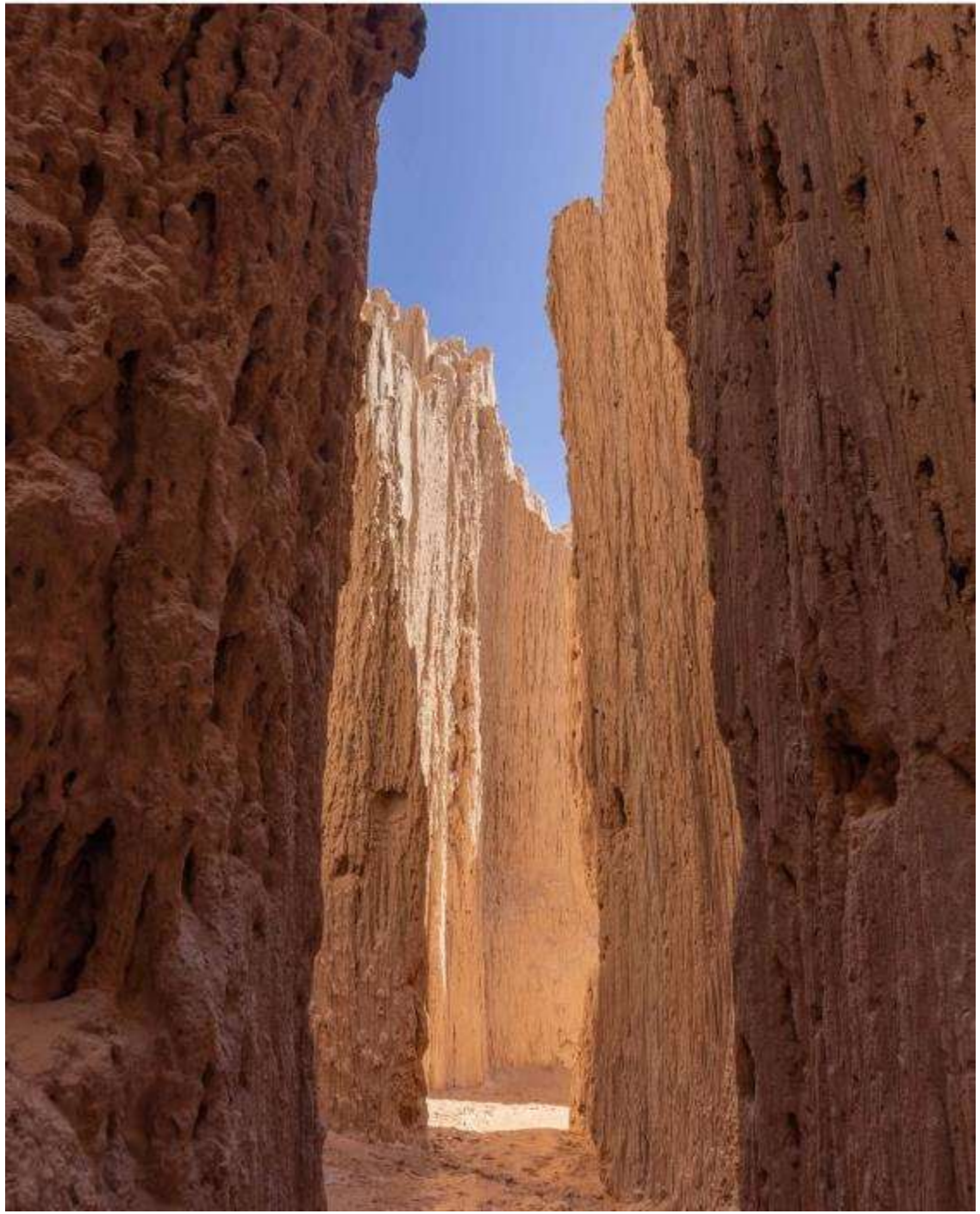
Skaftafelljokull (glacier)

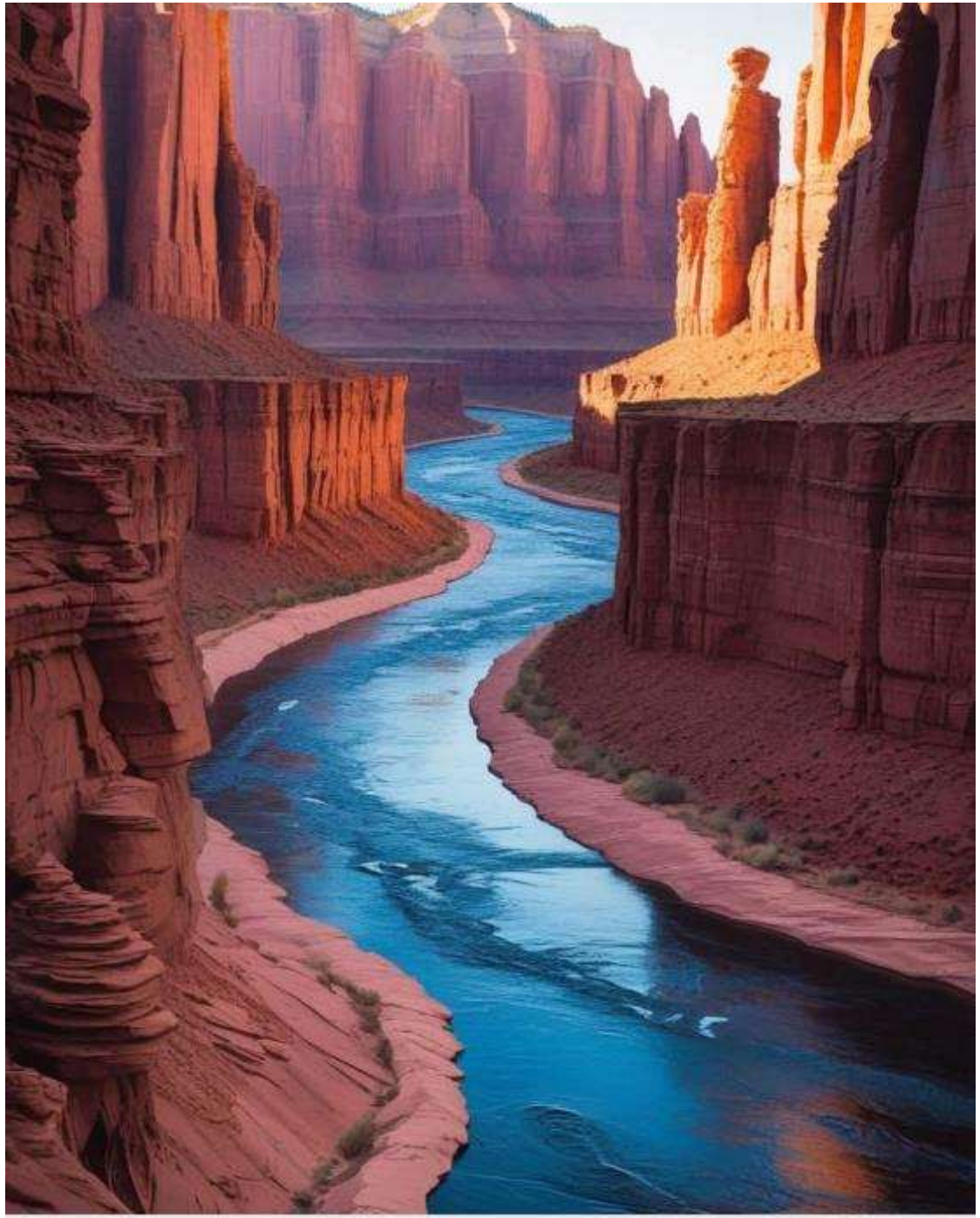
Part 0: Social Media



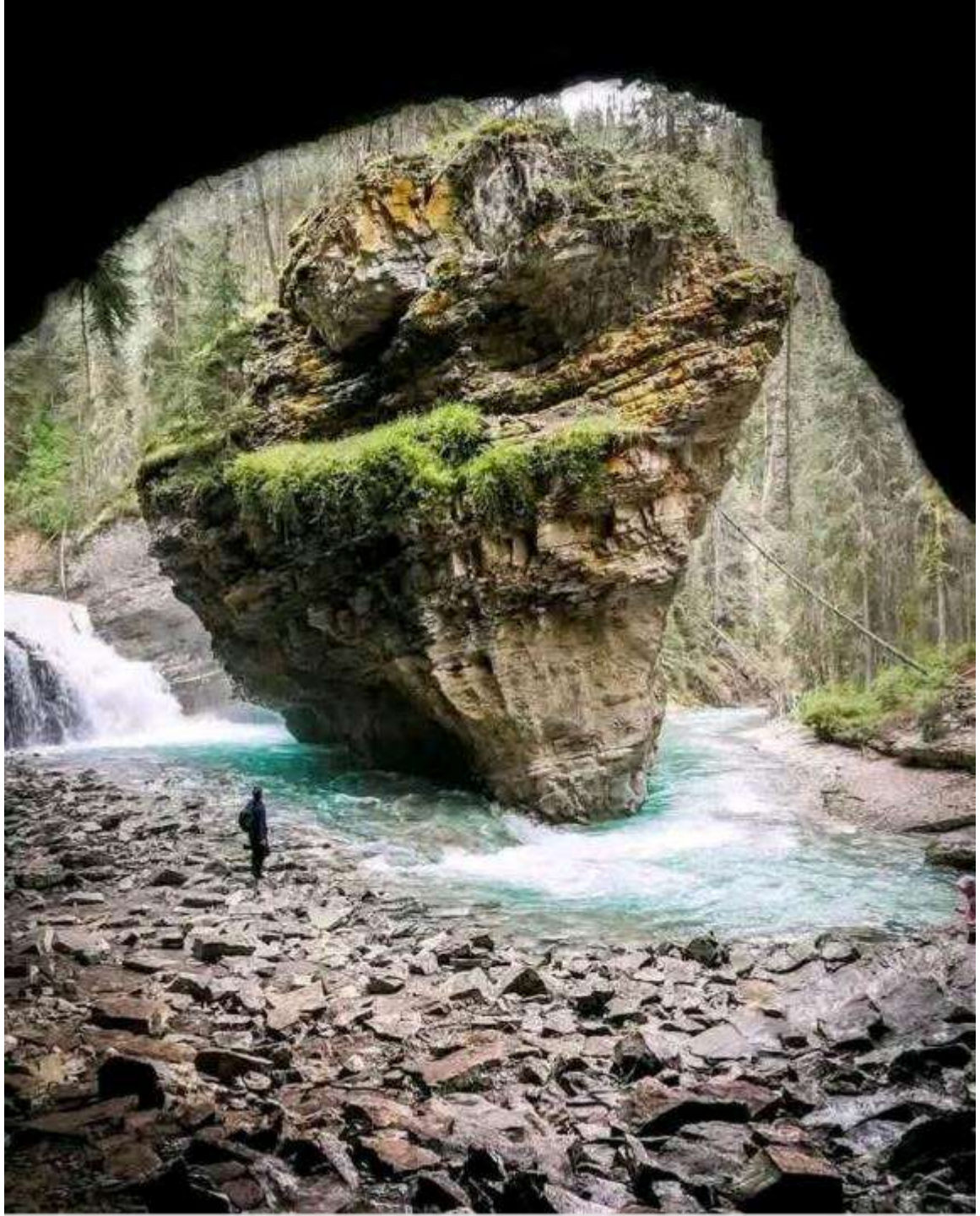
narrow steep-walled valley:

nothing specifically glacial

probably too narrow for glacial flow



- wider steep-walled valley:
  - steps mildly reminiscent of staircase cirques
  - pillars unlikely to survive glaciation
  - probably not glacial

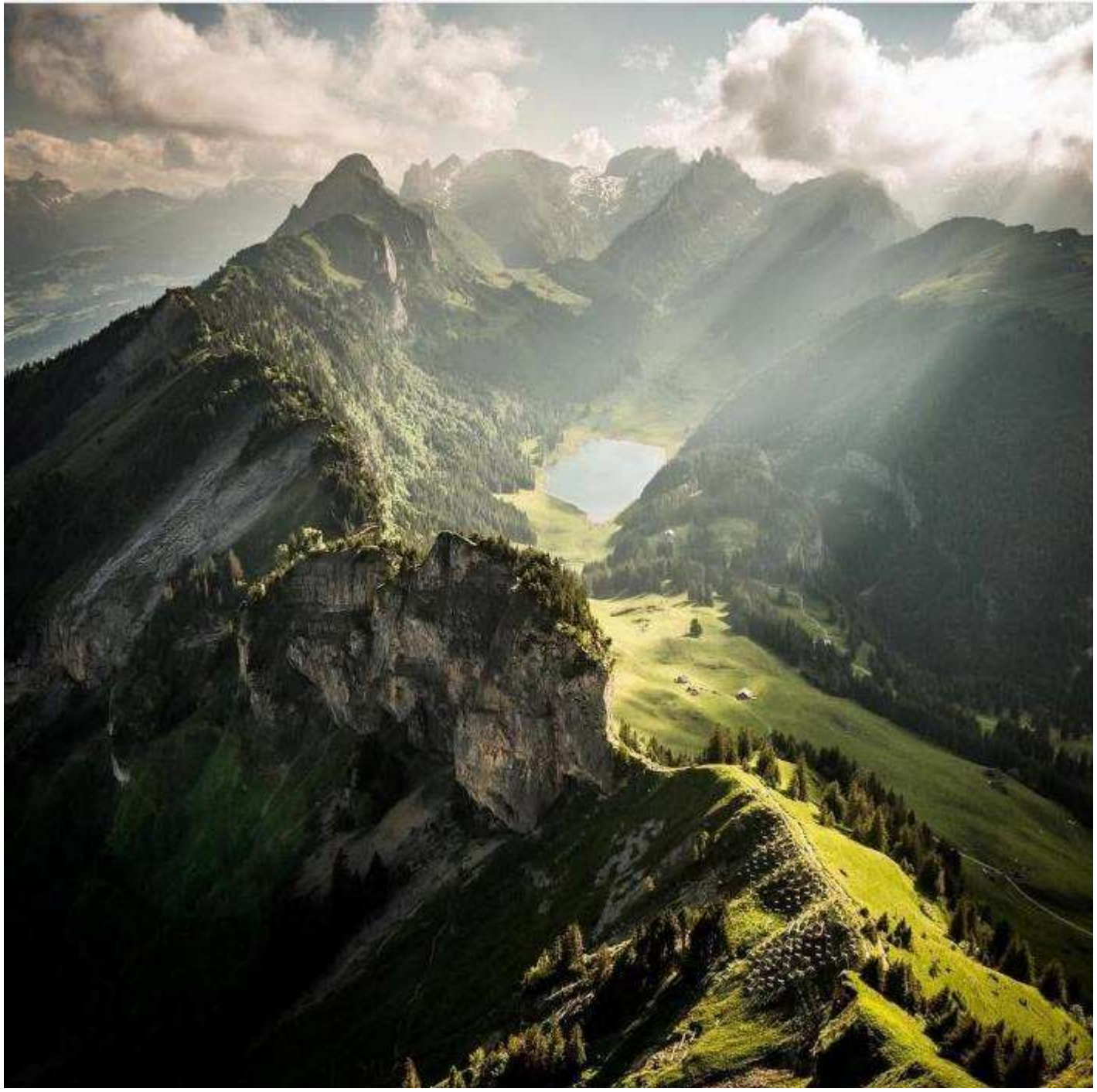


big boulder as seen from a cave:

probably fell off cliff

no reason to think it’s glacial

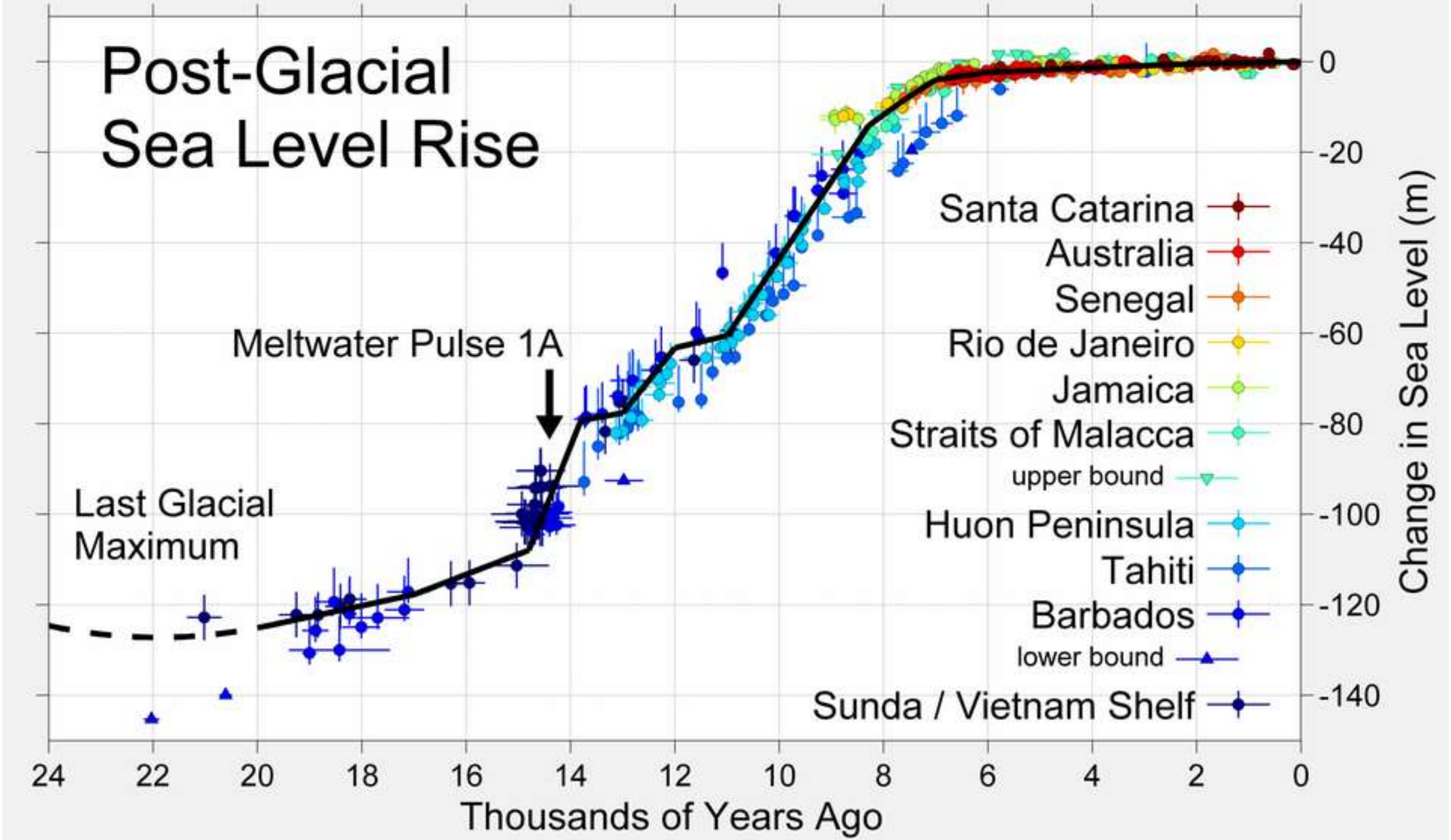
two glacial valleys
hanging cirque on right
moraine
lakes
outlet stream

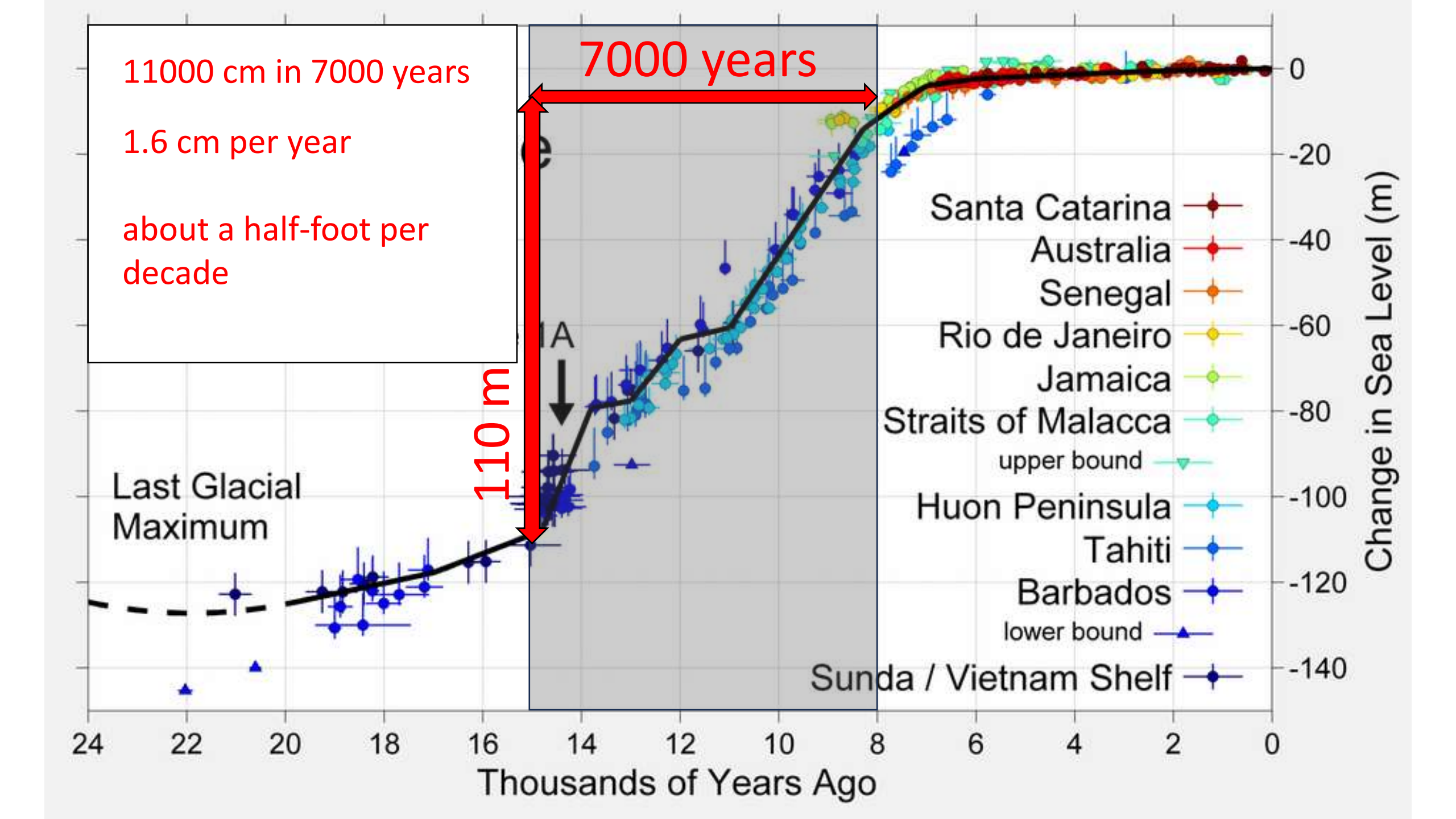


cirque
arete
cirque lake

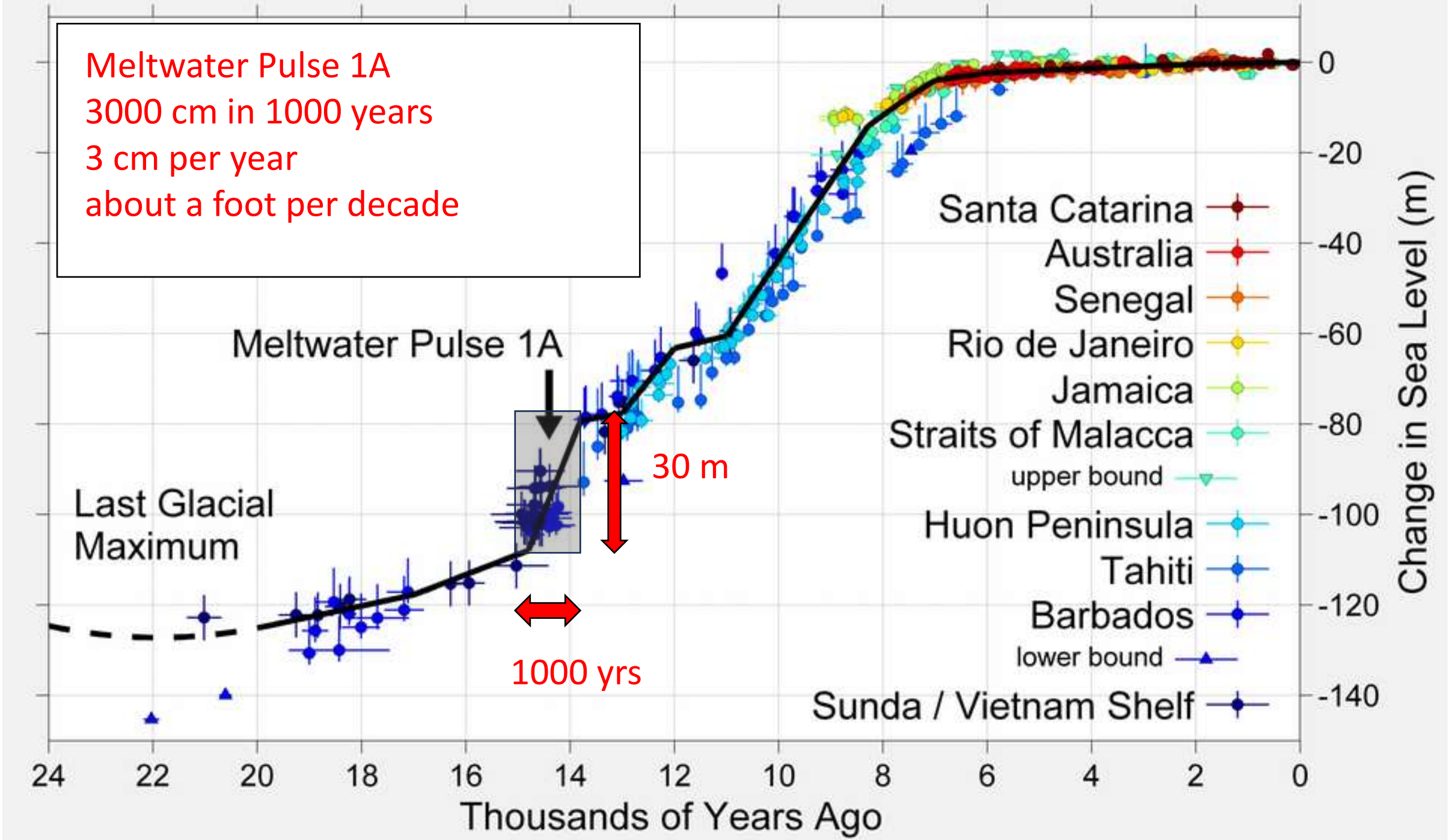
Part 1: Sea Level

More complicated than your might expect

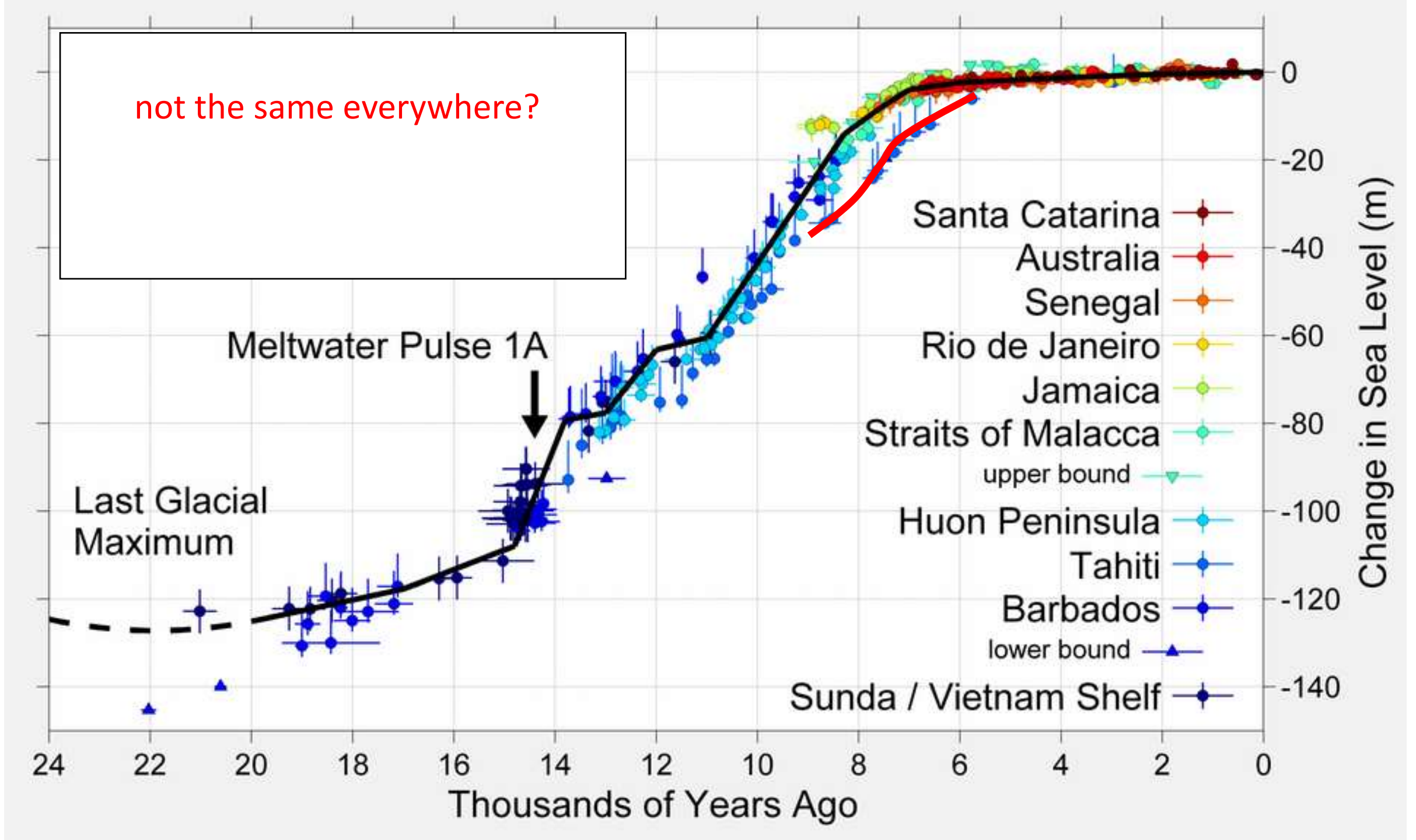

Post-Glacial
Sea Level Rise
Meltwater Pulse 1A
Last Glacial
Maximum
Santa Catarina
Australia
Senegal
Rio de Janeiro
Jamaica
Straits of Malacca
upper bound
Huon Peninsula
Tahiti
Barbados
lower bound
Sunda / Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Change in Sea Level (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago


11000 cm in 7000 years
1.6 cm per year
about a half-foot per decade
7000 years
110 m
Last Glacial Maximum
Santa Catarina
Australia
Senegal
Rio de Janeiro
Jamaica
Straits of Malacca
upper bound
Huon Peninsula
Tahiti
Barbados
lower bound
Sunda / Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Change in Sea Level (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

10 years


Meltwater Pulse 1A
3000 cm in 1000 years
3 cm per year
about a foot per decade
Meltwater Pulse 1A
30 m
1000 yrs
Last Glacial
Maximum
Santa Catarina
Australia
Senegal
Rio de Janeiro
Jamaica
Straits of Malacca
upper bound
Huon Peninsula
Tahiti
Barbados
lower bound
Sunda / Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Change in Sea Level (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

10 years


not the same everywhere?
Meltwater Pulse 1A
Last Glacial Maximum
Santa Catarina
Australia
Senegal
Rio de Janeiro
Jamaica
Straits of Malacca
upper bound
Huon Peninsula
Tahiti
Barbados
lower bound
Sunda / Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Change in Sea Level (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago

Reason for sea level changes

1. ice volume of glaciers
2. thermal expansion of oceans
3. gravitational attraction of glaciers
4. Earth rotation
5. shape of earth (isostacy)

1. ice volume of glaciers

$$height = \frac{glacial\ volume\ change}{surface\ area\ of\ oceans}$$

26.5 million
cubic
kilometers

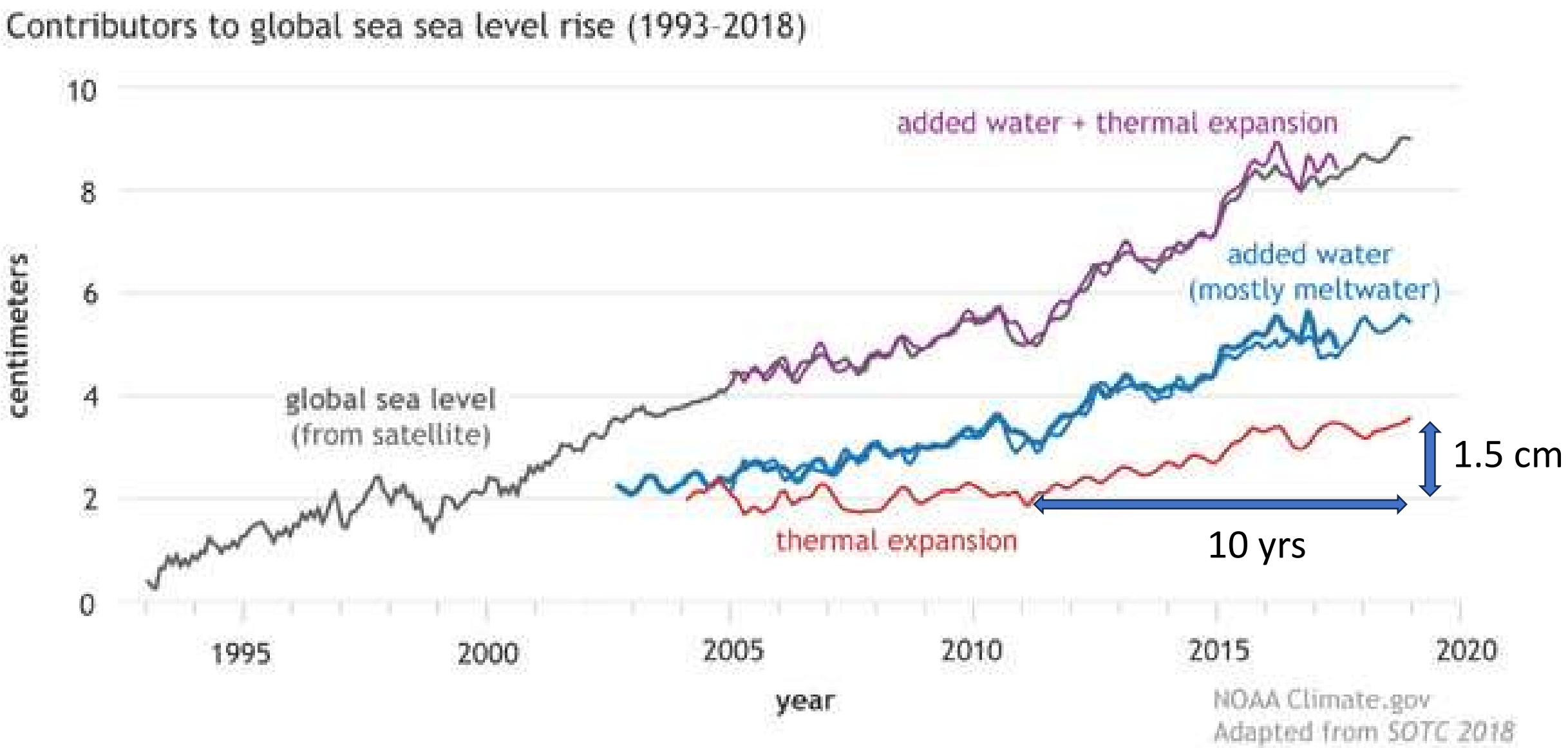
---

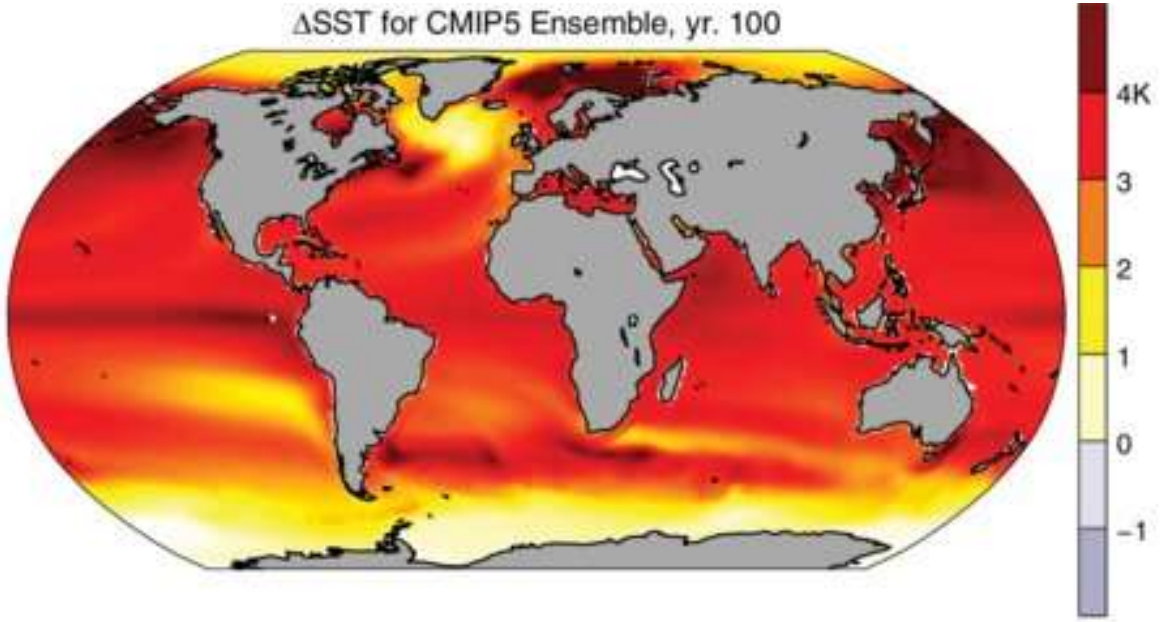
361 million
square
kilometers

= 73 meters

(2) Thermal Expansion of ocean

$$height = 2.1 \text{ x } 10^{-4} \times thickness \times \Delta\, temperature$$

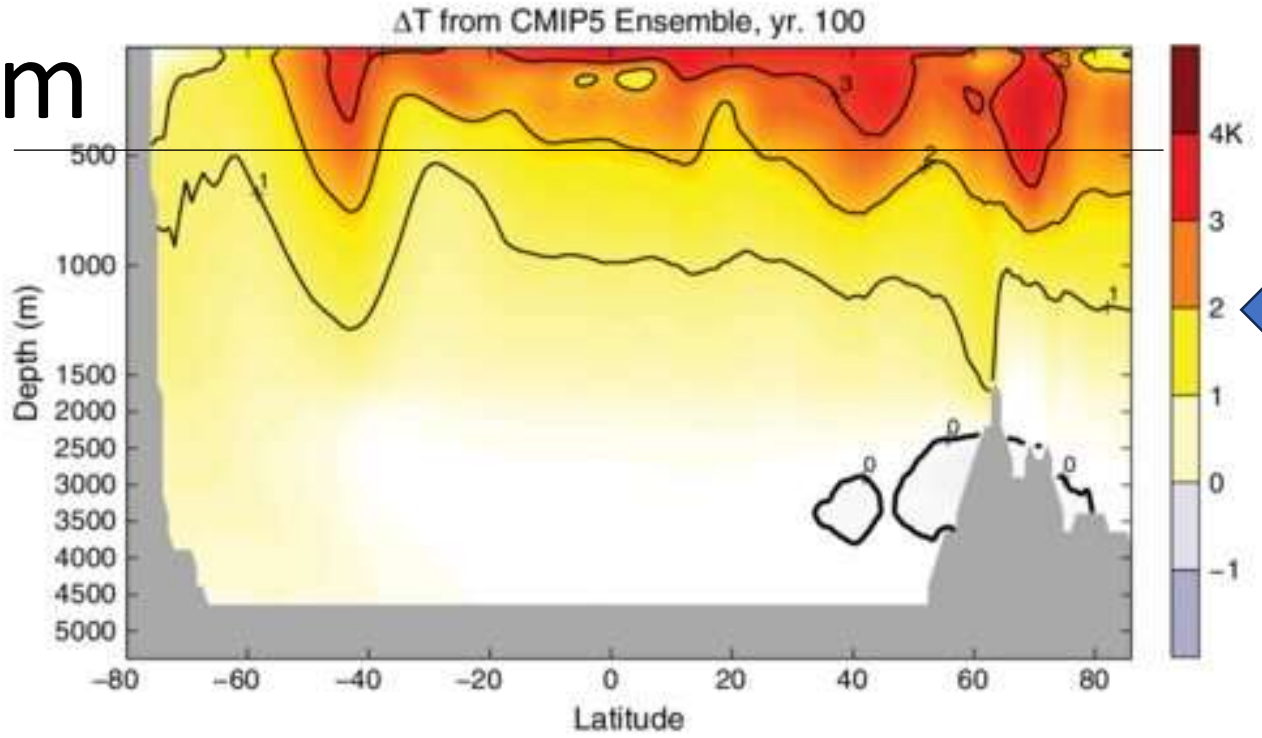

Contributors to global sea sea level rise (1993-2018)
10
8
6
4
2
0
centimeters
added water + thermal expansion
added water
(mostly meltwater)
global sea level
(from satellite)
thermal expansion
1.5 cm
10 yrs
1995
2000
2005
2010
2015
2020
year
NOAA Climate.gov
Adapted from SOTC 2018



Ocean Warming

Prediction for next 100 years

500 m



← 2 degC

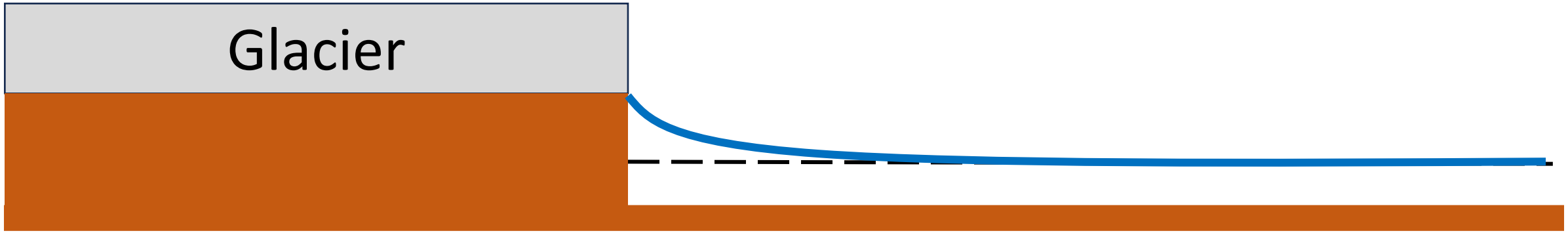
Thermal Expansion of ocean

$$height = 2.1 \text{ x } 10^{-4} \times 50000\ cm \times 2\ degC$$

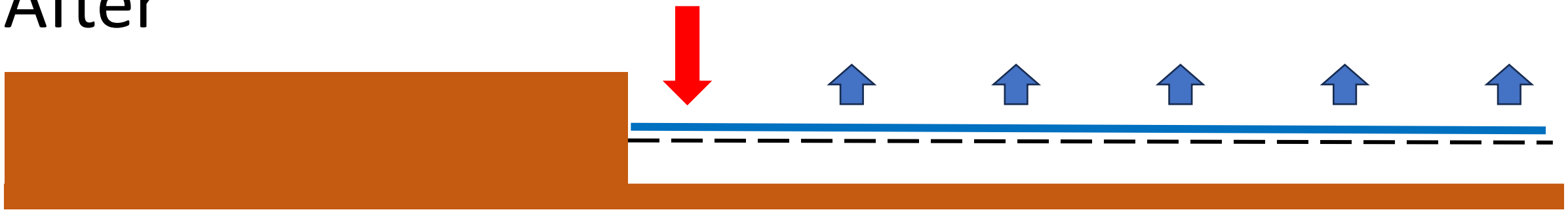
$$= 21 \text{ cm}$$

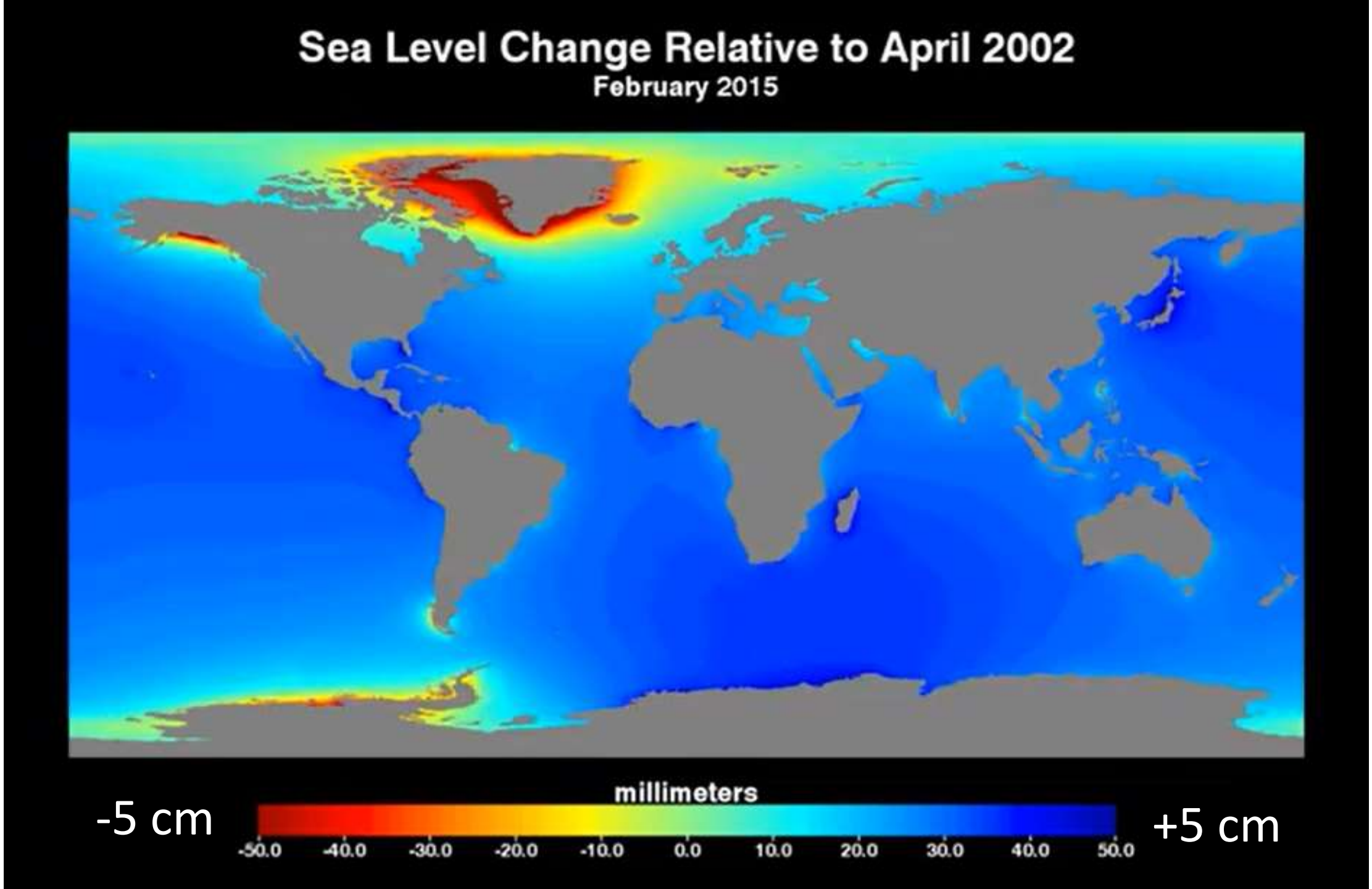
3. Gravitational Attraction of Glaciers

Before

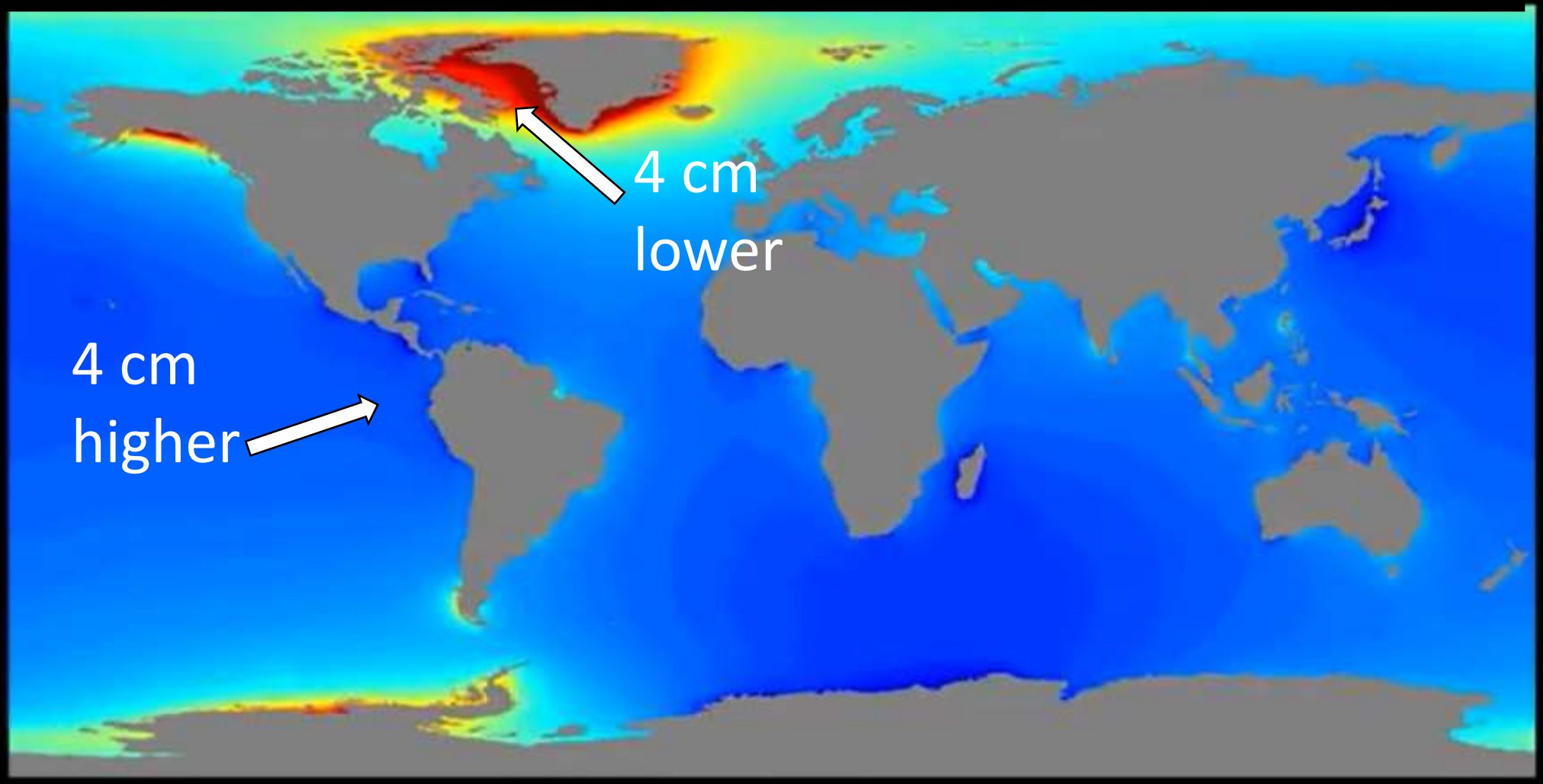


After




Sea Level Change Relative to April 2002
February 2015
millimeters
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
-5 cm
+5 cm

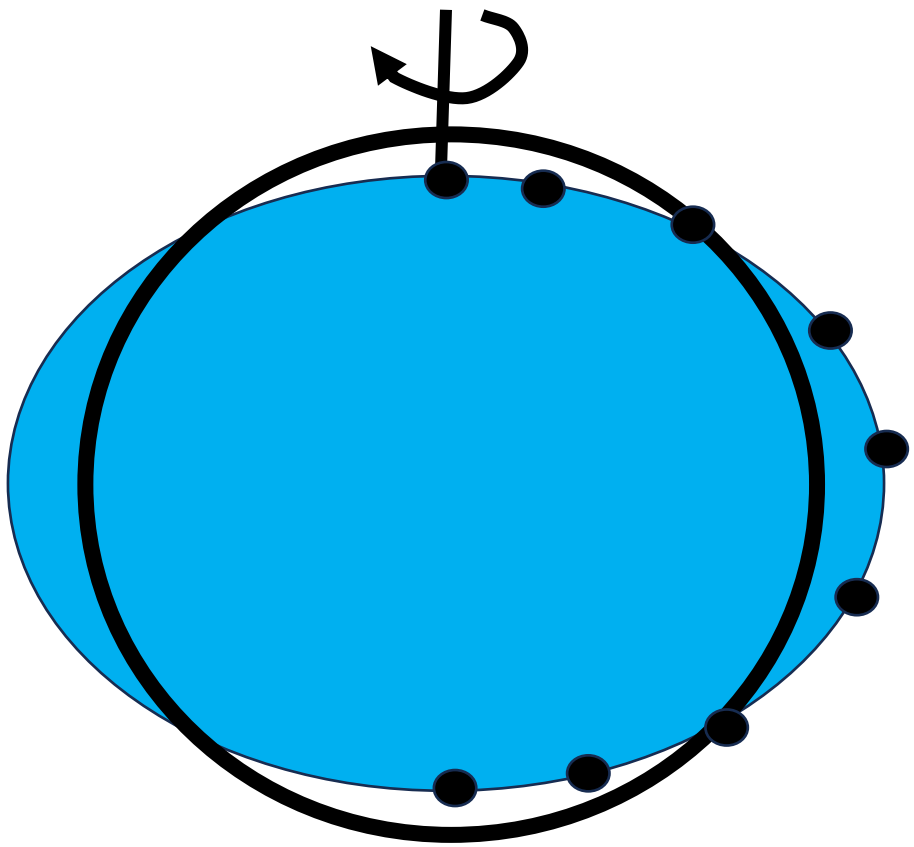
Sea level fall near Greenland comparable to sea level rise in equatorial ocean



-5 cm

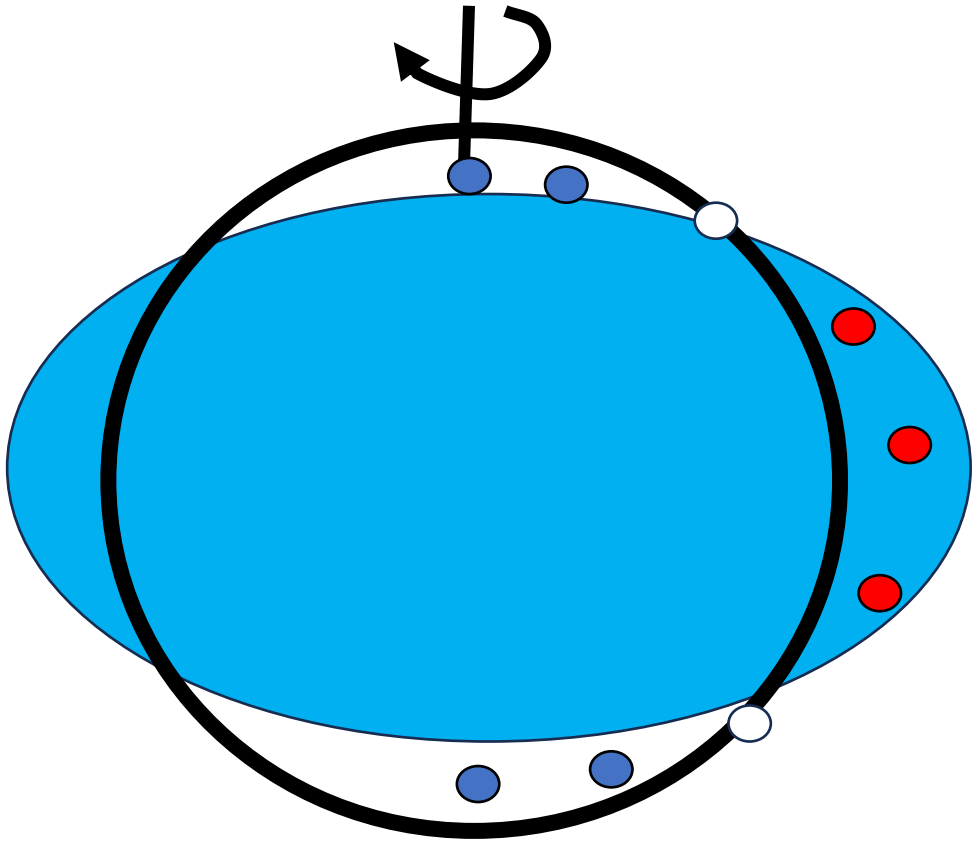
+5 cm

4. Rotation of Earth

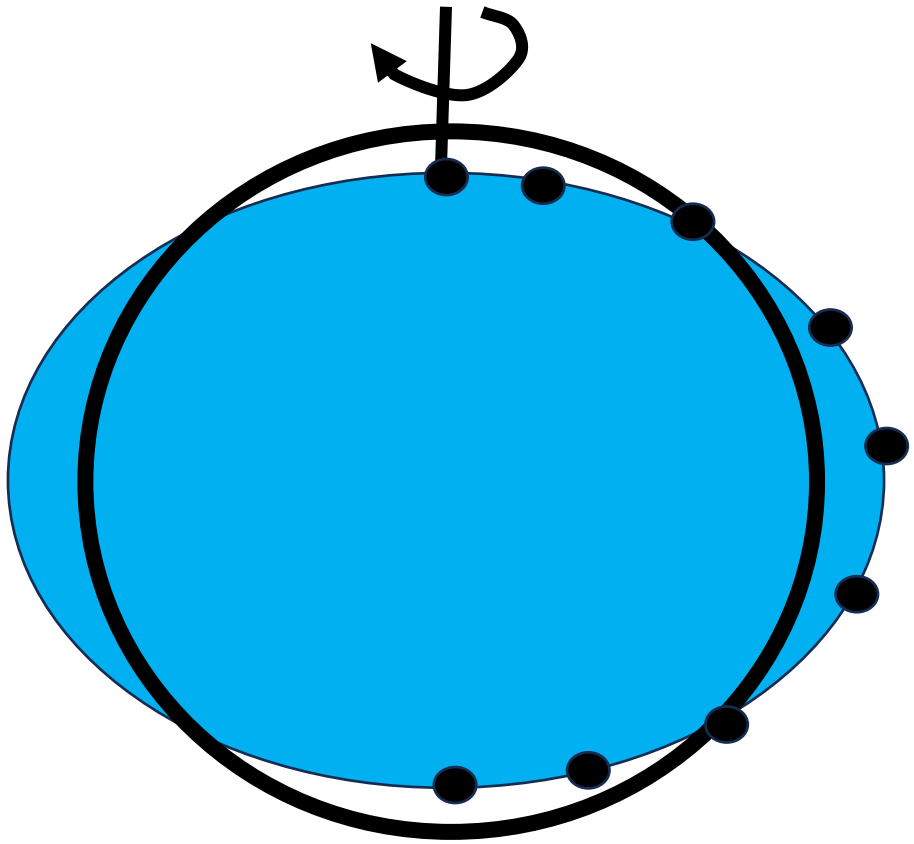


centrifugal force causes equatorial bulge

spin faster

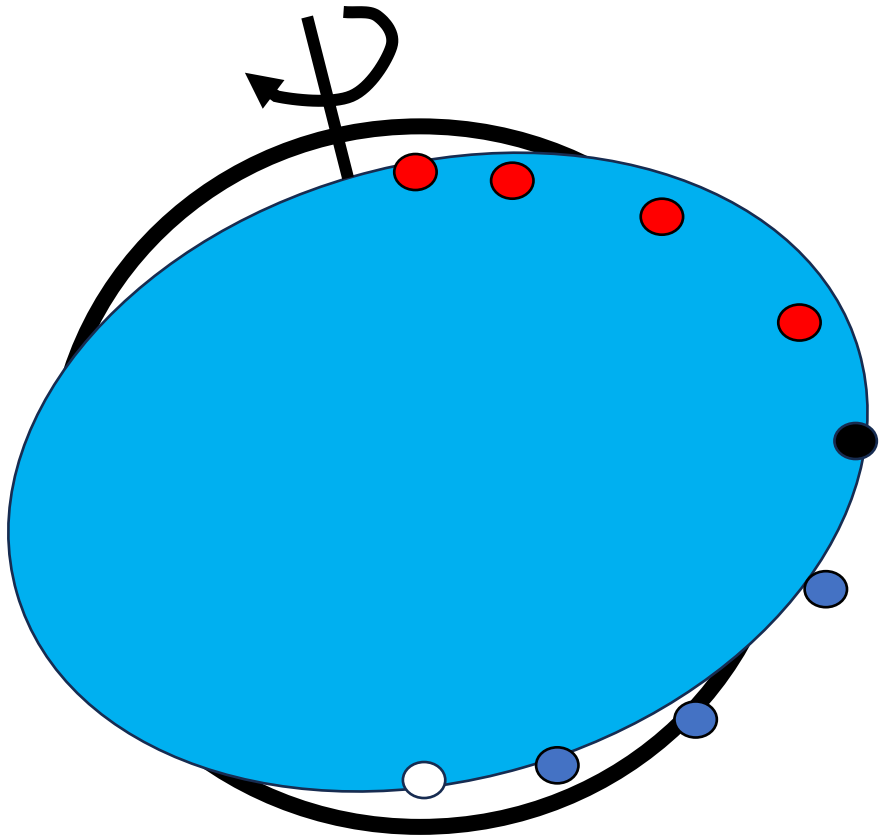


- falls
- rises

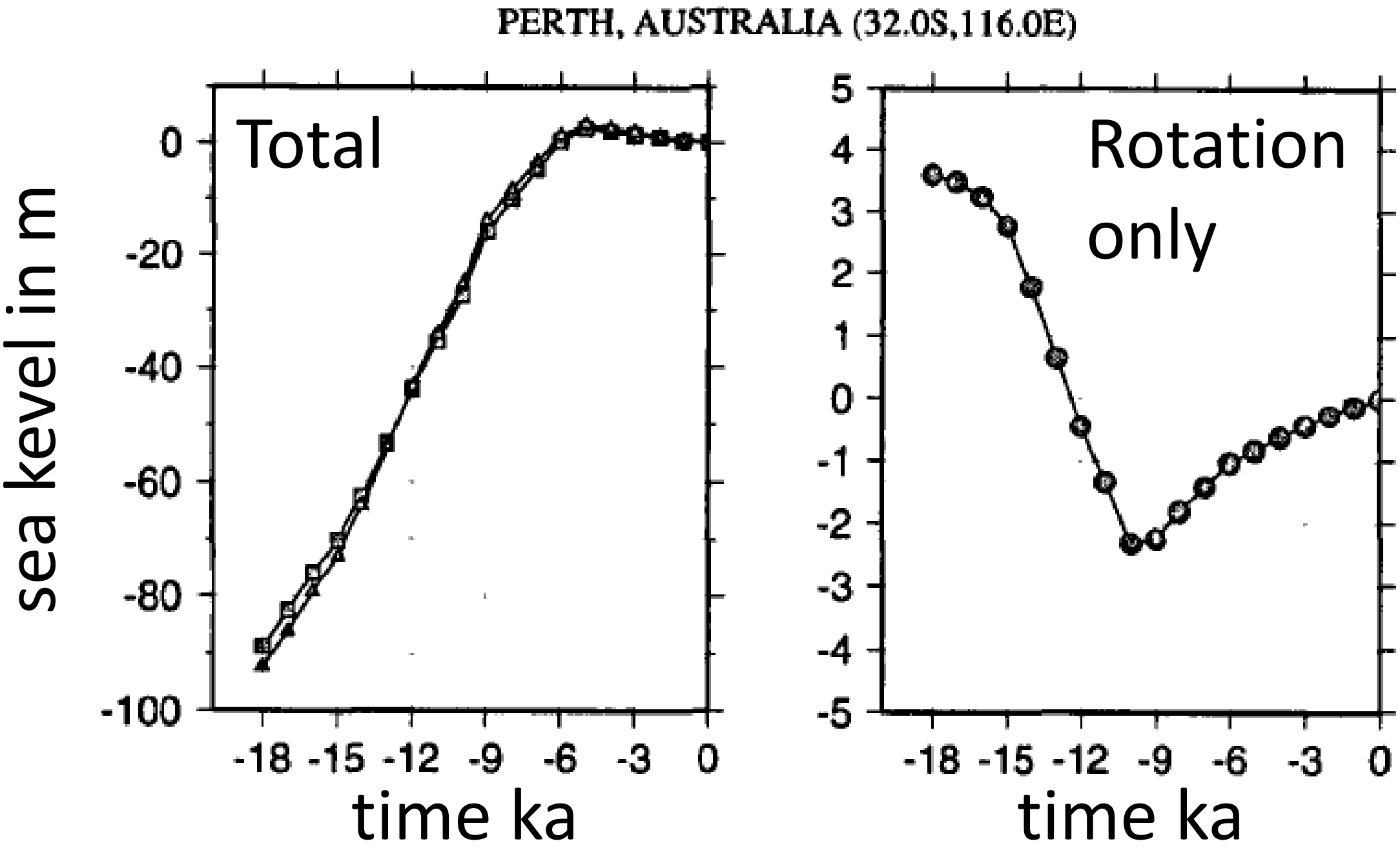


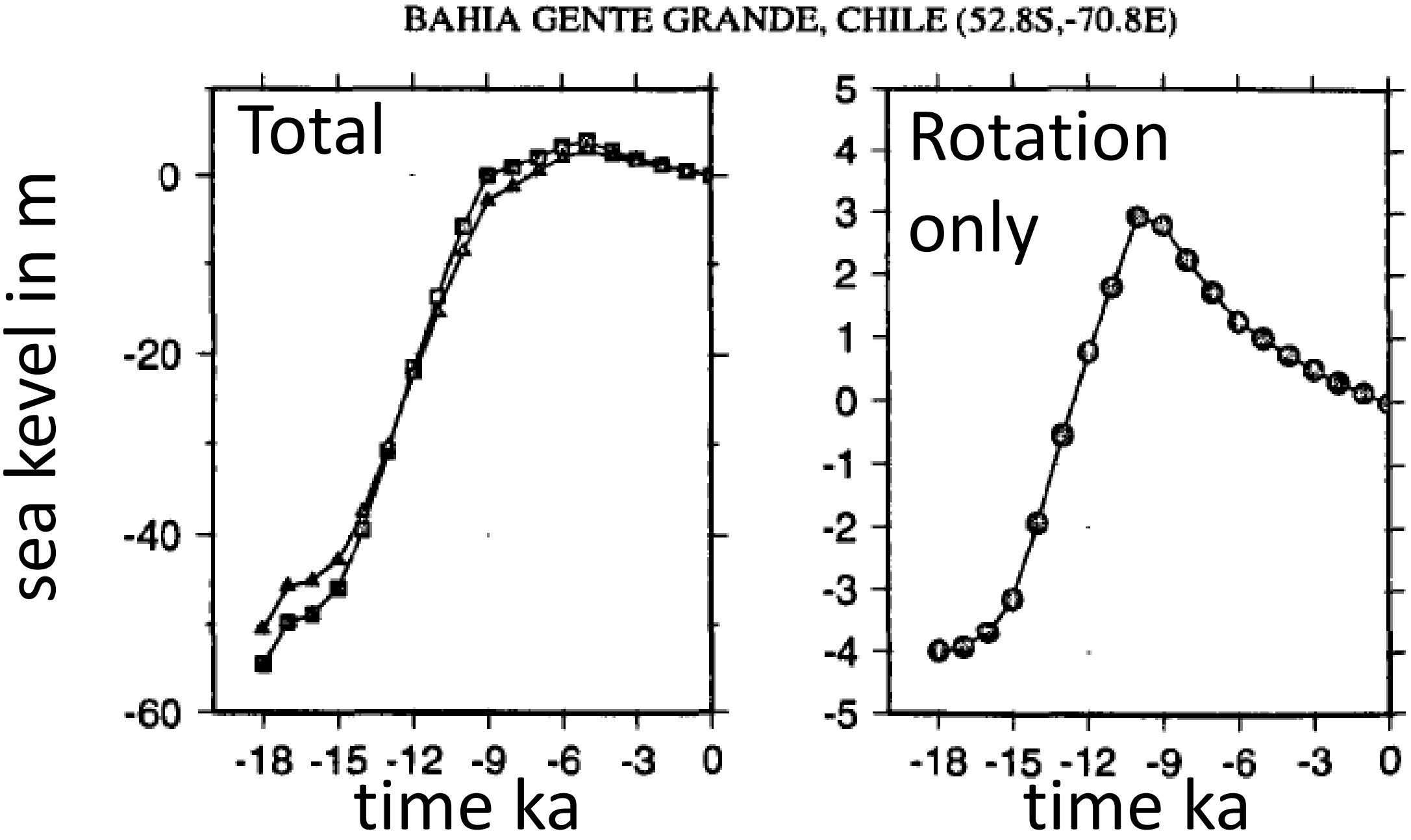
centrifugal force causes equatorial bulge

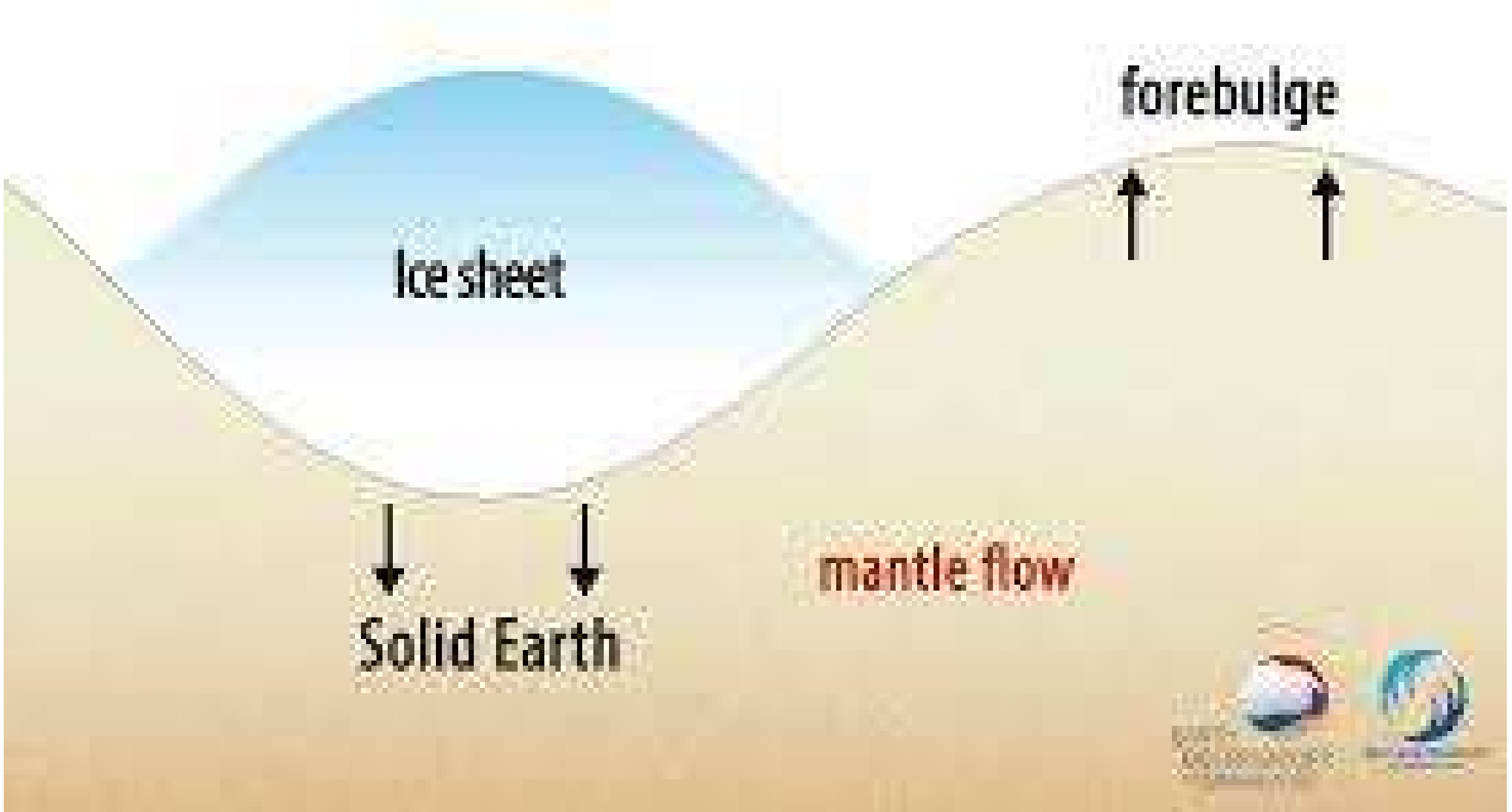
axis tilts

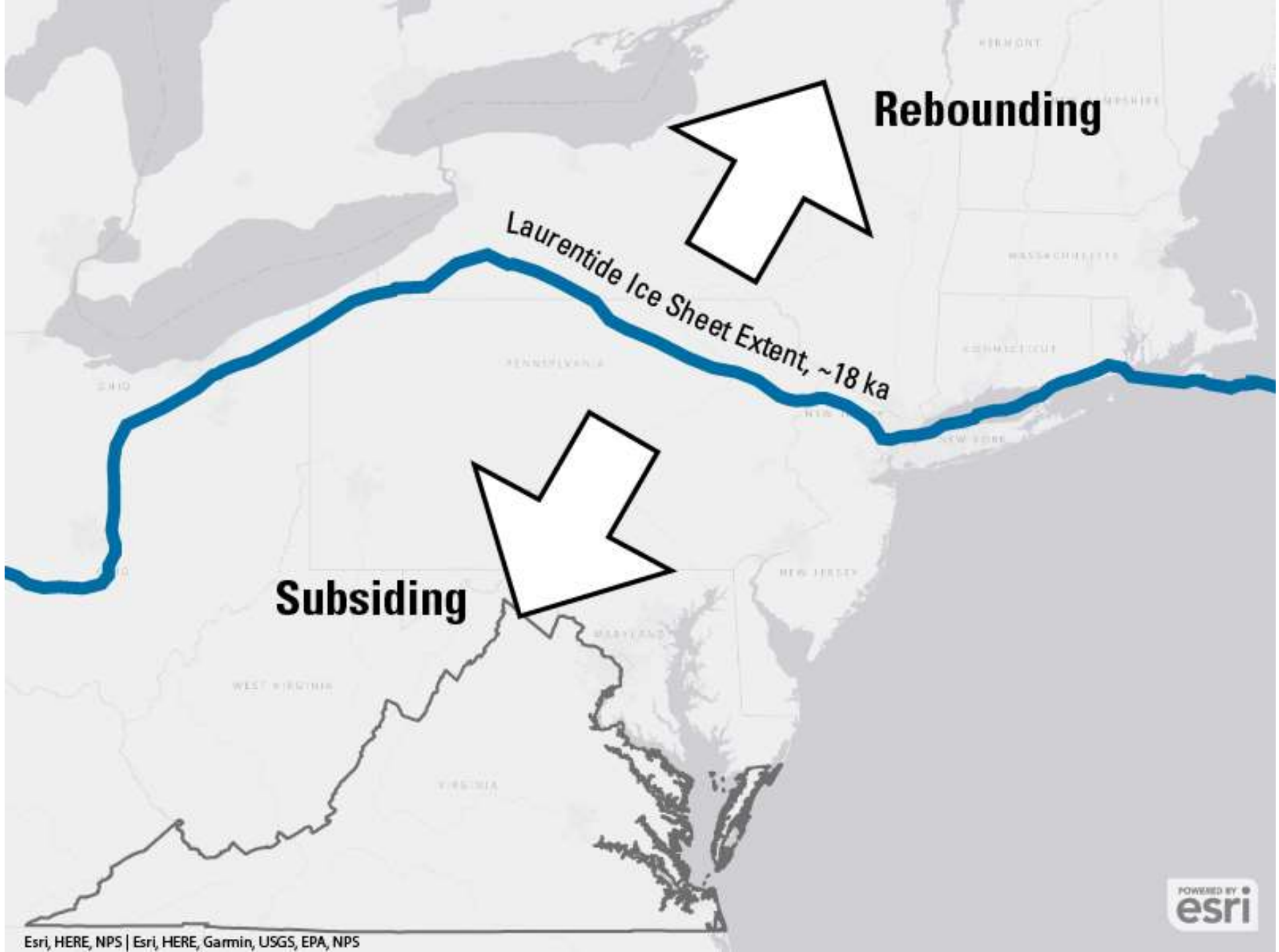


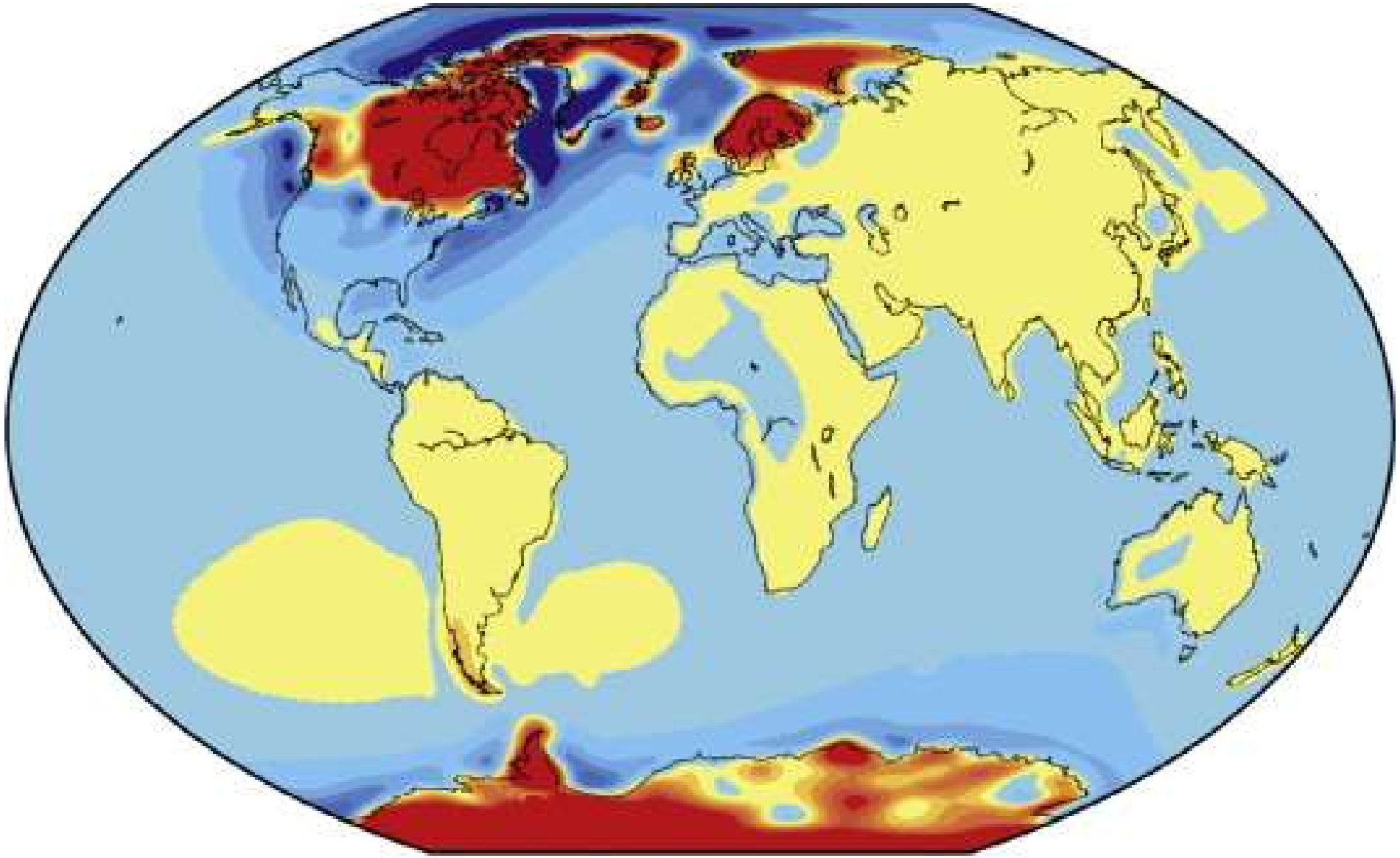
- falls
- rises


PERTH, AUSTRALIA (32.0S,116.0E)
Total
Rotation only
sea kevel in m
time ka
time ka
0
-20
-40
-60
-80
-100
5
4
3
2
1
0
-1
-2
-3
-4
-5
-18 -15 -12 -9 -6 -3 0
-18 -15 -12 -9 -6 -3 0


BAHIA GENTE GRANDE, CHILE (52.8S,-70.8E)
Total
Rotation only
sea kevel in m
time ka
time ka
0
-20
-40
-60
5
4
3
2
1
0
-1
-2
-3
-4
-5
-18 -15 -12 -9 -6 -3 0
-18 -15 -12 -9 -6 -3 0


forebulge
Ice sheet
mantle flow
Solid Earth


Rebounding
Laurentide Ice Sheet Extent, ~18 ka
Subsiding
Esri, HERE, NPS | Esri, HERE, Garmin, USGS, EPA, NPS



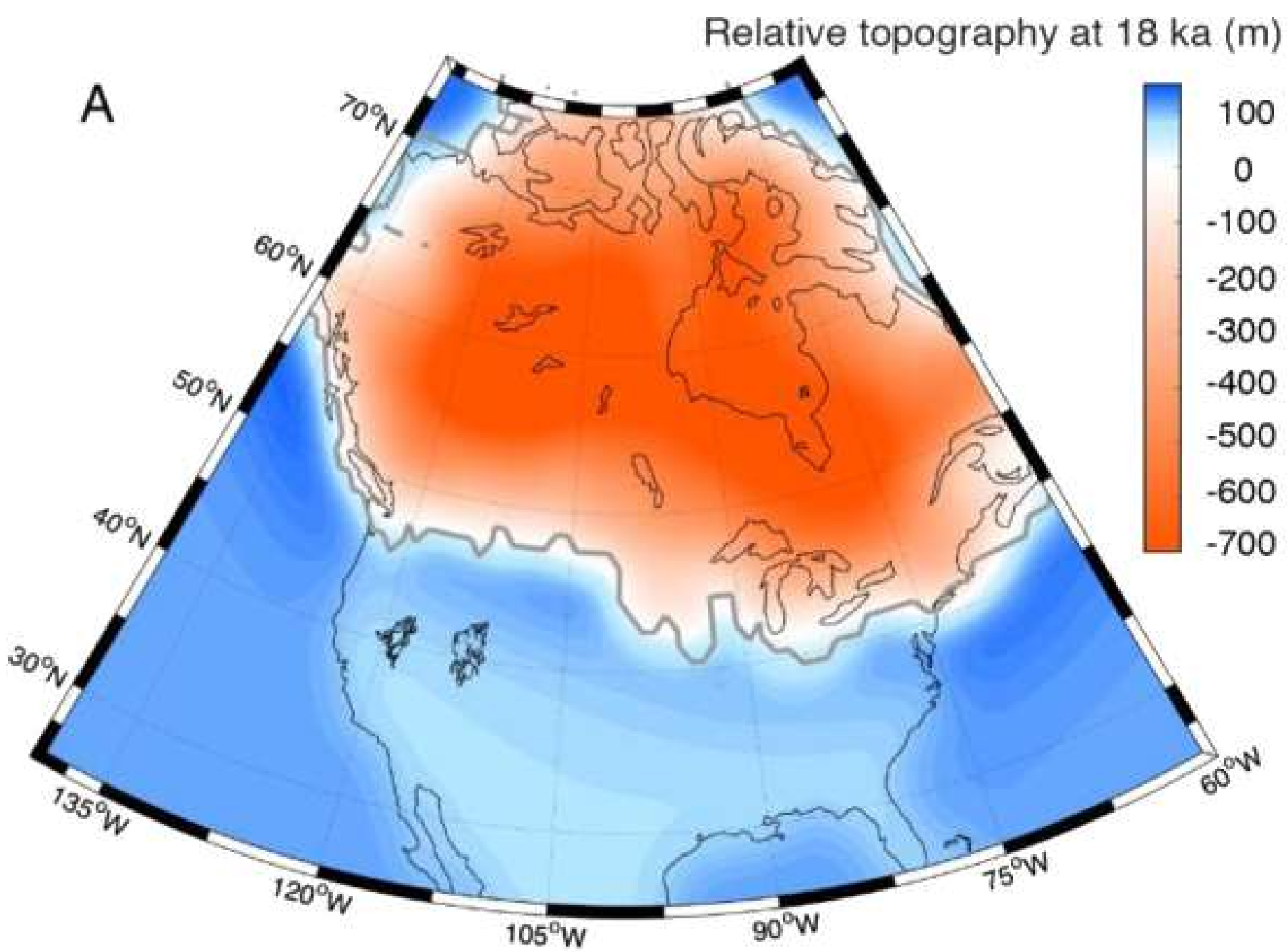
−7.0 −2.5 −2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0 2.5 18.0

Present-day radial deformation (mm yr^{-1})

Glacial-era sea cliff on Reykjanes

Beach terraces in Greenland

more interesting because they are dateable

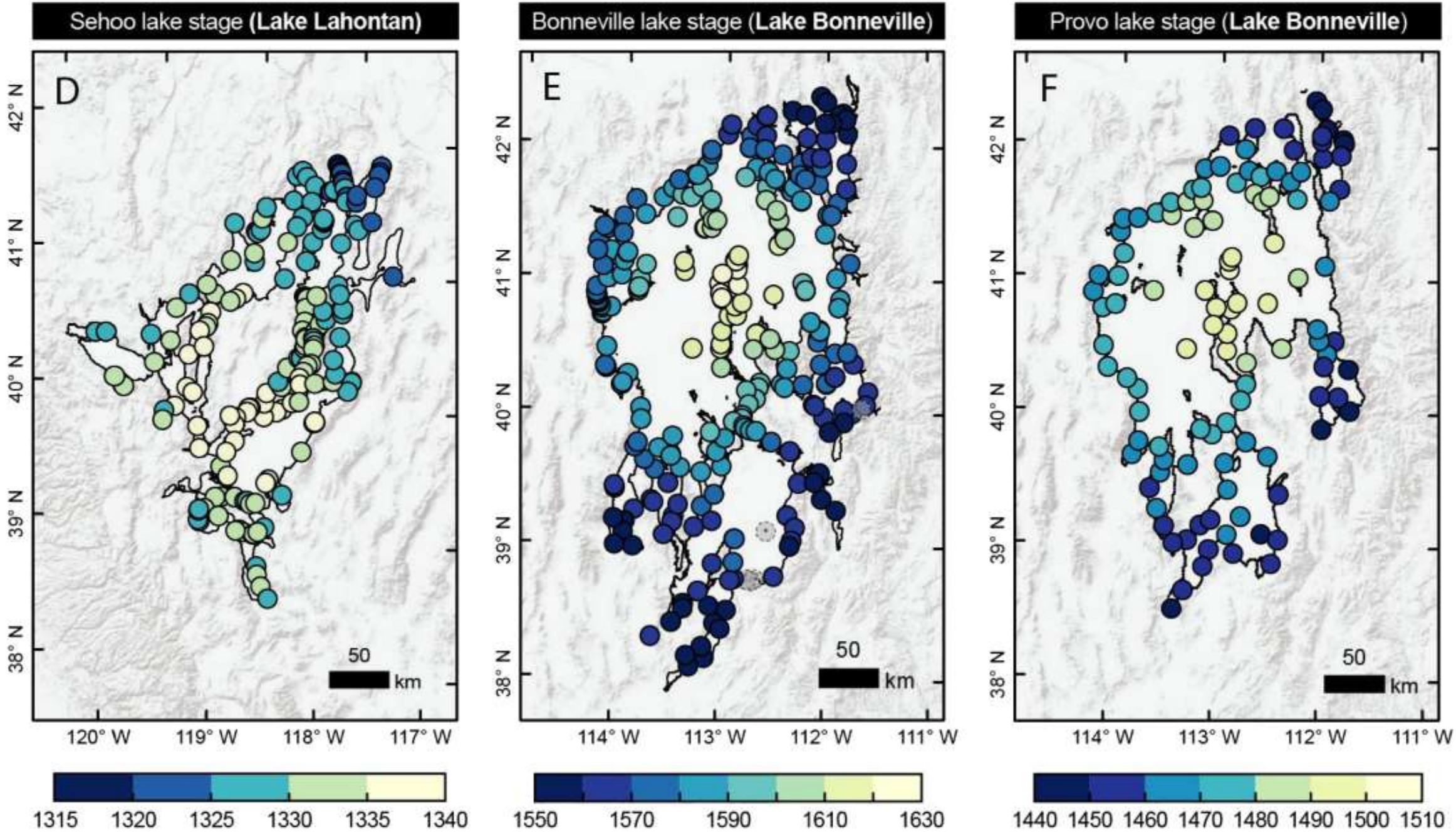

A
Relative topography at 18 ka (m)
100
0
-100
-200
-300
-400
-500
-600
-700
70°N
60°N
50°N
40°N
30°N
135°W
120°W
105°W
90°W
75°W
60°W

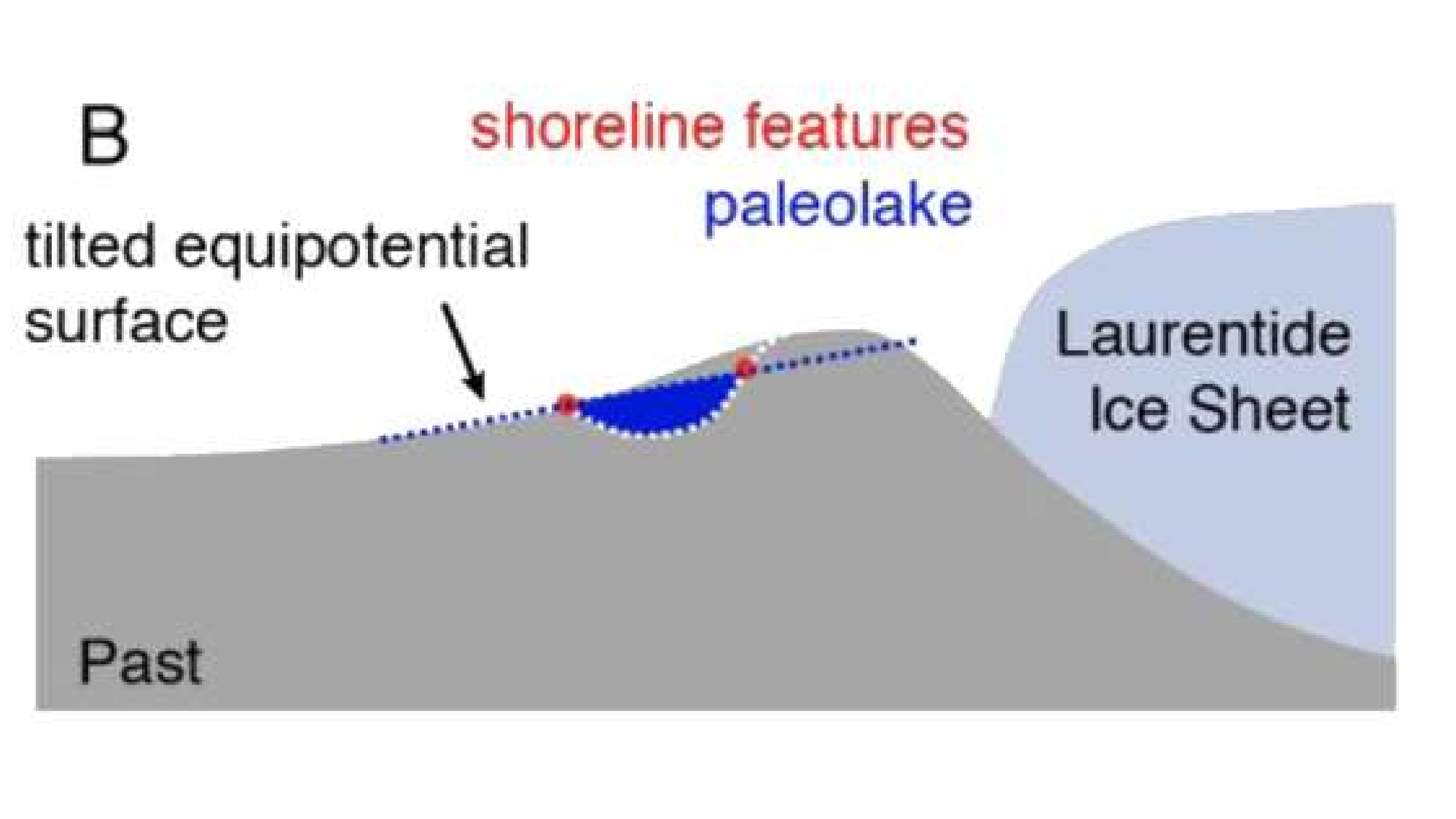

ICE
Lake Bonneville

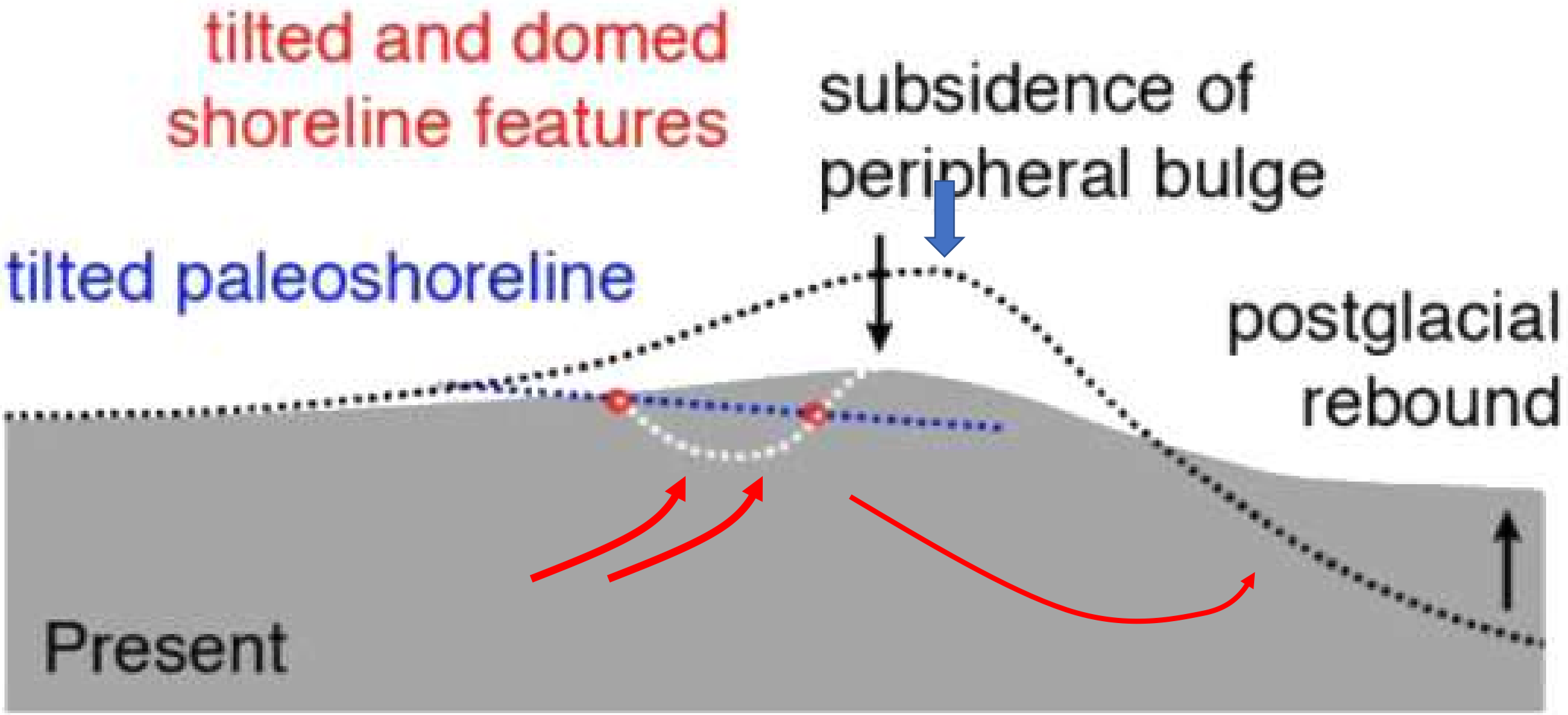
18 ka

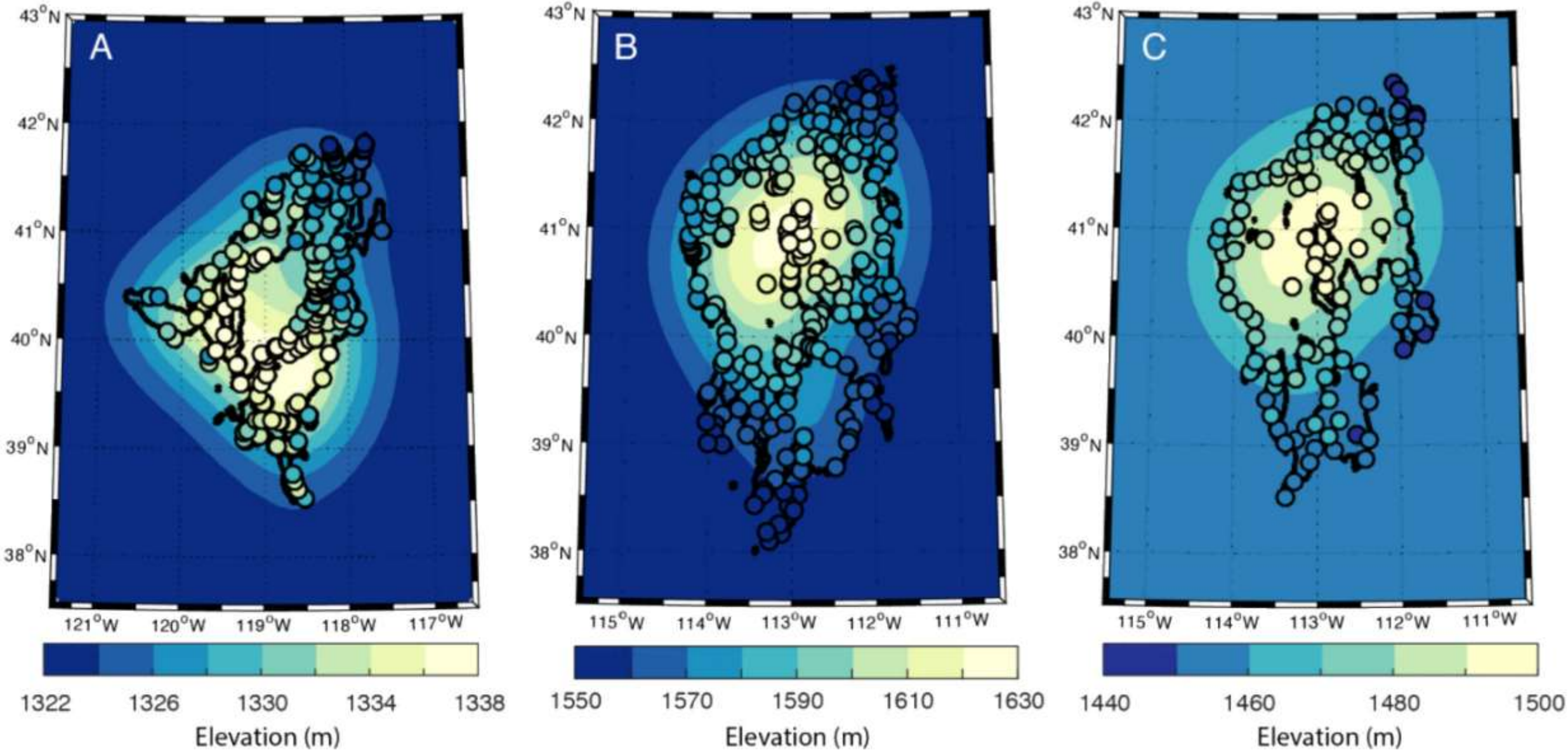
15 ka

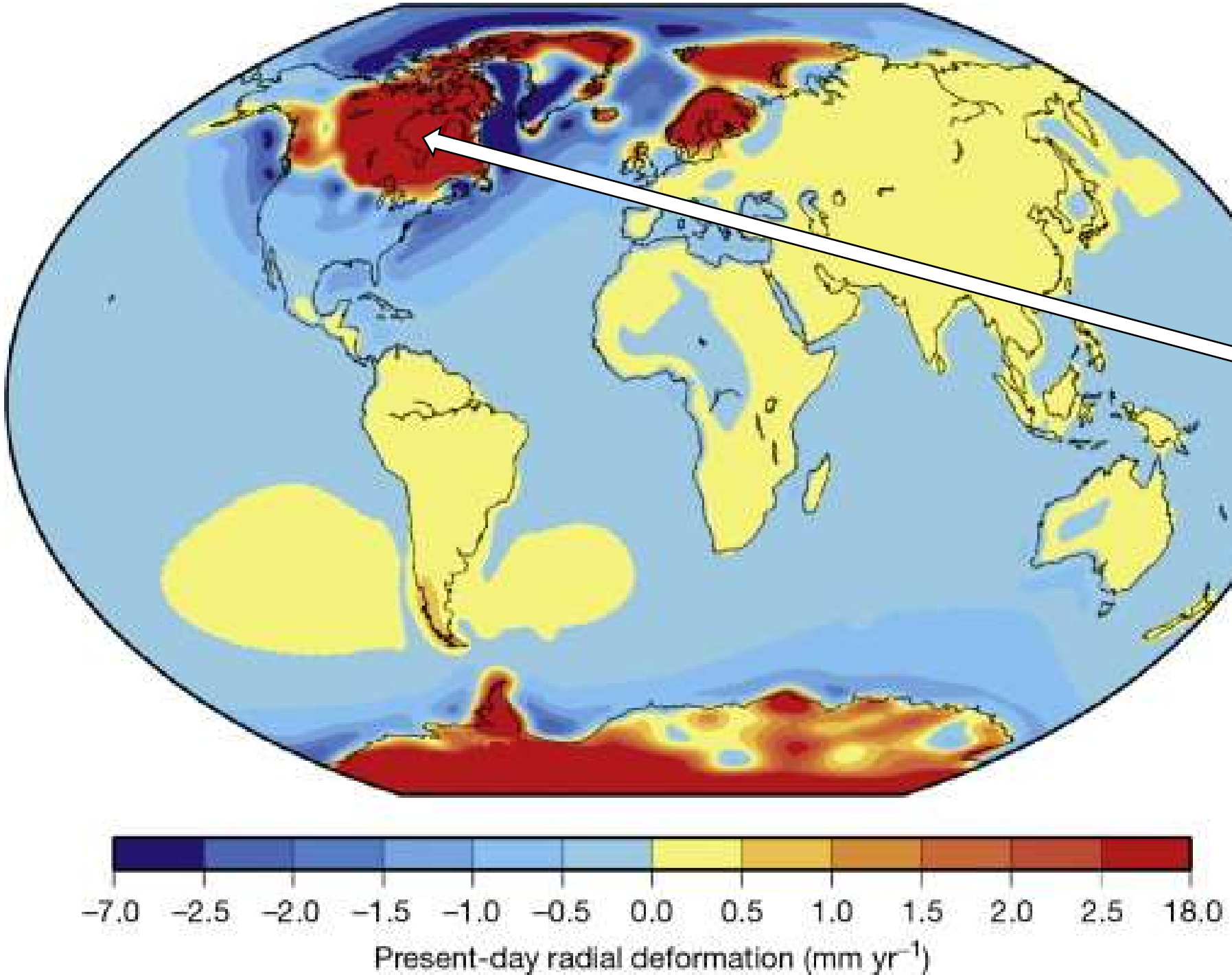
25 ka


Sehoo lake stage (Lake Lahontan)
Bonneville lake stage (Lake Bonneville)
Provo lake stage (Lake Bonneville)
D
E
F
42° N
41° N
40° N
39° N
38° N
50
km
120° W
119° W
118° W
117° W
114° W
113° W
112° W
111° W
1315 1320 1325 1330 1335 1340
1550 1570 1590 1610 1630
1440 1450 1460 1470 1480 1490 1500 1510
Estimate of the SWL Elevation from Shoreline Features (meters above sea level)


B
shoreline features
paleolake
tilted equipotential
surface
Laurentide
Ice Sheet
Past

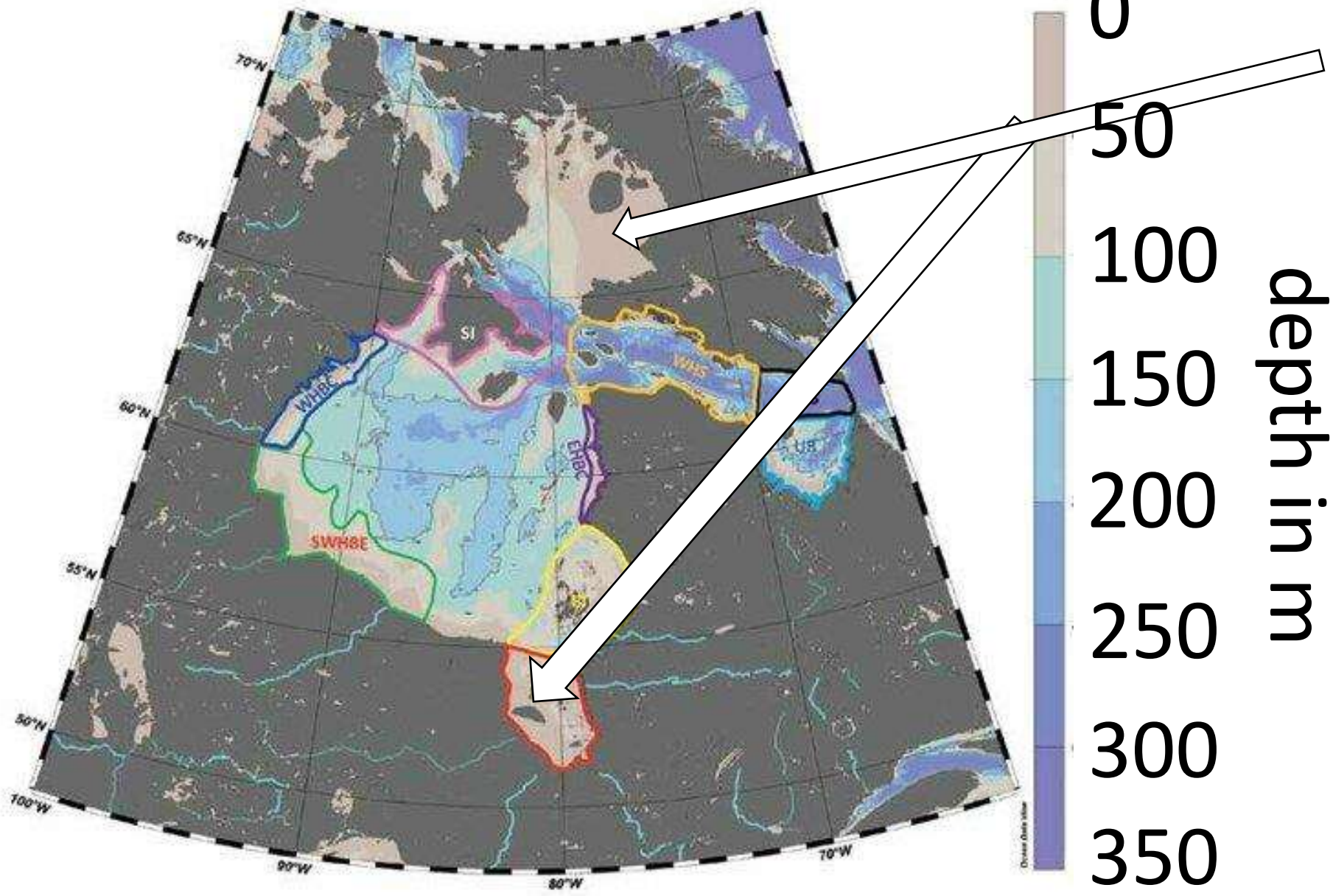

tilted and domed
shoreline features
subsidence of
peripheral bulge
tilted paleoshoreline
postglacial
rebound
Present


A
B
C
43°N
42°N
41°N
40°N
39°N
38°N
121°W
120°W
119°W
118°W
117°W
115°W
114°W
113°W
112°W
111°W
1322
1326
1330
1334
1338
1550
1570
1590
1610
1630
1440
1460
1480
1500
Elevation (m)
Elevation (m)
Elevation (m)



1.8 cm year of uplift

roughly 1 m in 50 years



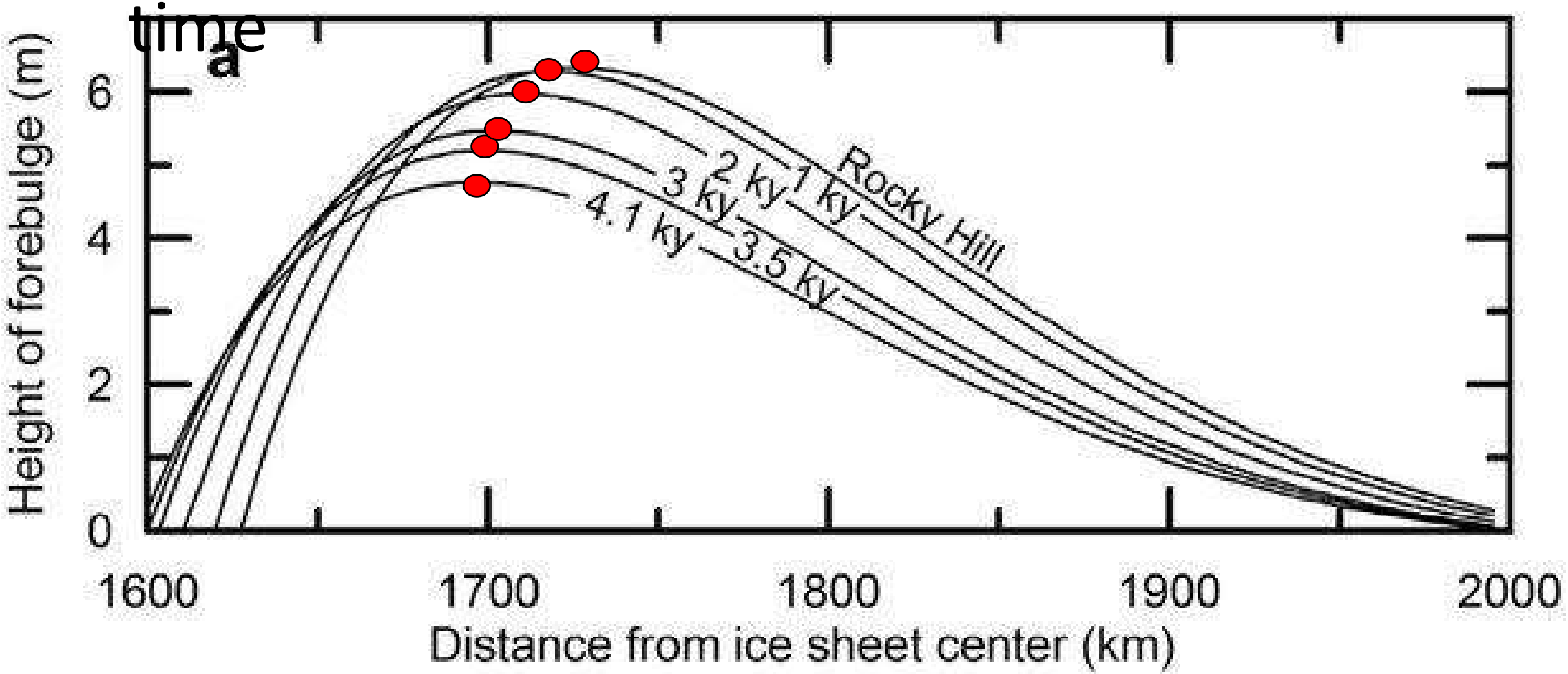
0
50
100
150
200
250
300
350

depth in m

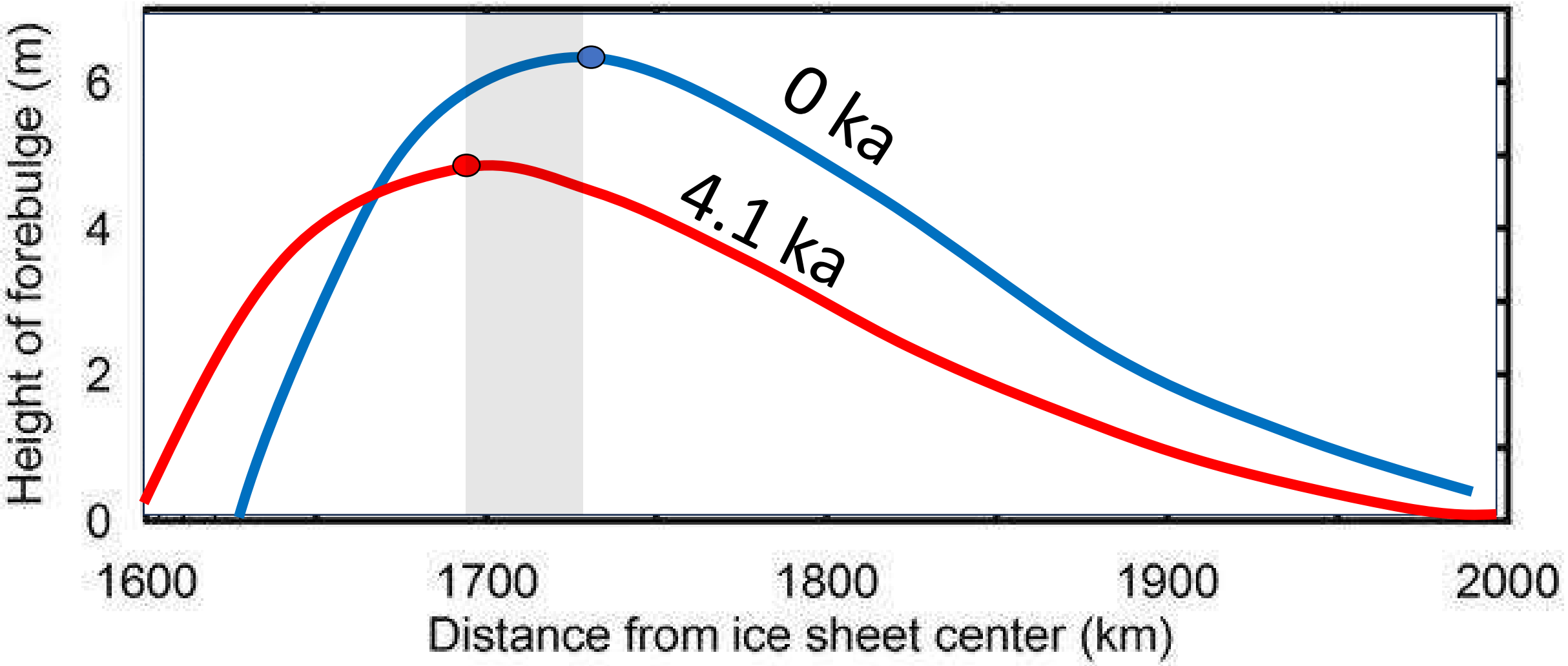
gone in
2500 yrs

position of peak • shifts glacier-ward with time

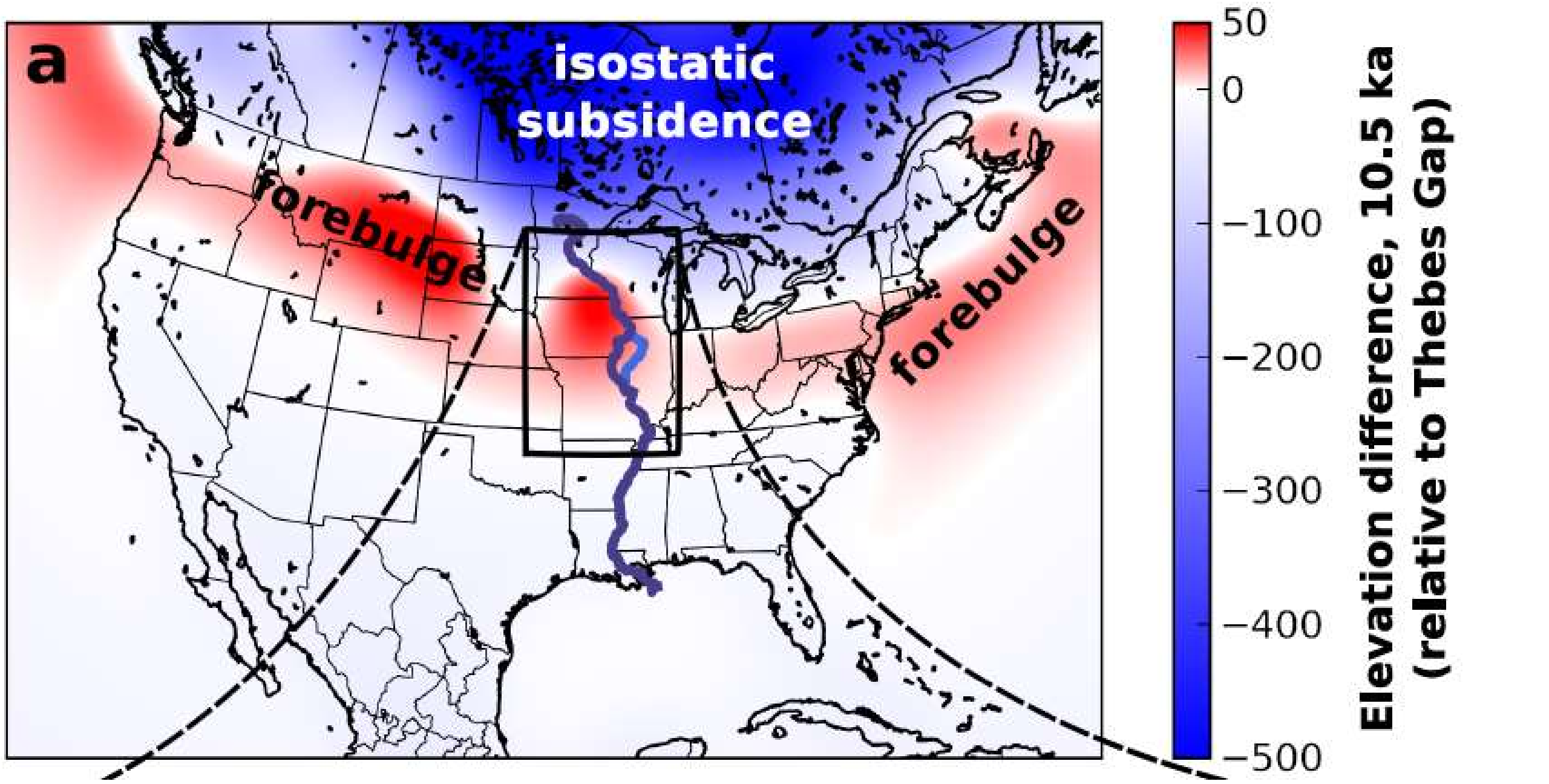
time

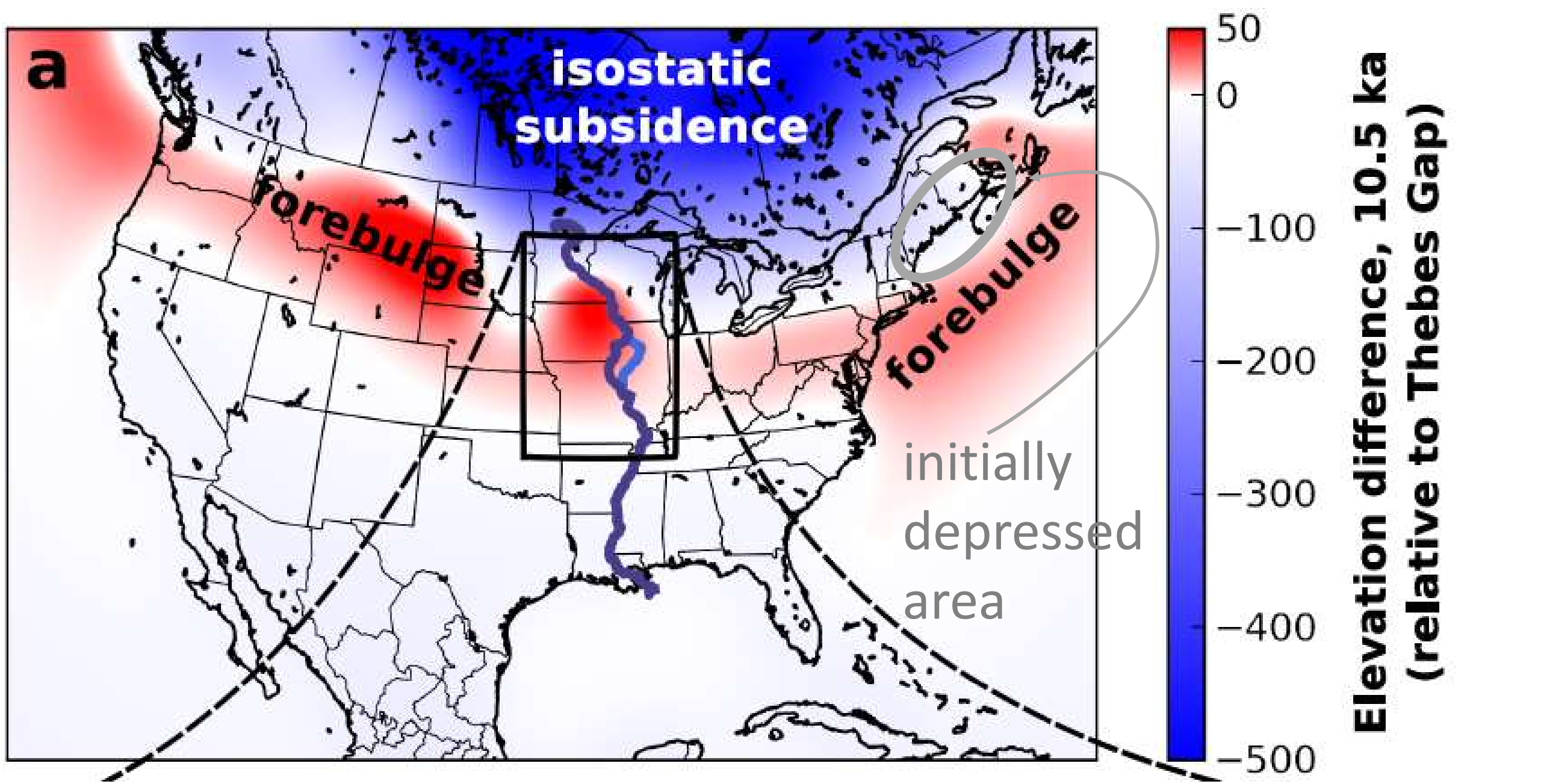


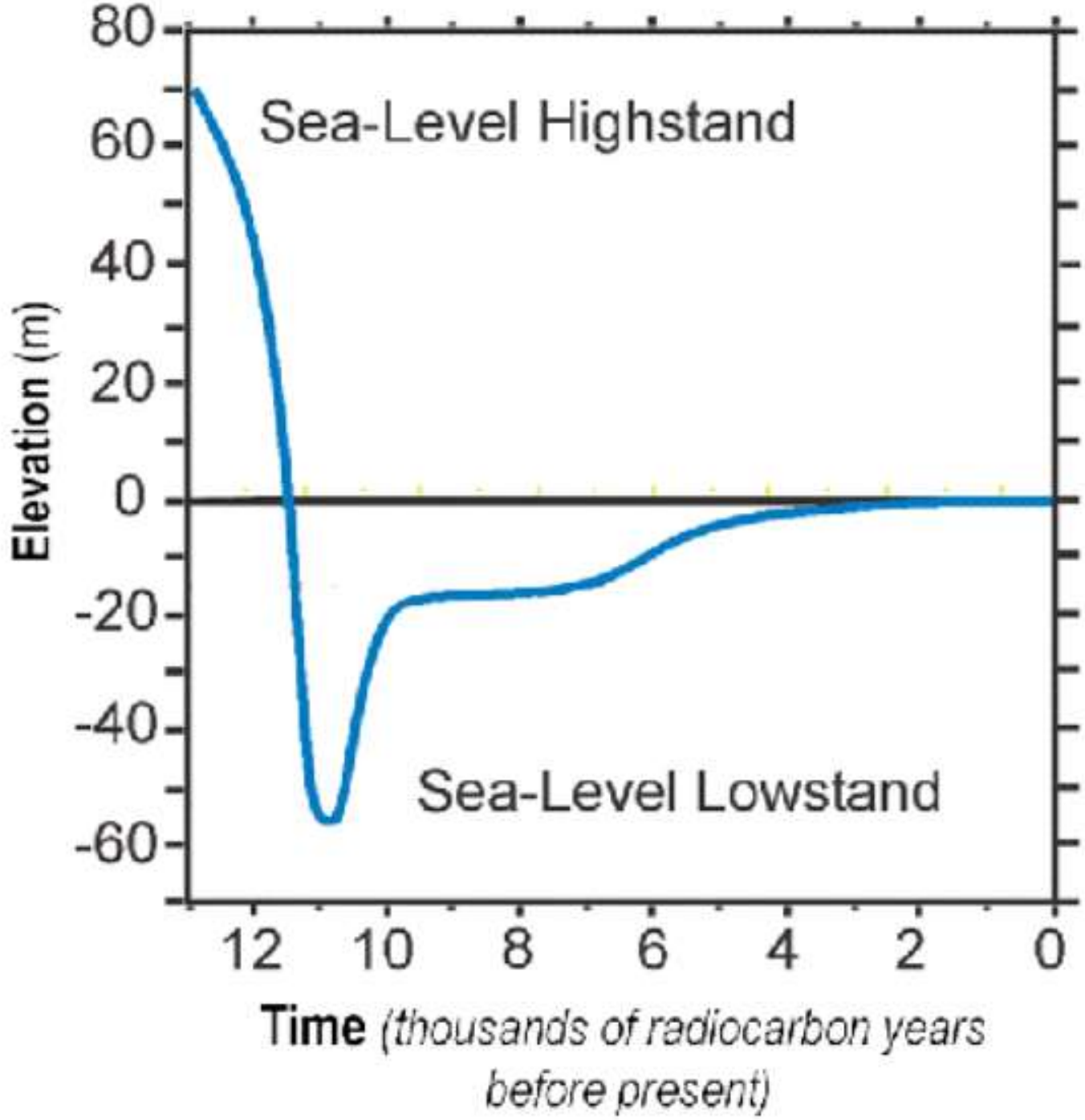
range where slope reverses



rivers could reverse direction

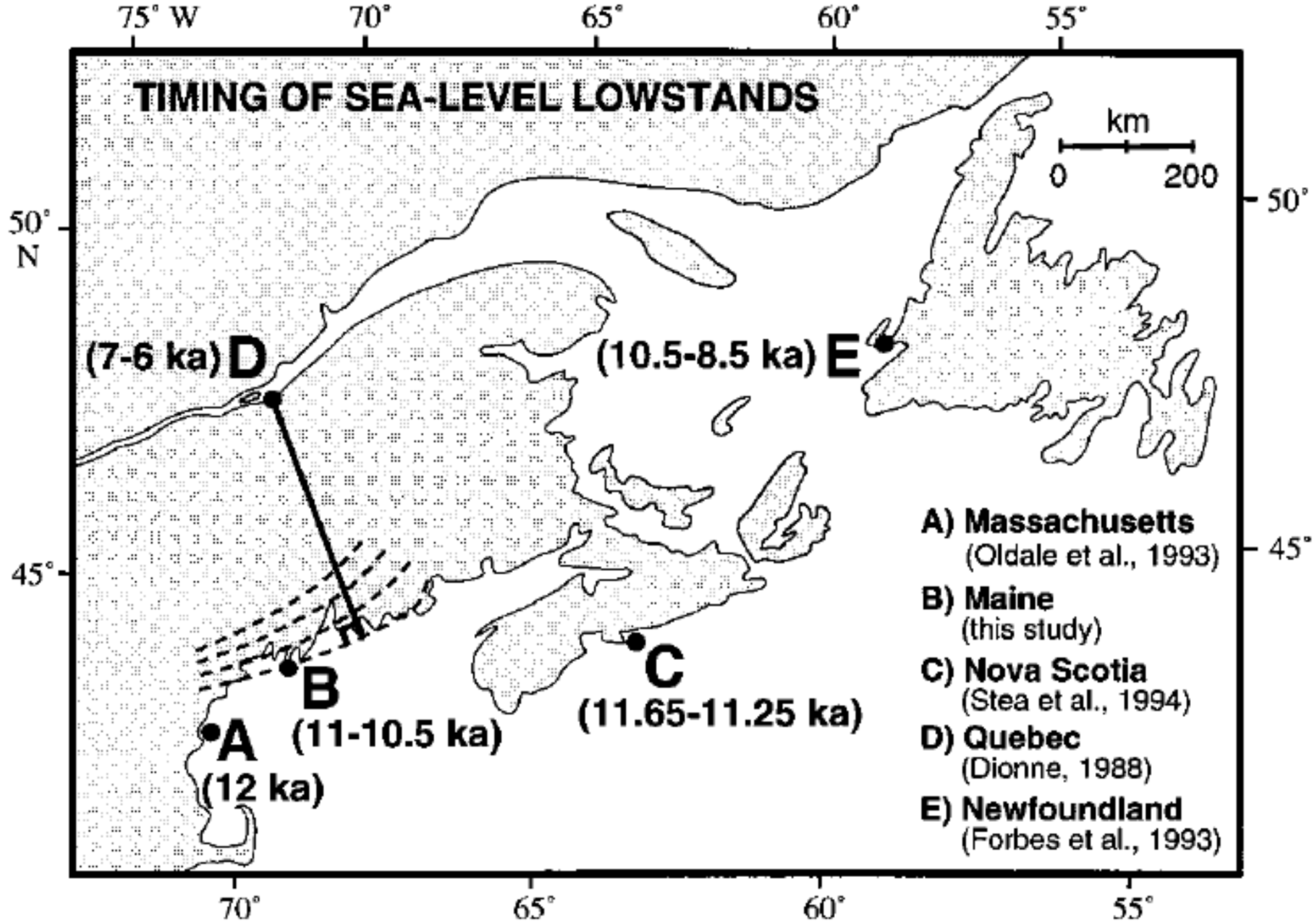

a
isostatic
subsidence
forebulge
forebulge
50
0
−100
−200
−300
−400
−500
Elevation difference, 10.5 ka
(relative to Thebes Gap)

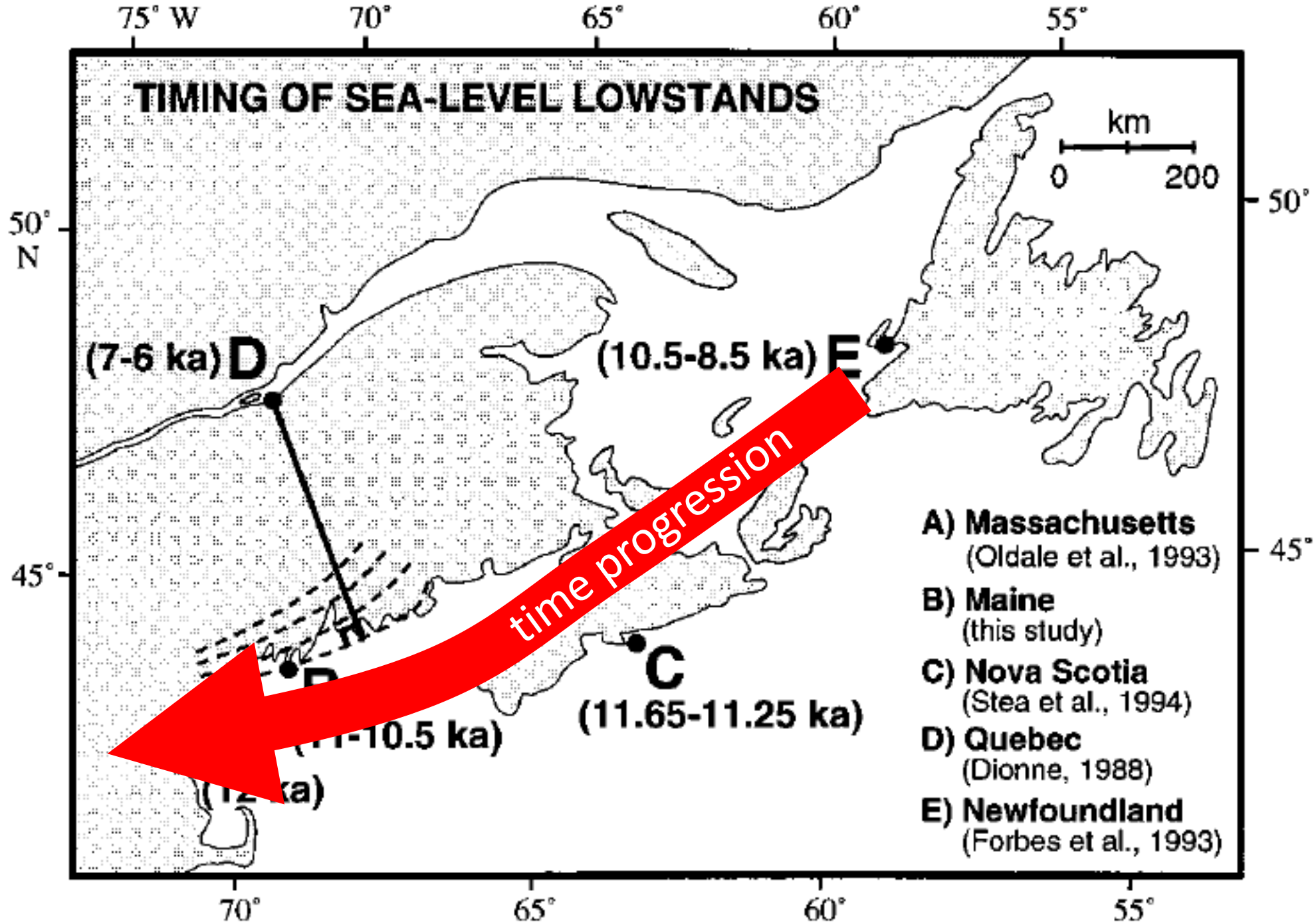

a
isostatic subsidence
forebulge
forebulge
initially depressed area
50
0
−100
−200
−300
−400
−500
Elevation difference, 10.5 ka (relative to Thebes Gap)


80
60
40
20
0
-20
-40
-60
Elevation (m)
Sea-Level Highstand
Sea-Level Lowstand
12
10
8
6
4
2
0
Time (thousands of radiocarbon years before present)

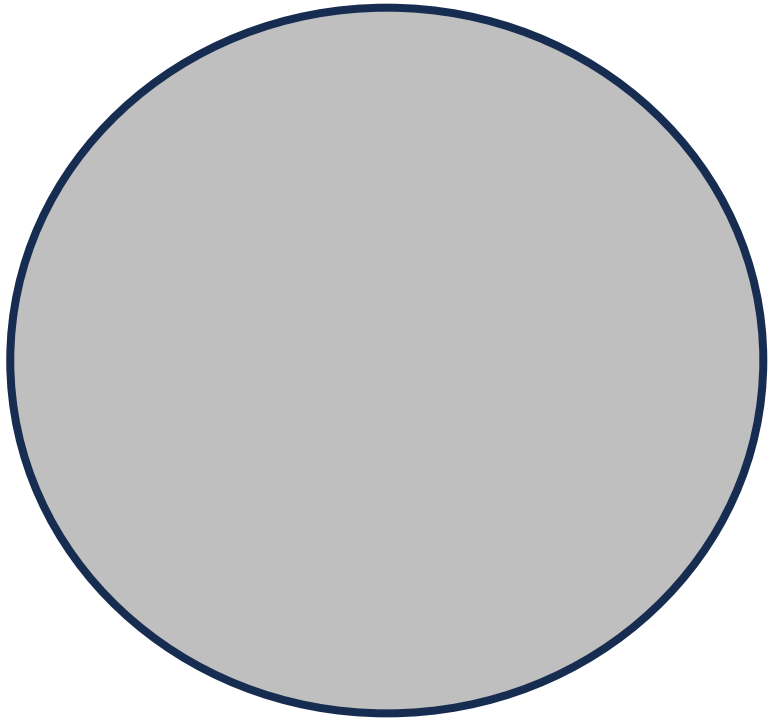
glacial marine sediments in Maine

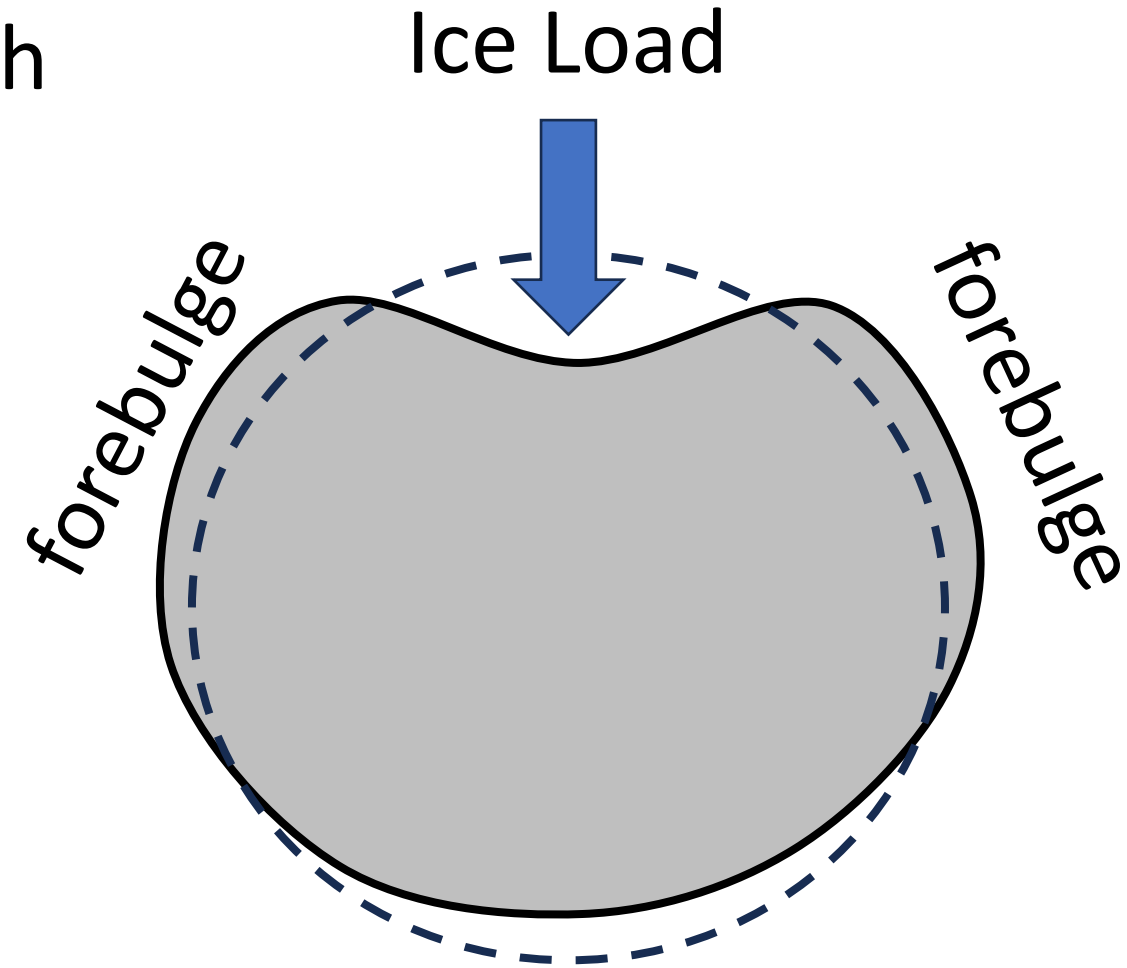
drop-stones?

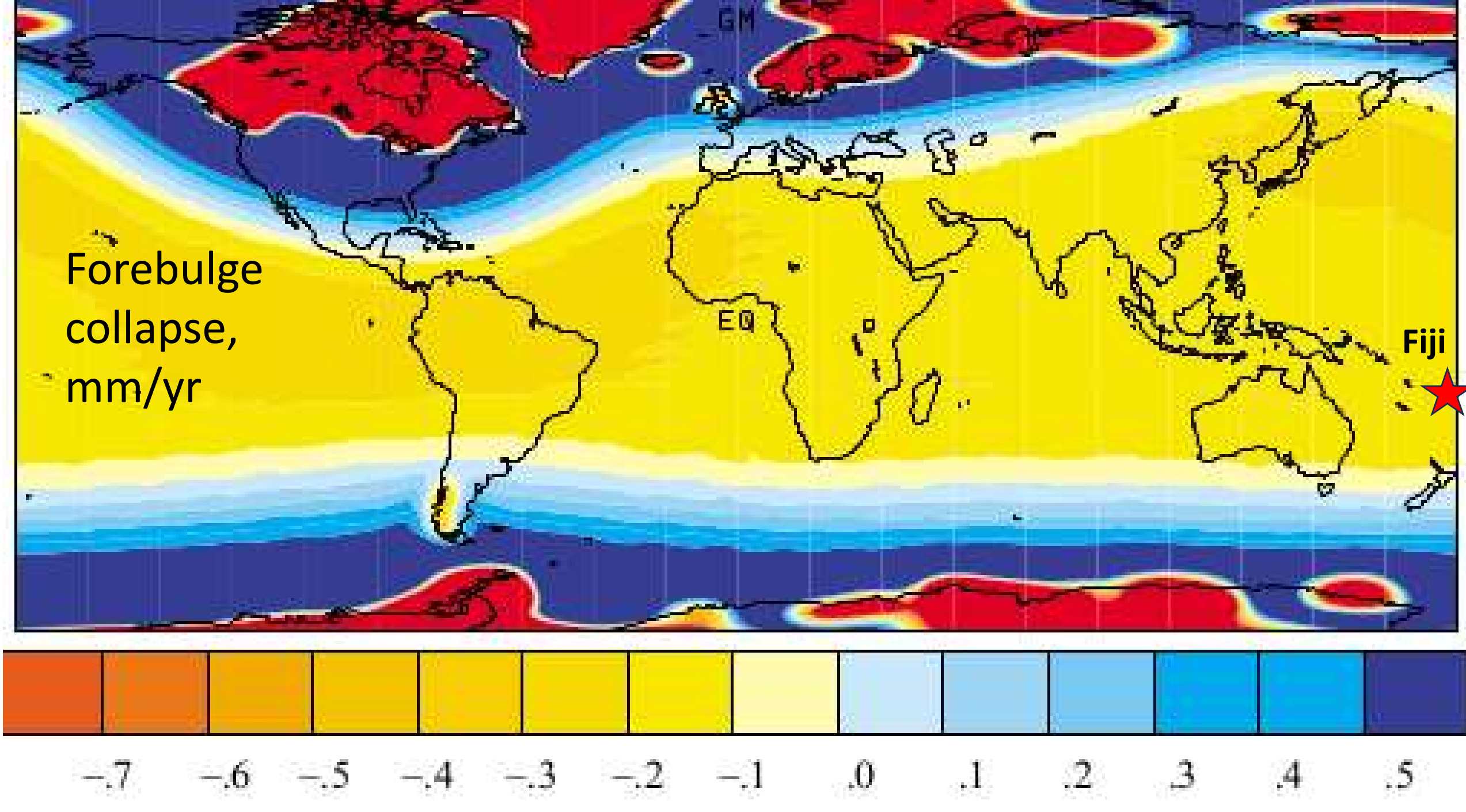

TIMING OF SEA-LEVEL LOWSTANDS
75° W
70°
65°
60°
55°
50° N
45°
km
0
200
(7-6 ka) D
(10.5-8.5 ka) E
B
(11-10.5 ka)
A
(12 ka)
C
(11.65-11.25 ka)
A) Massachusetts
(Oldale et al., 1993)
B) Maine
(this study)
C) Nova Scotia
(Stea et al., 1994)
D) Quebec
(Dionne, 1988)
E) Newfoundland
(Forbes et al., 1993)


TIMING OF SEA-LEVEL LOWSTANDS
75° W
70°
65°
60°
55°
50° N
45°
km
0
200
(7-6 ka) D
(10.5-8.5 ka) E
time progression
C
(11.65-11.25 ka)
A) Massachusetts
(Oldale et al., 1993)
B) Maine
(this study)
C) Nova Scotia
(Stea et al., 1994)
D) Quebec
(Dionne, 1988)
E) Newfoundland
(Forbes et al., 1993)

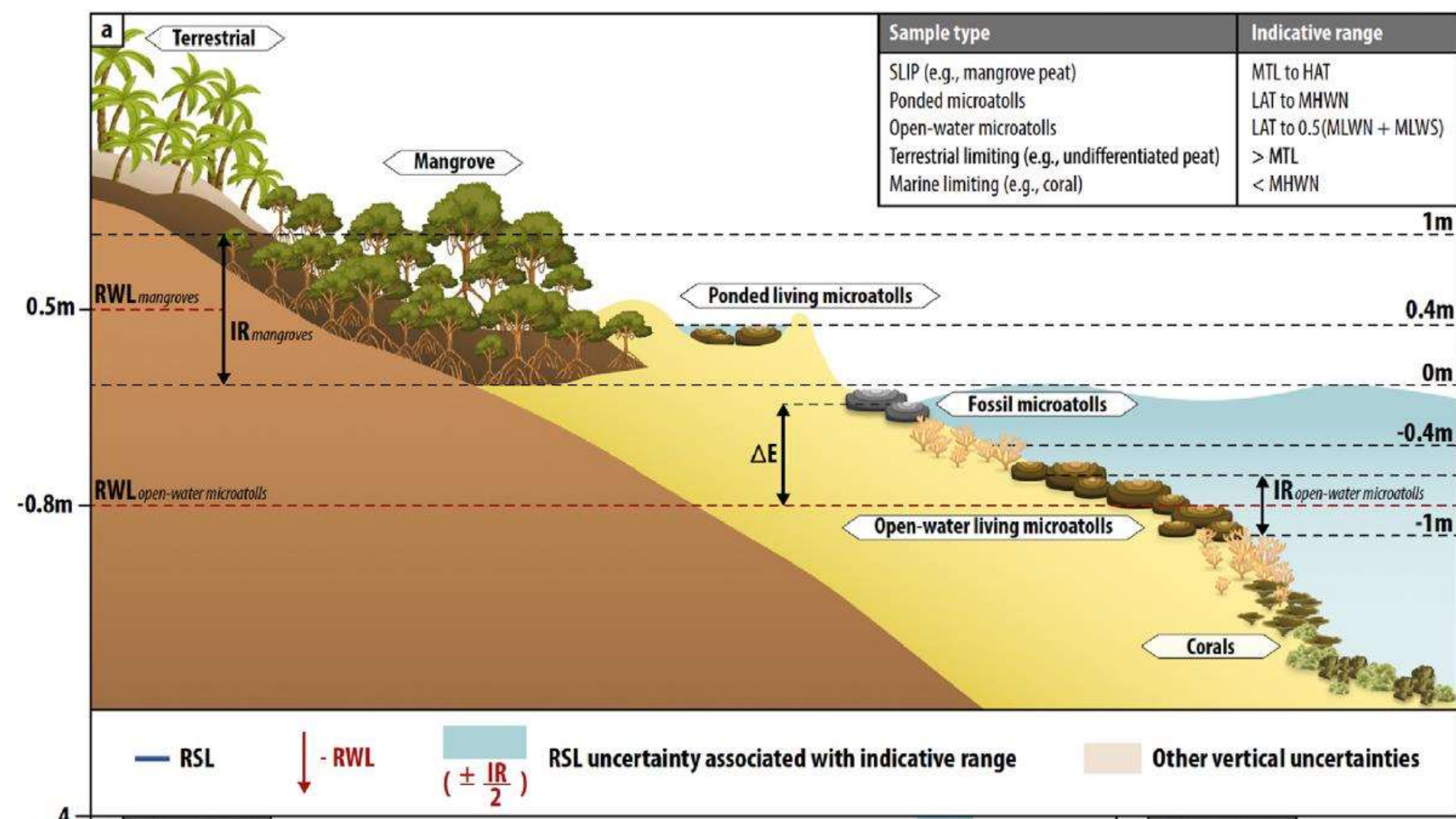
forebulge on a spherical earth

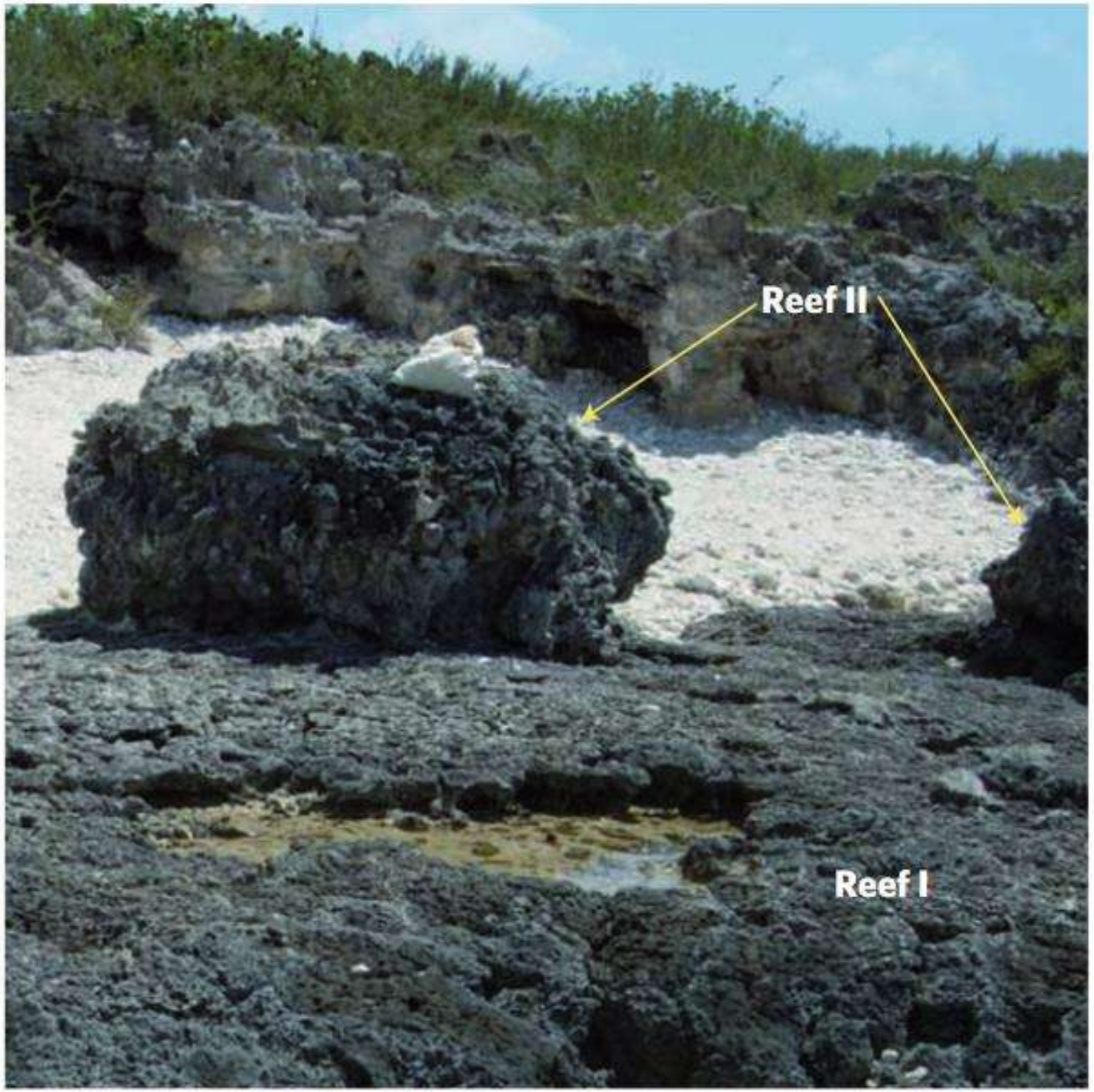





GM
EQ
Fiji
Forebulge collapse, mm/yr
−.7
−.6
−.5
−.4
−.3
−.2
−.1
.0
.1
.2
.3
.4
.5

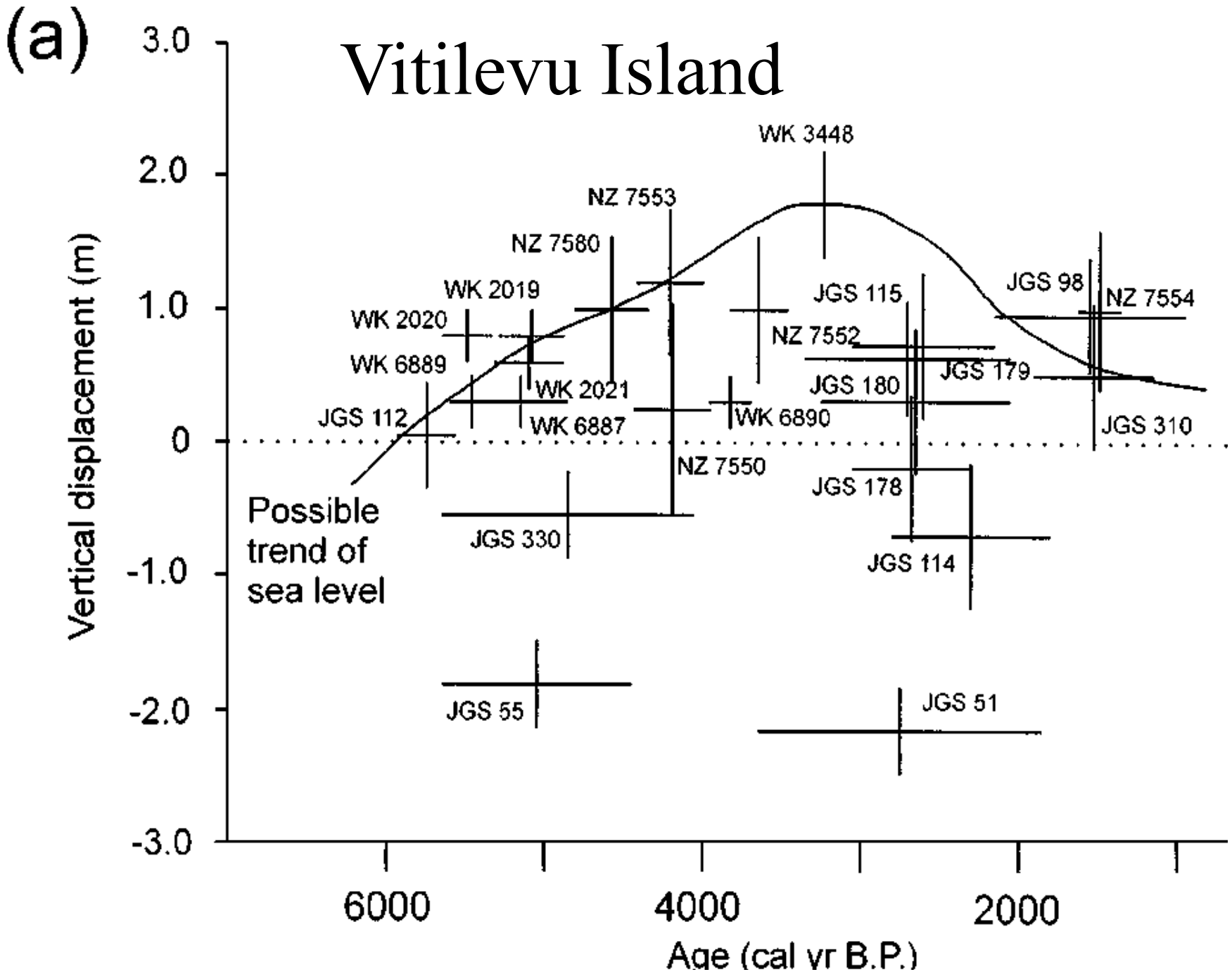

Vitilevu Island, Fiji

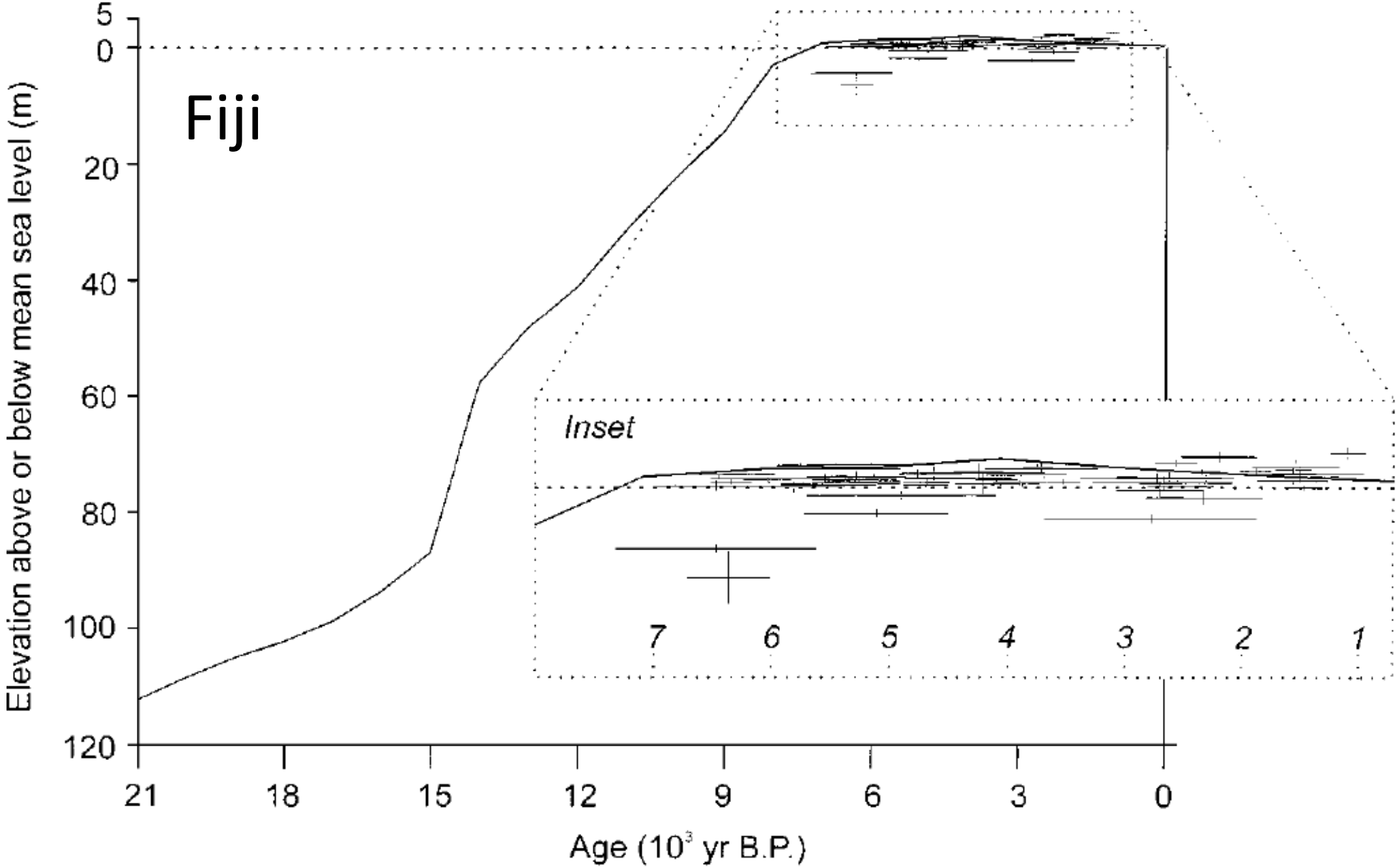

a
Terrestrial
Mangrove
Ponded living microatolls
Fossil microatolls
Open-water living microatolls
Corals
RWL mangroves
IR mangroves
RWL open-water microatolls
IR open-water microatolls
ΔE
1m
0.5m
0.4m
0m
-0.4m
-0.8m
-1m
Sample type
Indicative range
SLIP (e.g., mangrove peat)
MTL to HAT
Ponded microatolls
LAT to MHWN
Open-water microatolls
LAT to 0.5(MLWN + MLWS)
Terrestrial limiting (e.g., undifferentiated peat)
> MTL
Marine limiting (e.g., coral)
< MHWN
RSL
- RWL
(± IR/2)
RSL uncertainty associated with indicative range
Other vertical uncertainties

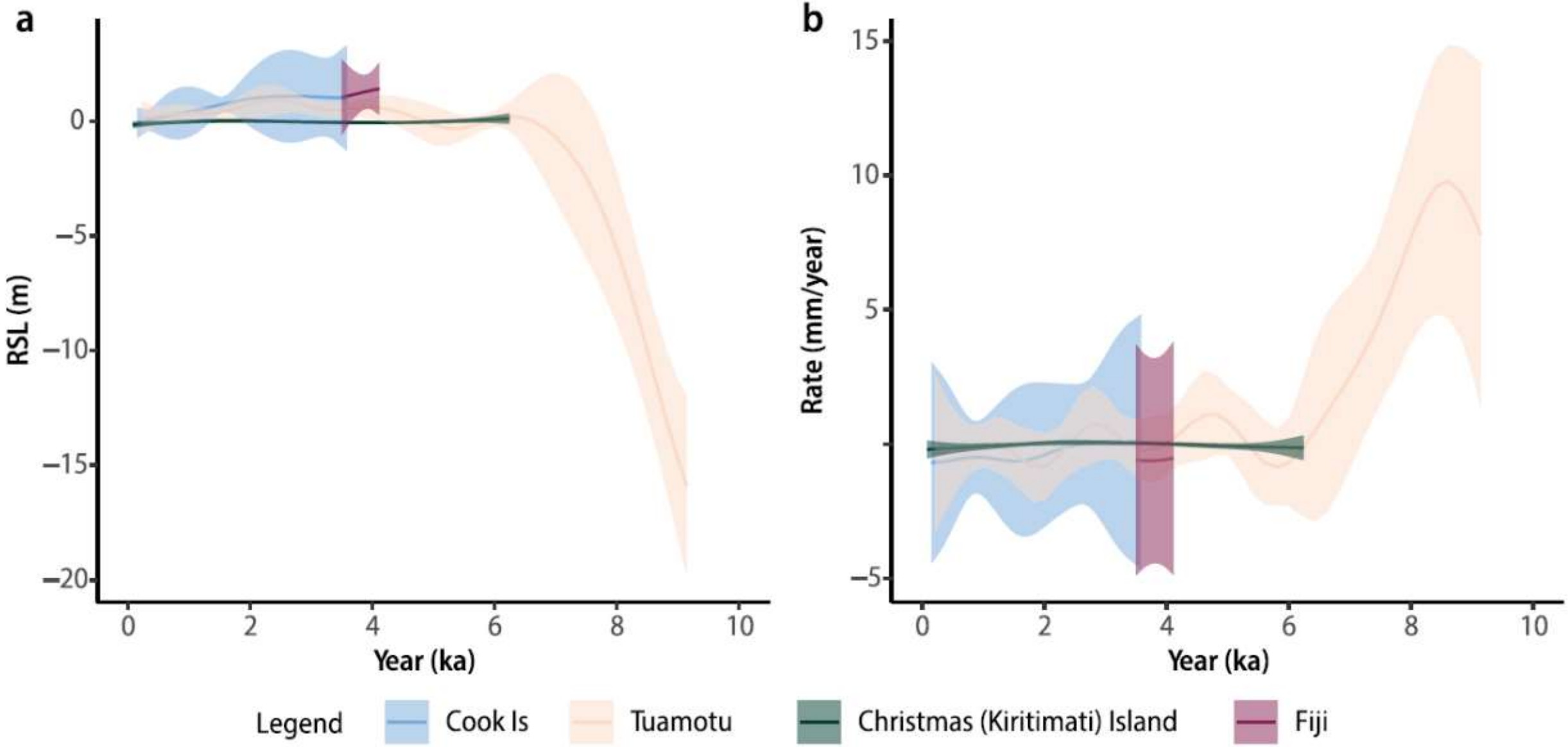


Reef 1: Modern coral

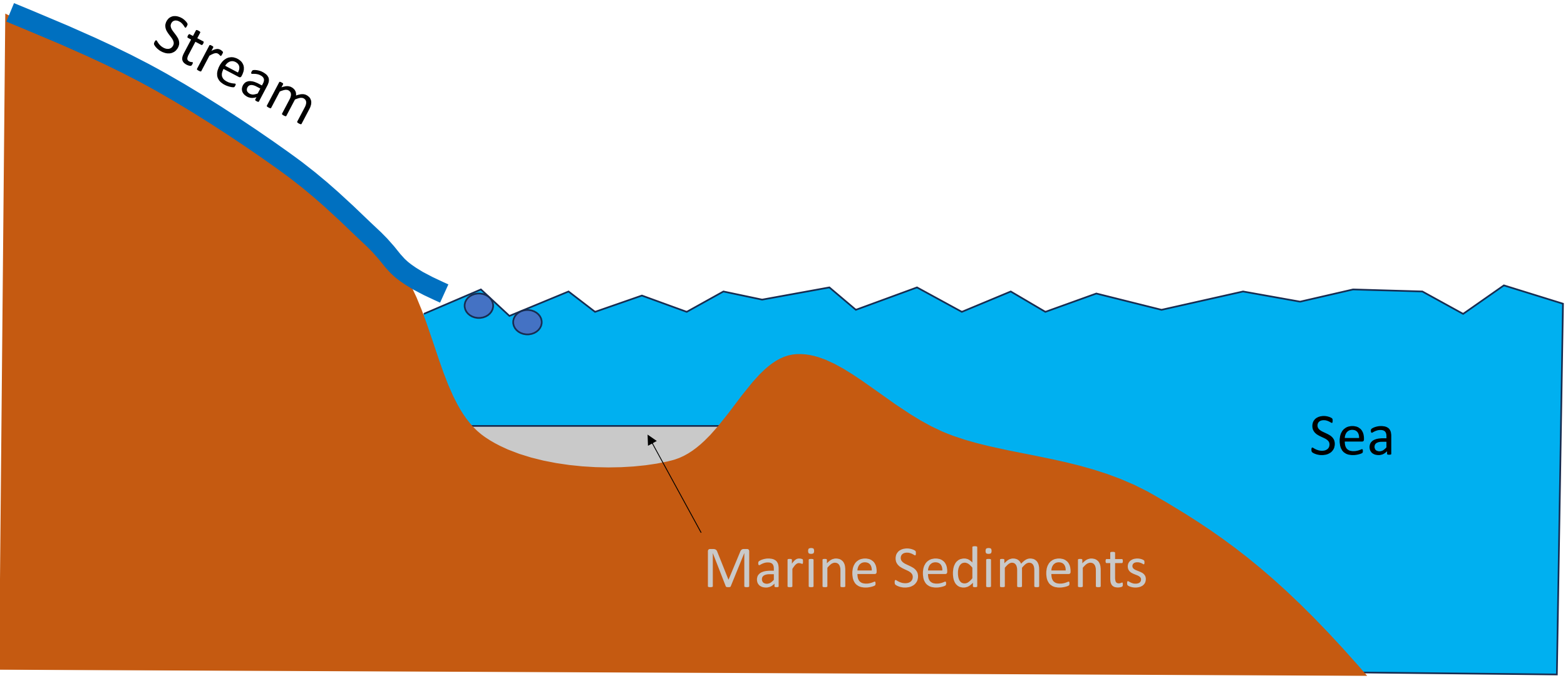
Reef 2: coral from a period of higher sea level


(a)
Vitilevu Island
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
Vertical displacement (m)
6000
4000
2000
Age (cal yr B.P.)
Possible trend of sea level
WK 3448
NZ 7553
NZ 7580
WK 2019
WK 2020
WK 6889
WK 2021
JGS 112
WK 6887
NZ 7550
JGS 330
JGS 55
WK 6890
JGS 115
NZ 7552
JGS 180
JGS 179
JGS 98
NZ 7554
JGS 310
JGS 178
JGS 114
JGS 51

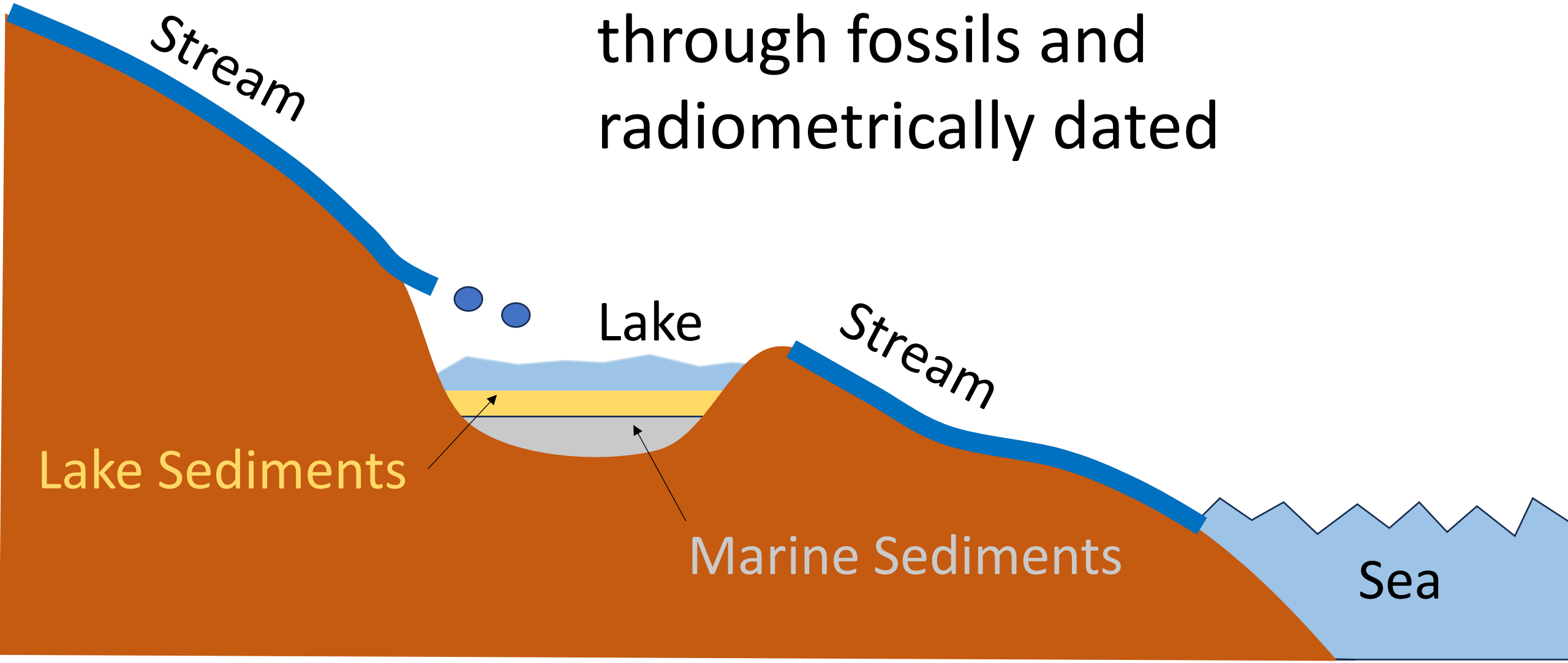

Fiji
Inset
Elevation above or below mean sea level (m)
5
0
20
40
60
80
100
120
21
18
15
12
9
6
3
0
Age (10^3 yr B.P.)
7
6
5
4
3
2
1

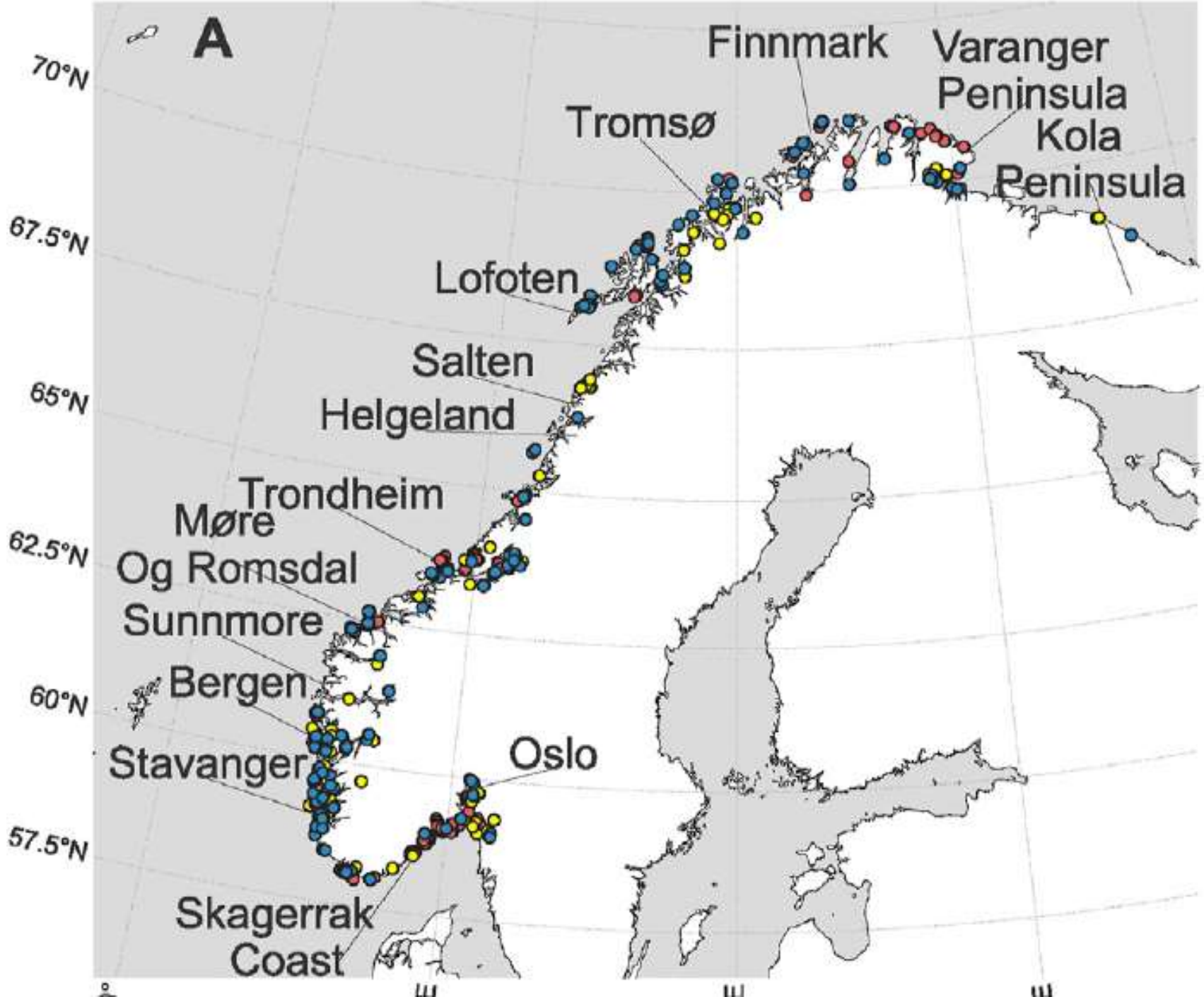

a
b
RSL (m)
0
−5
−10
−15
−20
Rate (mm/year)
15
10
5
−5
0
2
4
6
8
10
Year (ka)
Year (ka)
Legend
Cook Is
Tuamotu
Christmas (Kiritimati) Island
Fiji

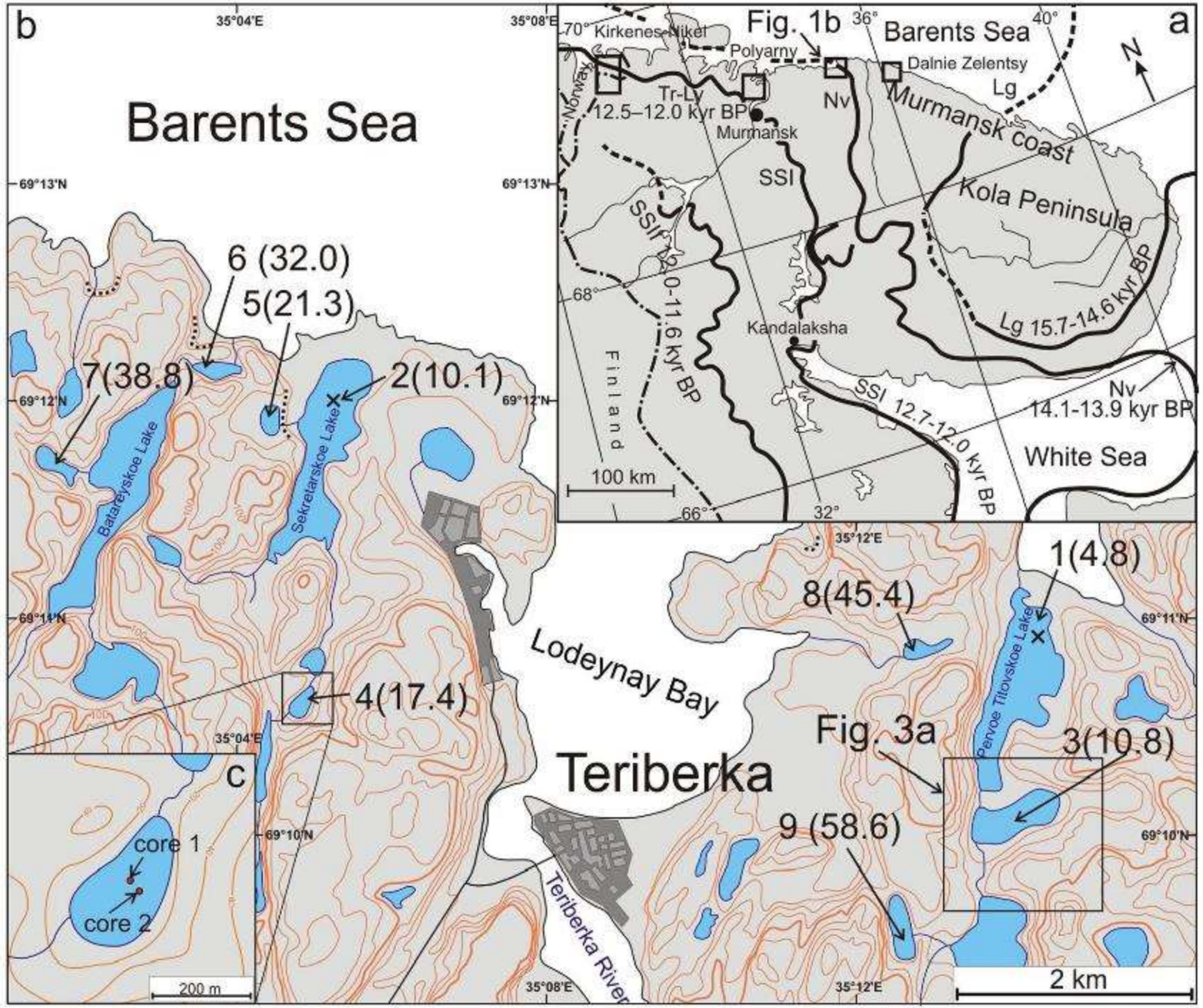
Isolation Basin

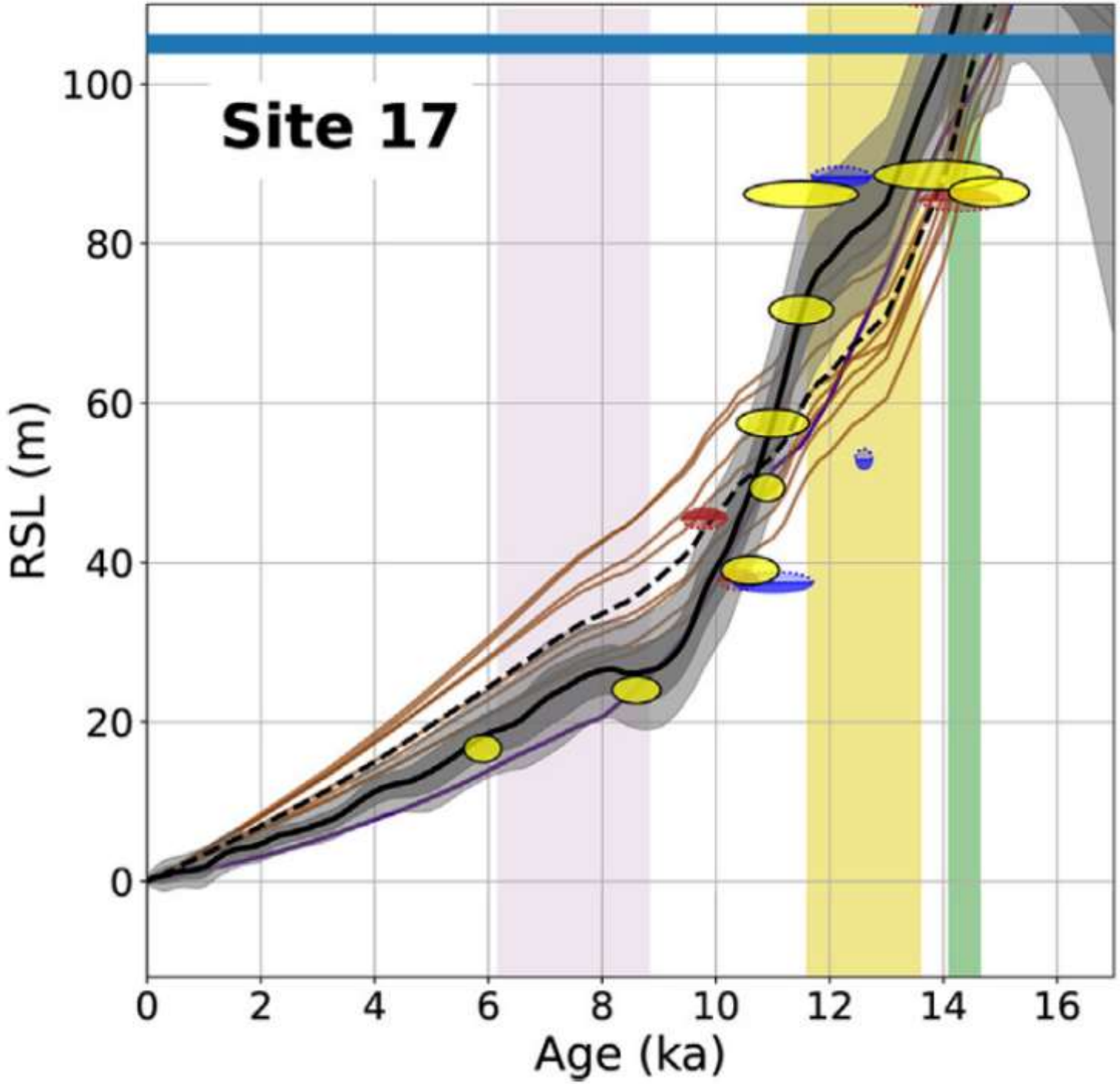


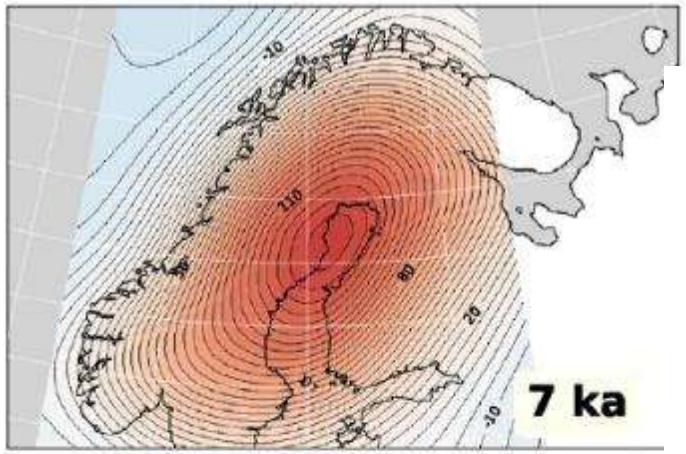
sediment transition recognized through fossils and radiometrically dated

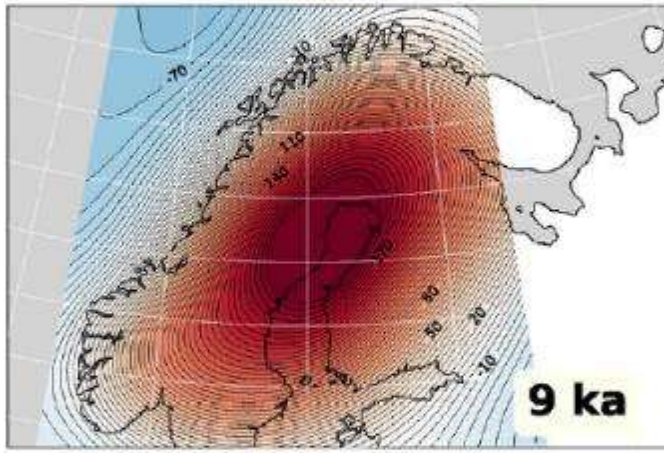


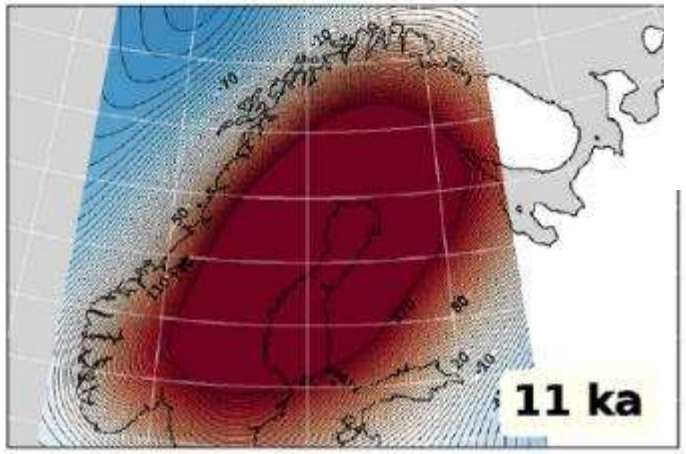

A
Finnmark
Varanger
Peninsula
Kola
Peninsula
Tromsø
Lofoten
Salten
Helgeland
Trondheim
Møre
Og Romsdal
Sunnmore
Bergen
Stavanger
Oslo
Skagerrak
Coast
70°N
67.5°N
65°N
62.5°N
60°N
57.5°N

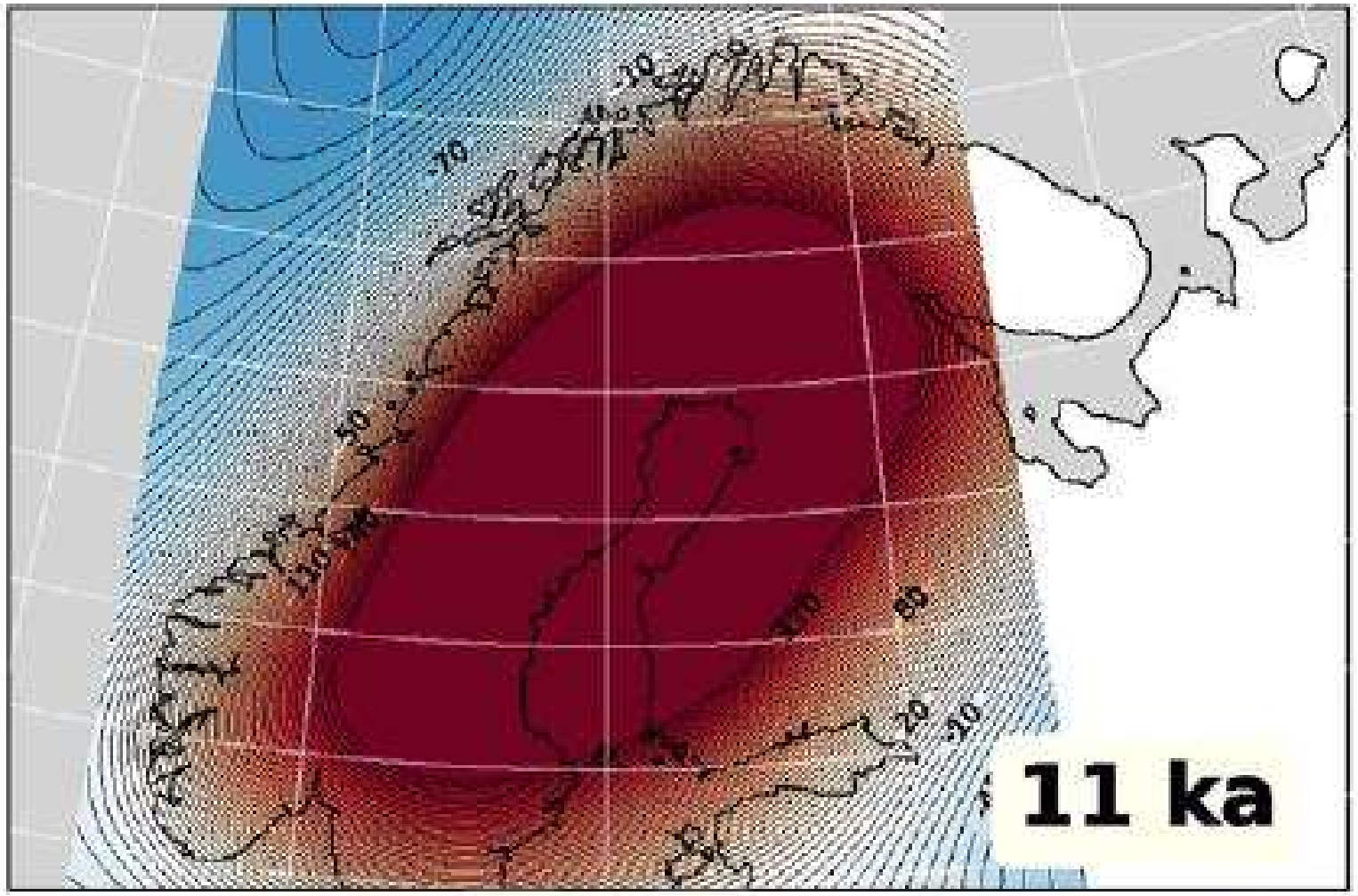

b
Barents Sea
35°04'E
35°08'E
69°13'N
69°12'N
69°14'N
69°11'N
69°10'N
6 (32.0)
5(21.3)
7(38.8)
2(10.1)
4(17.4)
Batareyskoe Lake
Sekretarskoe Lake
Lodeynay Bay
Teriberka
Teriberka River
8(45.4)
1(4.8)
Pervoe Titovskoe Lake
Fig. 3a
3(10.8)
9 (58.6)
35°12'E
2 km
c
core 1
core 2
200 m
a
Fig. 1b
Barents Sea
Kirkenes-Nikel
Polyarny
Dalnie Zelentsy
Lg
Tr-Ly
12.5–12.0 kyr BP
Murmansk
Nv
Murmansk coast
Kola Peninsula
SSI
SSI 12.0-11.6 kyr BP
Lg 15.7-14.6 kyr BP
Kandalaksha
Finland
Norway
SSI 12.7-12.0 kyr BP
Nv
14.1-13.9 kyr BP
White Sea
100 km
70°
68°
66°
36°
40°
32°
N


Site 17
RSL (m)
Age (ka)
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16









−160 −120 −80 −40 0 40 80 120 160

RSL (m)