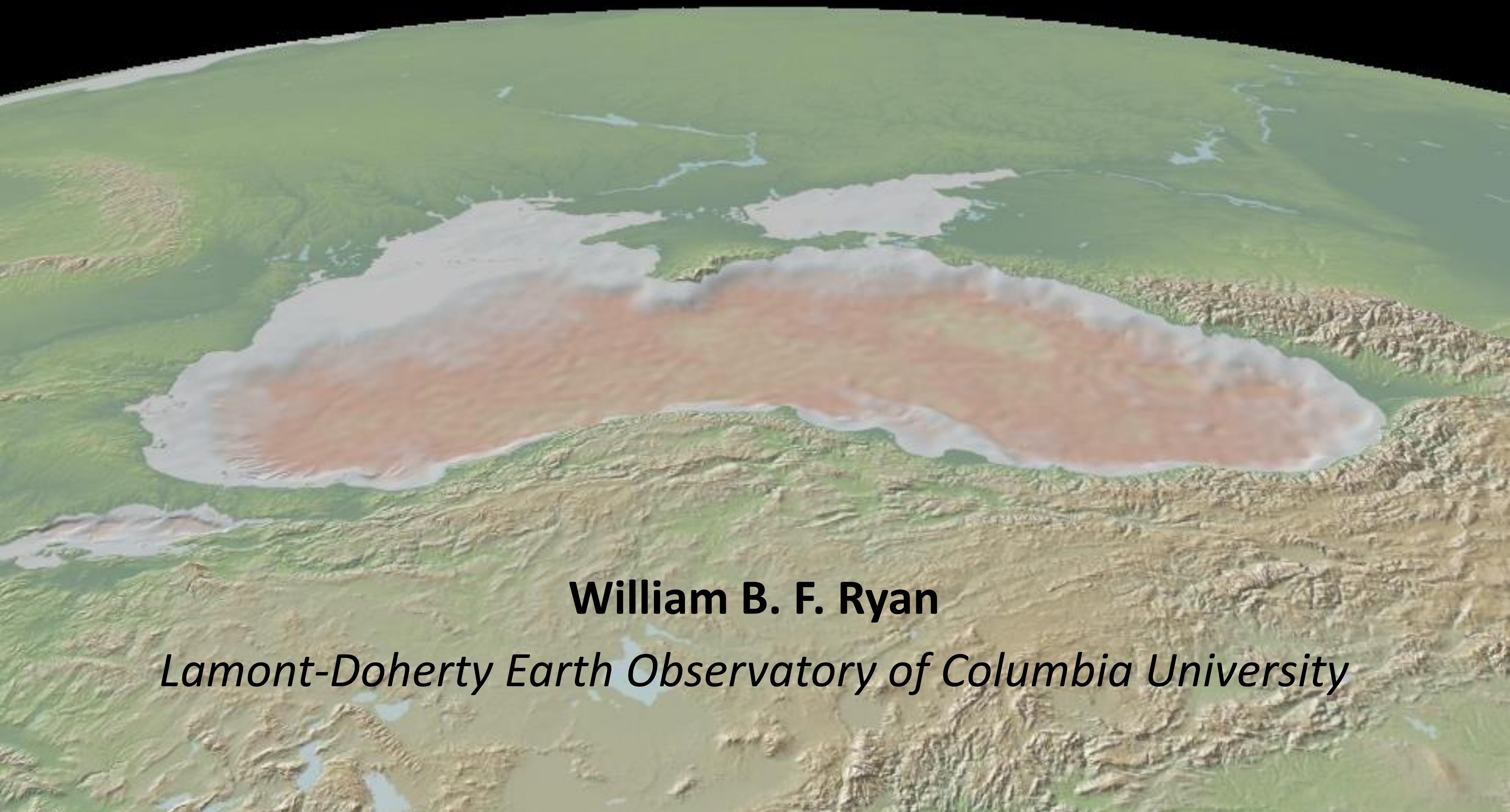
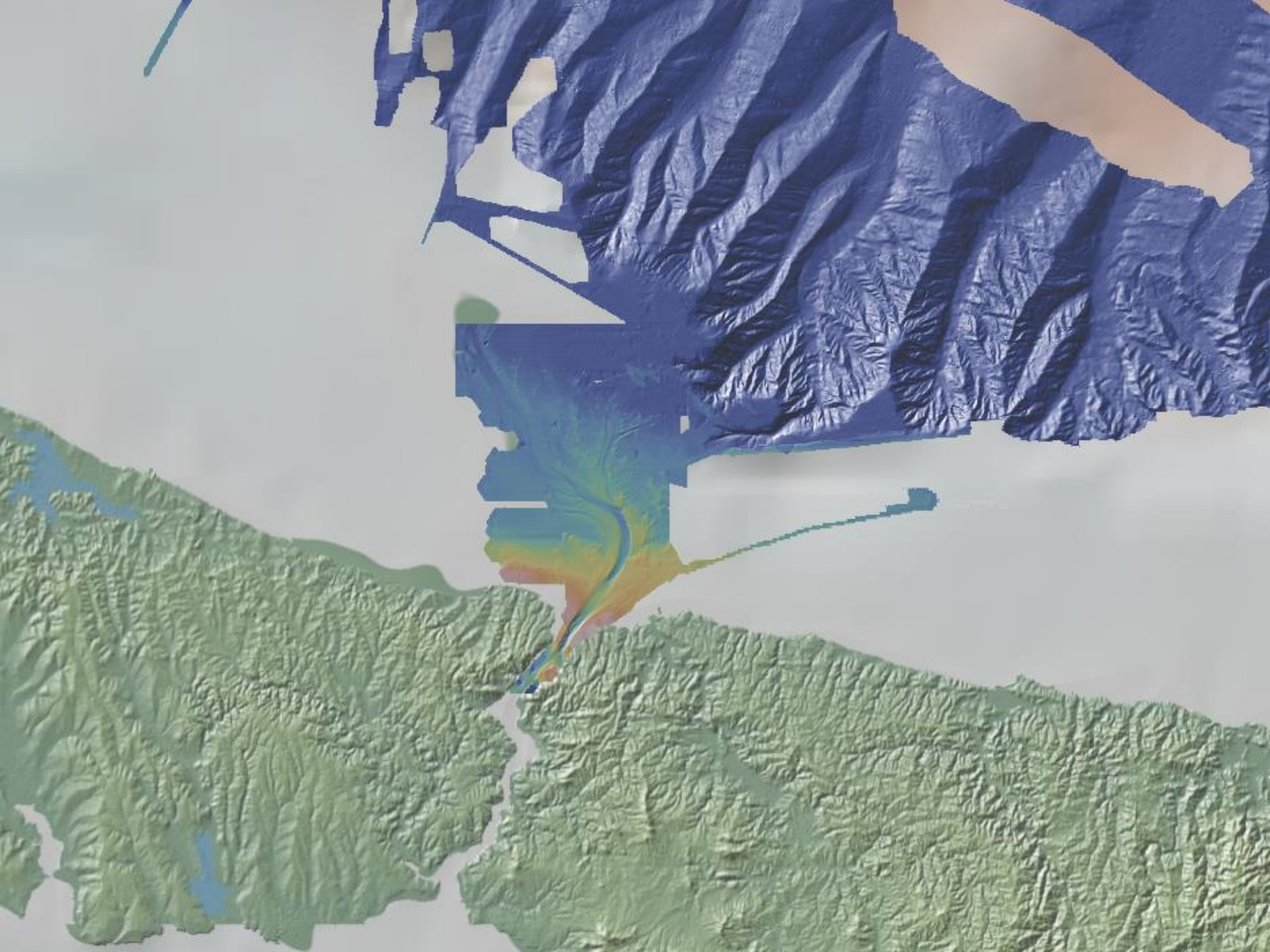
ENGINEERING FOR THE BLACK SEA FUTURE

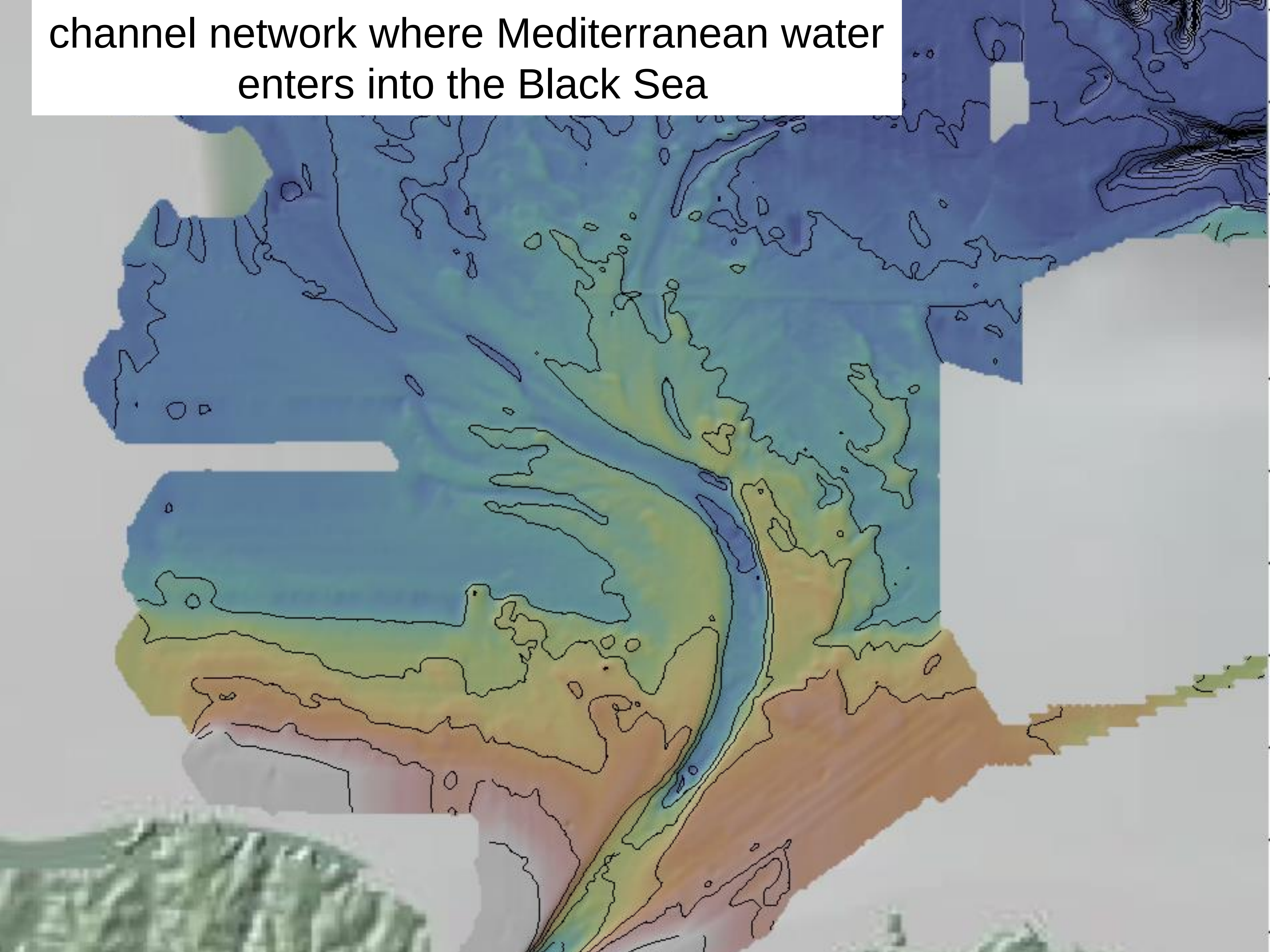


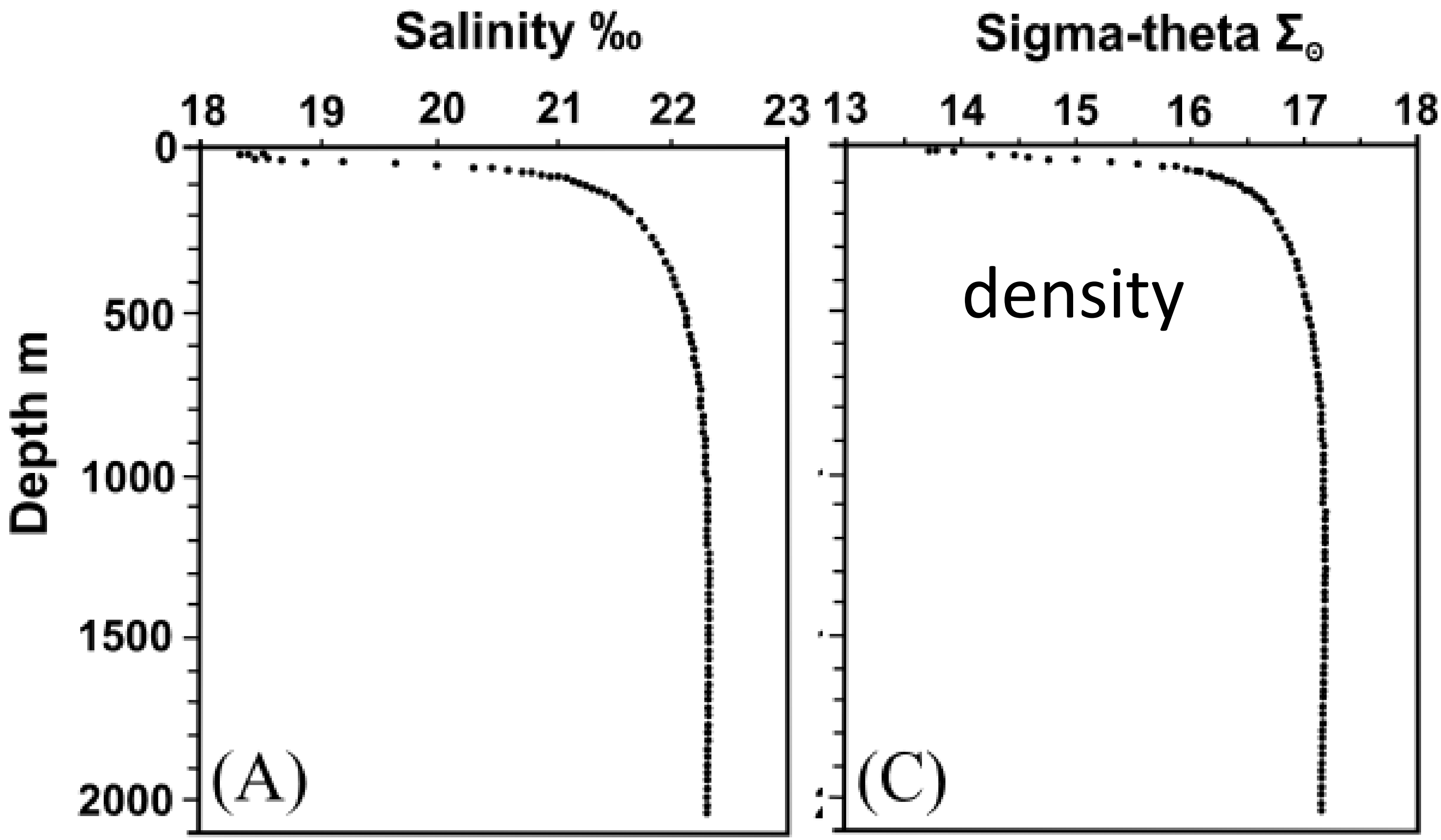
William B. F. Ryan

Lamont-Doherty Earth Observatory of Columbia University



channel network where Mediterranean water enters into the Black Sea

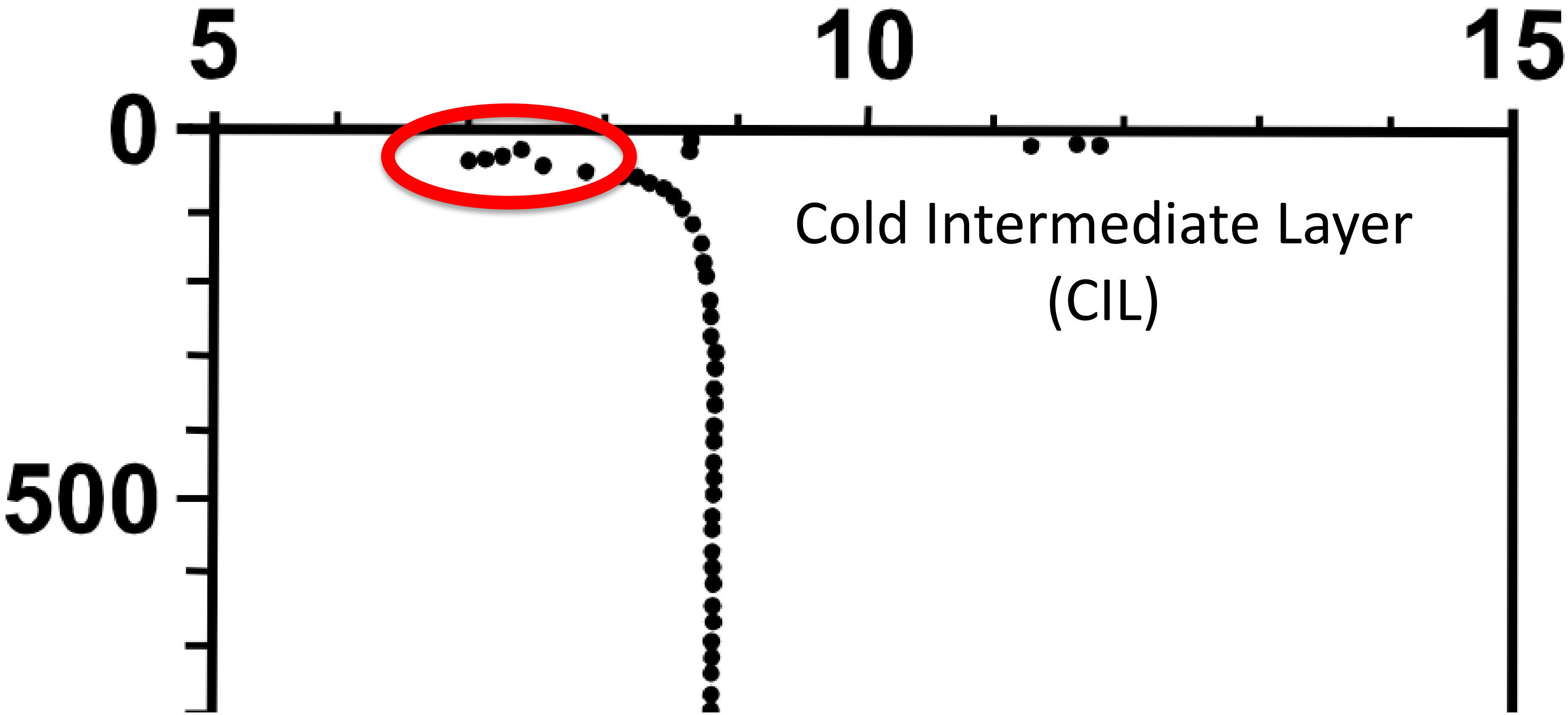




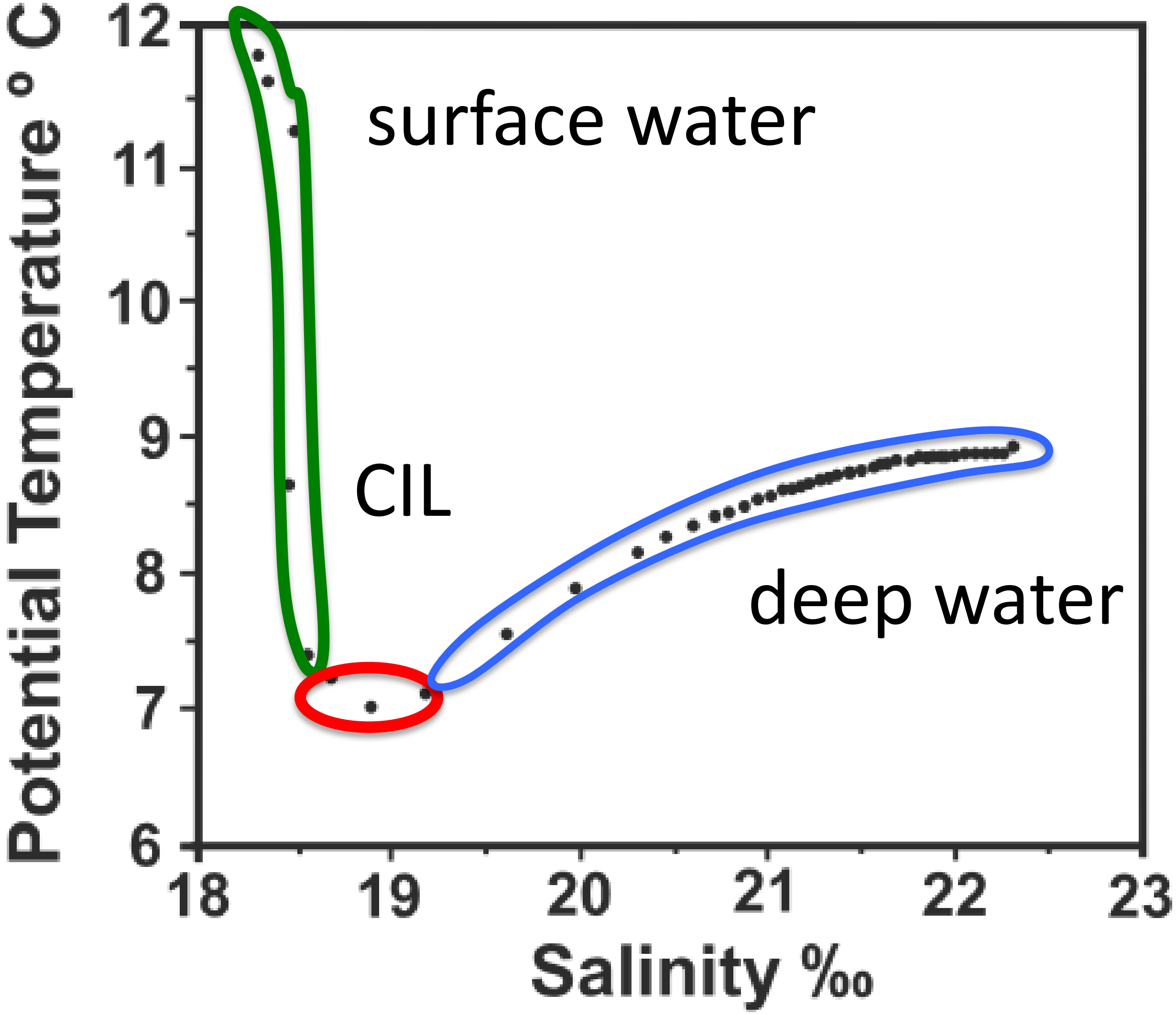
The Bosporus inflow creates a strong vertical stratification by delivering saltwater of higher salinity and hence greater density into a thick deep layer.

Murray et al., 2007

Potential Temperature ° C

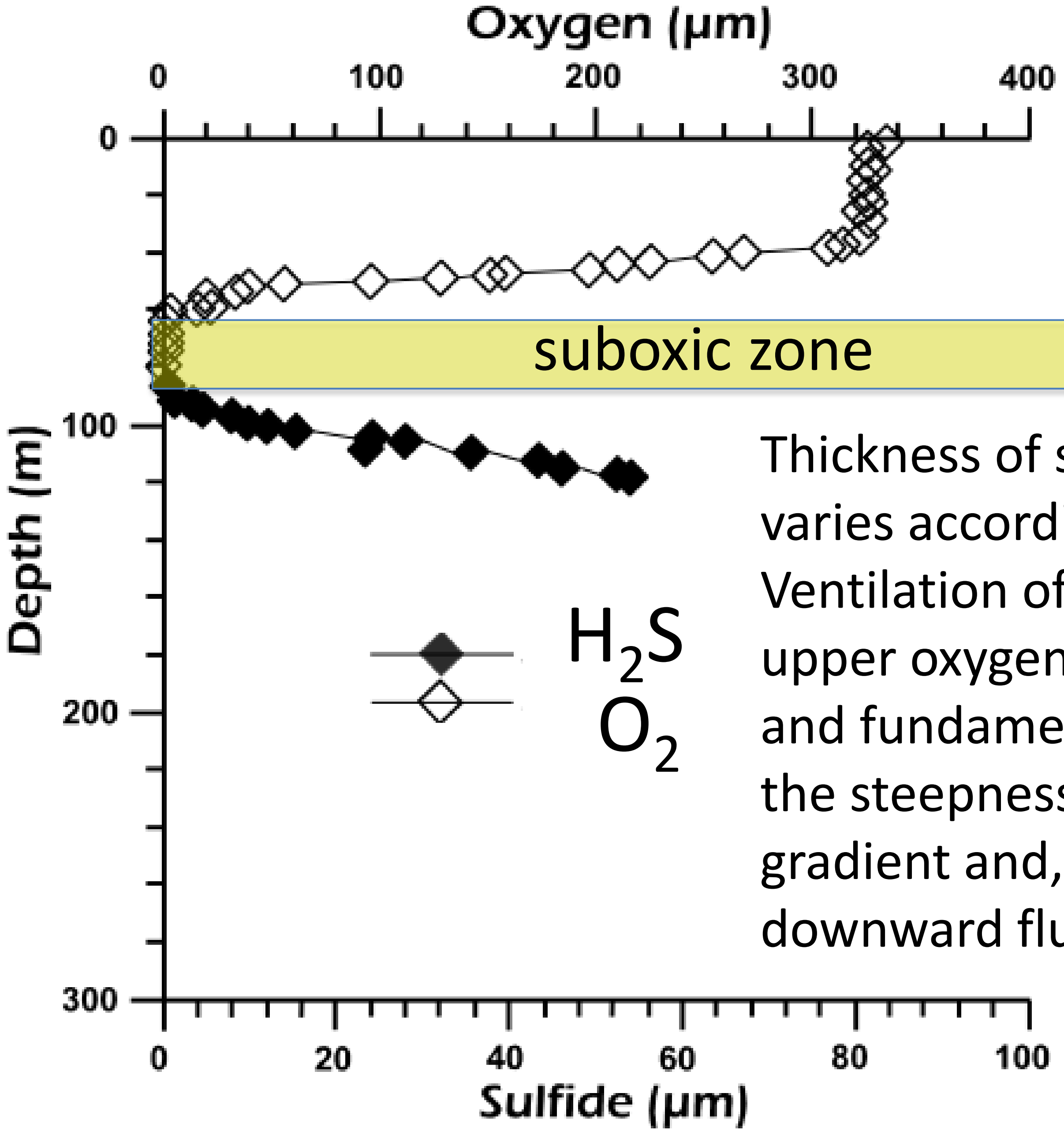


A temperature minimum occurs at about 50 m. Water in this layer forms in the winter and its replenishment depends upon the severity of the winter cooling.



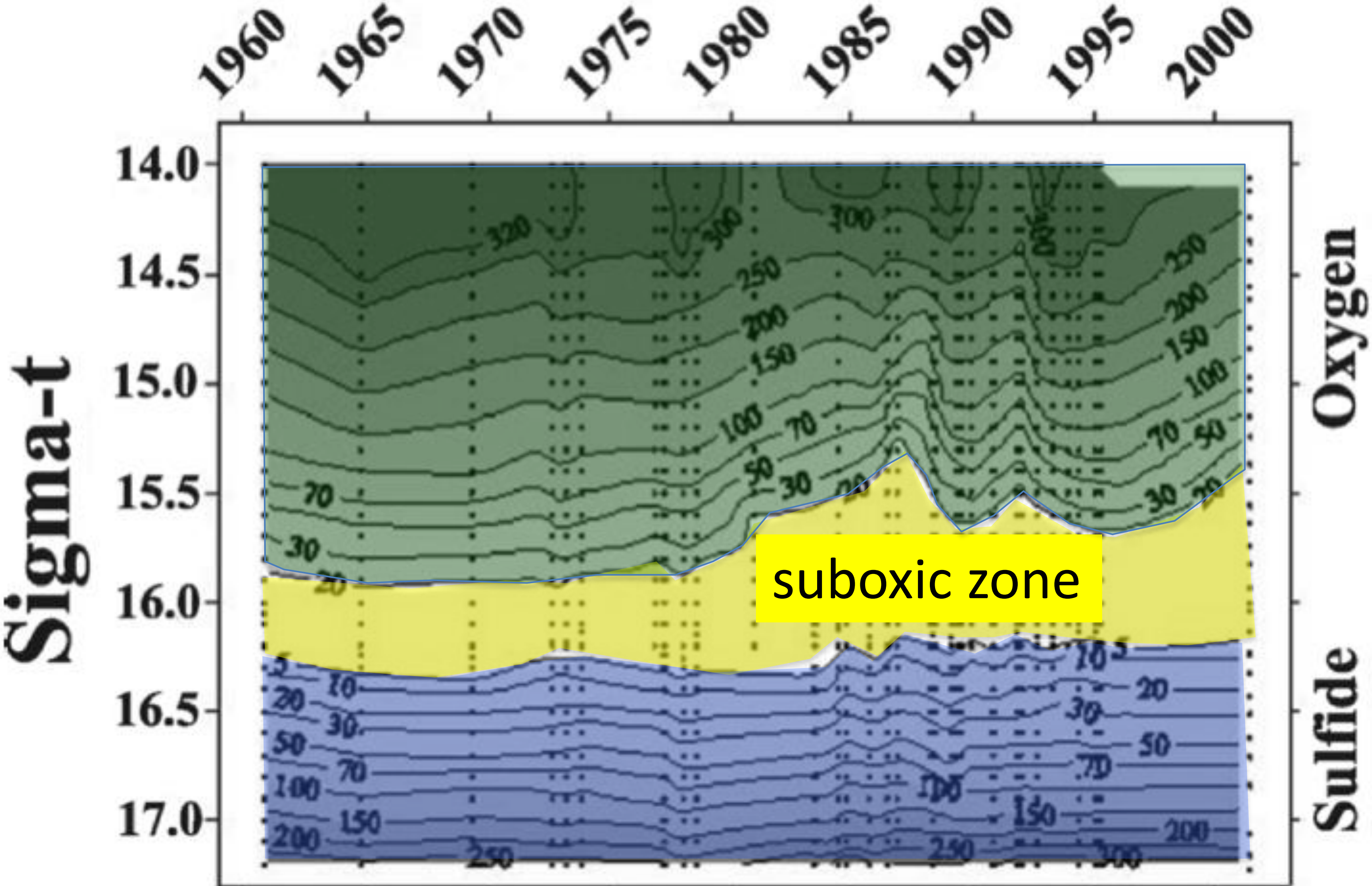
The cold intermediate layer has sources that are highly dependent upon climate.

Murray et al., 2007



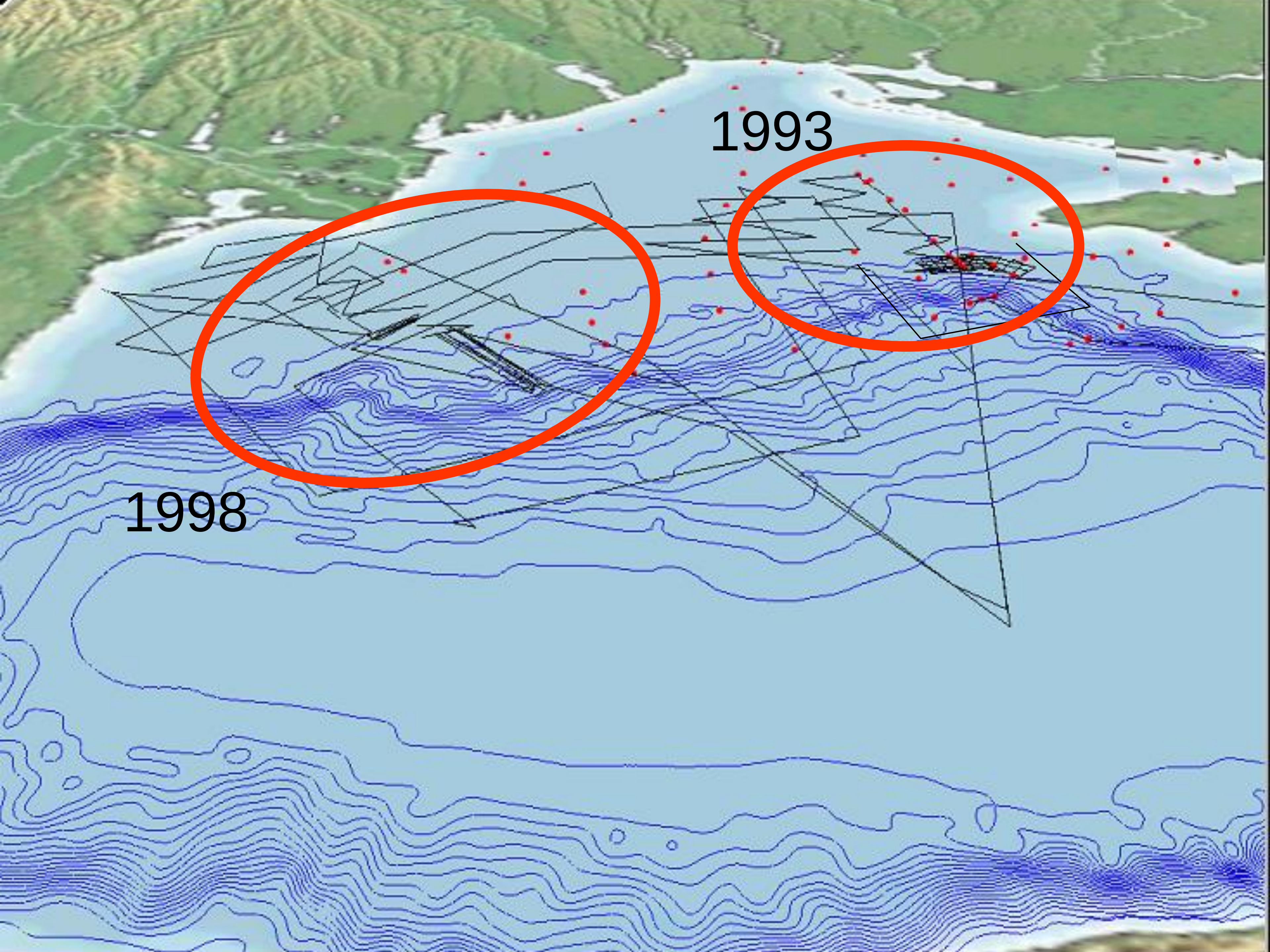
Thickness of suboxic zone varies according to climate. Ventilation of the CIL sets the upper oxygen concentration and fundamentally determines the steepness of the vertical gradient and, thus, the downward flux of oxygen.

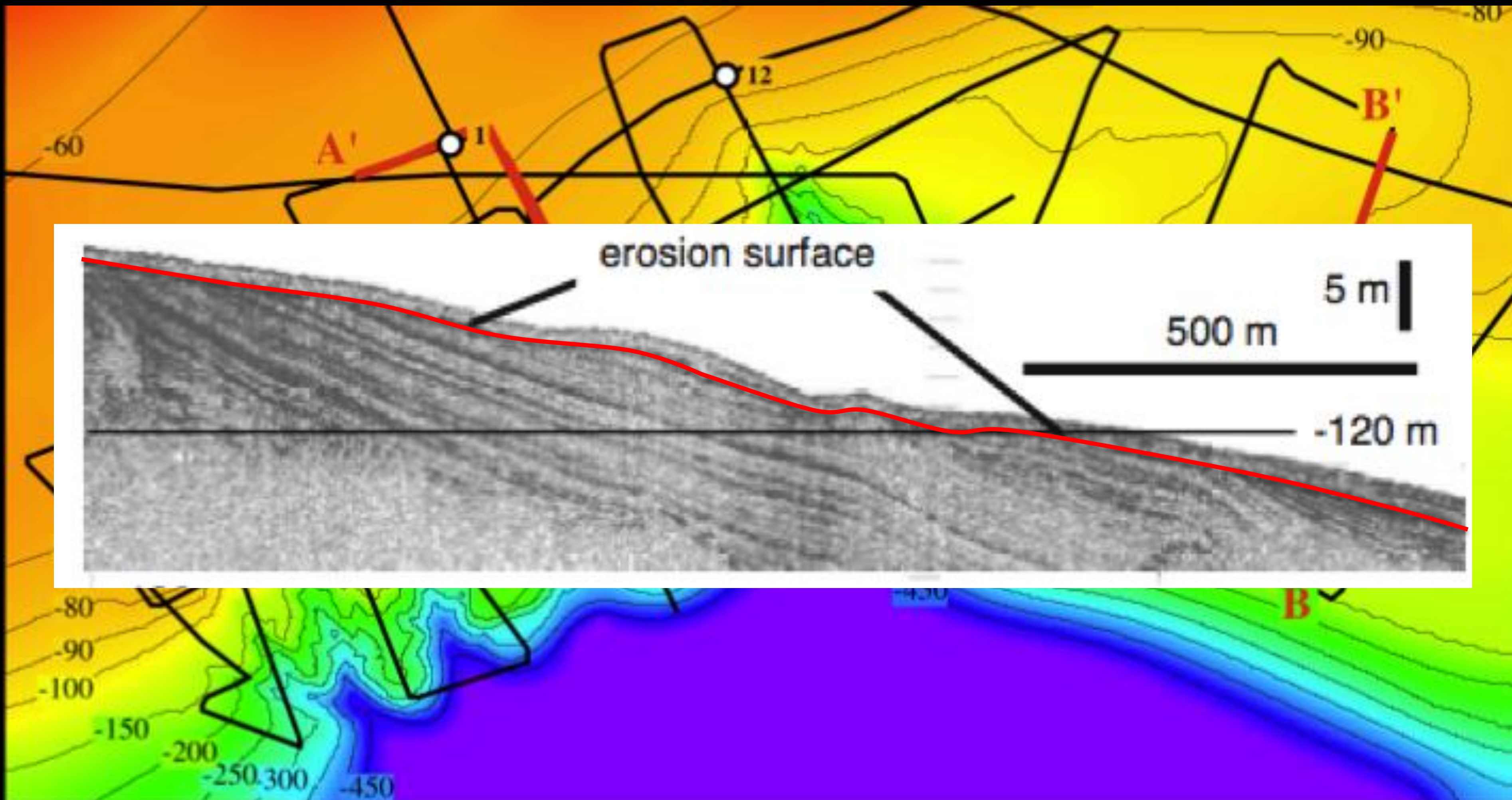
Murray et al., 2007



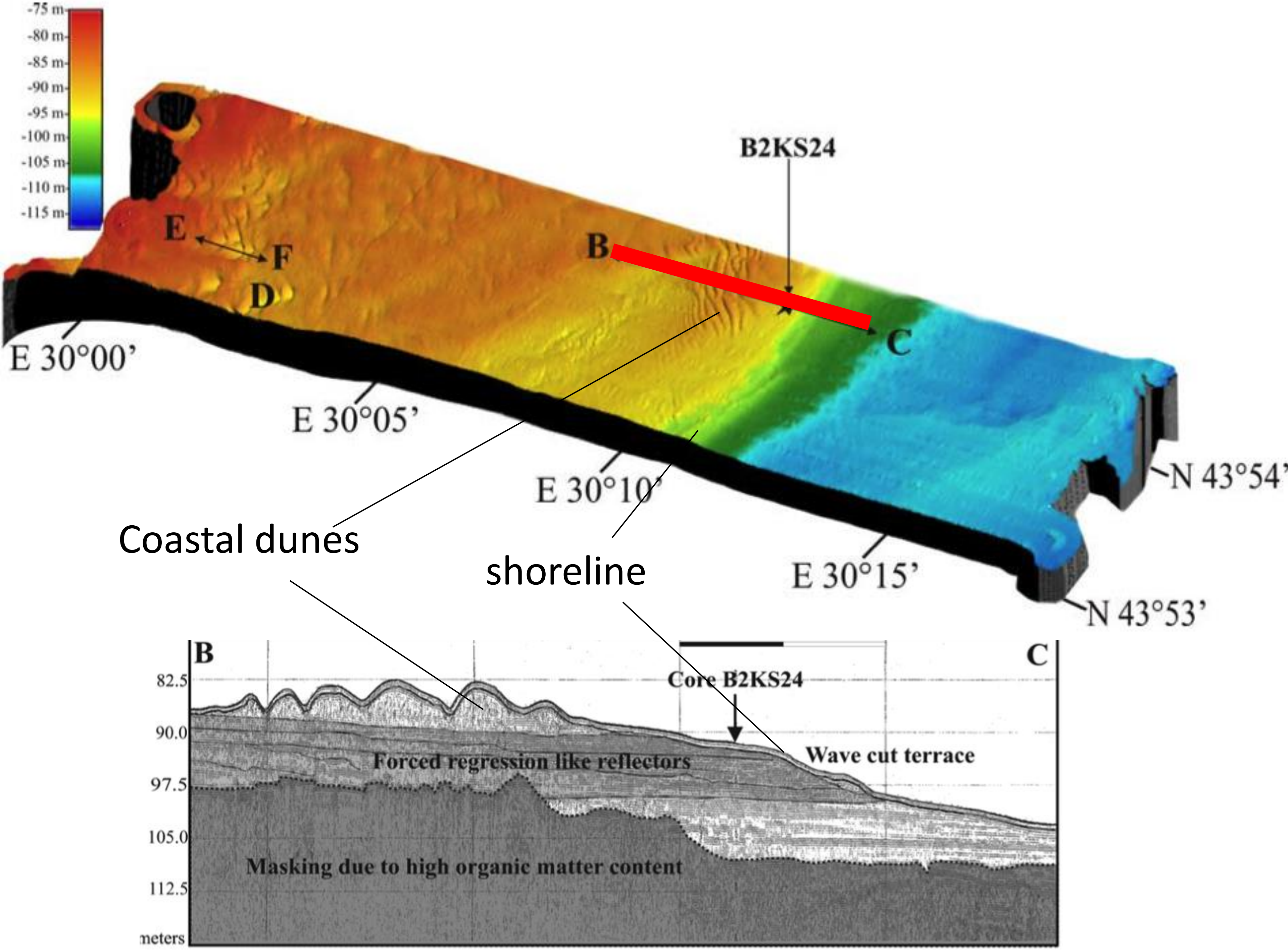
Top of the suboxic zone descends during cold winters and shoals in warm winters. Thus sustained climate warming has the potential to reduce the ventilation of the CIL.

Murray et al., 2007

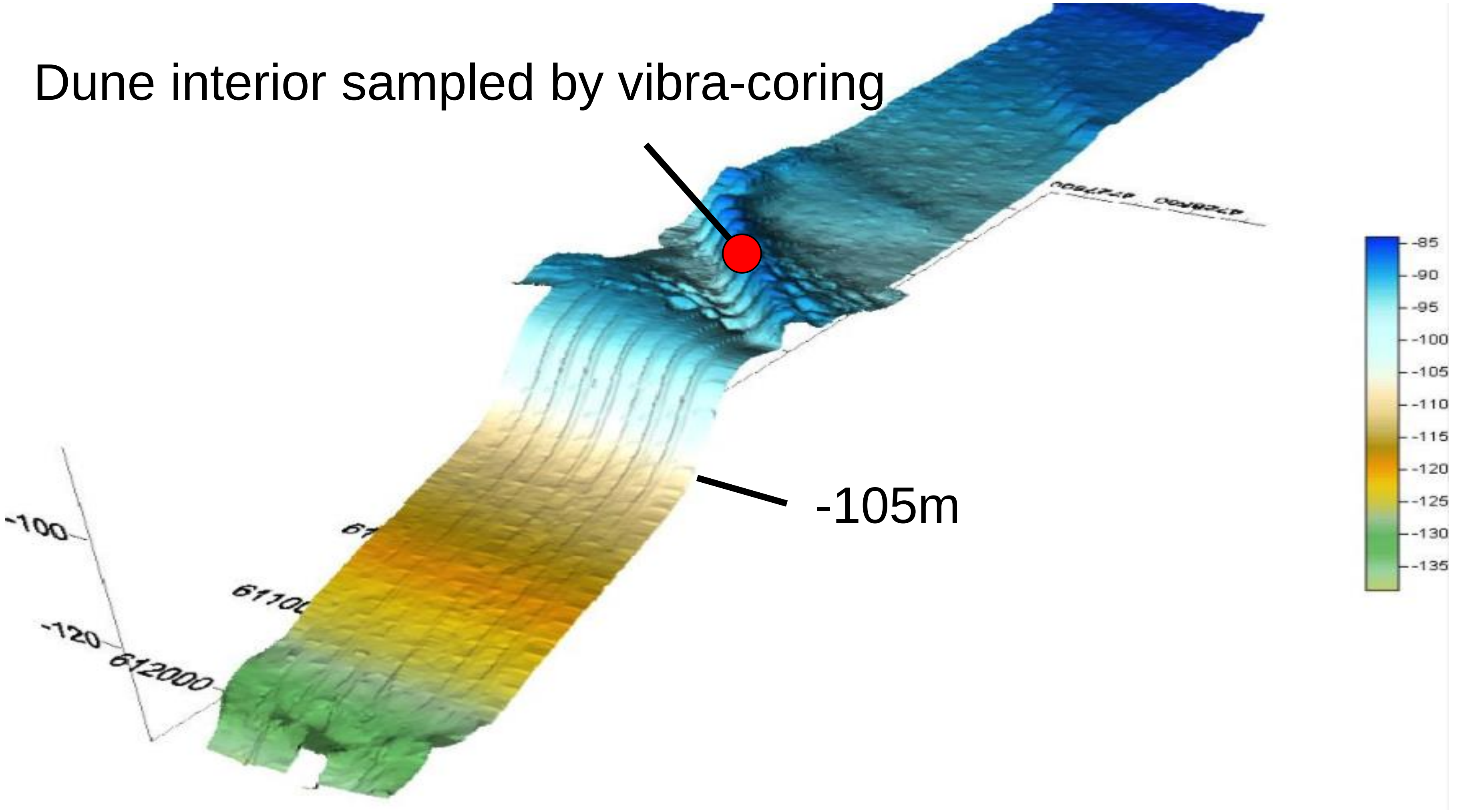

1993
1998



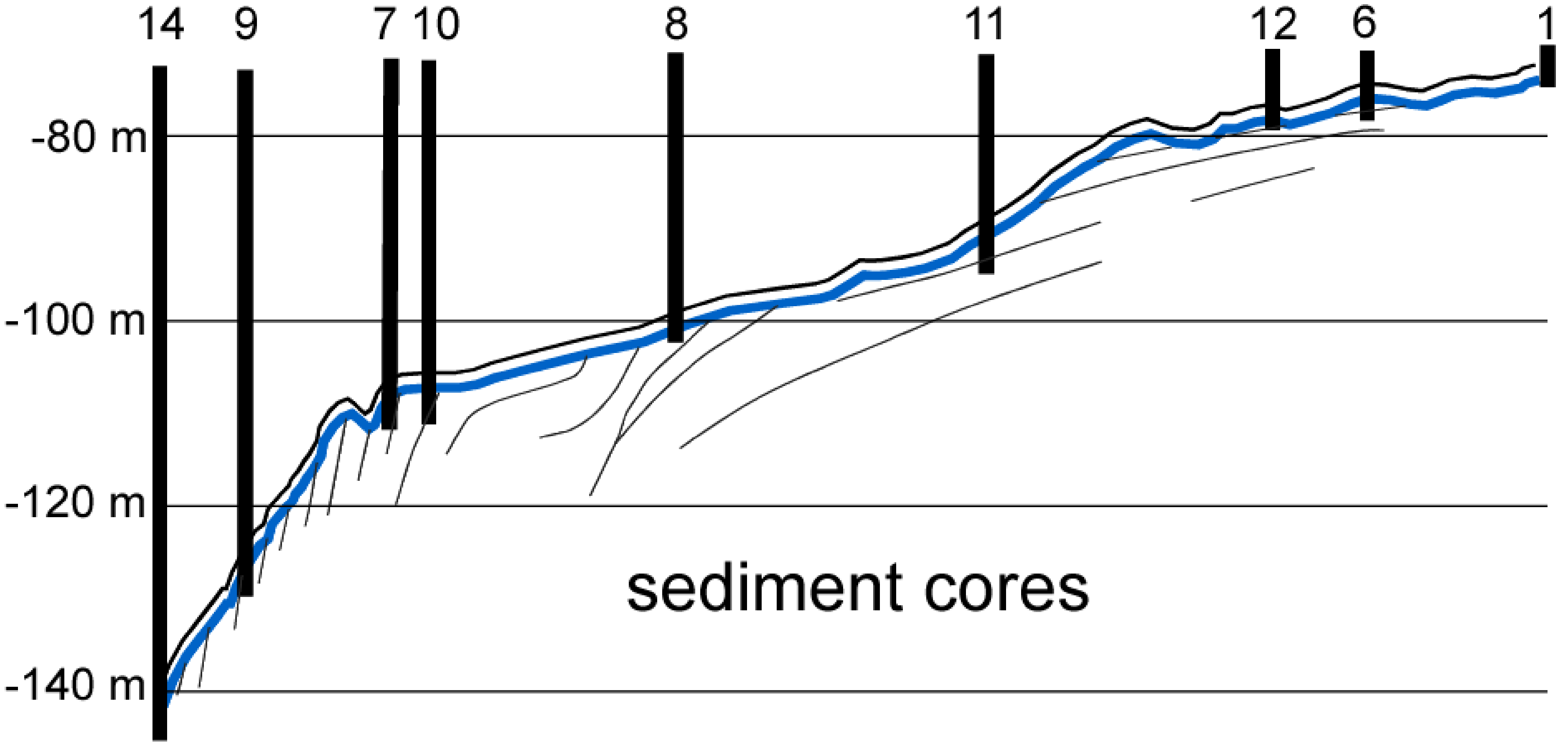
erosion surface
5 m
500 m
-120 m
A'
B'
B
1
12
-60
-80
-90
-100
-150
-200
-250
300
-450


-75 m
-80 m
-85 m
-90 m
-95 m
-100 m
-105 m
-110 m
-115 m
B2KS24
E
F
D
B
C
E 30°00'
E 30°05'
E 30°10'
E 30°15'
N 43°54'
N 43°53'
Coastal dunes
shoreline
B
C
82.5
90.0
97.5
105.0
112.5
meters
Core B2KS24
Wave cut terrace
Forced regression like reflectors
Masking due to high organic matter content

Perspective view of shoreface and "transverse coastal dune"



Mapped by R/V *Akademik* in 2009, courtesy Petko Dimitrov

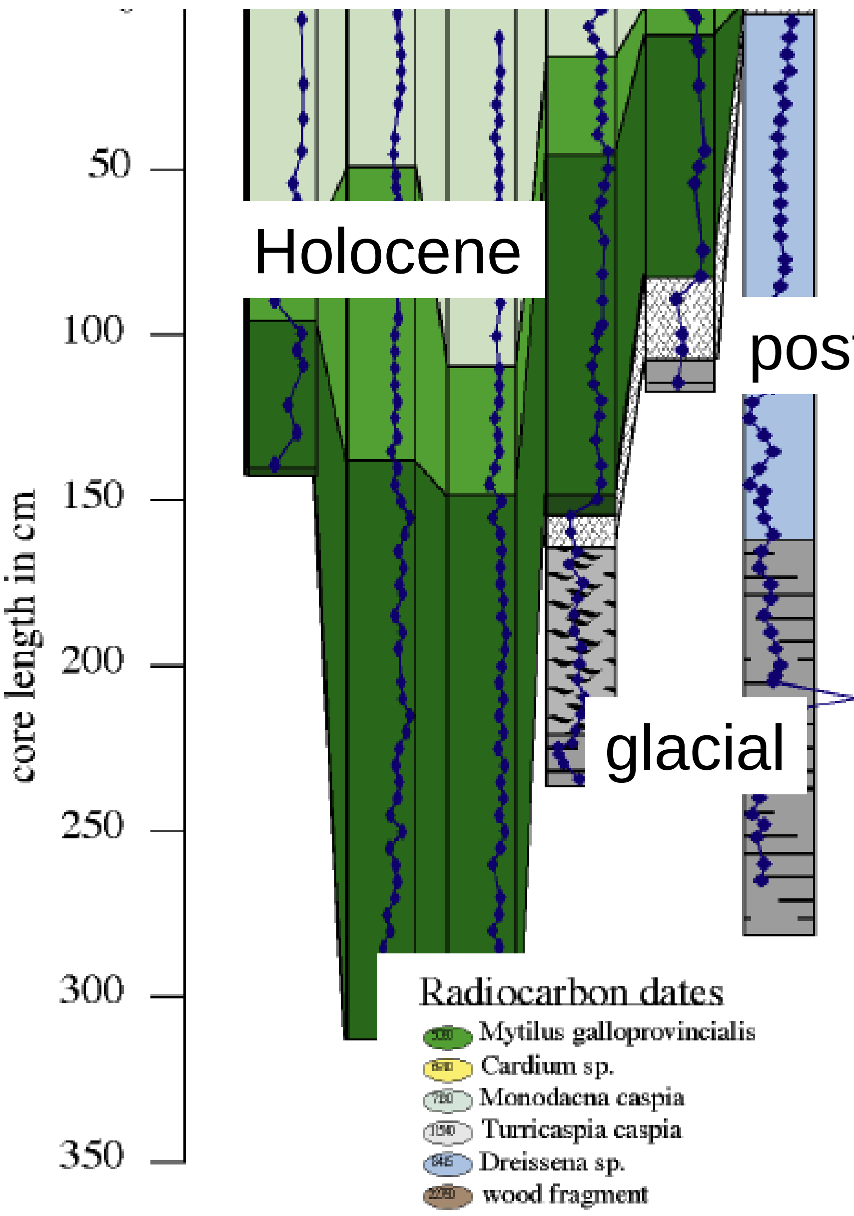

14
9
7
10
8
11
12
6
1
-80 m
-100 m
-120 m
-140 m
sediment cores

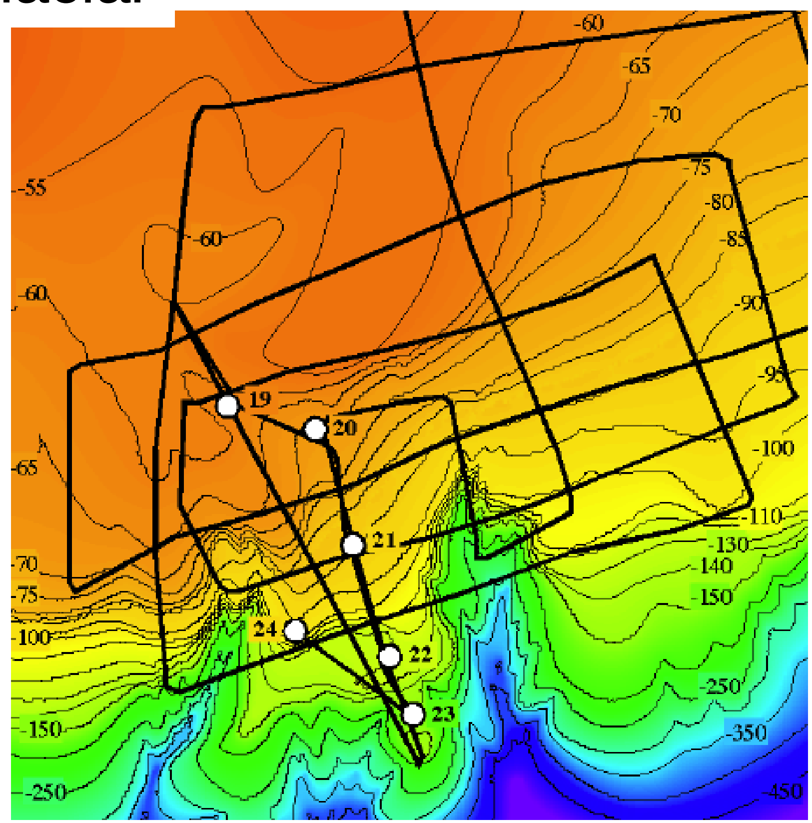
25
26
27
28
29
30
31
32
33
34
35
3 ft
37

Океанолозите Красимира Славова (вляво) и Анастасия сортират находките - мидички, рапанчета, гастроподи, по които после „пишат“ историята на Черно море.

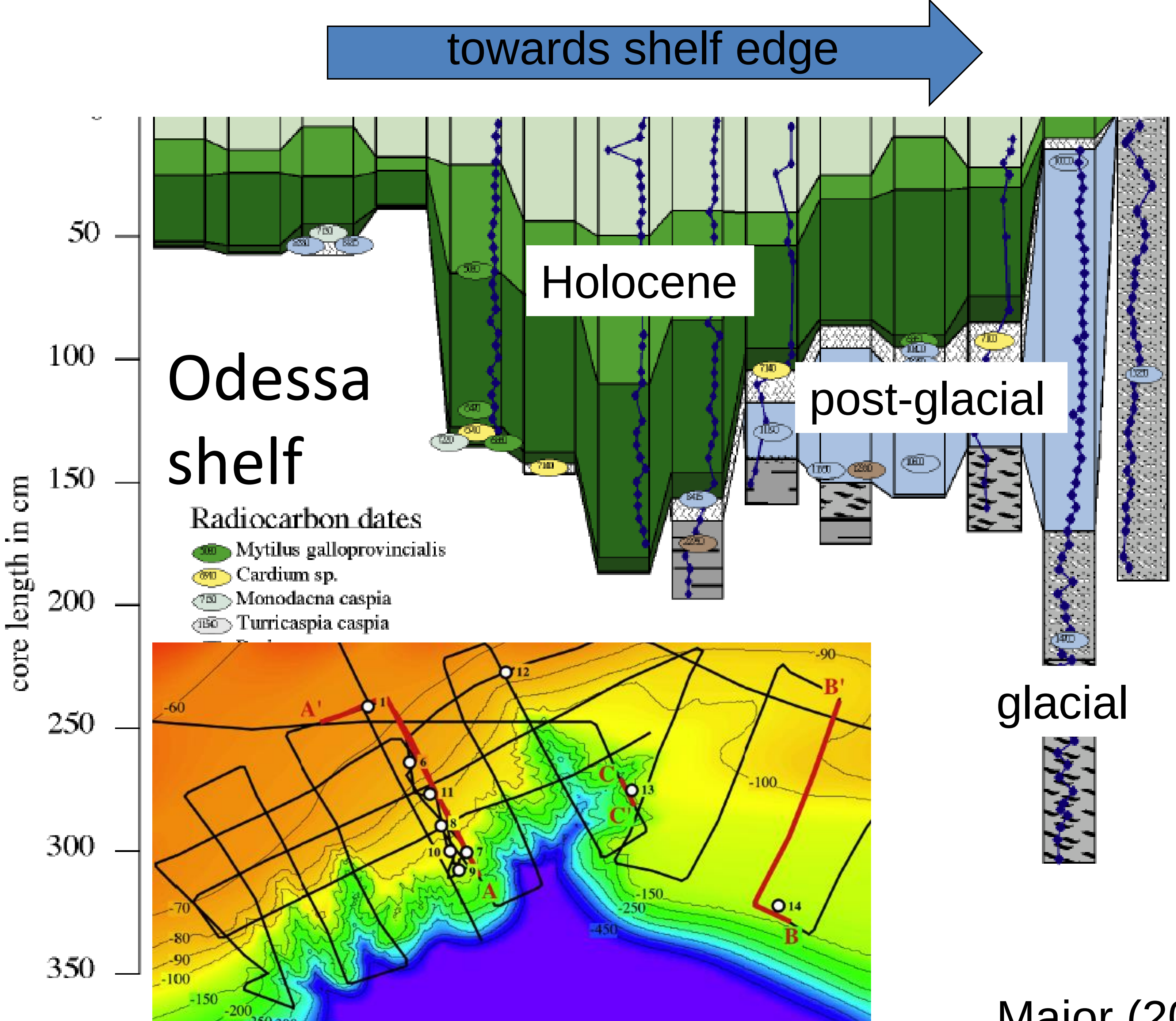
Kerch shelf

towards shelf edge





Major (2002)


towards shelf edge
Odessa shelf
Holocene
post-glacial
glacial
core length in cm
50
100
150
200
250
300
350
Radiocarbon dates
Mytilus galloprovincialis
Cardium sp.
Monodacna caspia
Turricaspia caspia
A'
A
B'
B
C
C'
-60
-70
-80
-90
-100
-150
-200
-250
-450

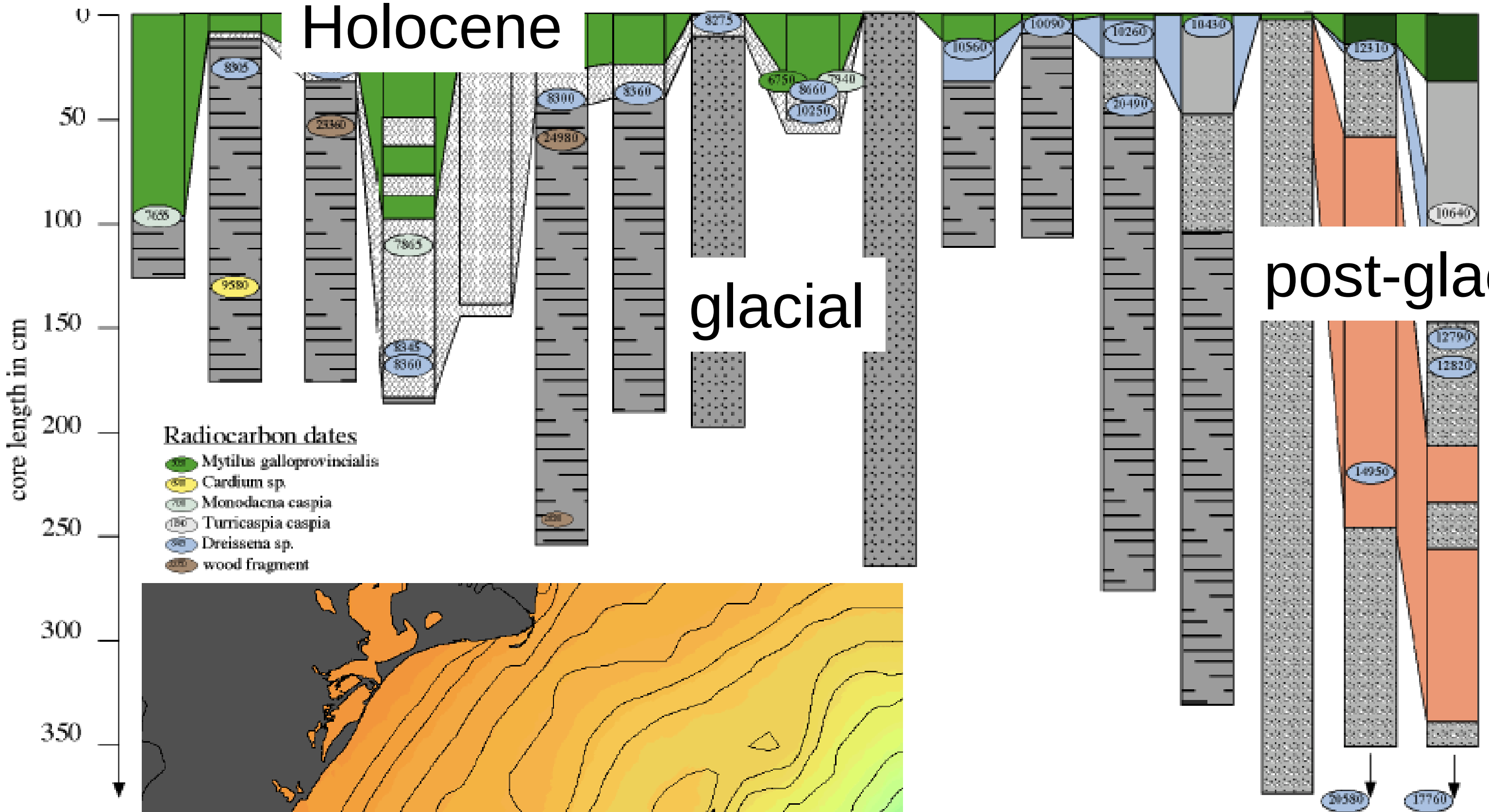
Major (2002)

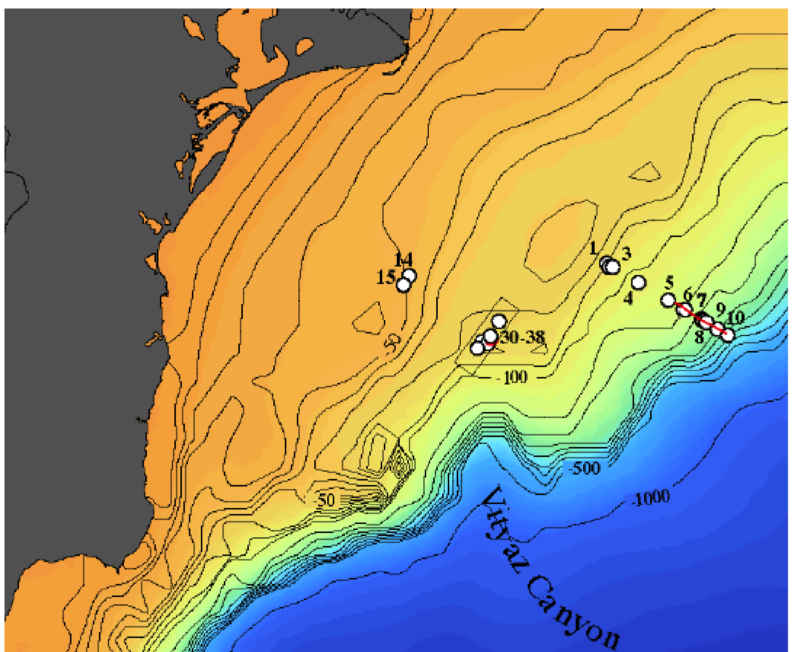
towards shelf edge

Holocene

glacial

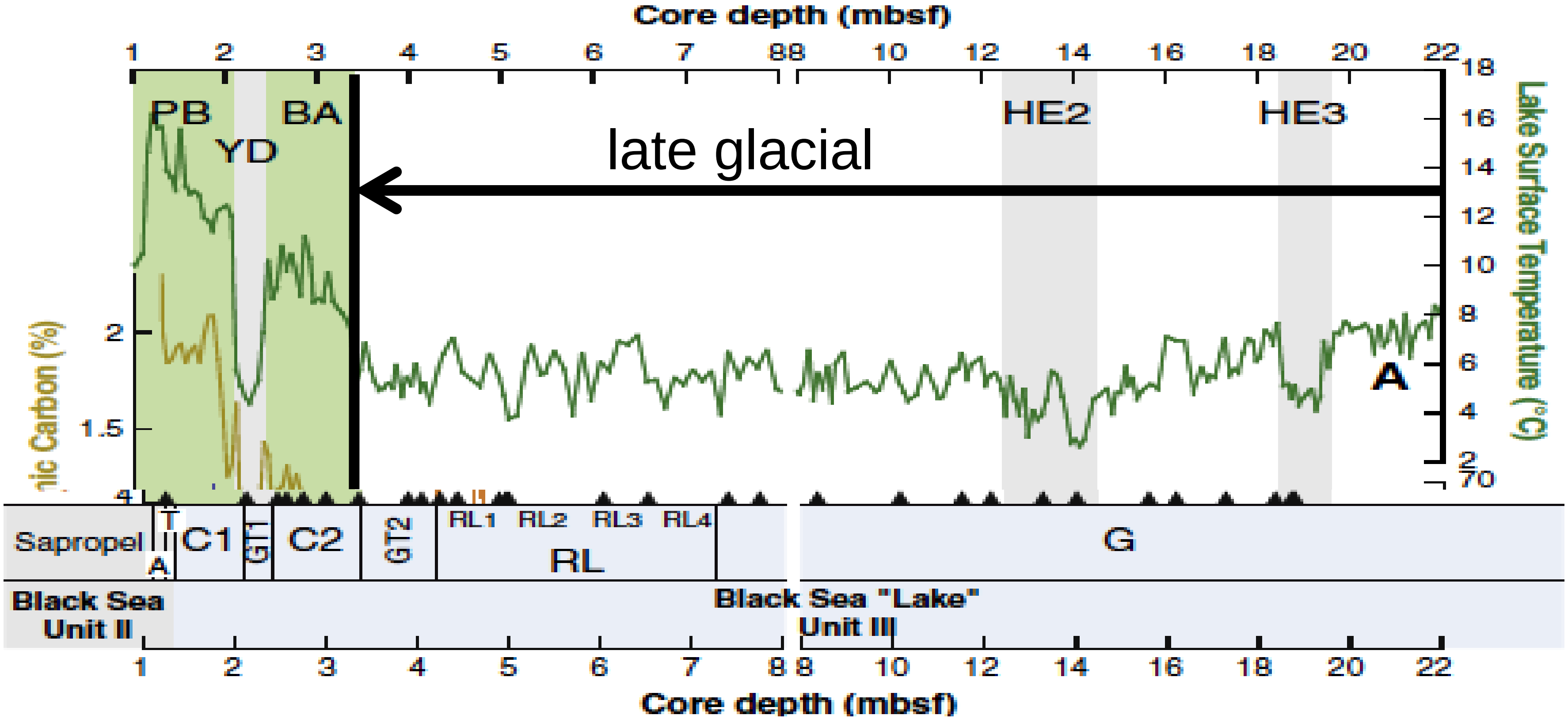
post-glacial





Danube shelf

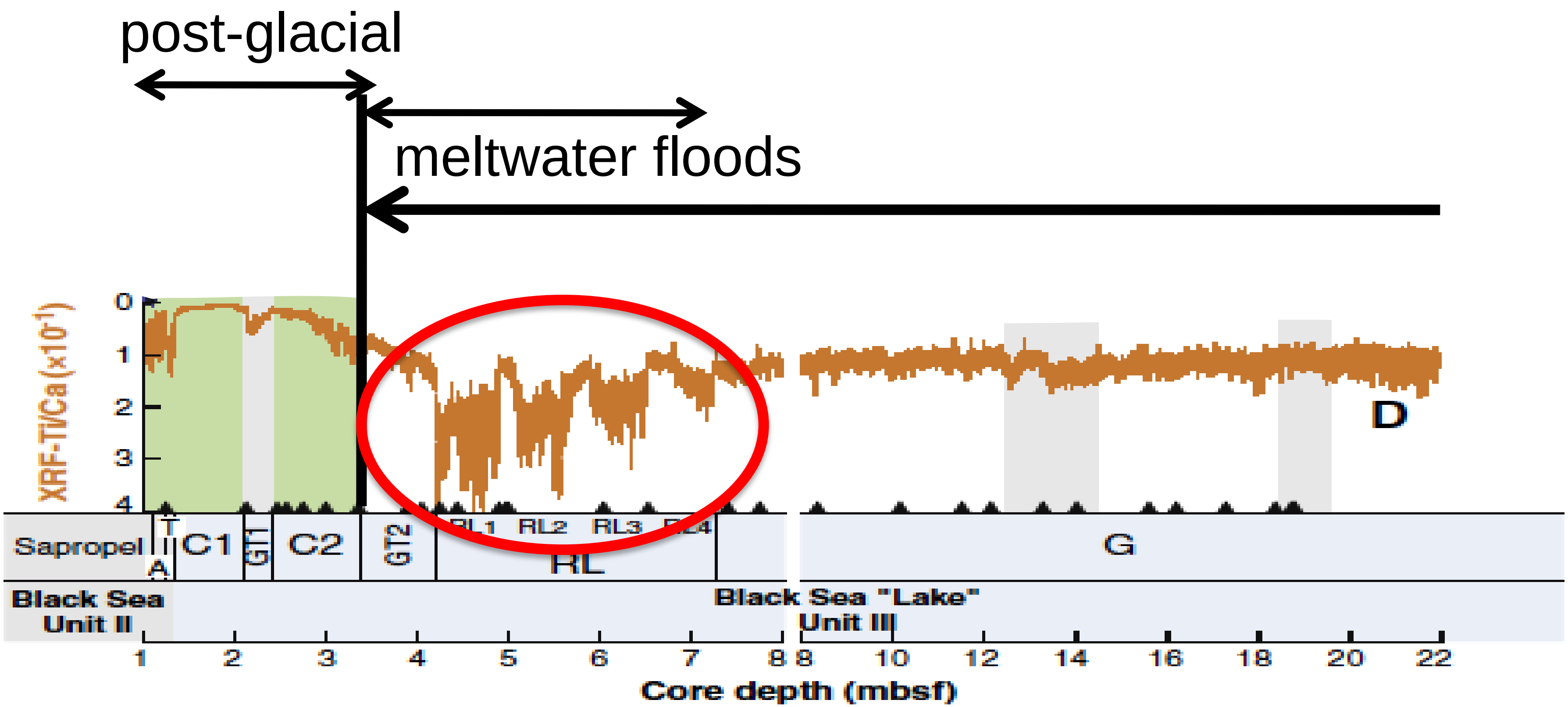
Major (2002)



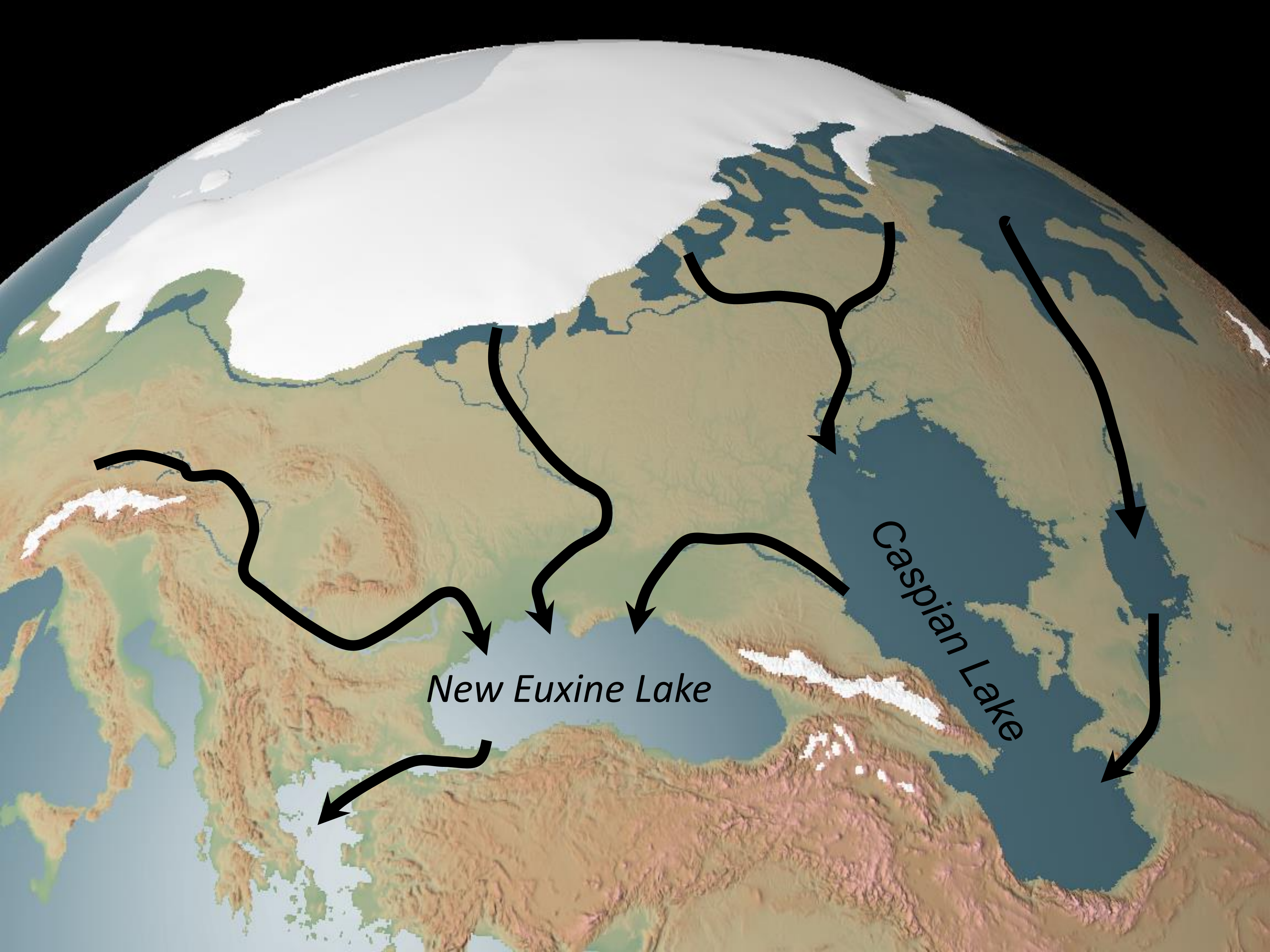
Lake surface temperature was cold in the late glacial (4-7° C) and again during the Younger Dryas.

Soulet et al., 2011

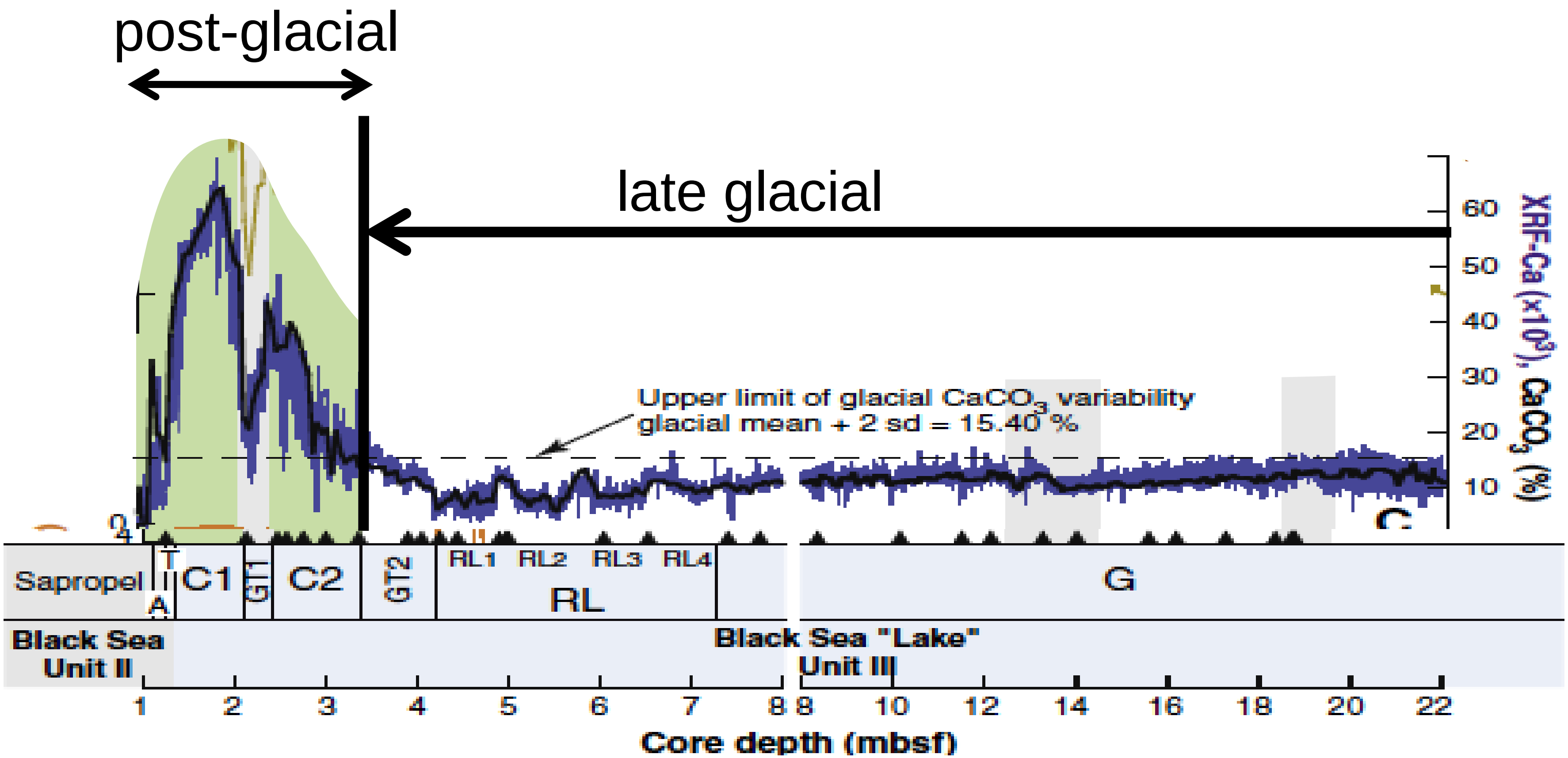
Red colored sediments rich in titanium and iron were delivered in repetitive floods as the Fennoscandian Ice Sheet melted beginning 17.5 thousand years ago.

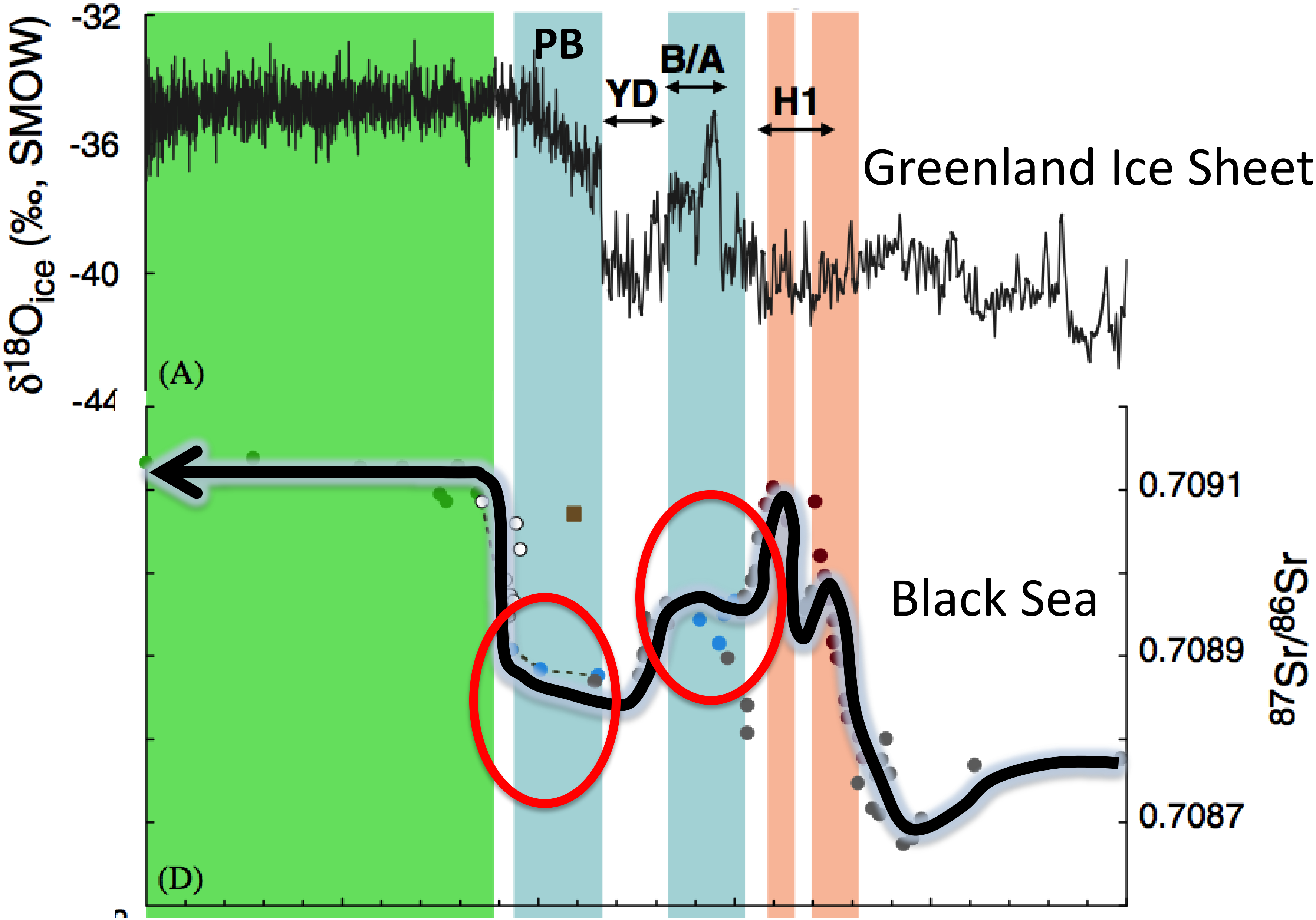


Soulet et al., 2011

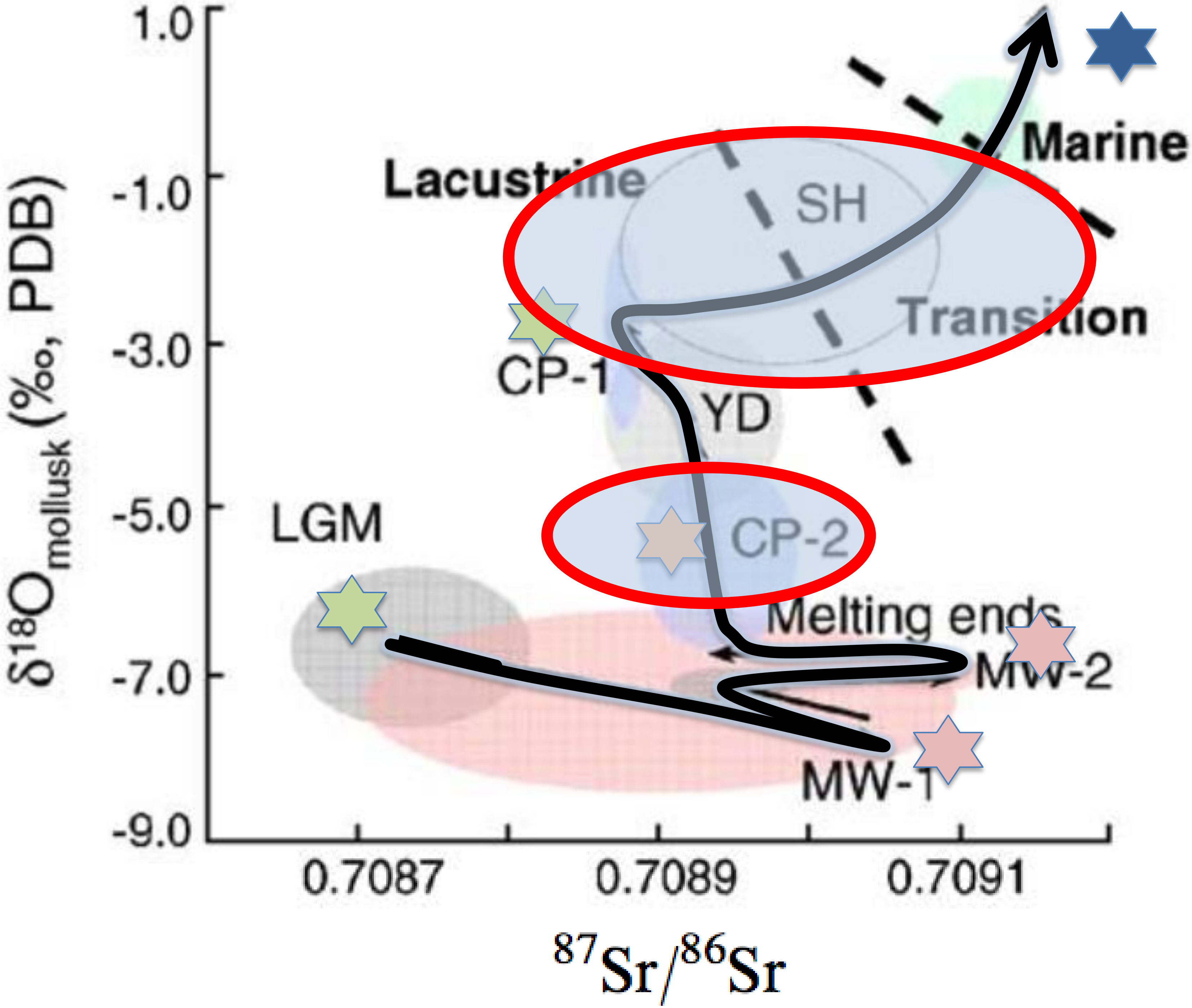

New Euxine Lake
Caspian Lake

CaCO$_3$ increase substantially during the post-glacial period of climate warming.

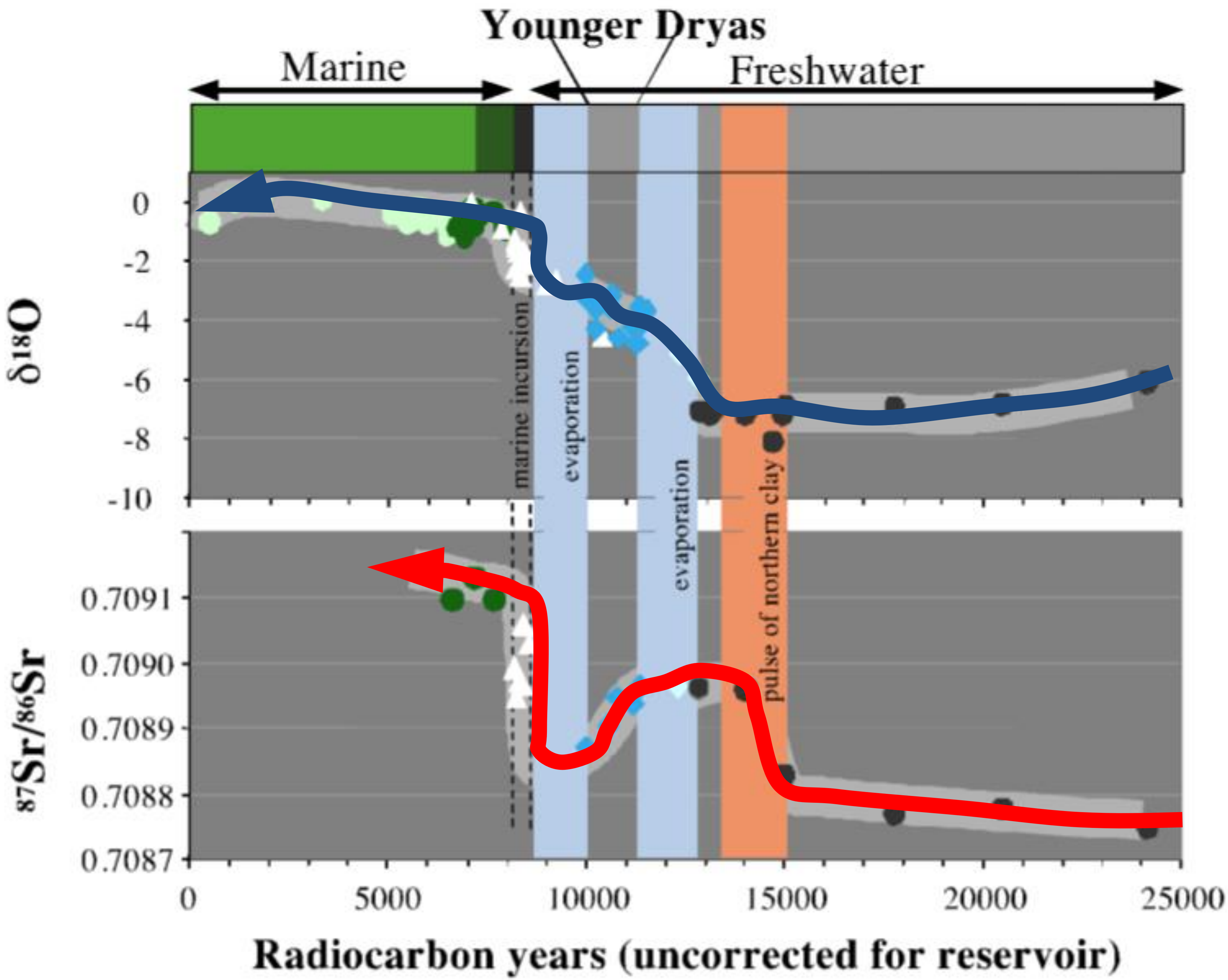




δ18Oice (‰, SMOW)
-32
-36
-40
-44
PB
YD
B/A
H1
Greenland Ice Sheet
(A)
Black Sea
0.7091
0.7089
0.7087
87Sr/86Sr
(D)

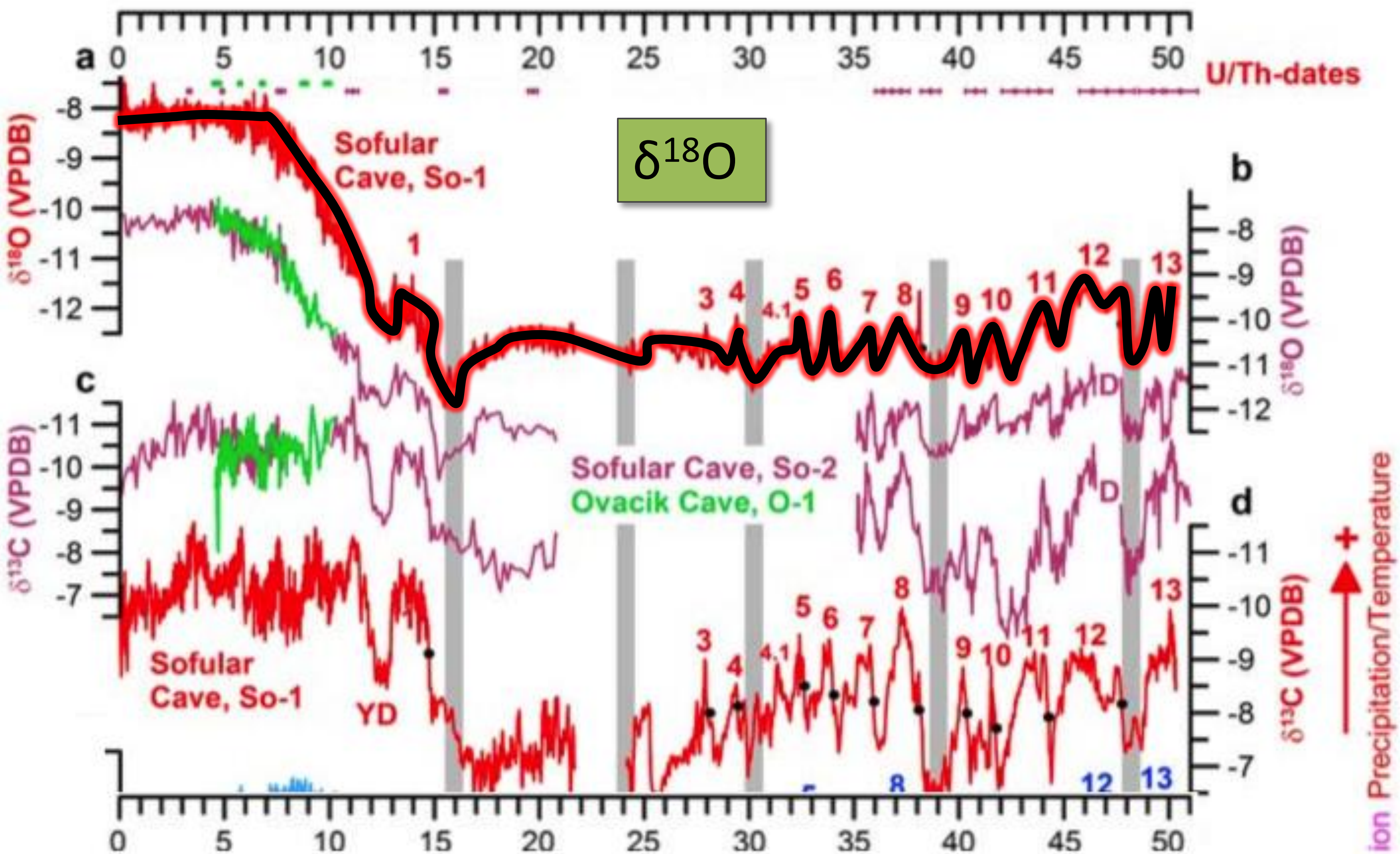


1.0
-1.0
-3.0
-5.0
-7.0
-9.0
δ18Omollusk (‰, PDB)
0.7087
0.7089
0.7091
87Sr/86Sr
Lacustrine
Marine
SH
Transition
CP-1
YD
LGM
CP-2
Melting ends
MW-2
MW-1



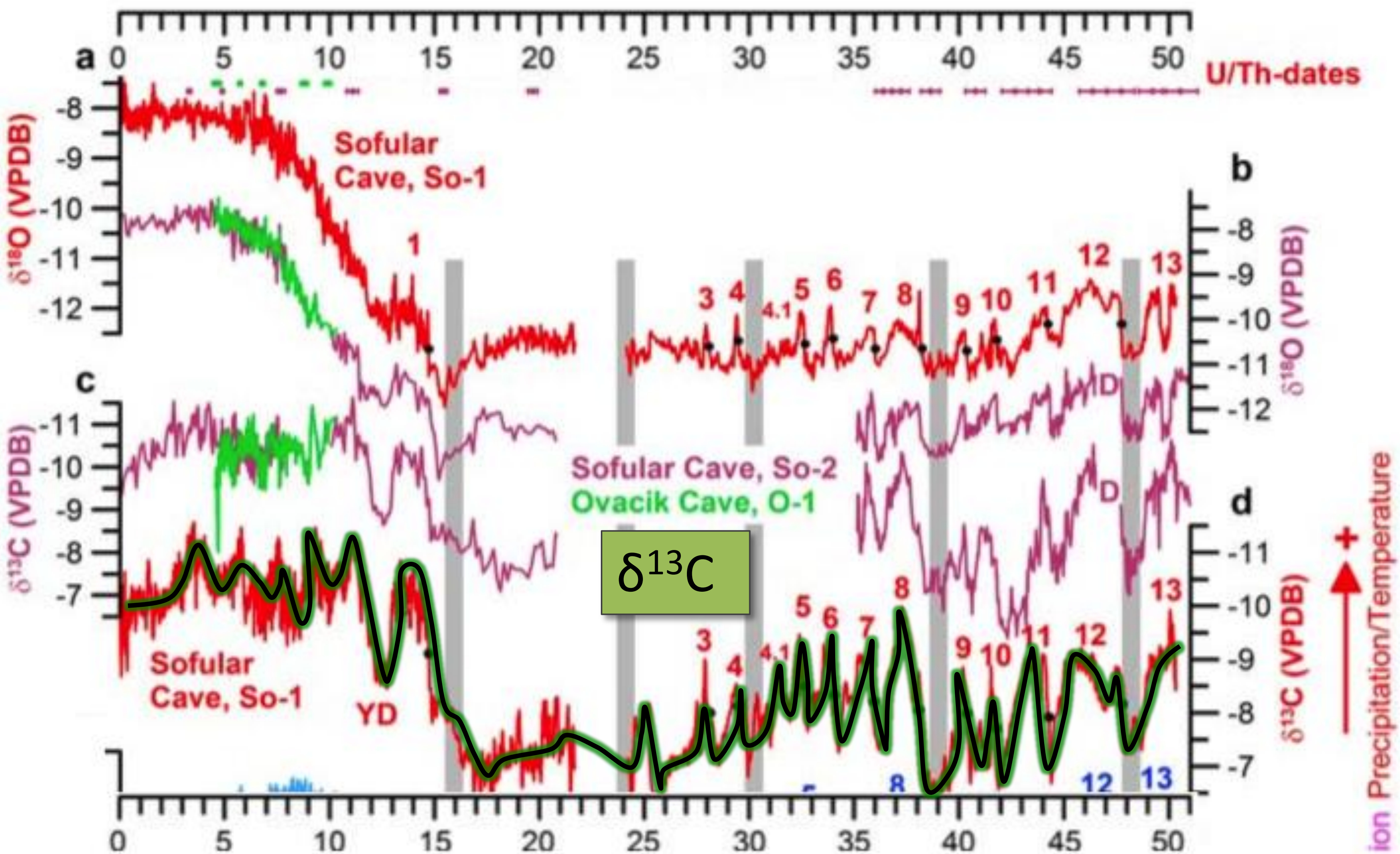
Younger Dryas
Marine
Freshwater
δ18O
0
-2
-4
-6
-8
-10
marine incursion
evaporation
evaporation
pulse of northern clay
87Sr/86Sr
0.7091
0.7090
0.7089
0.7088
0.7087
0
5000
10000
15000
20000
25000
Radiocarbon years (uncorrected for reservoir)

ky BP (Calendar Ages from U/Th dating methods)

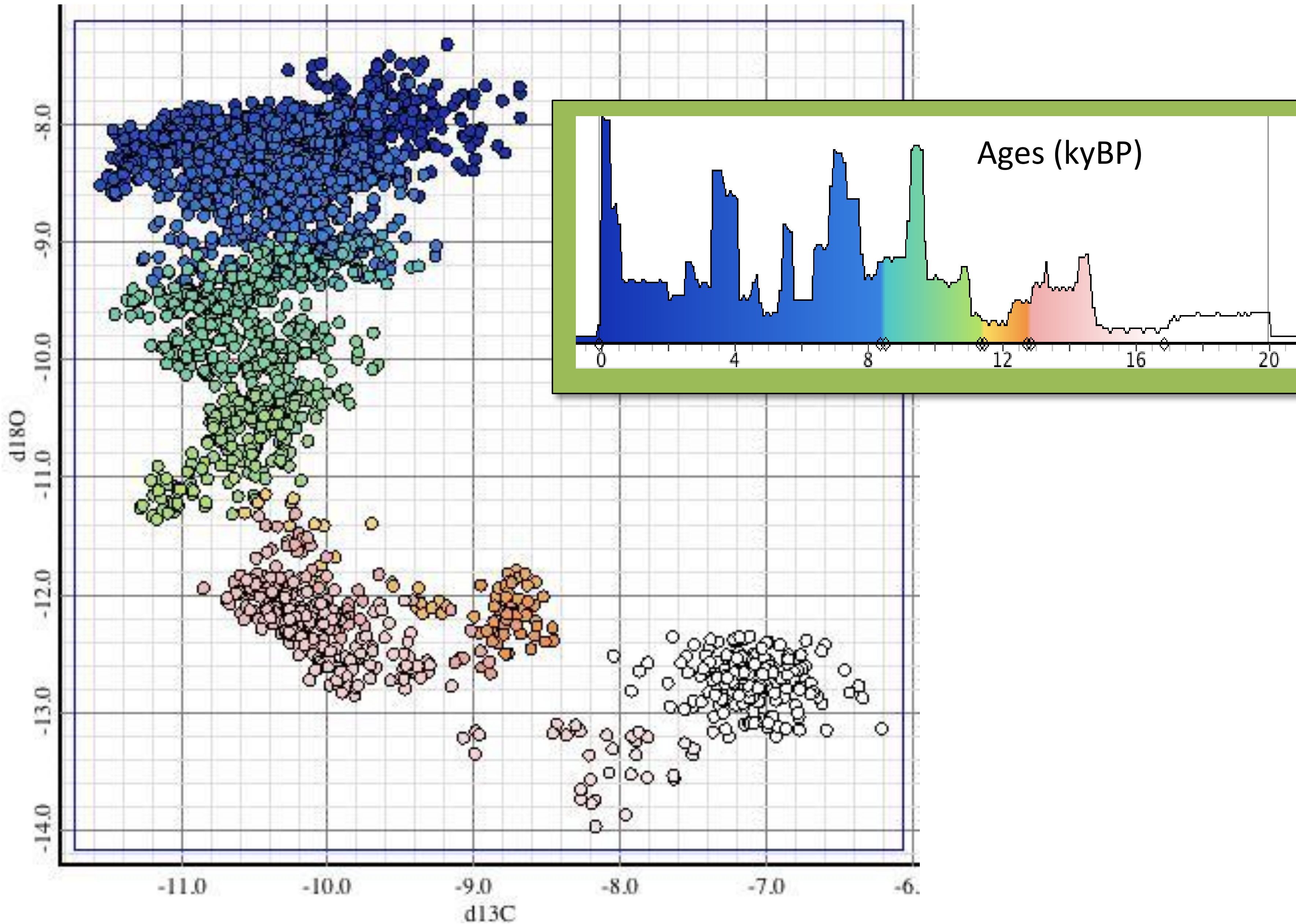


Fleitmann et al. 2009

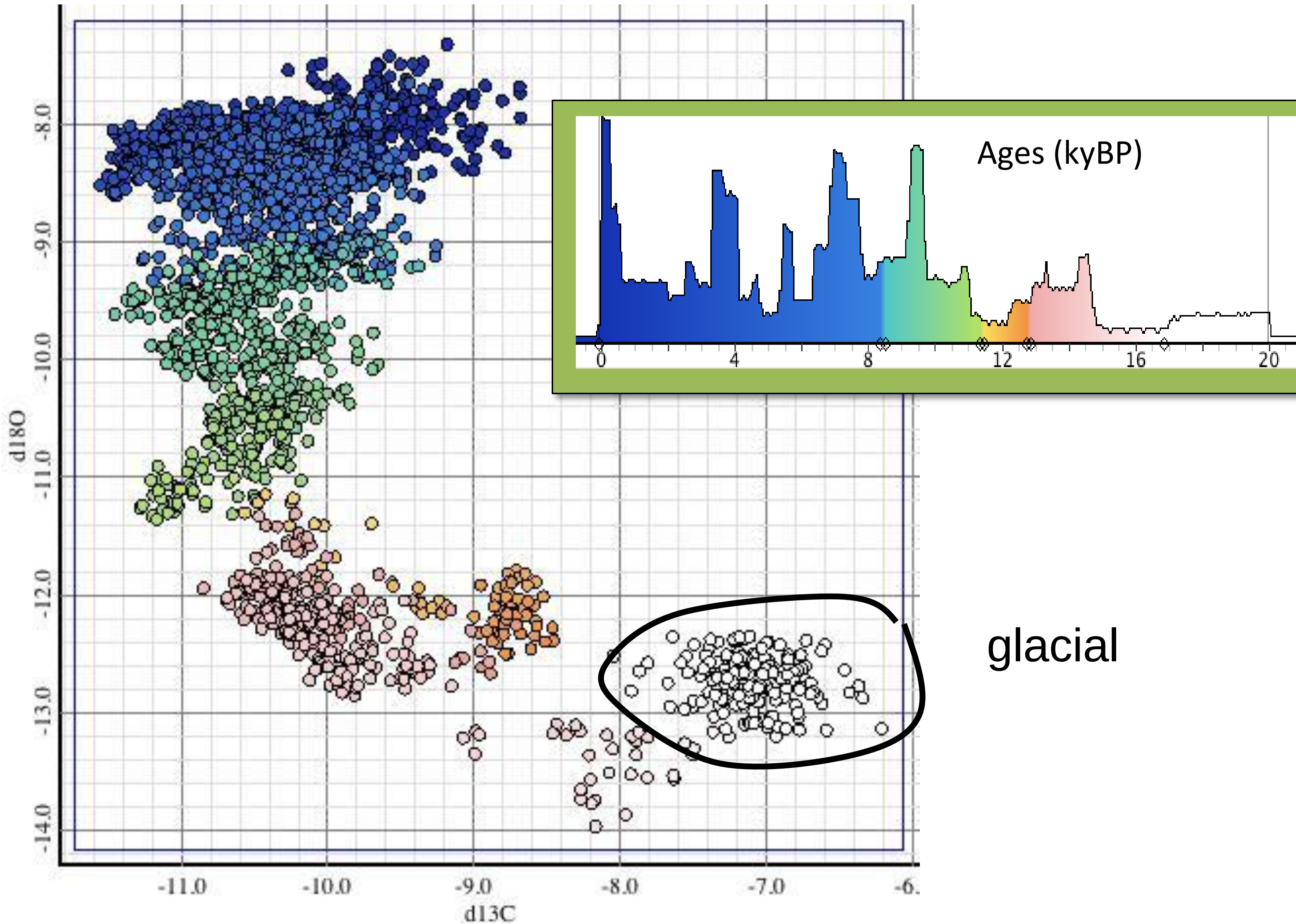
ky BP (Calendar Ages from U/Th dating methods)

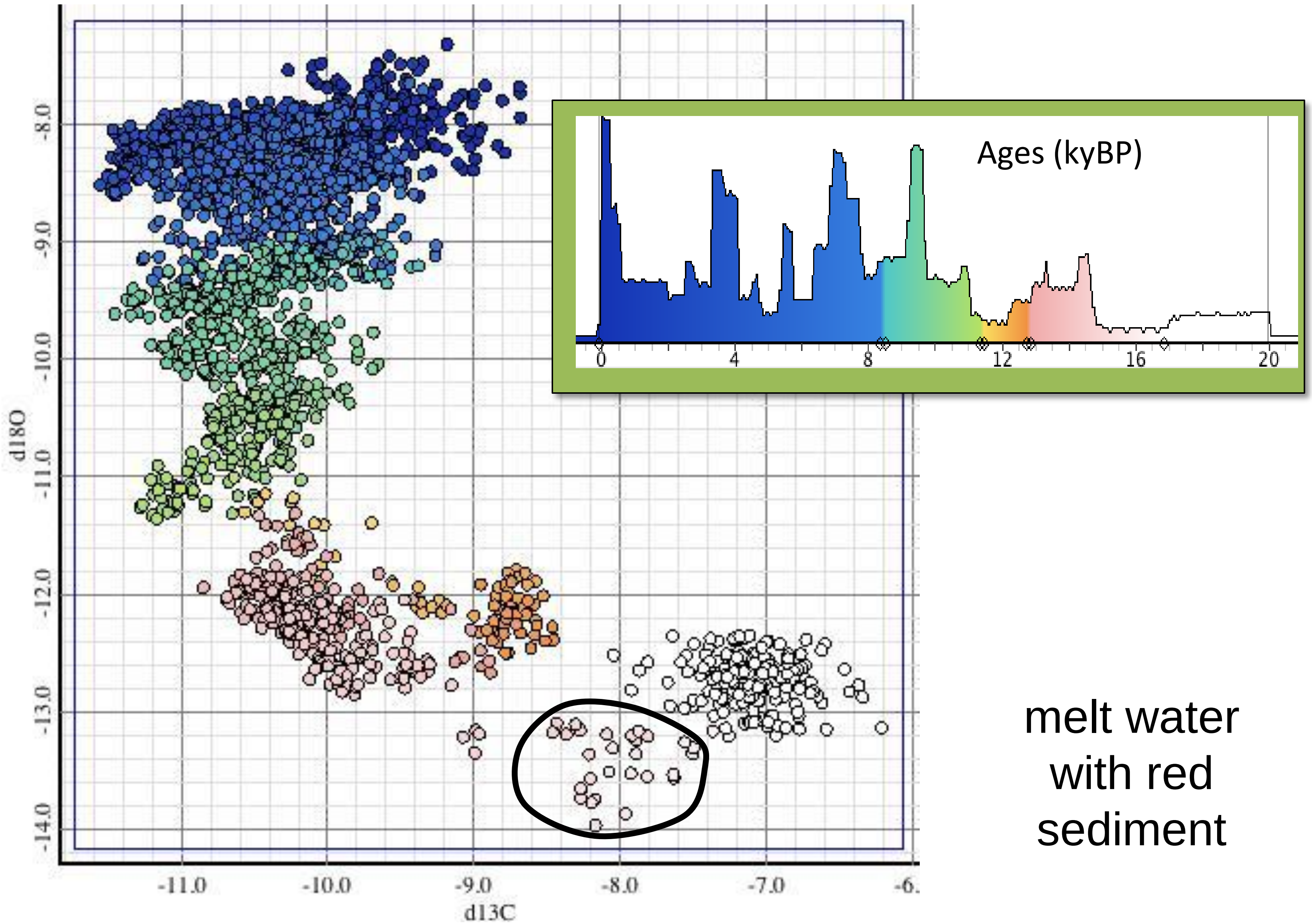


Fleitmann et al. 2009

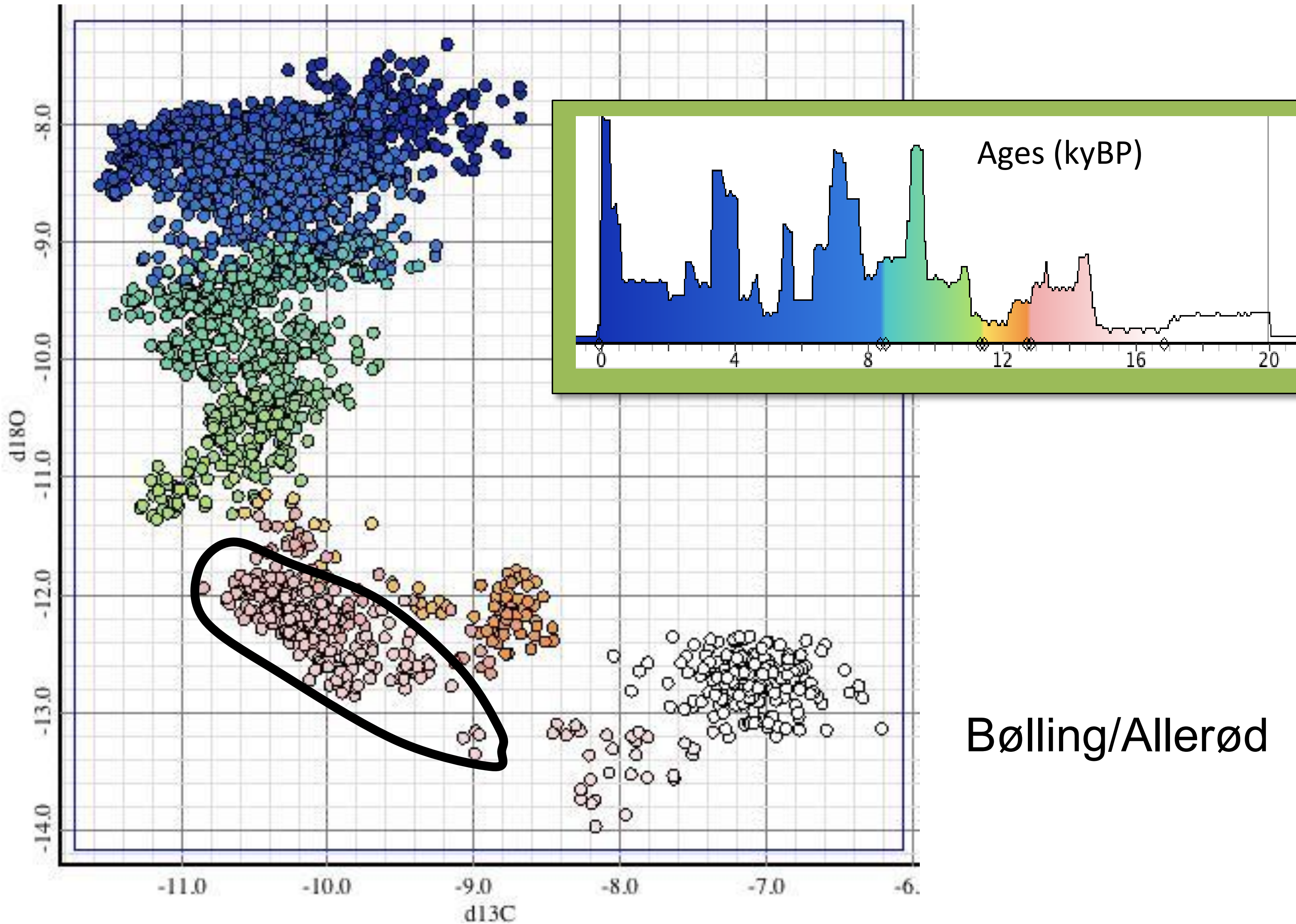


Ages (kyBP)
0
4
8
12
16
20
d18O
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
d13C
-11.0
-10.0
-9.0
-8.0
-7.0
-6.

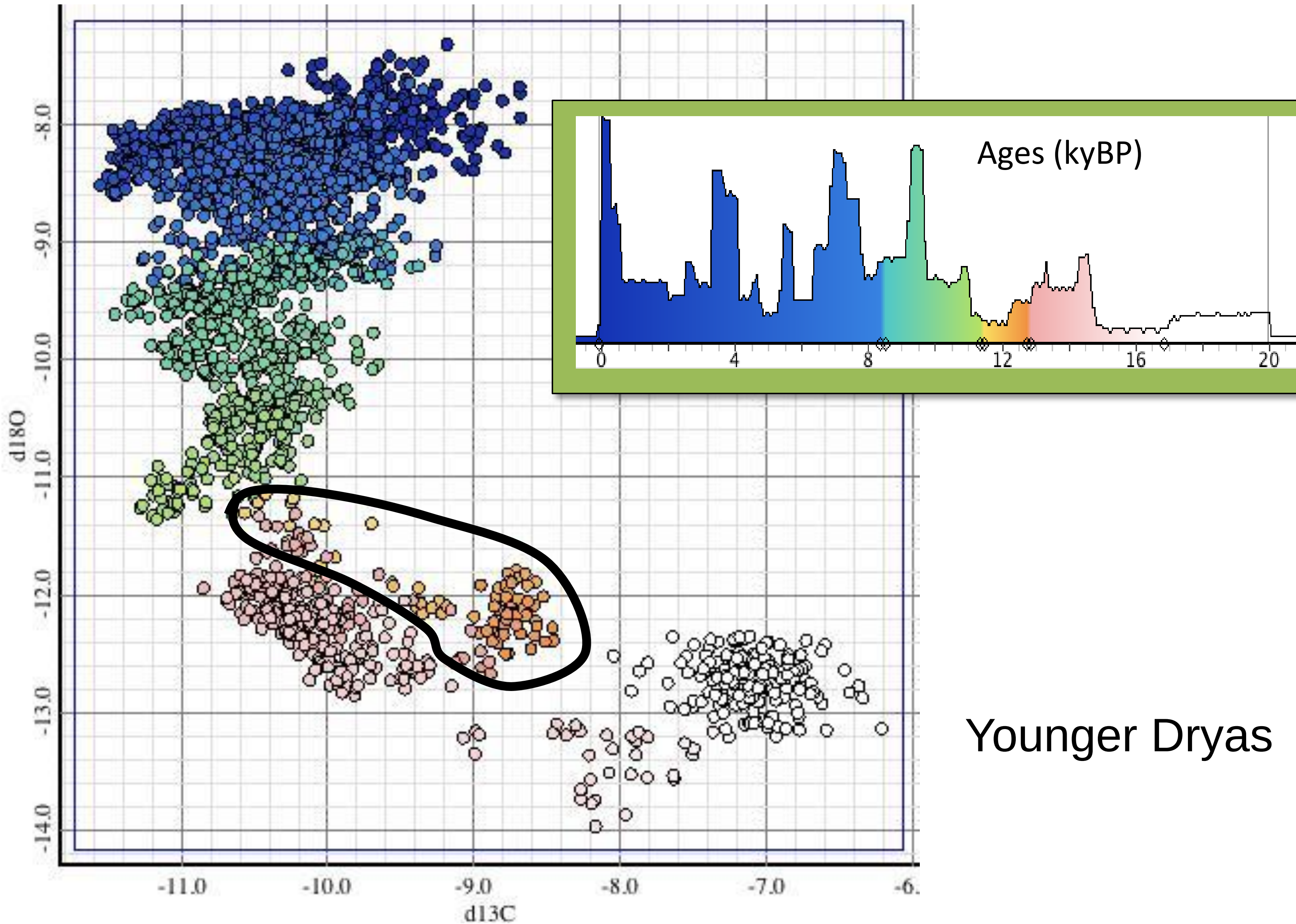

Ages (kyBP)
0
4
8
12
16
20
-8.0
-9.0
-10.0
-11.0
-12.0
-13.0
-14.0
d18O
-11.0
-10.0
-9.0
-8.0
-7.0
-6.
d13C
glacial



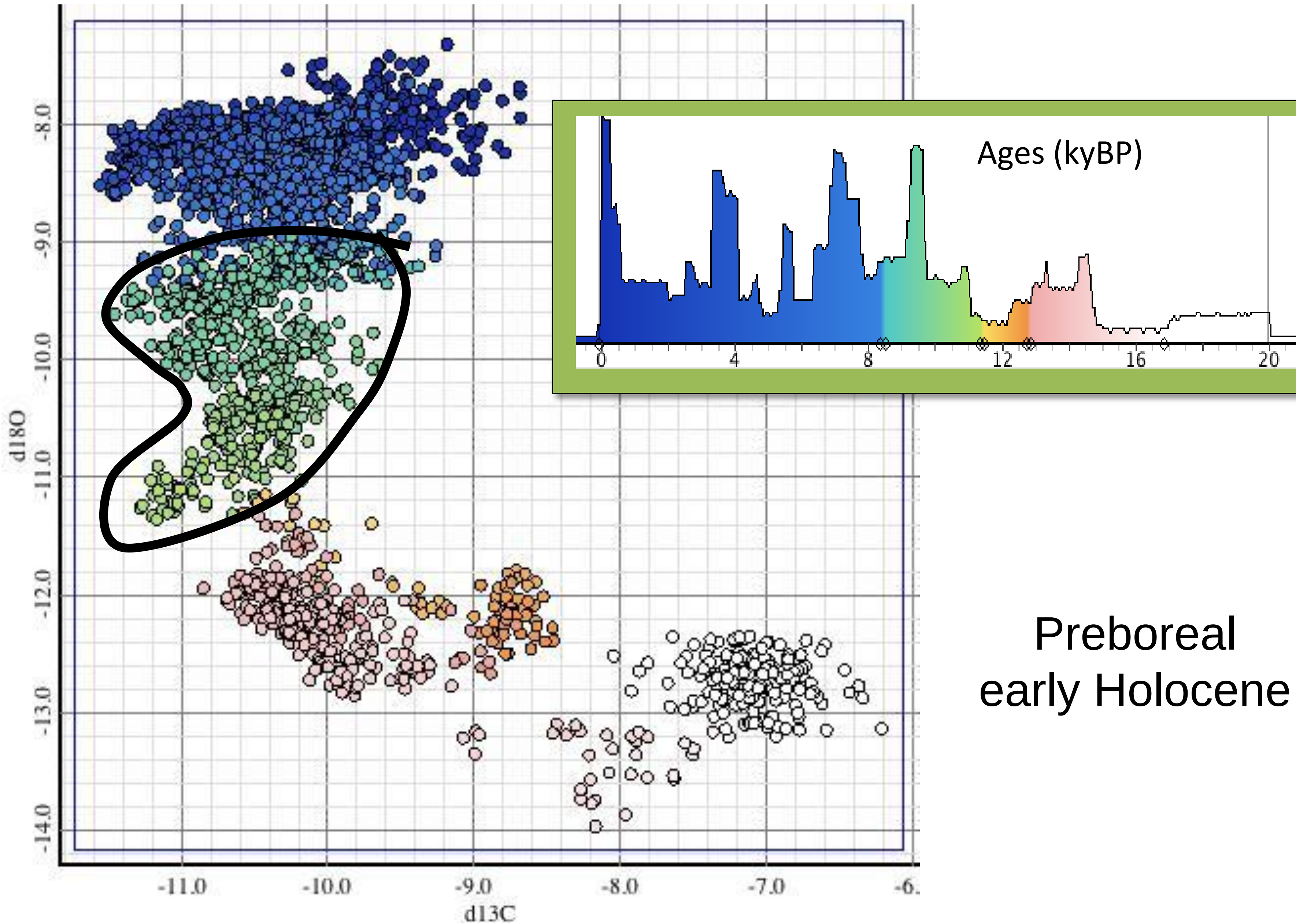
melt water
with red
sediment



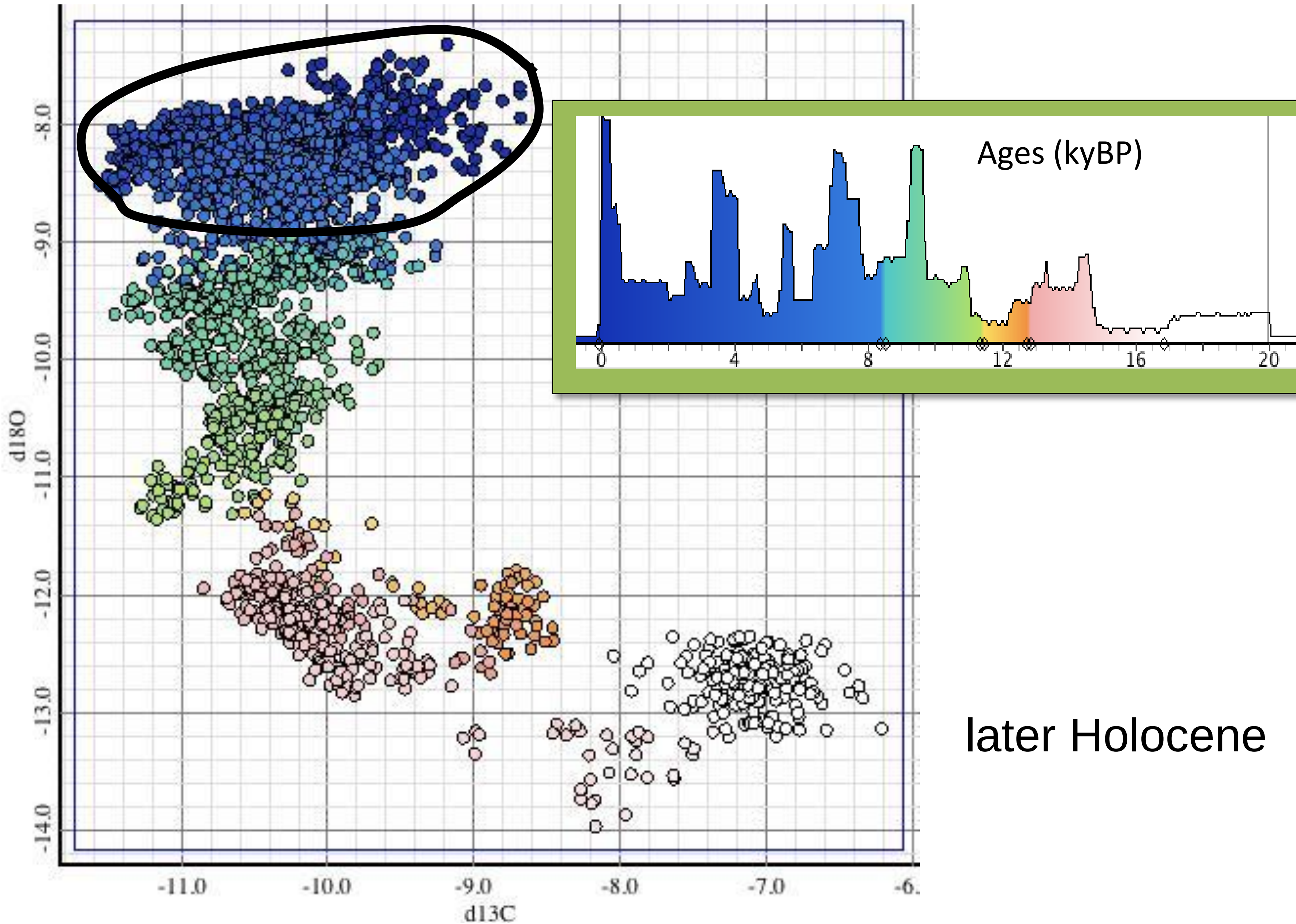
Bølling/Allerød



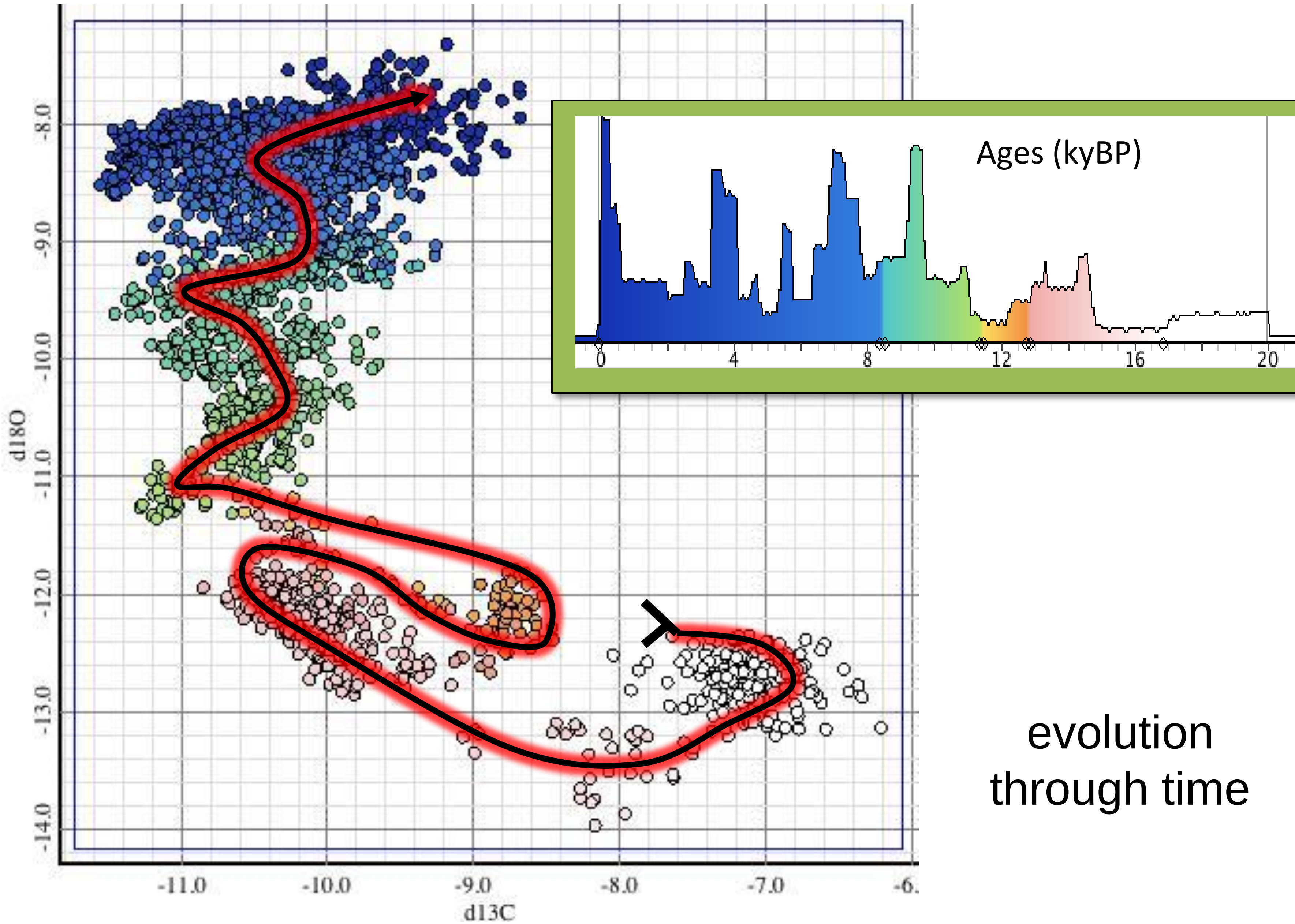
Younger Dryas



Preboreal
early Holocene



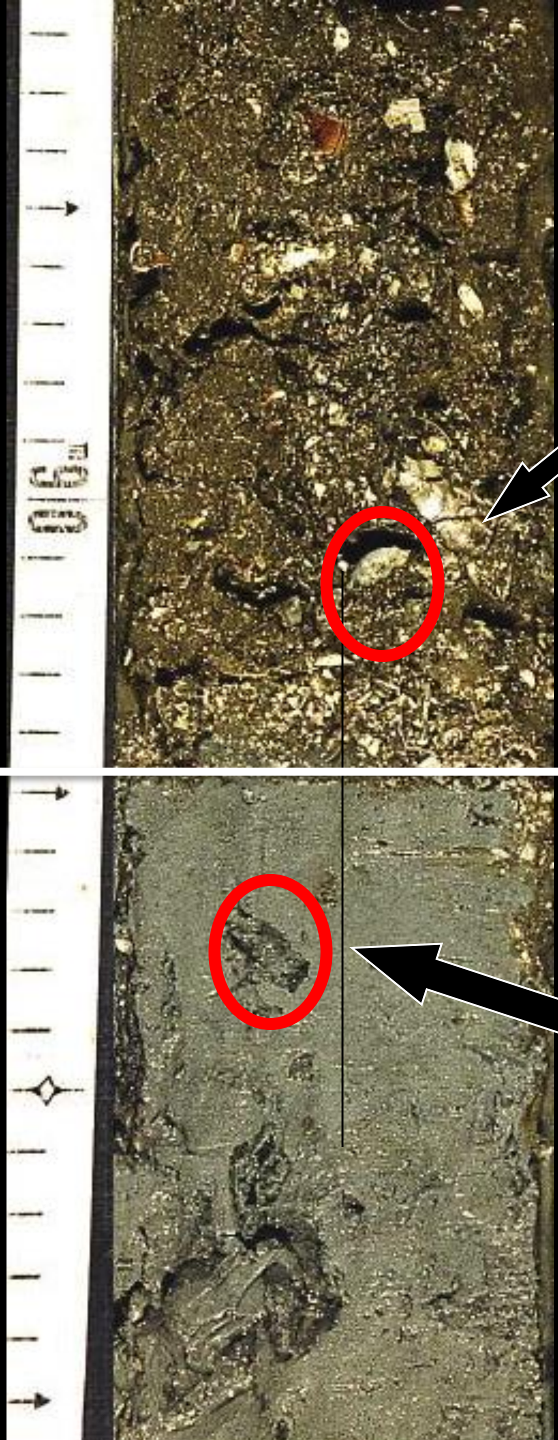
later Holocene



evolution through time

marine

fresh

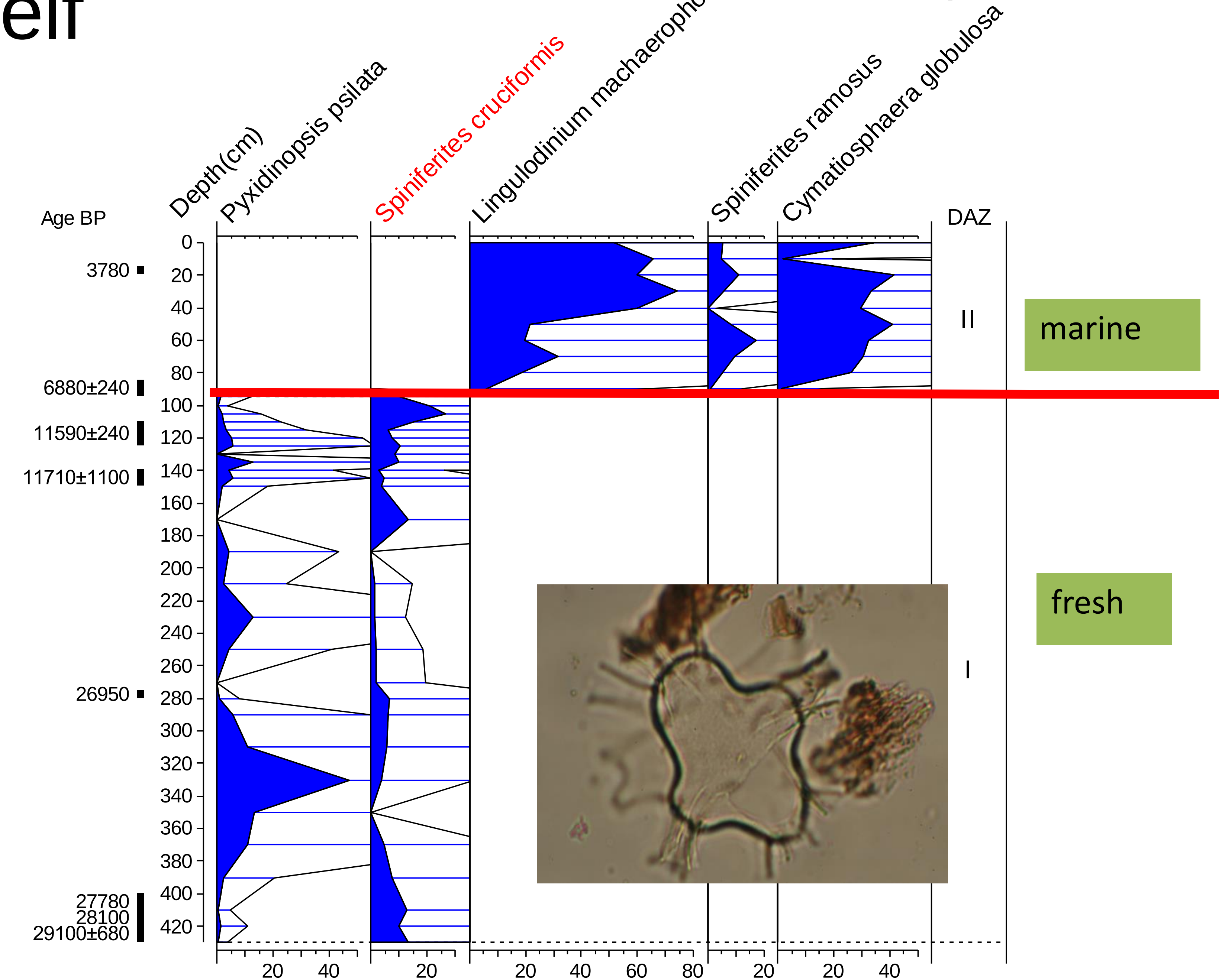


Mytilus galloprovincialis

Dreissena polymorpha

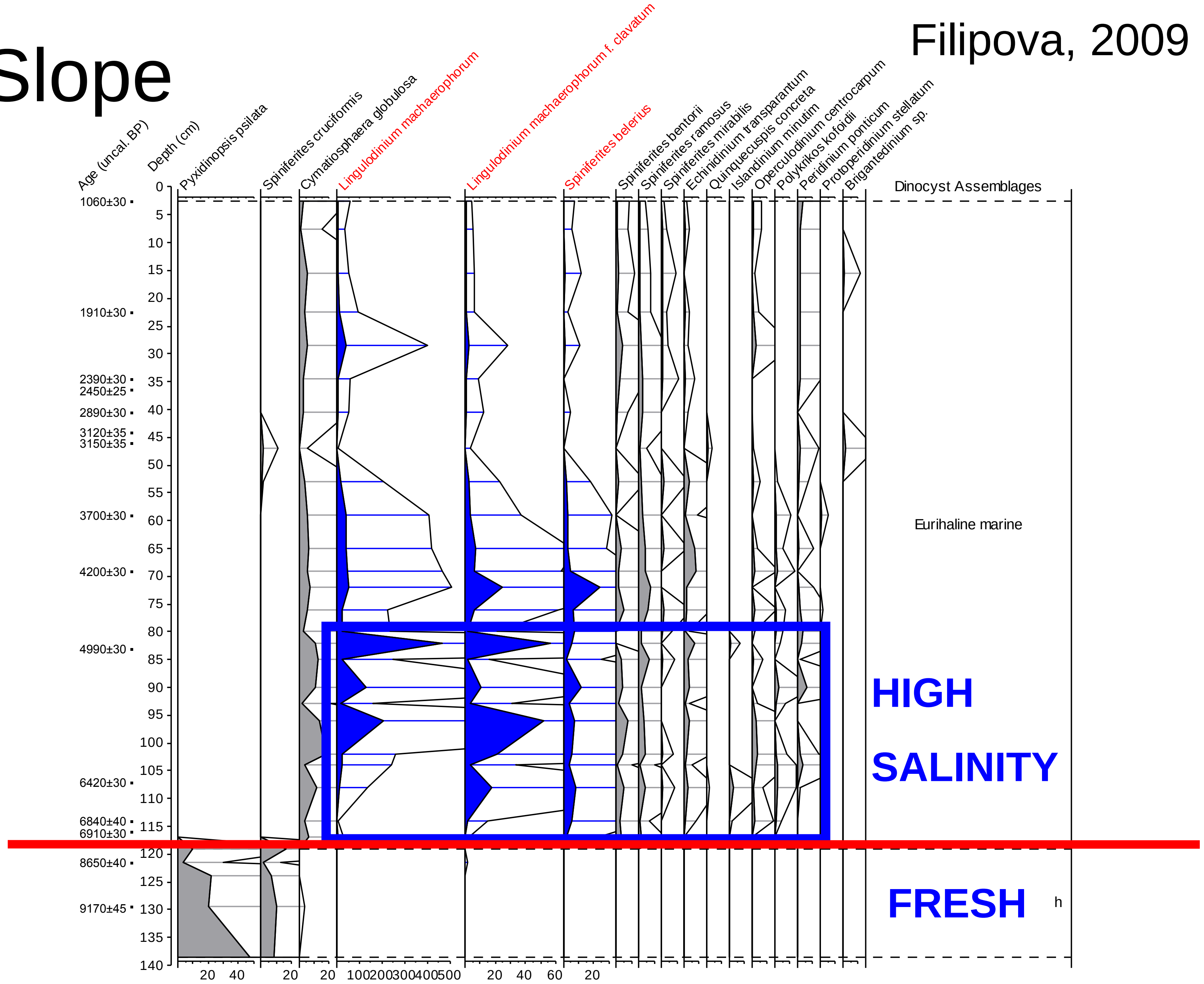
Shelf

Filipova, 2009

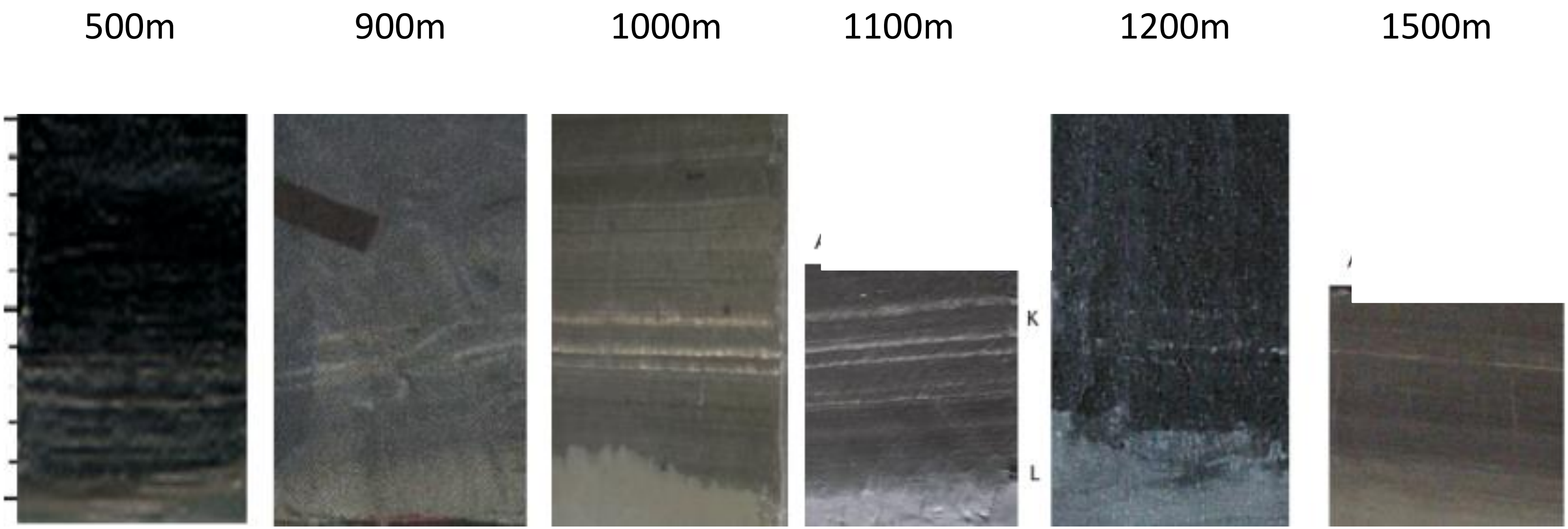


Slope

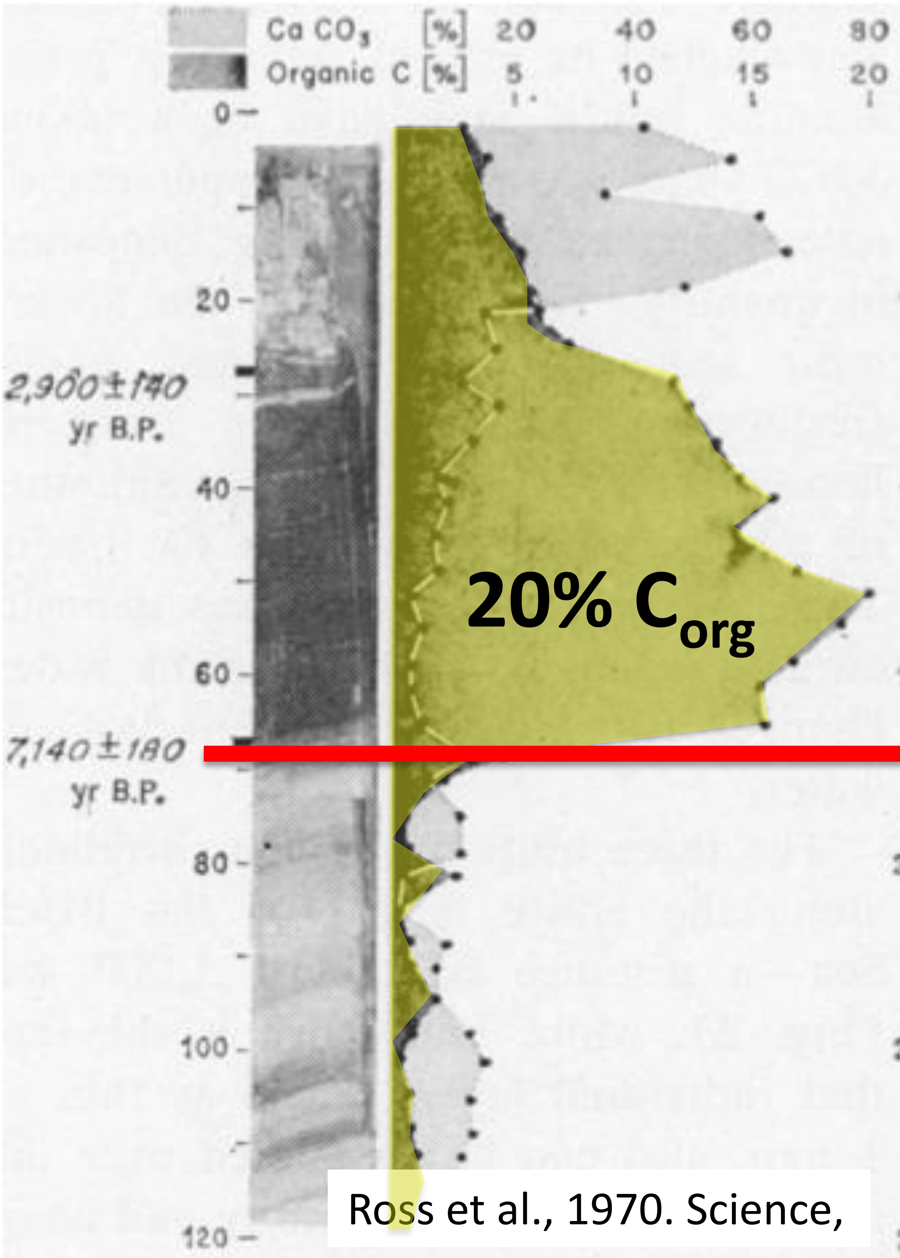
Filipova, 2009



After the introduction of Mediterranean saltwater the sediment becomes exceedingly rich in organic carbon beginning at exactly the same time at all water depths from shelf to abyss.



Core 1474 K



Ross et al., 1970. Science,

"On a dry-weight basis, the organic-matter content can reach almost 50 percent."

(Ross and Degans, 1974 AAPG Memoir)

An extraordinary reservoir of carbon!

“GEOCHEMICAL EVOLUTION OF THE BLACK SEA IN THE HOLOCENE”

Nikolai Mikhailovich Strakhov, 1971

“The enrichment of Black Sea sediments with organic matter coincided chronologically with the ingression of Mediterranean waters and with the emergence of hydrogen sulfide.”

“The accumulation of organic matter increased sharply, later on to drop considerably.”

What caused these changes?

"In the Black Sea it was not the hydrogen sulfide contamination in the near-bottom water that has given rise to the rich organic carbon content."

"On the contrary, it was the abundance of C_{org} in the muds that has caused the intensified generation of H_2S and its supply to the overlying water."

Strakhov, 1971.

“High concentrations of nutrient salts (N, P, SiO_2) were once present in the deeper waters of the New Euxine semi-freshwater basin that was then invaded by heavy Mediterranean waters.”

“By virtue of their greater weight the Mediterranean waters then, as now, sank to the bottom and spread over the seafloor. By the same token the mich-lighter semi-fresh water hydrochemical system was, as it were, uplifted, so that the once deep horizons with increased nutrient content entered the zone of photosynthesis to a progressively increasing extent.”

Strakhov, 1971.

"The accompanying rise in sealevel was, of course, compensated by the backflow of the uppermost freshened water layers through the Bosporus, these layers being the poorest in N, P, SiO_2."

"The reserve of P, N and SiO_2 stored in the deep horizons, and which had served as a basis for the bloom of plankton, was finite, and therefore could sustain that bloom for a limited time only."

Strakhov, 1971.

“The H_2S zone of the Black Sea contains at present large masses of nitrogen, phosphates and SiO_2 from the mineralization of dead plankton which sank to the bottom from the zone of photosynthesis. ”

Strakhov, 1971.

Lessons learned from the record of the past 25,000 years

- The properties of the Black Sea water have changed substantially in the span of just decades to centuries to millennia.

- The temperature, salinity, density, isotopic composition and biological productivity have had a great dependency upon climate. Climate changes global sealevel which is the causative mechanism for the opening and closing of the Bosporus Strait.

- **“Climate does the heavy lifting”**

So with this knowledge, can we prepare for future climate change?

- Mitigate against potential harm to Black Sea's water properties, ecosystems and coastal environments.

- Prevent further shoaling of the suboxic layer and future appearance of hydrogen sulfide on the continental shelf?

- Prevent rising sealevel and its threat to Black and Marmara Sea harbors, cities and wetlands.

A hydrogen sulfide bloom (green) stretching for about 150km along the coast of Namibia. As oxygen-poor water reaches the coast, bacteria in the sediment produce hydrogen sulfide which is toxic to fish.

Blue Stream gas pipeline

South Stream gas pipeline

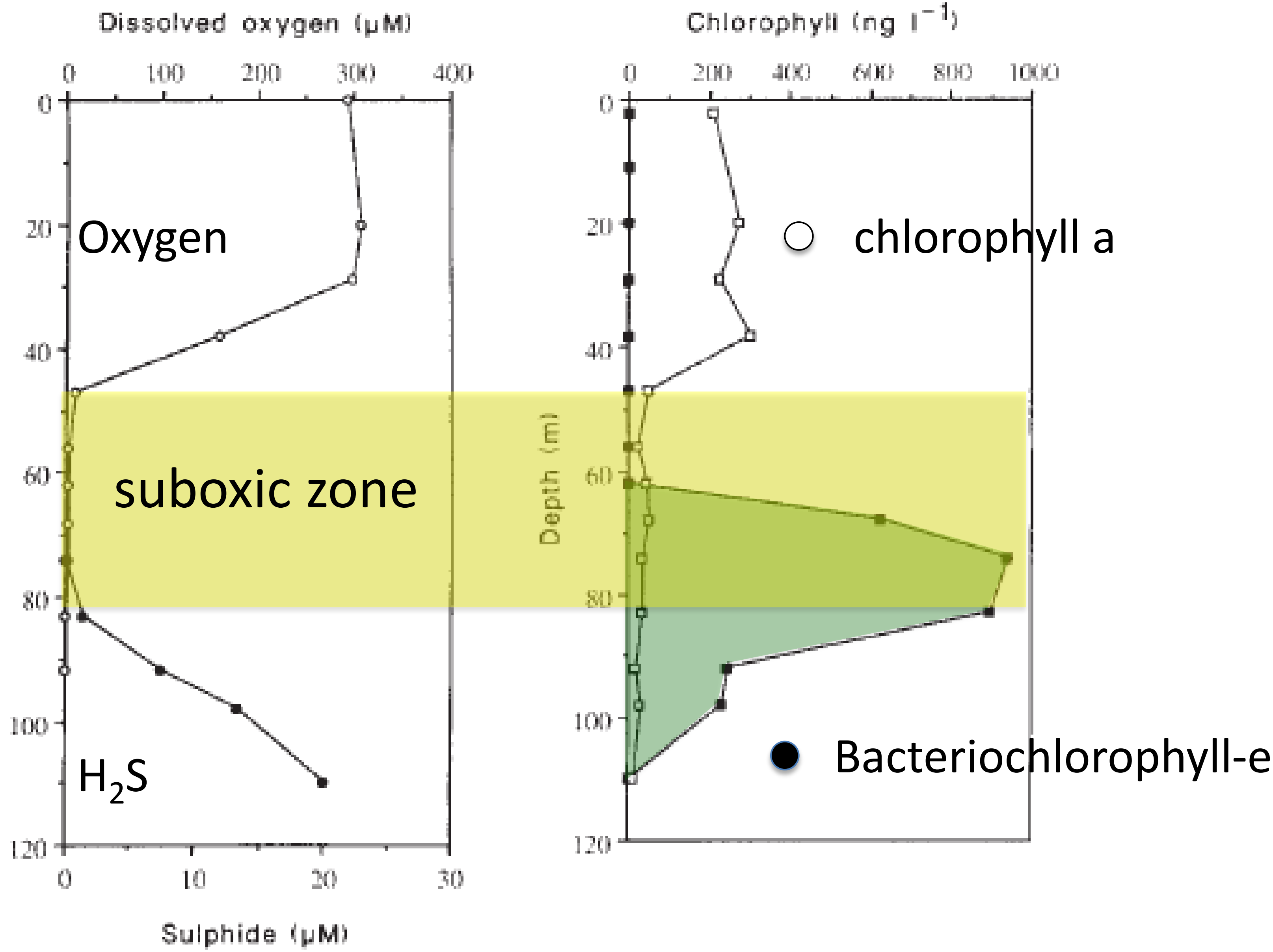
SAIPEM-7000 PIPE LAYING SHIP

www.gazprom.com


The Greenfield Energy Center in Courtright, Ontario

- Burn the natural gas in power plants offshore on the outer continental shelf of the Black Sea.
- Distribute the energy as electricity locally and into Europe using a much-needed new 21st century state-of-the-art grid.

- In the combustion produce CO, $C0_2$ and NOX.
- For cooling extract water from the cold intermediate layer and pump up water from the H_2S layer rich in P, N and SiO_2.
- Capture the CO, CO_2 and the NOX and mix it into the nutrient rich water extracted from deep pool of H_2S.
- Obtain carbon credits for the sequestration of the CO_2 to defray costs.



The Black Sea supports the largest community of green sulfur (anoxygenic) photosynthetic bacteria in the world.

Repeta et al. (1989)

The photosynthetic bacteria living at the top of the anoxic zone and the base of the euphotic zone are green sulfur bacteria.

They use photosynthesis to fix CO_2 and use H_2S as a source of electrons.

They were dominant in the mid-Proterozoic more than 1.5 billion years ago when the entire global ocean was anoxic.

Proposed Concept 1

Take advantage of the unique anoxic environment of your internal Black Sea to mimic the Proterozoic Ocean.

Exploit the requirement of water for cooling of the gas-fired power plant by uplifting (pumping) nutrients upwards from the cold interior of the Black Sea just as it happened naturally after the connection of the Black Sea with the Mediterranean 7,500 years ago as described by Strakhov, 1971.

In this offshore factory combine CO, CO2, NOX with SiO_2, P, N and H_2S to nurture vast blooms of green sulfur (anoxygenic) photosynthetic bacteria and other plankton (such as haptophytes) below and above the suboxic zone, especially when it shoals more and more into the photic zone as a consequence of global warming.

Proposed Concept 2

As more and more river water is diverted to agriculture, industry, and residential demands, the balance between freshwater input and loss from evaporation will change. The Black Sea experienced such a negative hydrologic budget during the rapid climate warming of the early Holocene.

Create a barrier (first submerged, and later exposed) across the bottom of the Dardanelles entrance. Use the barrier to regulate the amount of incoming Mediterranean salt water. Use this regulation to maintain the sea surface in the Black and Marmara Seas at or near its current height to protect the surrounding harbors, coasts and wetlands from submergence as the ice caps of Greenland and West Antarctica continue to shrink from global warming.

A Dardanelle Dam and Locks already exists.

But it is across the Arkansas River in the United States!.

CONCLUSION

The very special and unique properties of the Black Sea, both today and in its past, offer the possibility of engineering for a better Black Sea future.

This conference can act as a springboard to discuss and evaluate the feasibly of environmental engineering as a means of coping with future climate change and heightened global warning.

I look forward to meeting and talking with many of you during the next three days.

ACKNOWLEDGEMENTS

Many thanks to my colleagues from Russia, Romania, Bulgaria, Turkey, France, Israel and the USA that I have worked with aboard ship in the Black Sea and in the laboratory.

Special gratitude to the Institute of Oceanology-Bulgarian Academy of Sciences for the very successful expeditions aboard their research ship AKADEMIK.

Petko Dimitrov, Dimitar Dimitrov, Mariana Filipova-Marinova, Candace Major, Anastasia Yanchilina and Raymond Sambrotto for their scientific contributions.

ENGINEERING FOR THE BLACK SEA FUTURE

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Keywords: carbon dioxide, greenhouse, hydrogen sulfide, hydrologic deficit, sequestration

It is now evident that our human society is not going to reduce its demand for fossil fuels before the level of carbon dioxide in the atmosphere reaches such extremes that rising sea level and increasing annual temperatures become inescapable and our Black Sea environment is radically altered. The Danube delta with its vital wetlands will submerge as well as our coastal cities with their historical heritage and economic importance. Surface salinity will increase, the pycnocline will shoal, and the poisonous hydrogen sulfide within the interior of the sea will threaten fisheries and our breathable air during storms of predicted greater intensity. Either we wait for this to happen, or we take action in planning for and then undertaking the engineering to minimize the impact. The delivery of fresh river water is diminishing as more and more of this resource is diverted to support agriculture and industrial consumption. The climate history of the Black Sea shows two post-glacial periods of rapid warming when the Black Sea lake lost its outflow to the global ocean. This condition of hydrologic deficit lies in our future as the atmospheric greenhouse returns us to the intense heat and aridity of the past.

I propose that when applying our knowledge for societal benefit we consider two engineering projects. The first is to take the hydrocarbons arriving at our Black Sea coasts through the new undersea pipelines and burn these resources at the edge of the sea to make electricity for consumption and export. Capture the carbon dioxide there and pump it into the abyss to oxidize the hydrogen sulfide and detoxify the Black Sea interior. Use the money from the carbon tax income during sequestration and the selling of the electricity to pay for the enterprise. The second project is to build a dam across the Dardanelles so that the combination of rising external global sea level and the internal hydrologic deficit can be balanced to keep the surface of the Black and Marmara Seas close to the present height. Increasing salinity in the Black Sea is inevitable even without a dam. The reduced contrast between the salinity and hence the density of the surface and interior water will eventually lead to an overturn of the water masses. Either we begin to detoxify the interior or nature will take its course with consequences for the coastal environment.

We have at MARES2020 the scientists, industry and policy experts assembled to address sustainable management. This conference provides the ideal opportunity to put all of our ideas on the table for discussion and consideration as we engage in the strategic planning for HORIZON 2020.