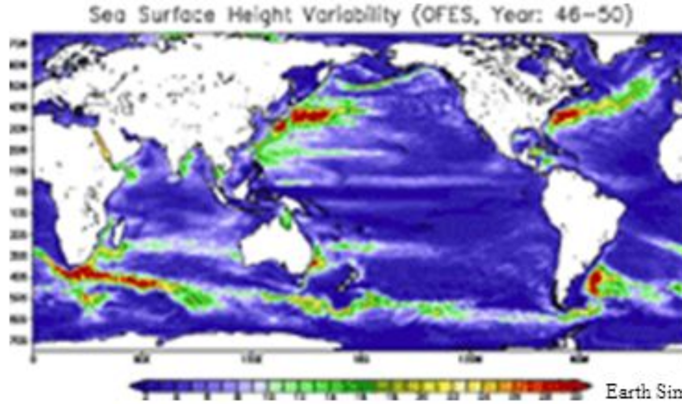
Future work:

Numerical Ocean Circulation Model

Global Scale

Modular Ocean Model

(MOM : GFDL)



Earth Simulator

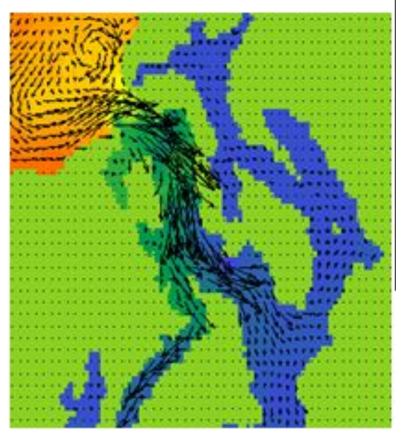
Local Scale

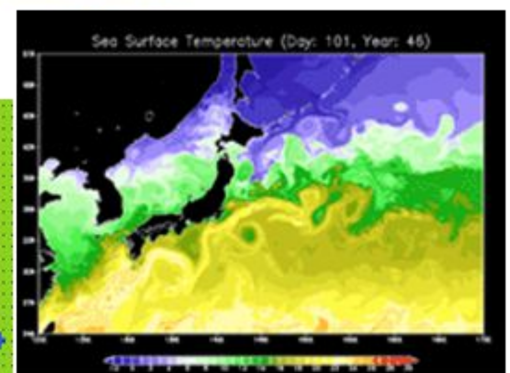
Princeton Ocean Model

(POM)

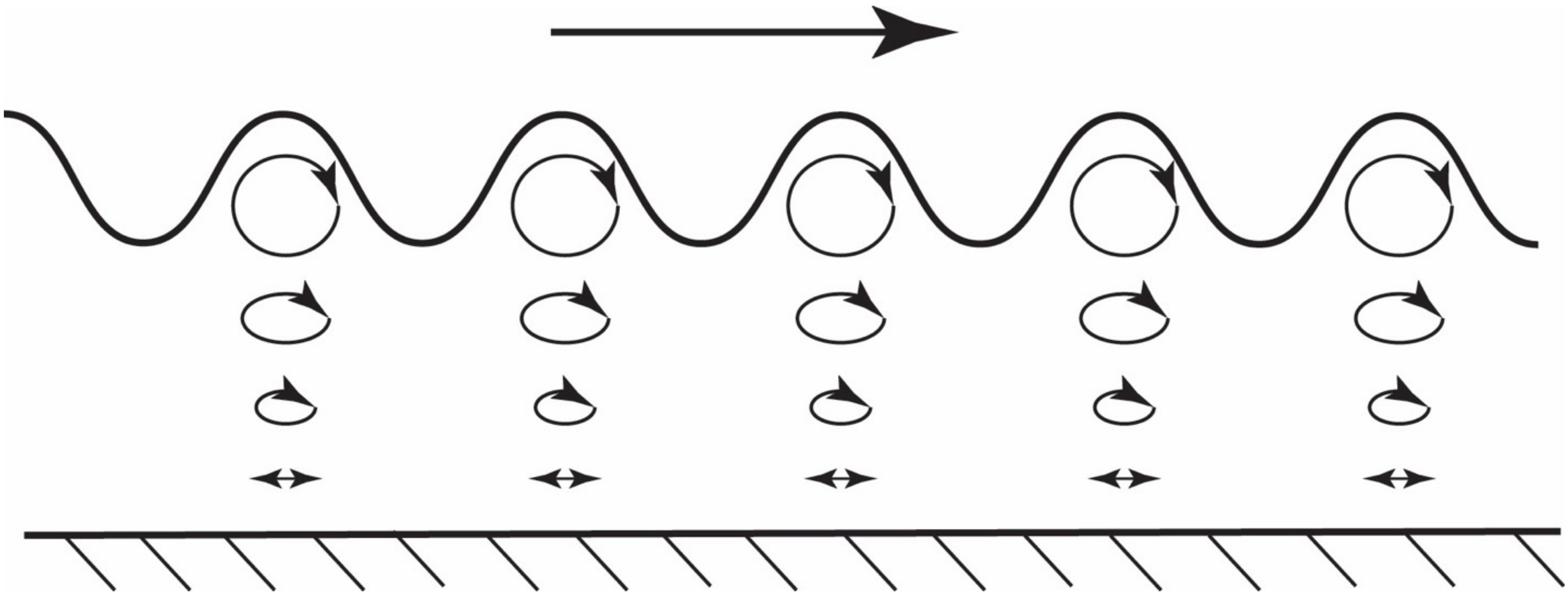
Marine Environmental Committee Model

(MEC Model)





Washington university




Somewhere along that long, lonesome
road of Lake Bonneville research ….

Geodynamics of Large Lakes: Bonneville, Lahontan, and Minchin

Bruce G. Bills

Asteroids, Comets, and Satellites Group
Jet Propulsion Laboratory

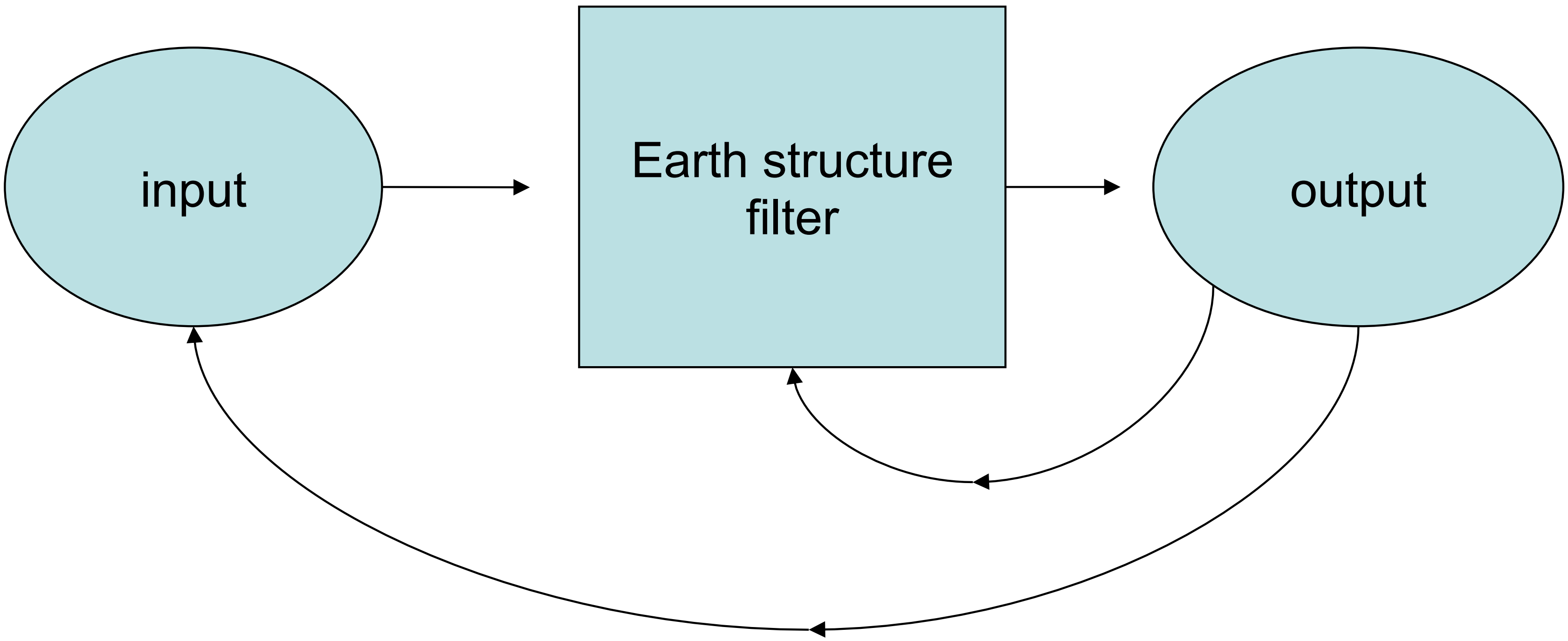
outline

- objectives of geodynamics research
  - ways of measuring “strength” of the Earth
  - why large lakes are useful
  - data requirements for models
- applications:
  - Bonneville (western Utah)
  - Lahontan (western Nevada)
  - Minchin (western Bolivia)

basic problem

- on time-scales shorter than a day
  - Earth behaves like an elastic solid
  - from the surface to the core-mantle boundary
- on plate tectonic time-scales (millions of years)
  - Earth behaves like a viscous fluid
  - from the lithosphere on down
- how does that transition occur?

generic forcing model



methods of probing Earth structure

type	input	output	time scale
earthquakes	impulsive displacement	displacement	seconds-days
tides	periodic gravitational potential	displacement, gravity anomaly	hours-weeks
ice sheets	complex vertical load	displacement	10^2-10^4 years
large lakes	complex vertical load	displacement	10^2-10^4 years

advantages of large lakes

- significant vertical deflection
  - produced via loading
  - recorded in shoreline elevations
- complex load
  - spatial complexity
  - temporal complexity
- temporal record
  - sedimentary layers
  - less destructive than glaciers

more advantages of lakes

- loads are easily reconstructed
  - top surface is level
  - bottom surface is existing topography
- shorelines are often traceable basin-wide
  - decouples spatial and temporal problems
  - internal consistency
- lateral variation in viscosity between basins easily accommodated

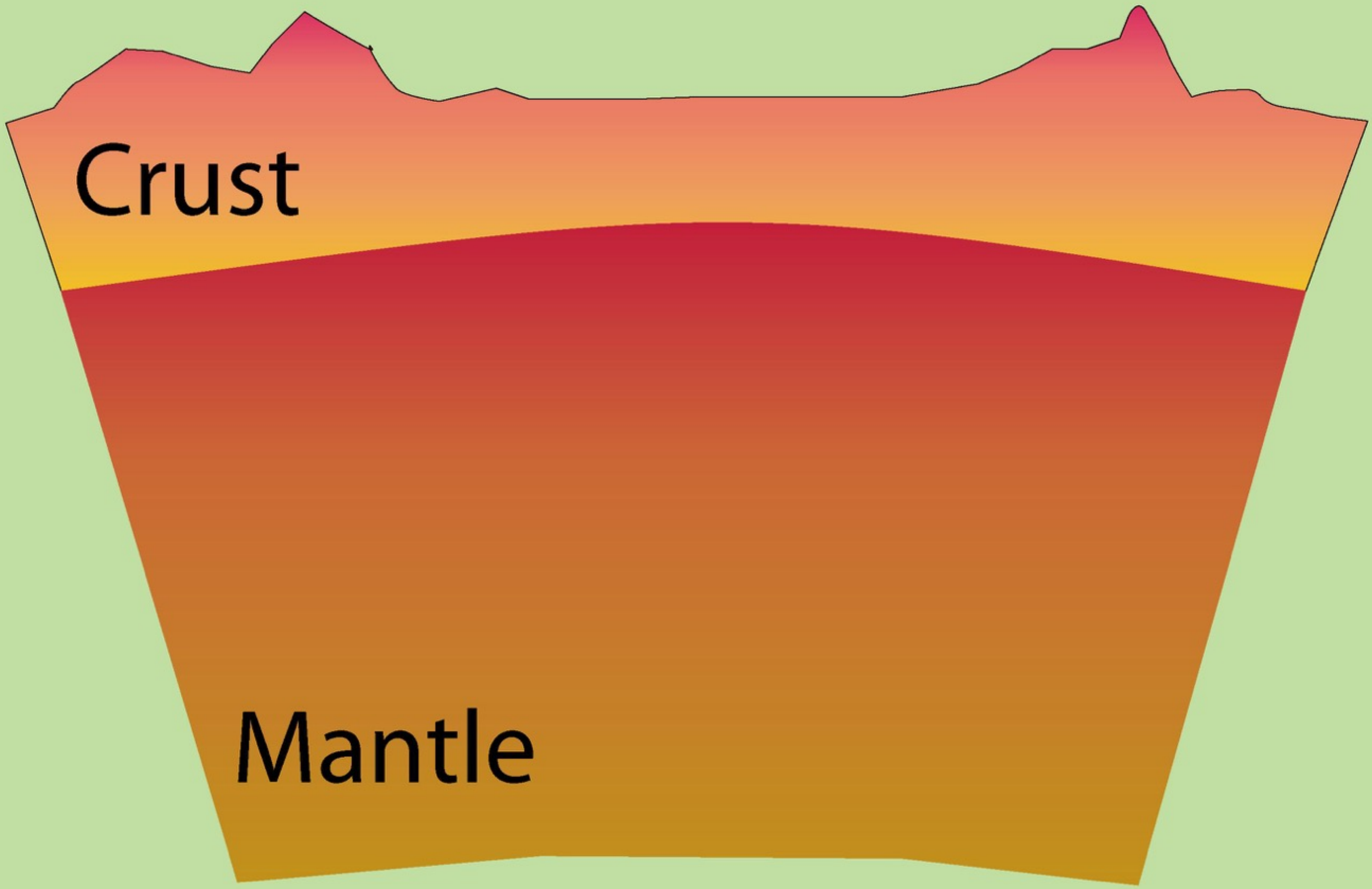
main points

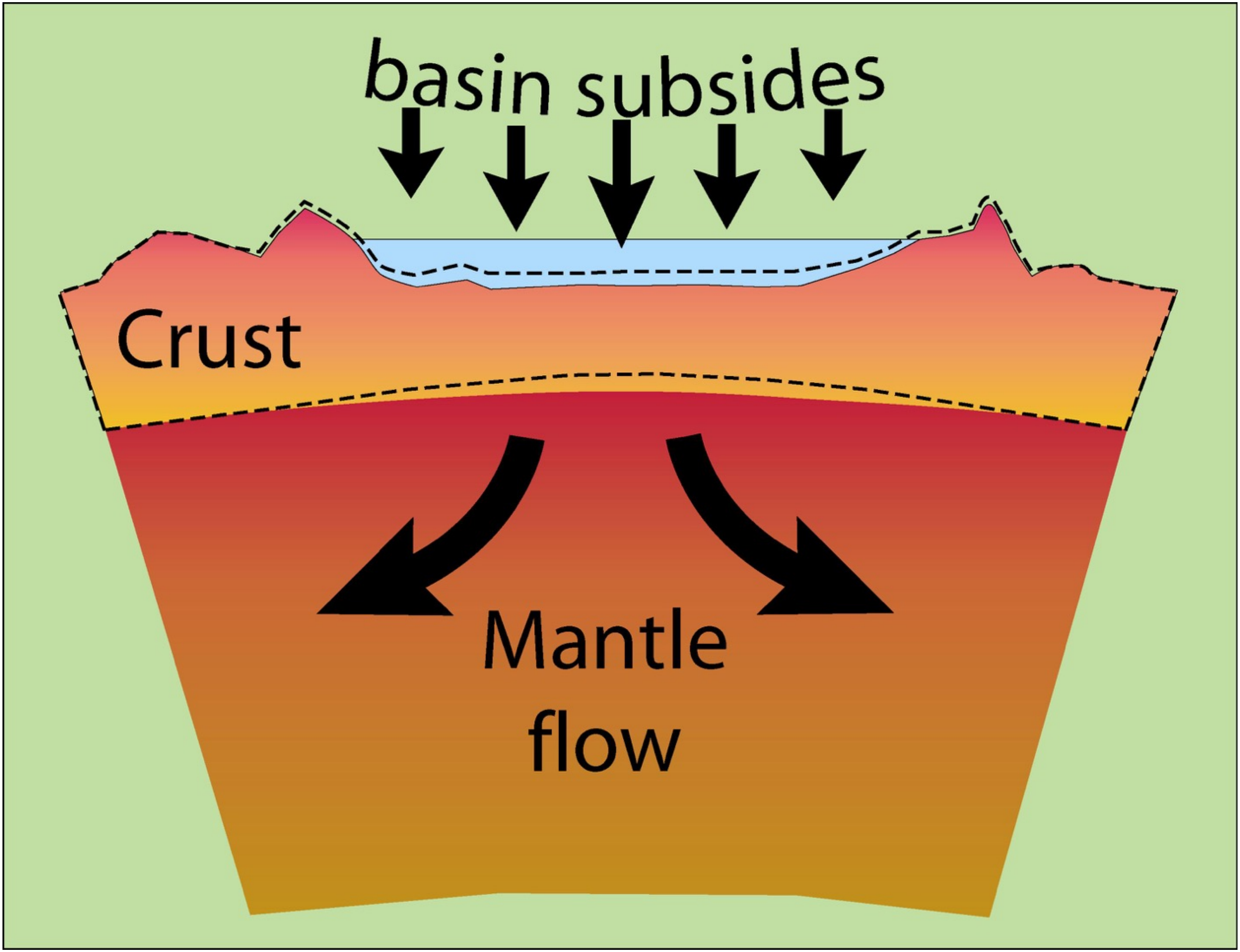
- lakes are important sources of information
  - paleo-climate history
  - rebound and rheology
- density and viscosity should both be adjusted
  - both influence rebound
  - spatial patterns of influence are separable
- lateral variations in viscosity?
  - contrasting geologic provinces
  - lithospheric age variations

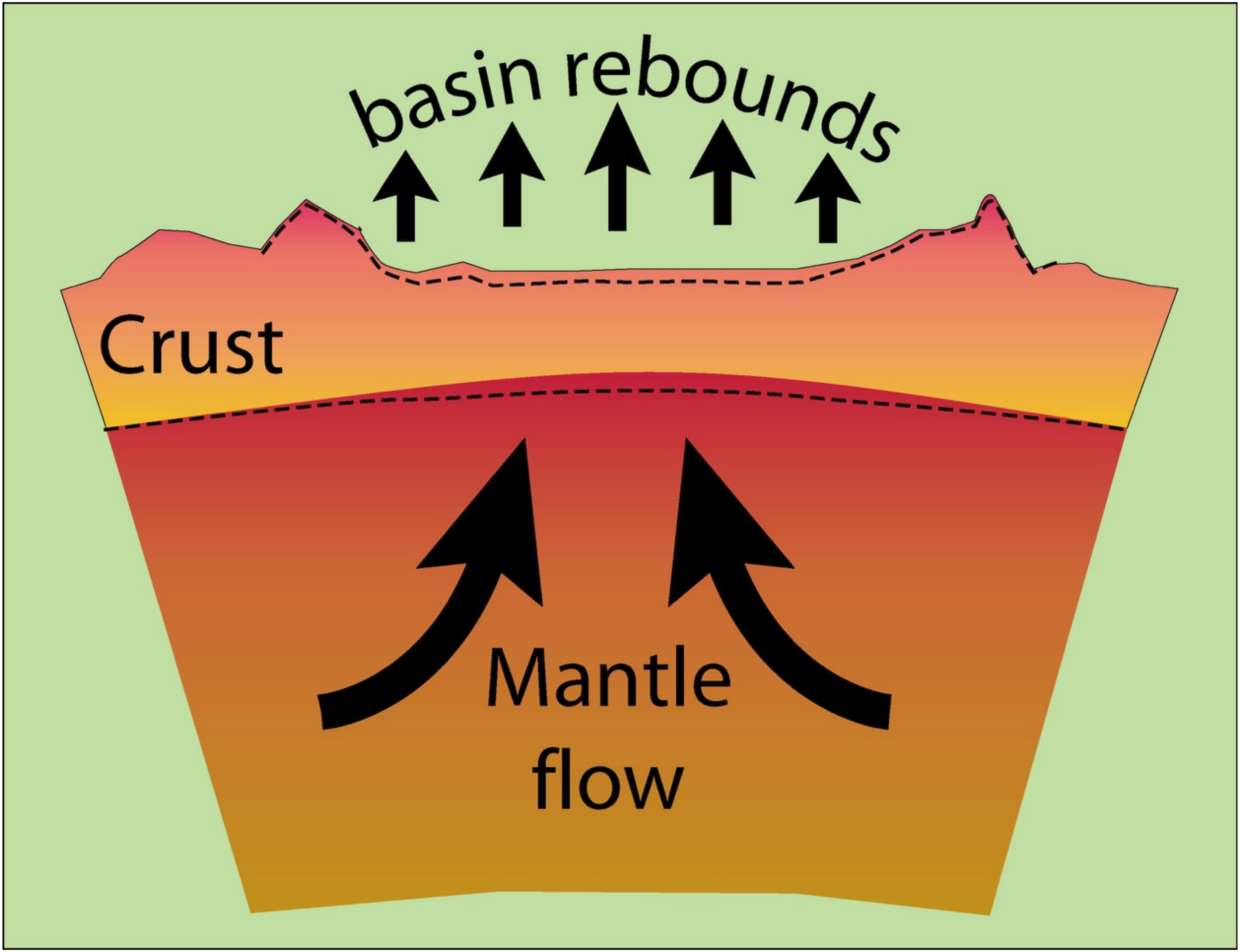
density versus viscosity

- density and viscosity
  - both determine response function
  - partial derivatives are separable
- density is reasonably well known a priori

A simple model of the Earth....



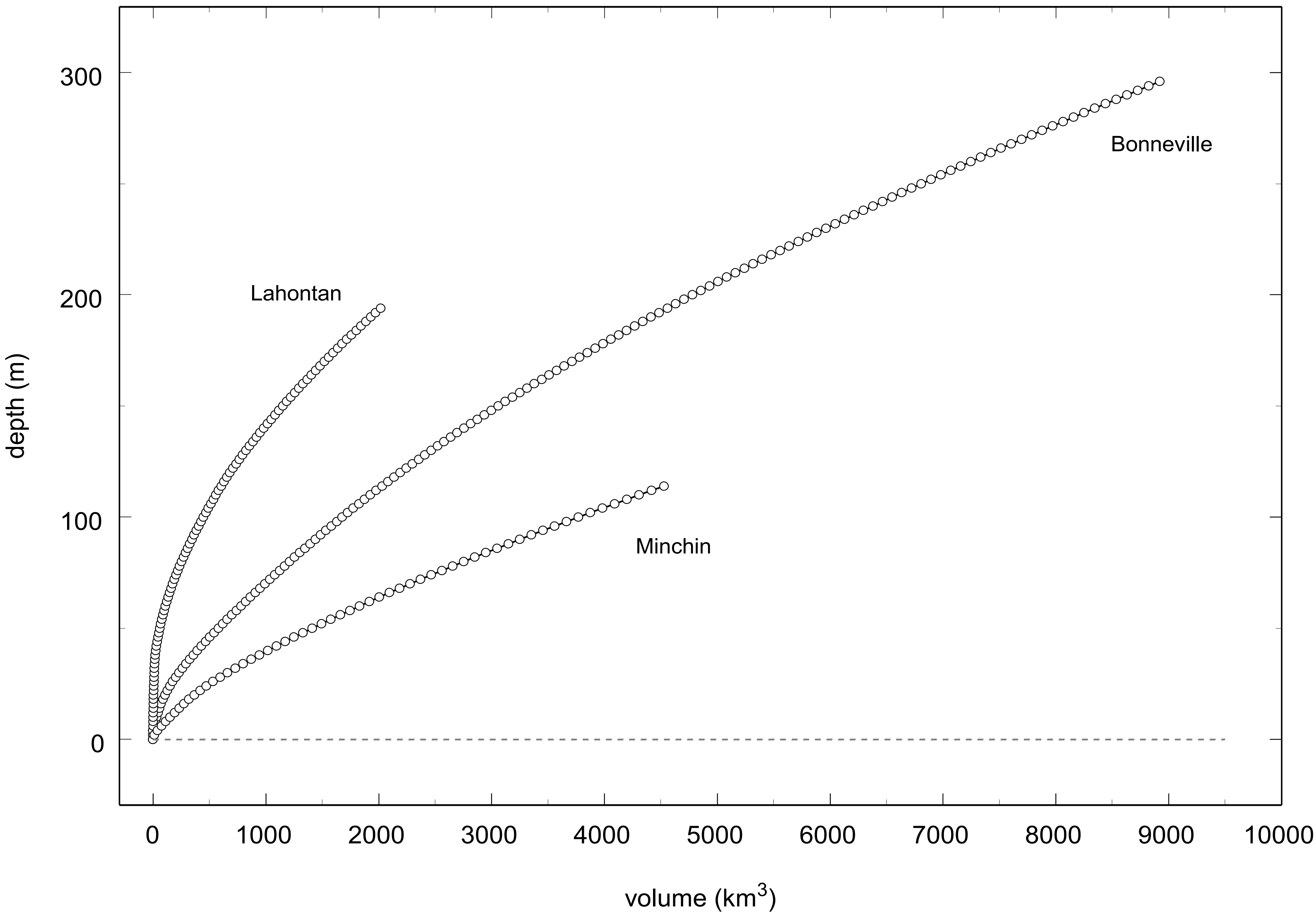

basin subsides
Crust
Mantle
flow

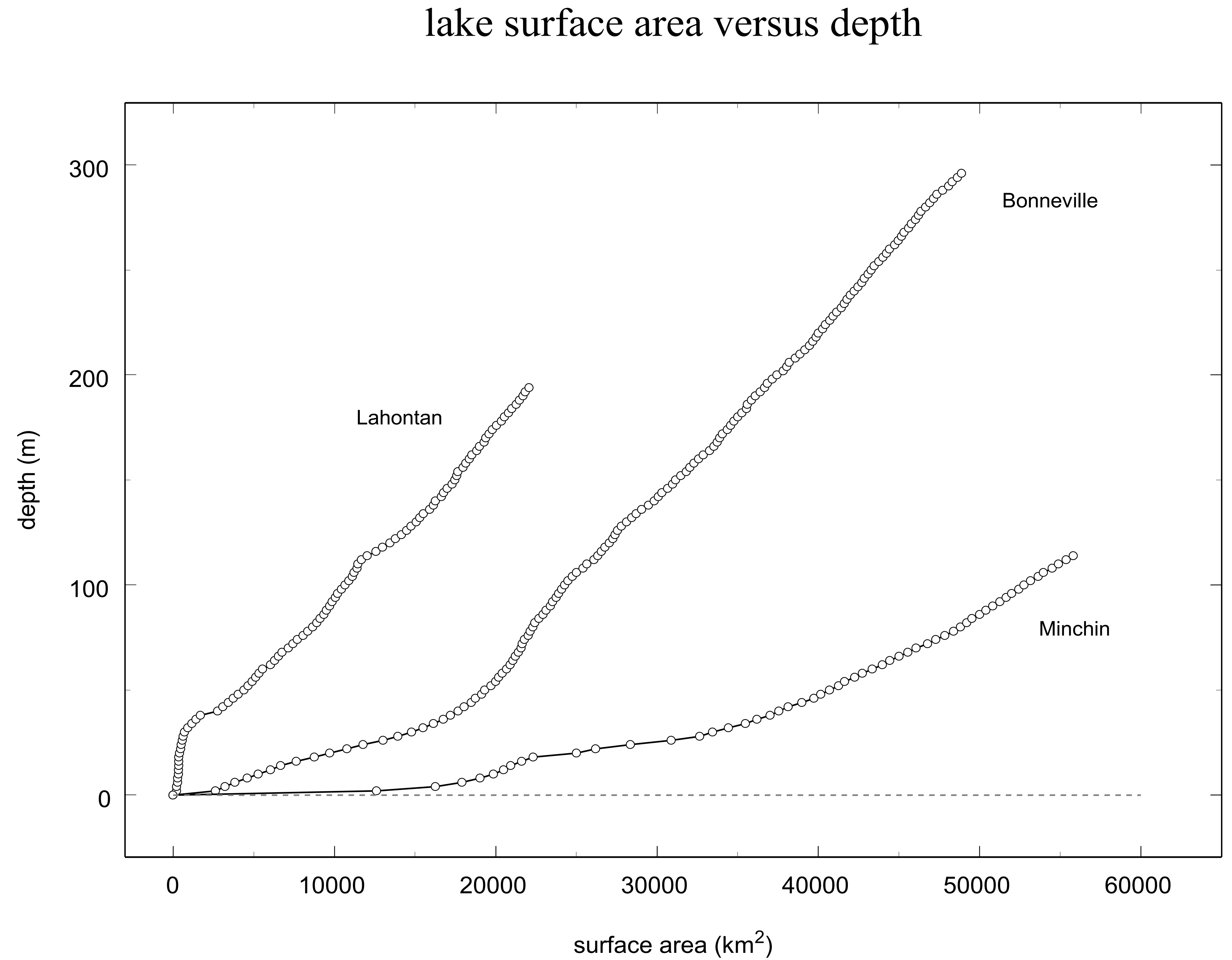

basin rebounds
Crust
Mantle
flow

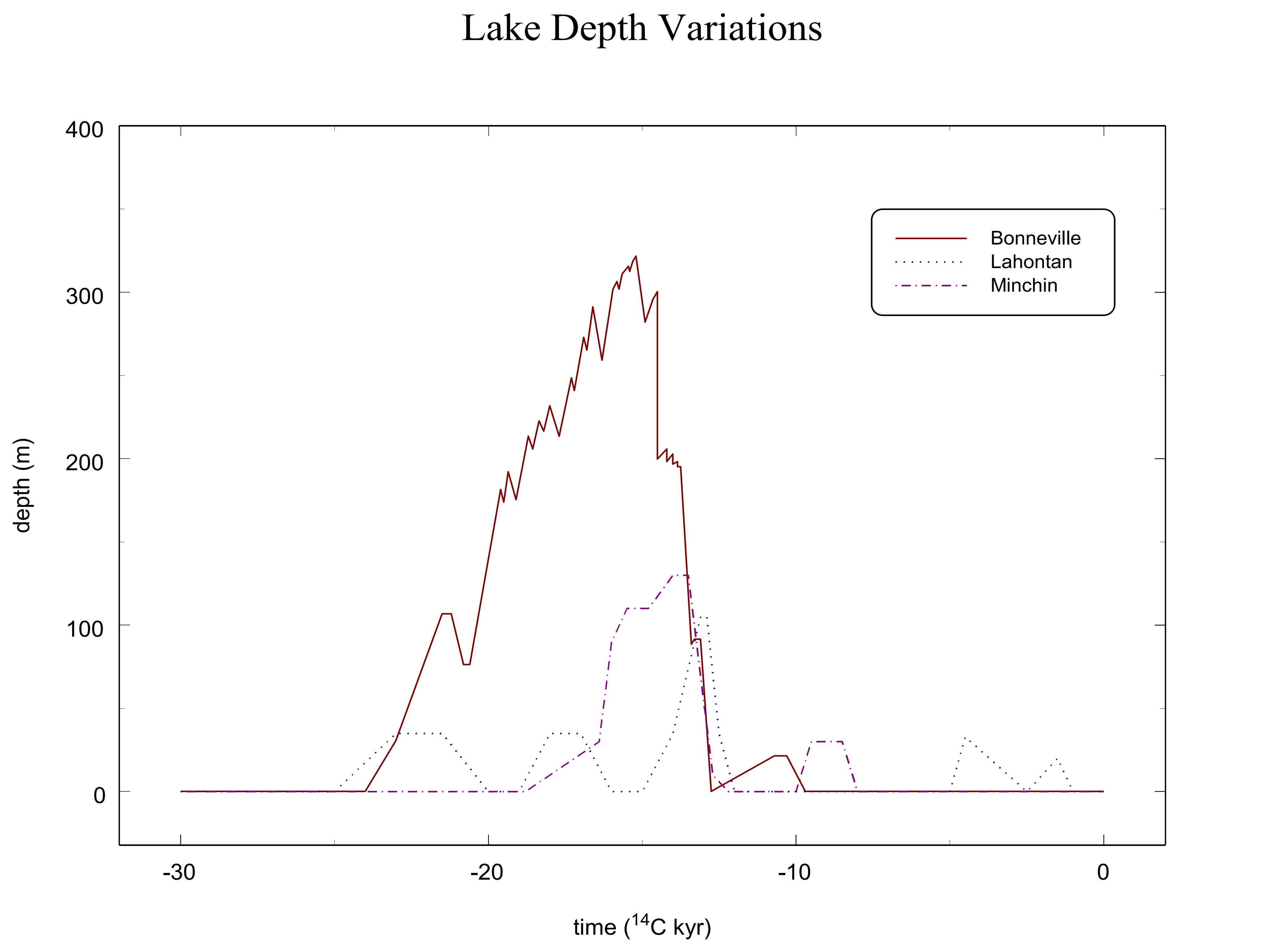
compare 3 large lakes

- Bonneville
  - location: western Utah
  - max volume: 9,000 km^3 max rebound: 75 m
  - max area: 48,000 km^2 max depth: 330 m
- Lahontan
  - location: western Nevada
  - max volume: 2,000 km^3 max rebound: 18 m
  - max area: 22,000 km^2 max depth: 110 m
- Minchin
  - location: western Bolivia
  - max volume: 4,600 km^3 max rebound: 32 m
  - max area: 56,000 km^2 max depth: 140 m

lake volume versus depth

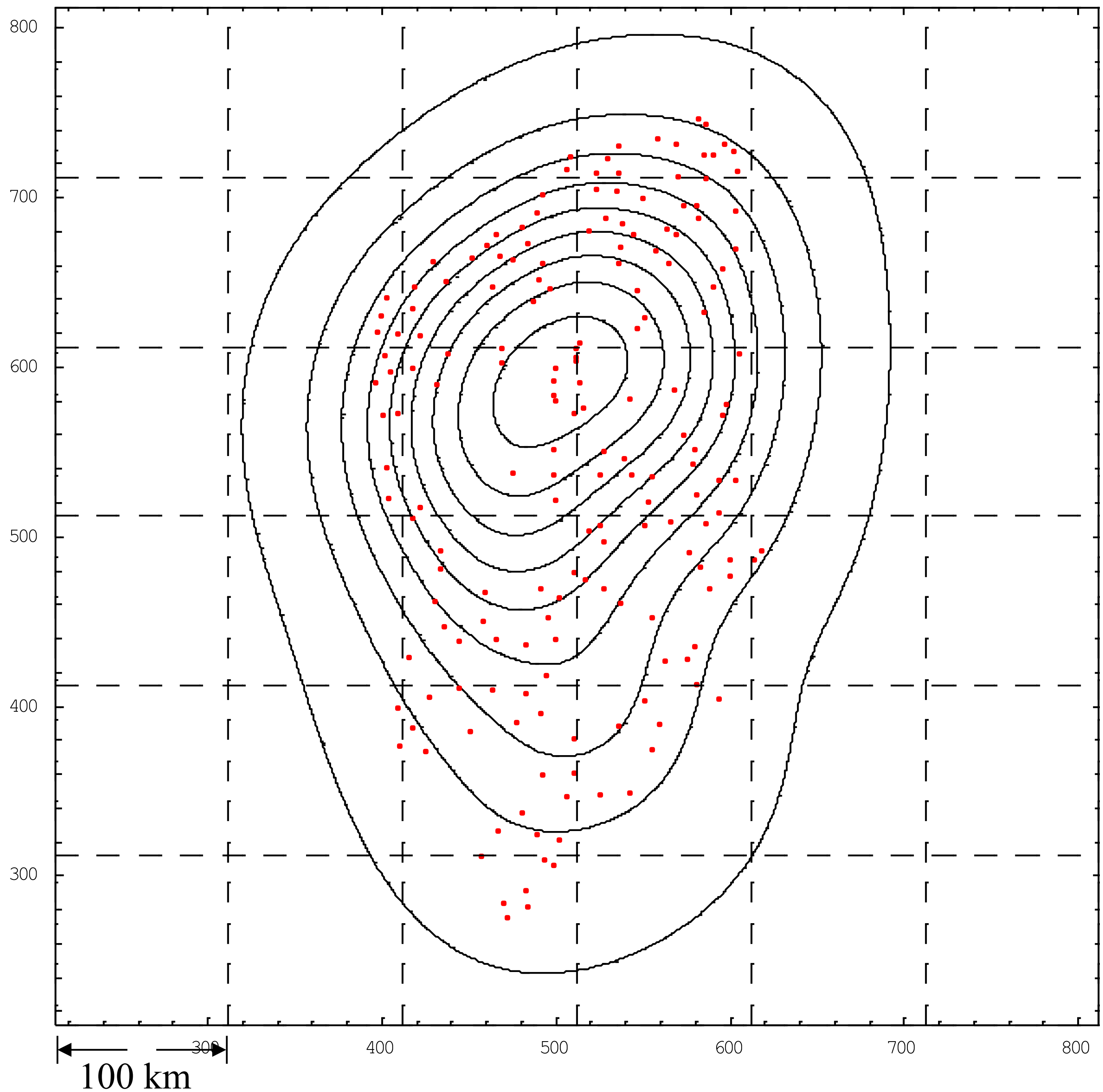



lake surface area versus depth
300
200
100
0
depth (m)
0
10000
20000
30000
40000
50000
60000
surface area (km2)
Lahontan
Bonneville
Minchin



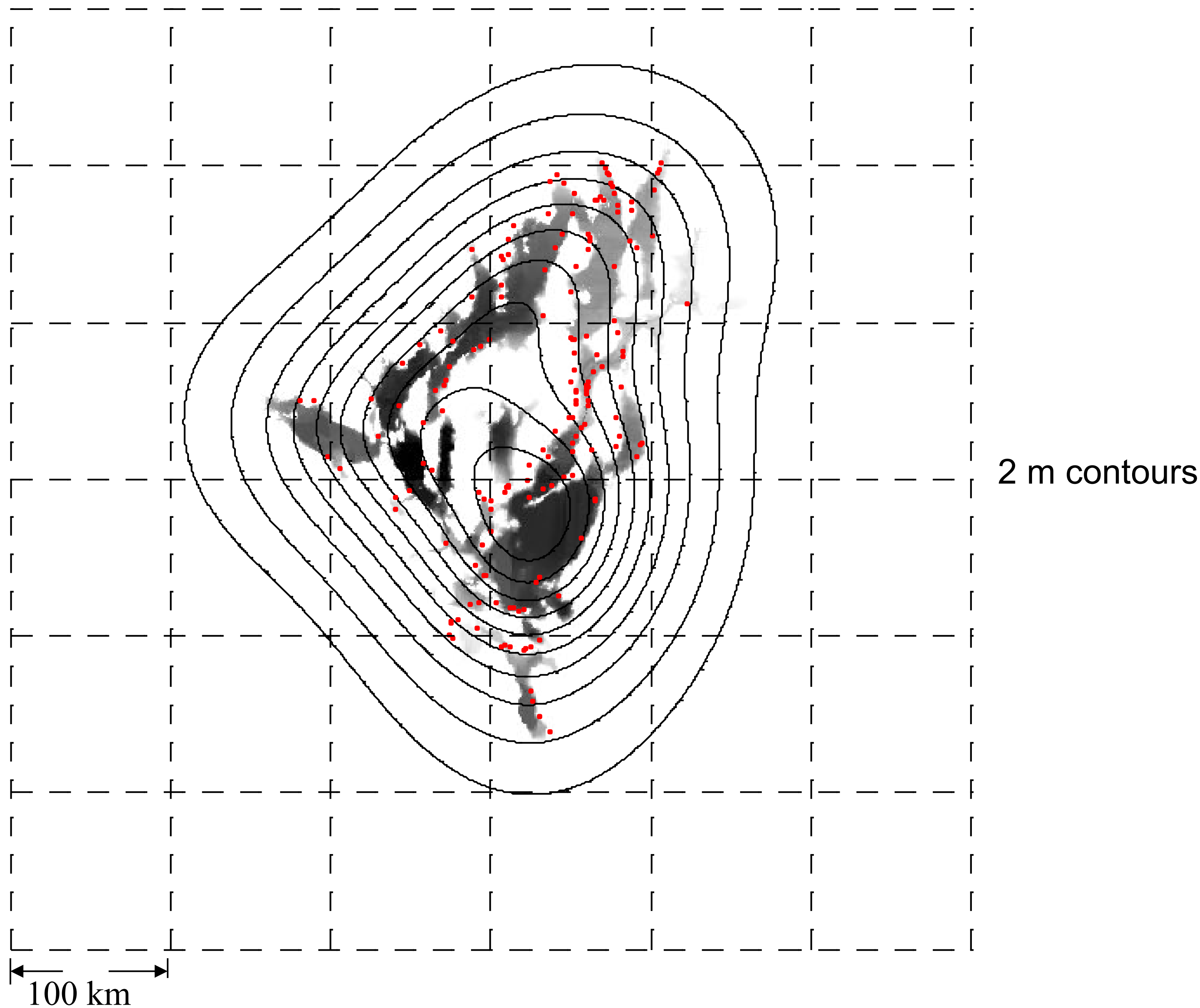
Lake Depth Variations
400
300
200
100
0
depth (m)
-30
-20
-10
0
time (^{14}C kyr)
Bonneville
Lahontan
Minchin

lake Bonneville load and rebound pattern

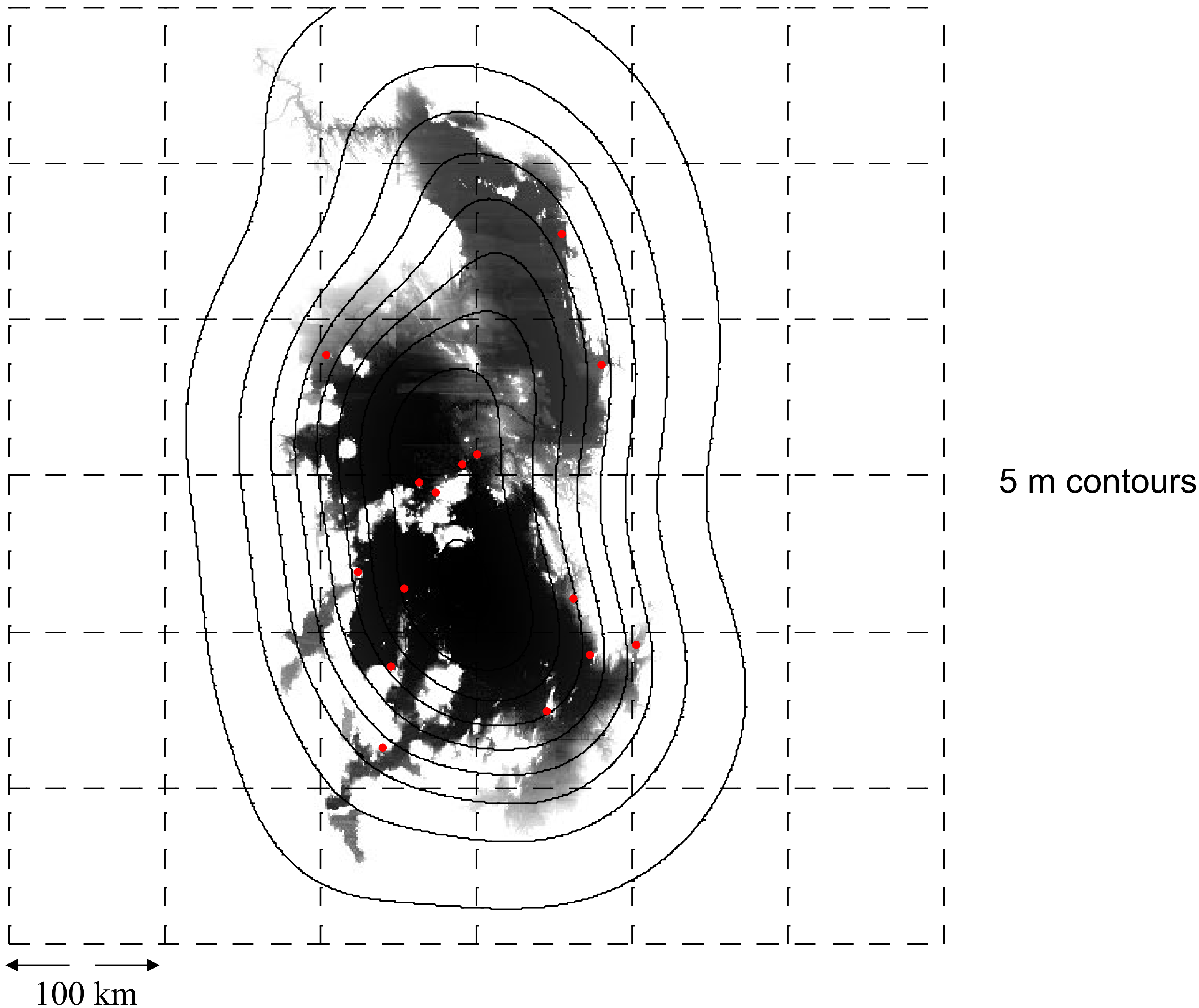


10 m contours

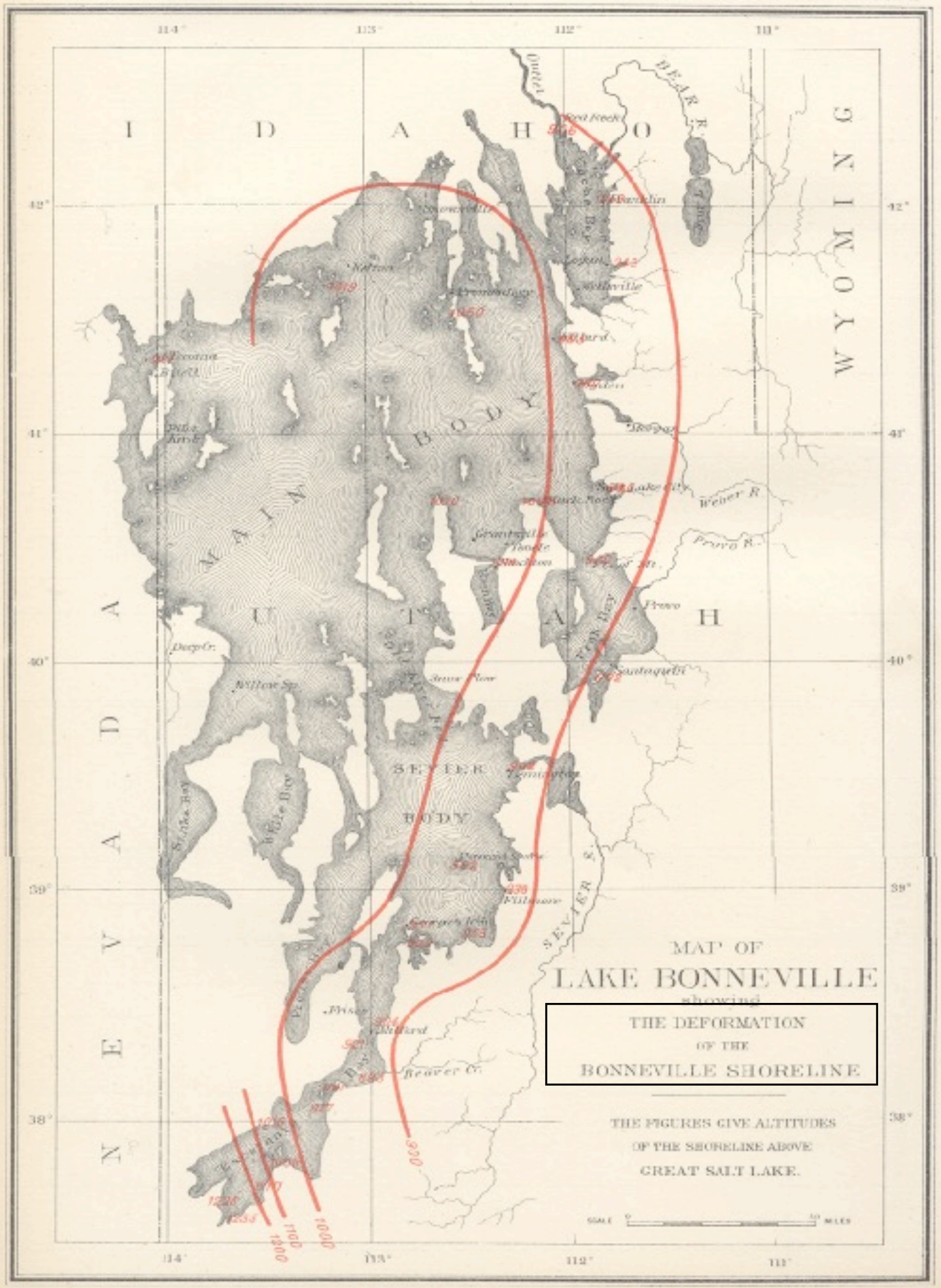
lake Lahontan load and rebound pattern

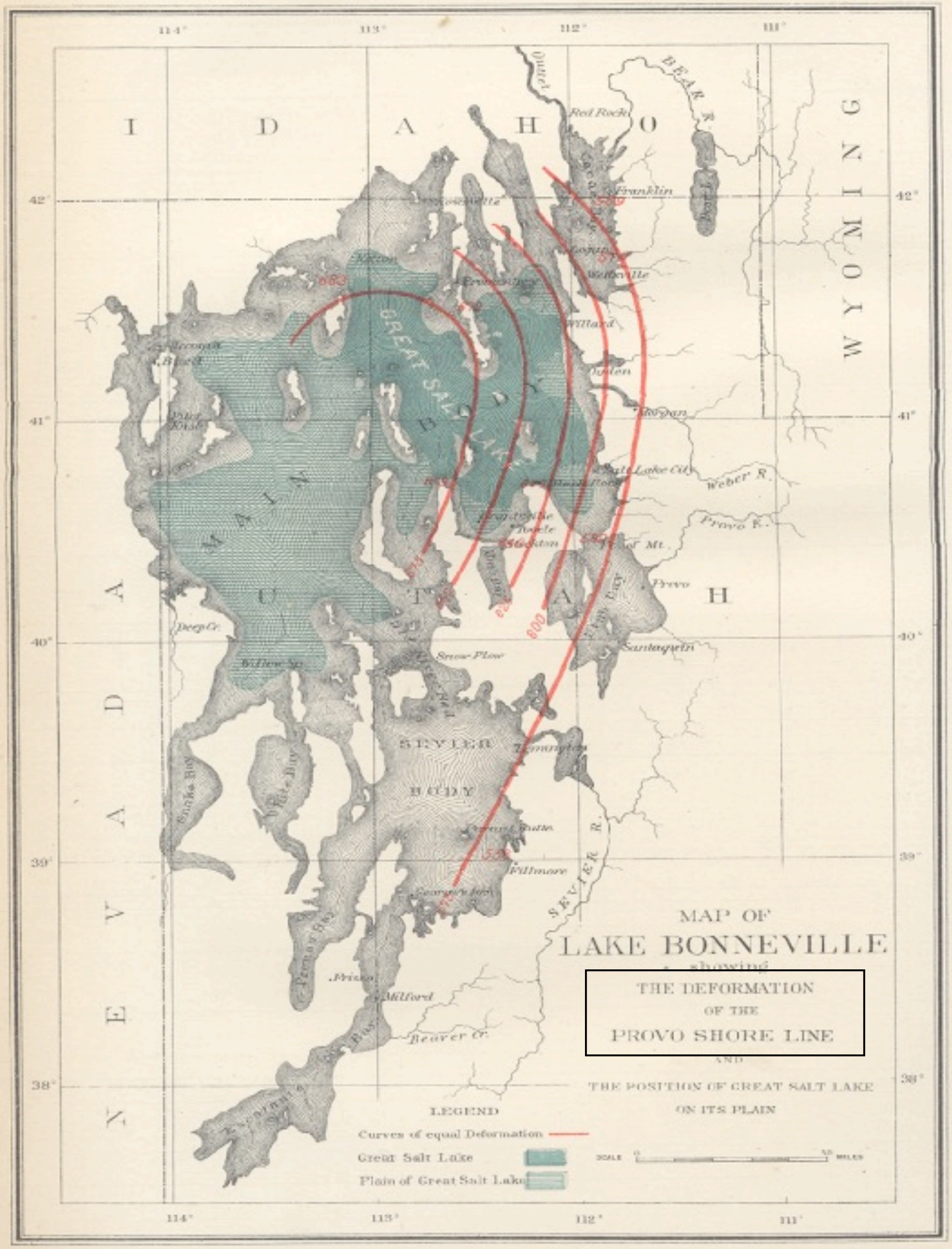


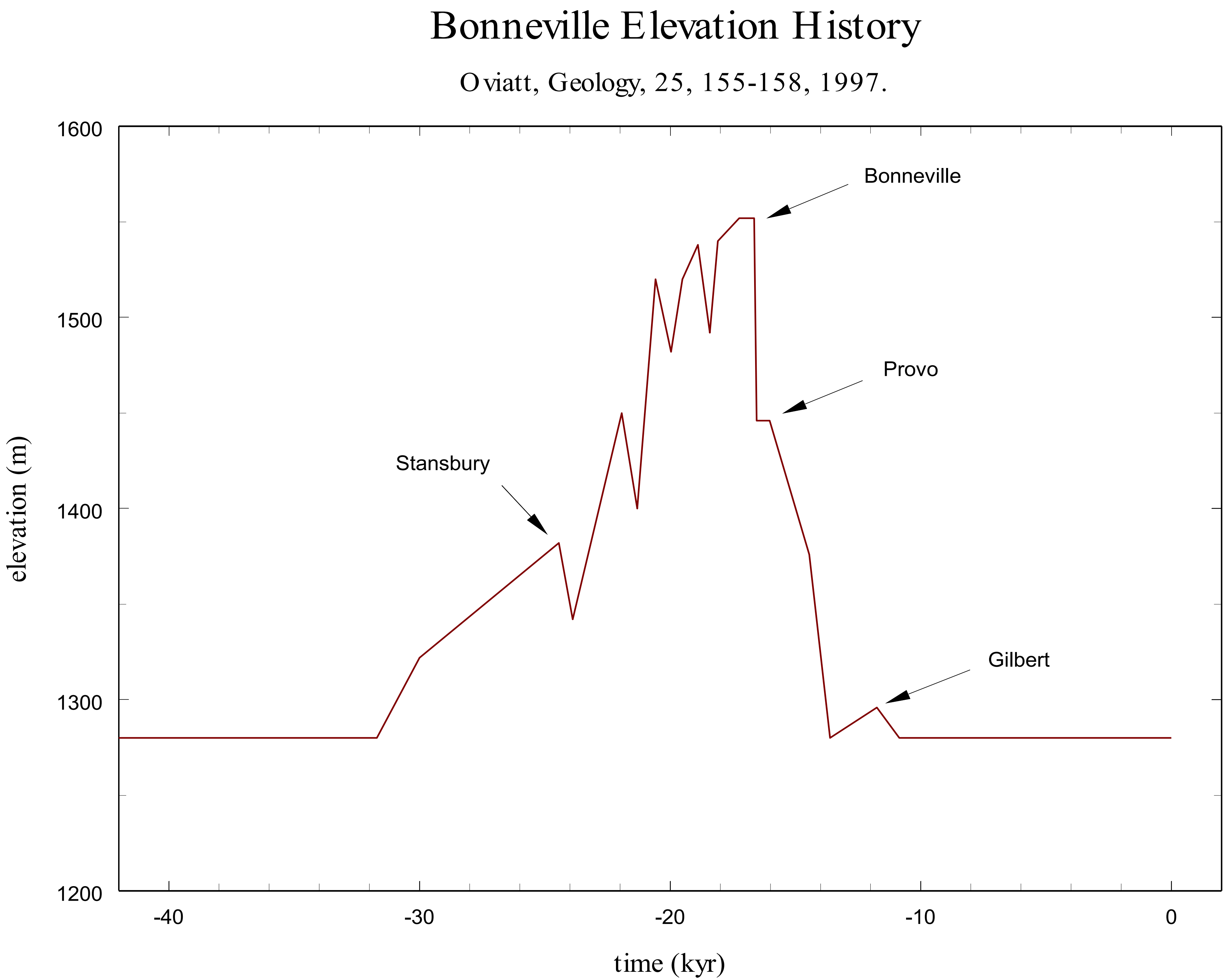
lake Minchin load and rebound pattern

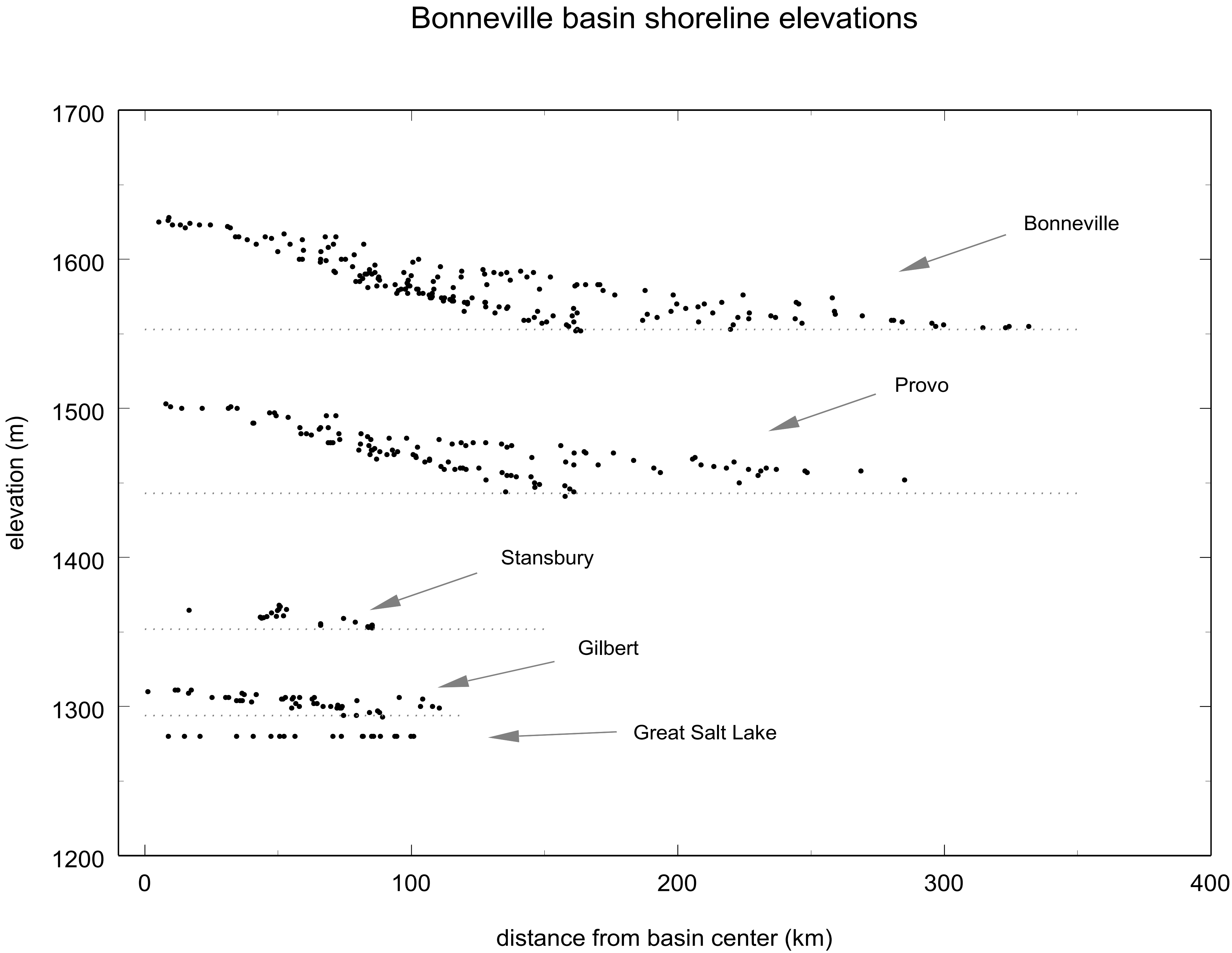


lake Bonneville

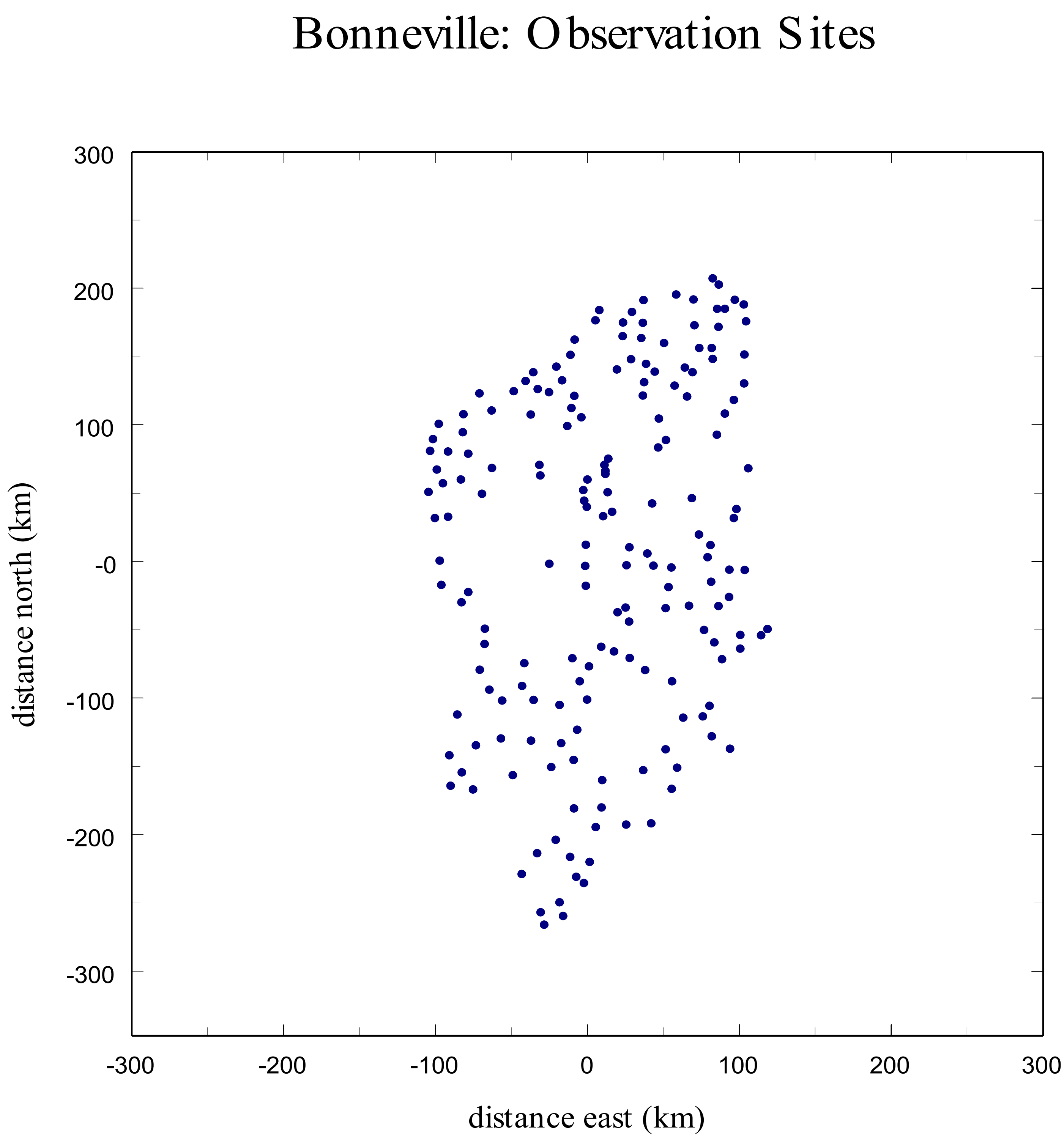

MAP OF
LAKE BONNEVILLE
showing
THE DEFORMATION
OF THE
BONNEVILLE SHORELINE
THE FIGURES GIVE ALTITUDES
OF THE SHORELINE ABOVE
GREAT SALT LAKE.
IDAHO
WYOMING
NEVADA
UTAH
MAIN BODY
SEVIER BODY
BEAR R.
Weber R.
Provo R.
Sevier R.
Beaver Cr.
Salt Lake City
Provo
Logan
Frisco
Deep Cr.
Willow Sp.

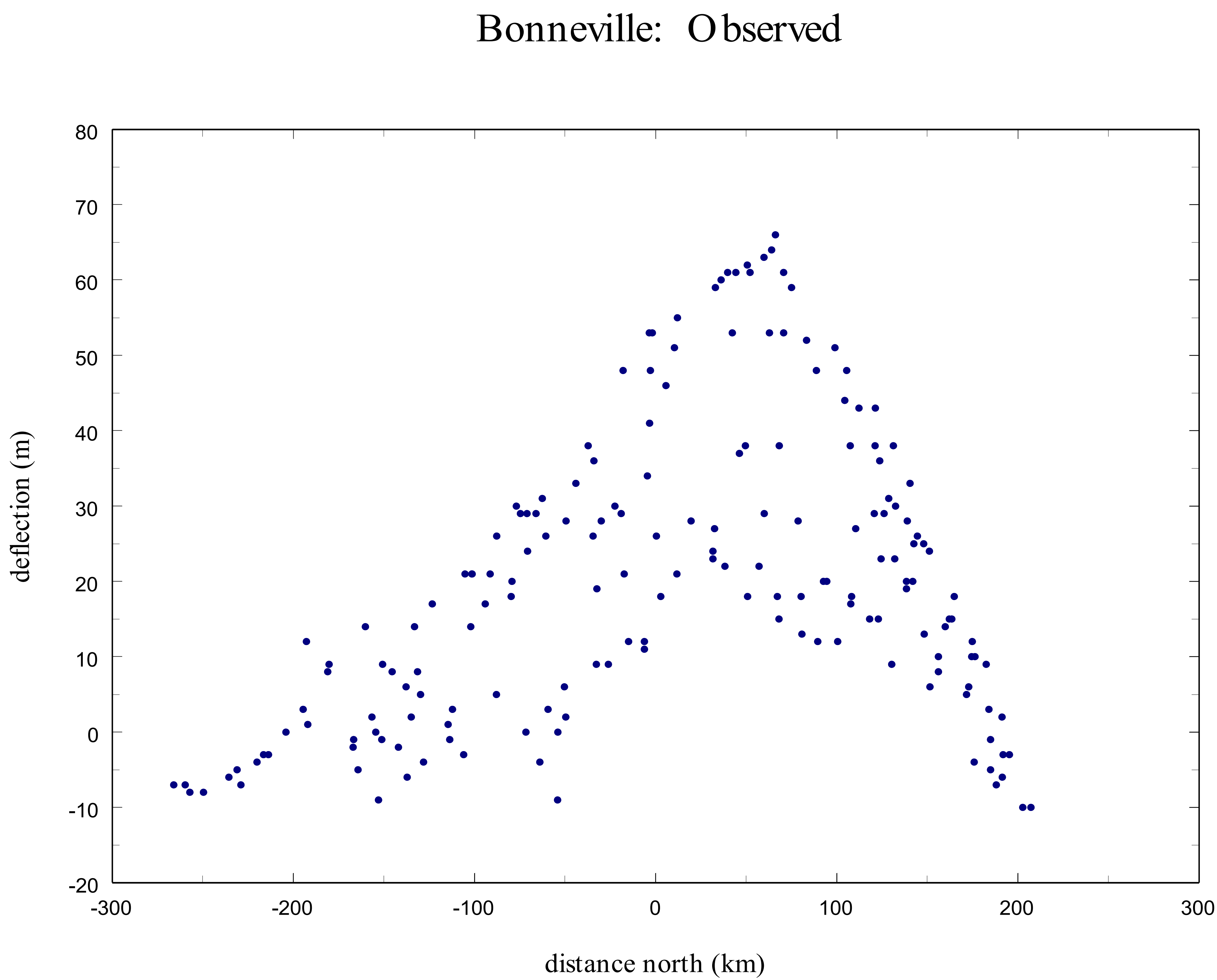

IDAHO
WYOMING
NEVADA
UTAH
GREAT SALT LAKE
MAIN BODY
SEVIER BODY
BEAR R.
Weber R.
Provo R.
SEVIER R.
Red Rock
Franklin
Logan
Wellsville
Willard
Ogden
Morgan
Salt Lake City
Stockton
Provo
Santaquin
Snow Flow
Deep Cr.
Fillmore
Milford
Beaver Cr.
MAP OF
LAKE BONNEVILLE
showing
THE DEFORMATION
OF THE
PROVO SHORE LINE
AND
THE POSITION OF GREAT SALT LAKE
ON ITS PLAIN
LEGEND
Curves of equal Deformation
Great Salt Lake
Plain of Great Salt Lake
SCALE
MILES

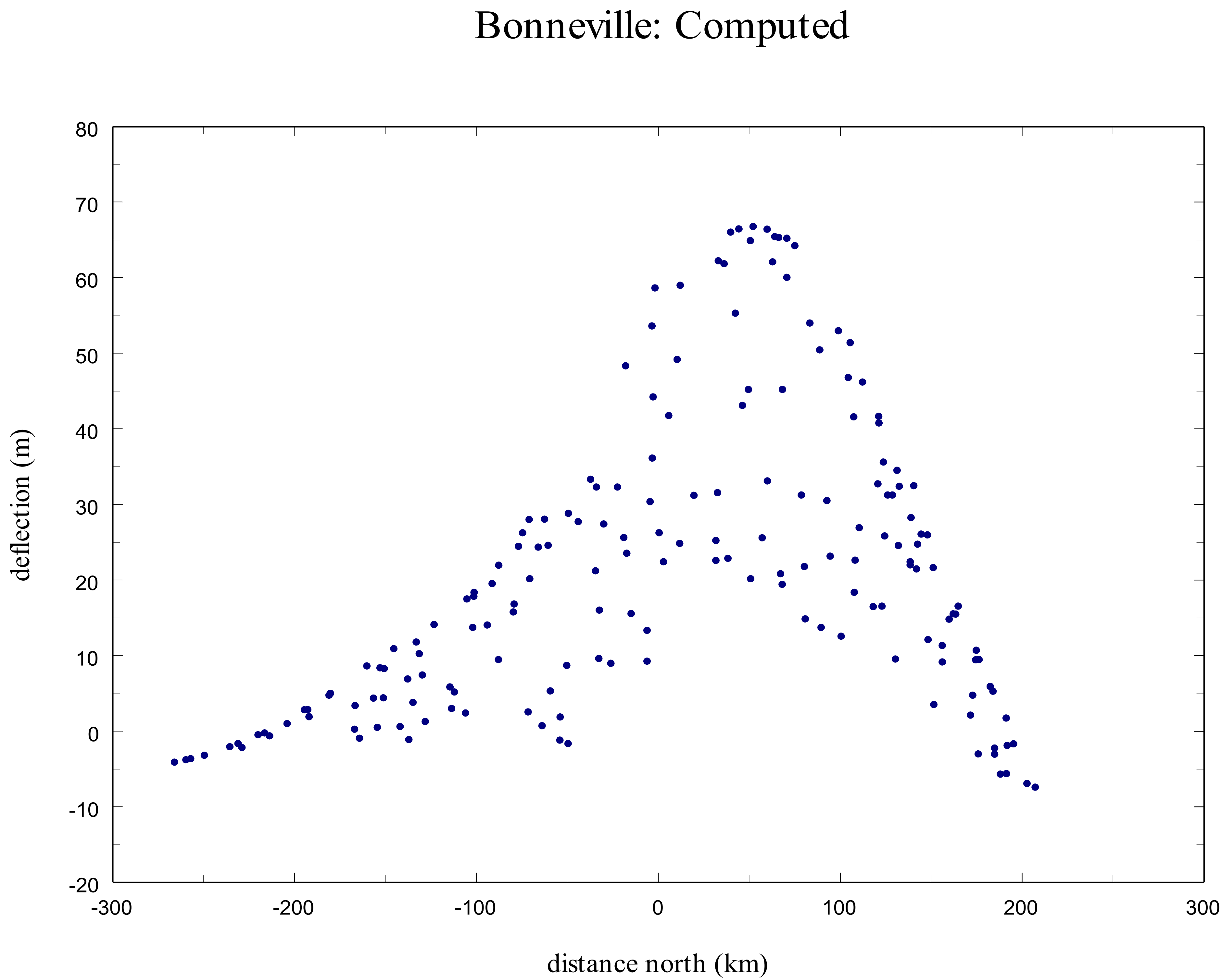

Bonneville Elevation History
Oviatt, Geology, 25, 155-158, 1997.
1600
1500
1400
1300
1200
elevation (m)
-40
-30
-20
-10
0
time (kyr)
Bonneville
Provo
Stansbury
Gilbert



Bonneville basin shoreline elevations
1700
1600
1500
1400
1300
1200
elevation (m)
0
100
200
300
400
distance from basin center (km)
Bonneville
Provo
Stansbury
Gilbert
Great Salt Lake

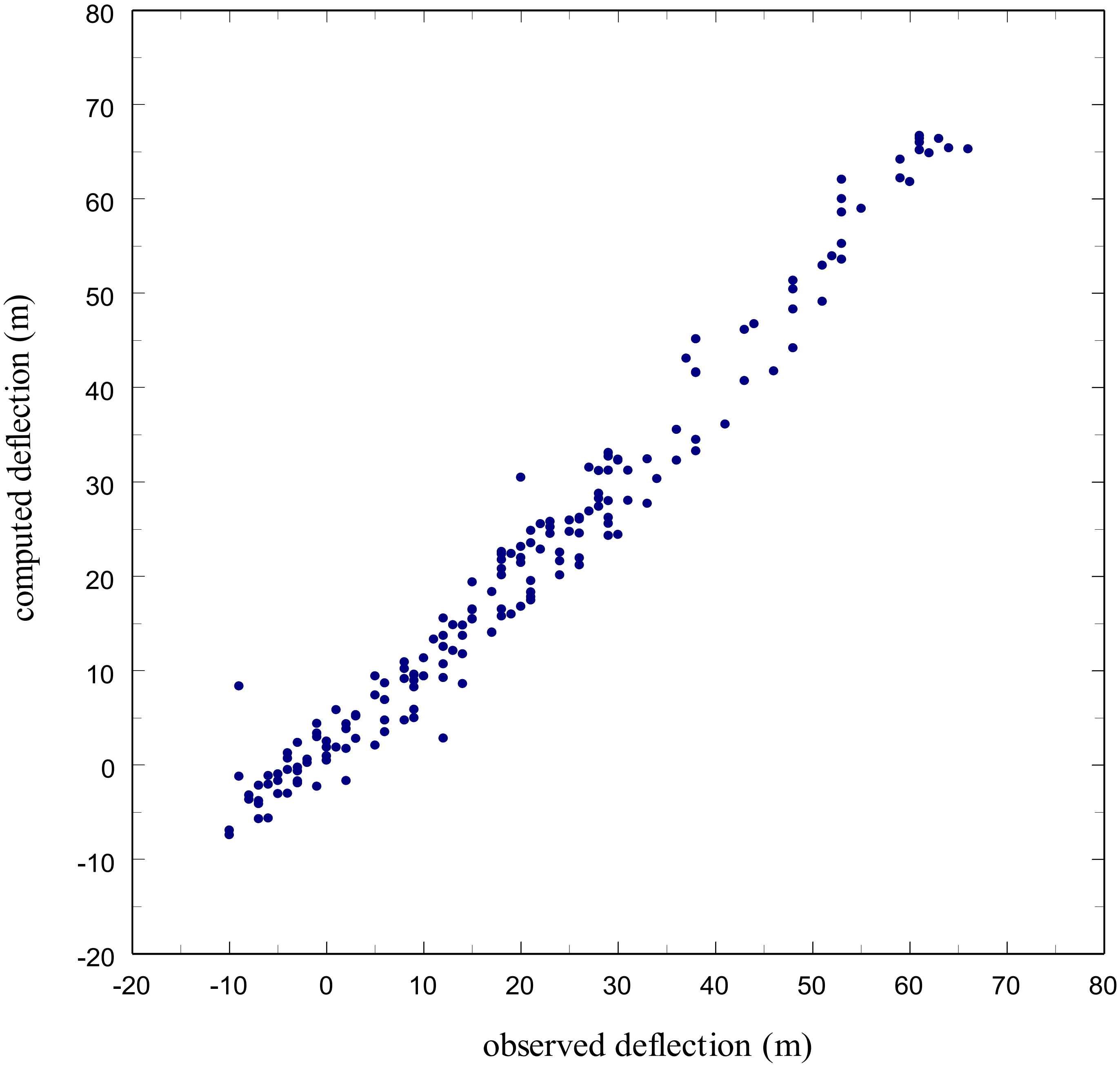

Bonneville: Observation Sites
300
200
100
-0
-100
-200
-300
-300
-200
-100
0
100
200
300
distance north (km)
distance east (km)


Bonneville: Observed
80
70
60
50
40
30
20
10
0
-10
-20
deflection (m)
-300
-200
-100
0
100
200
300
distance north (km)

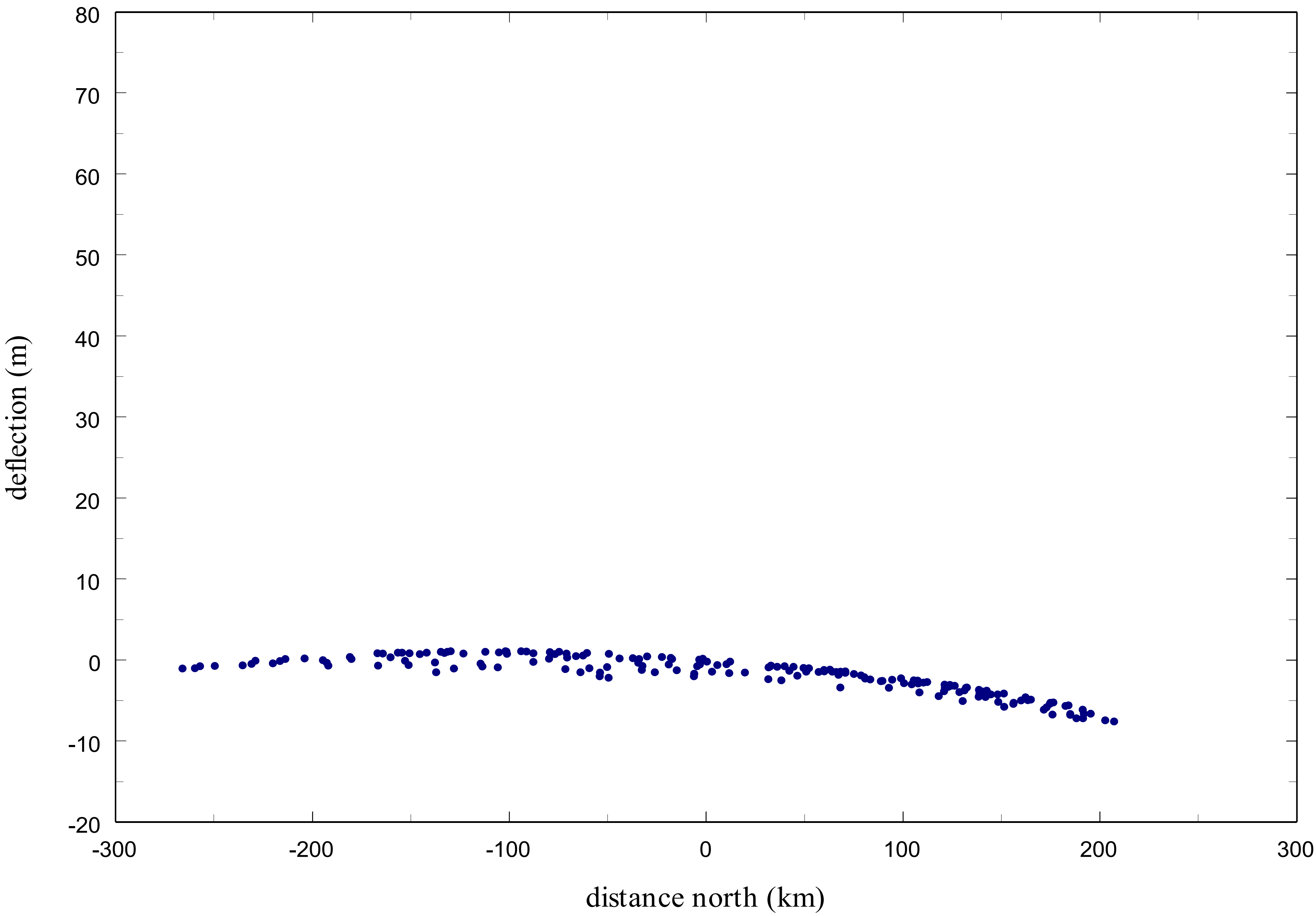


Bonneville: Computed
deflection (m)
80
70
60
50
40
30
20
10
0
-10
-20
-300
-200
-100
0
100
200
300
distance north (km)

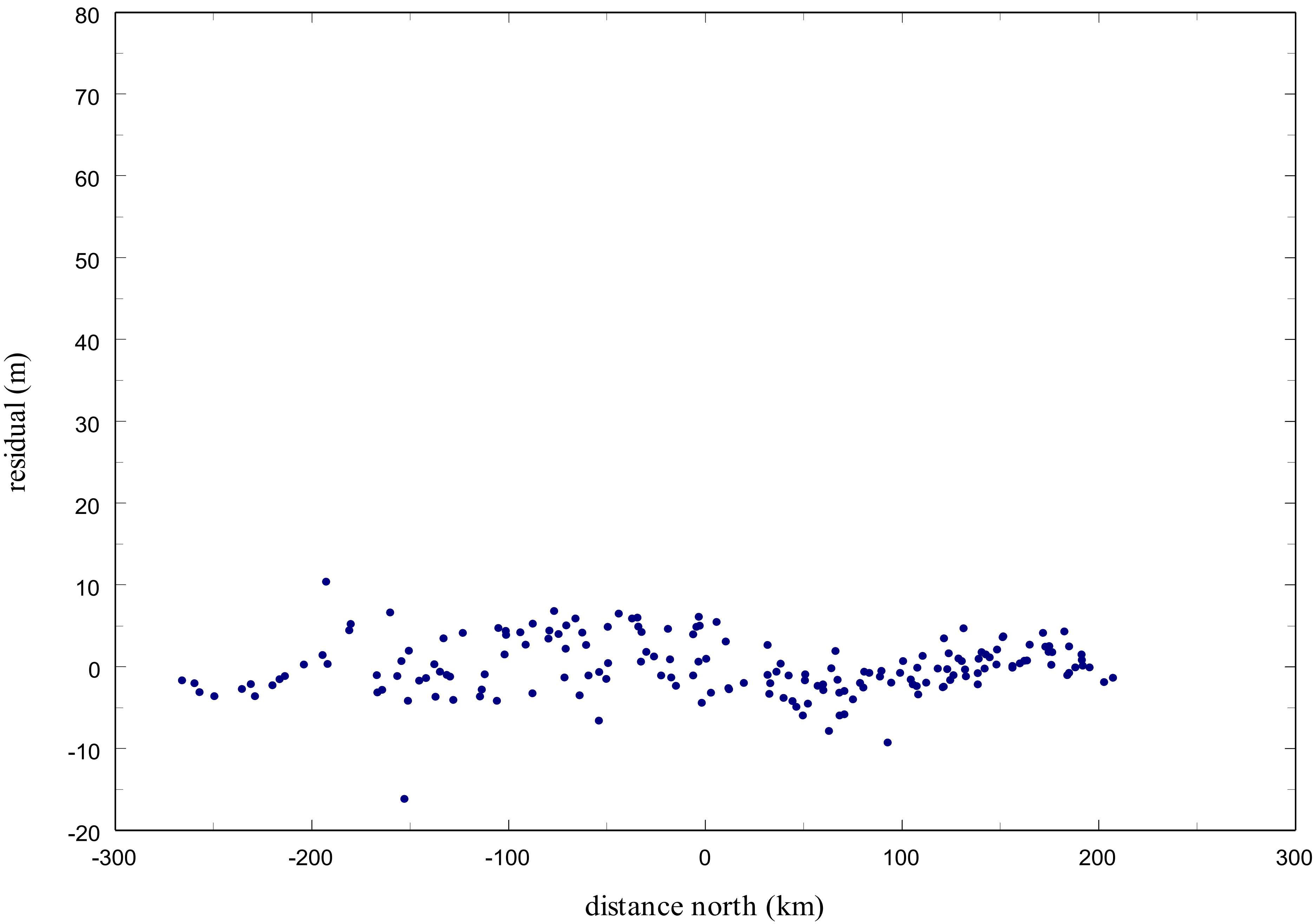
Bonneville: Observed vs Computed



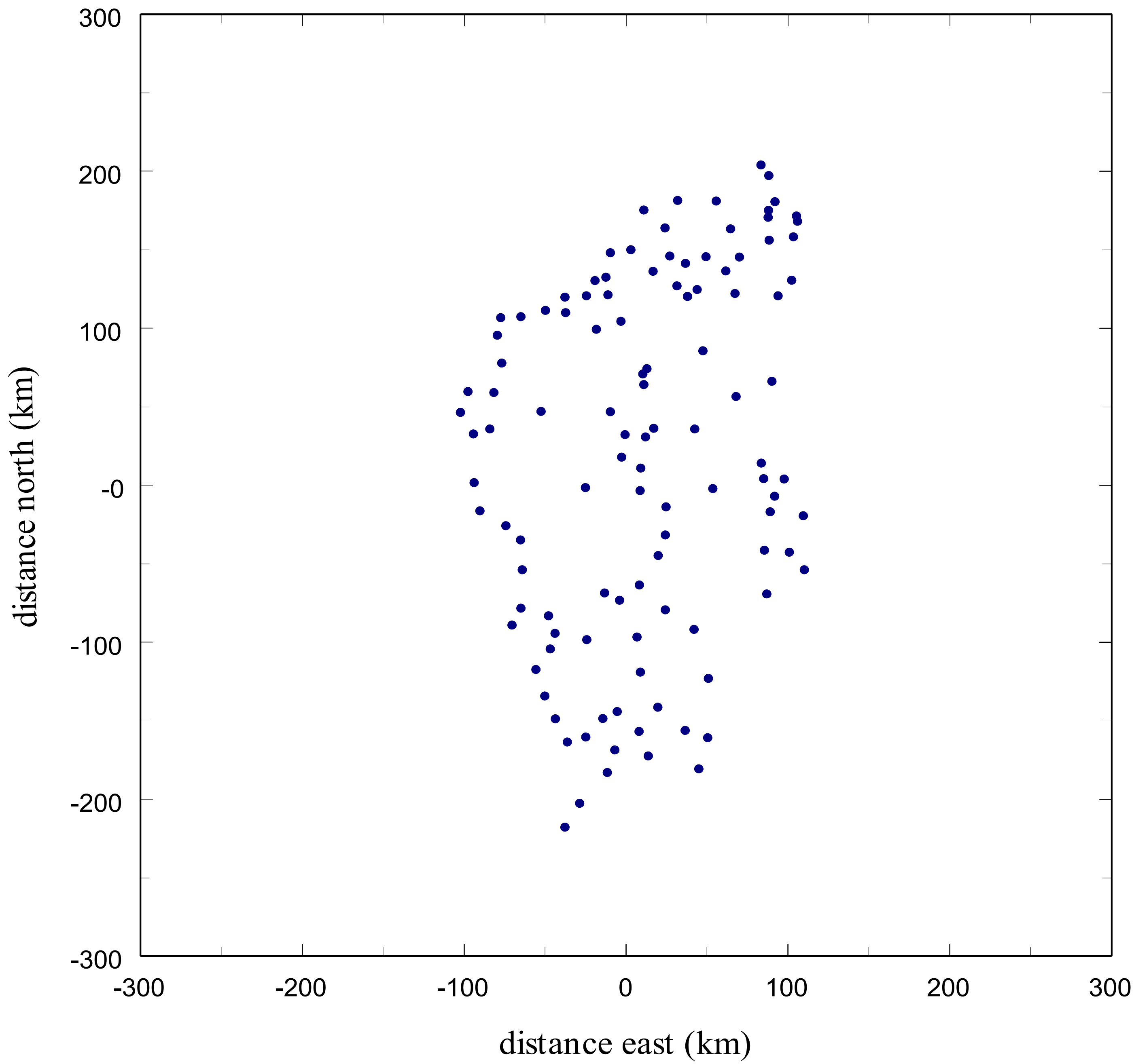
Bonneville: Linear & Quadratic Trend

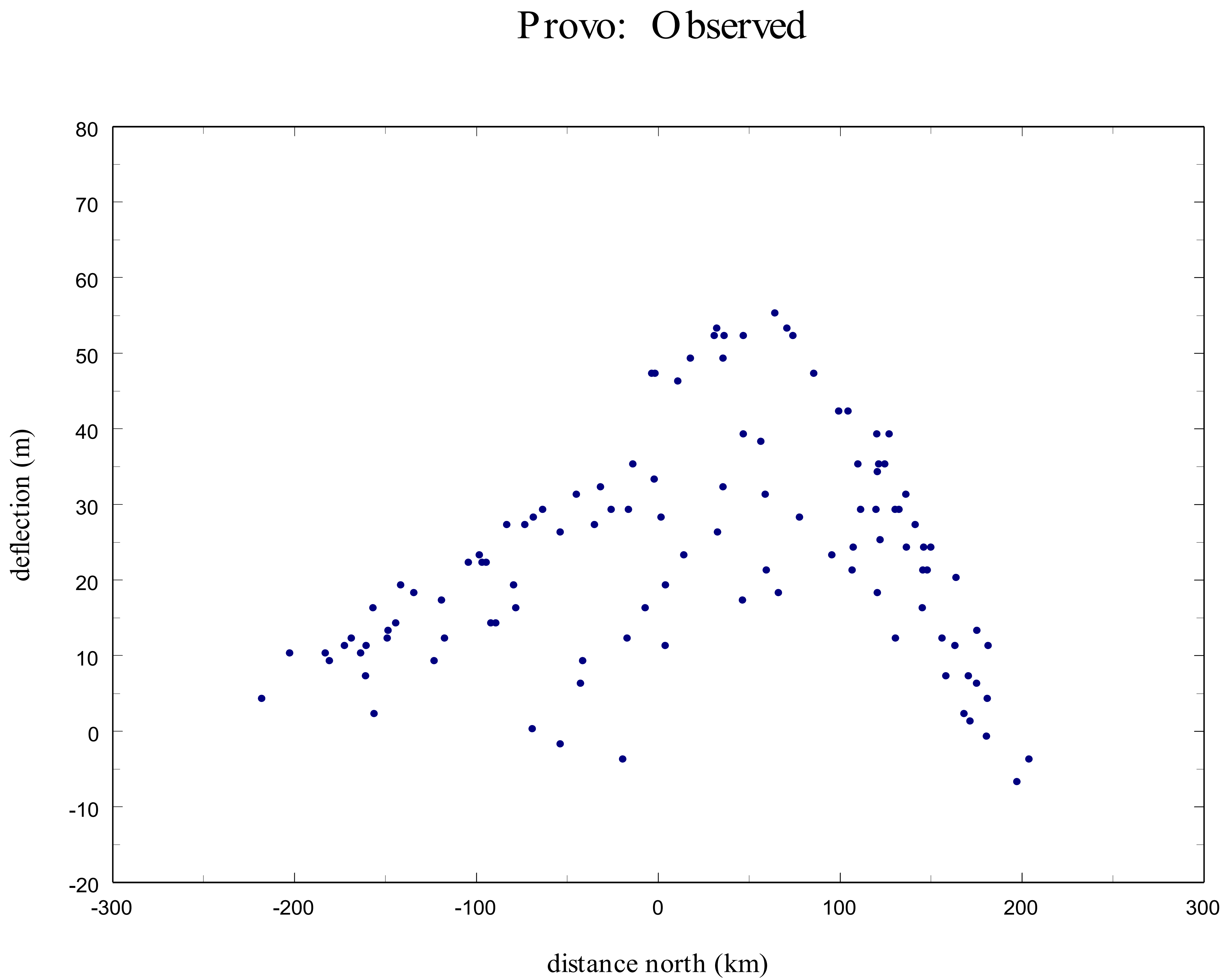


Bonneville: Residuals

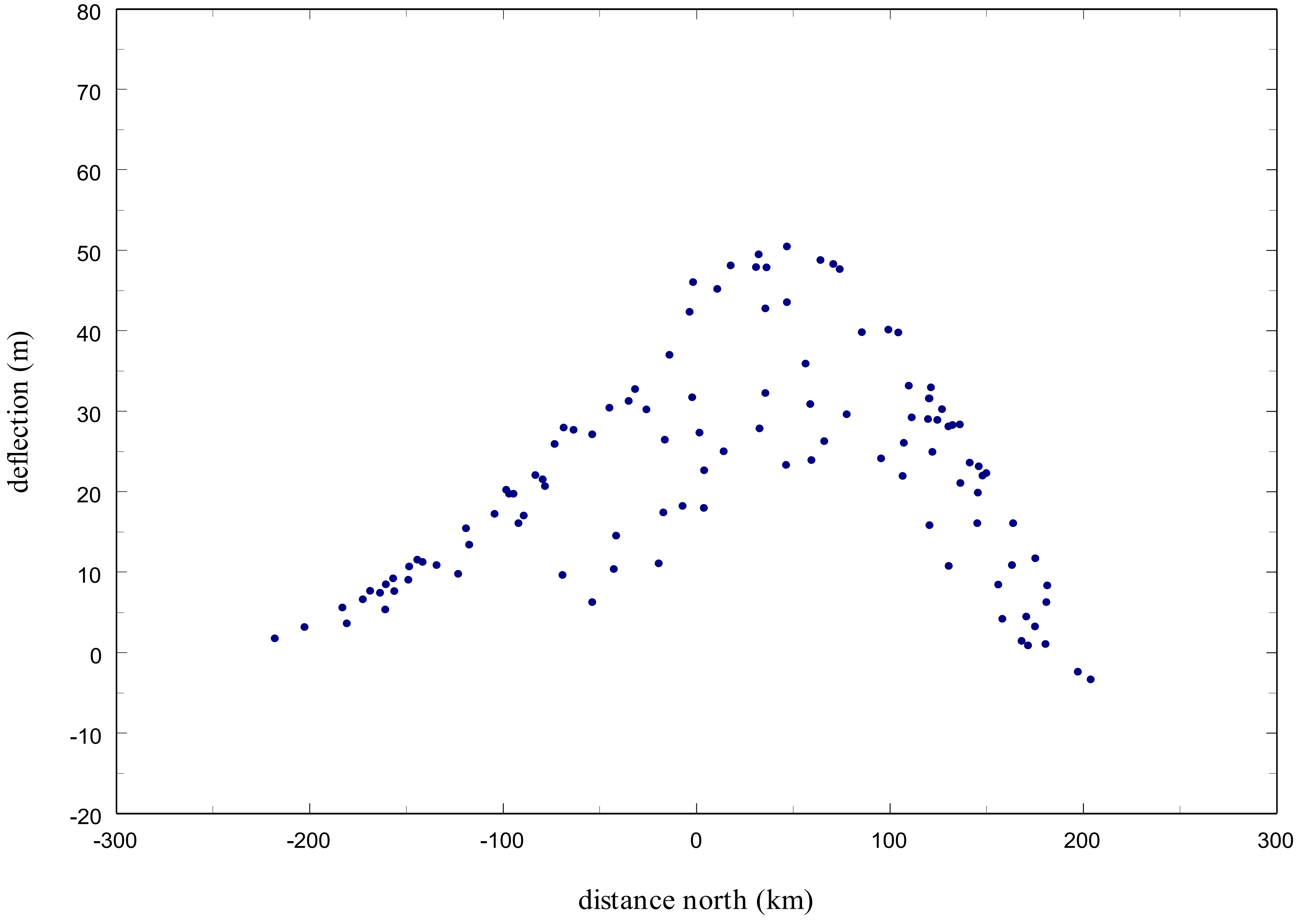


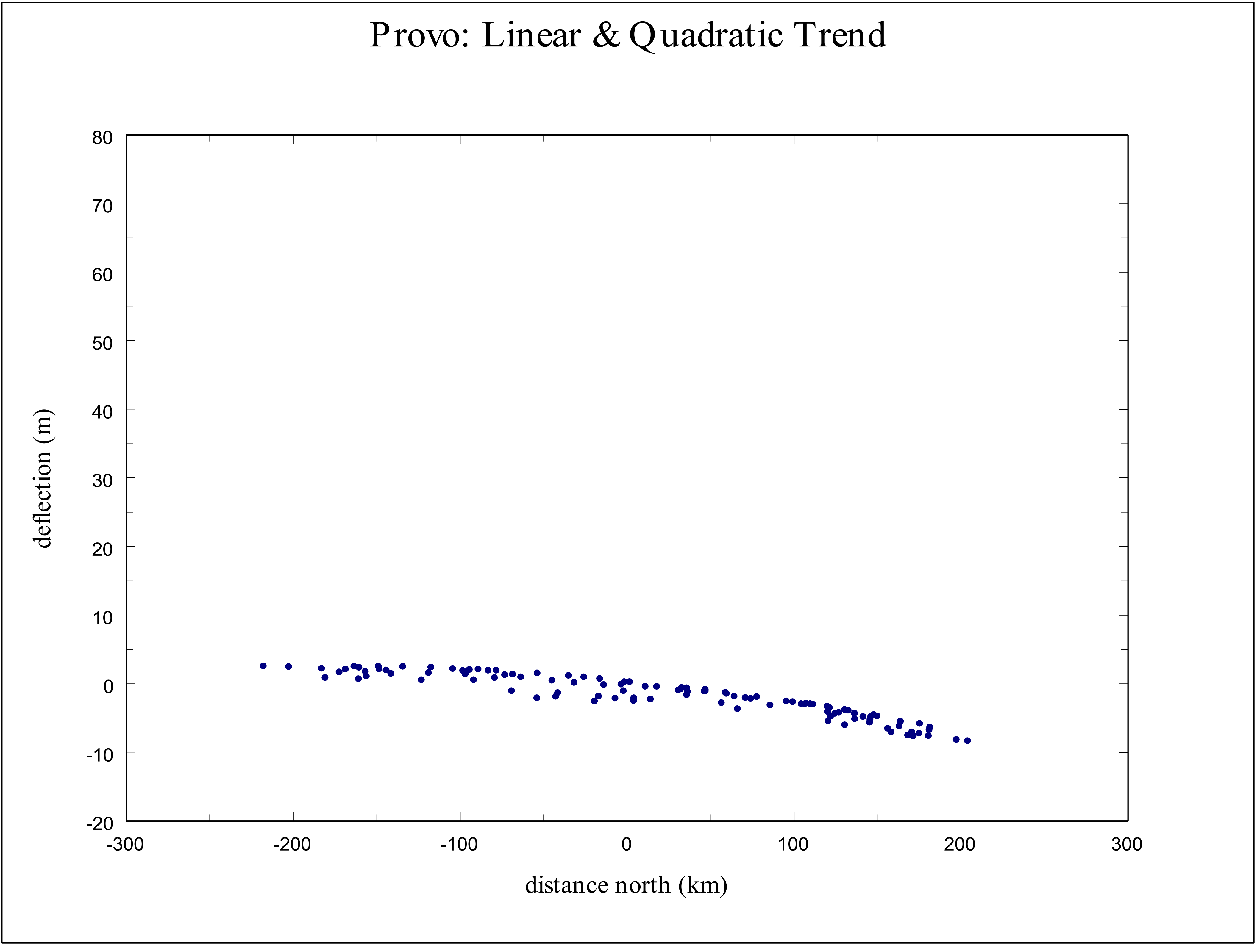
Provo: Observation Sites




Provo: Observed
deflection (m)
distance north (km)
80
70
60
50
40
30
20
10
0
-10
-20
-300
-200
-100
0
100
200
300

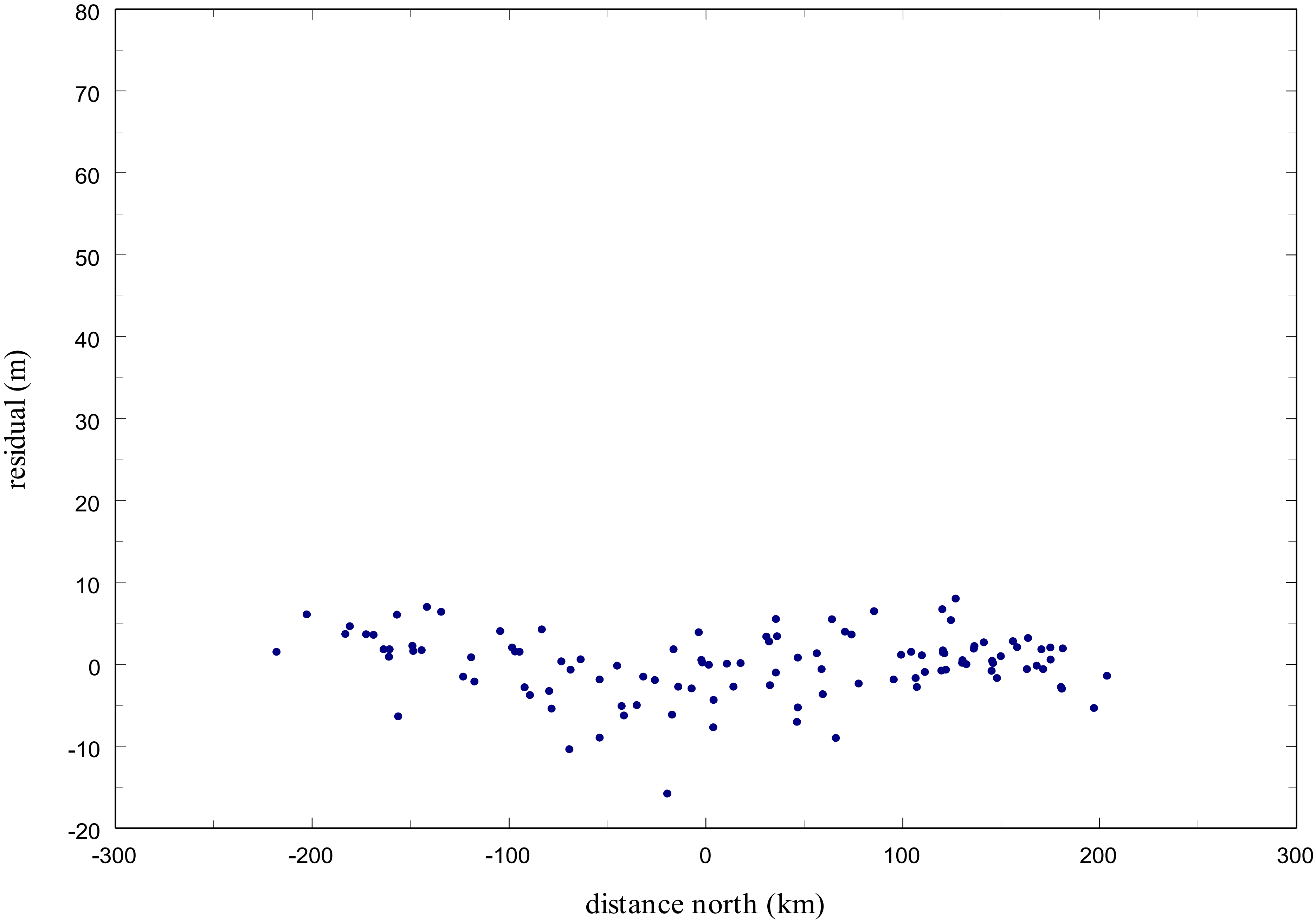
Provo: Computed



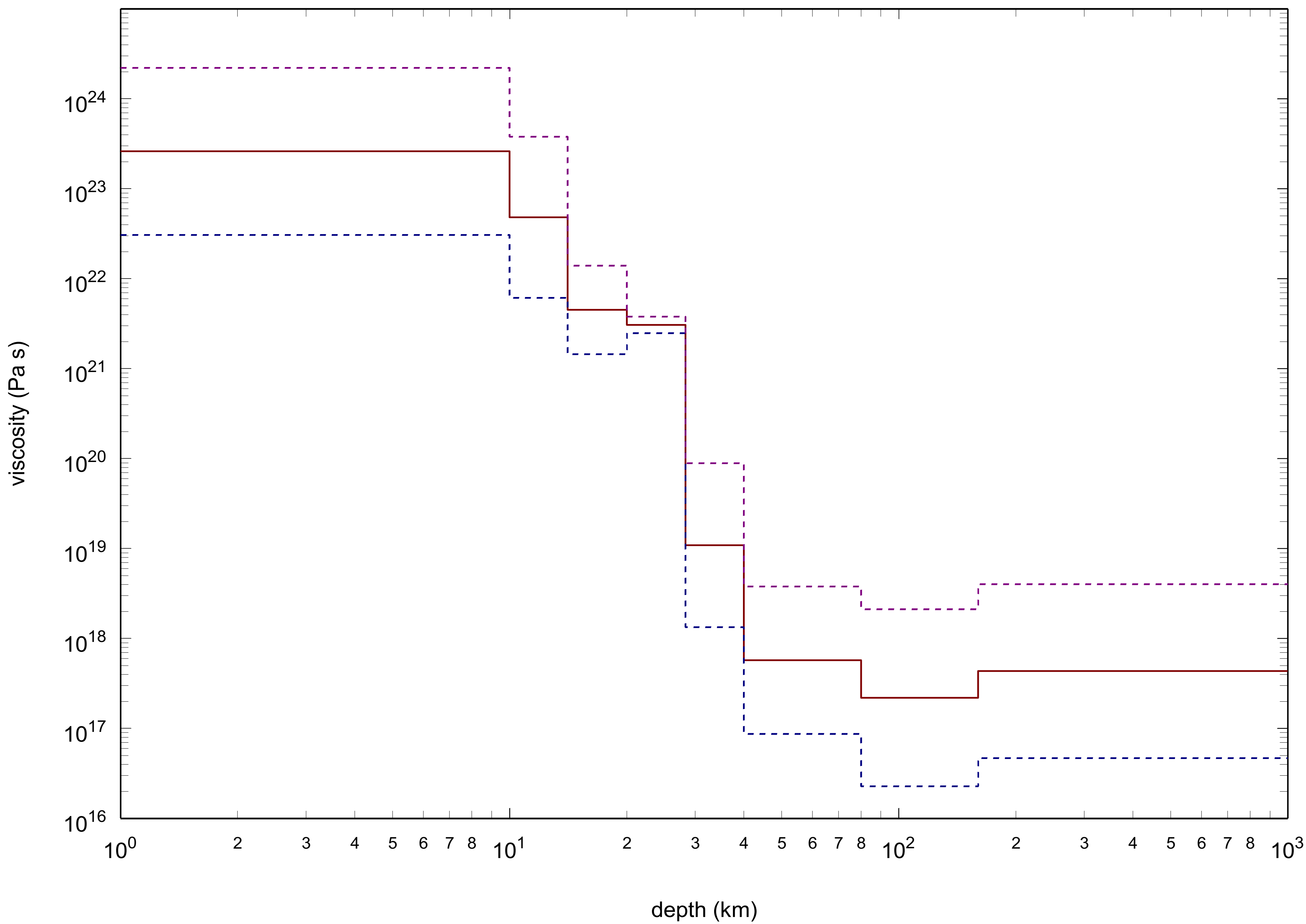


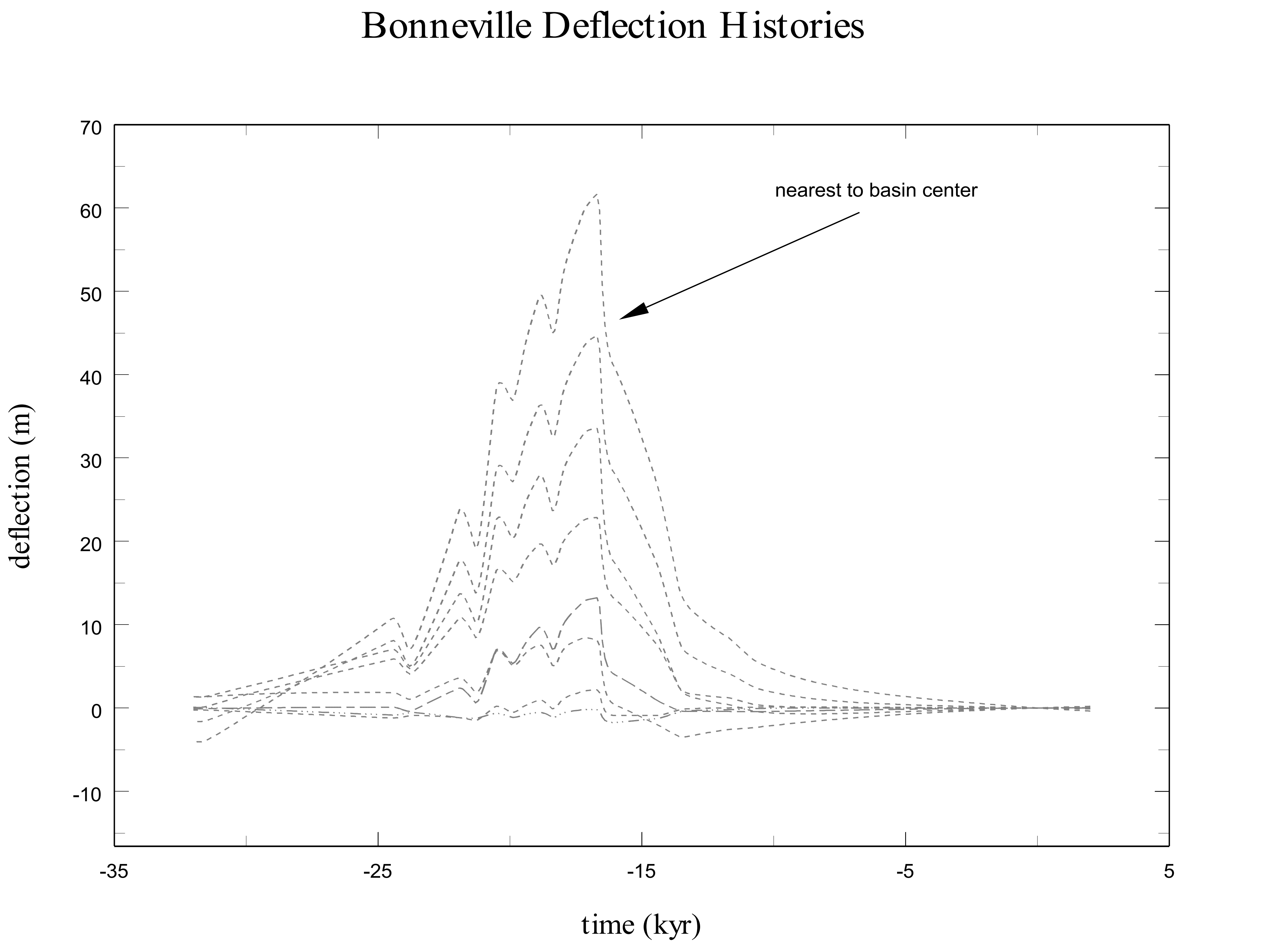
Provo: Linear & Quadratic Trend
80
70
60
50
40
30
20
10
0
-10
-20
deflection (m)
-300
-200
-100
0
100
200
300
distance north (km)

Provo: Residuals



Bonneville Earth Model




Bonneville Deflection Histories
nearest to basin center
deflection (m)
time (kyr)
70
60
50
40
30
20
10
0
-10
-35
-25
-15
-5
5

lake Lahontan

Lahontan rebound references

Isostatic rebound, active faulting, and potential geomorphic effects in the Lake Lahontan basin, Nevada and California

Kenneth D. Adams* } *Center for Neotectonic Studies* and *Department of Geological Sciences,*
Steven G. Wesnousky } *University of Nevada, Reno, Nevada 89557-0135*

Bruce G. Bills *Institute for Geophysics and Planetary Physics, Scripps Institution of Oceanography, University of California–San Diego, La Jolla, California 92093-0208*

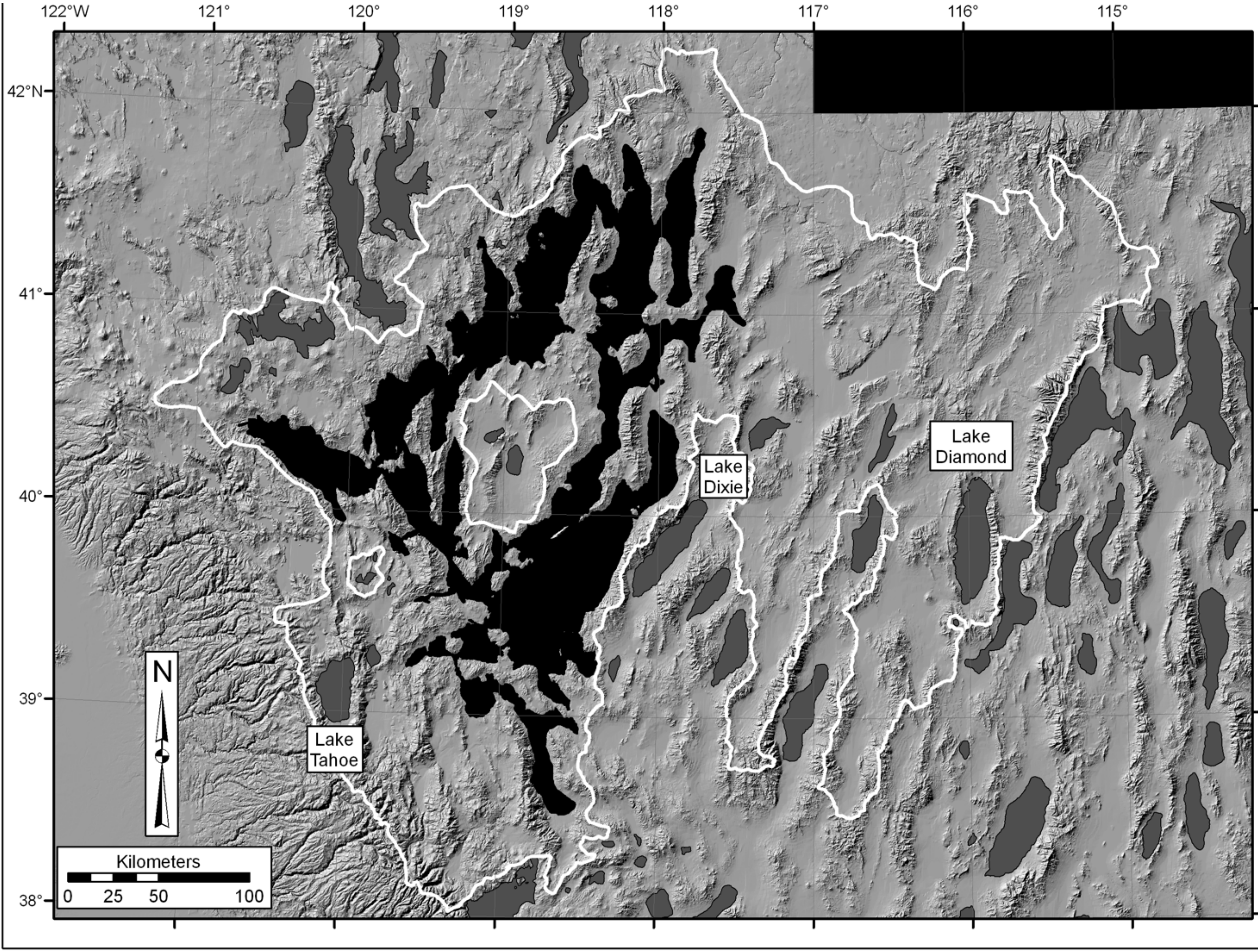
GSA Bulletin; December 1999; v. 111; no. 12; p. 1739–1756;

Viscosity structure of the crust and upper mantle in western Nevada from isostatic rebound patterns of the late Pleistocene Lake Lahontan high shoreline

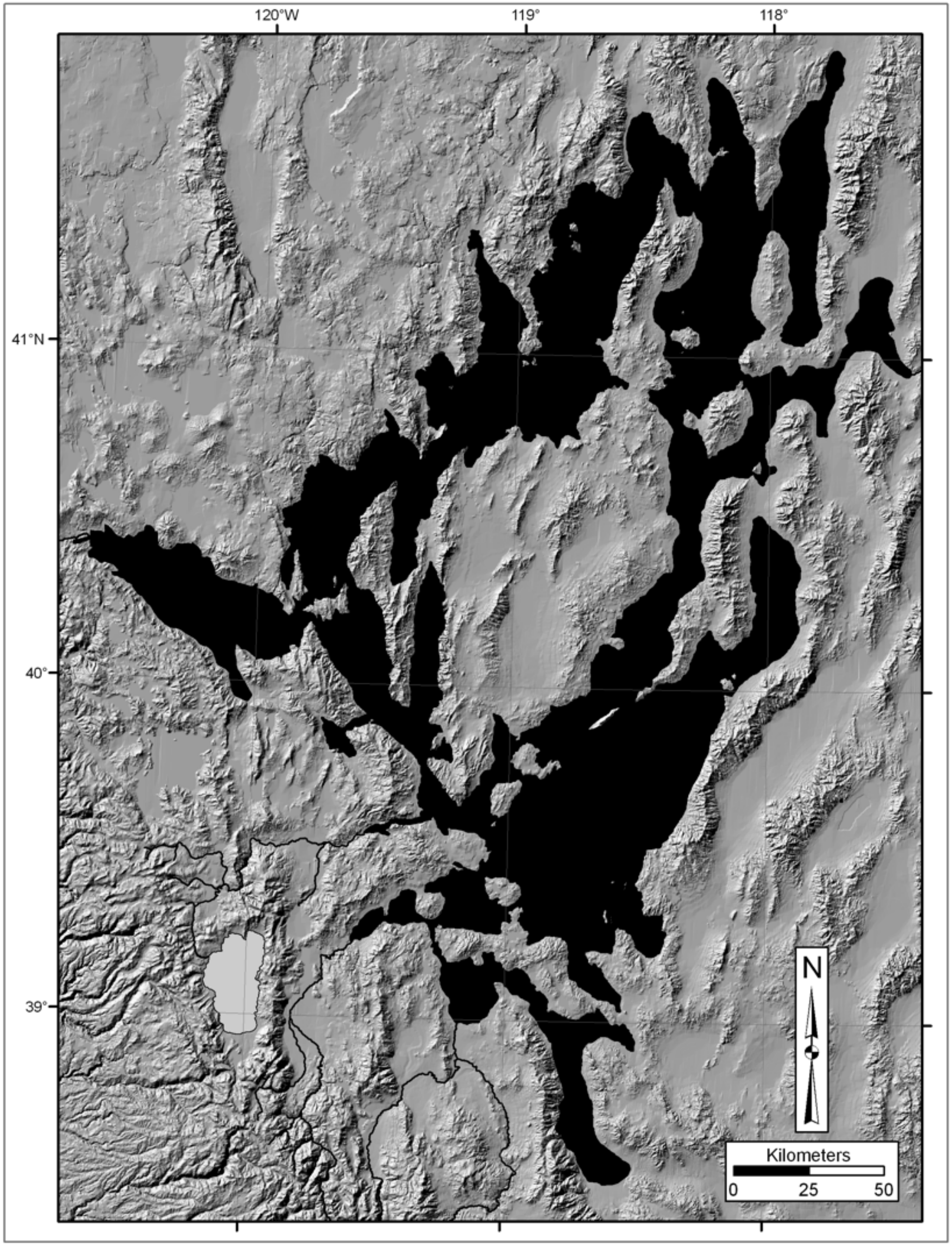
Bruce G. Bills,[1,2] Kenneth D. Adams,[3] and Steven G. Wesnousky[4]

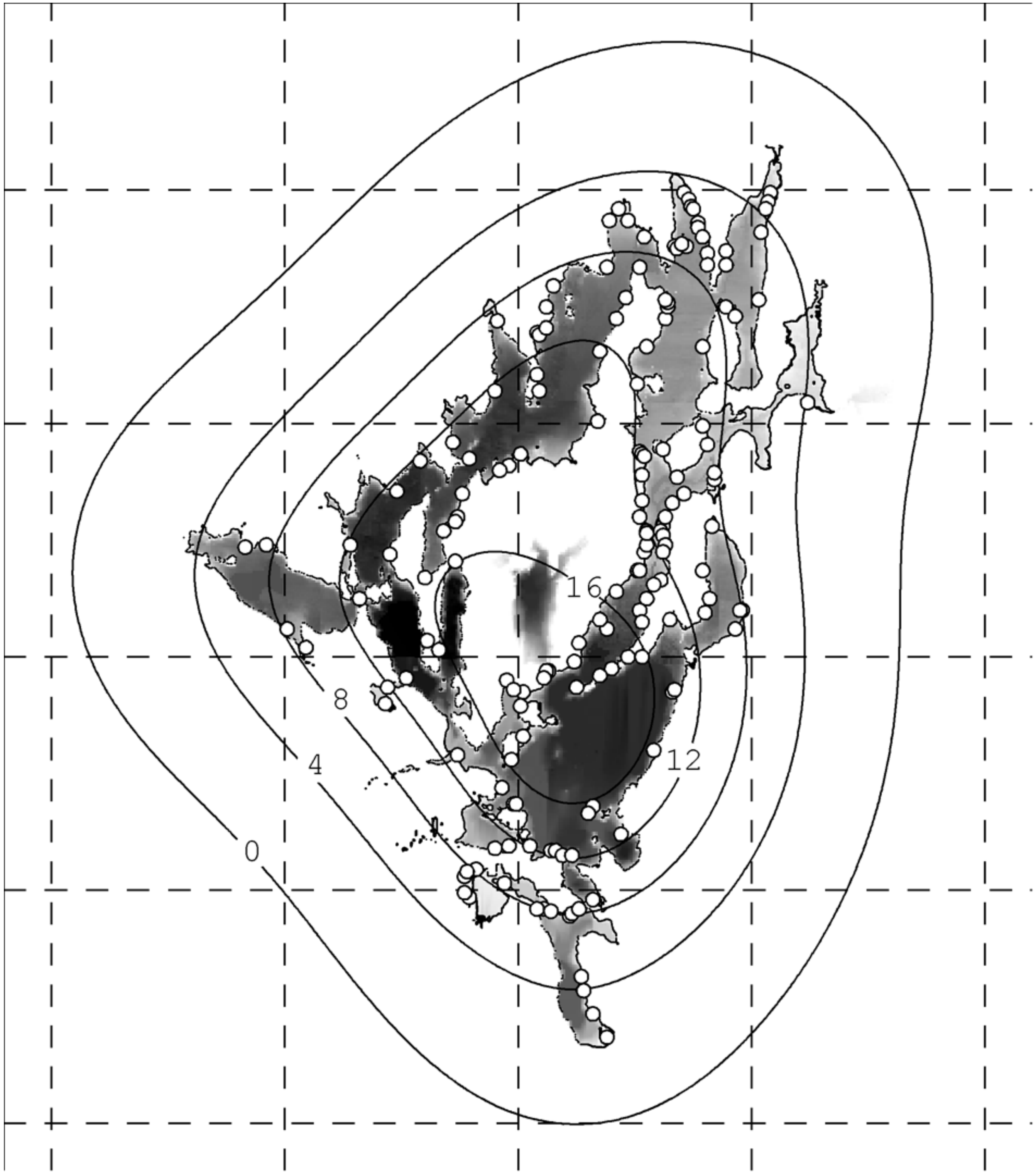
Received 13 July 2005; revised 26 October 2006; accepted 31 January 2007; published 8 June 2007.

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 112, B06405, doi:10.1029/2005JB003941, 2007

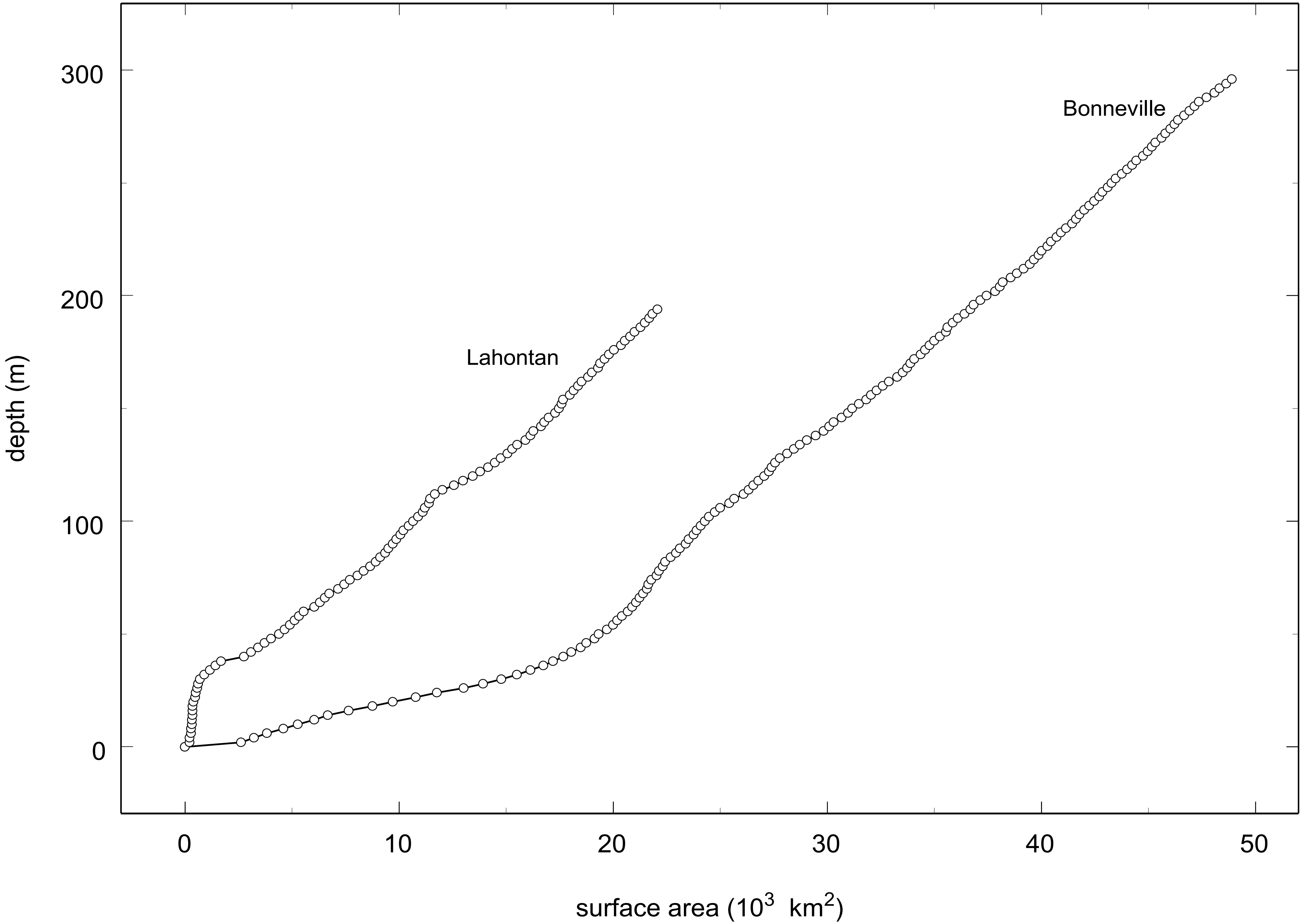


122°W
121°
120°
119°
118°
117°
116°
115°
42°N
41°
40°
39°
38°
Lake Dixie
Lake Diamond
Lake Tahoe
N
Kilometers
0 25 50 100

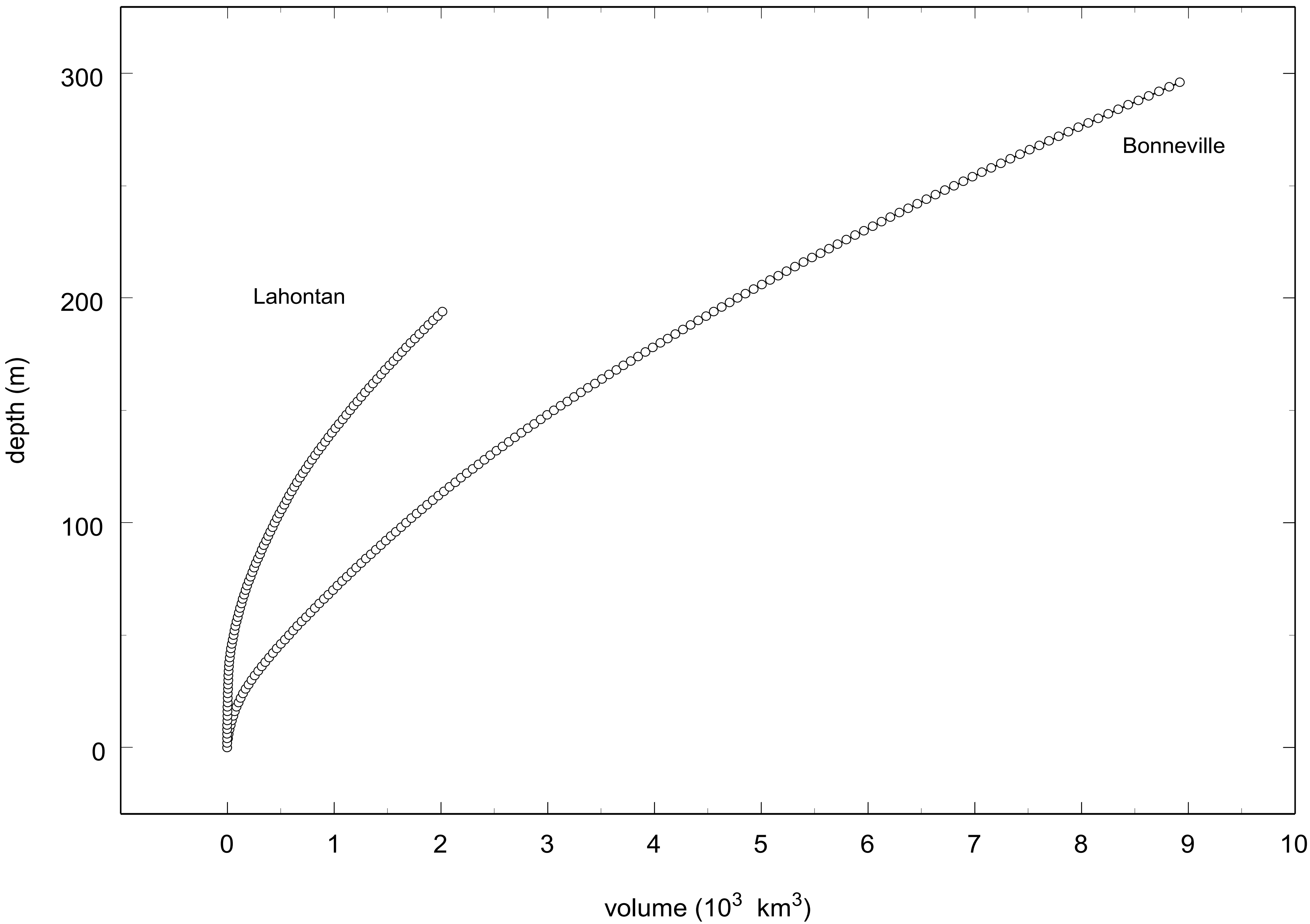

120°W
119°
118°
41°N
40°
39°
N
Kilometers
0
25
50


16
12
8
4
0

lake surface area versus depth



lake volume versus depth



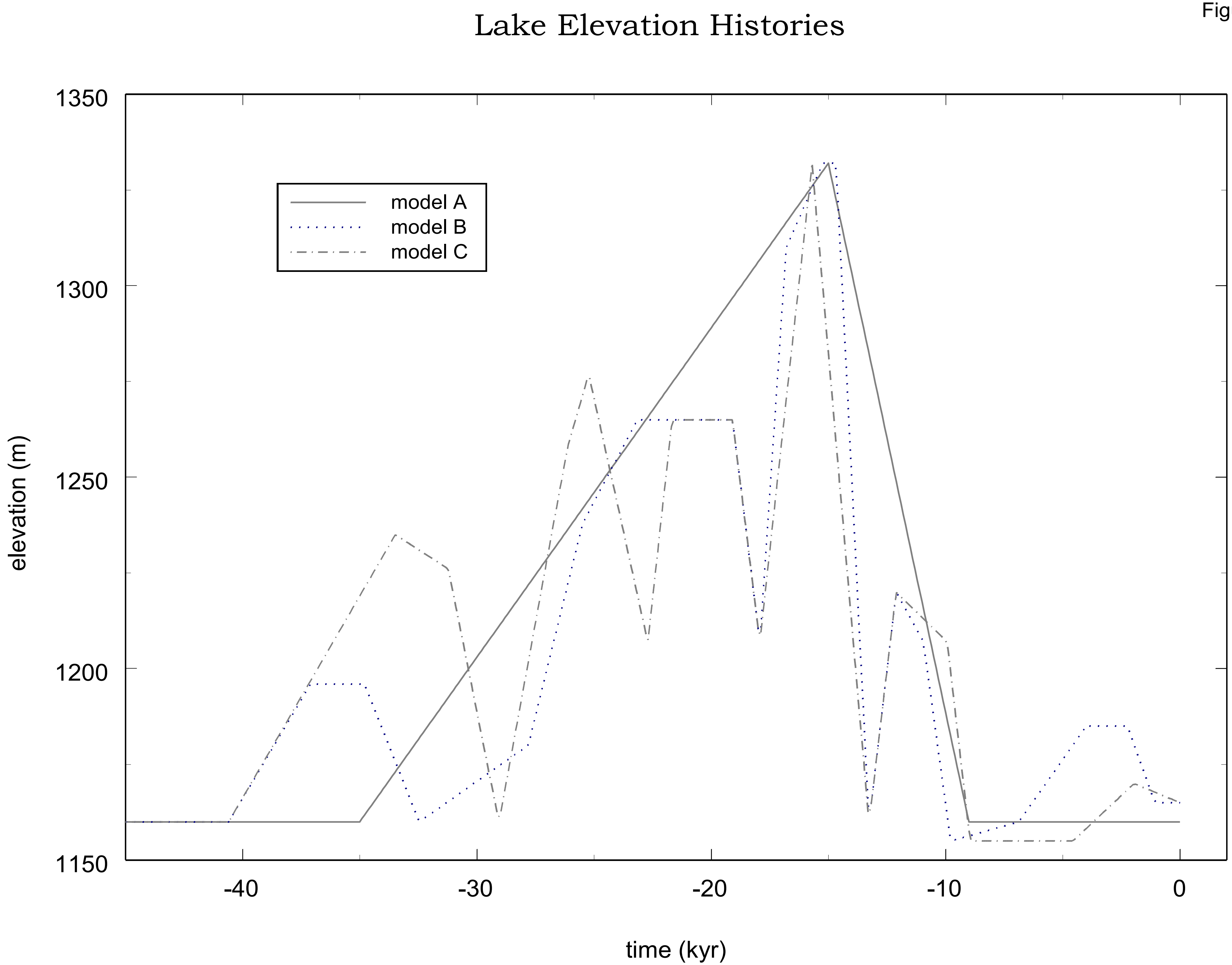

Lake Elevation Histories
model A
model B
model C
1350
1300
1250
1200
1150
elevation (m)
-40
-30
-20
-10
0
time (kyr)

Figure 6a

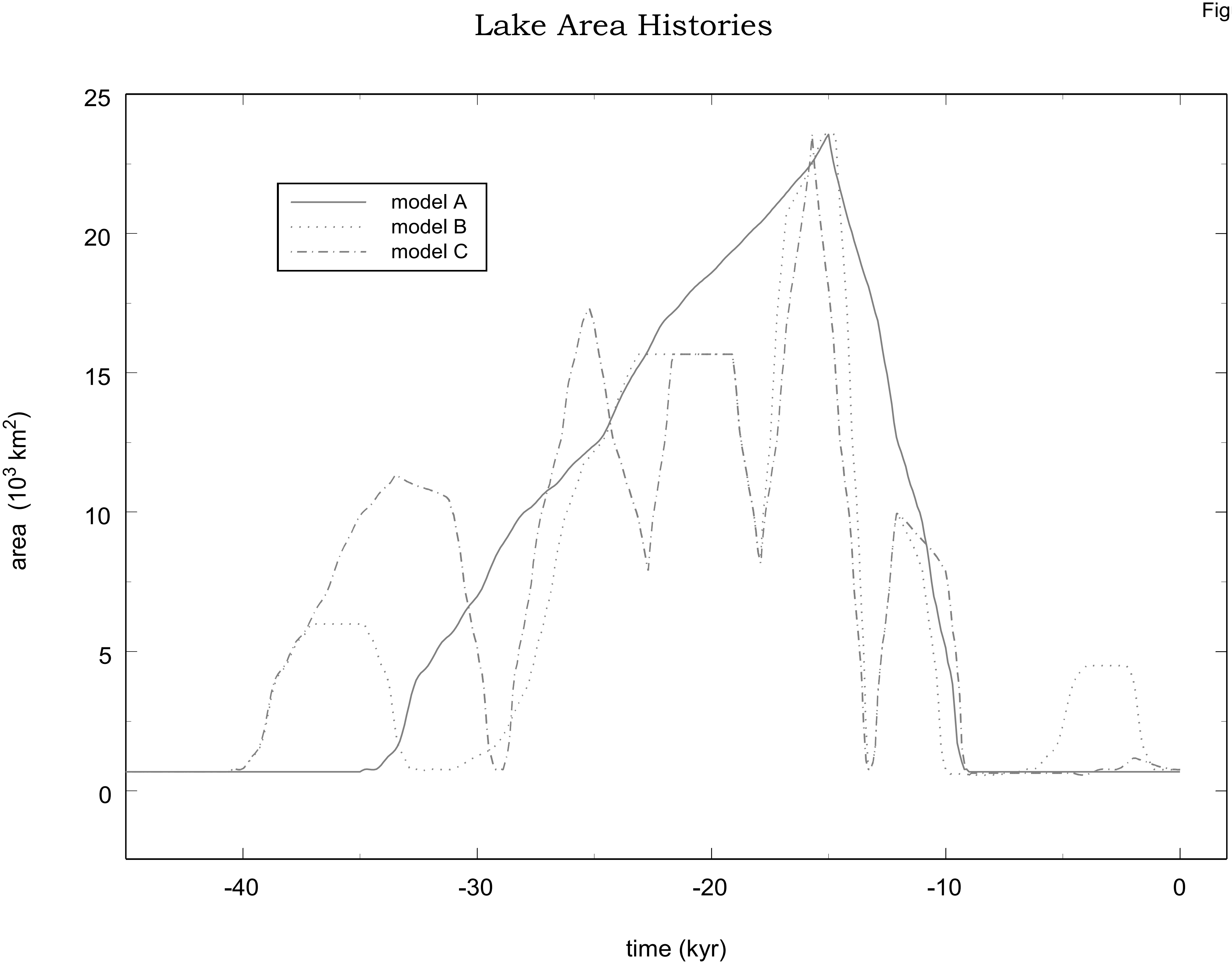

Lake Area Histories
model A
model B
model C
area (10^3 km^2)
time (kyr)
25
20
15
10
5
0
-40
-30
-20
-10
0

Figure 6b

Lake Volume Histories

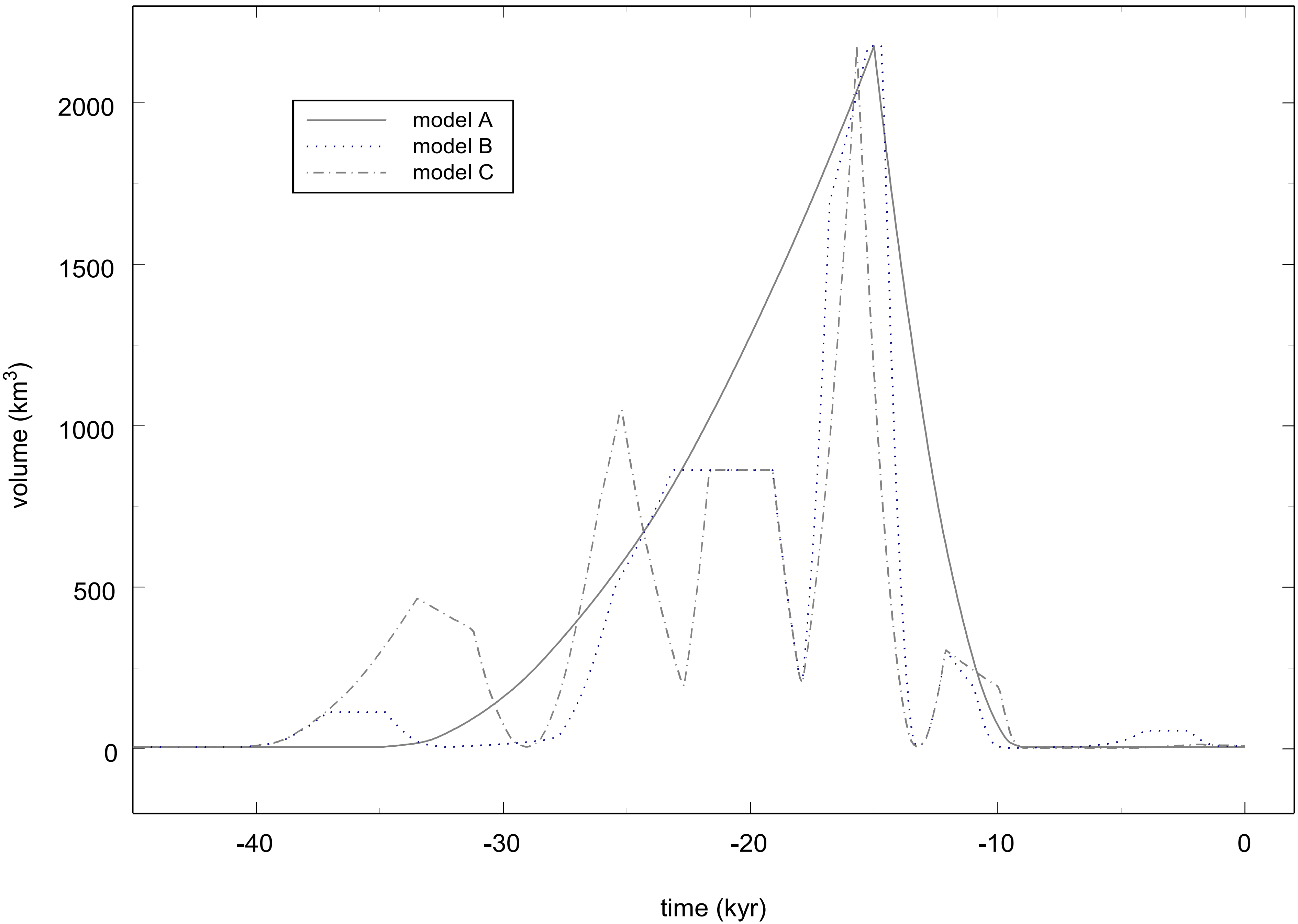
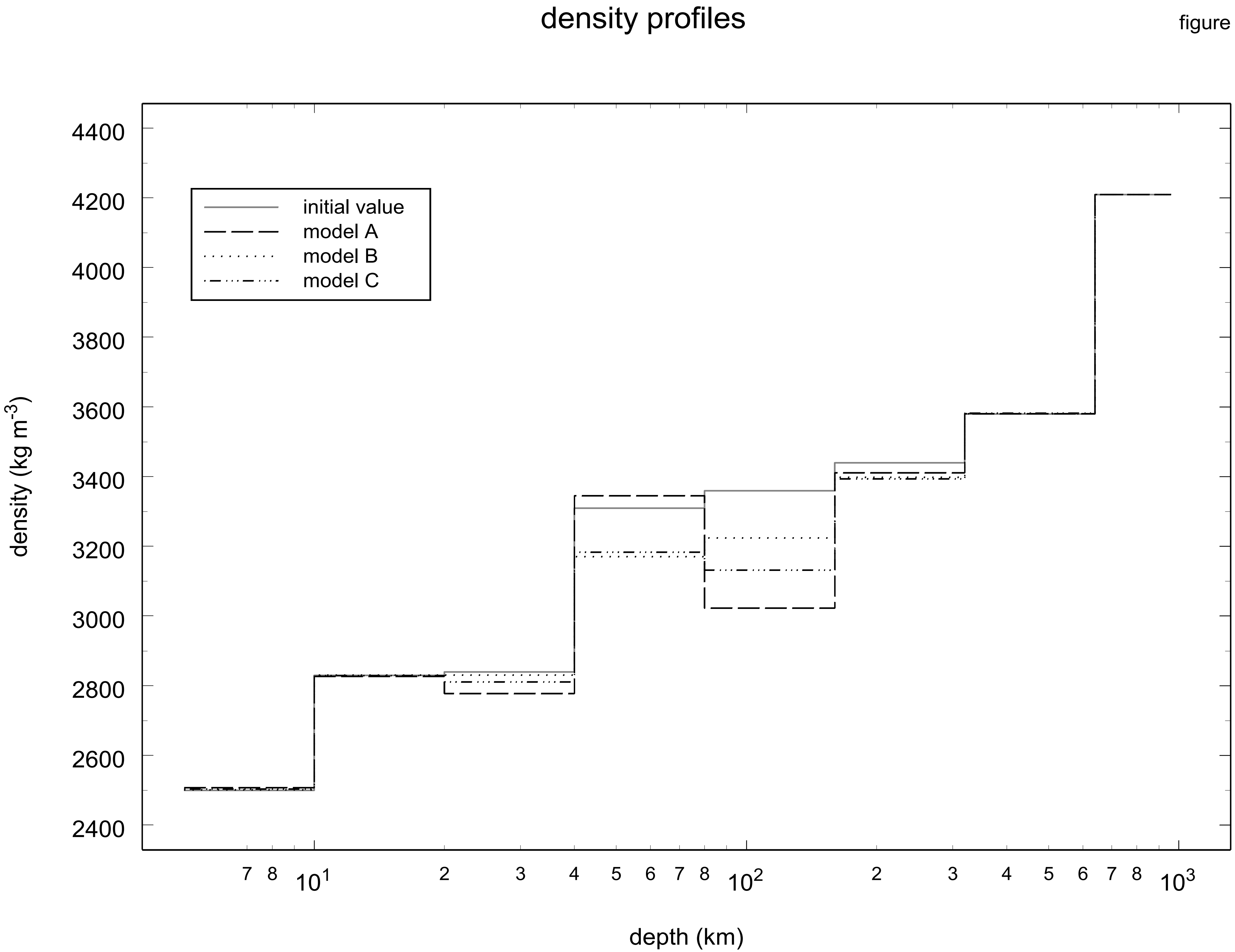
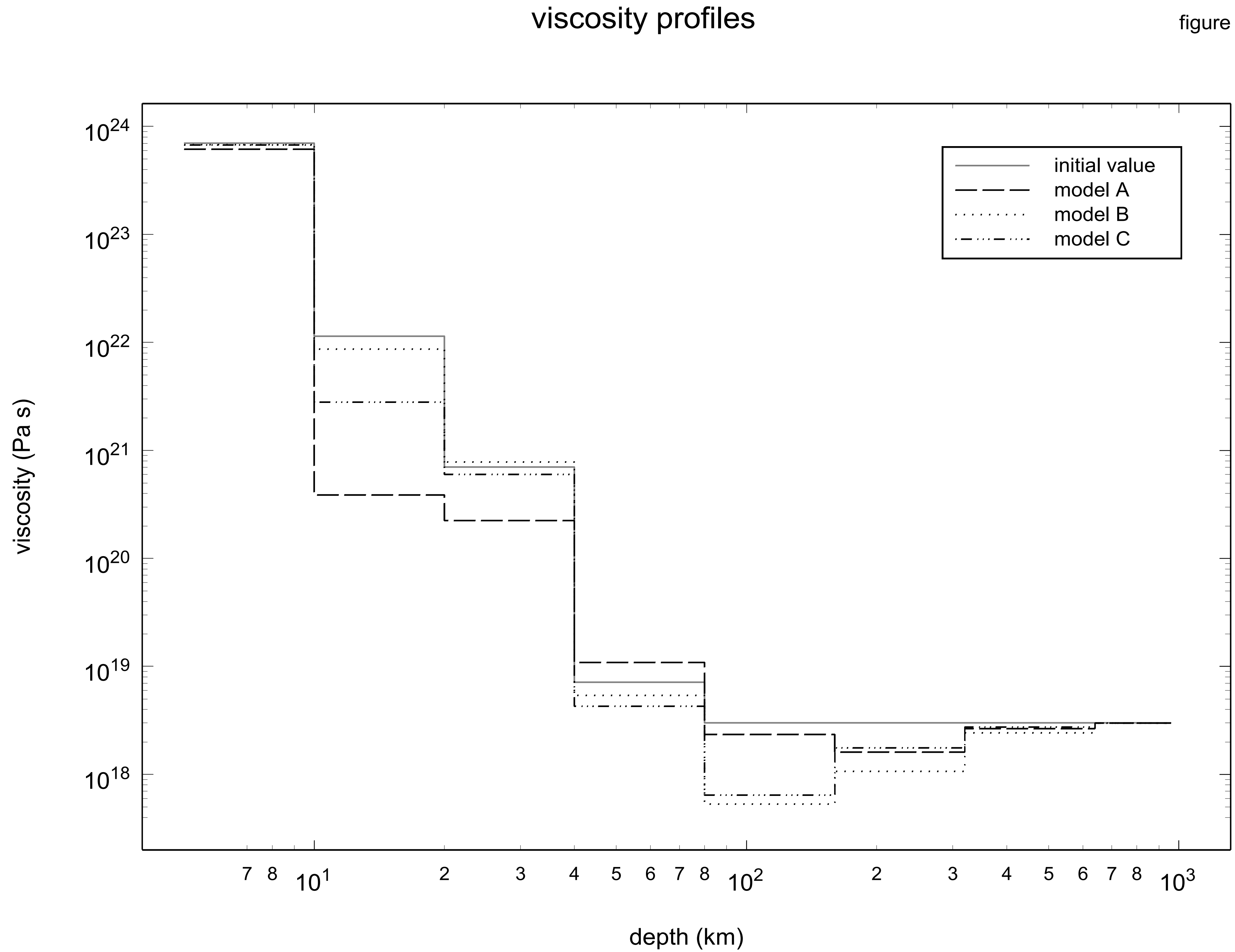


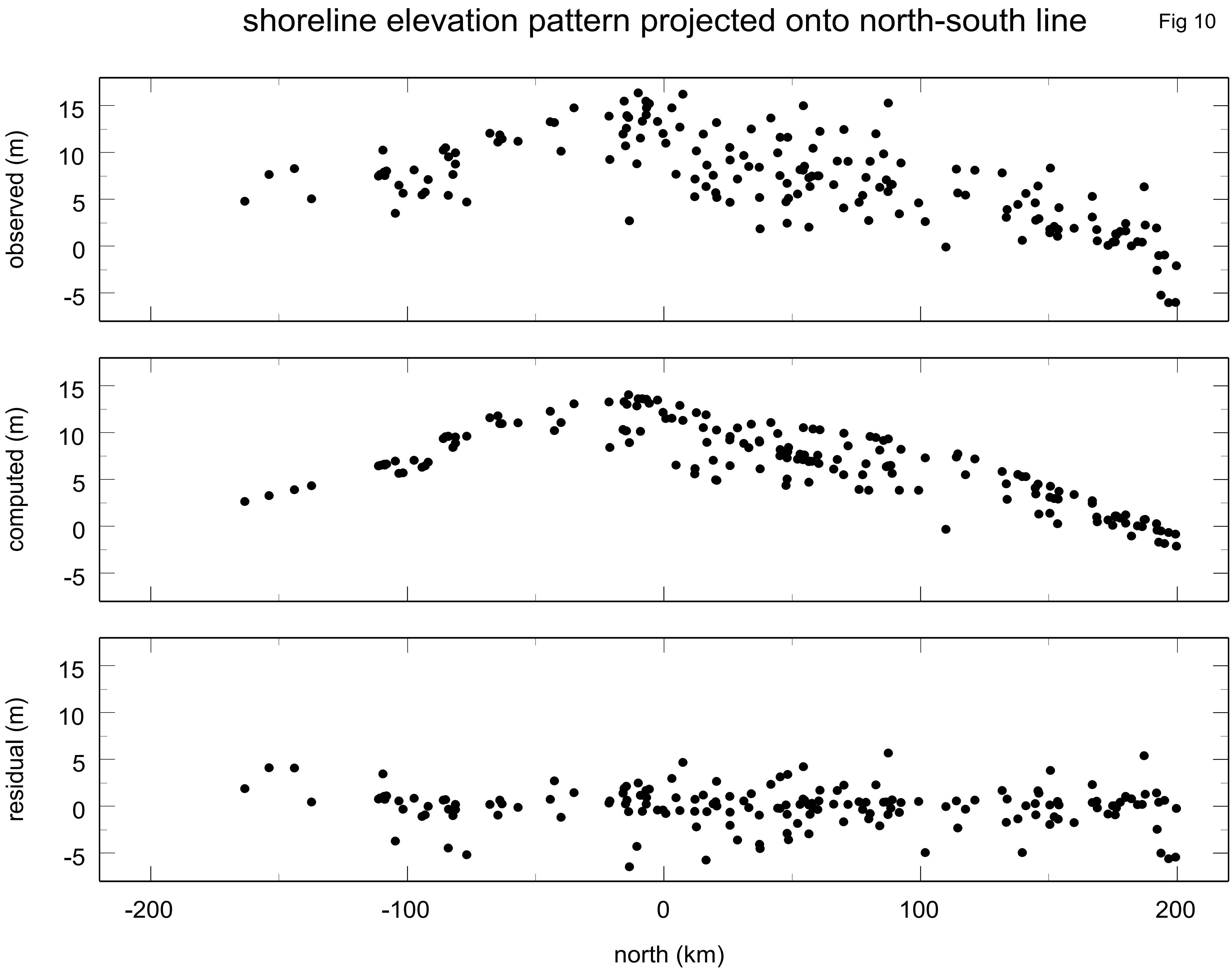
figure 8



density profiles
initial value
model A
model B
model C
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
density (kg m-3)
7 8 10^1 2 3 4 5 6 7 8 10^2 2 3 4 5 6 7 8 10^3
depth (km)

figure 9


viscosity profiles
initial value
model A
model B
model C
viscosity (Pa s)
10^{24}
10^{23}
10^{22}
10^{21}
10^{20}
10^{19}
10^{18}
7 8 10^1 2 3 4 5 6 7 8 10^2 2 3 4 5 6 7 8 10^3
depth (km)


shoreline elevation pattern projected onto north-south line
Fig 10
observed (m)
computed (m)
residual (m)
15
10
5
0
-5
-200
-100
0
100
200
north (km)

shoreline elevation pattern projected onto east-west line

Fig 11

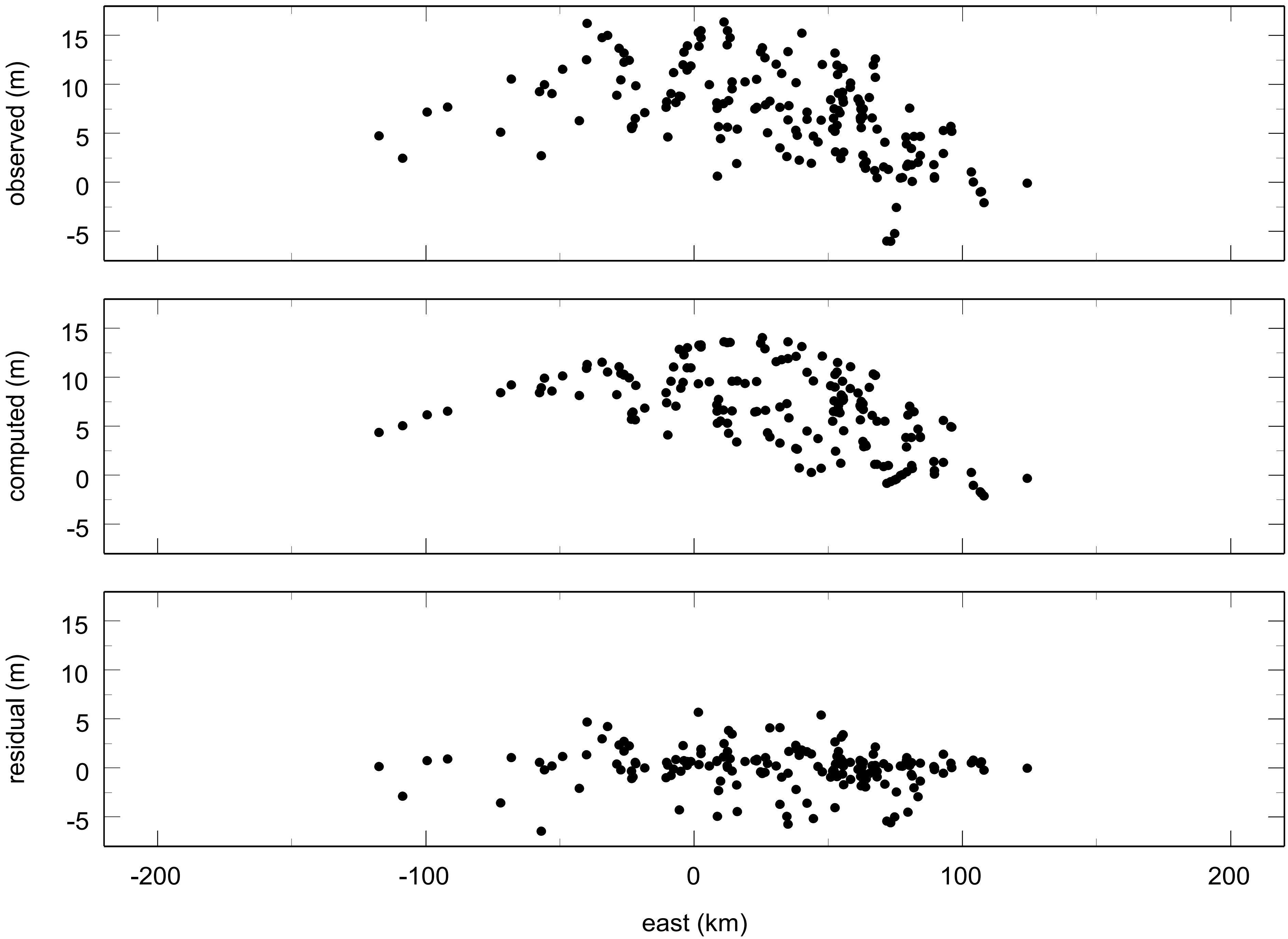
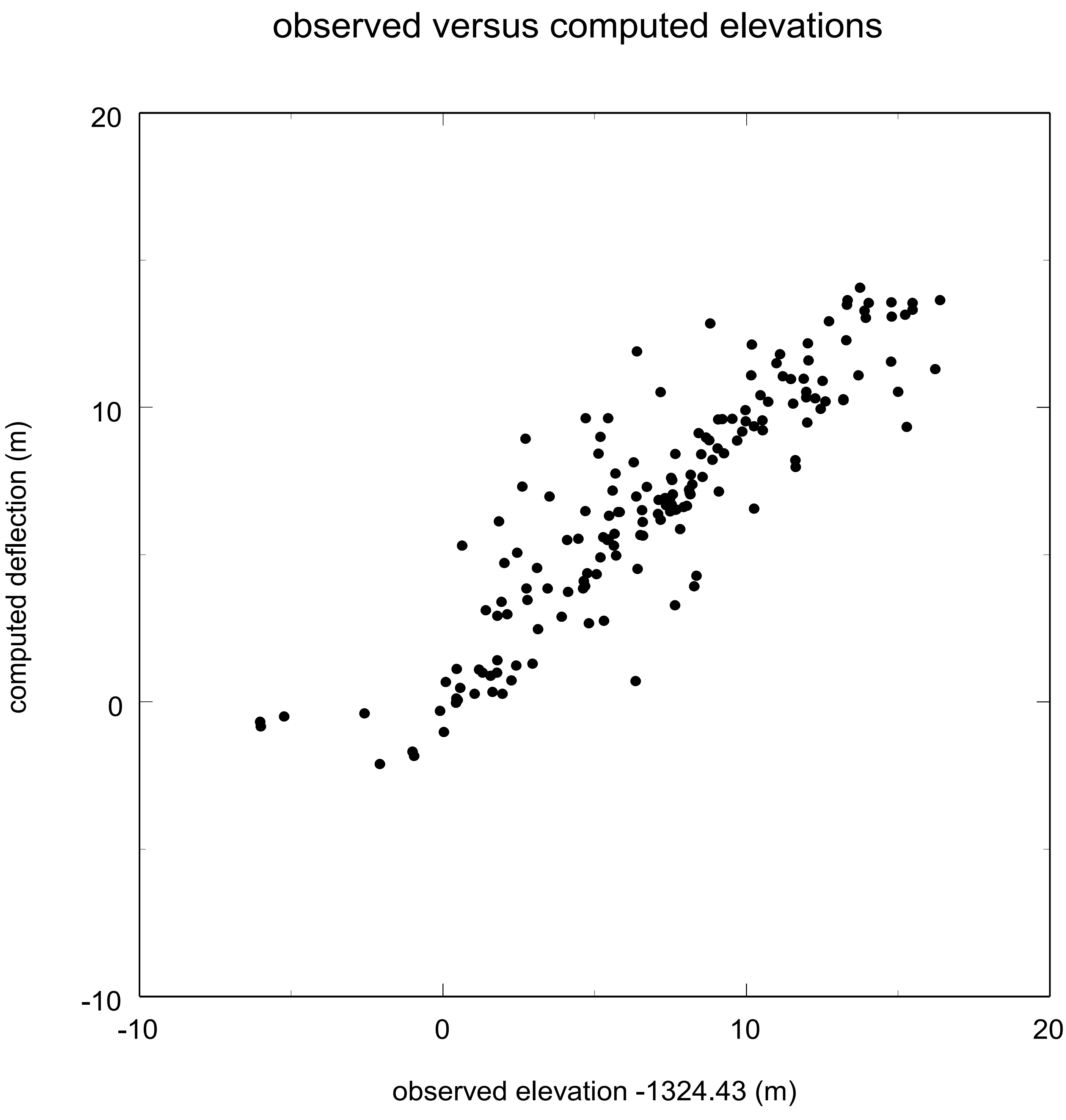
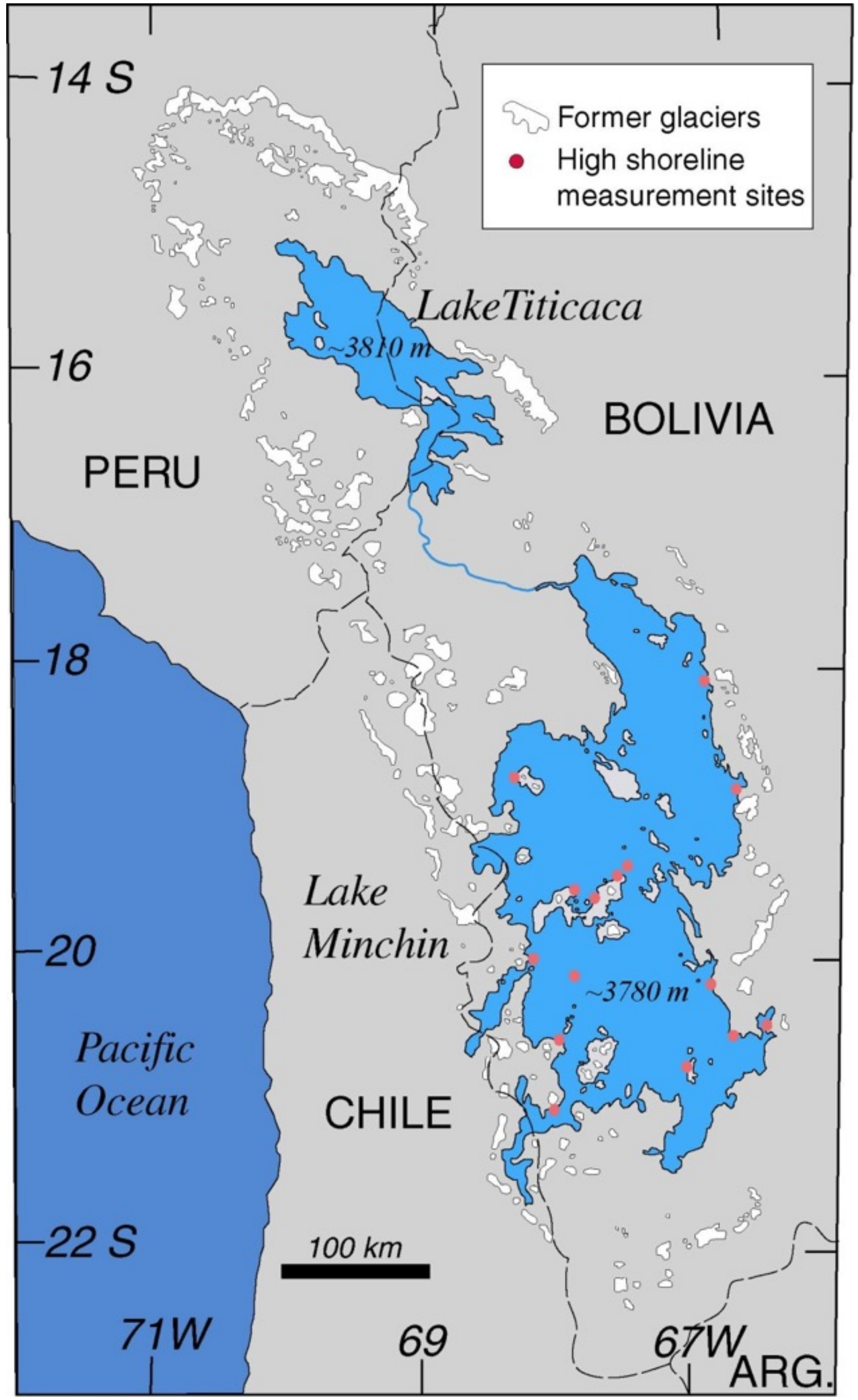


Figure 12

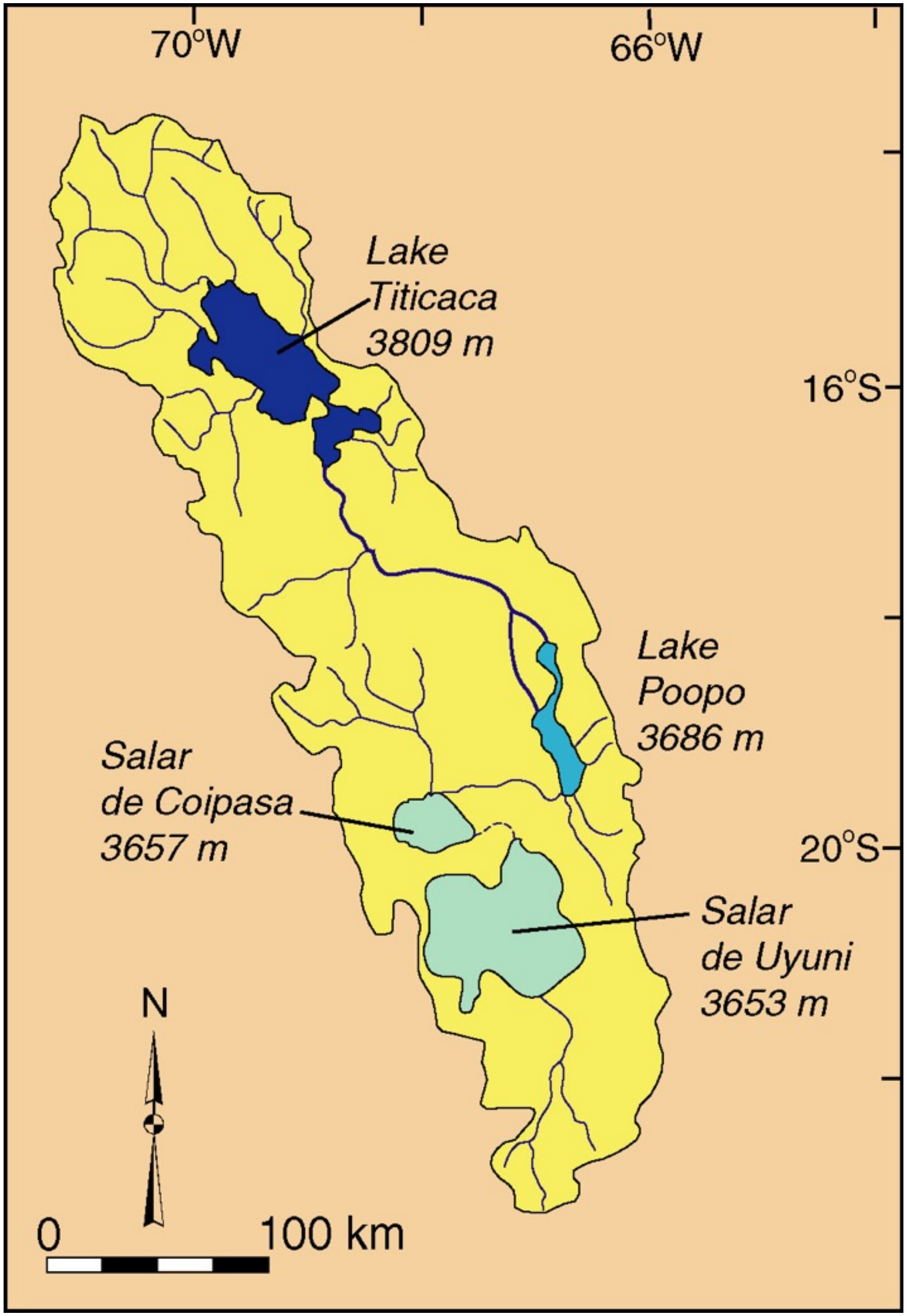

observed versus computed elevations
20
10
0
-10
-10
0
10
20
computed deflection (m)
observed elevation -1324.43 (m)

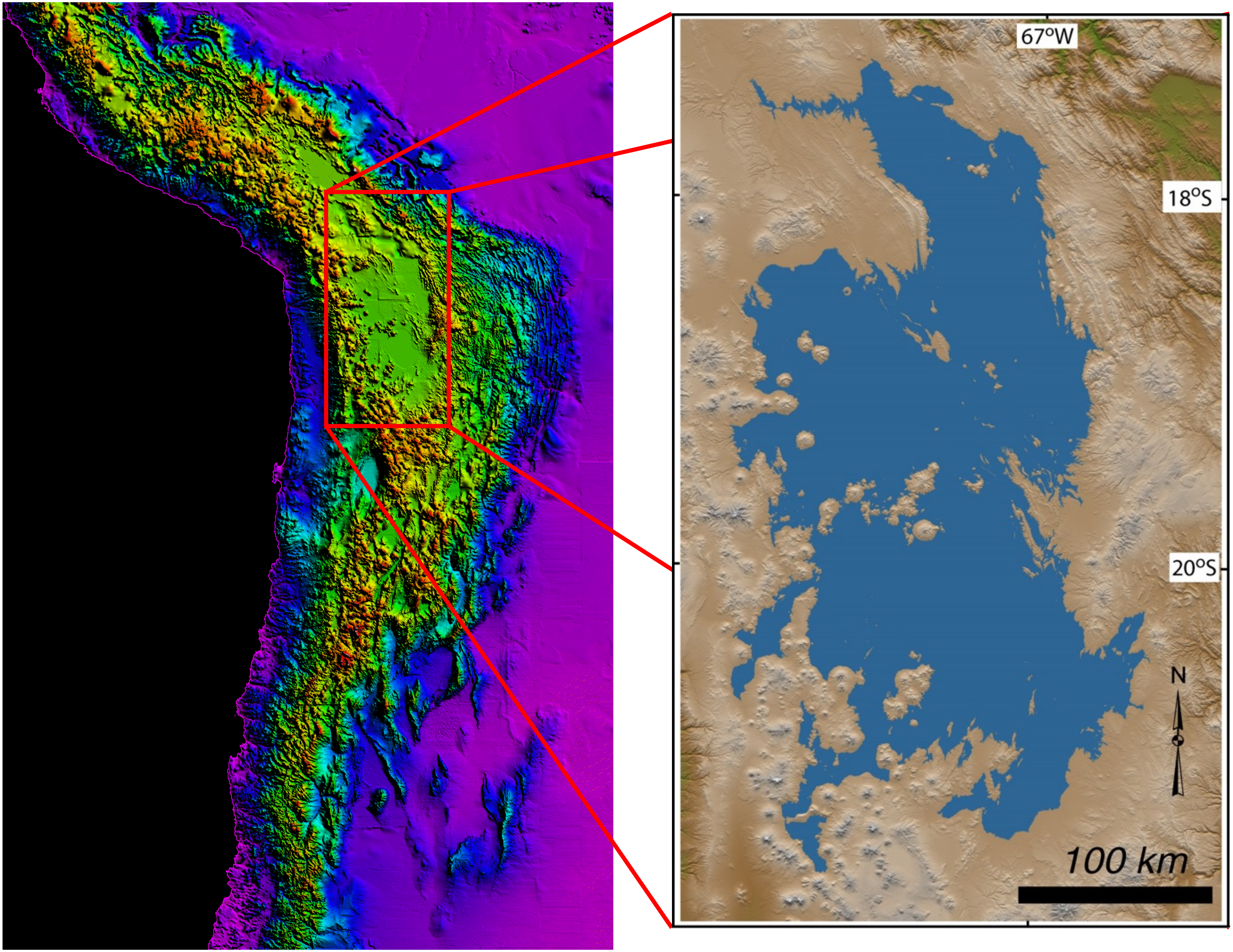
lake Minchin

late Pleistocene configuration

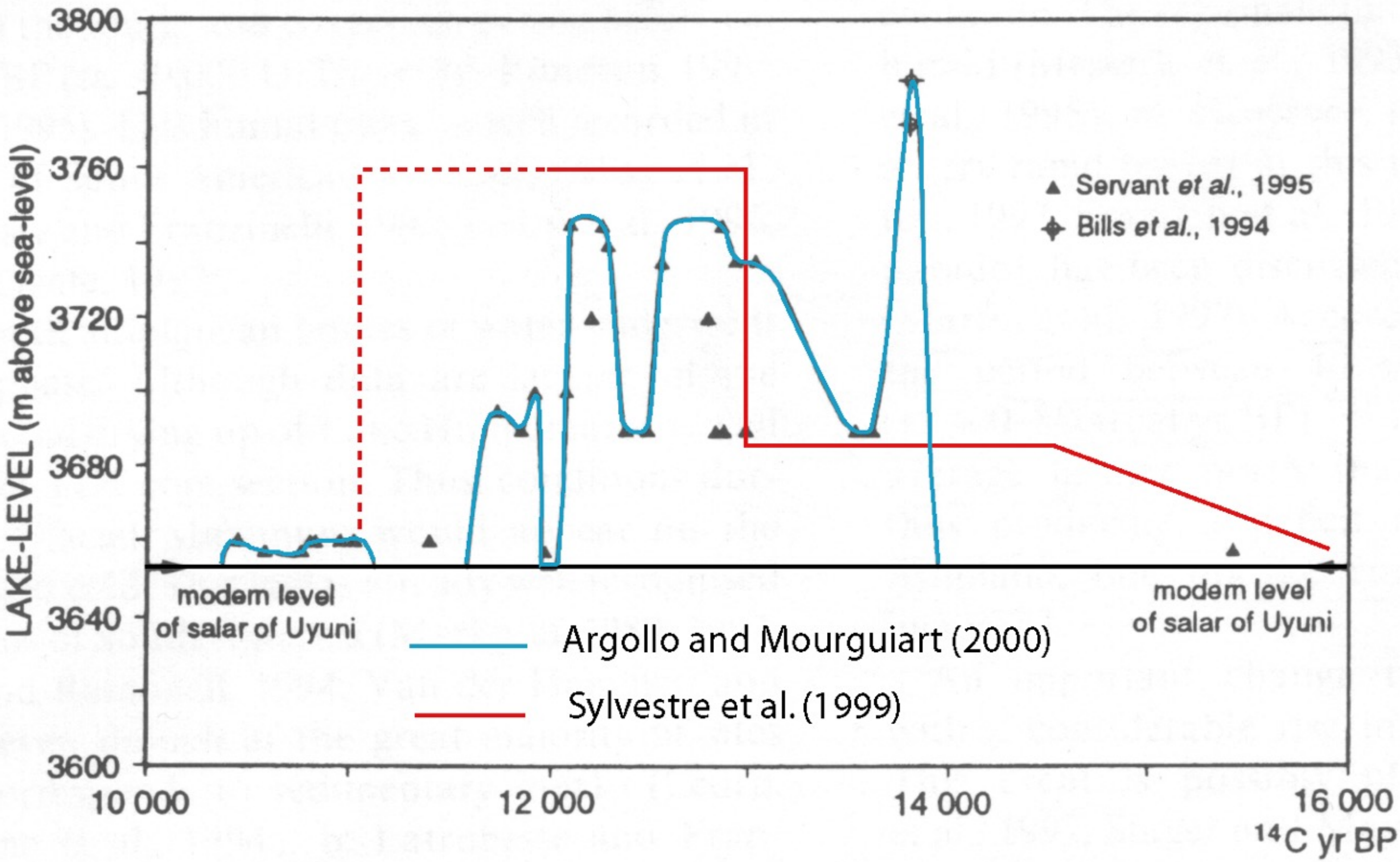


drainage basin
and present lakes




67°W
18°S
20°S
N
100 km

lake level history (work in progress)

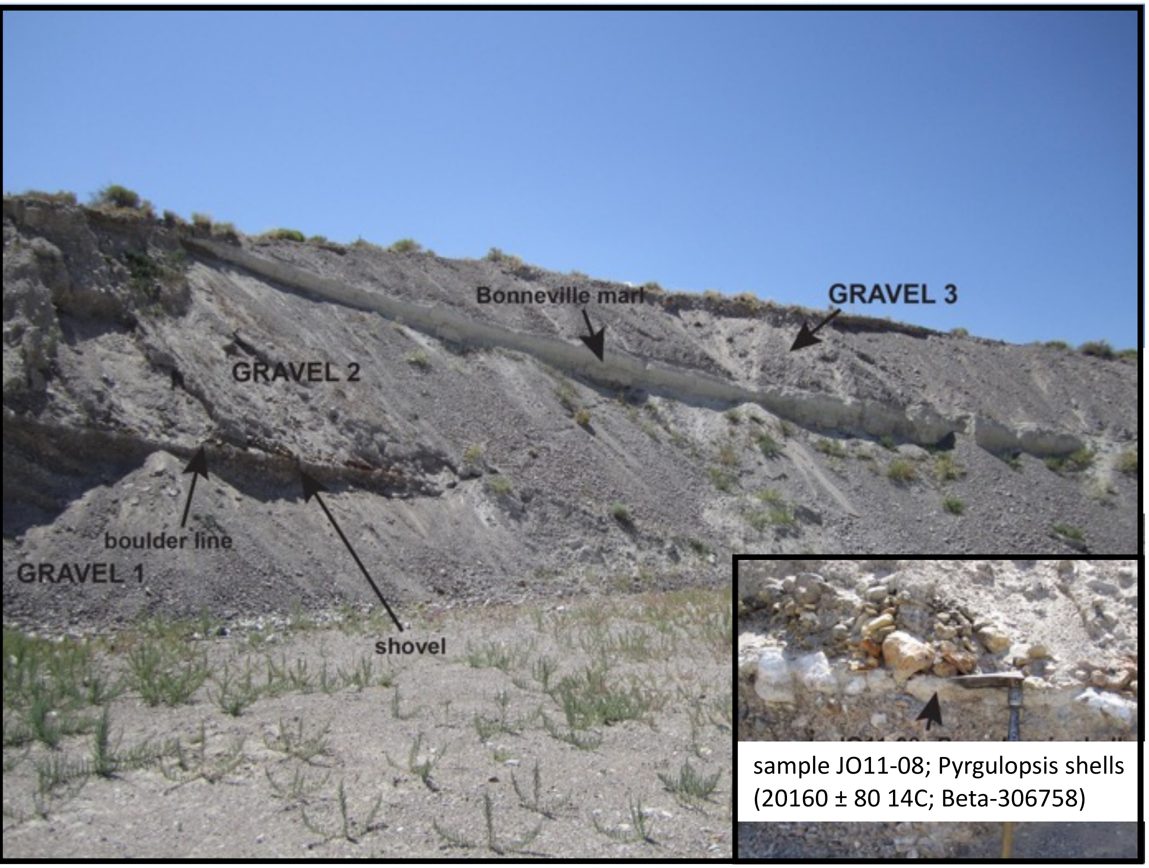


Where Things are Going in Lake Bonneville and Great Salt Lake Research

Jack Oviatt
Kansas State University
(retired)

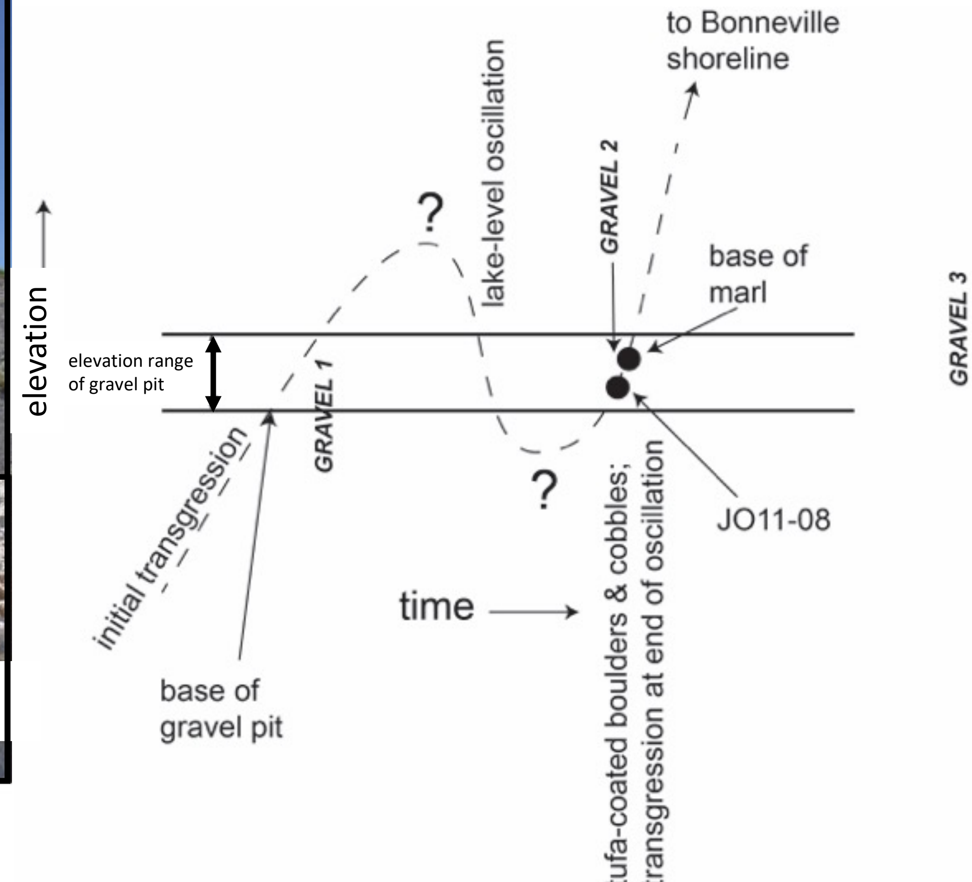
transgressive-phase oscillation

gravel pit along Highway 30, 1.7 km west of Grouse Creek Junction (113.9092 W, 41.4182 N)

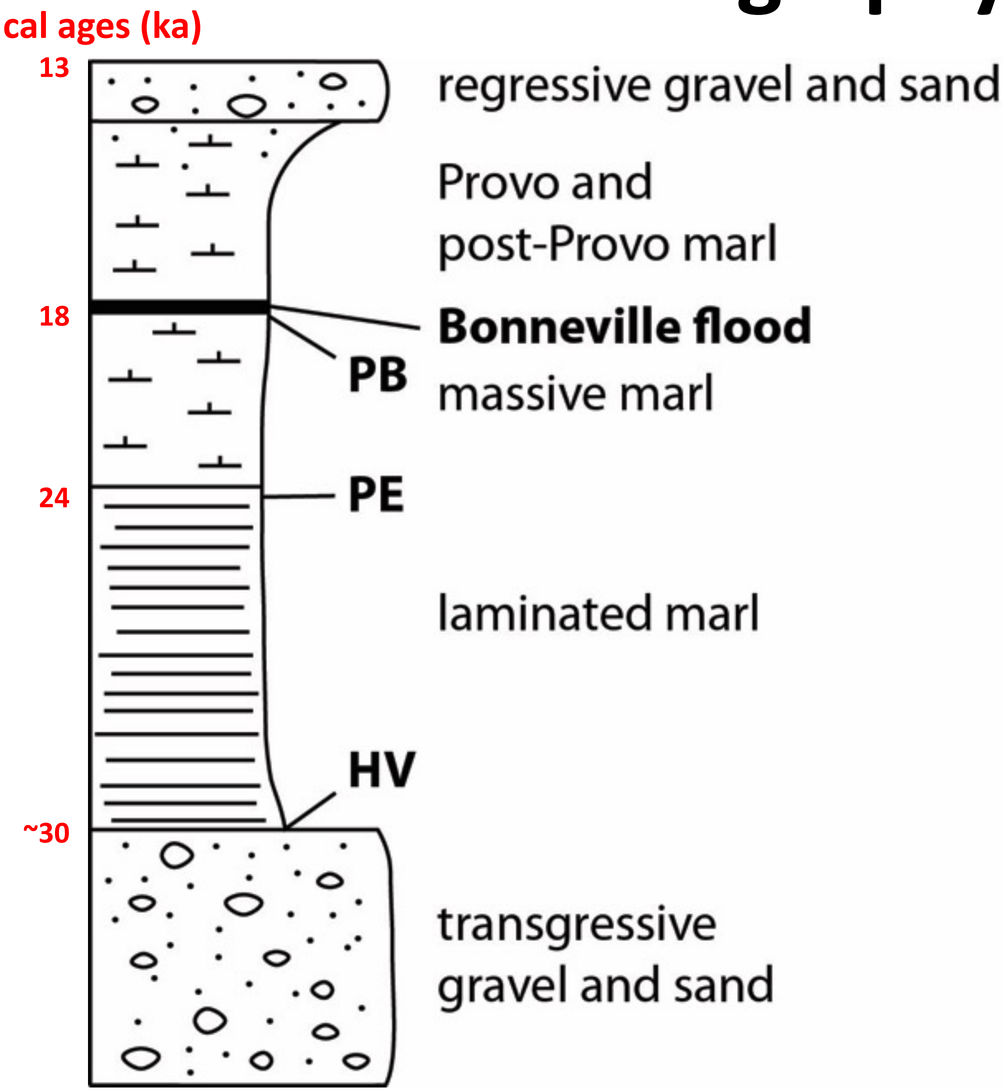


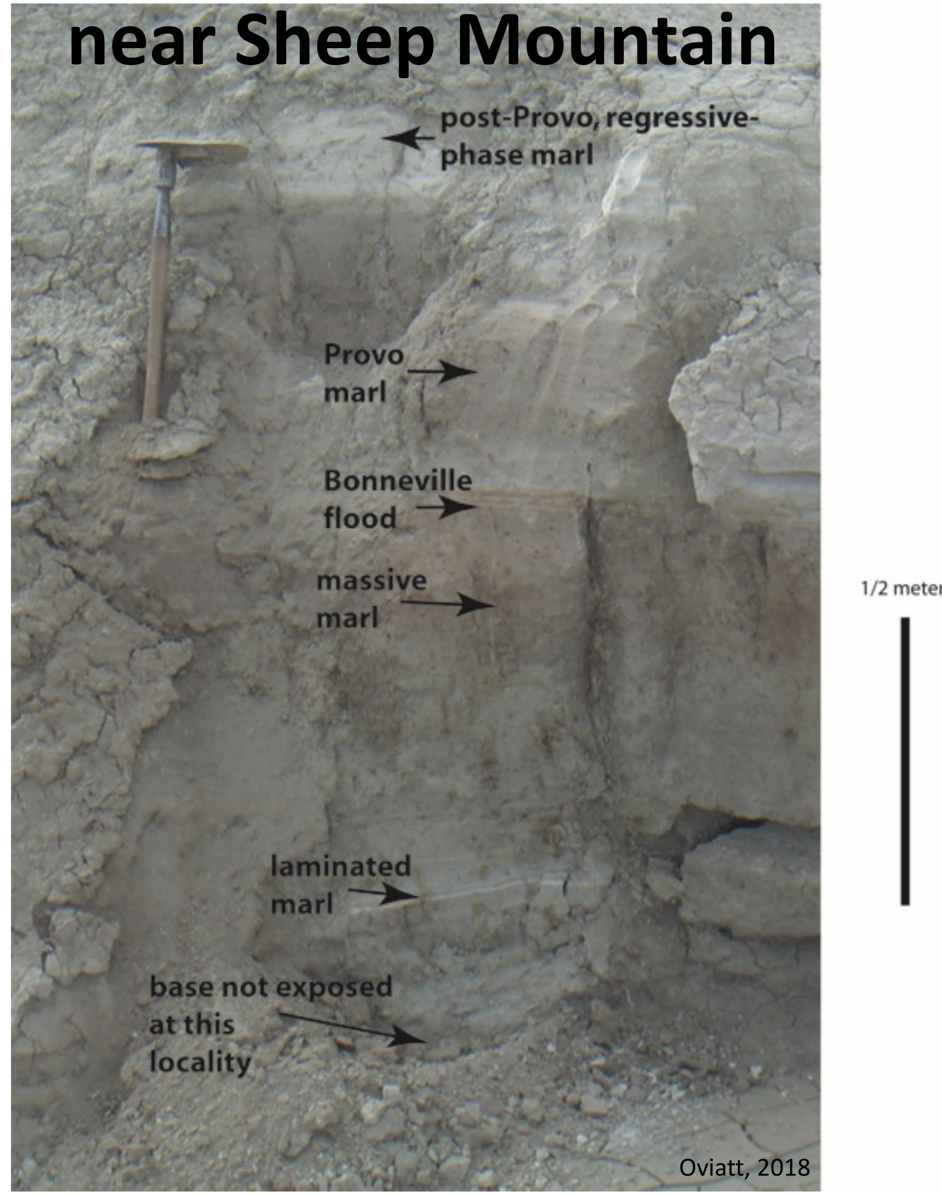
for scale, shovel handle is about 1.5 feet (~50 cm) long

GRAVEL 1 was deposited first in the shallow lake, then lake level was lowered so that waves winnowed out the finer pebbles and left the boulder and cobbles, which show up as a line on the wall of the gravel pit. Then lake level rose again and GRAVEL 2 was deposited, followed by continued lake-level rise and the Bonneville marl was deposited (this is the fine-grained lake bottom mud of Lake Bonneville). GRAVEL 3 was deposited by waves as Lake Bonneville dried up and lake level dropped across this site.

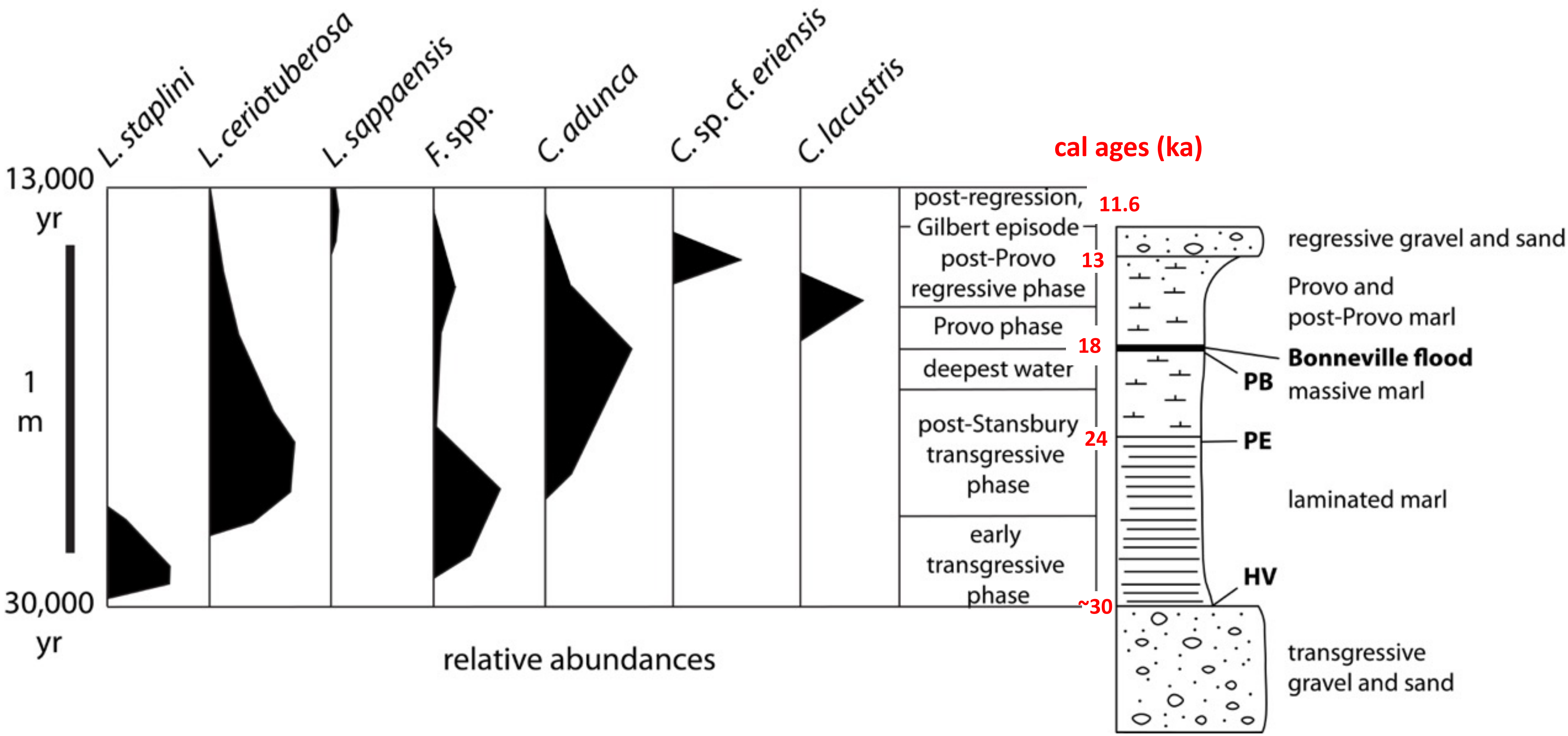


Bonneville stratigraphy



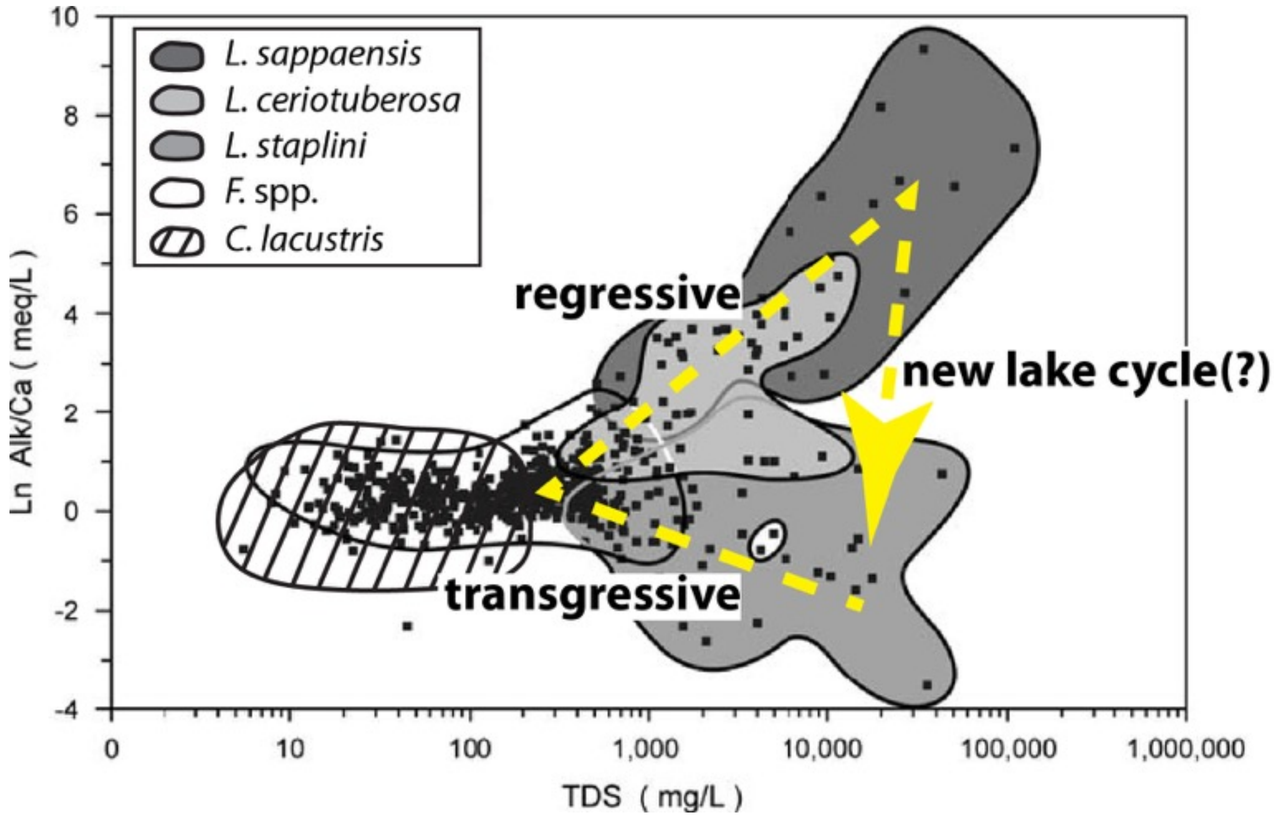


ostracodes in Lake Bonneville

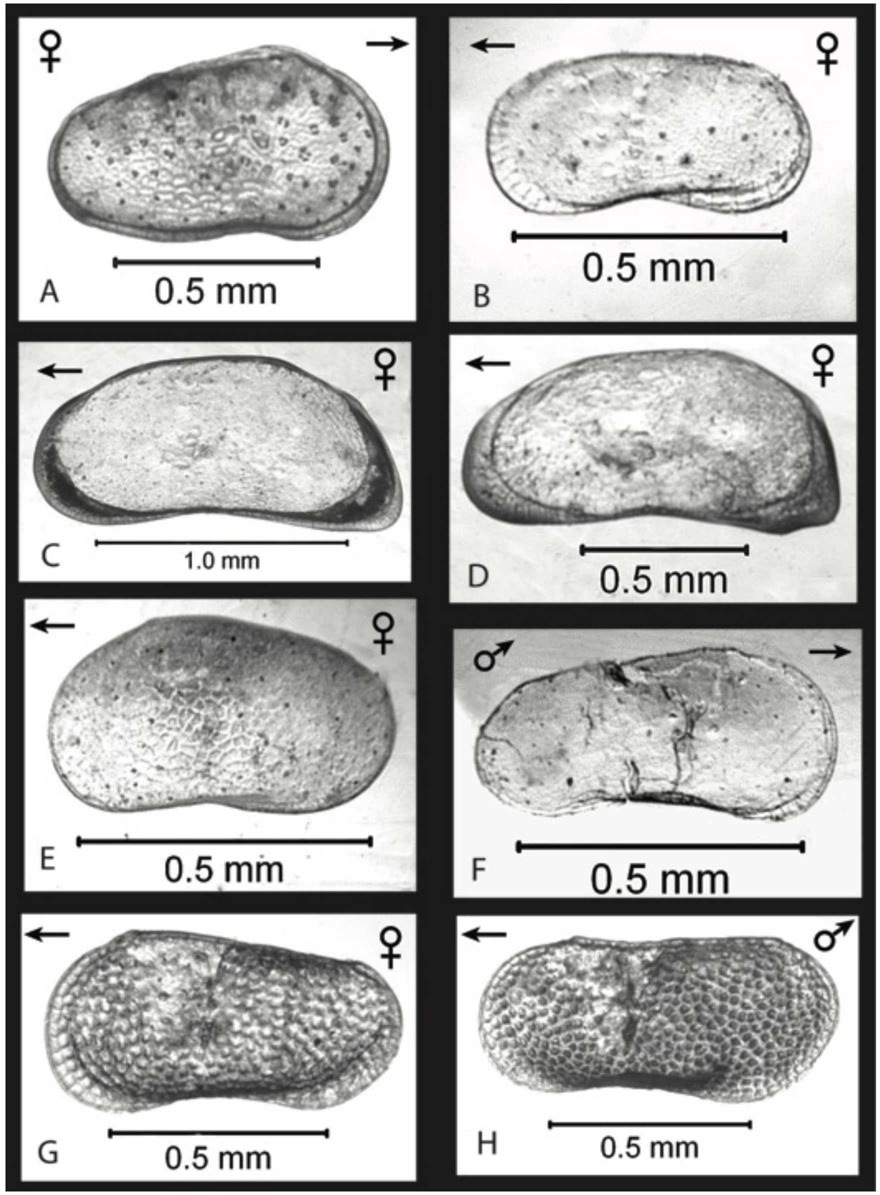


Forester, 1987; Oviatt, 2017; Oviatt, unpublished

ostracodes yield information about water chemistry



Oviatt, 2017; NANODe website http://www.personal.kent.edu/~alisonjs/nanode/



Cytherissa lacustris

Limnocythere sappaensis

Candona adunca

Fabaeformiscandona caudata
(formerly called *Candona caudata*)

Limnocythere staplini

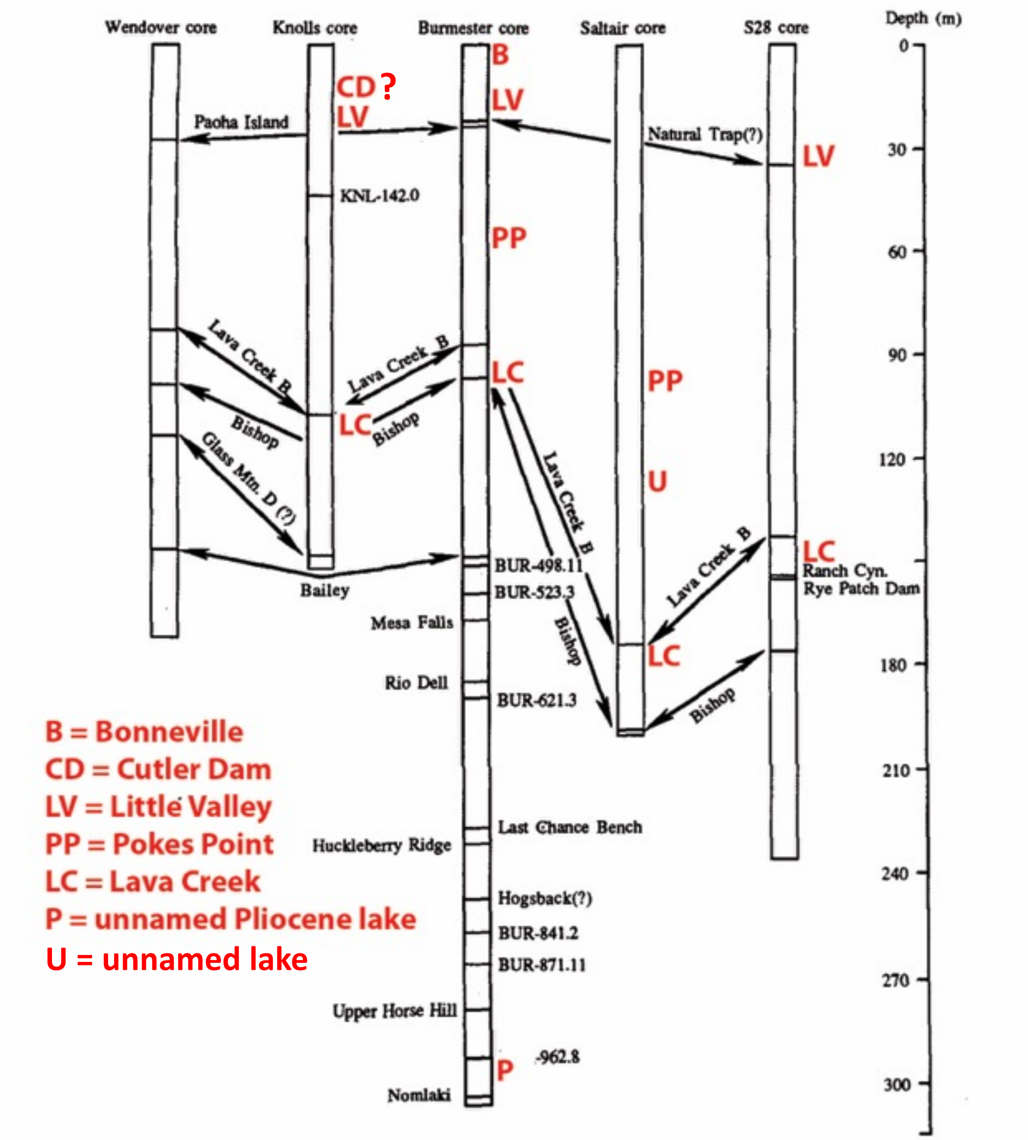
Limnocythere staplini

Limnocythere ceriotuberosa

Limnocythere ceriotuberosa

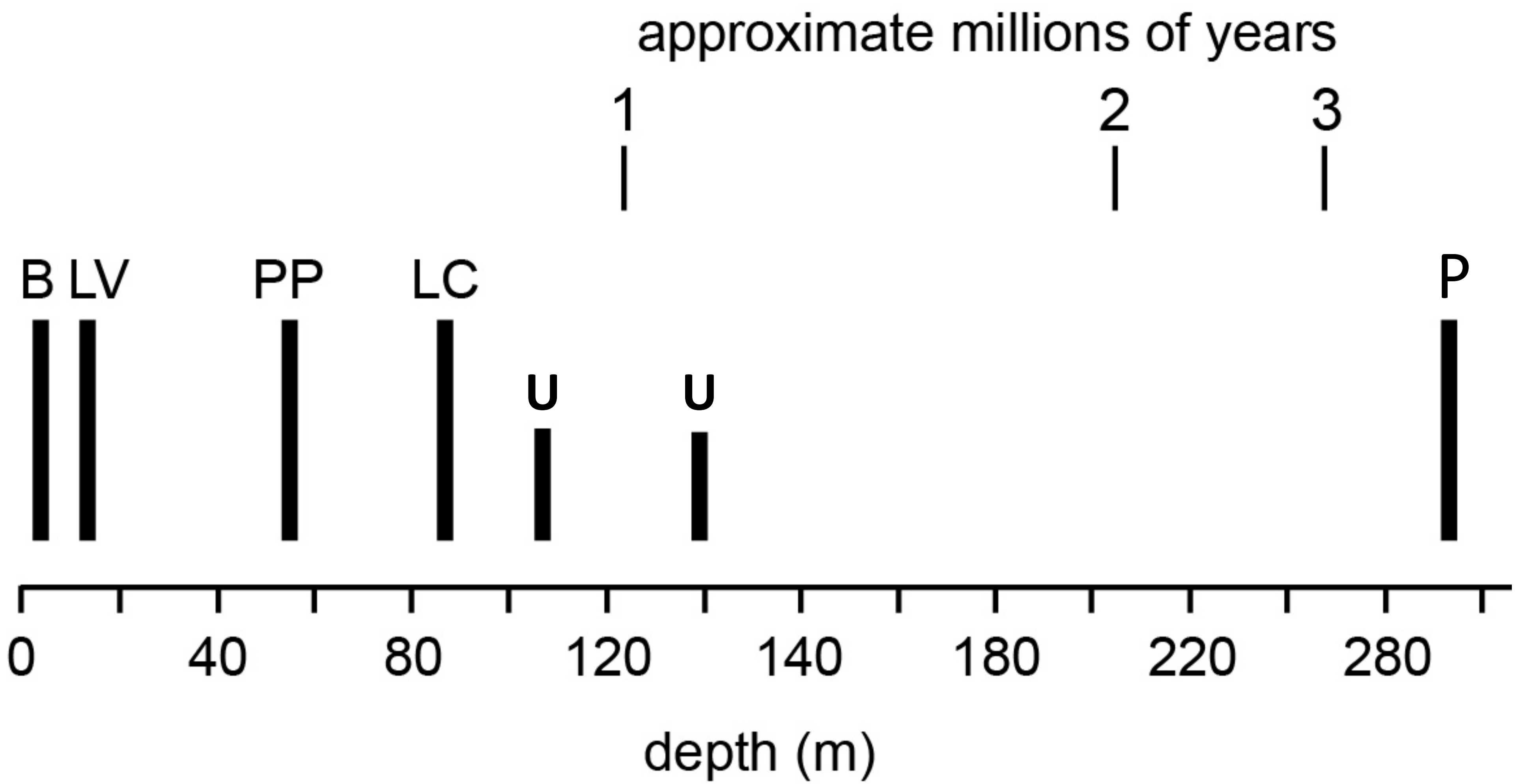
photos by Alison Smith
in Oviatt, 2017

Eardley cores

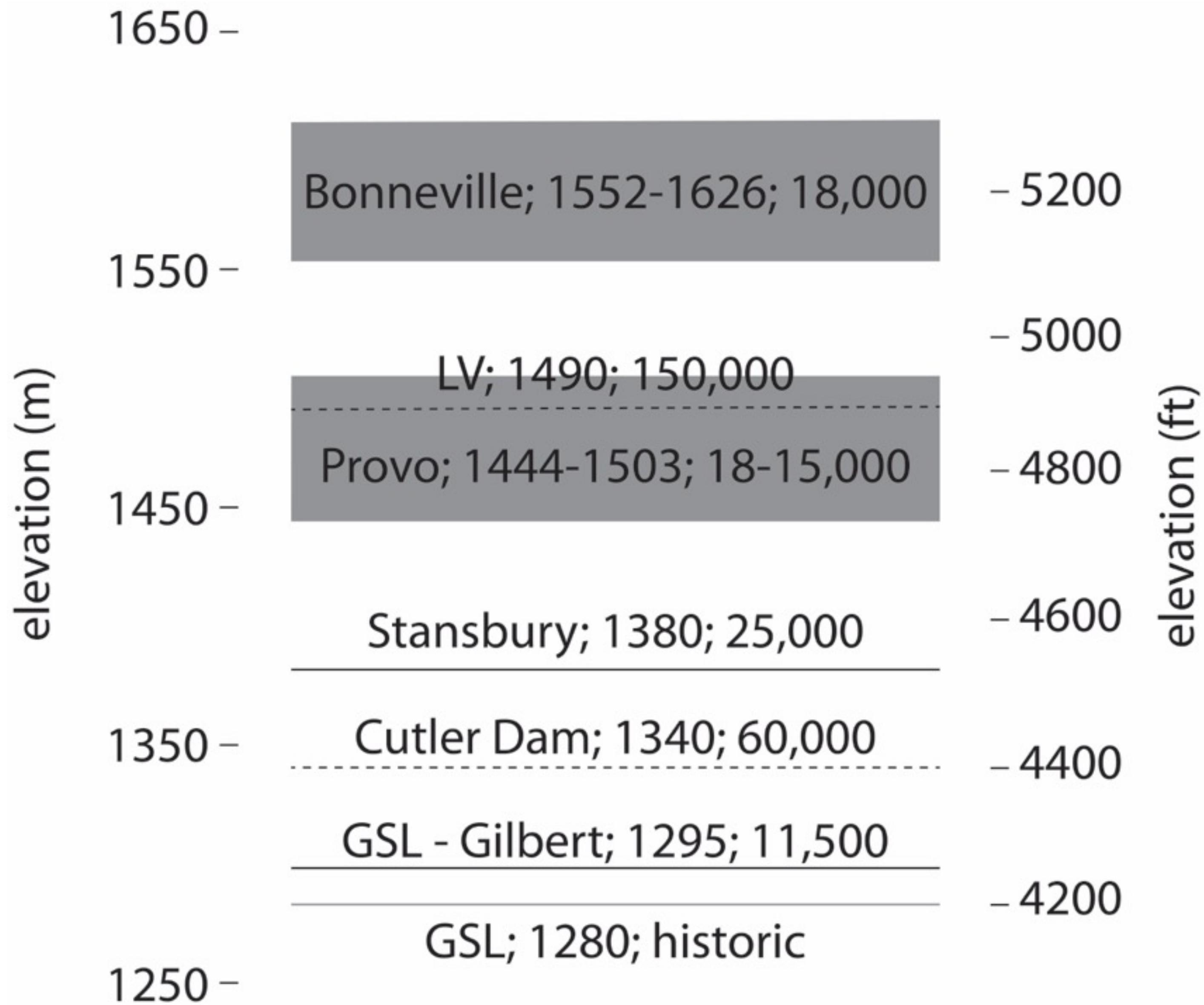


Thompson and Oviatt, unpublished; Oviatt and others, 1999; Williams, 1994; Bright, unpublished

Burmester core, large lakes



Bonneville and pre-Bonneville elevations



Currey (1982);
Scott and others (1983);
Oviatt and others (1987);
Oviatt, unpublished

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