

A map of the North Atlantic region, showing the eastern coast of North America, Greenland, and Iceland. The map is overlaid with a grid of latitude and longitude lines. Several sampling locations are marked with red dots and labeled: WEST GREENLAND SHELF, LABRADOR SHELF, GRAND BANKS, DISKO-NUUSSUAQ, KANGERLUSSUAQ, ICELAND, FAEROE SHELF, ROCKALL, and PORCUPINE. The text "LABRADOR" is also visible on the North American coast. The title "Paleogene Oceanography and Climate of the North Atlantic" is centered over the map in large, bold, black font. Below the title, the subtitle "The key to a regional biostratigraphic scheme" is also centered in bold, black font. At the bottom, the author's name "Dr Jonathan Bujak" and his affiliation "Bujak Research International Ltd" are centered in bold, black font.

Paleogene Oceanography and Climate of the North Atlantic

The key to a regional biostratigraphic scheme

Dr Jonathan Bujak

Bujak Research International Ltd

A map of the North Atlantic region, including parts of North America, Greenland, and Europe. The map is overlaid with a grid of latitude and longitude lines. Several sampling locations are marked with red dots and labeled: WEST GREENLAND SHELF, LABRADOR SHELF, GRAND BANKS, DISKO-NUUSSUAQ, KANGERLUSSUAQ, ROCKALL, FLOE-SHETLANDS, and PORCUPINE. The text 'The Challenge' is centered on the map in a large, bold, black font. Below it, a paragraph of text is also centered, describing the goal of the study.

The Challenge

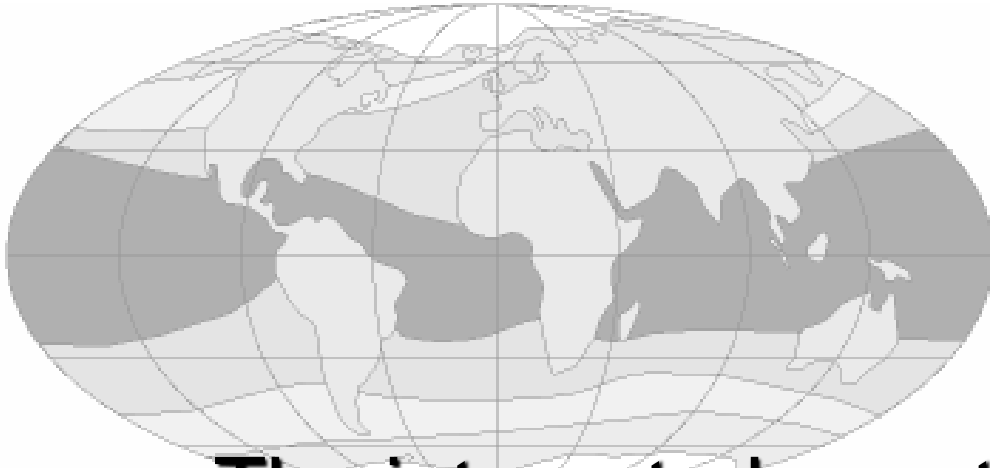
To erect a palynological-foraminiferal zonation for the North Atlantic region including the North Sea and adjacent basins.

A map of the North Atlantic region, including parts of North America, Greenland, and Europe. The map highlights several geological features: the West Greenland Shelf, Labrador Shelf, Grand Banks, Porcupine, Rockall, and Faeroe-Shetlands. Sampling sites are marked with red dots. Key locations on Greenland are labeled: Disko-Nuussuaq and Kangerlussuaq. The text 'The Strategy' is overlaid on the map.

The Strategy

Integrate the zonation with plate tectonic, mantle plume, oceanographic and climatic events that affected the region.

icehouse



Spinoffs

The integrated zonation highlights

bioevent diachronism in

different basins that resulted from

the greenhouse to icehouse shift.



greenhouse

The image is a paleogeographic map of the North Atlantic region. It shows the continental shelves of Laurentia (North America) and Greenland. Key features include:

- Baffin Bay:** A large body of water to the north of Greenland, containing a pink oval highlighting a specific area.
- Greenland:** A large landmass in the center, with a pink oval highlighting its eastern coast.
- Laurentia:** The North American continent to the west.
- North Sea:** A body of water to the east of Greenland.
- DAV STRAIT HIGH:** A pink shaded area representing a high in the Davis Strait, with a white arrow pointing north.
- Other features:** Labels for 'RHB', 'WTR', 'RT', and 'PB' are scattered in the North Atlantic. A blue shaded area is visible in the lower part of the map, with white arrows indicating flow directions.

Plus microfaunal differences resulting from basin isolation during the Paleocene – Eocene transition.

**As well as potential Paleogene
oil-prone source rocks.**

Disko-
Nuussuaq

GREENLAND

Kangerlussuaq

ICELAND

LAB

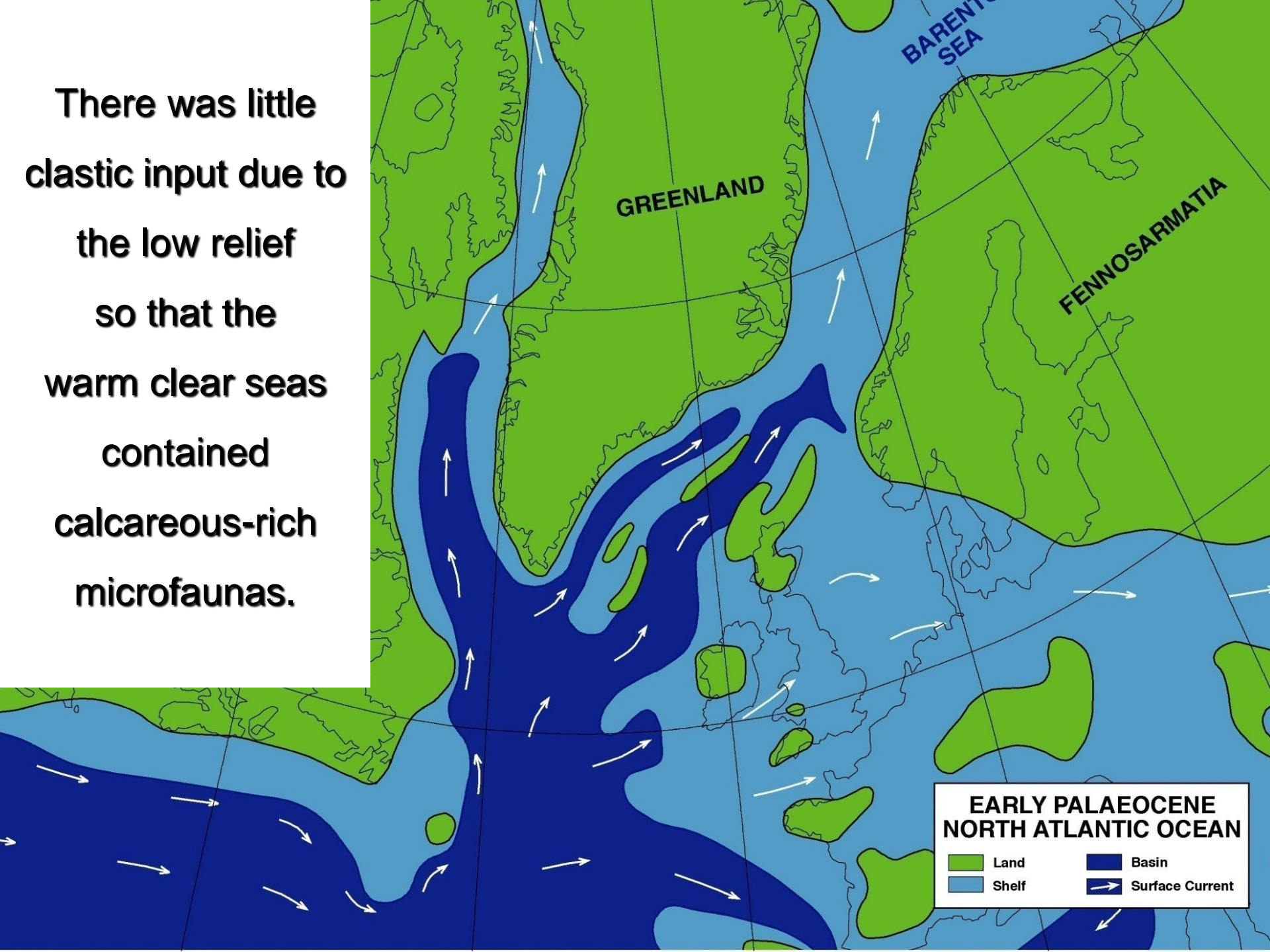
WEST GREENLAND SHELF

**First let's look at how plate tectonic opening
and Greenland mantle plume uplift
affected North Atlantic oceanography.**

Early Paleocene

**Prior to uplift of the Greenland plume
the North Atlantic and NW Europe
comprised an open marine region
dotted with low subtropical islands.**

There was little
clastic input due to
the low relief
so that the
warm clear seas
contained
calcareous-rich
microfaunas.



**EARLY PALAEOCENE
NORTH ATLANTIC OCEAN**

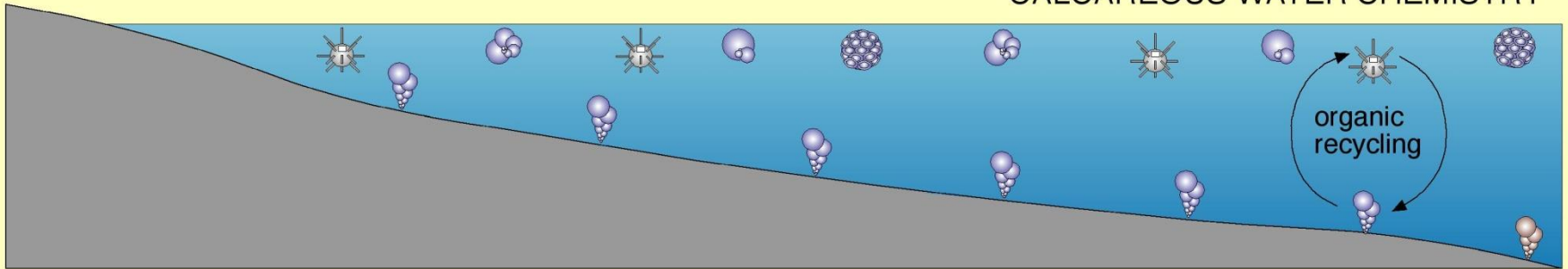
Land	Basin
Shelf	Surface Current

Including calcareous foraminifera and nannoplankton

NORTH SEA DANIAN MARINE BIOFACIES

LOW RELIEF
LITTLE CLASTIC INPUT

CALCAREOUS WATER CHEMISTRY

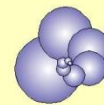


CALCAREOUS



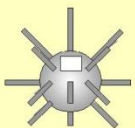
benthic foraminifer

CALCAREOUS



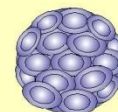
planktonic foraminifera

ORGANIC WALLED



dinoflagellate cysts

CALCAREOUS



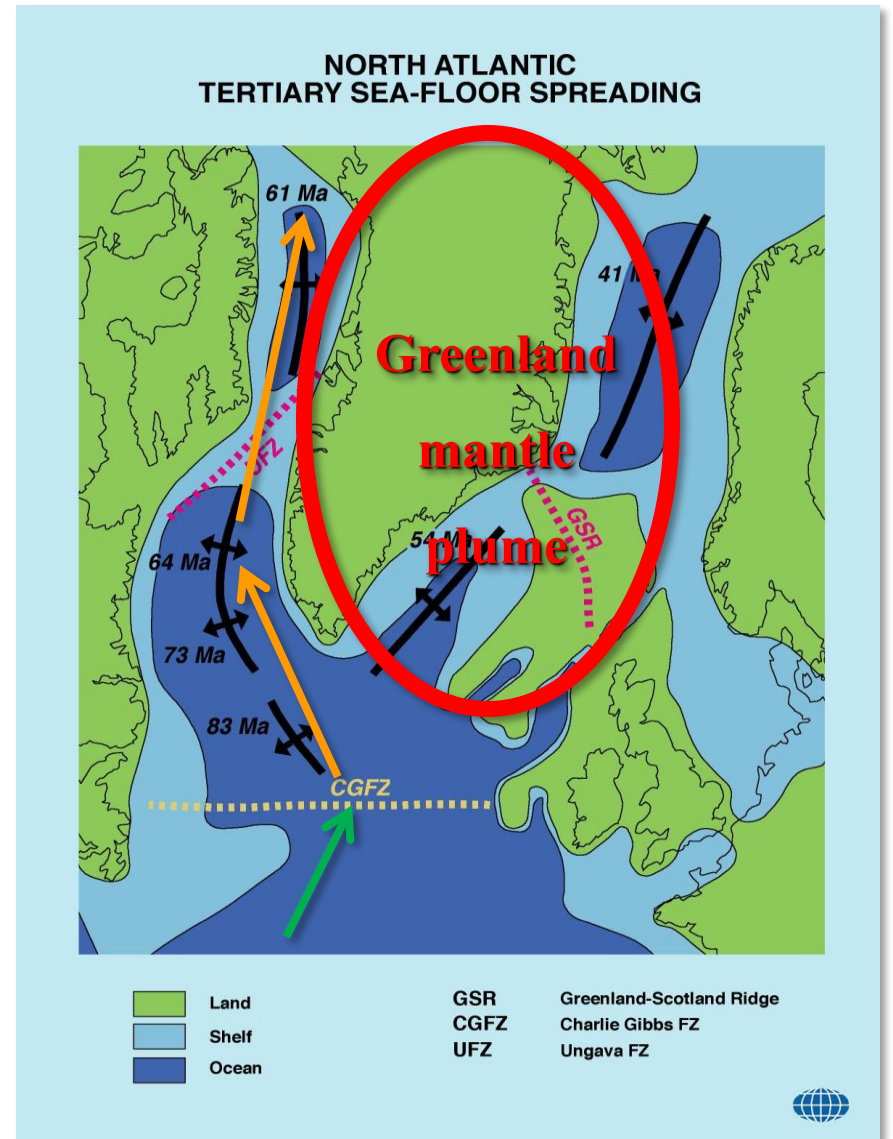
coccoliths

Late Paleocene

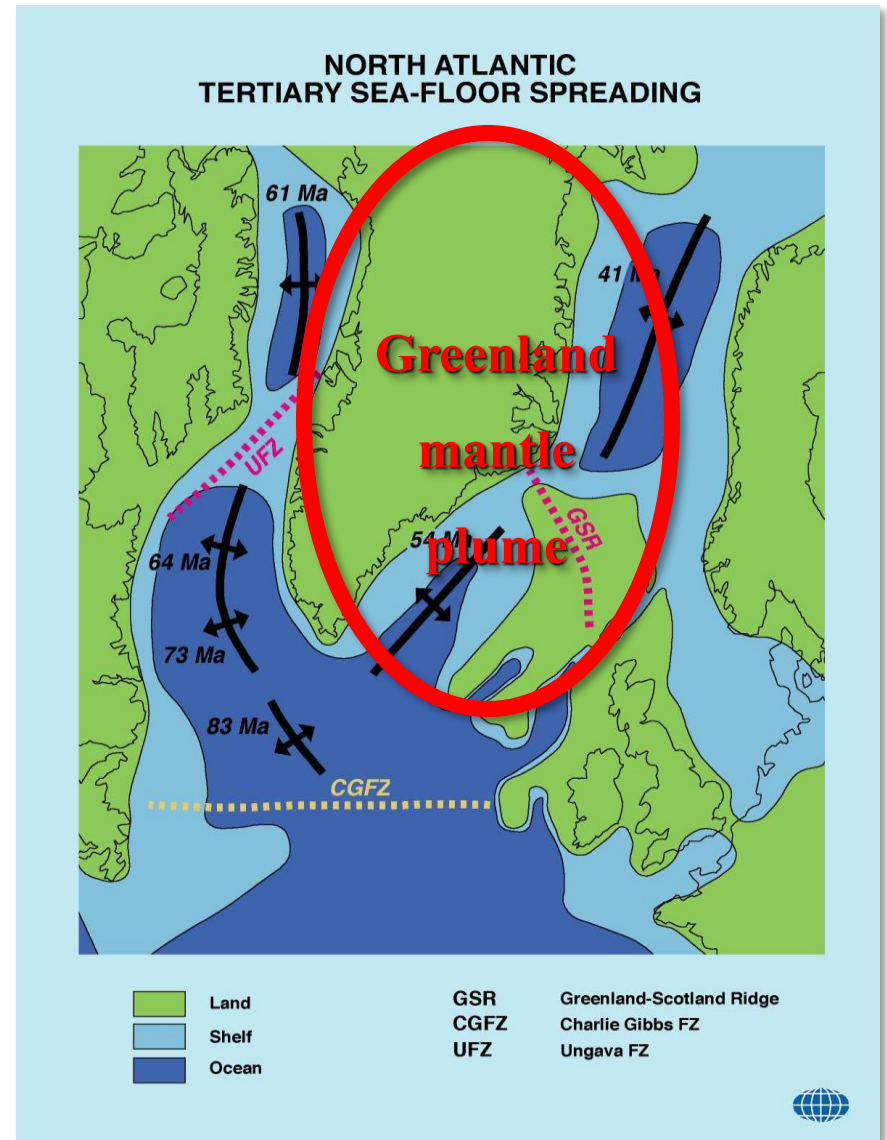
But uplift of the Greenland mantle plume
had a major impact on both
the sedimentation and microfaunas.

It diverted North Atlantic plate
tectonic opening to the west
of Greenland

→ late Paleocene
→ Late Cretaceous

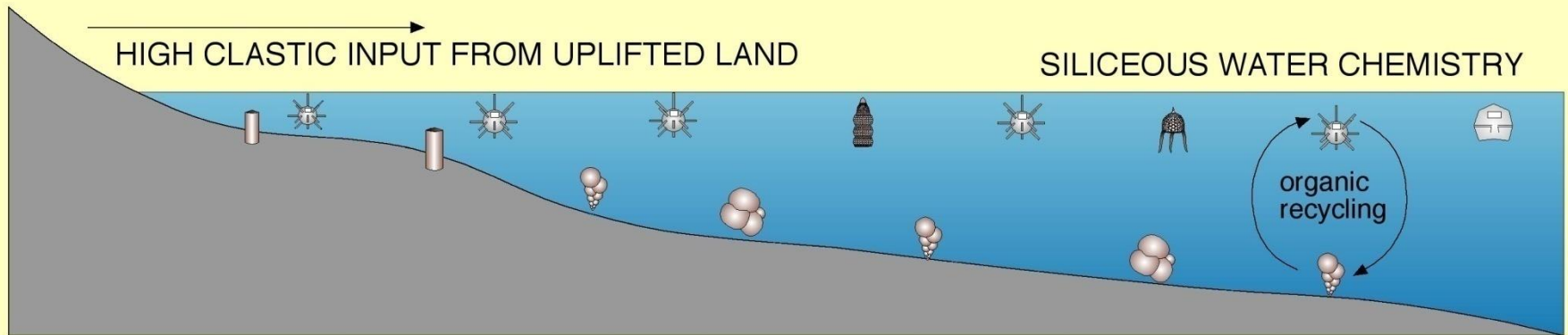


and it increased the amount
of clastic input into the basin
around the
uplifted plume.....

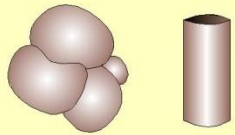


.....resulting in a shift from calcareous to siliceous microfossils especially in the North Sea, Norwegian-Greenland Sea and NW Europe

NORTH SEA SILICEOUS MARINE BIOFACIES

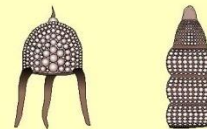


SILICEOUS BENTHIC



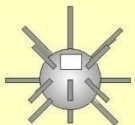
arenaceous
foraminifera

SILICEOUS PLANKTONIC



radiolaria
sporadic diatoms

ORGANIC WALLED PLANKTONIC



photosynthetic
dinoflagellates

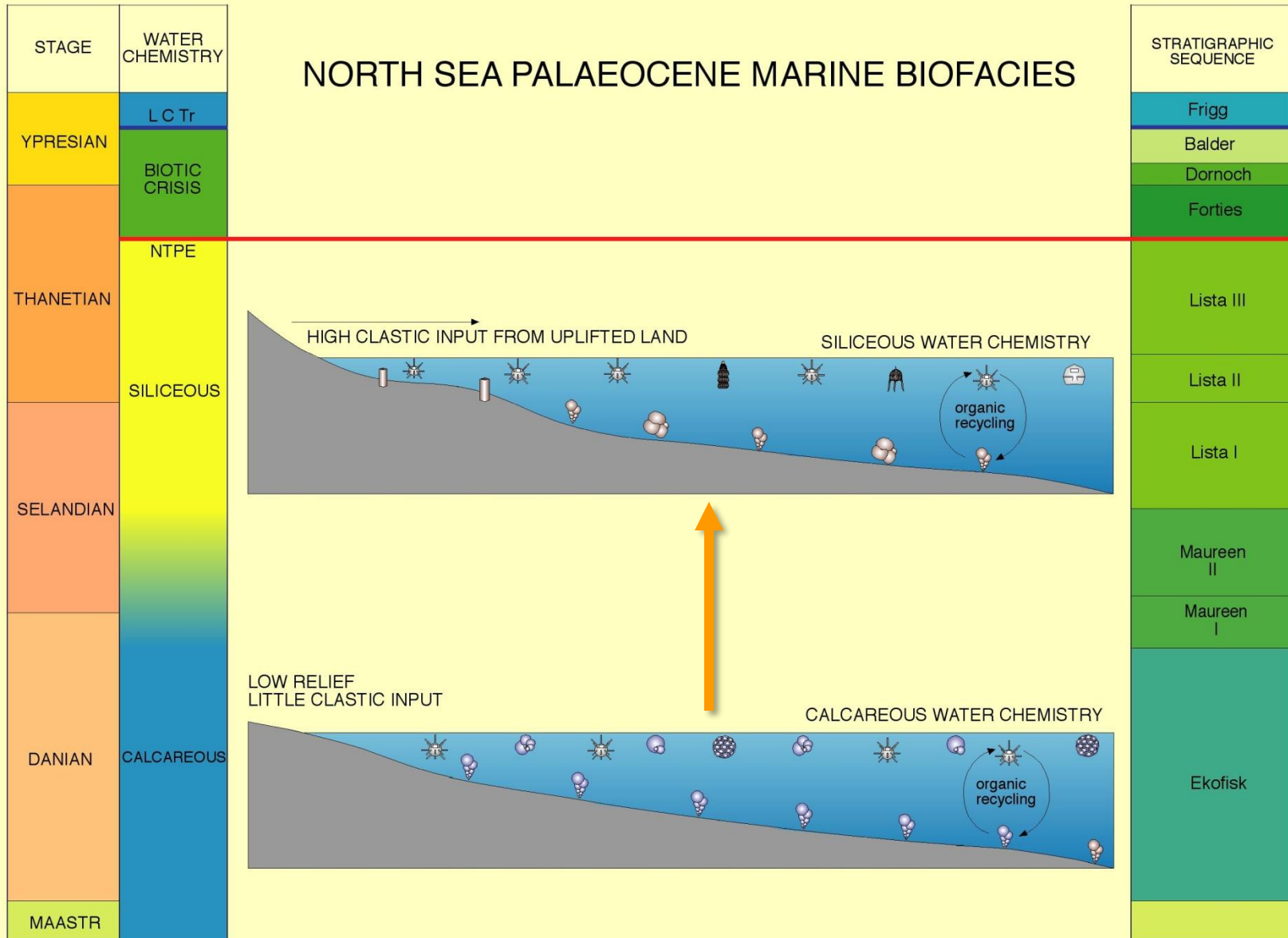


carnivorous
dinoflagellates

as seen in the early to late Paleocene shift from calcareous-rich to siliceous-rich assemblages

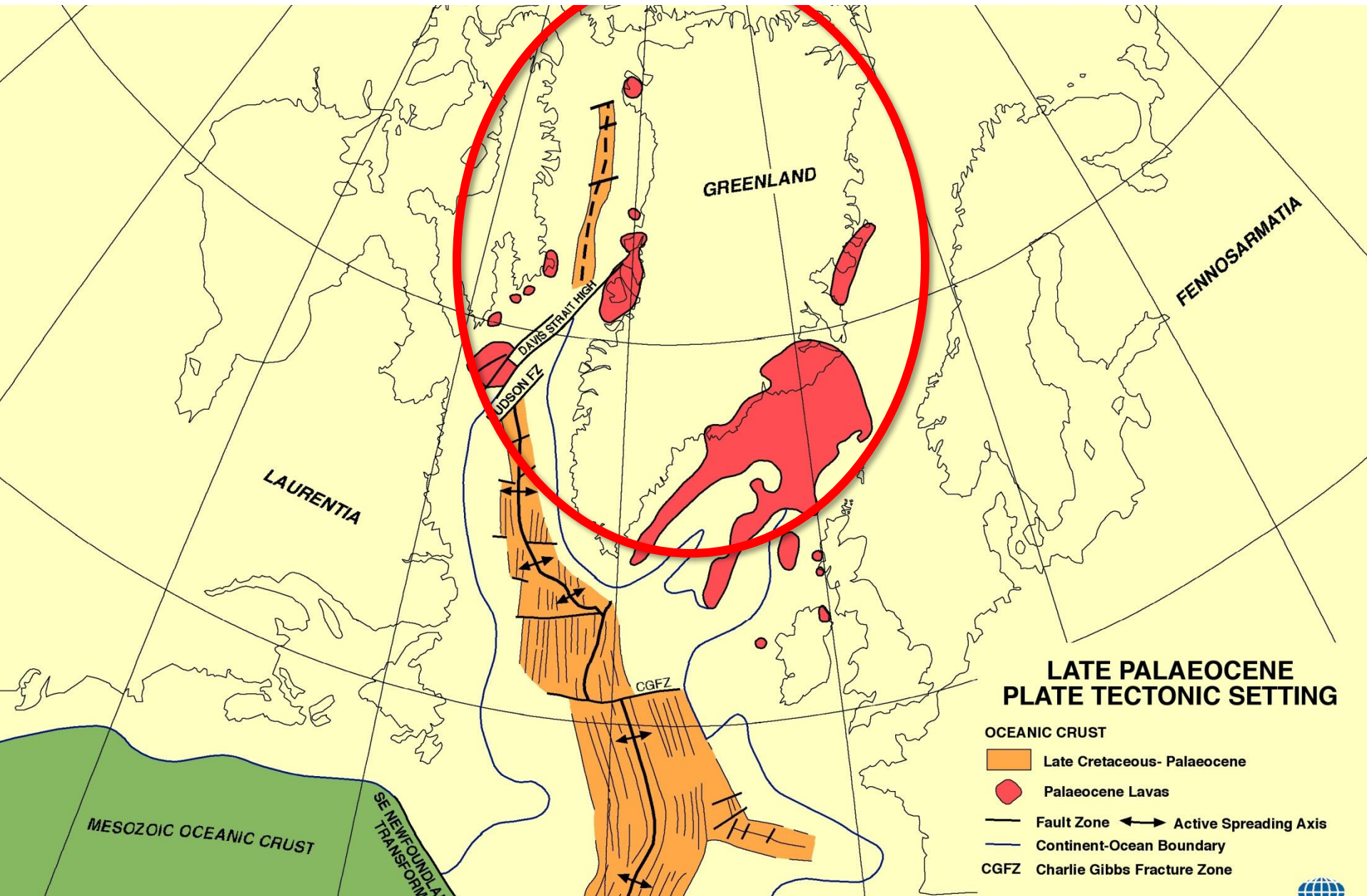
mantle plume uplift

NORTH SEA PALAEOCENE MARINE BIOFACIES

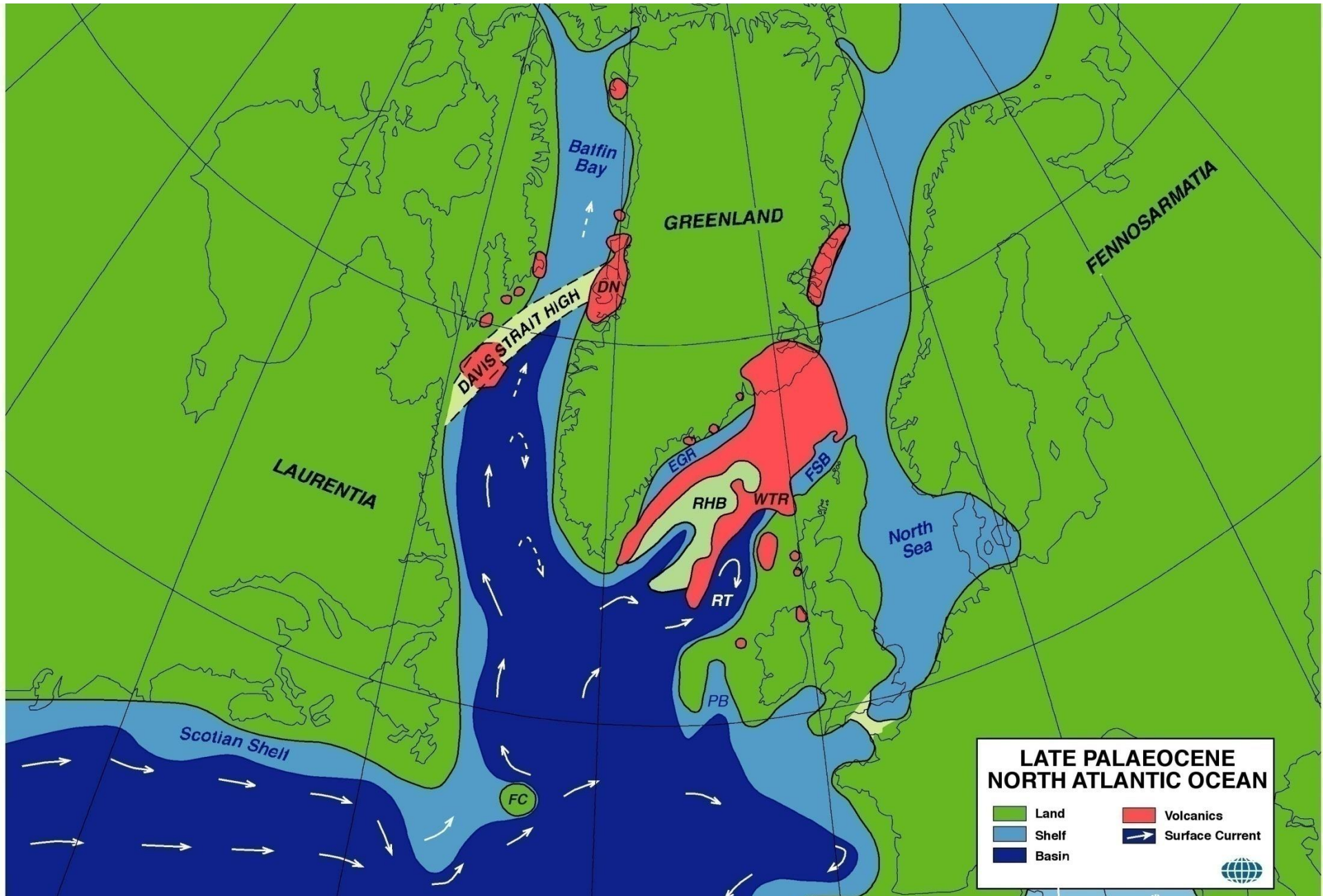


But the greatest change occurred during
the Paleocene-Eocene transition

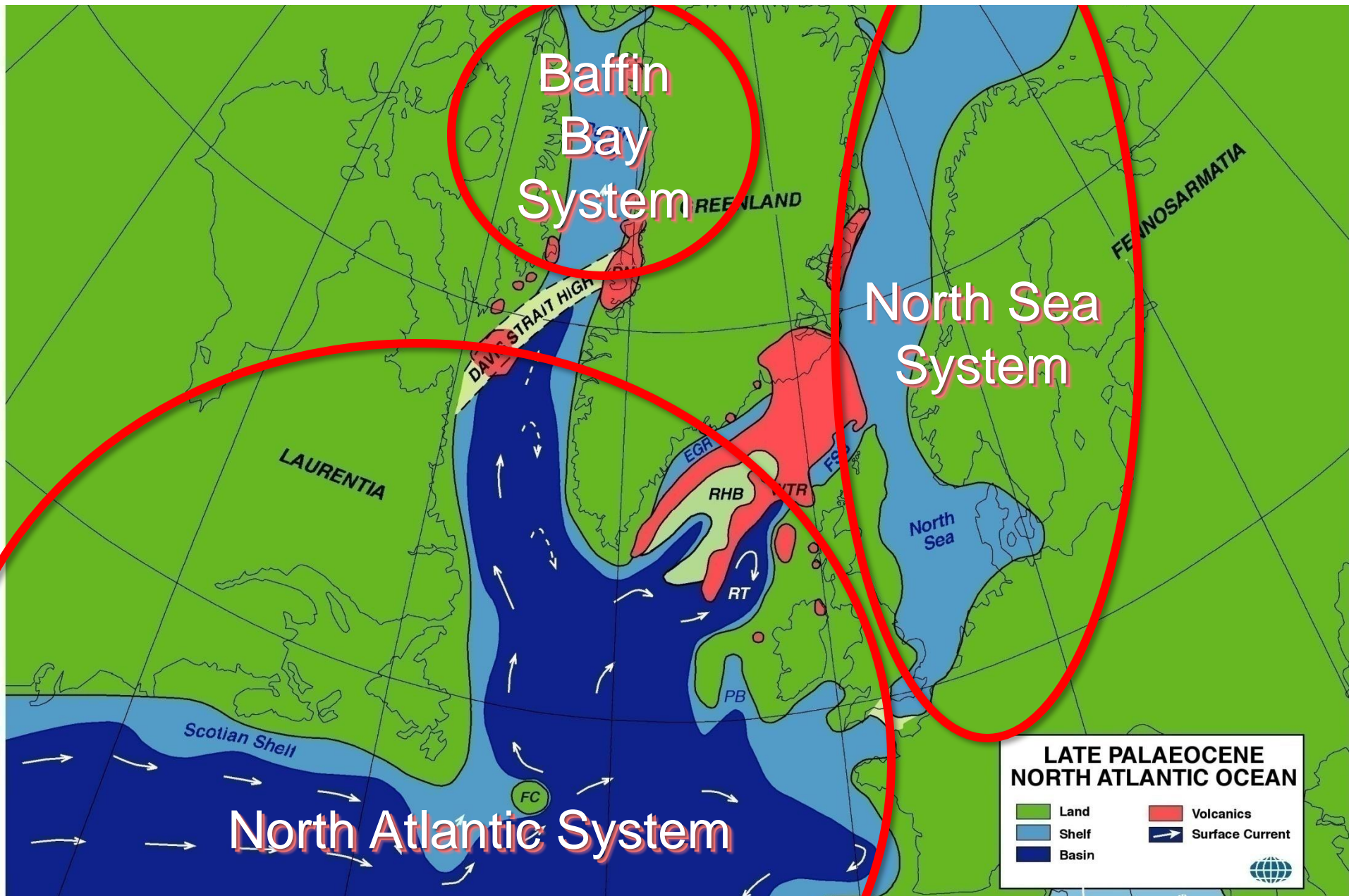
because this was the period of maximum mantle plume uplift

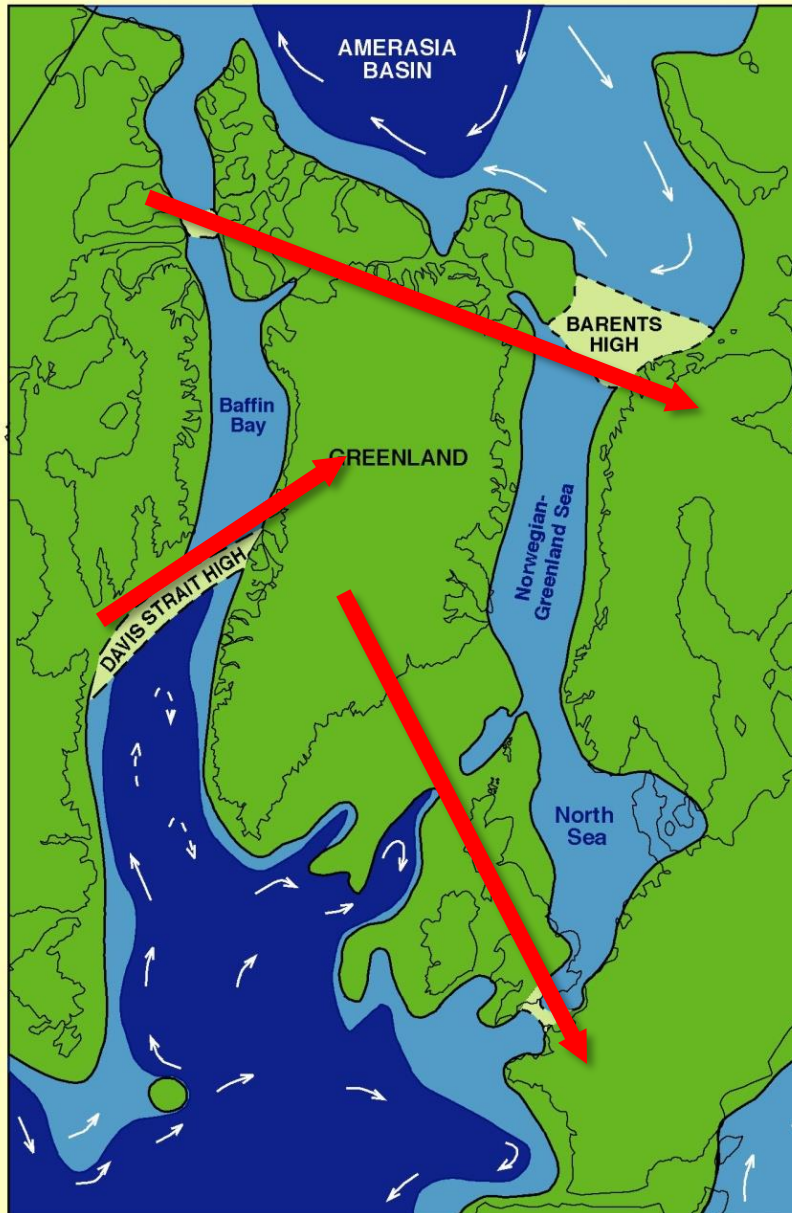


resulting in an enormous shift in the oceanographic framework



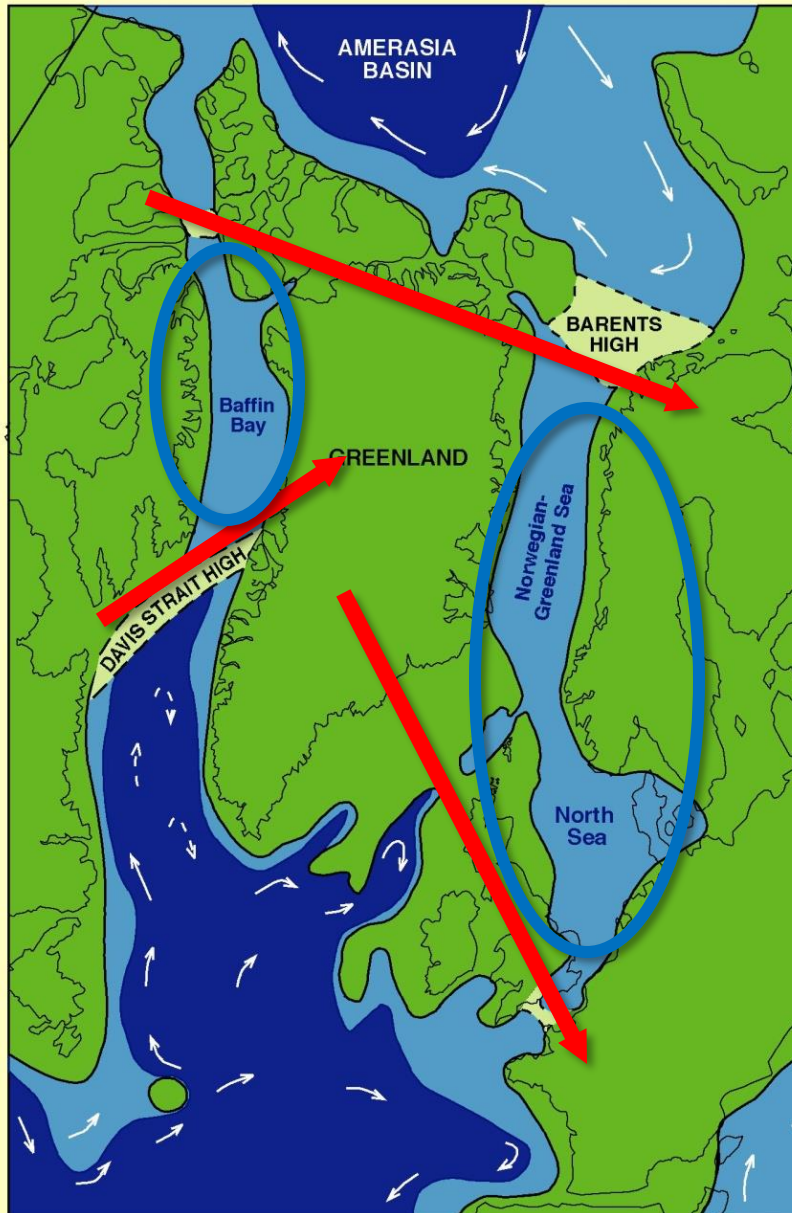
and the separation of three distinct marine systems.





LATEST PALEOCENE AND EARLIEST EOCENE BASIN ENCLOSURE

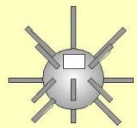
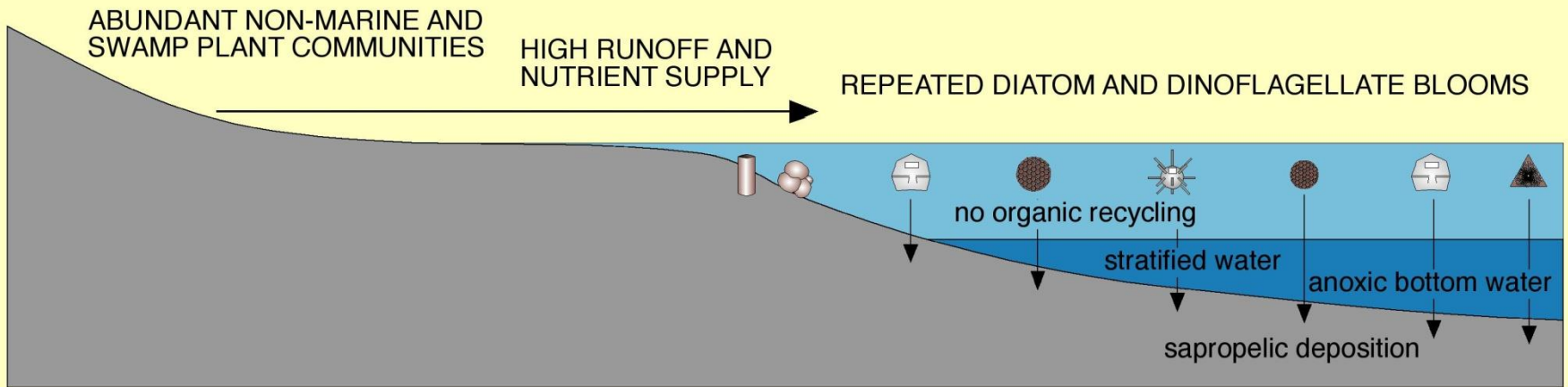
It also resulted in
land bridges
used for mammalian
migrations



LATEST PALEOCENE AND EARLIEST EOCENE BASIN ENCLOSURE

as well as massive changes in marine biotas within the enclosed basins

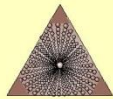
causing the North Sea biotic crisis



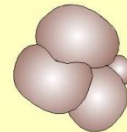
photosynthetic dinoflagellates



carnivorous dinoflagellates

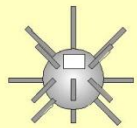
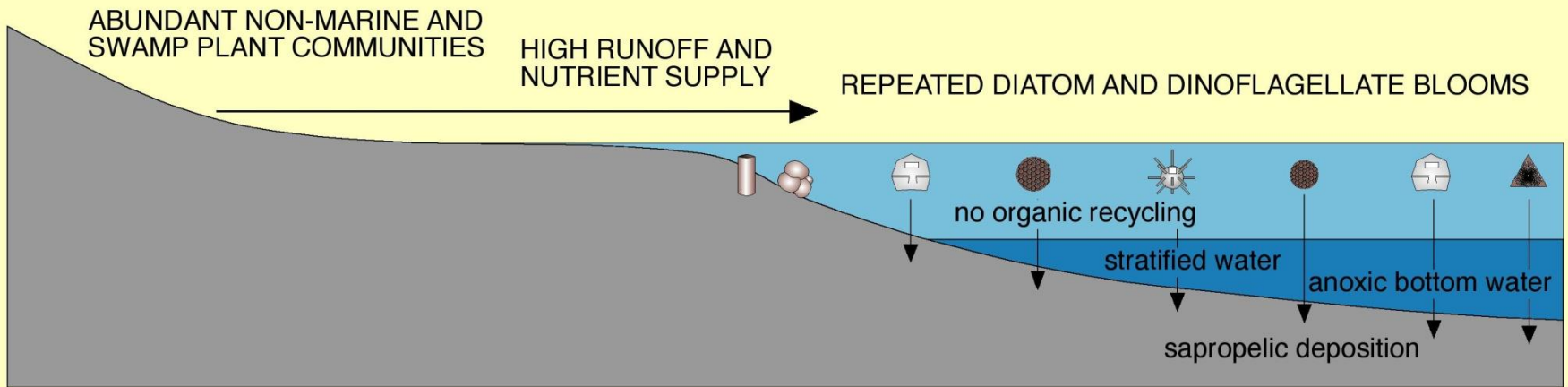


diatoms



arenaceous foraminifera

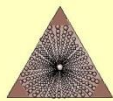
with the microfaunal assemblages becoming dominated first by arenaceous forams and then by coscinodiscid diatoms.....



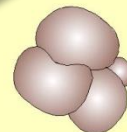
photosynthetic dinoflagellates



carnivorous dinoflagellates

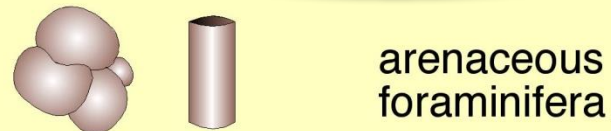
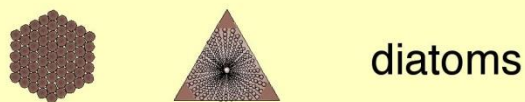
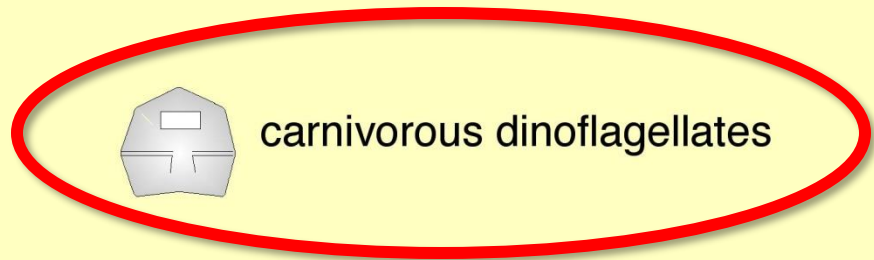
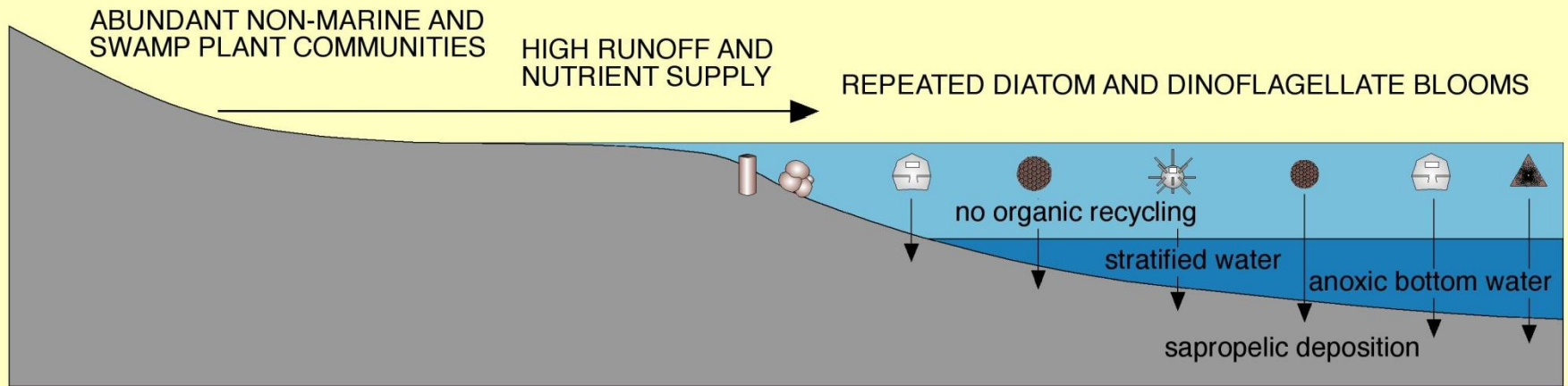


diatoms

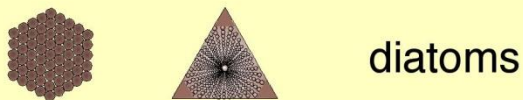
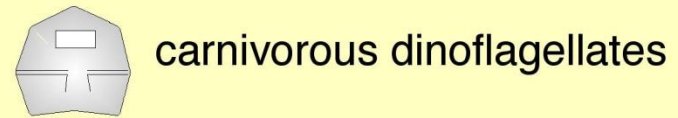
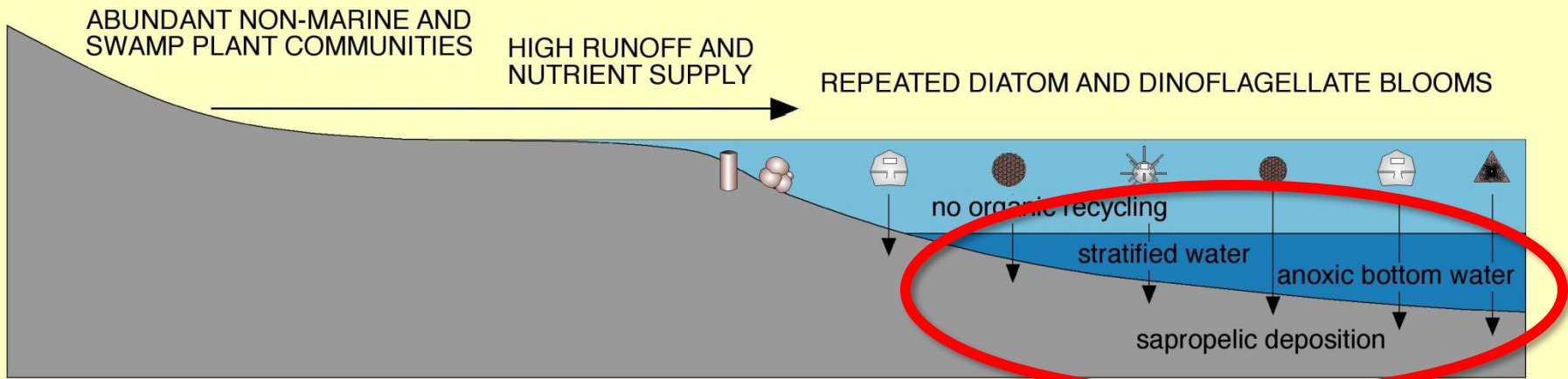


arenaceous foraminifera

that were preyed upon by the diatom-eating carnivorous dinoflagellates such as *Apectodinium*, *Ceratium* and *Deflandrea*



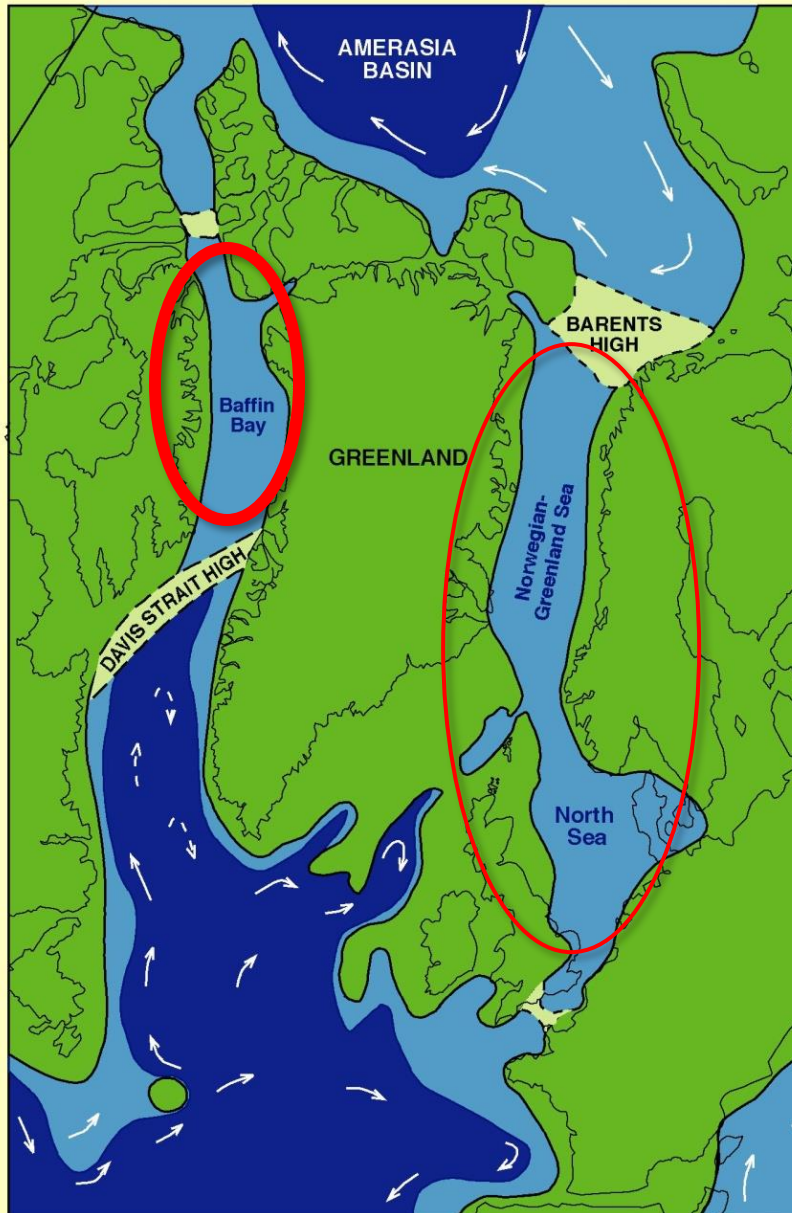
with basin stratification causing bottom-water anoxia and the deposition of oil-prone sapropel rocks.





LATEST PALEOCENE AND EARLIEST EOCENE BASIN ENCLOSURE

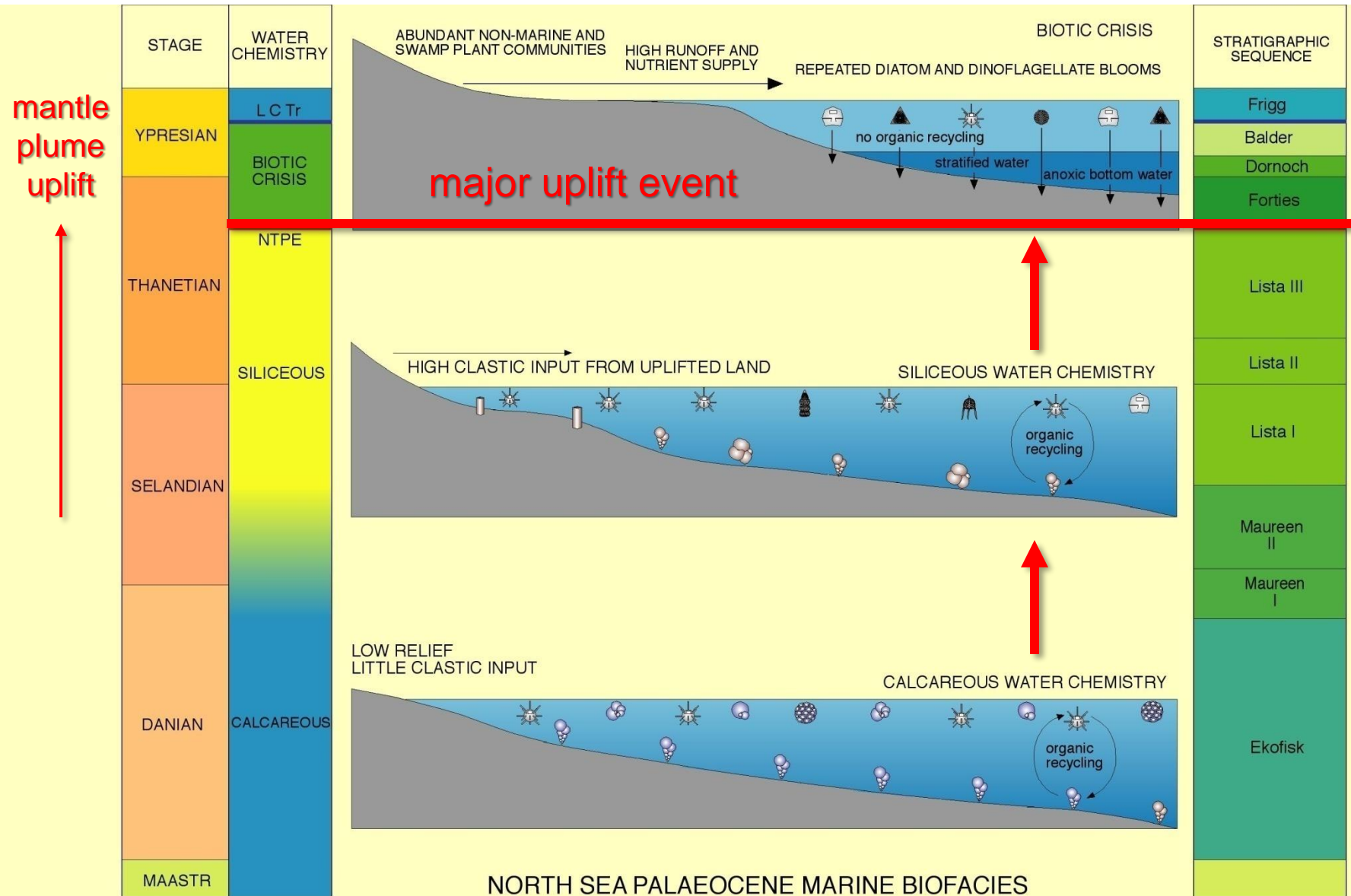
This situation is well-documented in the North Sea basin system including the Norwegian-Greenland Sea and Faroe Shetland Basin



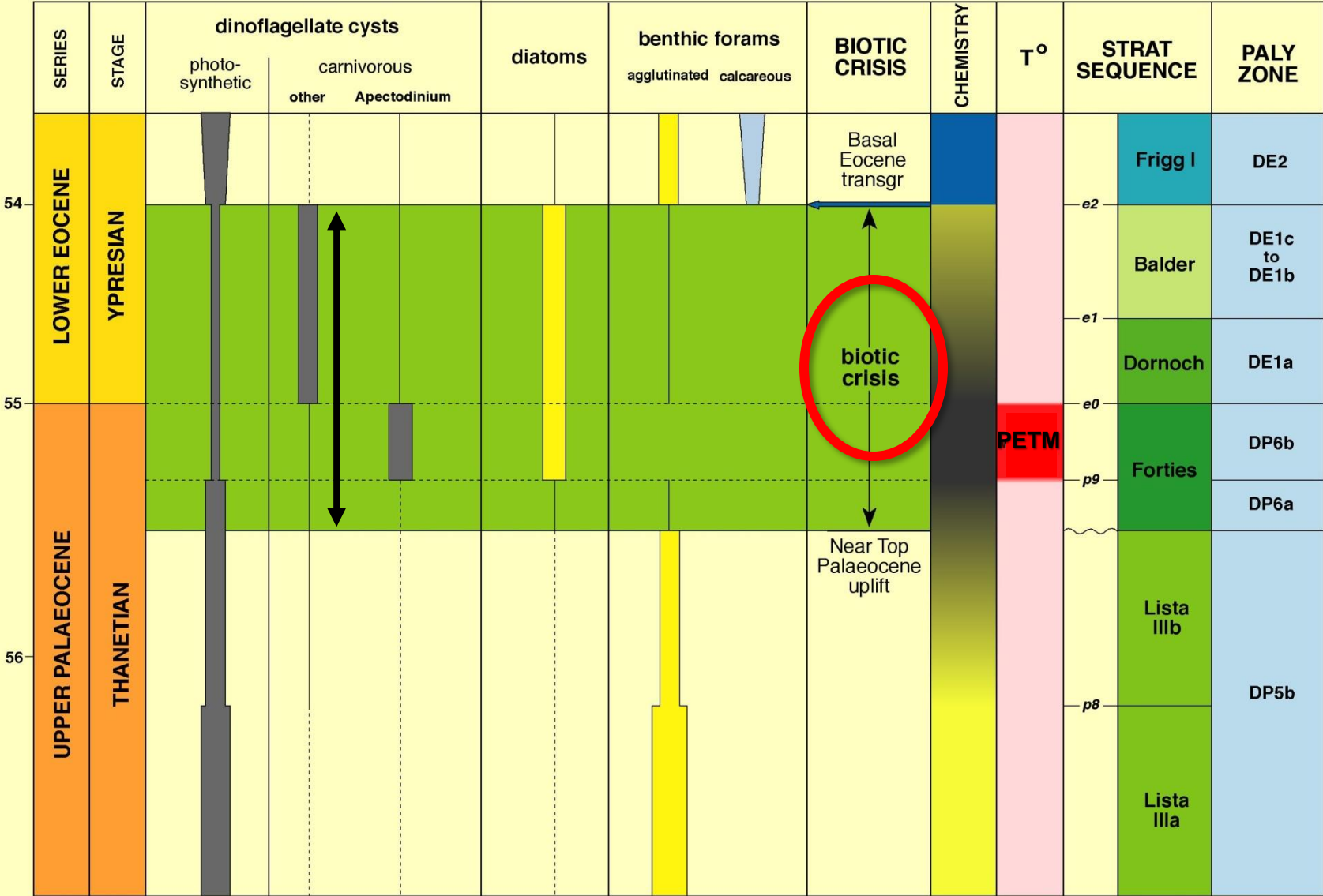
LATEST PALEOCENE AND EARLIEST EOCENE BASIN ENCLOSURE

and it is predicted in the Labrador / Baffin seaway where existing but limited data indicate diatom-dominated microfaunas similar to those in the North Sea

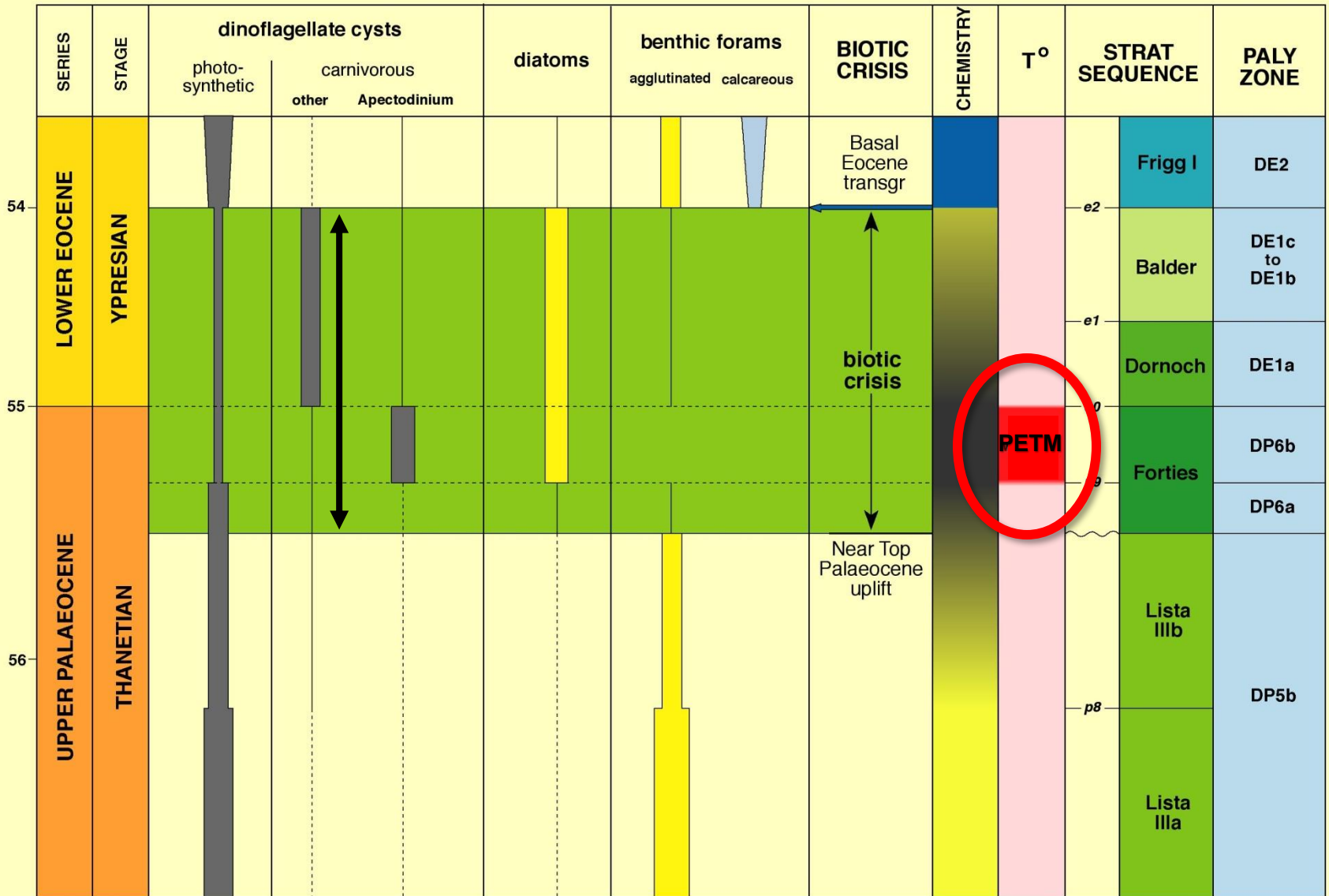
So our integrated model explains the assemblage changes that occurred during the Paleocene



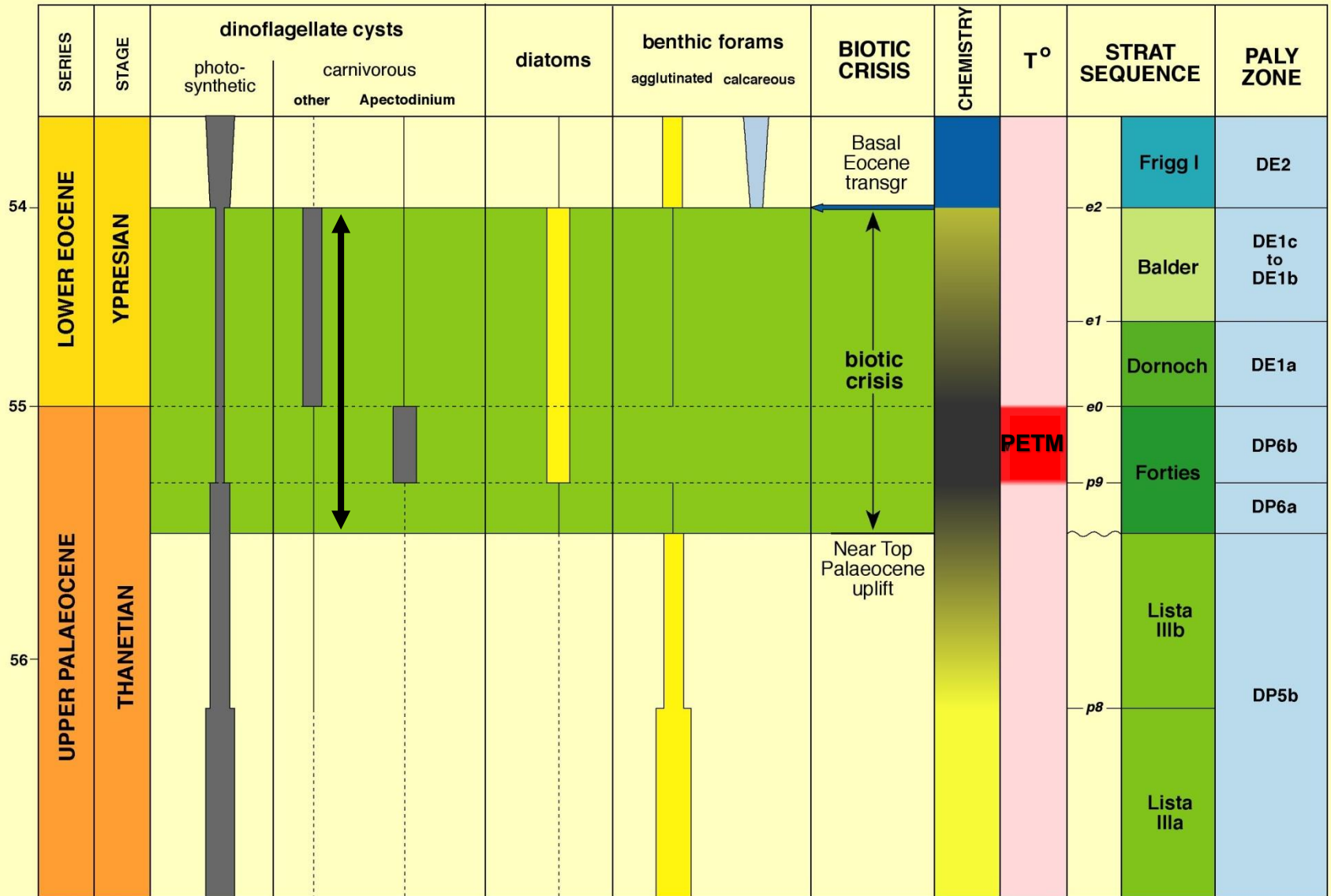
and the biotic crisis spanning the Paleocene-Eocene transition



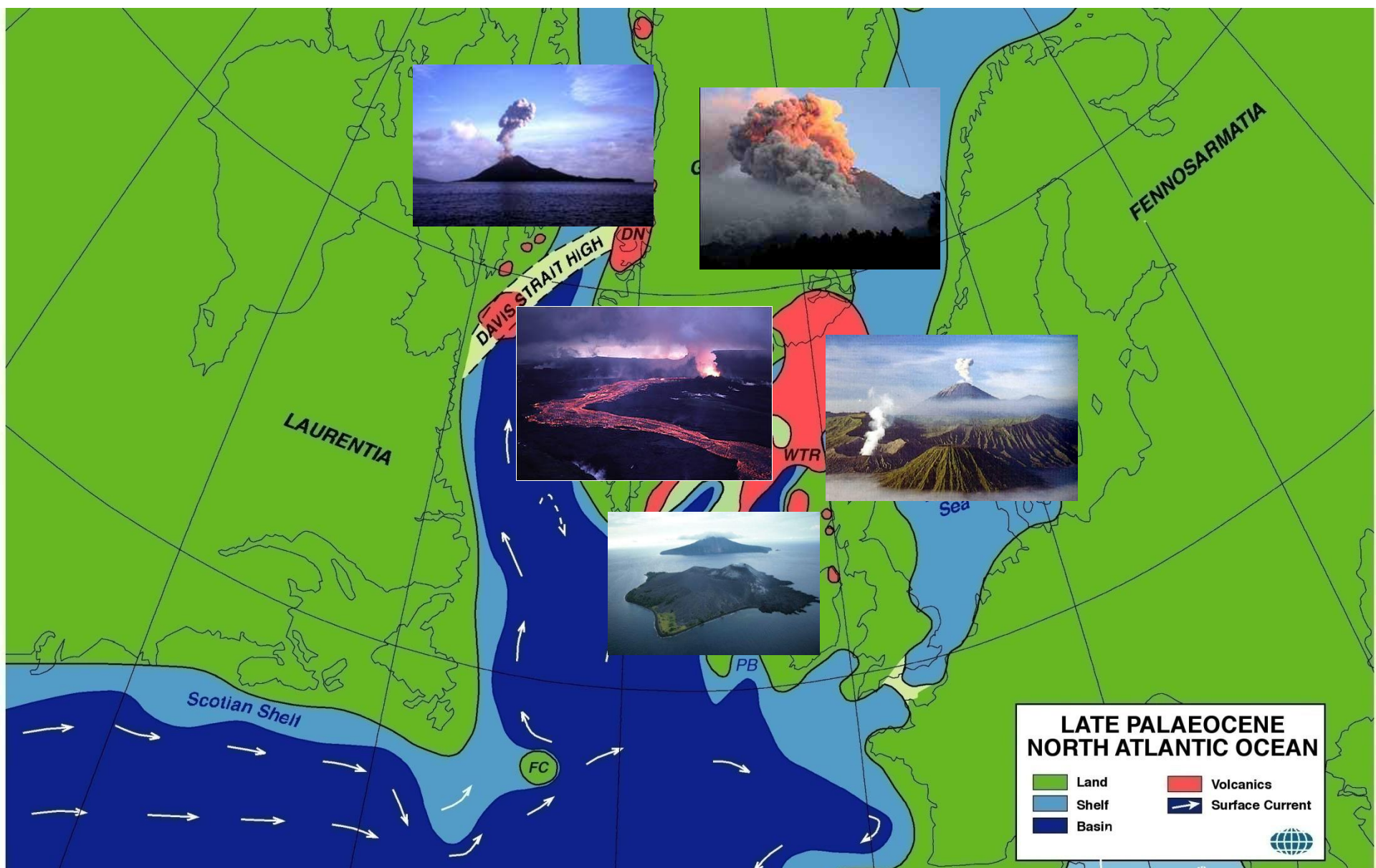
But how does this relate to the Palaeocene Eocene Thermal Maximum?



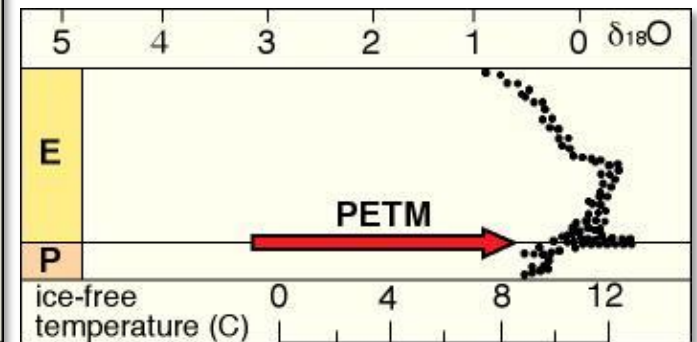
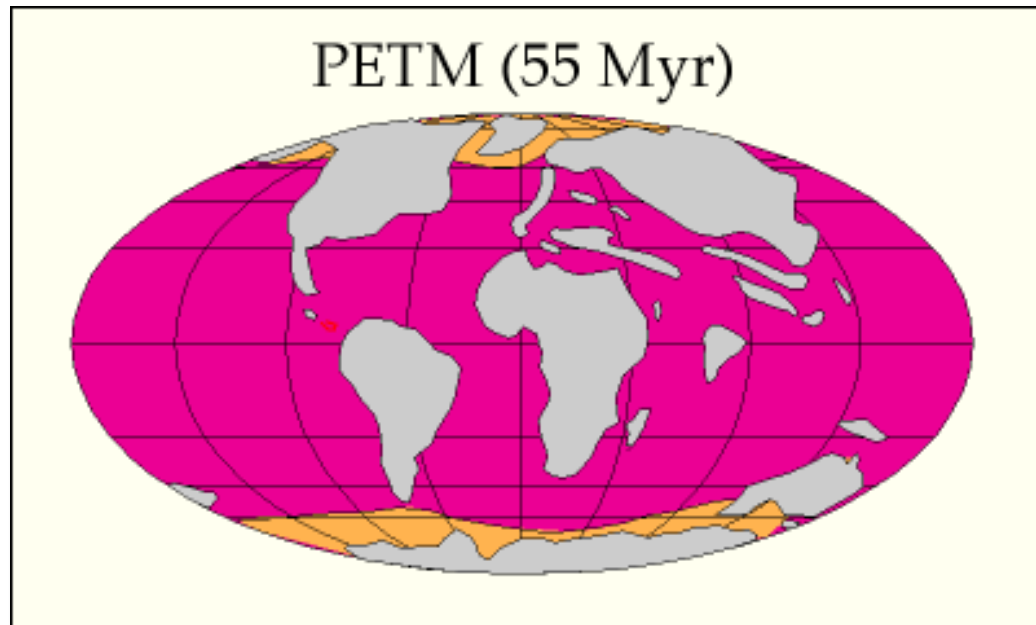
The biotic crisis and PETM were both caused by Greenland plume uplift



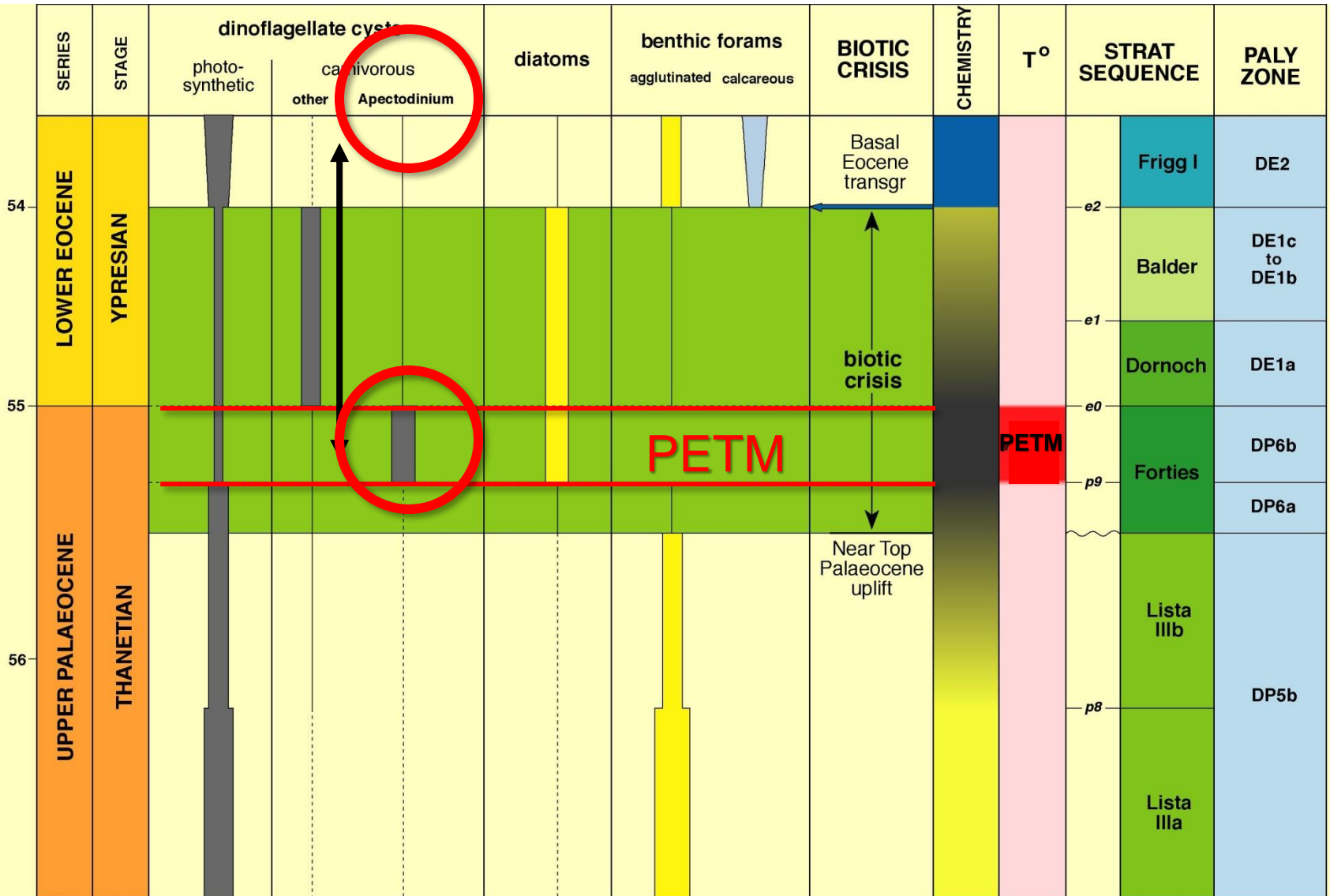
because the PETM was triggered by greenhouse gases associated with extensive Greenland plume volcanism



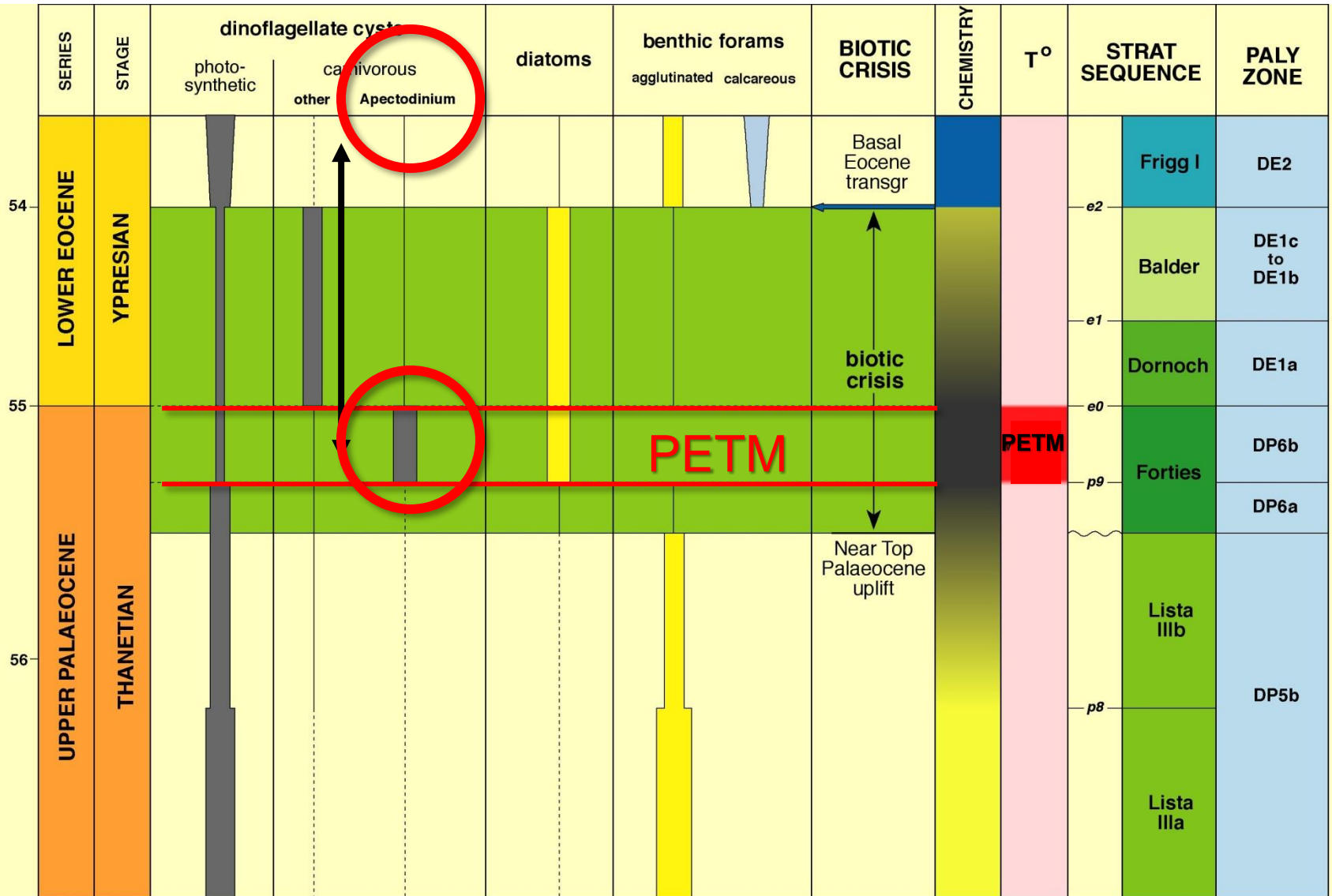
With greenhouse levels being amplified by methane expulsion from submarine gas hydrates (methane clathrates)



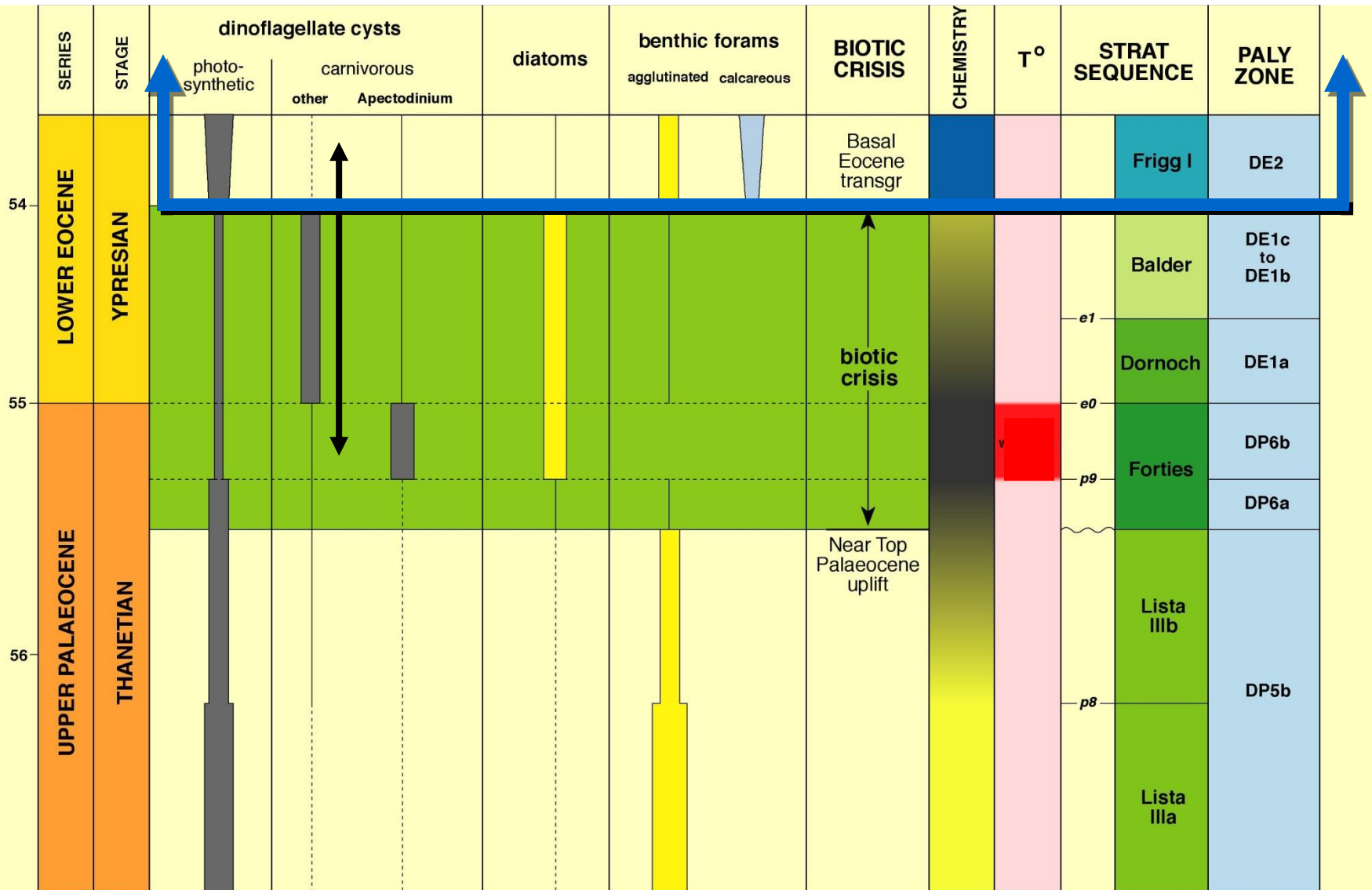
with the warm-water Apectodinium acme resulting from the PETM



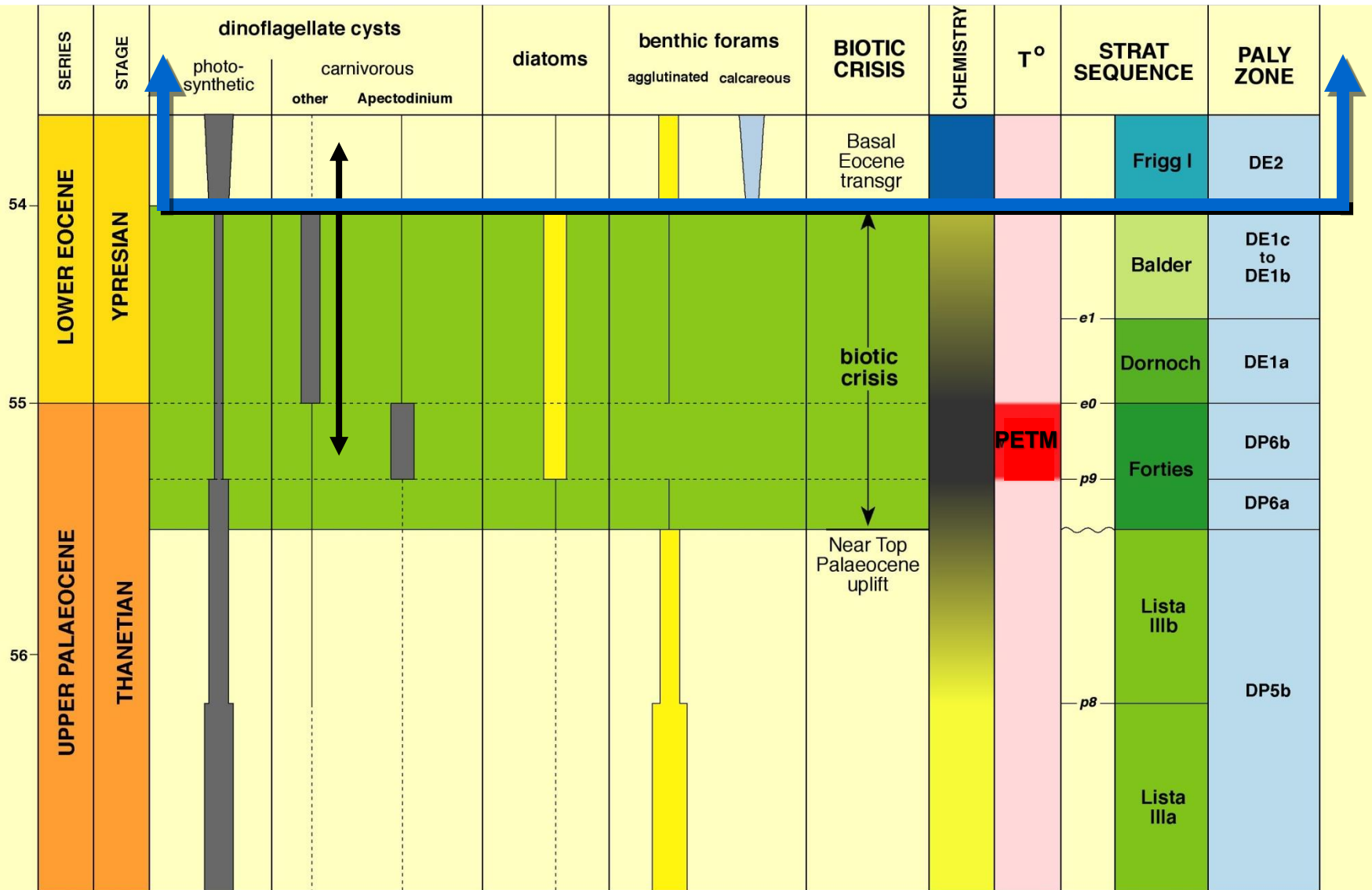
which was first proposed by Bujak & Brinkhuis in 1997



The biotic crisis was terminated by mantle plume collapse and the Ypresian marine transgression that extended across the entire region

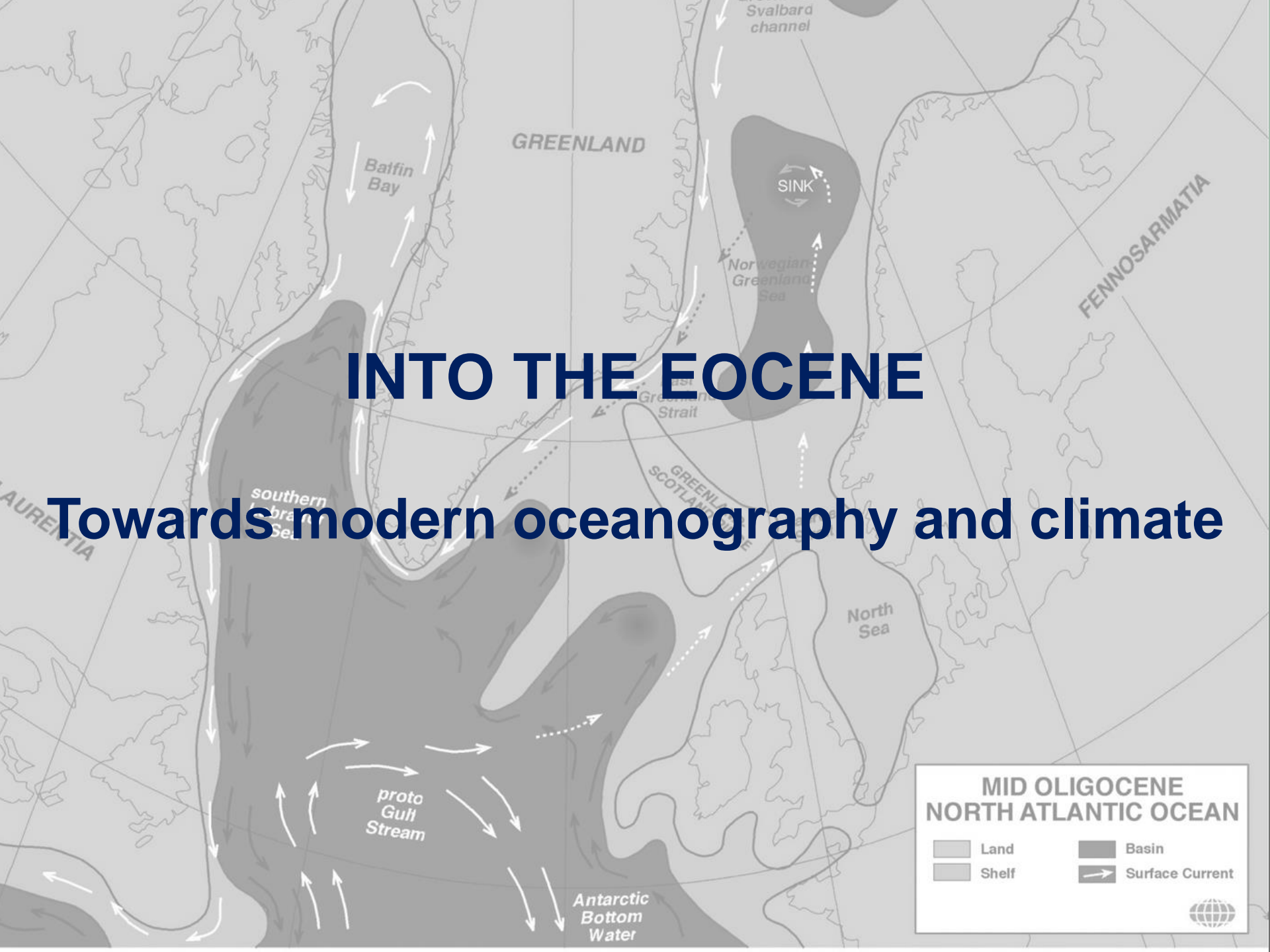


marking the break between Paleocene and Eocene tectonics and oceanography in the North Atlantic and NW European region



INTO THE EOCENE

Towards modern oceanography and climate

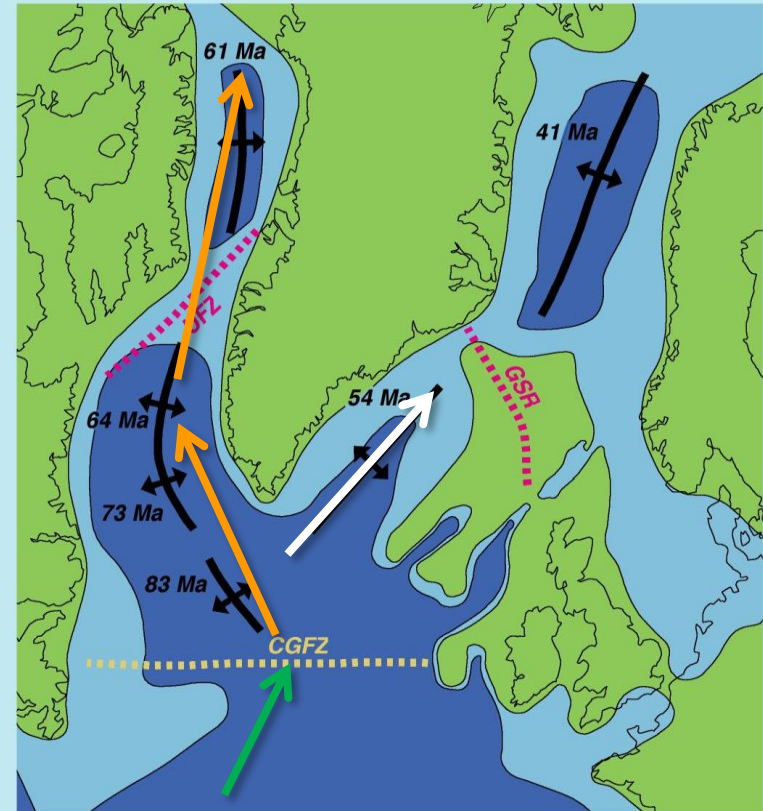


Collapse of the Greenland

mantle plume allowed
spreading to revert to its
original north-eastward
direction

- early Eocene
- late Paleocene
- Late Cretaceous

NORTH ATLANTIC TERTIARY SEA-FLOOR SPREADING

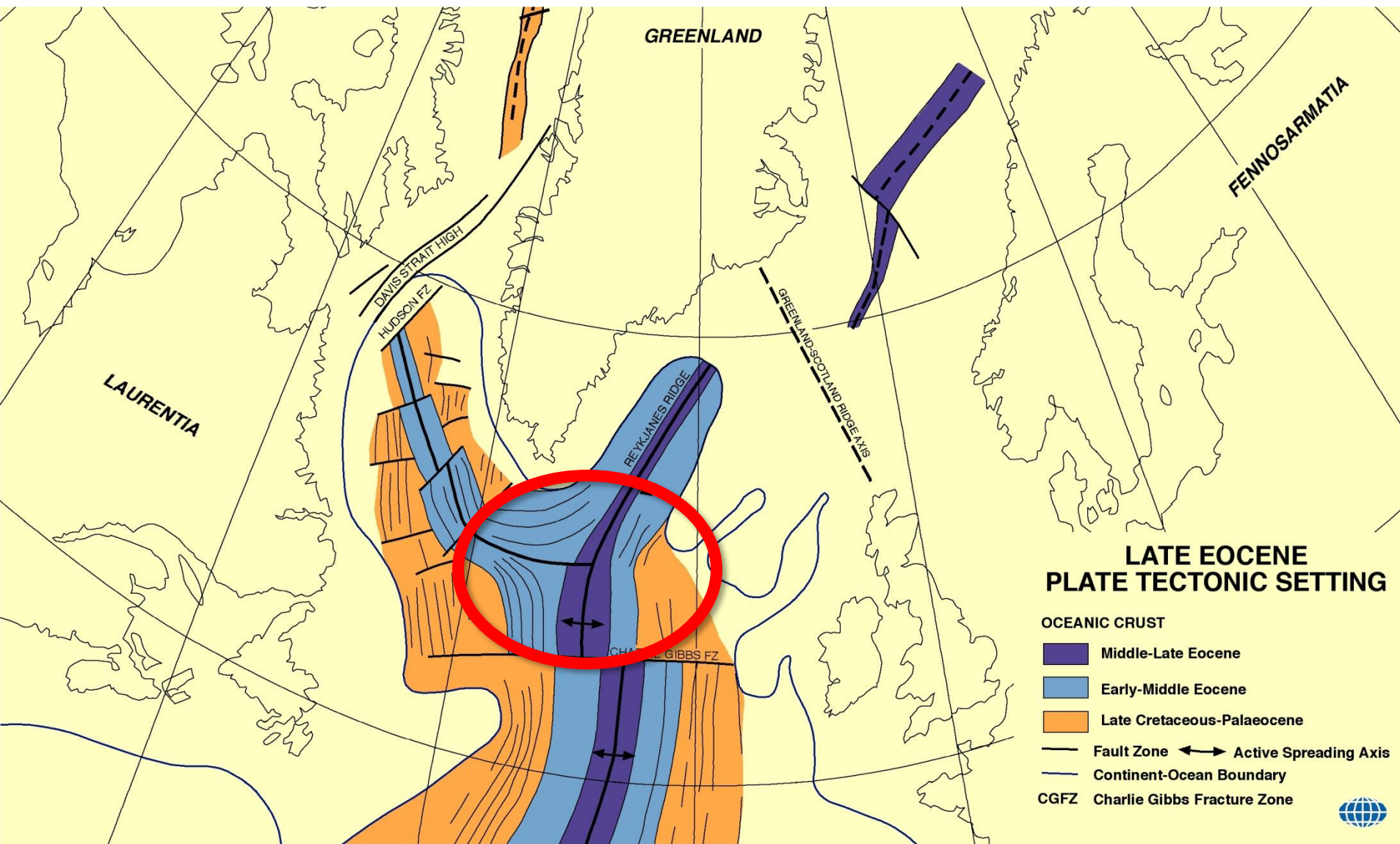


- Land
- Shelf
- Ocean

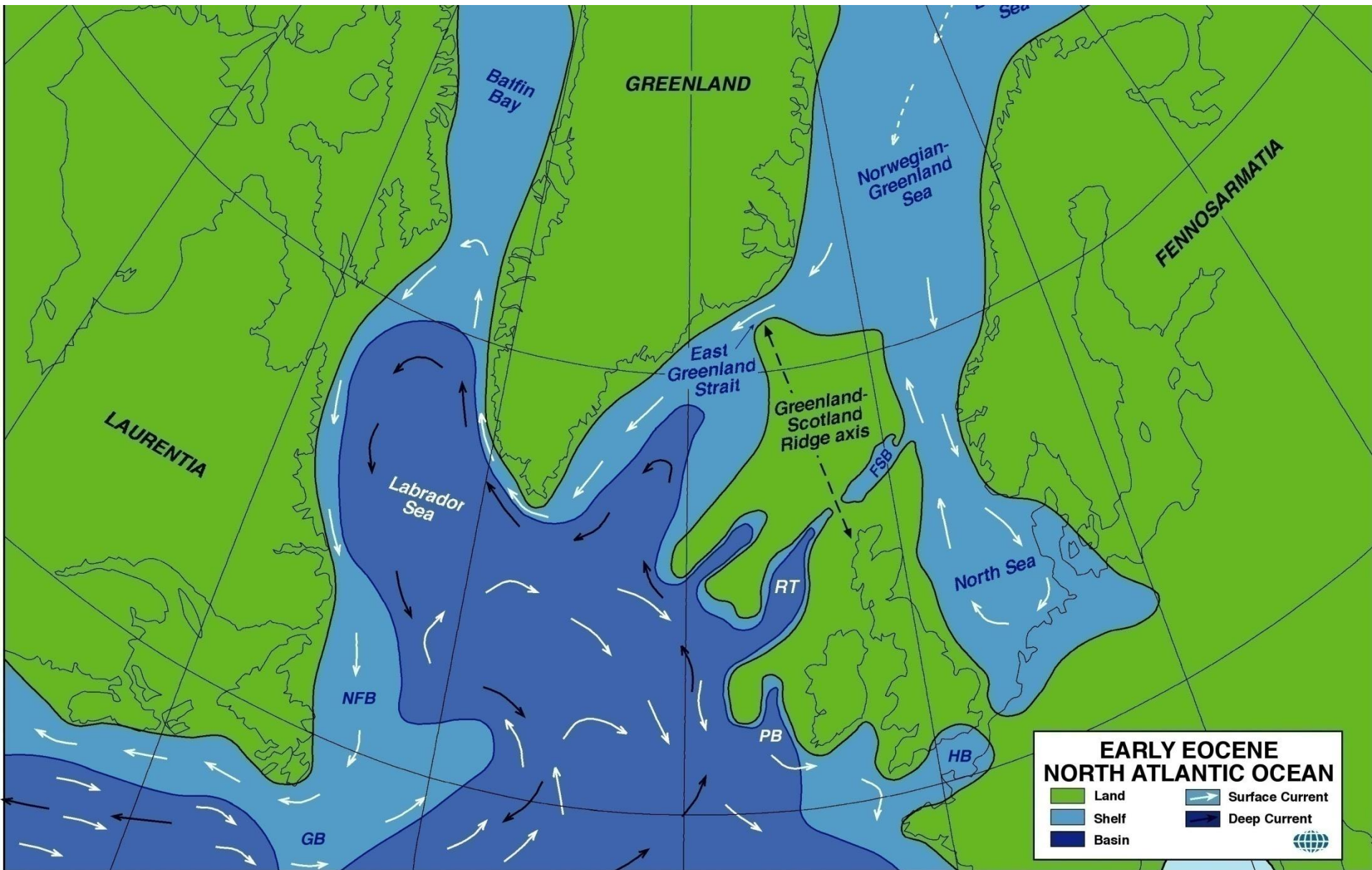
- GSR Greenland-Scotland Ridge
- CGFZ Charlie Gibbs FZ
- UFZ Ungava FZ



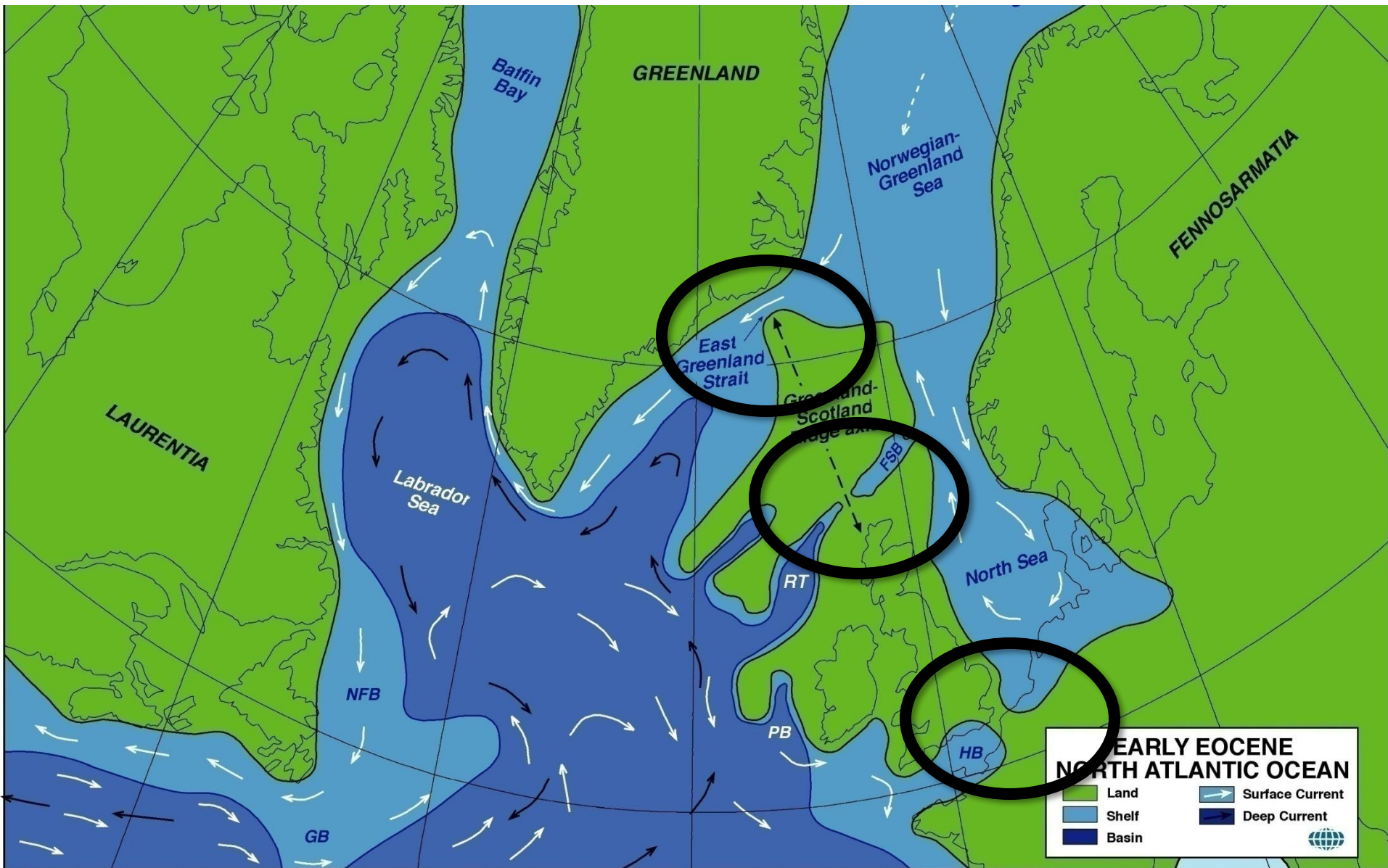
but spreading continuing to the west of Greenland until the middle Eocene - resulting in a triple junction



Collapse of the plume also caused widespread marine transgression



but connections between the northern Atlantic and North Sea / Norwegian-Sea system were still narrow or remained closed



icehouse



This lack of open oceanic connection

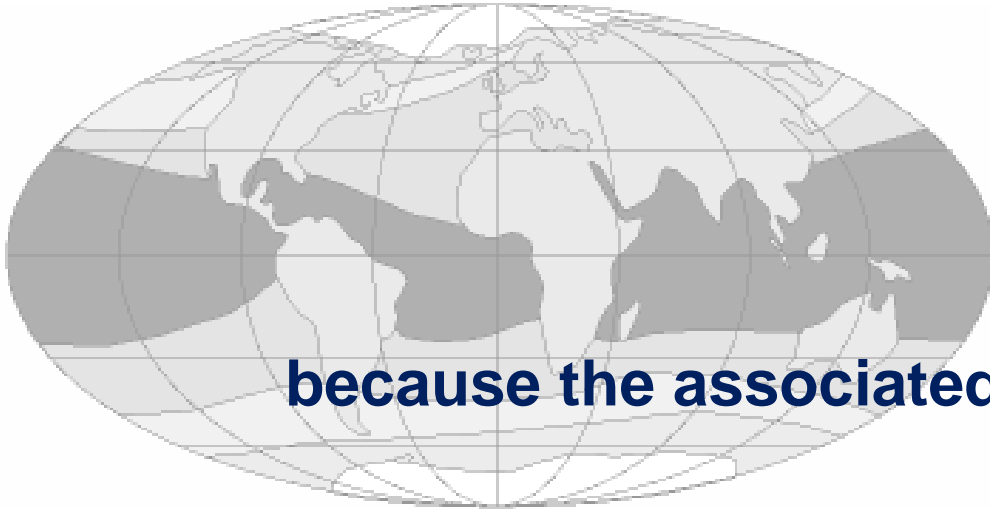
played a major role during the

greenhouse to icehouse shift

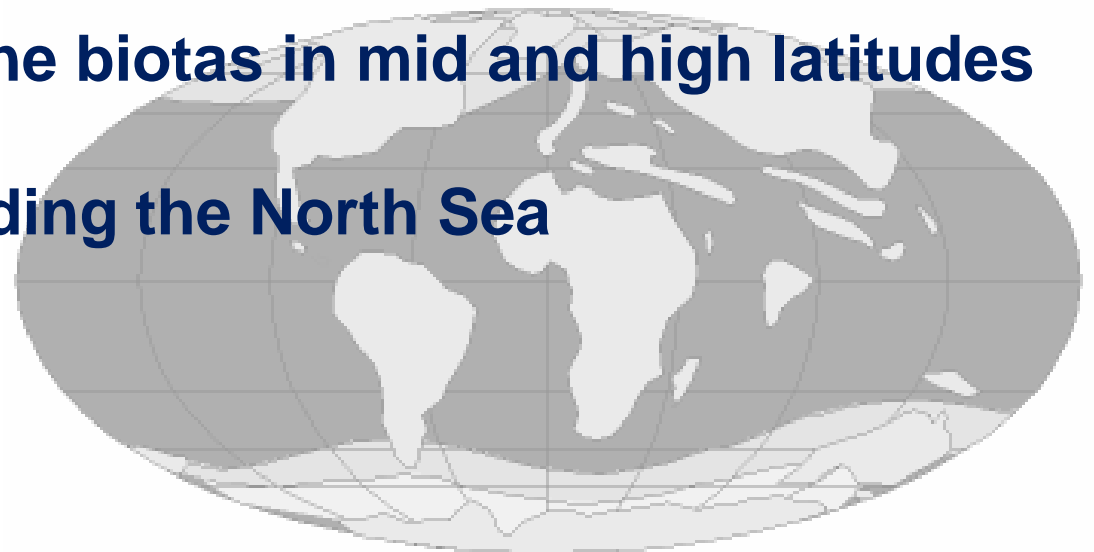


greenhouse

icehouse

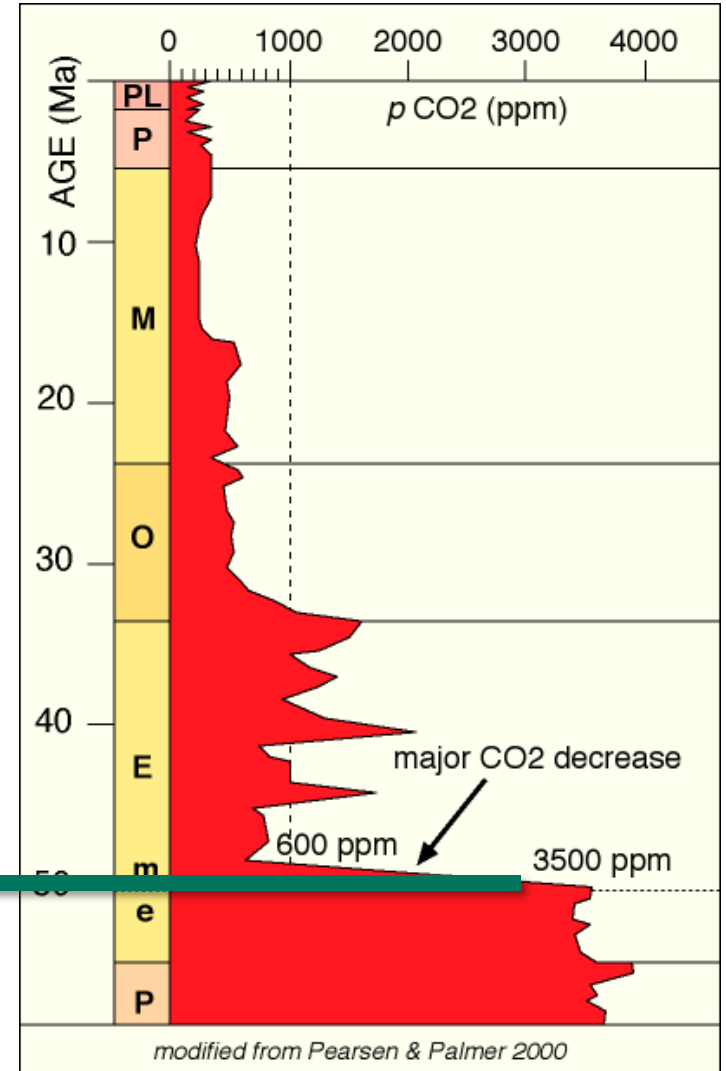
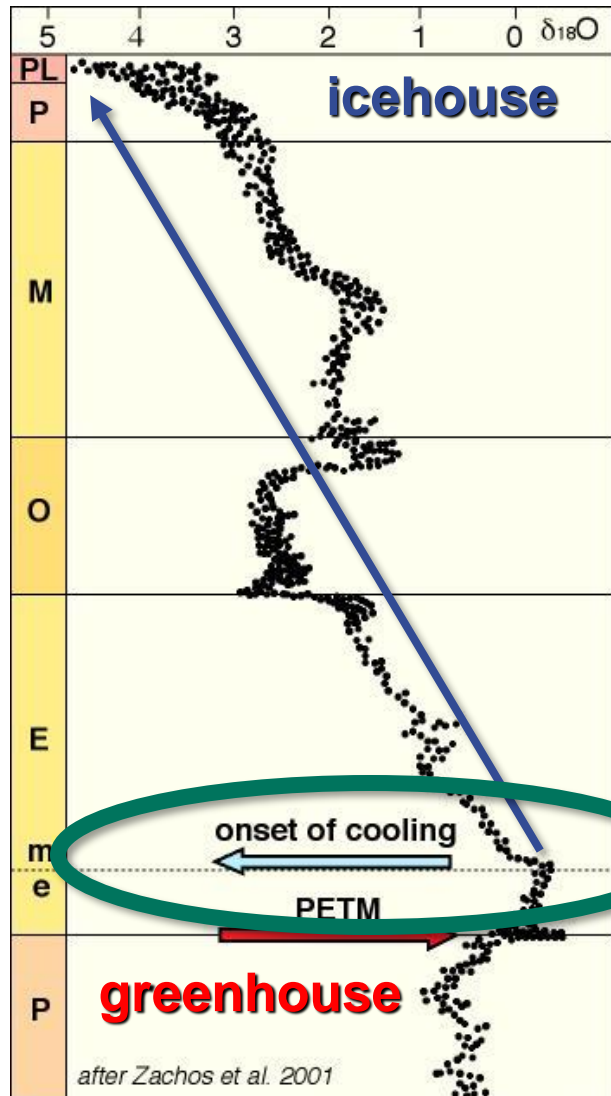


because the associated fall in air and sea-surface temperature (SST) had an enormous impact on Eocene to Holocene biotas in mid and high latitudes including the North Sea



greenhouse

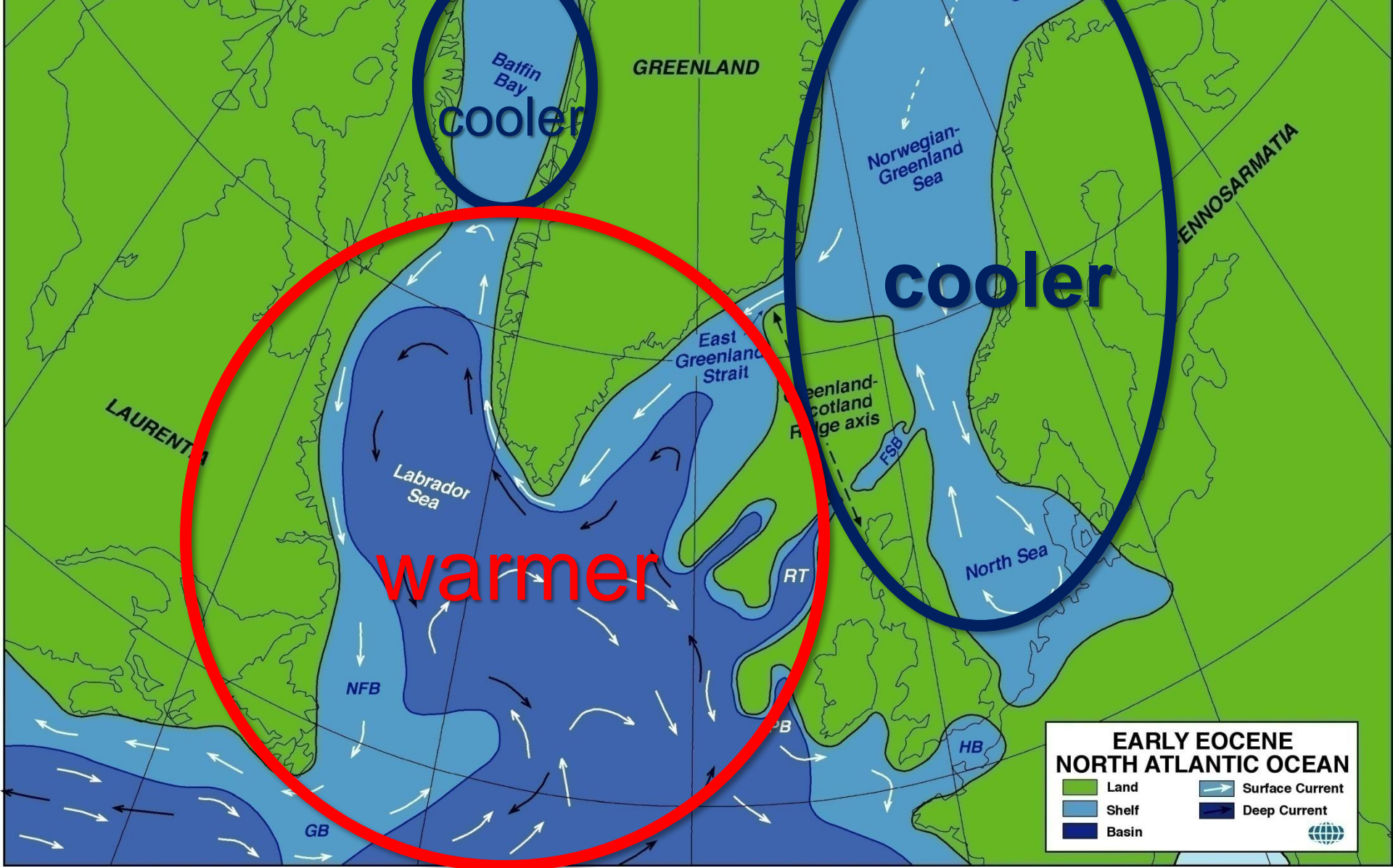
The base Middle Eocene Arctic Azolla event was the initial trigger for the greenhouse to icehouse shift



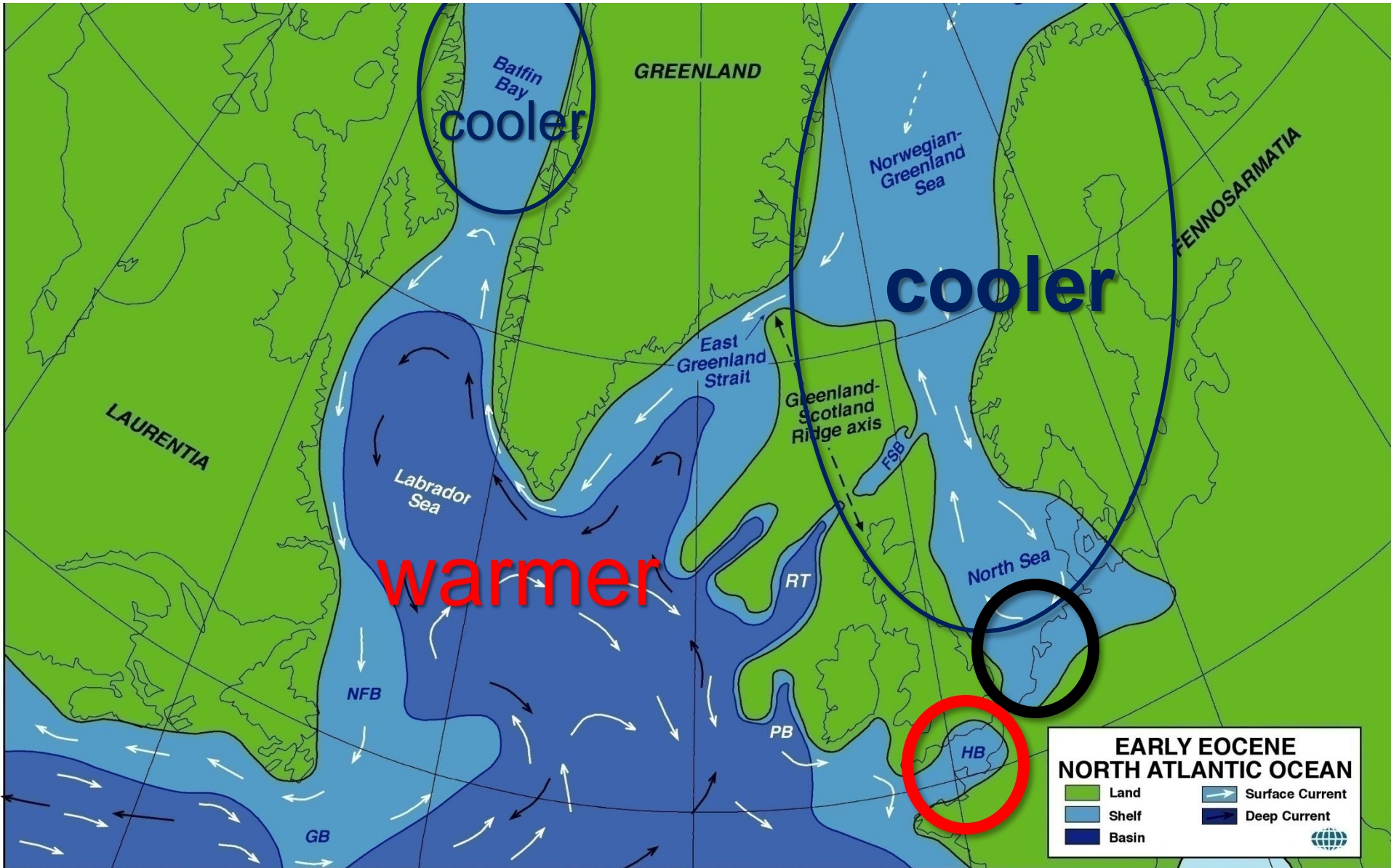
Azolla event



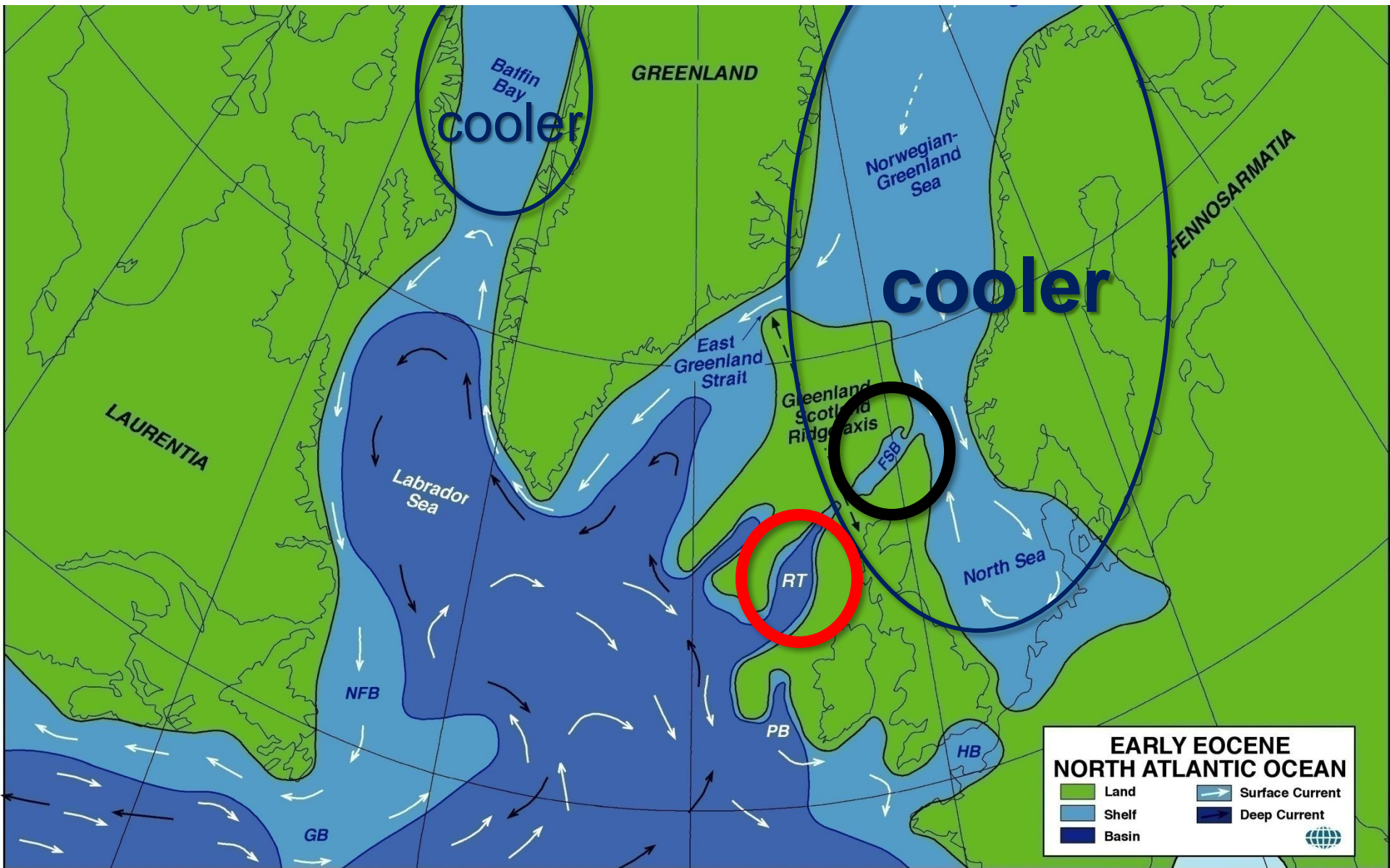
The associated cooling resulted in diachronous ranges because the three N Atlantic basin systems retained their independent temperature regimes



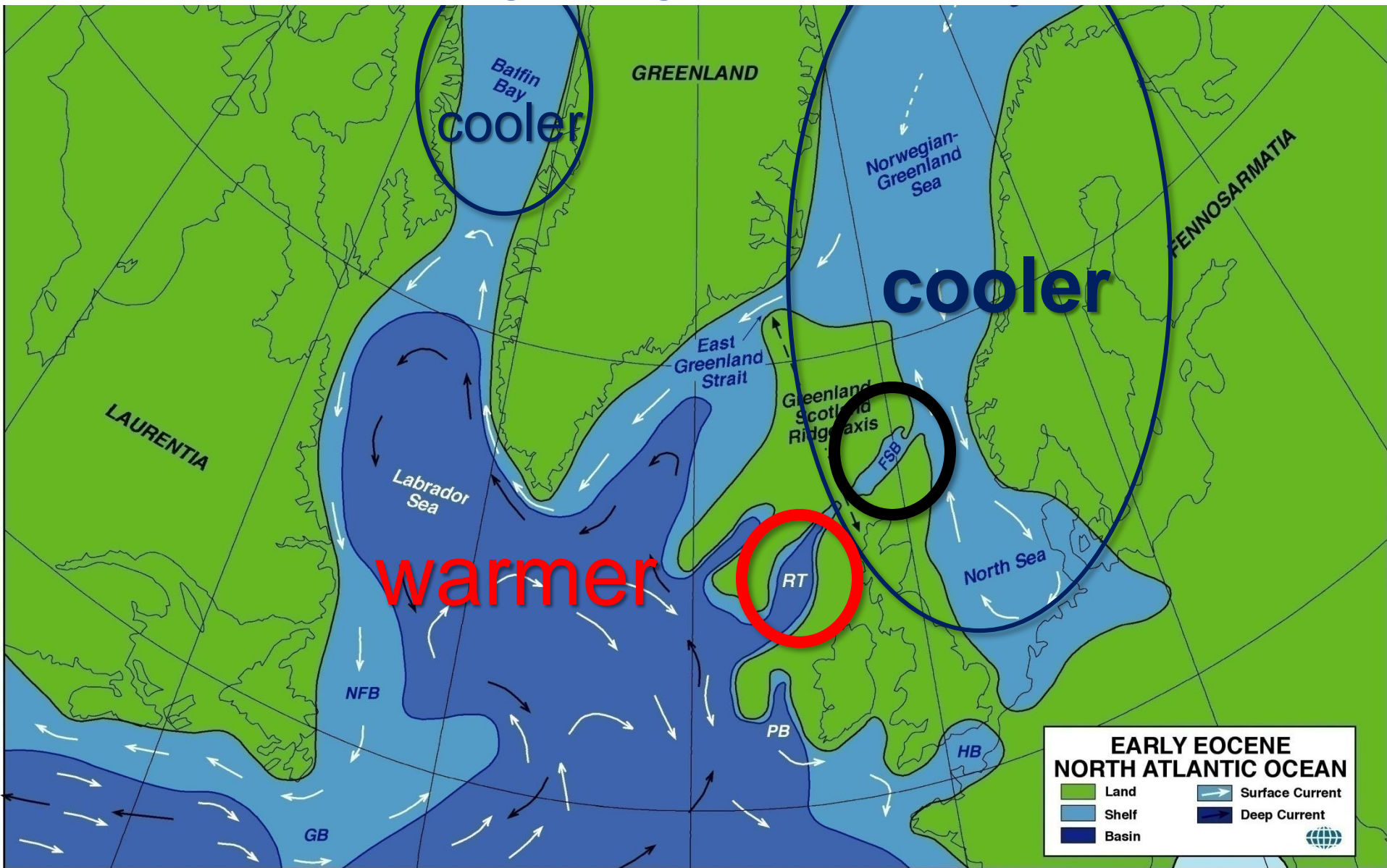
So we see this temperature difference in subbasins that are just a few kilometres apart such as the southern North Sea and Hampshire Basin



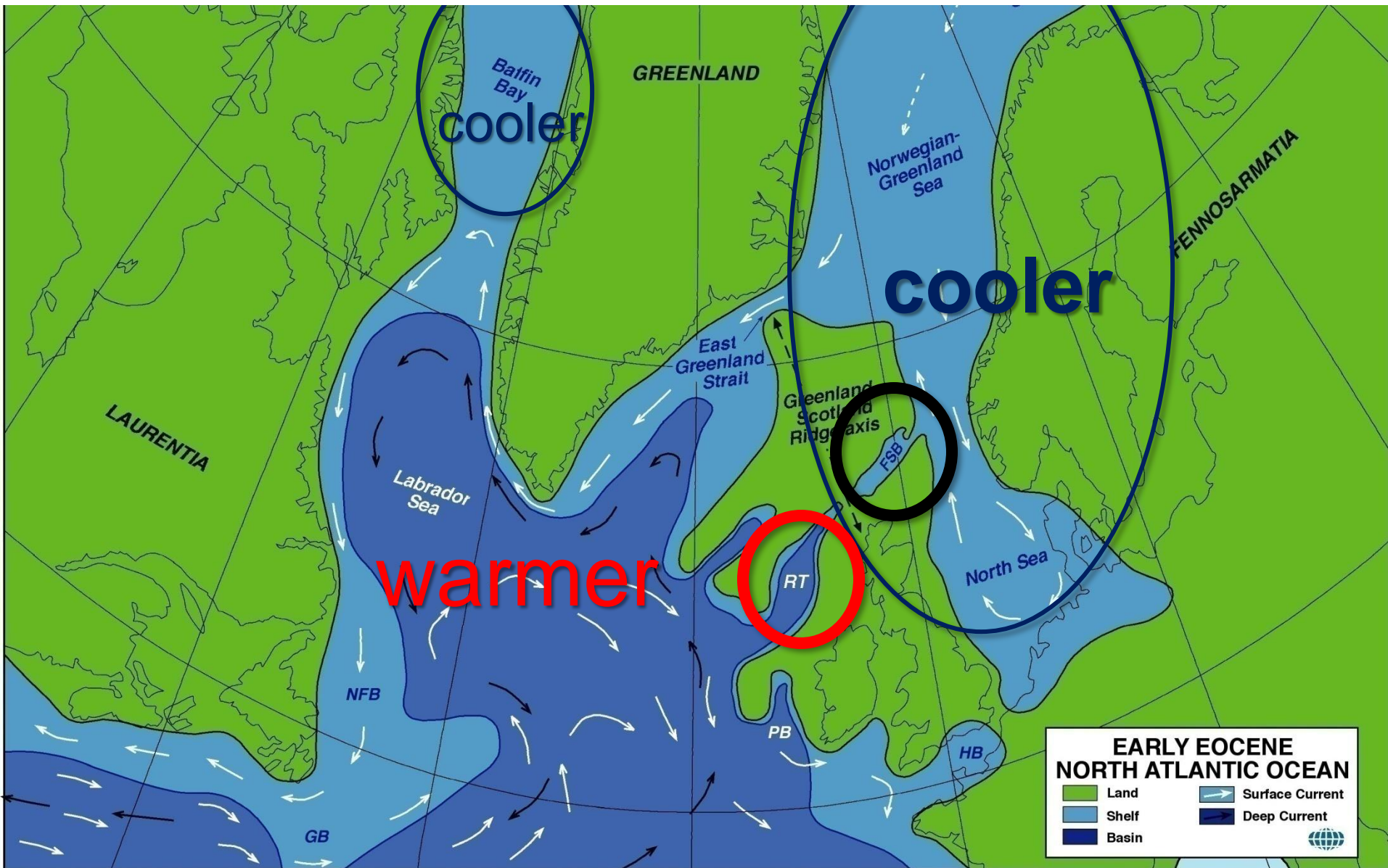
and between the Rockall Trough and Faroe Shetland Basin



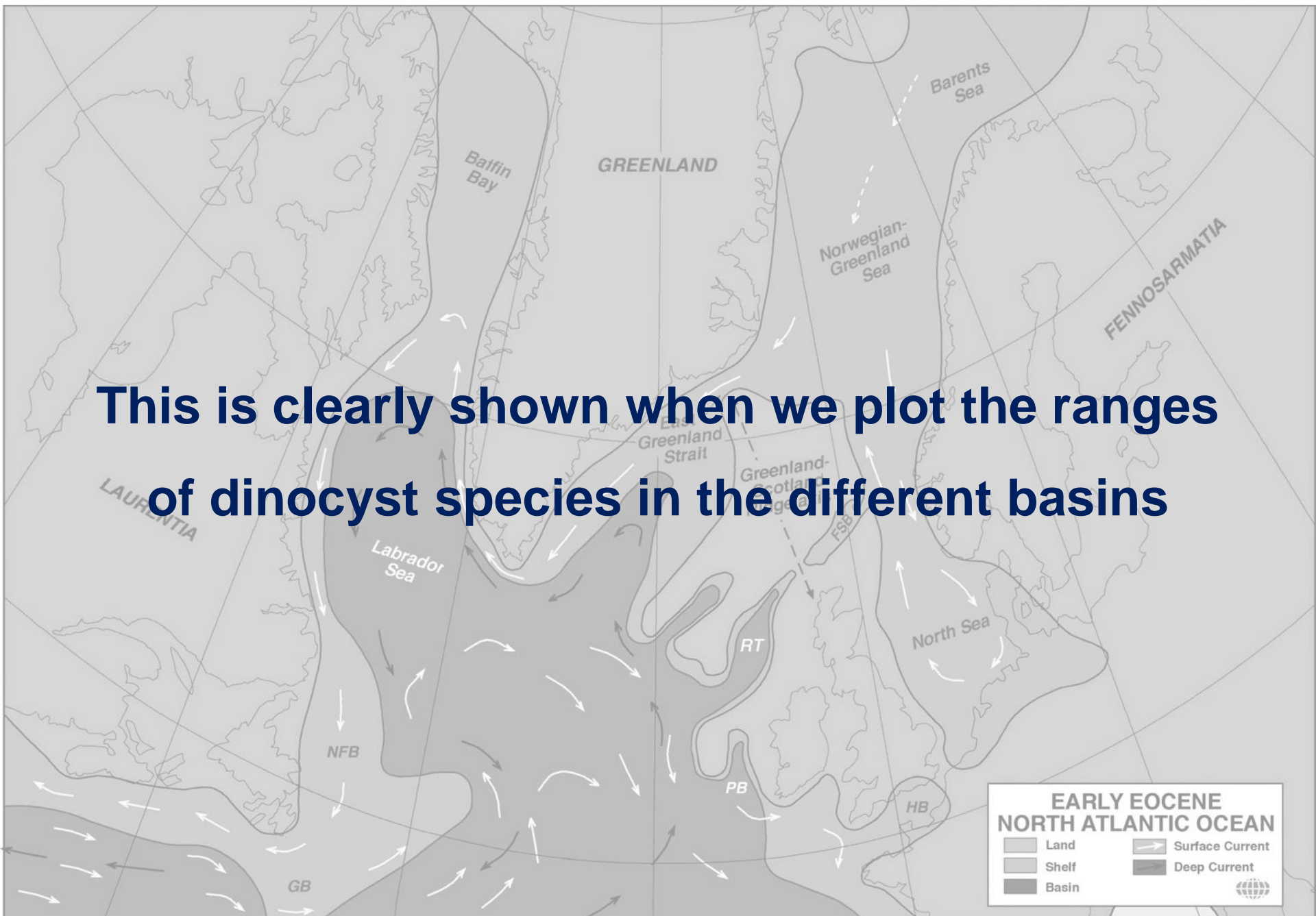
This is why North Sea dinocyst ranges can result in erroneous ages assignments in Rockall wells



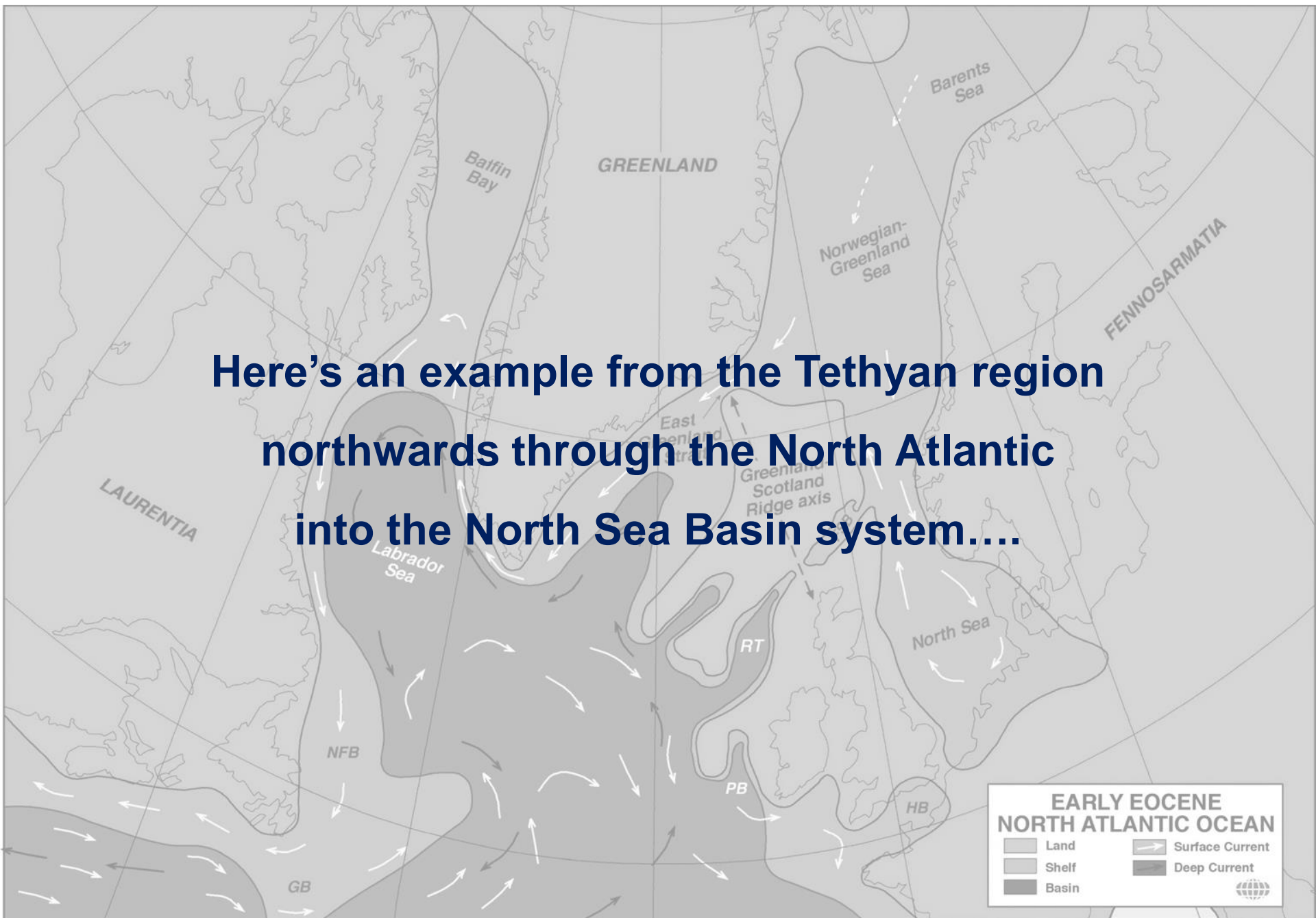
.....which have a biostratigraphic succession that is more similar to that of the Scotian Shelf, Grand Banks and NE Newfoundland basins



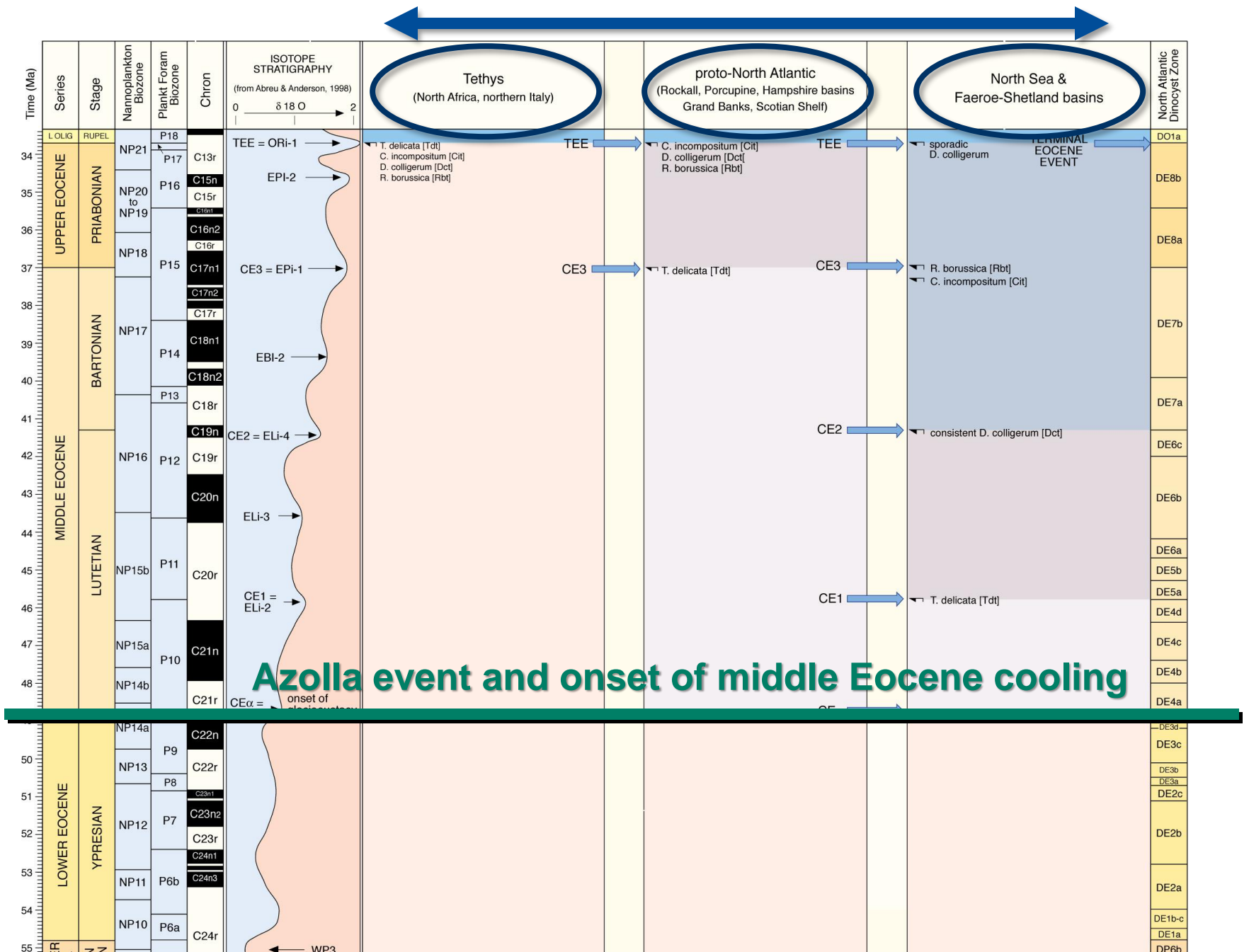
This is clearly shown when we plot the ranges of dinocyst species in the different basins



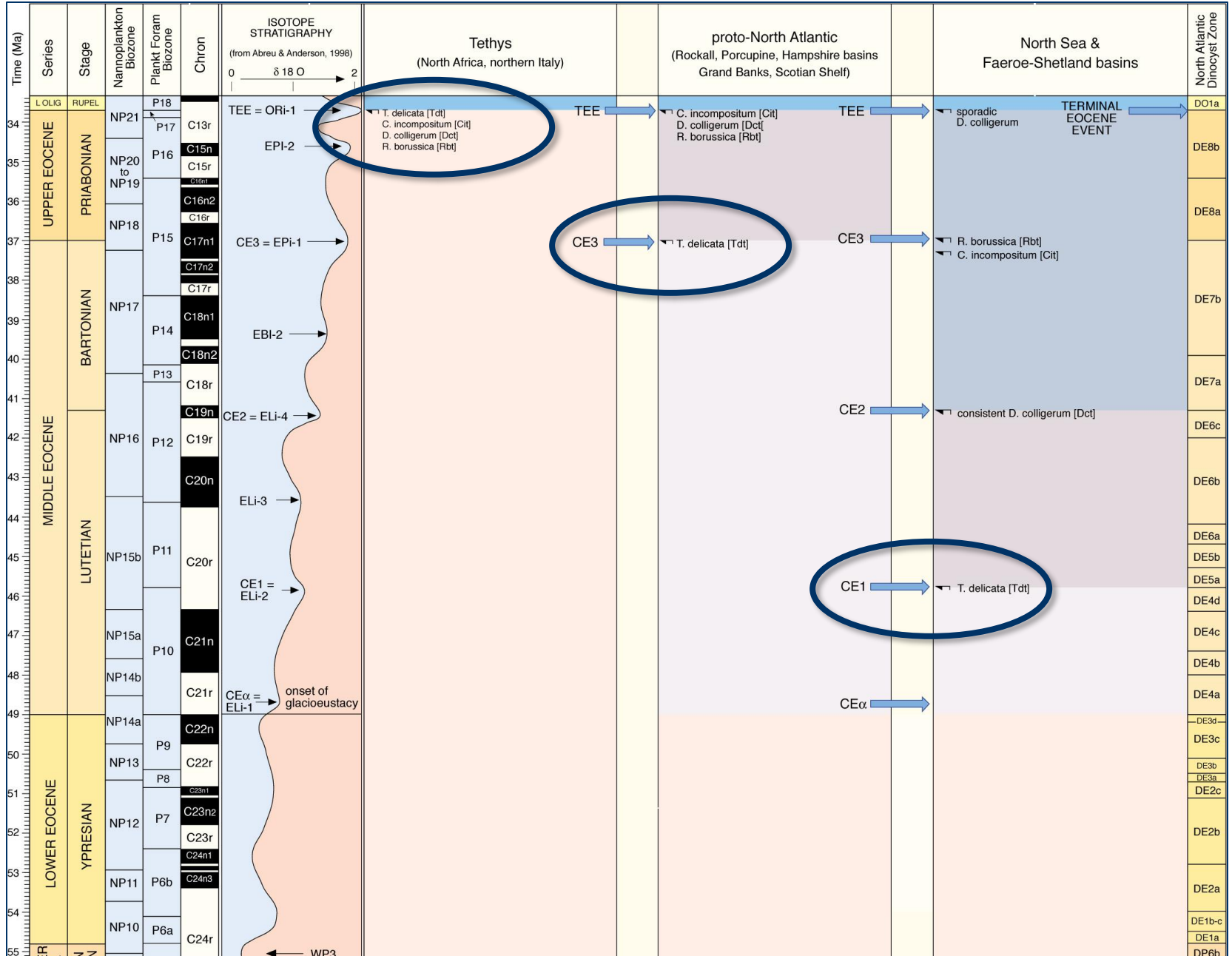
Here's an example from the Tethyan region northwards through the North Atlantic into the North Sea Basin system....



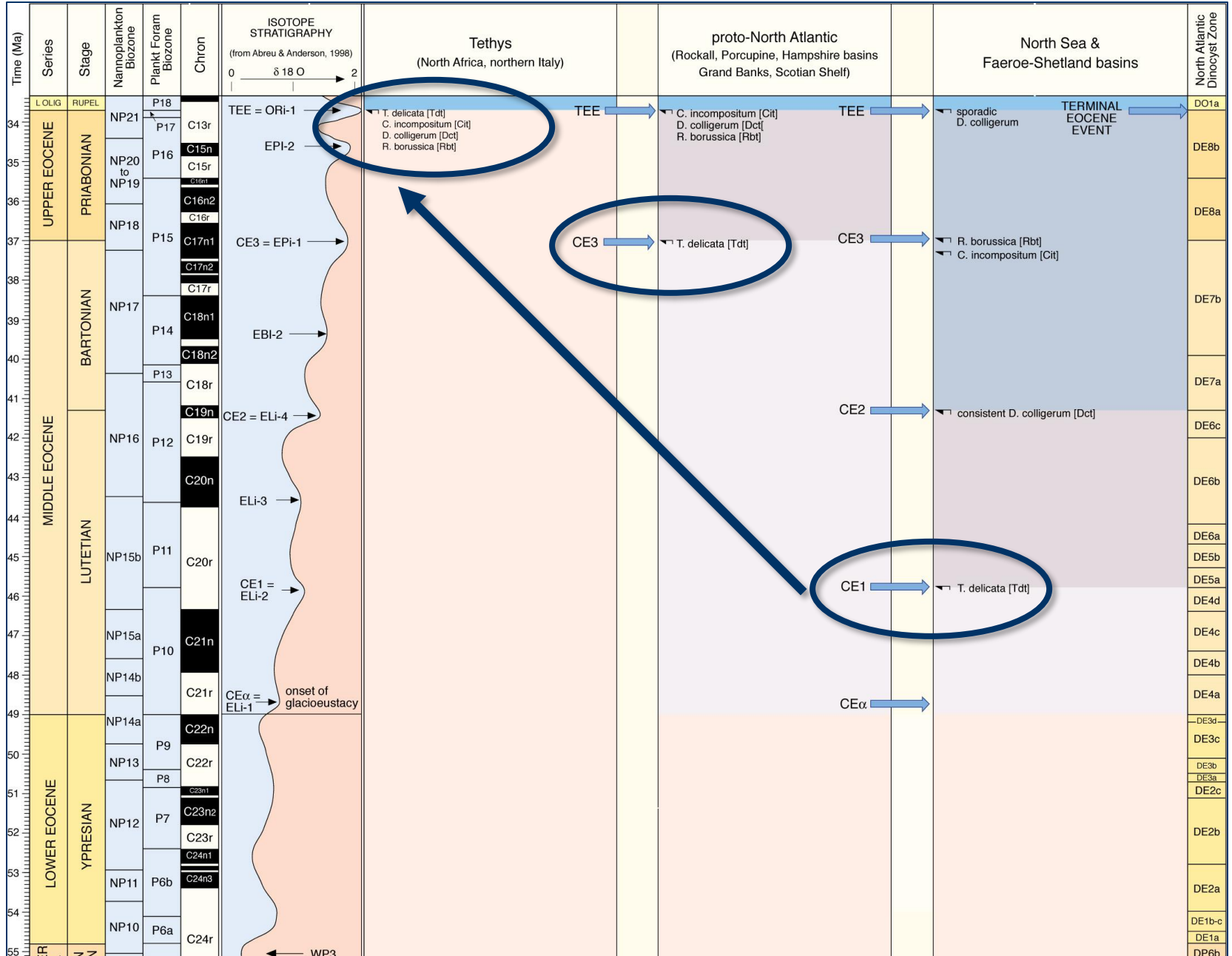
.....a Tethyan – N Atlantic – N Sea / Norwegian-Greenland Sea transect through time



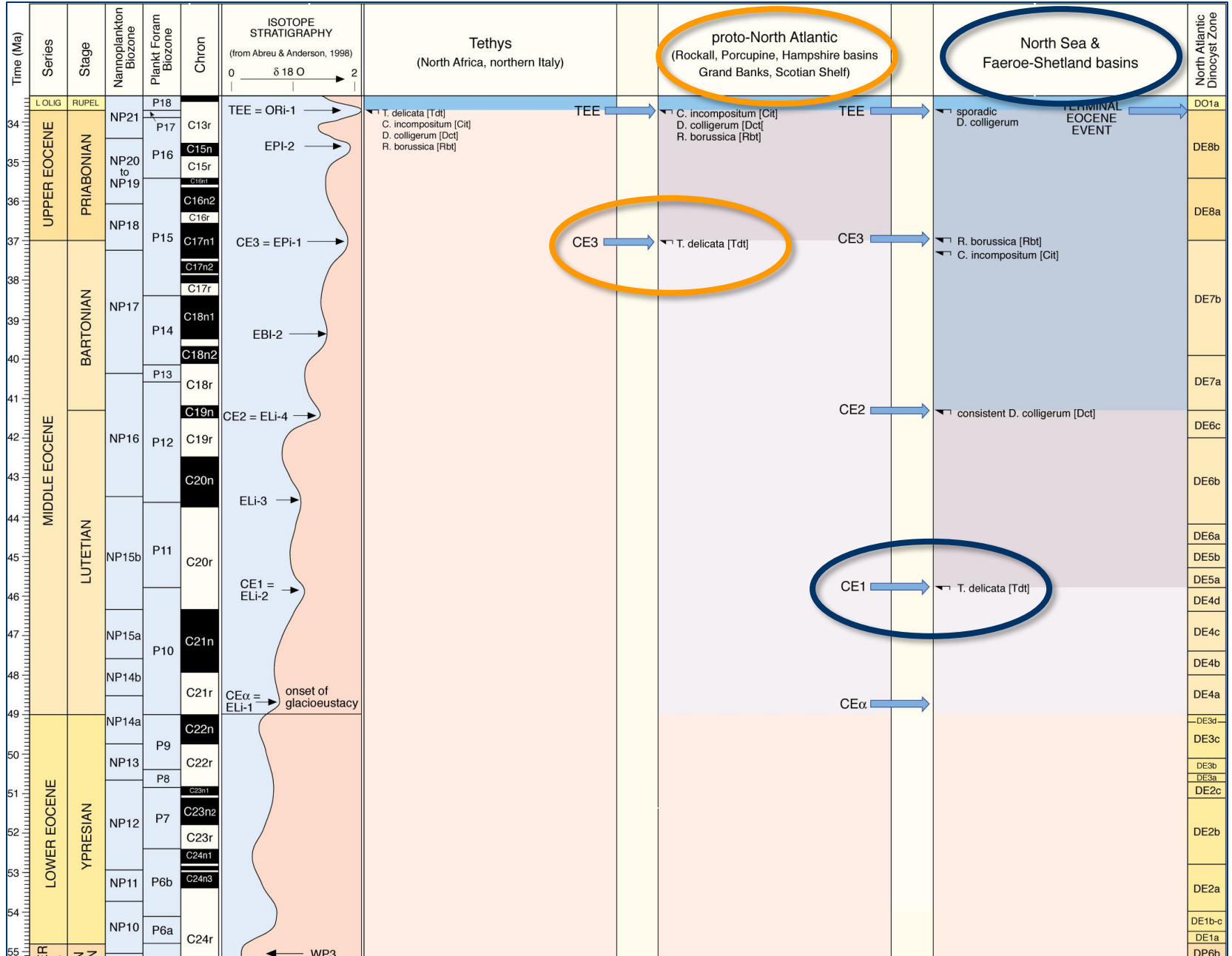
which shows that the extinction of temperature-sensitive dinocysts is diachronous in different SST regimes (e.g. *Thalassiphora delicata*)



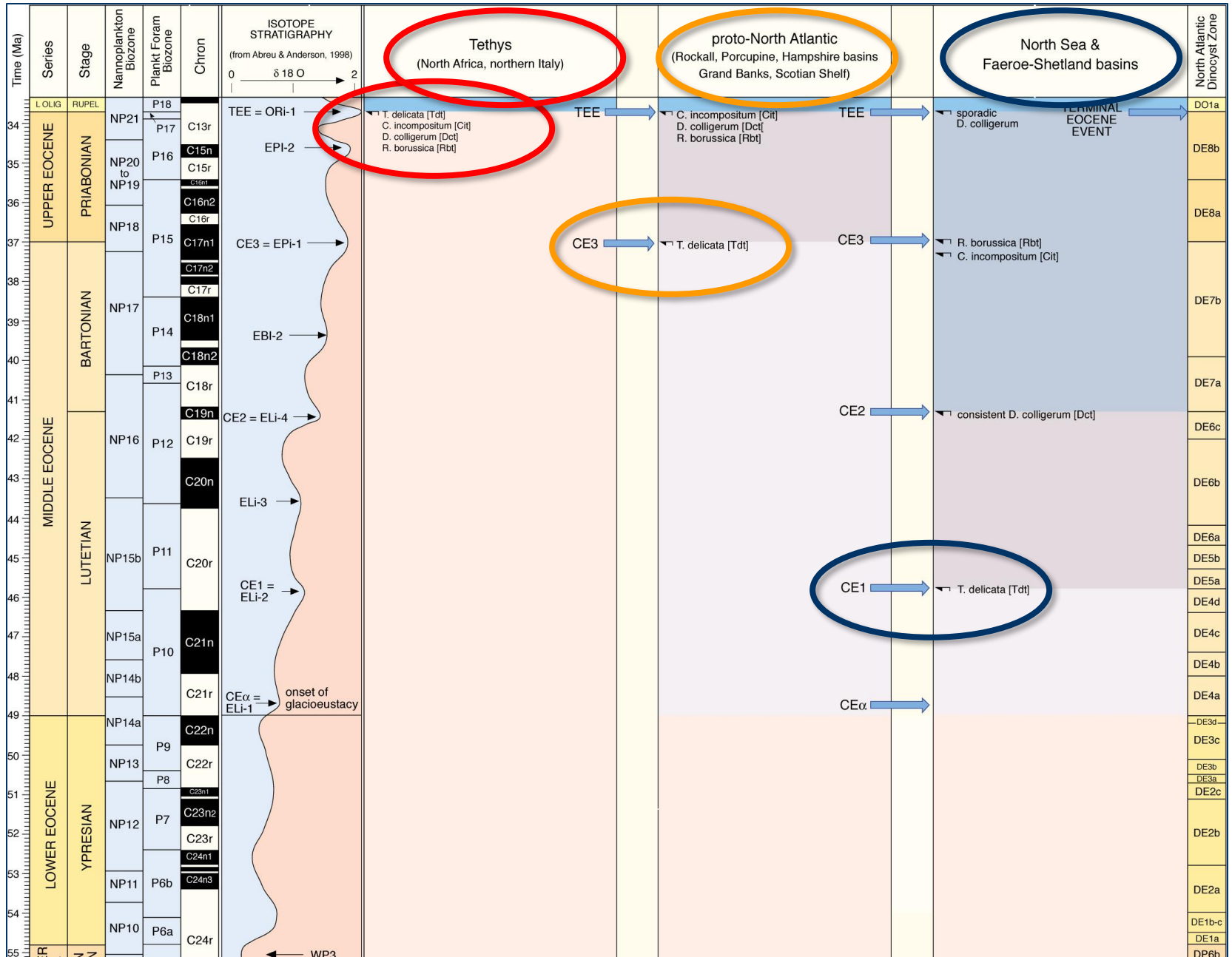
and that they occur later to the south



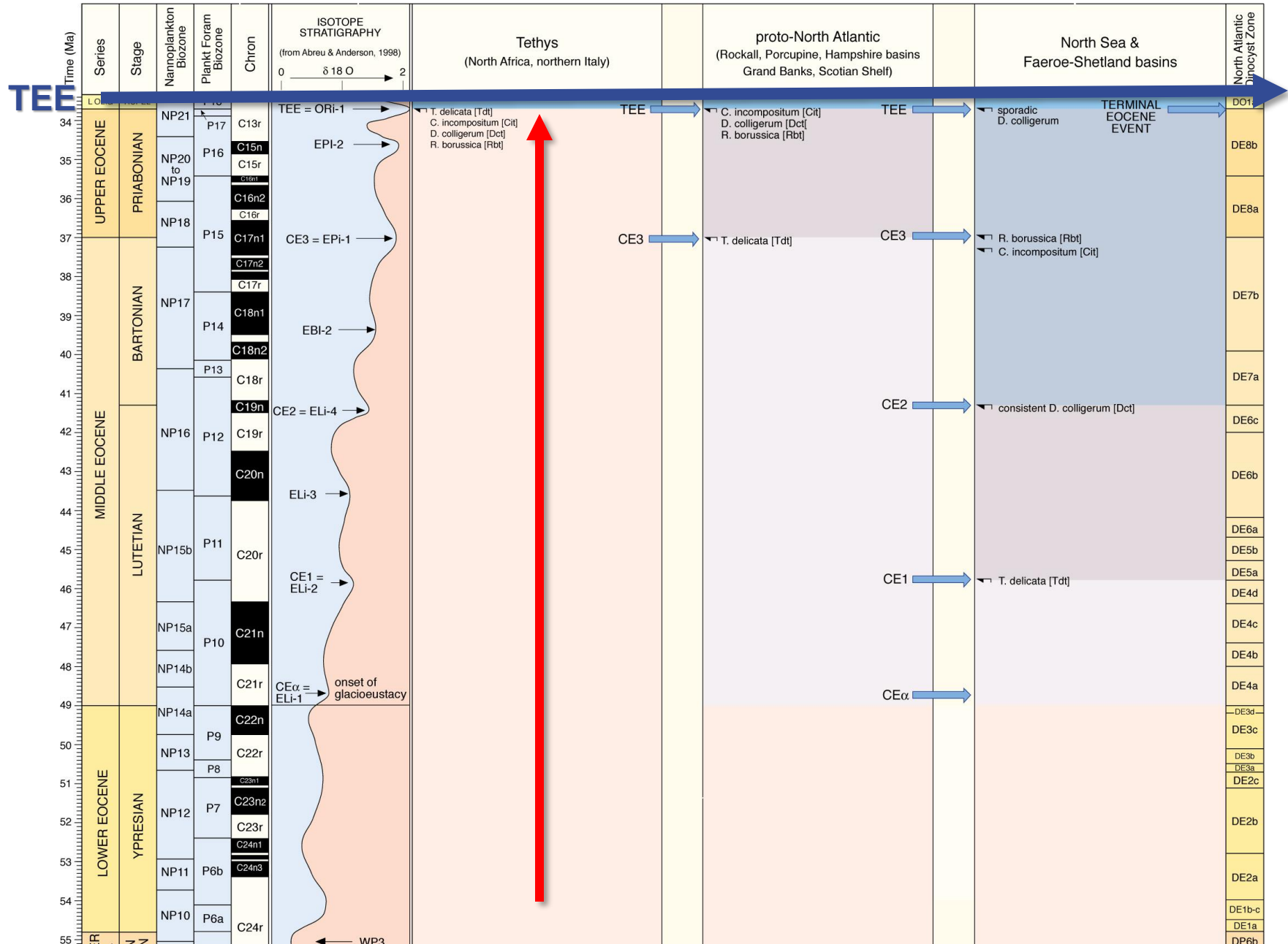
This indicates that the North Sea / N-G Sea system had a cooler SST than the North Atlantic System

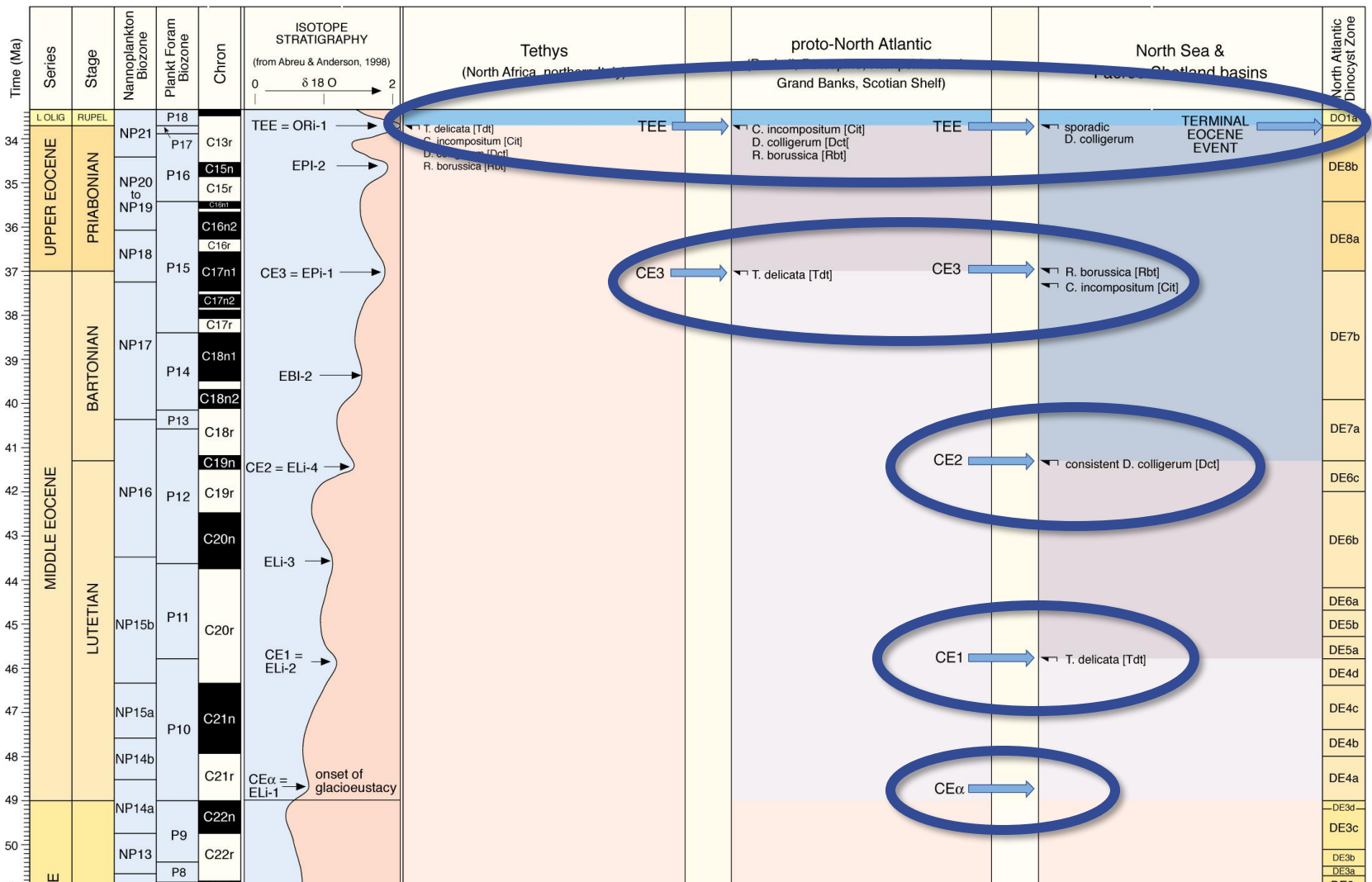


and that the North Atlantic was cooler than the Tethys (as we would expect)

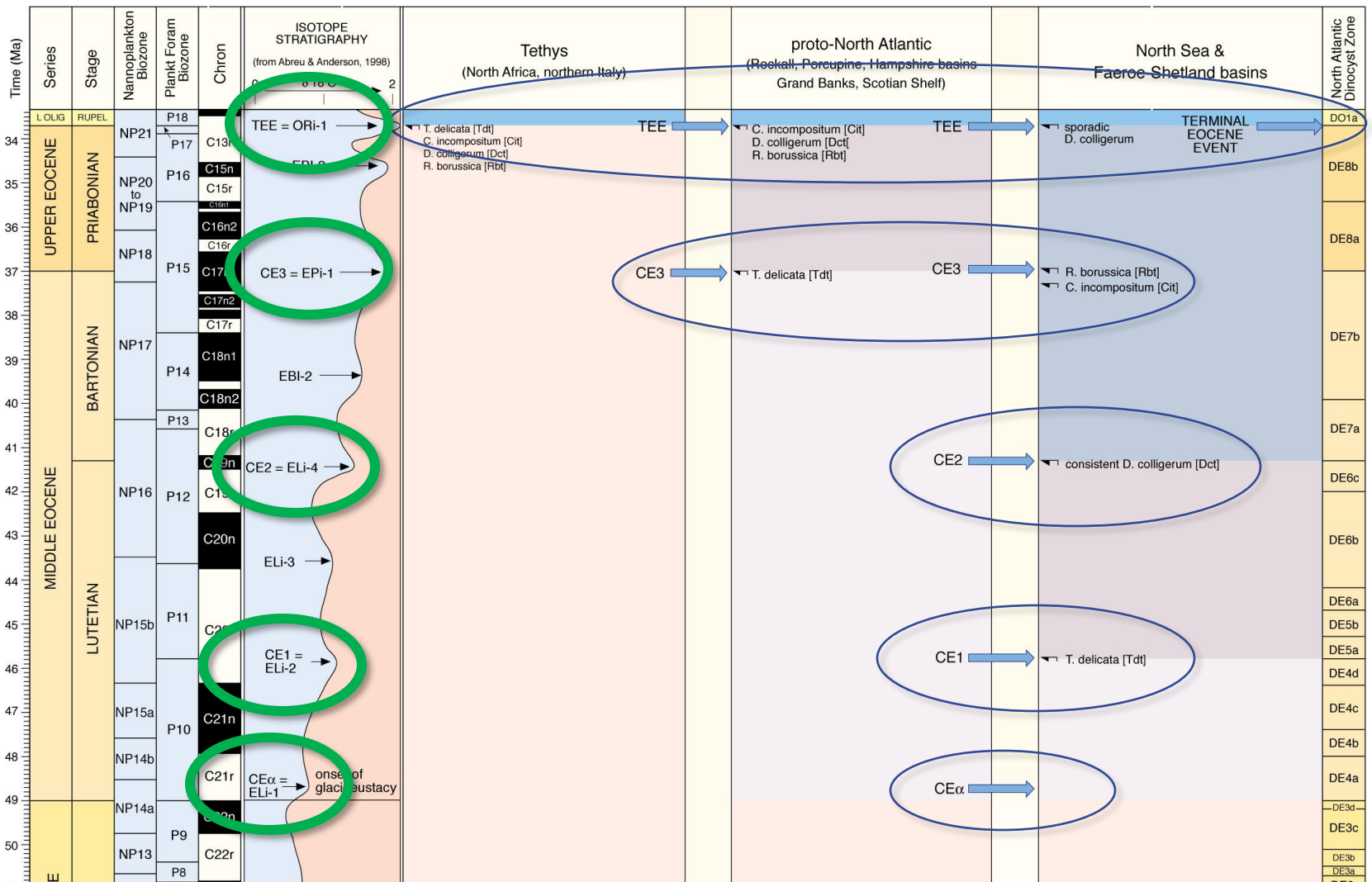


It also shows that cooling did not significantly affect the Tethyan region until the Terminal Eocene Event

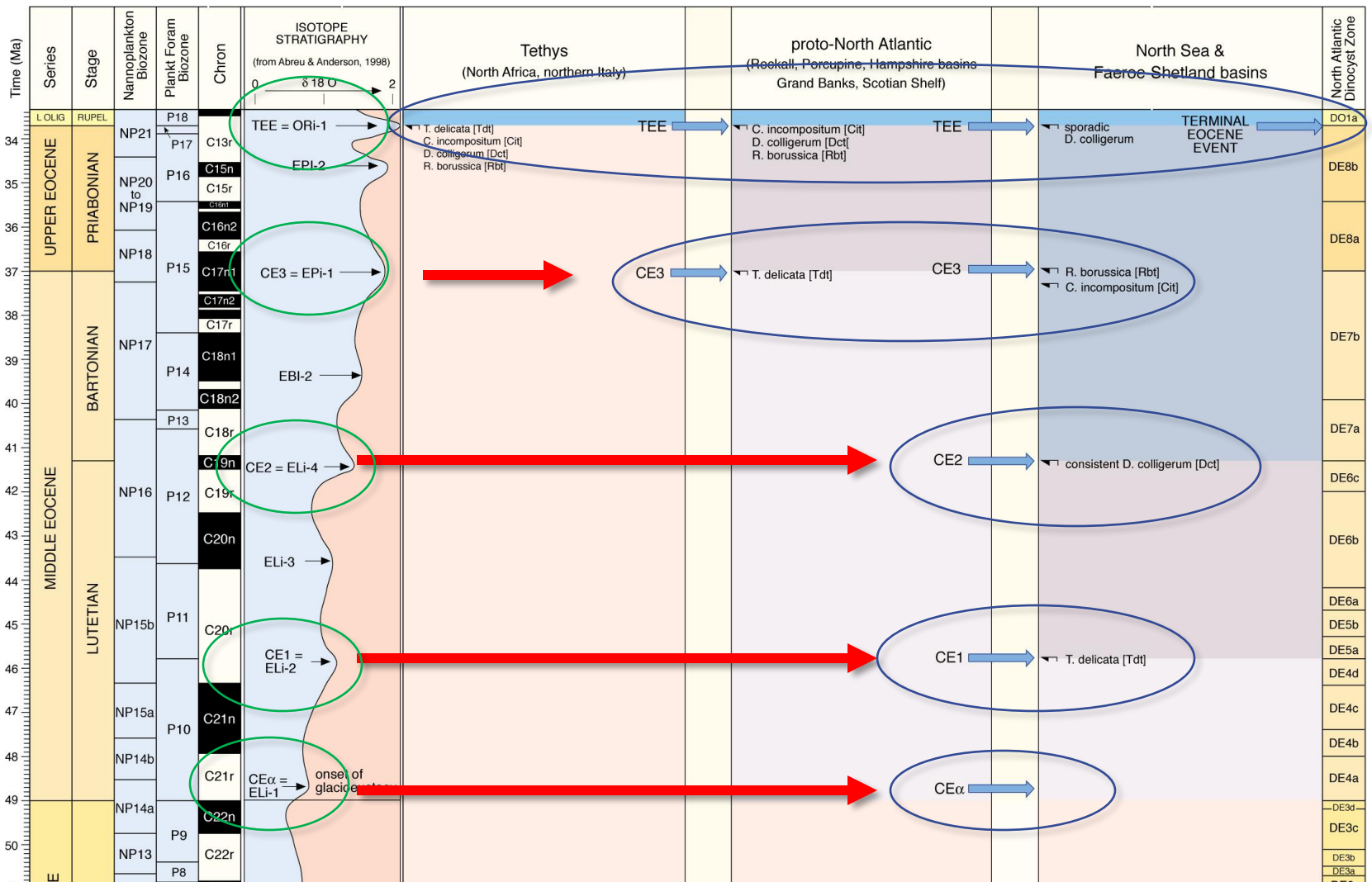




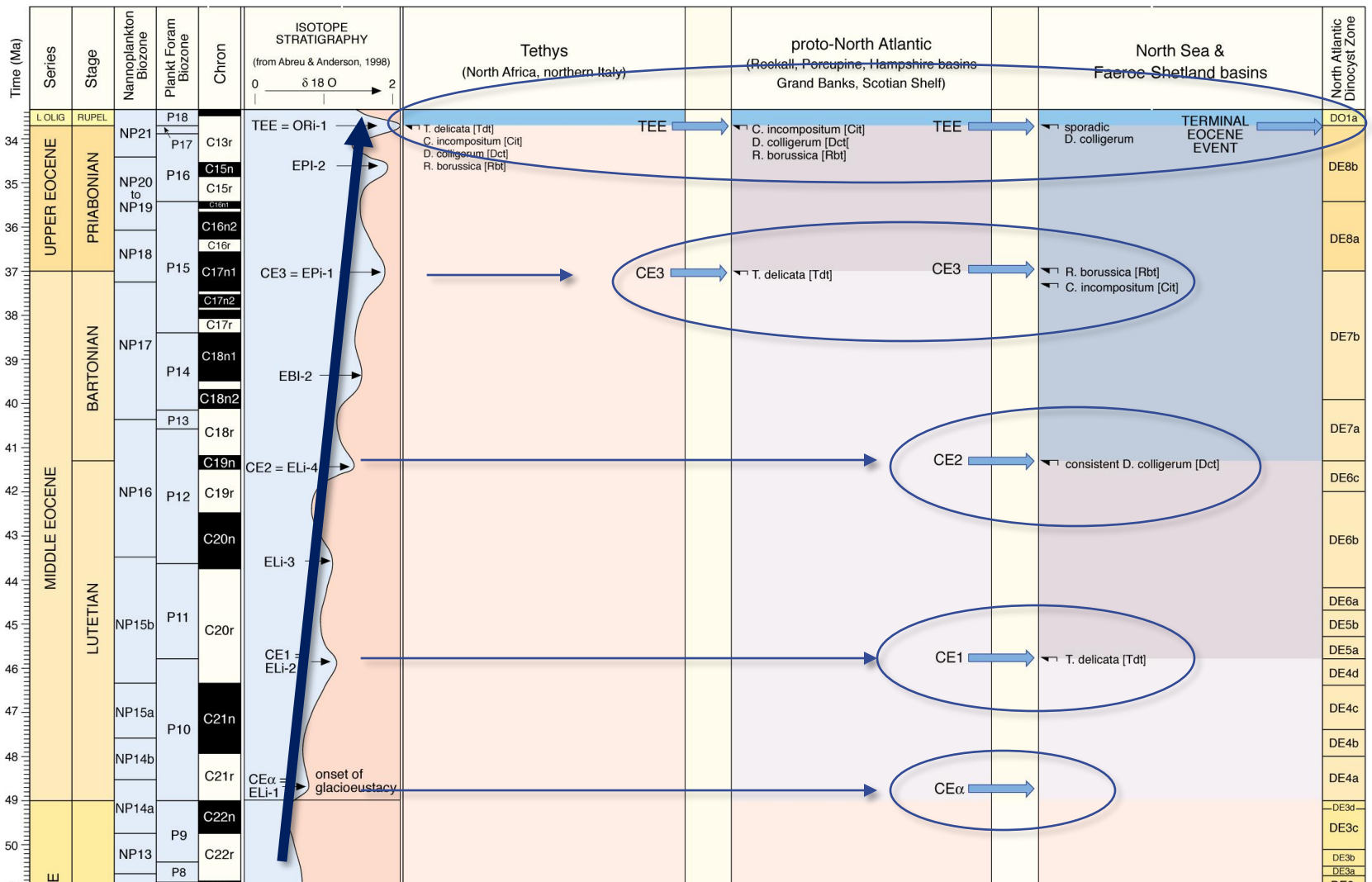
The succession of cooling steps is reflected by changes in sea-surface (dinocysts) and air temperatures (angiosperm pollen)



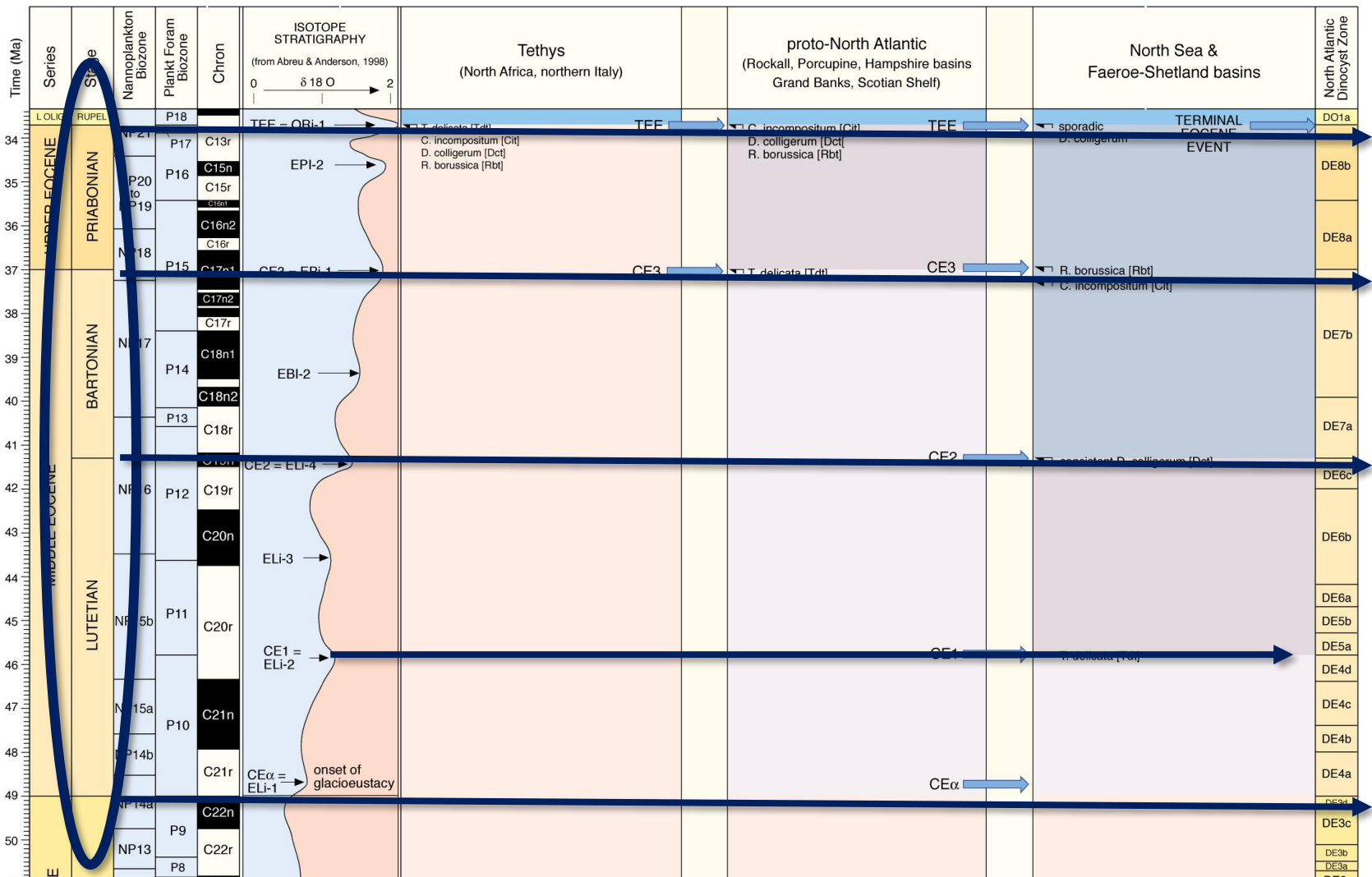
as well as the isotope record



The close correlation of these events indicates that they do not reflect local facies changes

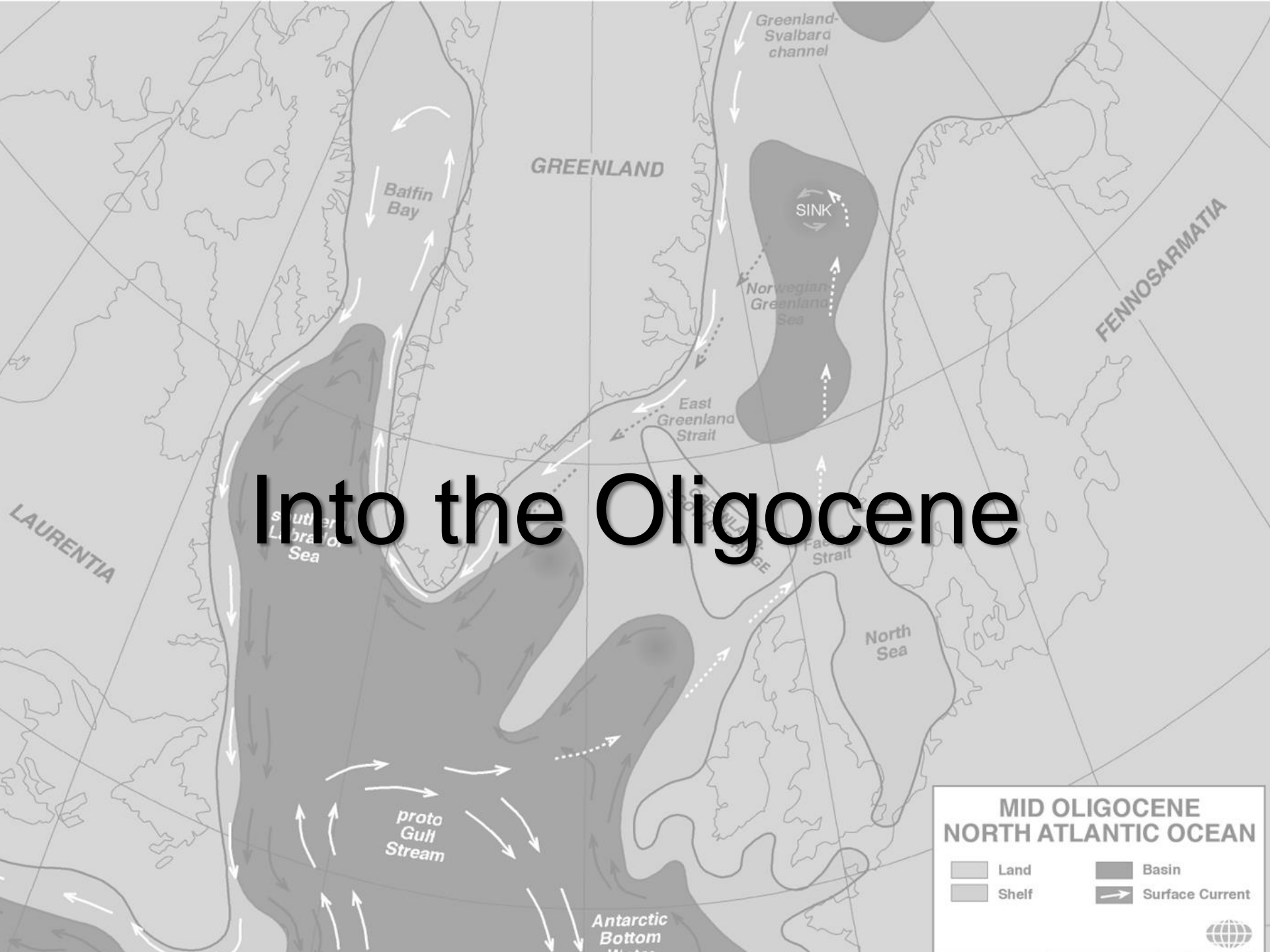


and that they were caused by a succession of Eocene cooling steps associated with the greenhouse to icehouse shift



The cooling steps correspond to NW European stage or substage boundaries because the stages were originally defined on major changes observed in the North Sea / NE European basin system

Into the Oligocene

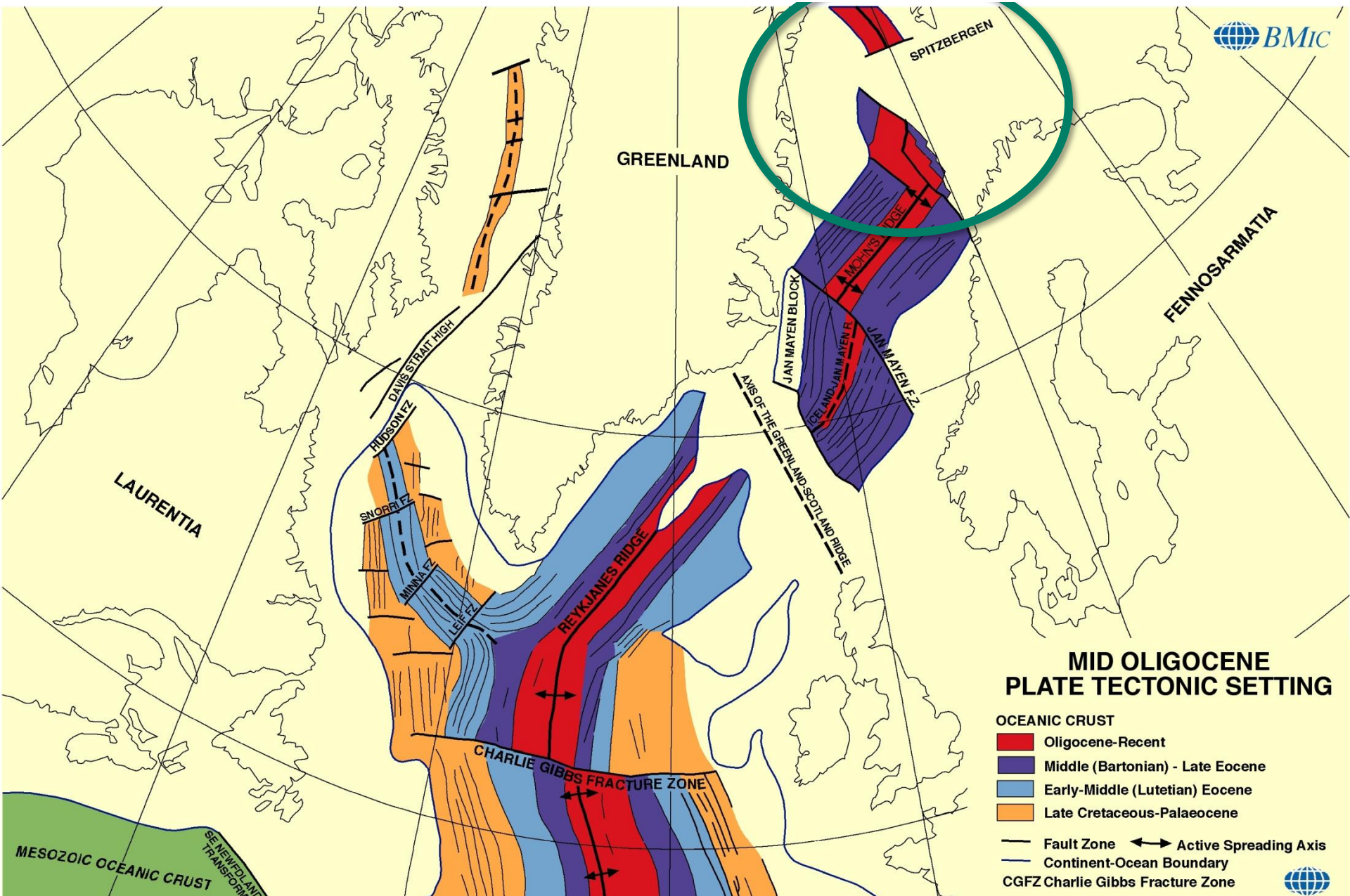


**MID OLIGOCENE
NORTH ATLANTIC OCEAN**

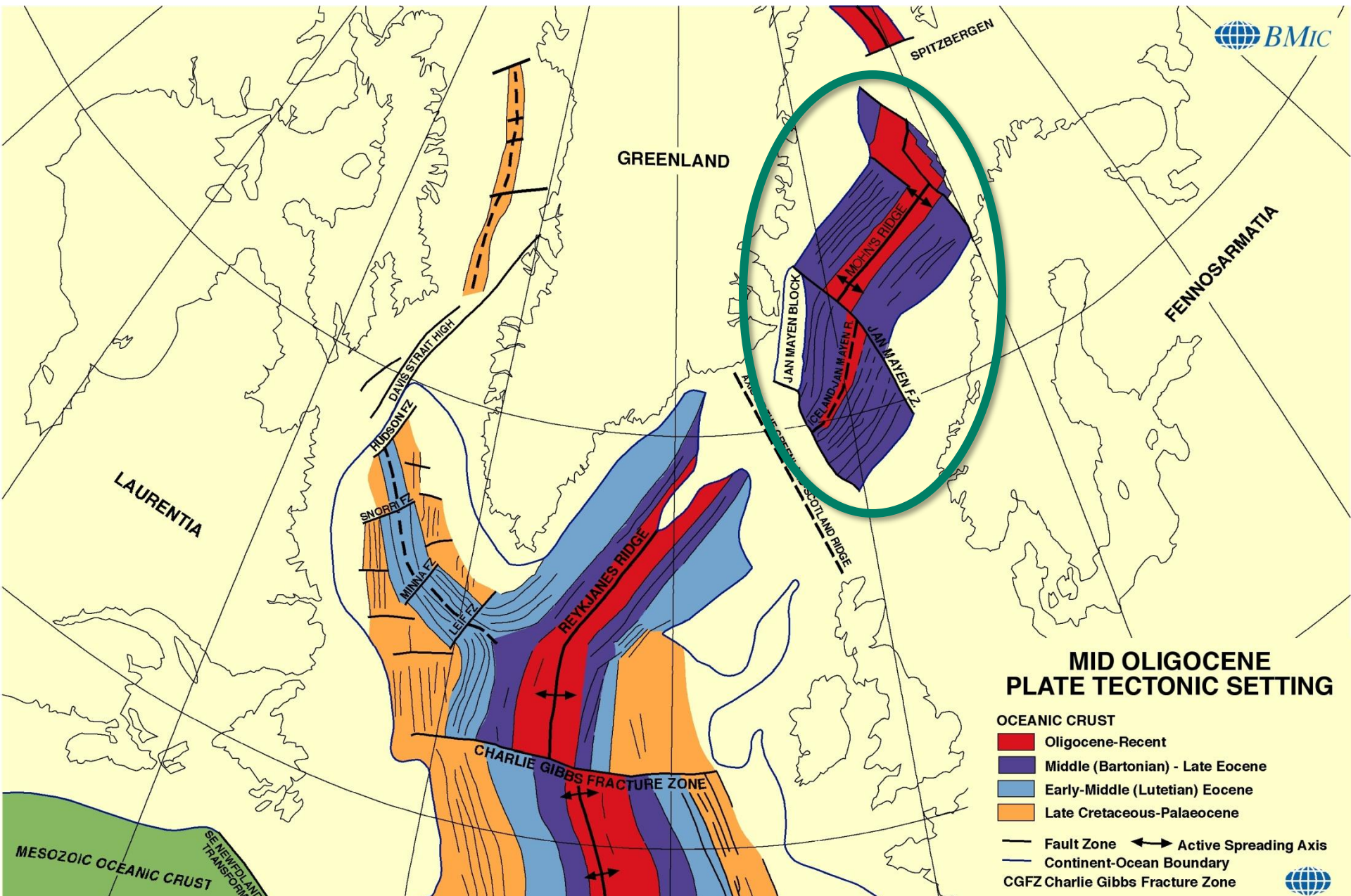
Land	Basin
Shelf	Surface Current



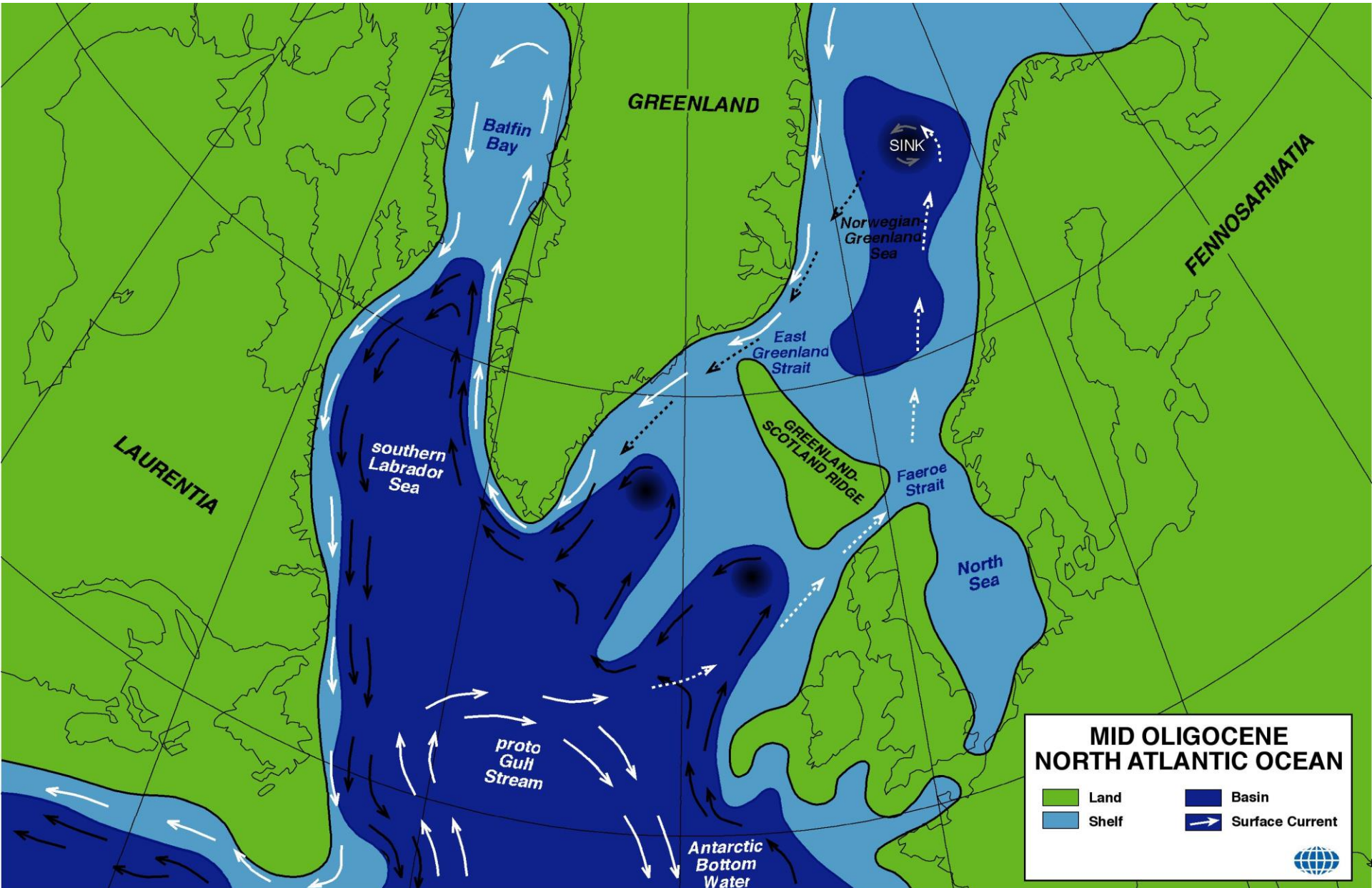
Plate tectonic spreading between Spitsbergen and Greenland opened a seaway deep enough for benthic forams to migrate into the Arctic.....



.....and it also deepened the Norwegian-Greenland Sea



Initiating the proto-Gulf Stream and shifting circulation towards today's North Atlantic oceanographic system



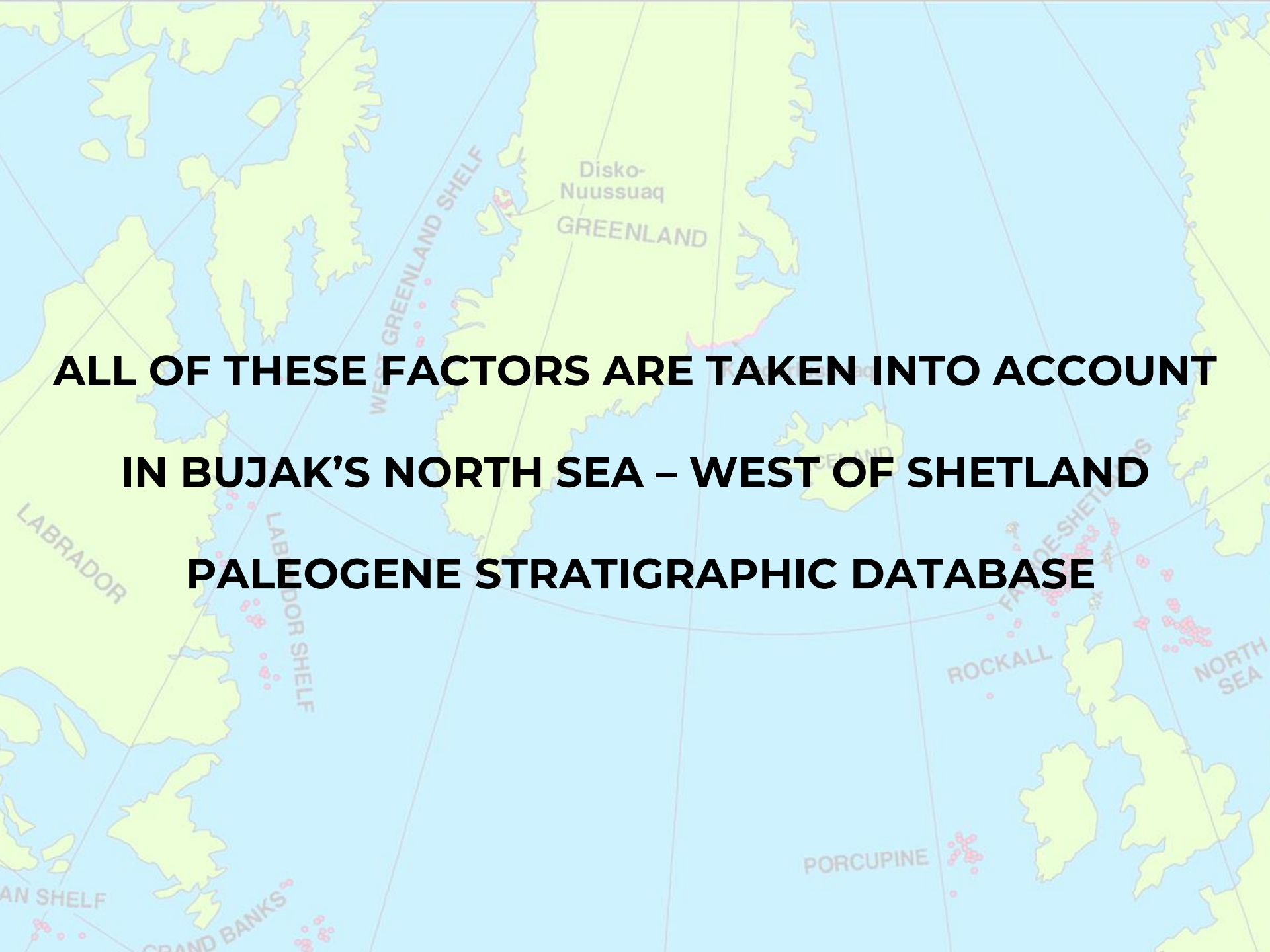


Interglacial

**With its icehouse climate and
succession of
glacial-interglacial cycles**

Glacial

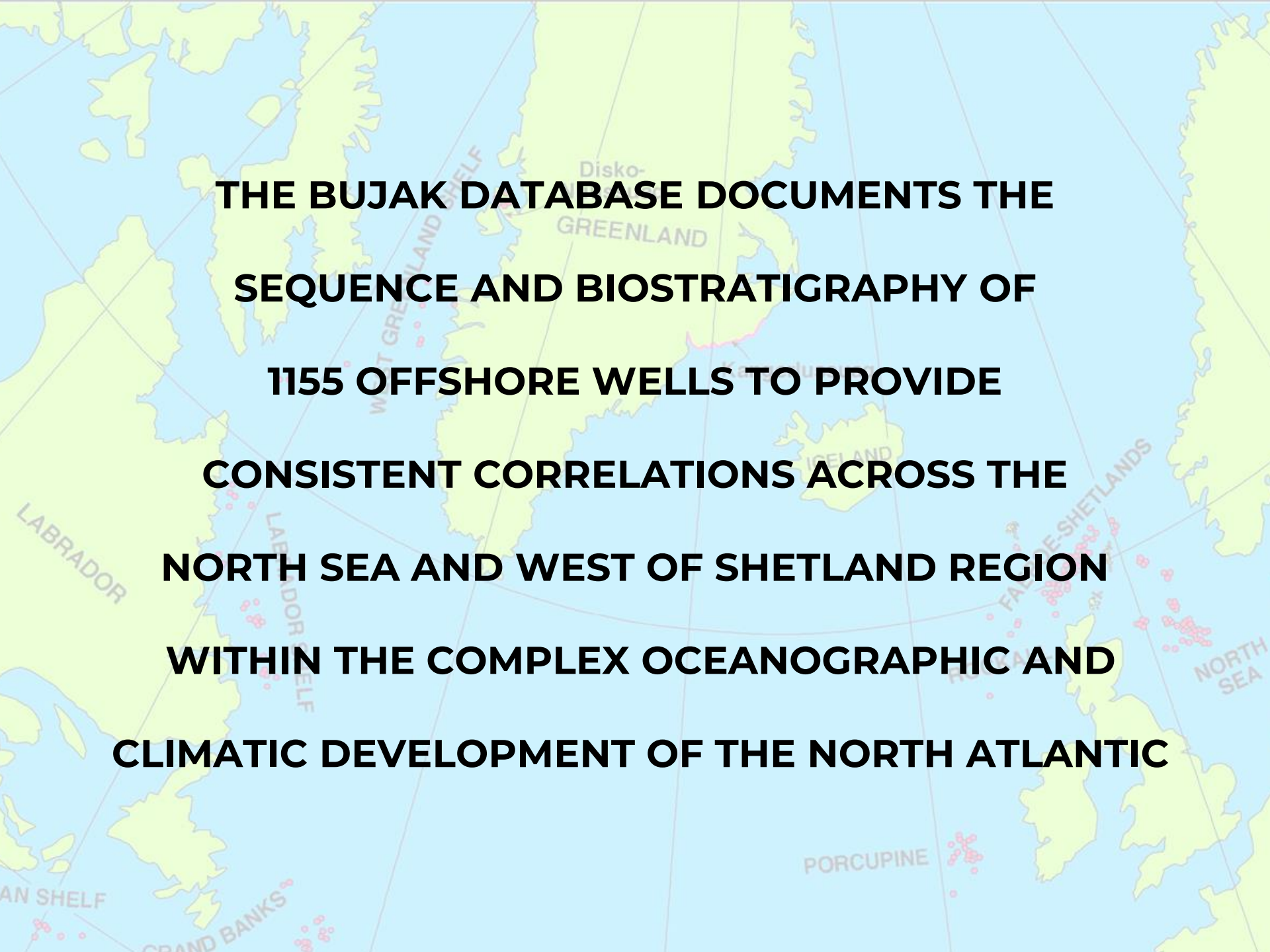


A map of the North Sea region, showing the coastlines of Greenland, Iceland, and the British Isles. The map highlights several geological shelves: the West Greenland Shelf, Labrador Shelf, and the Porcupine, Rockall, and Farnes-Shetland shelves. Numerous red dots are scattered across these shelves, representing data points. The text 'ALL OF THESE FACTORS ARE TAKEN INTO ACCOUNT IN BUJAK'S NORTH SEA – WEST OF SHETLAND PALEOGENE STRATIGRAPHIC DATABASE' is overlaid in the center of the map. The word 'GREENLAND' is written in large letters across the island, and 'Disko-Nuussuaq' is labeled on its west coast. 'LABRADOR' is labeled on the northern coast of North America. 'Iceland' is labeled between Greenland and the British Isles. 'NORTH SEA' is labeled in the eastern part of the map. 'PORCUPINE', 'ROCKALL', and 'FARNES-SHETLANDS' are labeled near the British Isles. 'GRAND BANKS' is labeled near the southern coast of Greenland. The text 'ALL OF THESE FACTORS ARE TAKEN INTO ACCOUNT IN BUJAK'S NORTH SEA – WEST OF SHETLAND PALEOGENE STRATIGRAPHIC DATABASE' is centered over the map in a large, bold, black font.

**ALL OF THESE FACTORS ARE TAKEN INTO ACCOUNT
IN BUJAK'S NORTH SEA – WEST OF SHETLAND
PALEOGENE STRATIGRAPHIC DATABASE**

A map of the North Atlantic region, including parts of North America, Greenland, Iceland, and the British Isles. The map highlights several geological features: the Labrador Shelf, West Greenland Shelf, and Grand Banks. Sampling locations are marked with red dots, with a concentration in the Rockall area. Labels for 'Disko-Nuussuaq' and 'Kangerlussuaq' are present on Greenland. The text is overlaid in the center of the map.

**WHICH ALSO INTEGRATES THEM WITH
THE SEQUENCE STRATIGRAPHIC FRAMEWORK
PUBLISHED IN A SERIES OF PAPERS
BY BUJAK, COPESTAKE AND MUDGE**

A map of the North Atlantic region, showing the coasts of North America, Greenland, and Europe. The map is overlaid with a grid of latitude and longitude lines. Numerous small red dots are scattered across the ocean, representing the locations of offshore wells. Labels on the map include 'LABRADOR', 'LABRADOR SHELF', 'WEST GREENLAND SHELF', 'GREENLAND', 'Disko', 'ICELAND', 'FAROE-SHETLANDS', 'NORTH SEA', and 'PORCUPINE'.

**THE BUJAK DATABASE DOCUMENTS THE
SEQUENCE AND BIOSTRATIGRAPHY OF
1155 OFFSHORE WELLS TO PROVIDE
CONSISTENT CORRELATIONS ACROSS THE
NORTH SEA AND WEST OF SHETLAND REGION
WITHIN THE COMPLEX OCEANOGRAPHIC AND
CLIMATIC DEVELOPMENT OF THE NORTH ATLANTIC**



The image is a map of the North Sea and West of Shetland region. It shows the coastlines of Greenland, Iceland, and the British Isles. Several oil and gas fields are marked with red dots and labeled: West Greenland Shelf, Disko-Nuussuaq, Kangerlussuaq, Labrador, Bradi Shelf, Grand Banks, Porcupine, Faeroe-Shetlands, and Rockall. The text is overlaid on the map in a large, bold, black font.

**IT IS UNIQUE IN ITS APPROACH
AND AN INVALUABLE AID FOR
NORTH SEA AND WEST OF SHETLAND
PETROLEUM EXPLORATION AND DEVELOPMENT**

A map of the North Atlantic region, showing Greenland, Iceland, and parts of Labrador and the British Isles. The map highlights several continental shelves: West Greenland Shelf, Labrador Shelf, and Porcupine. Numerous red dots are scattered across the ocean floor, indicating potential oil or gas reserves. Labels include 'Disko-Nuussuaq', 'Kangerlussuaq', 'ICELAND', 'FAEROE-SHETLANDS', 'ROCKALL', 'NORTH SEA', 'LABRADOR', 'WEST GREENLAND SHELF', 'LABRIOR SHELF', 'GRAND BANKS', and 'AN SHELF'.

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