Neogene Uplift of The Barents Sea

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FORCE seminar April 4, 2013

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The project (2010-2012)

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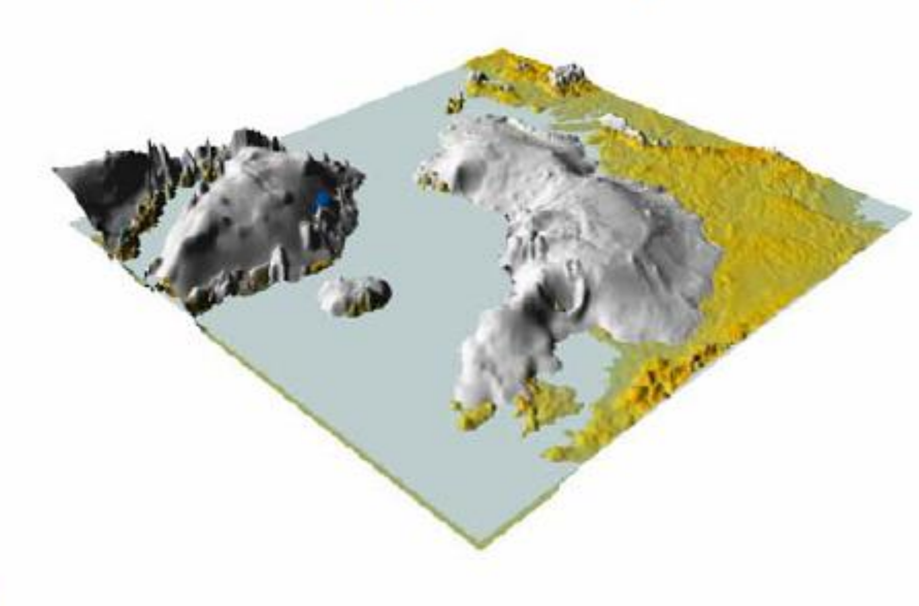
Neogene Uplift of the Barents Sea



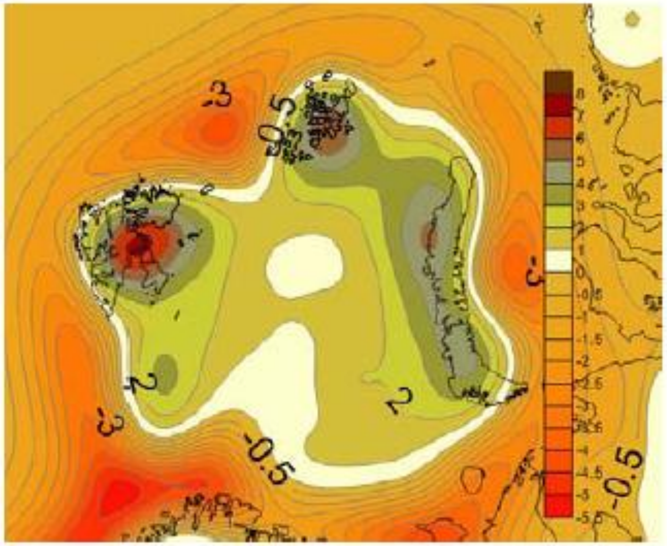


Figure 1a. Modelled ice sheet at Last Glacial Maximum; 1b. Calculated present rate of uplift for the Barents Sea (mm/yr).

A study by Tectonor, IRIS, VSEGEI, Royal Holloway University of London, and Cornell University

TECTONOR IRIS ВСЕГЕИ Royal Holloway University of London Cornell University

Funding companies

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TOTAL
DETNORSKE
OMV
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Insight changes reality
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Objective

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The objective of the work was to improve our understanding of the timing, geometry and magnitude of the Neogene and Quaternary erosion and uplift of the Russian and Norwegian parts of the Barents Sea.

Outline

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- ✓Plio-Pleistocene glaciations - extent and timing
  - ✓Effects of glaciers
- ✓Estimates/modelling of glacial erosion
  - ✓Isostatic effects (tilting of reservoirs)
- ✓Temperature- og maturity effects
- ✓Estimations of Neogene Erosion

Plio-Pleistocene glaciations

Deglaciation - last glaciation

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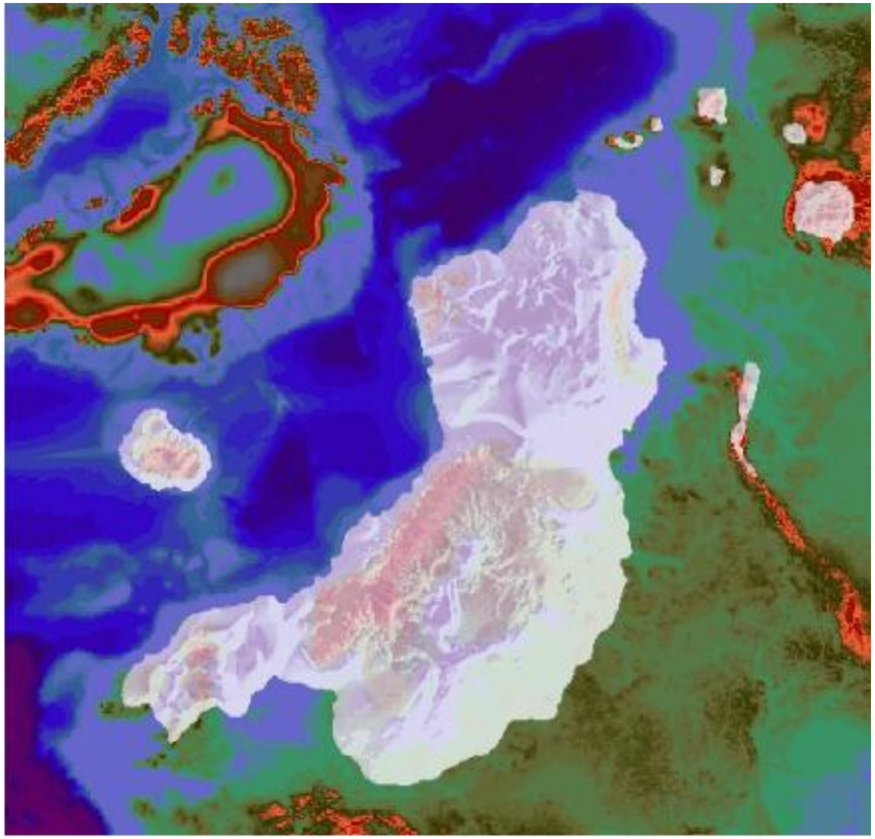

20 000 BP

Glacial-Interglacial cycles

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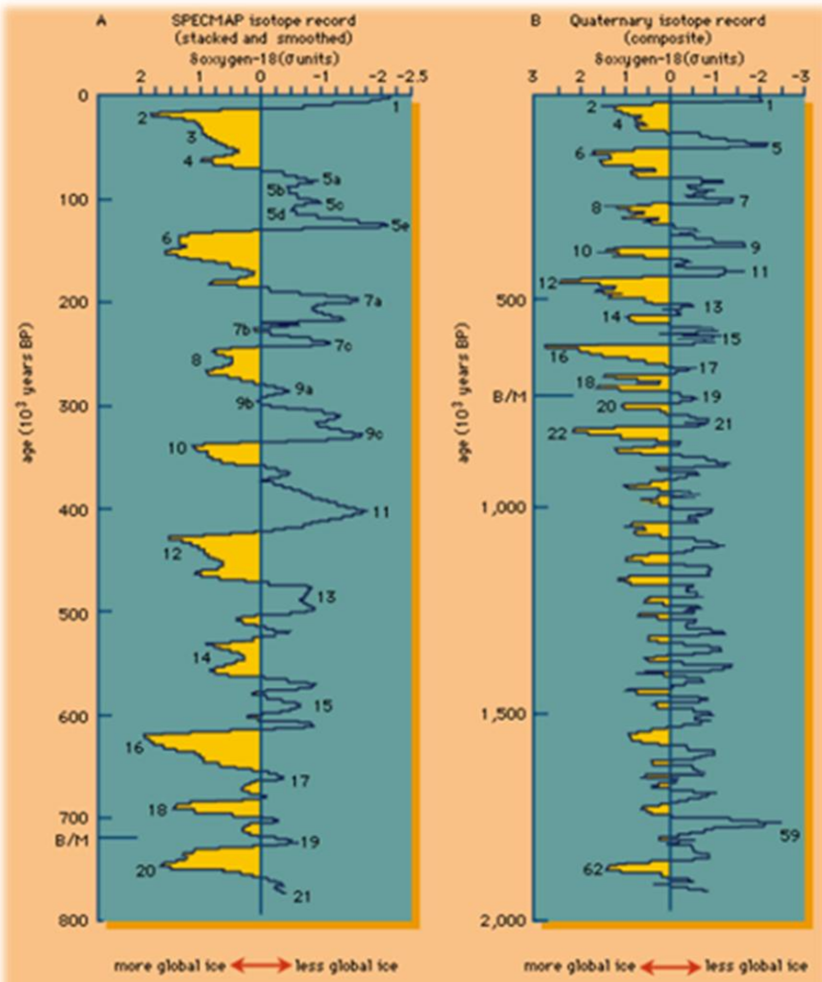


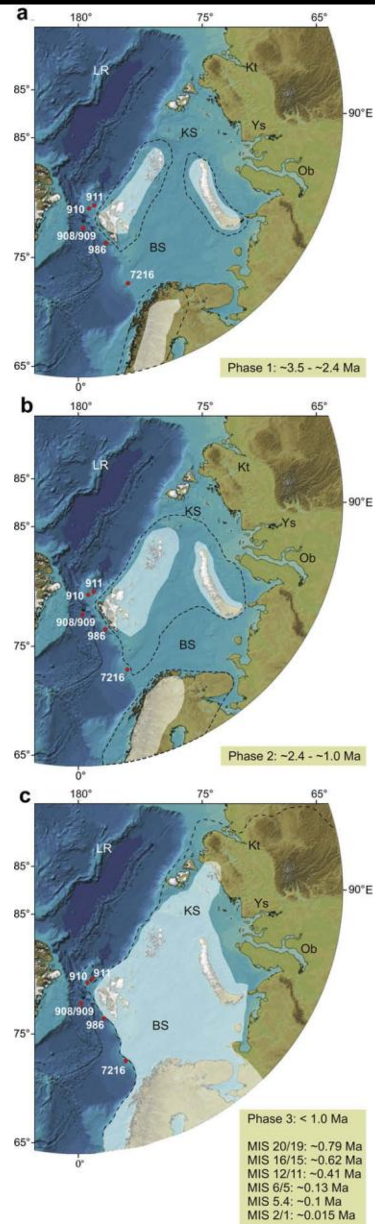
(A) The SPECMAP (Spectral Mapping Project) record based on five low- and middle-latitude deep-sea cores and (B) a composite record of four cores from the equatorial Pacific, the Caribbean, and the North Atlantic. Isotopic stages and substages are indicated; B/M shows the level of Brunhes/Matuyama reversal

From deep sea sediments

At least 8 glacial-interglacial cycles over the last 800 000 years, and maybe 30 cycles since late Pliocene.

3 Plio-Pleistocene phases

Typical glaciations



3.5-2.4 Ma

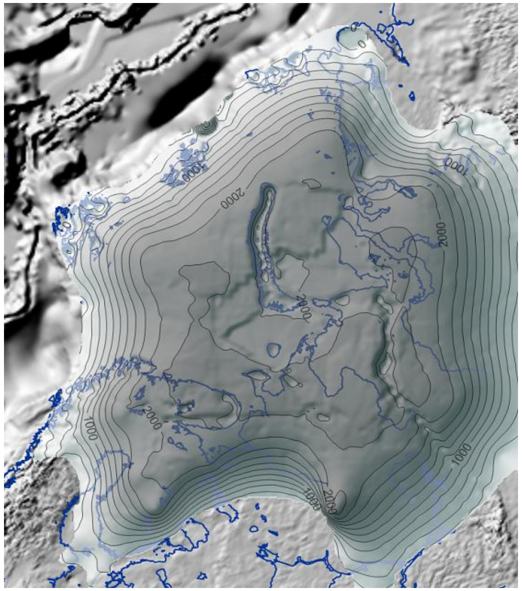
2.4–1.0 Ma

< 1.0 Ma

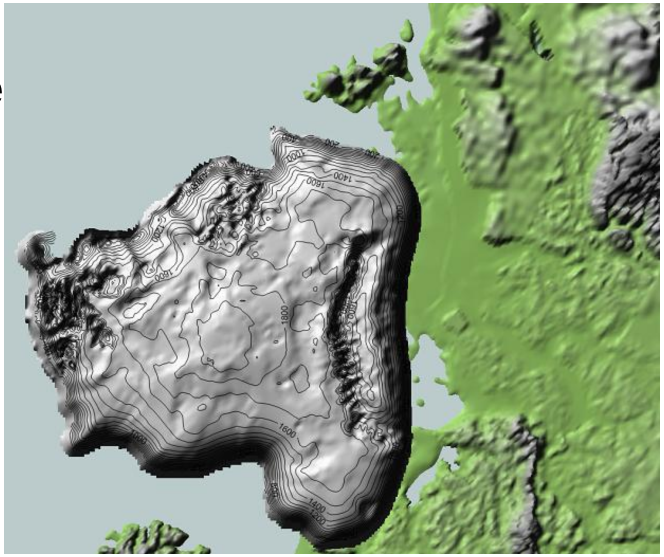
Knies et al (2009)

Plio-Pleistocene Glaciations

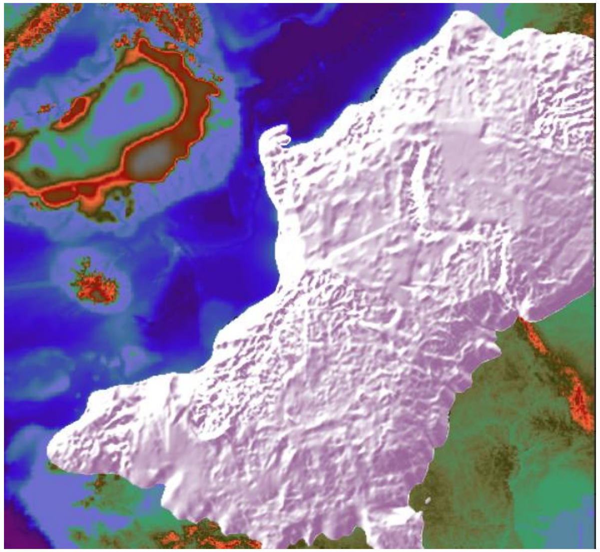
1st phase



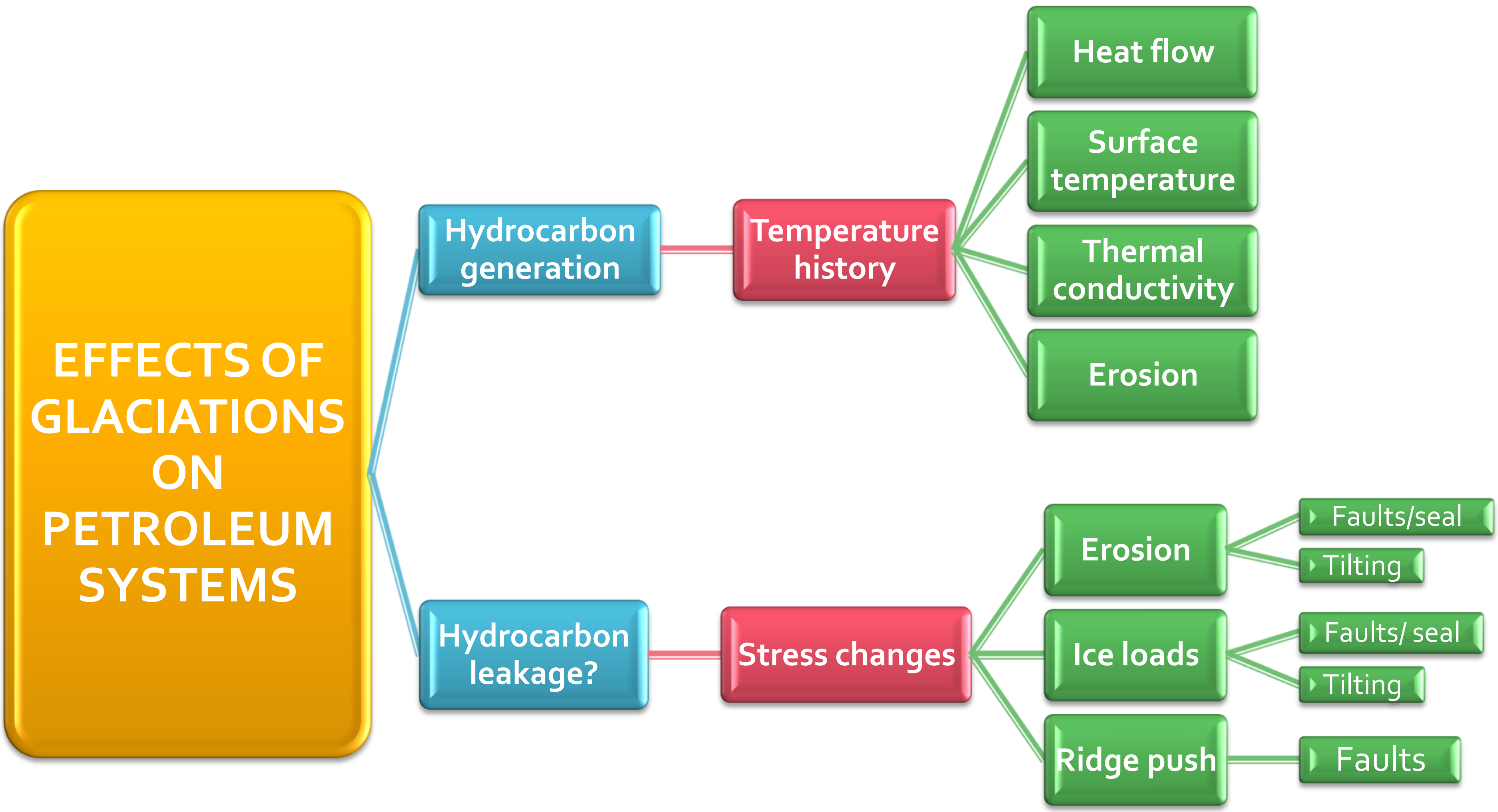
2nd phase



3rd phase



Maximum possible ice extent and thicknesses for three periods of Plio-Pleistocene


EFFECTS OF GLACIATIONS ON PETROLEUM SYSTEMS
Hydrocarbon generation
Temperature history
Heat flow
Surface temperature
Thermal conductivity
Erosion
Hydrocarbon leakage?
Stress changes
Erosion
Faults/seal
Tilting
Ice loads
Faults/ seal
Tilting
Ridge push
Faults

Effects

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Glaciations

- ✓Surface temperature
- ✓Thermal conductivity
- ✓Compaction
- ✓Isostatic effects
- ✓Elastic effects
- ✓Stress effects
- ✓Erosion

Petroleum systems

- ✓temperature
- ✓maturity
- ✓migration routes
- ✓leakage
- ✓reservoir quality

Glacial erosion

Implications

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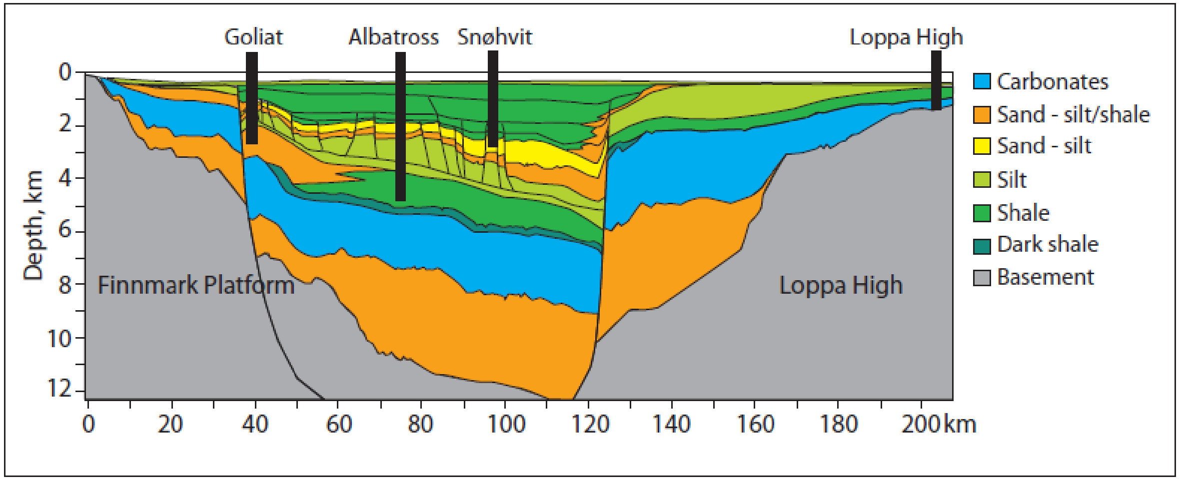
Source rock is generally located at too low temperatures to be generating hc recently.

Quantifying the amount of erosion in the glacial period will be an important step in the direction of quantification of max burial (time and amount).

This is important for the understanding of petroleum systems in the Barents Sea.



Effects of glaciations – Glacial erosion

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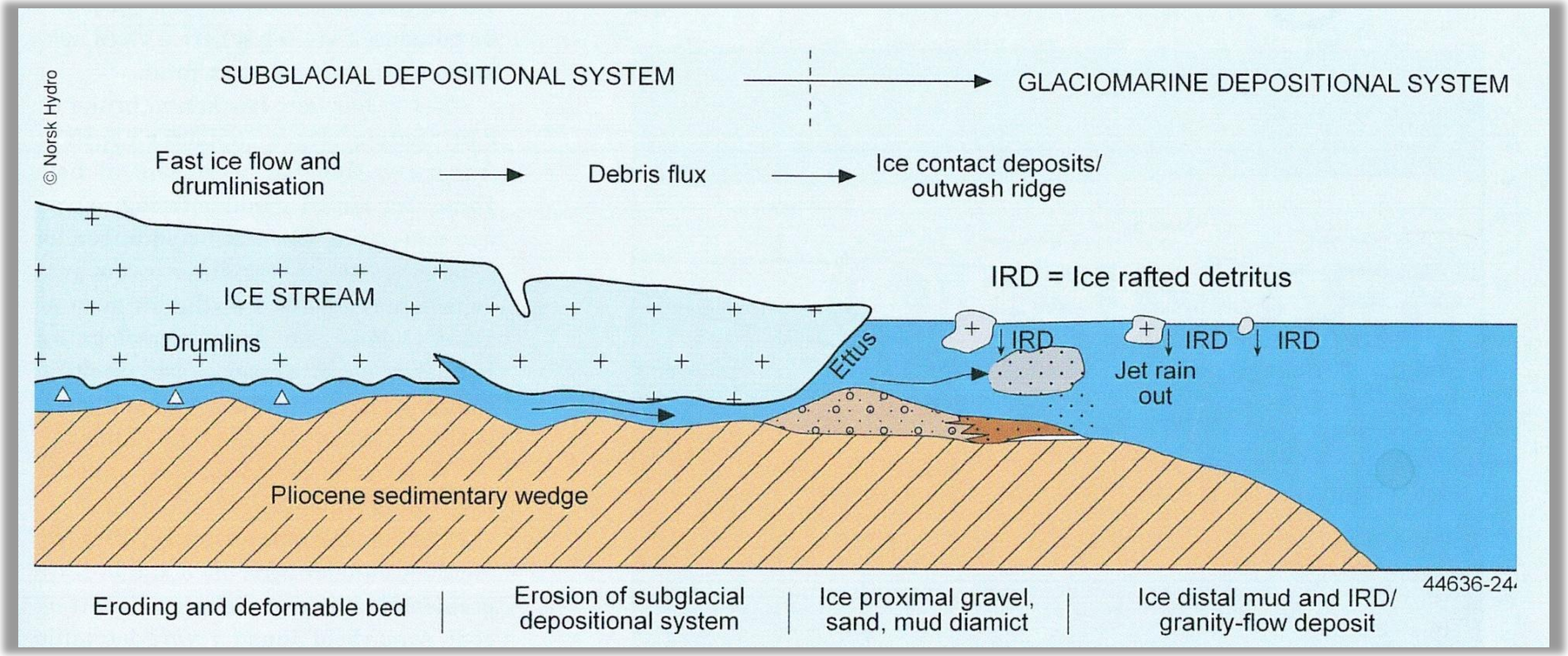
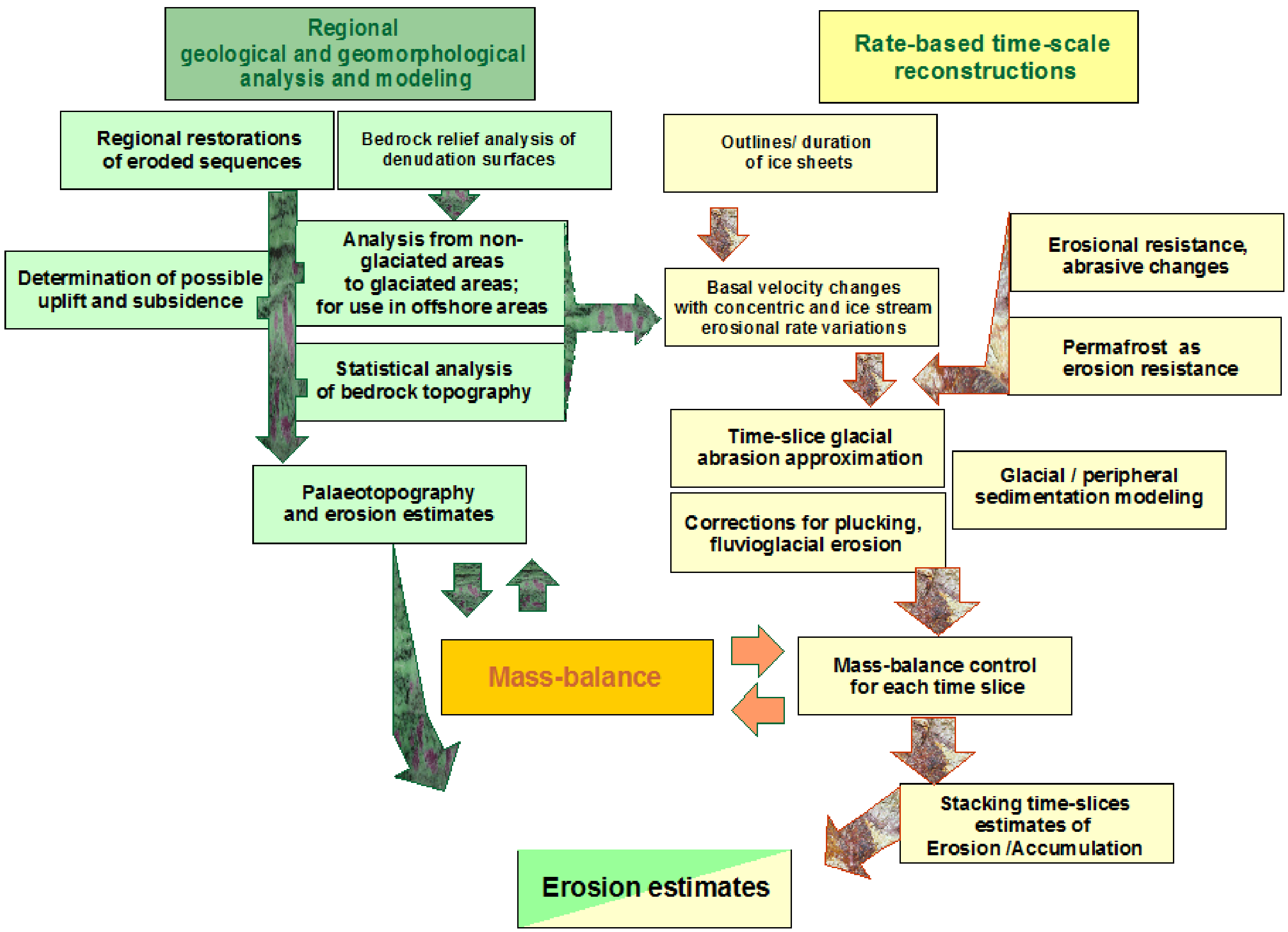


Morphological modelling



Morphological modelling

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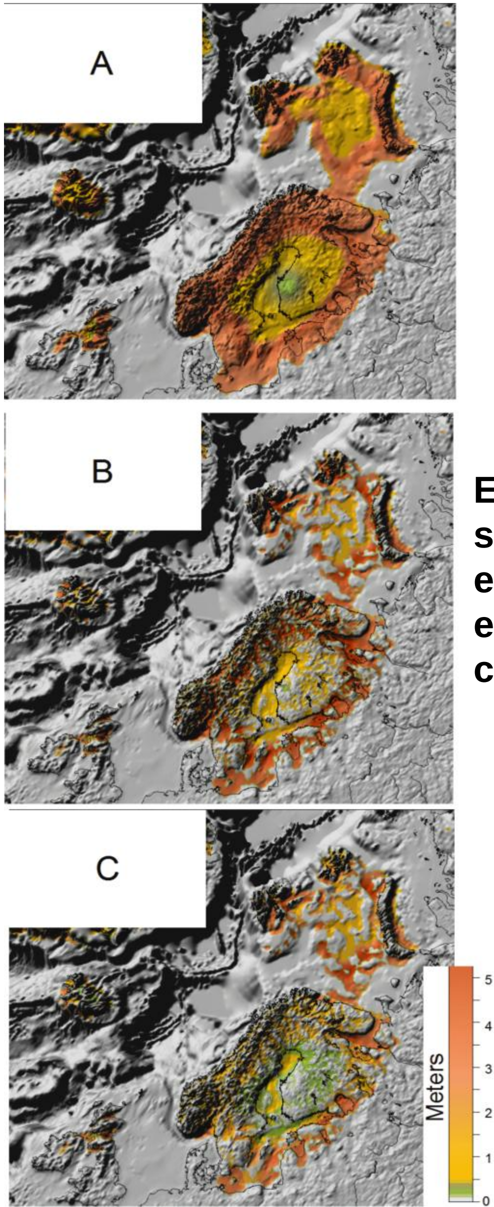
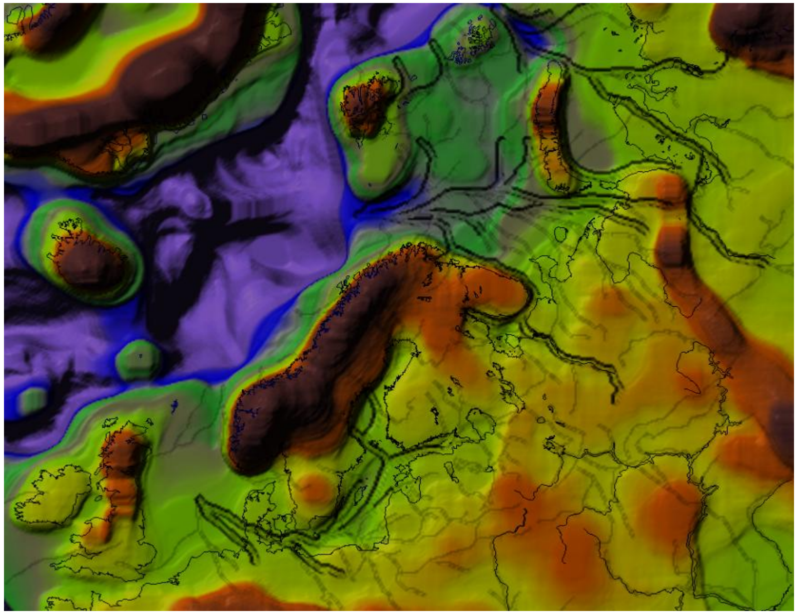
Concentric pattern forms due to low ice velocity under the center, and more rapid basal ice velocity near the margins



Effect of ice streams with enhanced erosional capacity

Different erodability of sedimentary bedrock and basement lithologies

Illustration of the erosion model



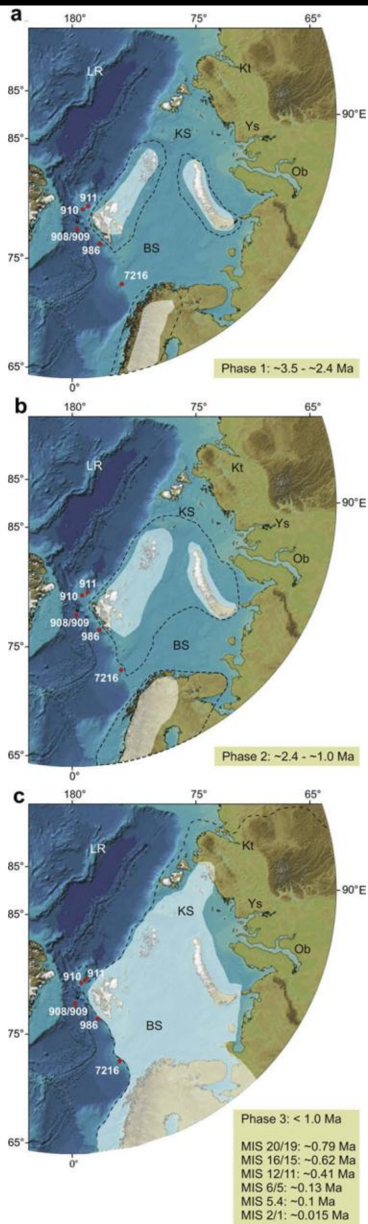
Model of pre-glacial landscape with major drainage pattern

Erosion modeling

Early phase

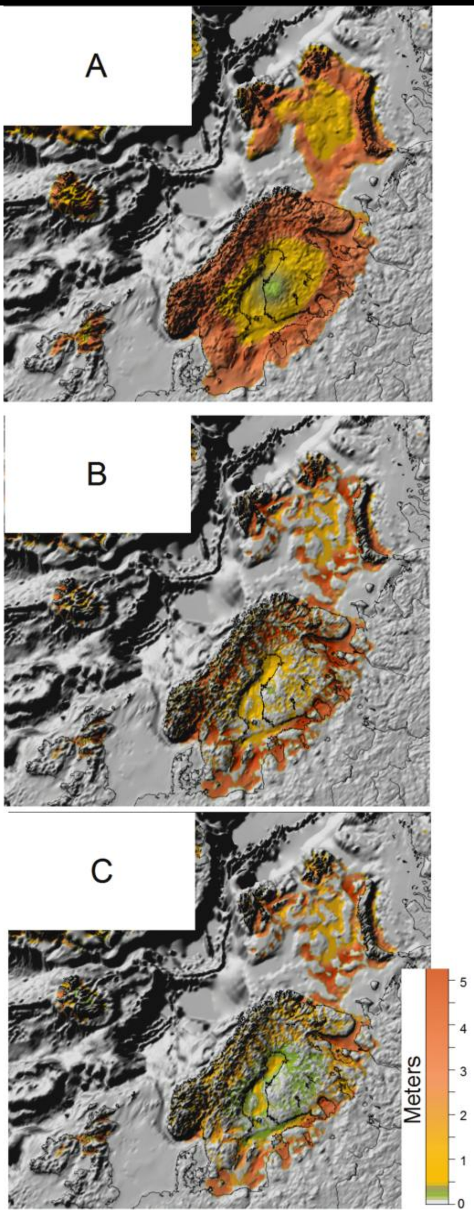
Mid phase

Late phase



Predict erosion

Knies et al (2009)



Plio-Pleistocene Glaciations

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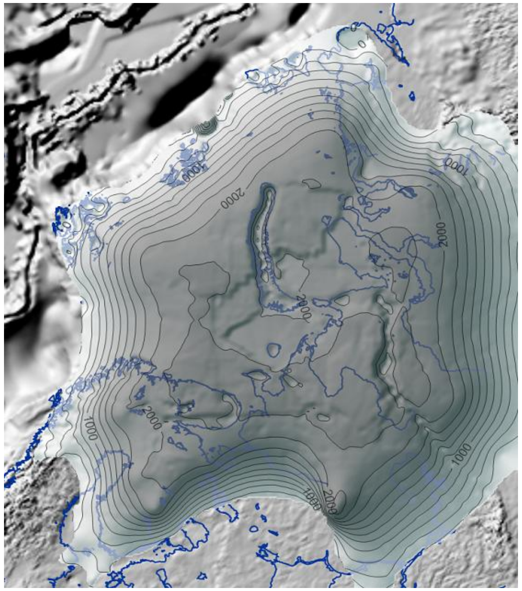
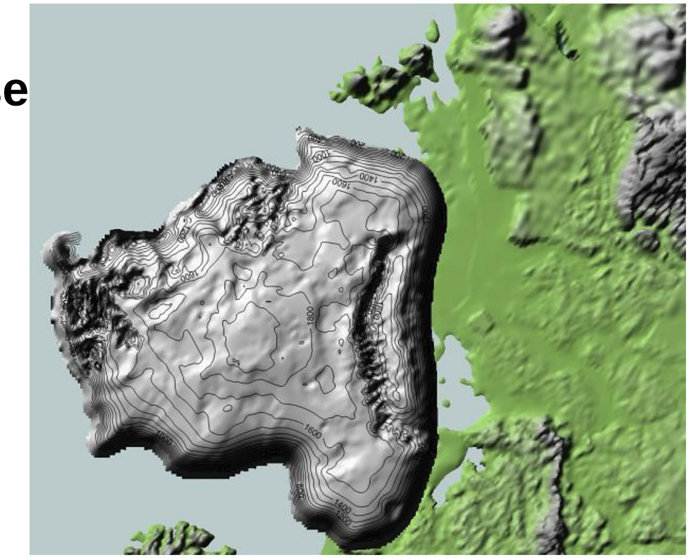
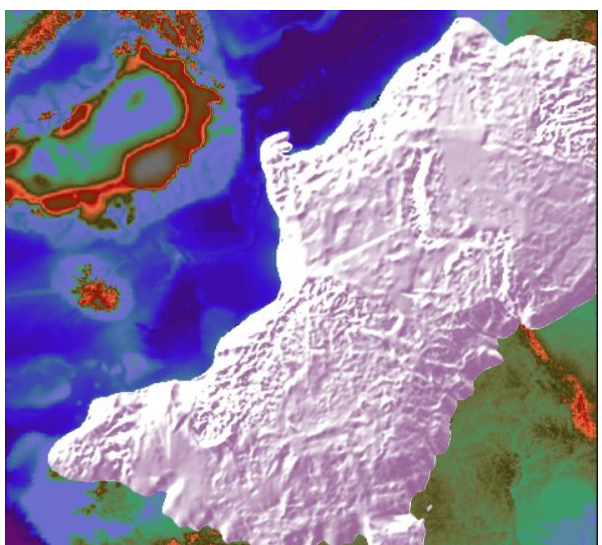
1st phase



2nd phase

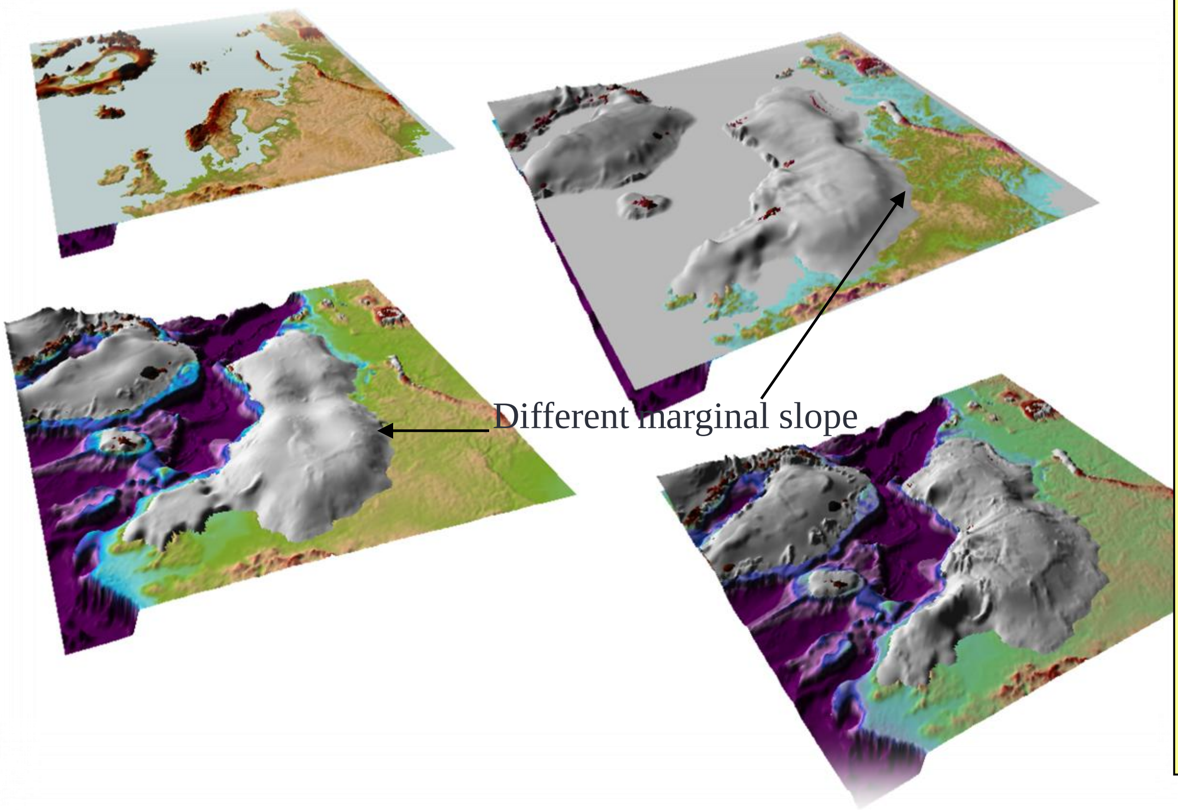


3rd phase



Maximum possible ice extent and thicknesses for three periods of Plio-Pleistocene

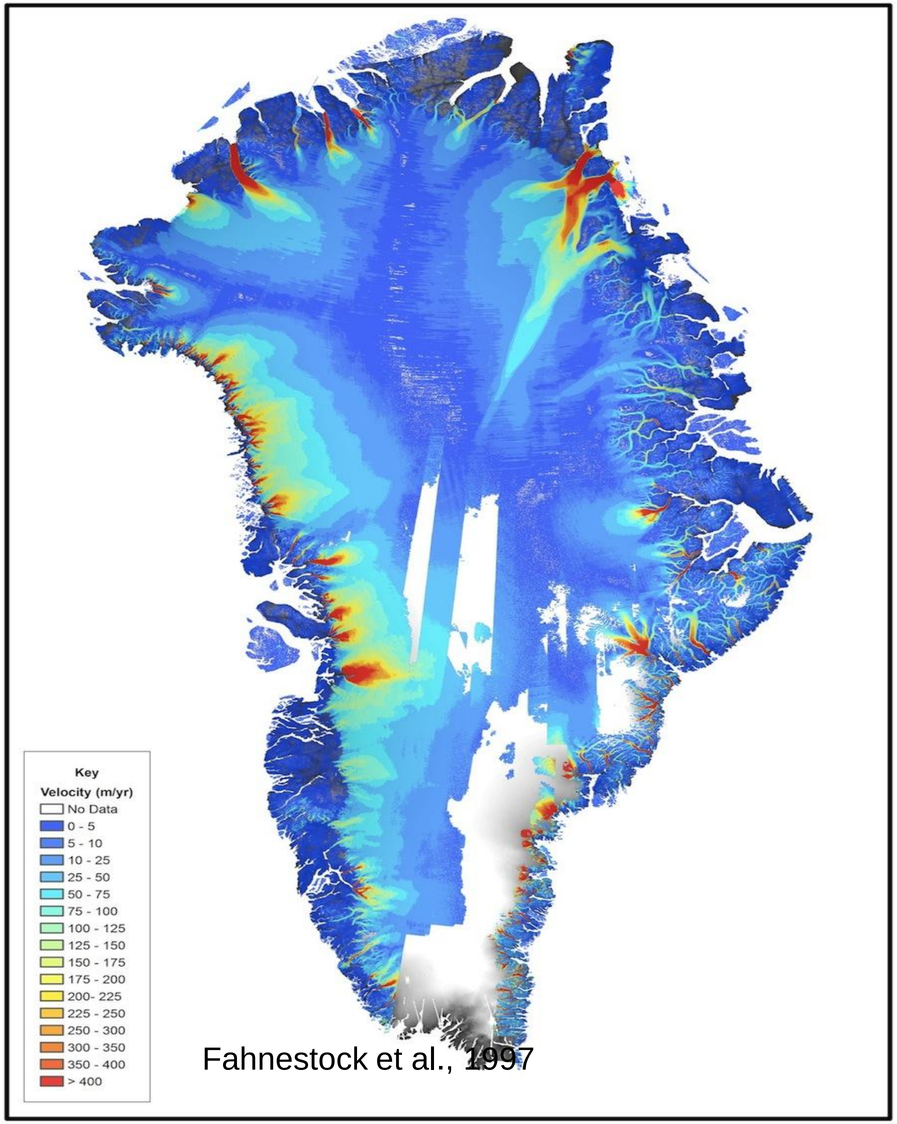
Ice Thickness Module



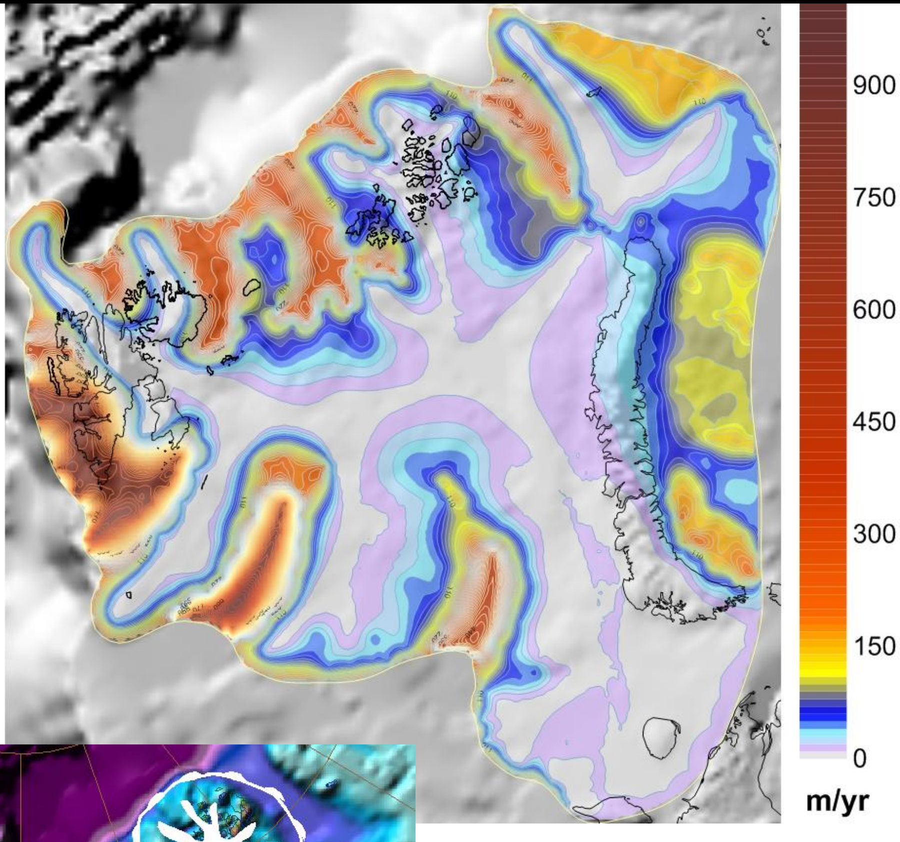
Ice Thickness computed from:

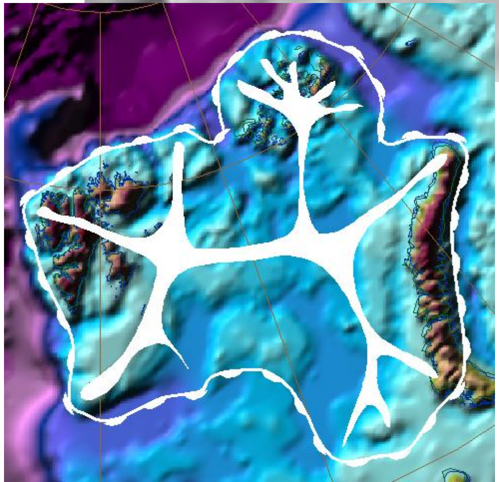
1. Ice margin outline
2. Topography
3. Basal lithology
4. Ice velocity
5. Floating or frozen base
6. Marginal slope (specified)
7. Continental or ocean margin

Ice surface velocities



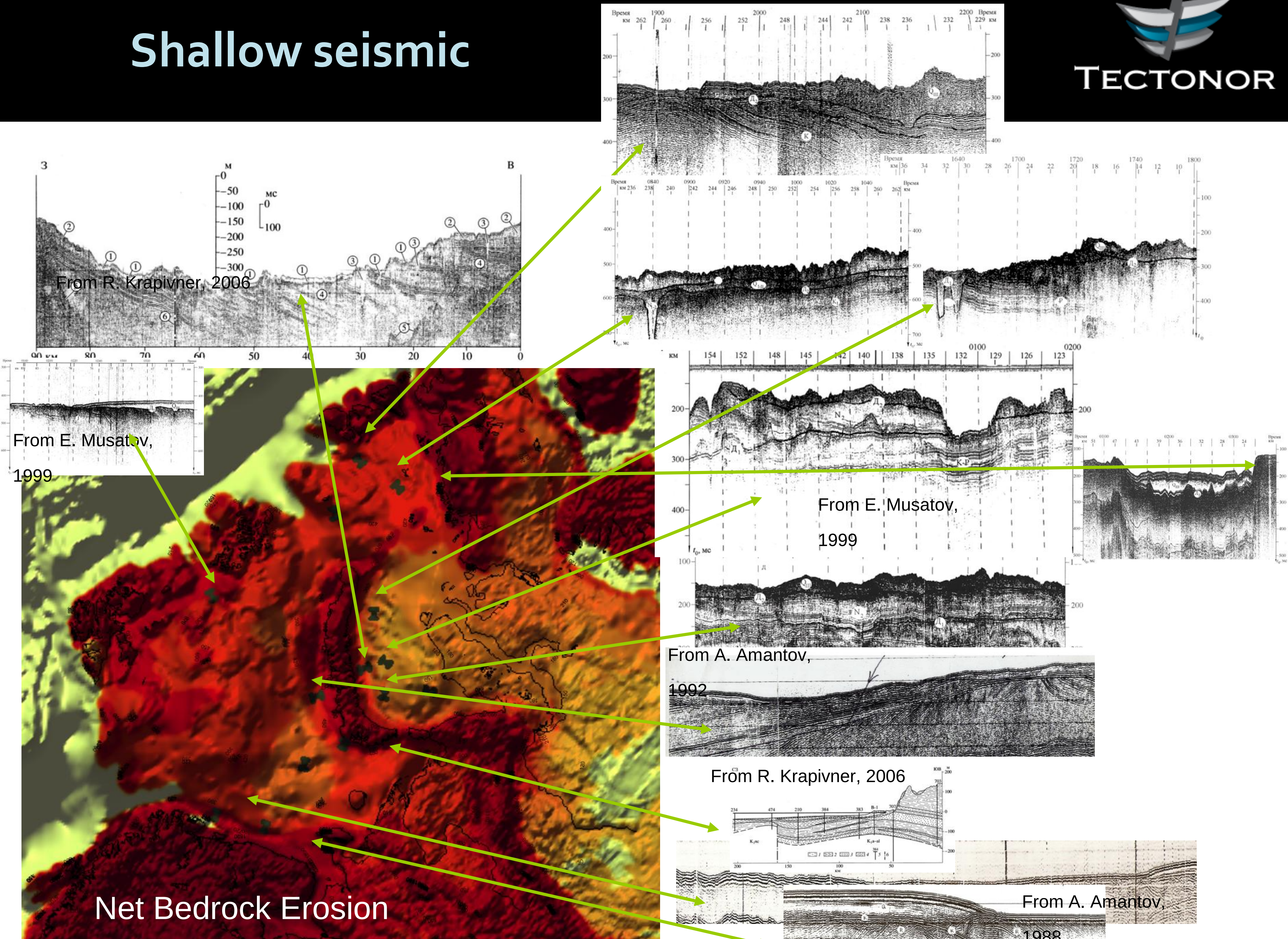
Fahnestock et al., 1997



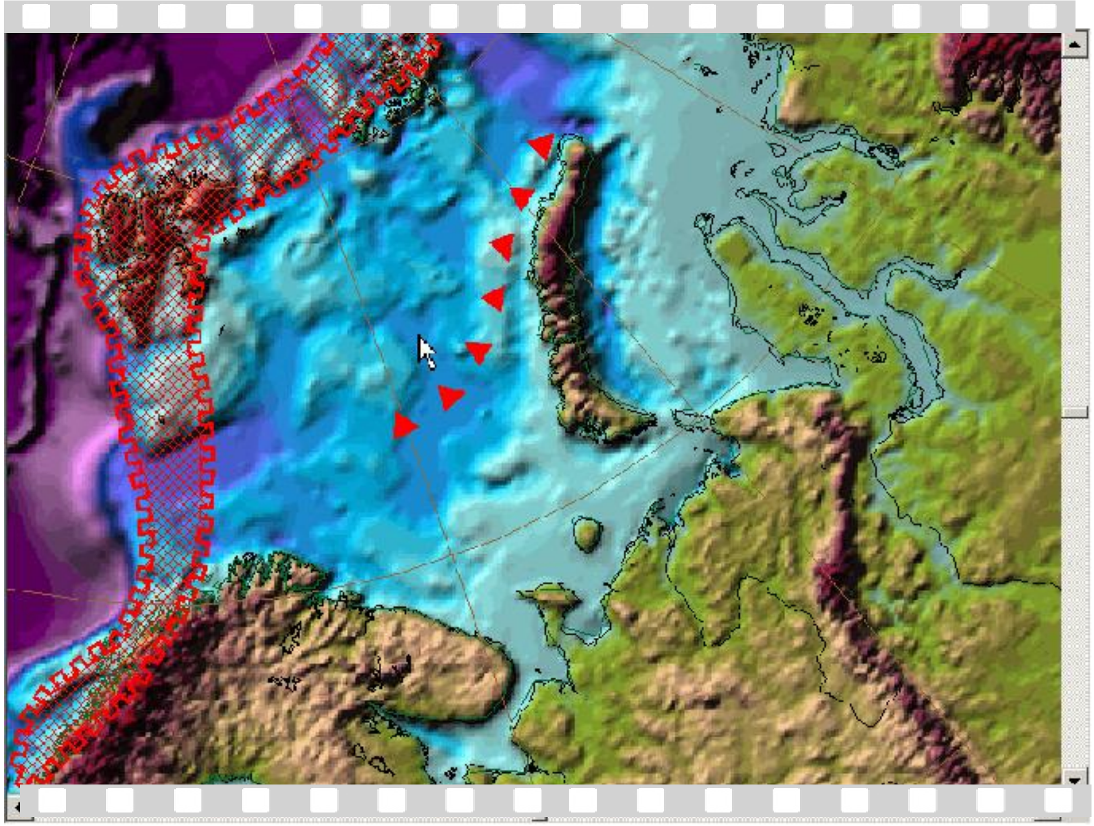


Skeleton

Shallow seismic



Zone of maximum glacial erosion



Maximum glacial erosion has stable position along the Atlantic coast, while eastern flank is migrating due to ice sheet grow and decay

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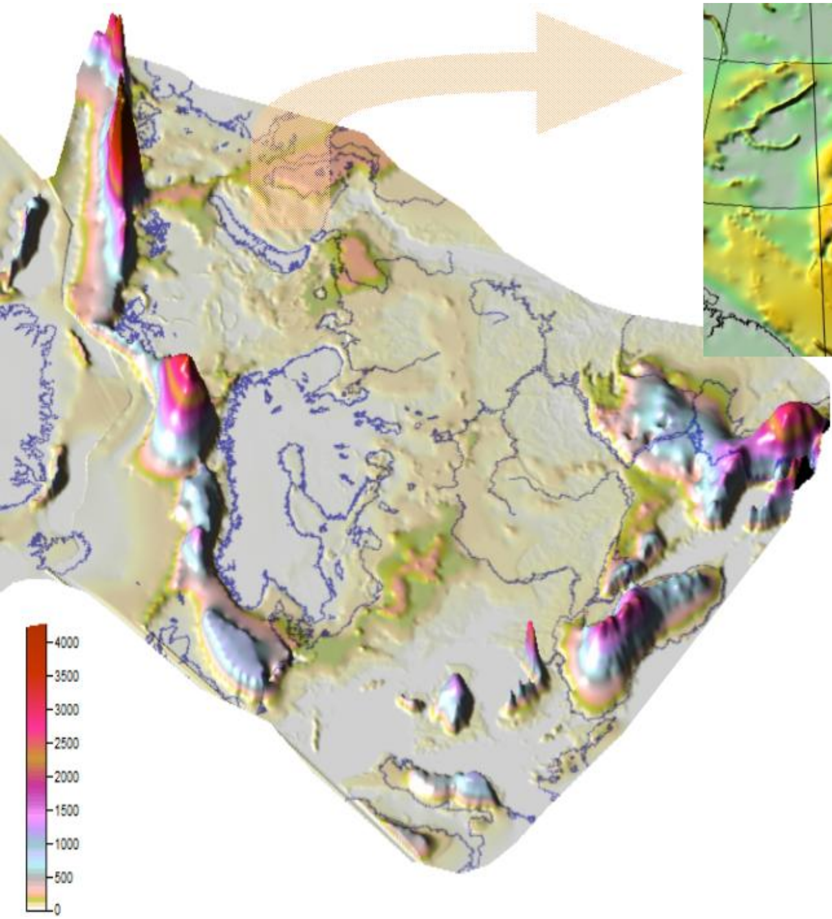
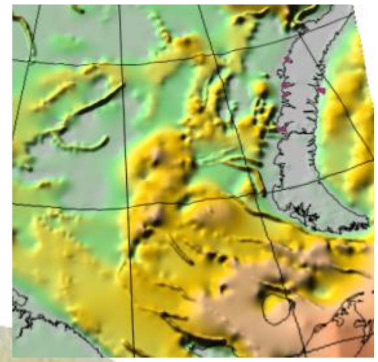
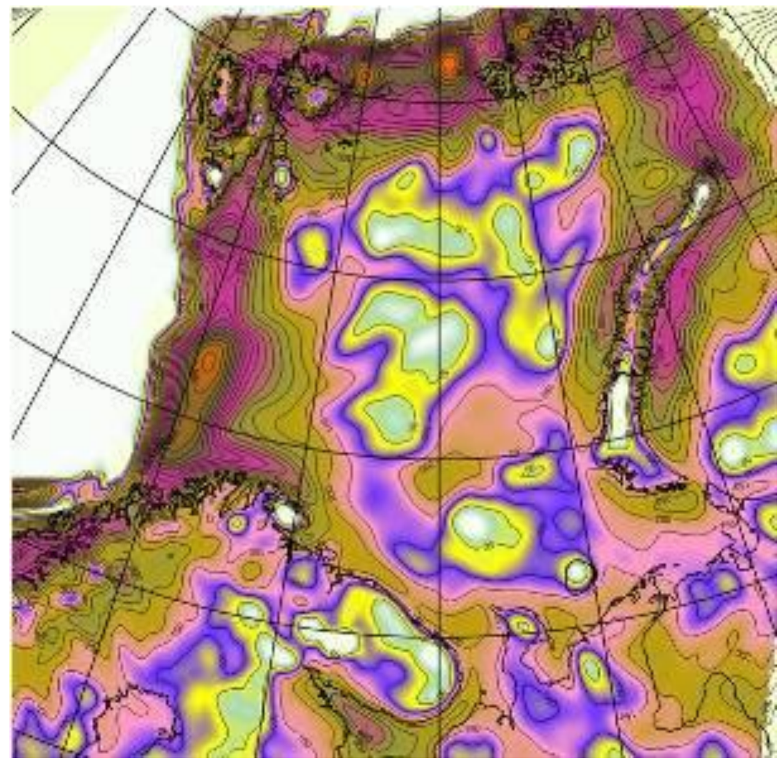






Plio-Pleistocene
erosion and deposition
(Amantov, unpublished)

Isostatic response

Archimedes of Syracuse

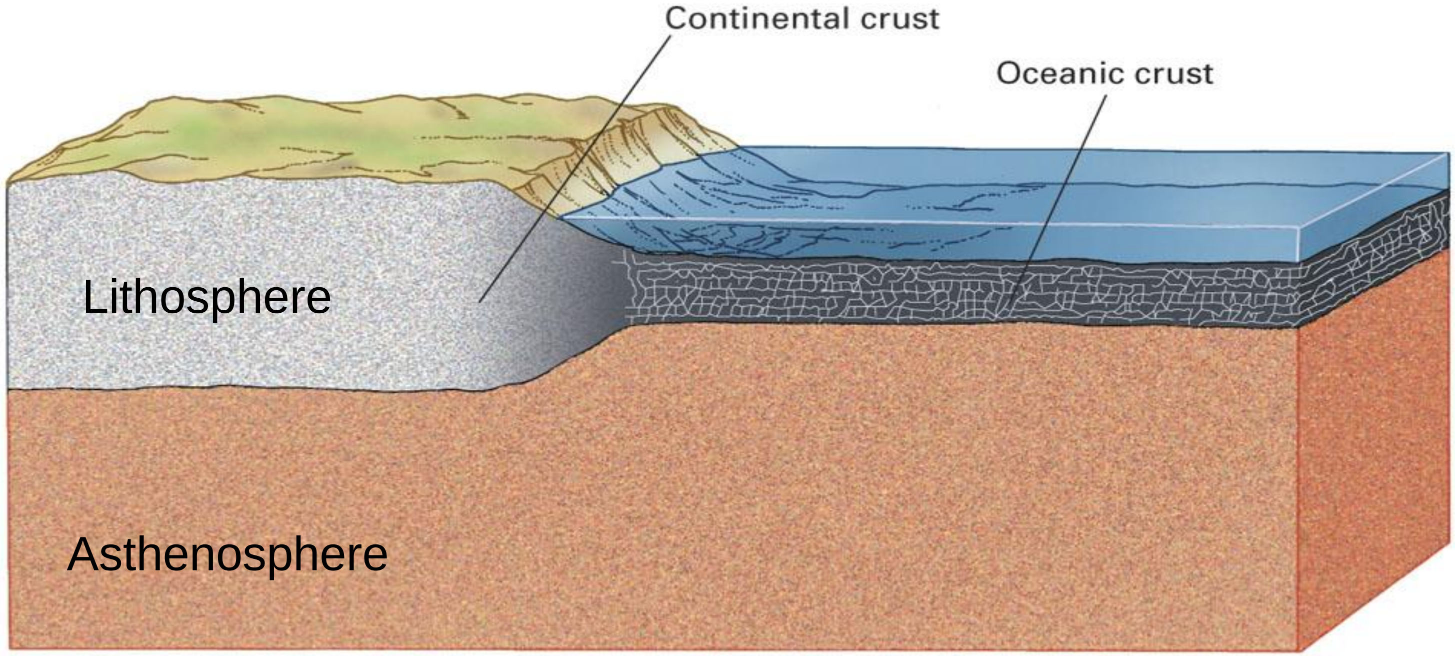
(Greek: Ἀρχιμήδης)

Archimedes is generally considered to be the greatest mathematician of antiquity and one of the greatest of all time

A buoyancy force arises when a solid object is placed into an (ideal)-liquid.

The buoyancy force is specified by Archimede's Principle which states: the decrease in weight of the object equals the weight of the liquid displaced by the submerged portion of the body.

Isostasy



- The lithosphere in floating equilibrium on the asthenosphere is isostasy

Glacial Isostatic Adjustment

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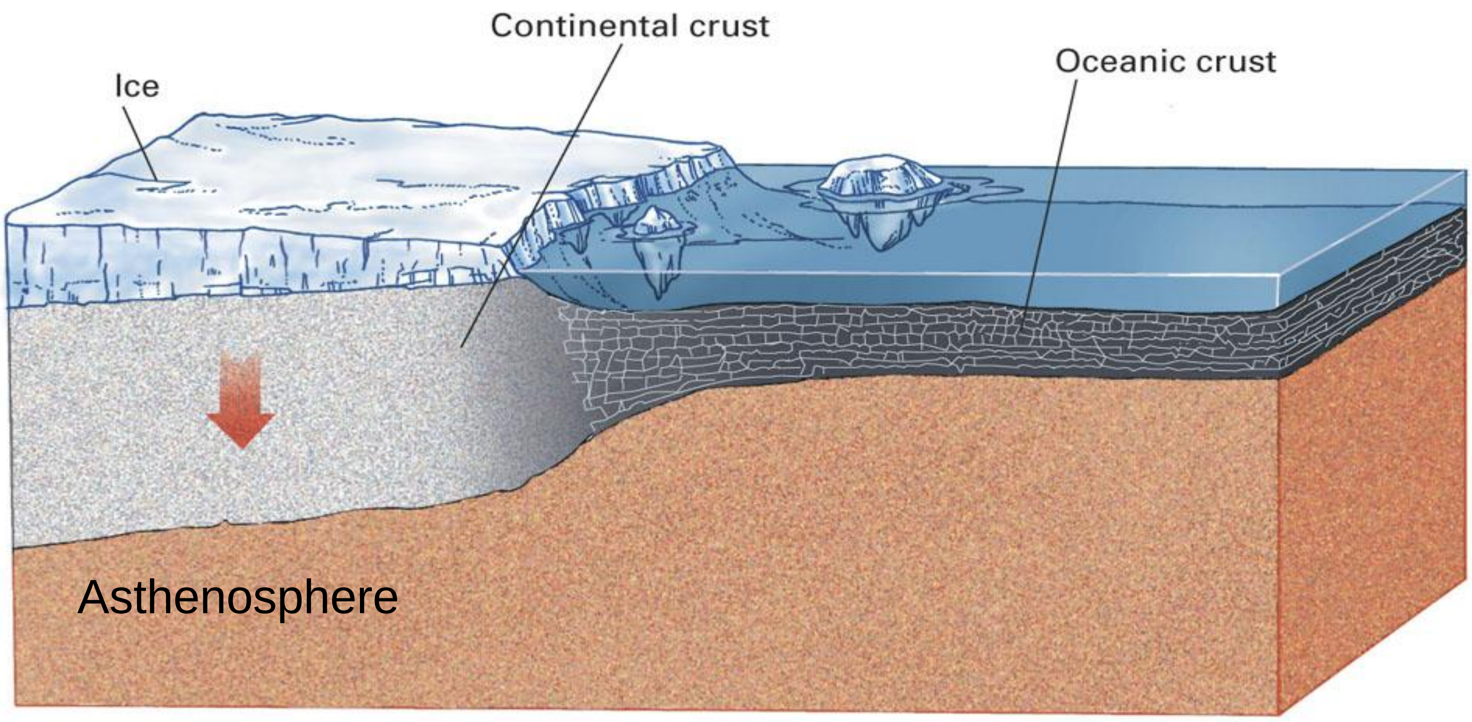
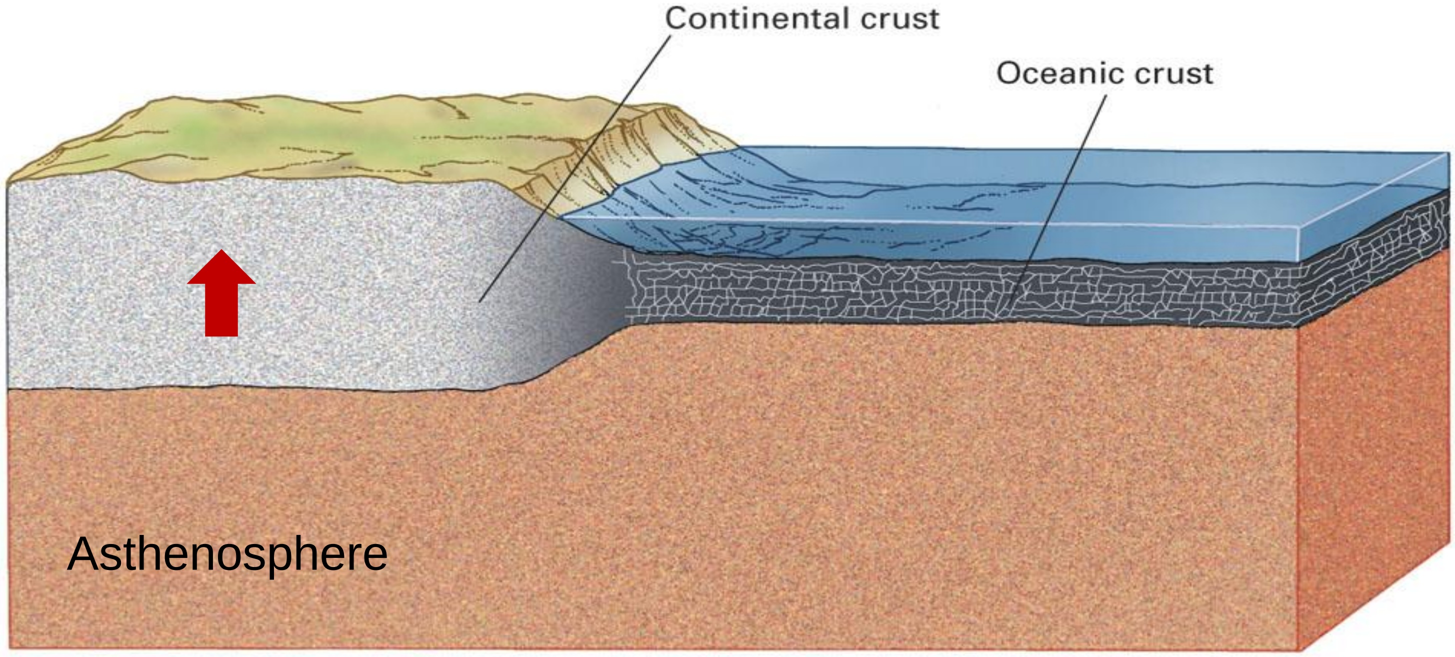


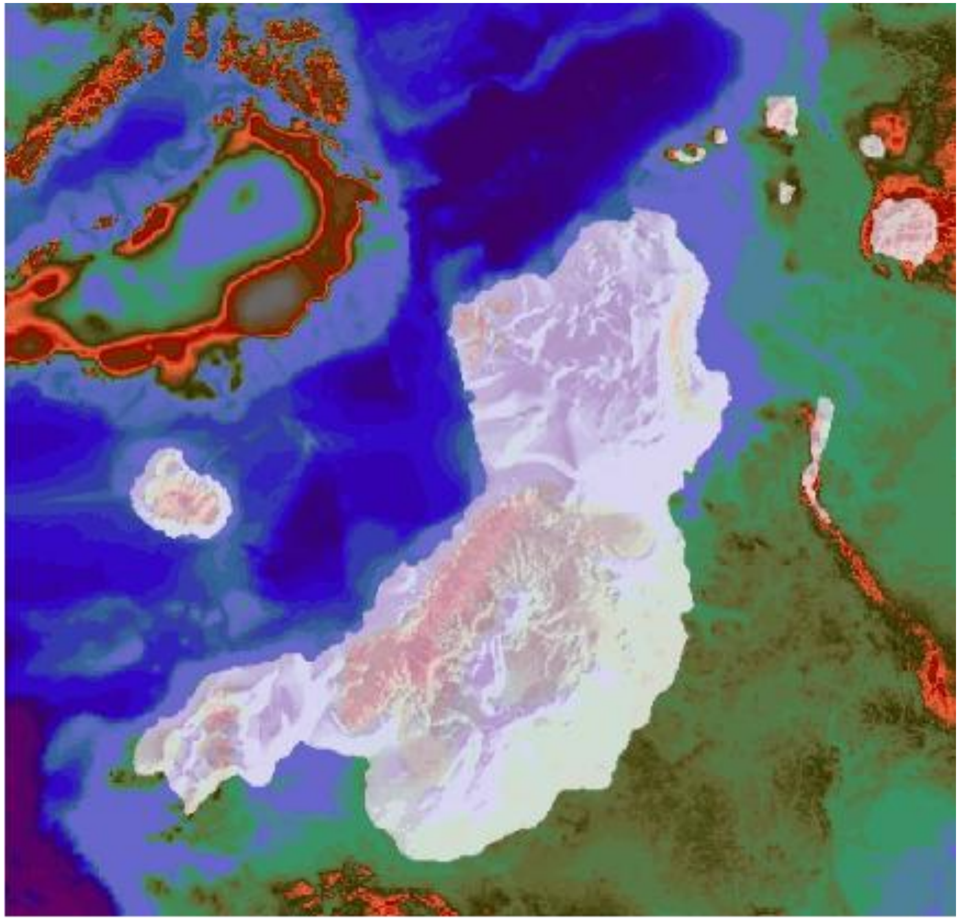
- Vertical movement in response to changing burden is called isostatic adjustment
- The crust is subsiding due to the ice load

Glacial rebound



- When the load is removed, the crust is experiencing uplift
  - until new equilibrium is established

Deglaciation model ('AA1')



20 000 BP

Calculated glacial isostasy

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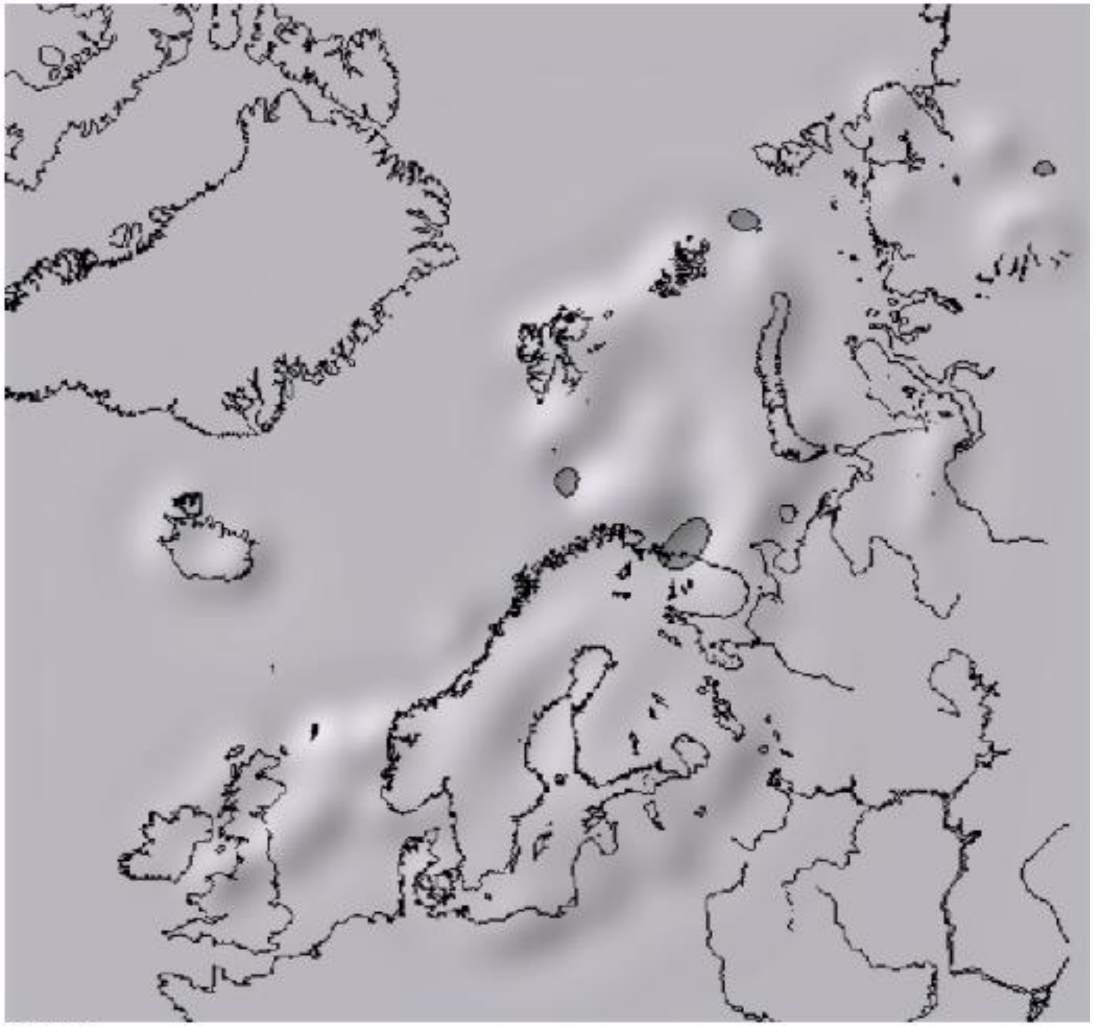
last 20 000 years



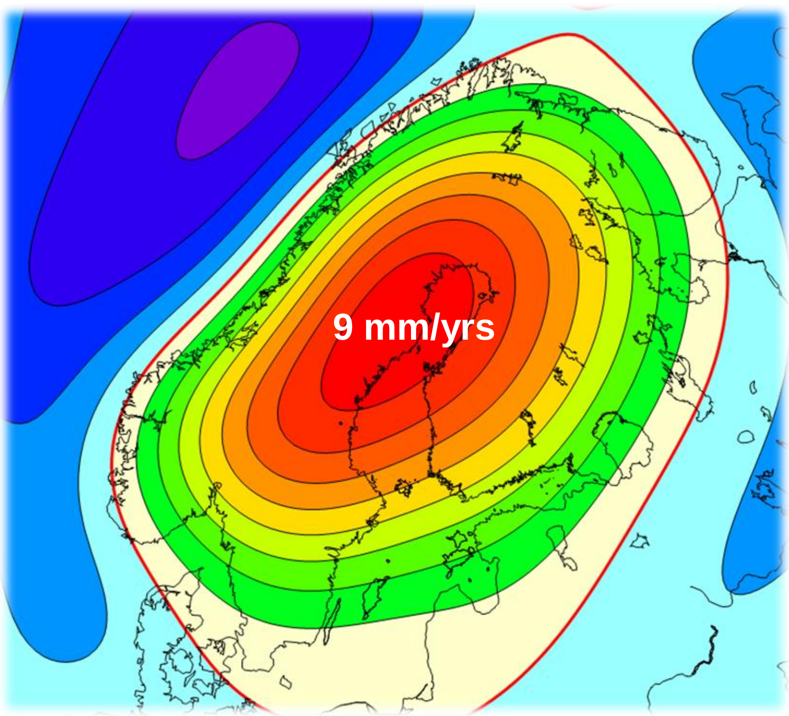
19000

Observed palaeo shorelines

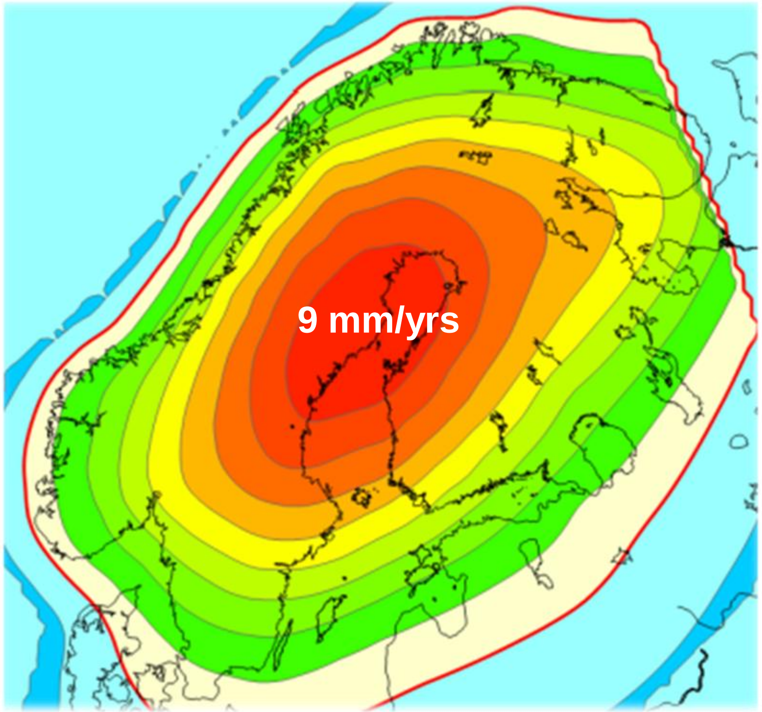
Post-glacial shorelines from Roddines, Porsangerfjord (north Norway)

Observed vs. calculated present rate of uplift

Calculated



Observed

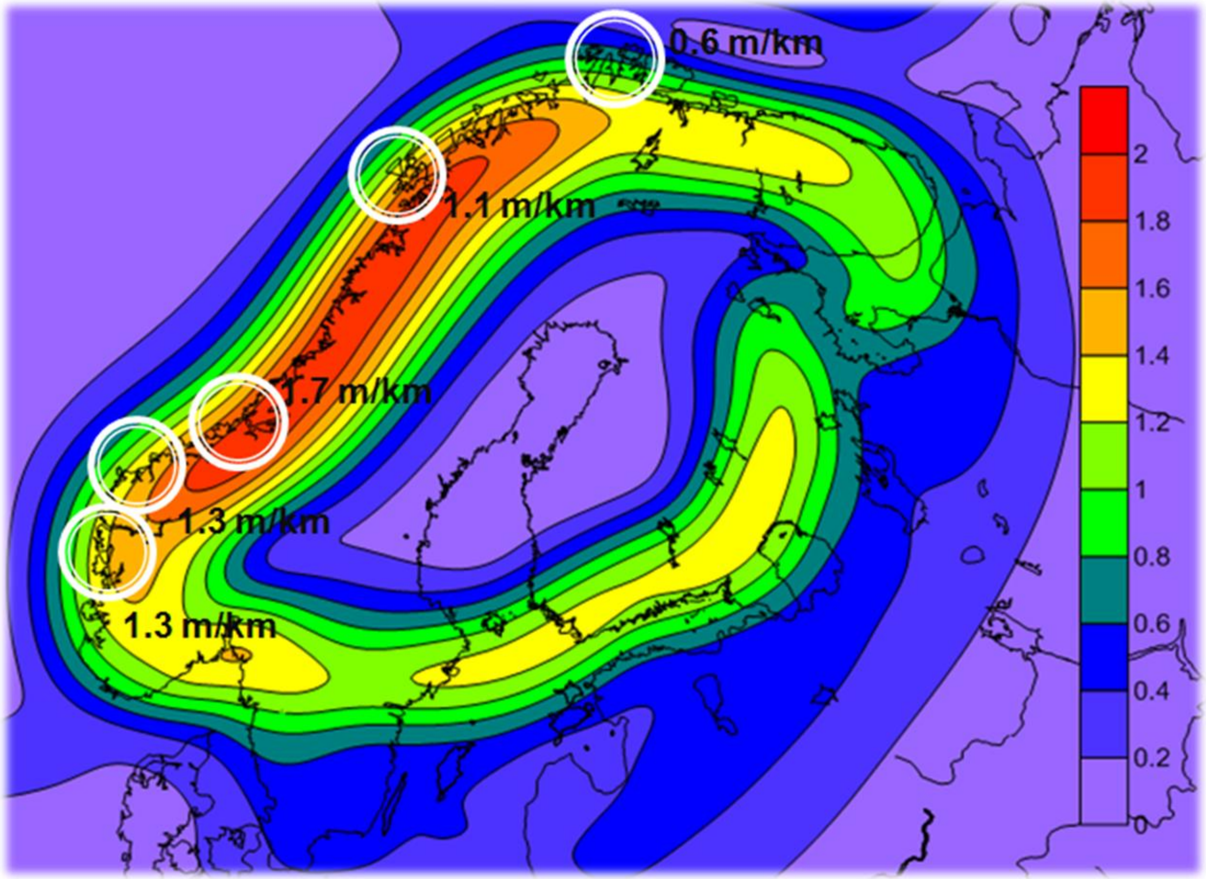


Observed (Vestøl, 2006)
- corrected for eustasy

Effect of ice model

Earth model:

- *A low viscosity asthenosphere (2.5 x 10^{19} Pa s)*
- *Lithosphere rigidity 5 x 10^{23} Nm (40 km)*



Plio-Pleistocene glacier and isostasy

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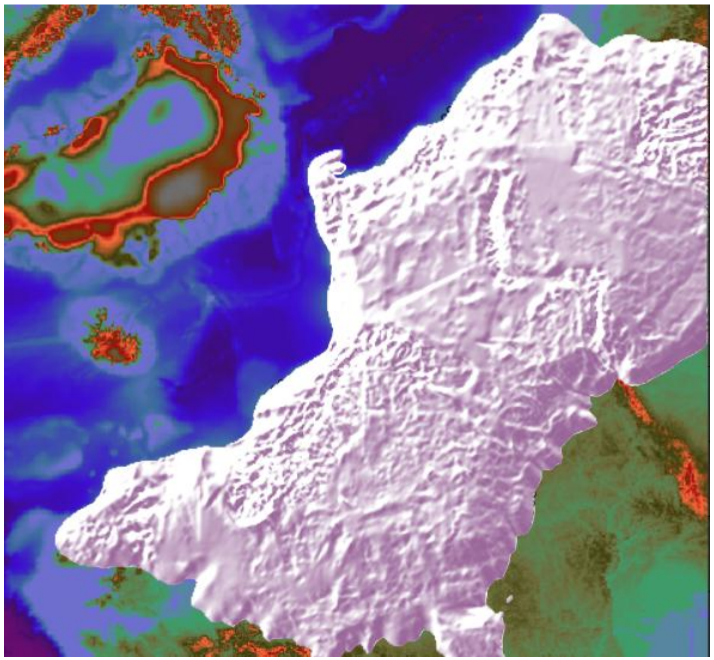
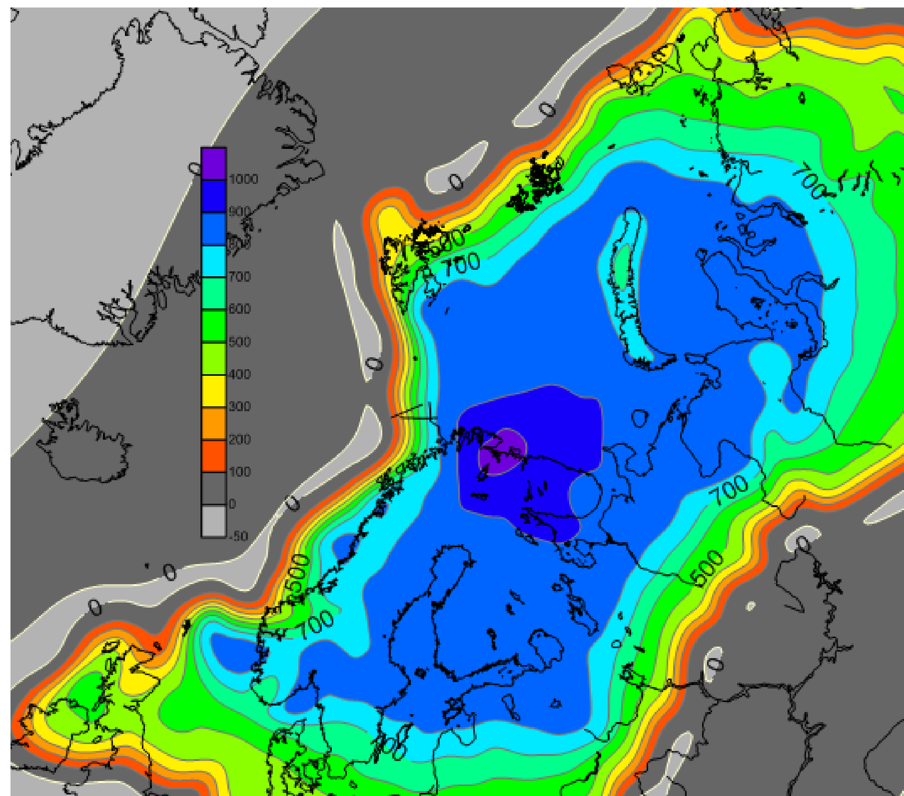
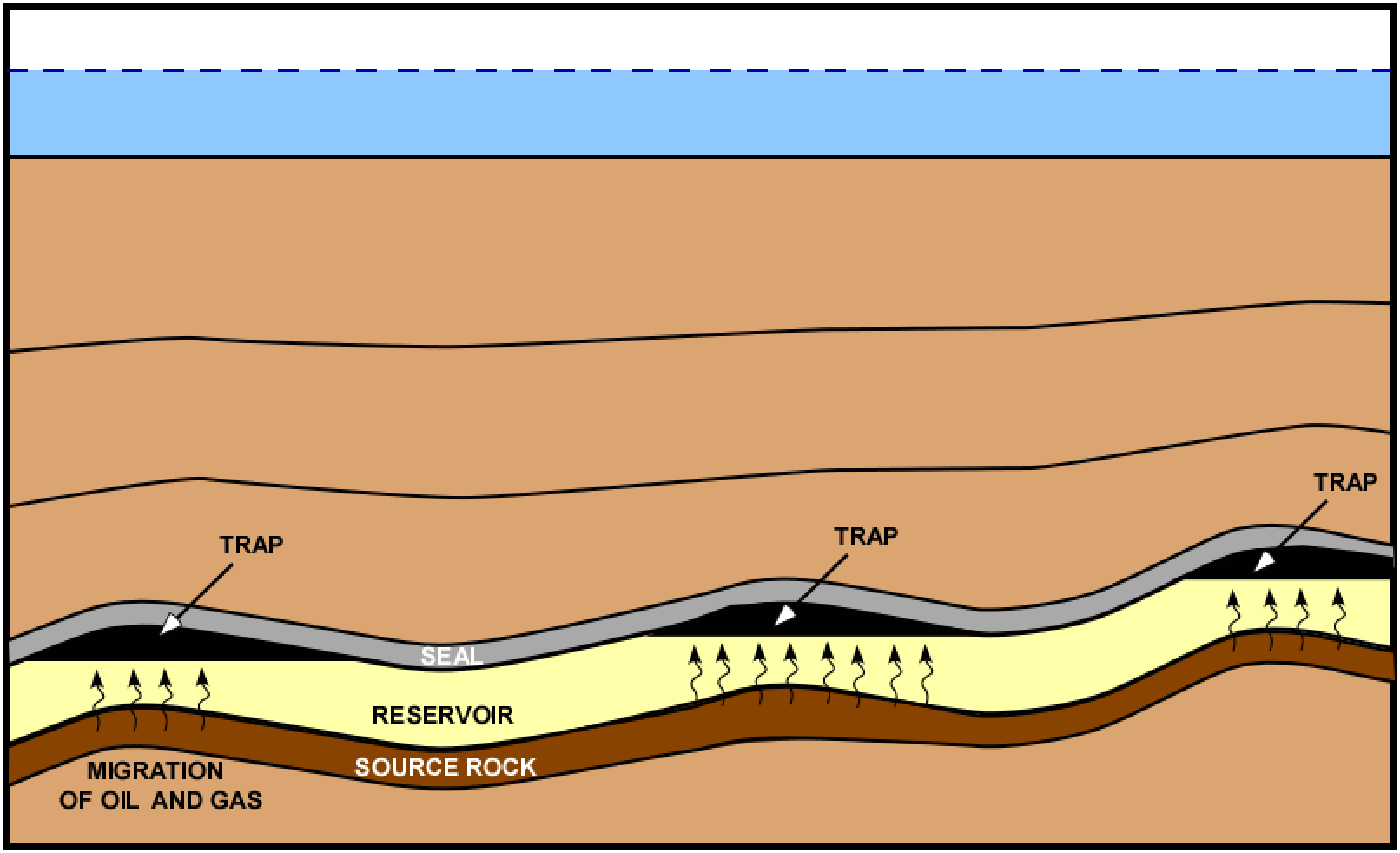
< 1.0 Ma





Isostasy

Petroleum system



Isostatic effects on petroleum system

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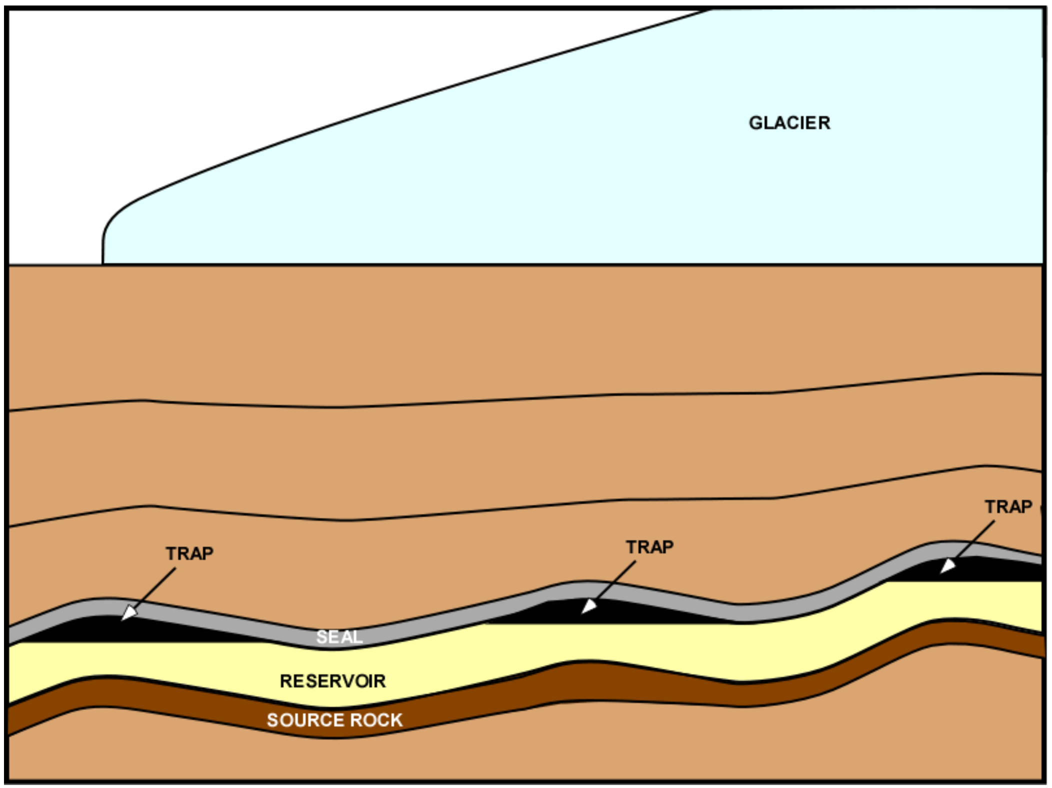

Basin in isostatic equilibrium during glaciation.

Petroleum system is located in the area near the edge of the glacier.

What happens when the ice melts?

Isostatic effects on petroleum system

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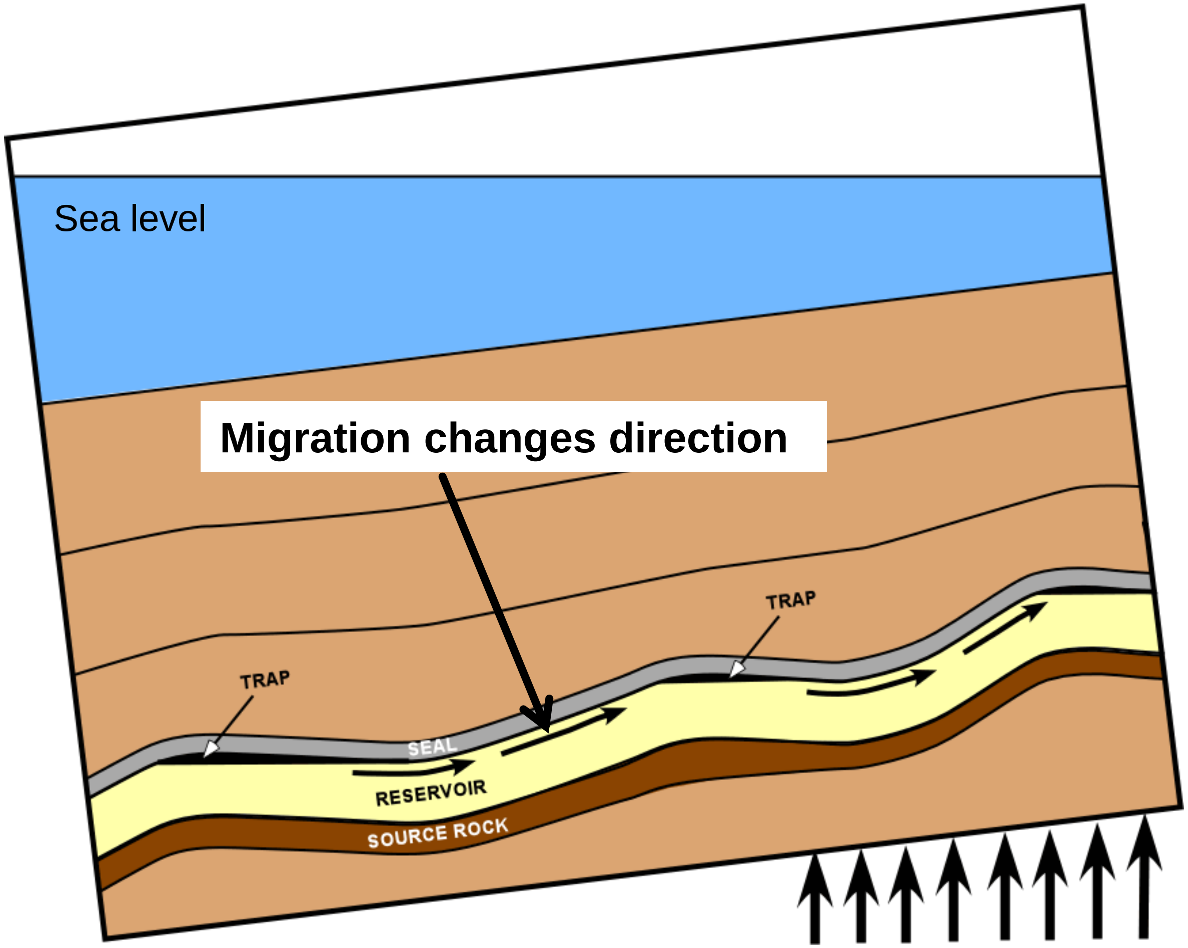
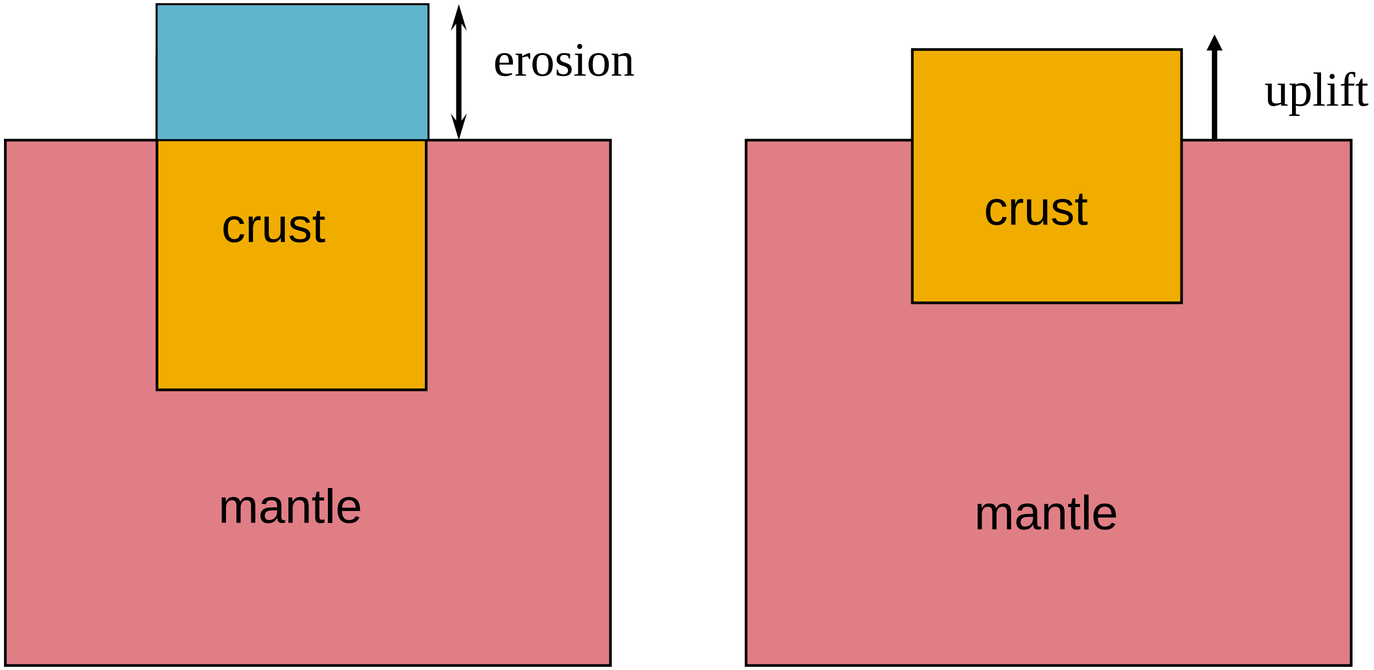


Basin in isostatic equilibrium during glaciation.

Petroleum system is located in the area near the edge of the glacier.

Erosion and uplift



Glacial erosion and uplift

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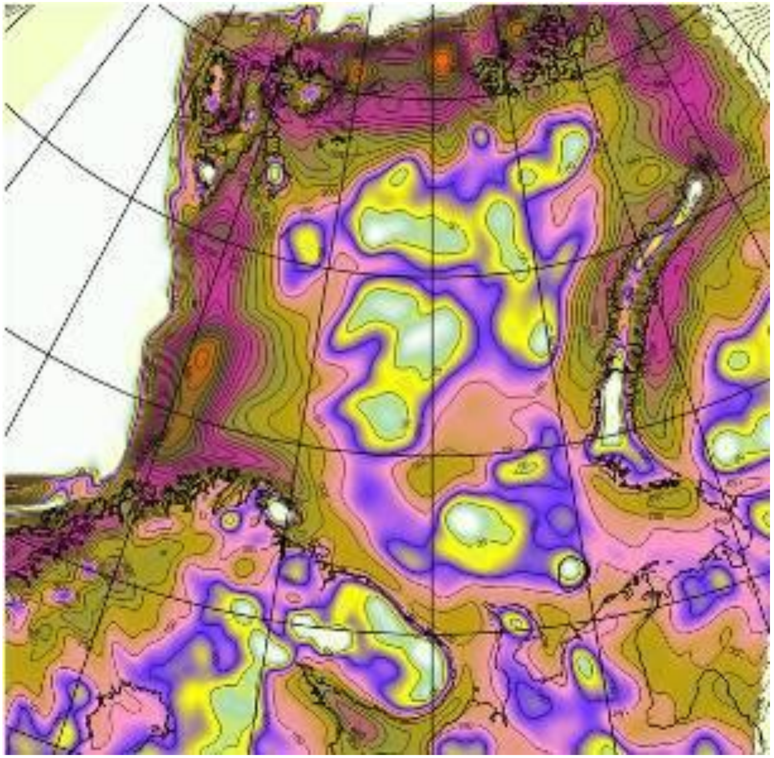
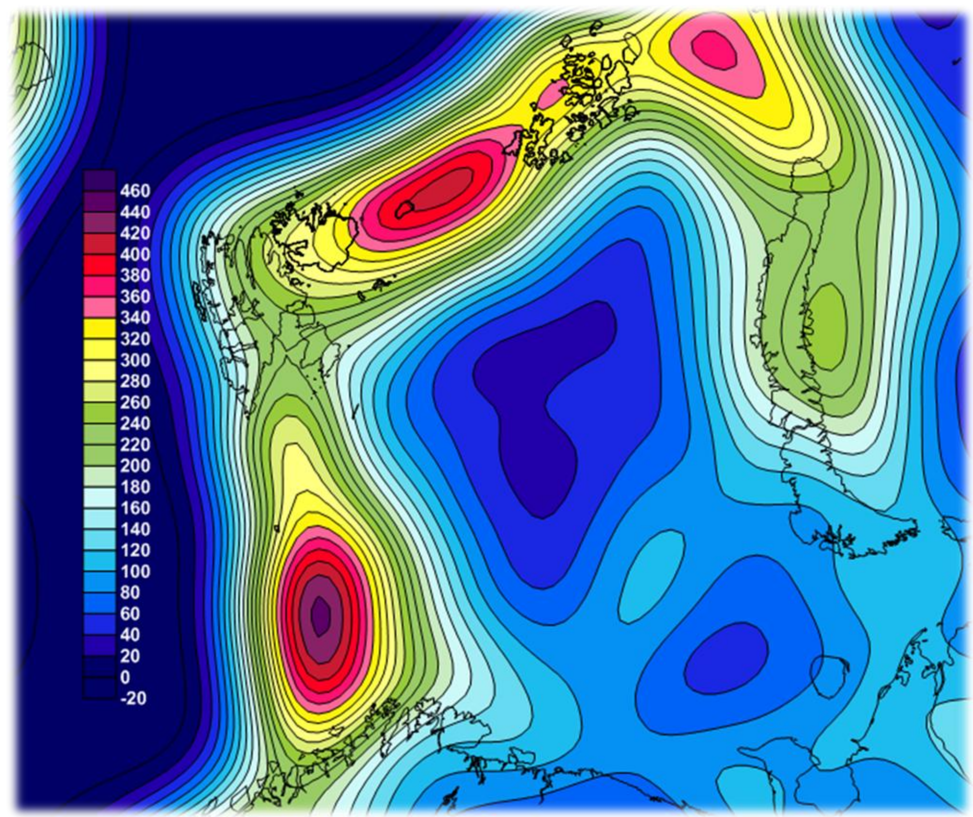


Isostasy



Conclusion-1

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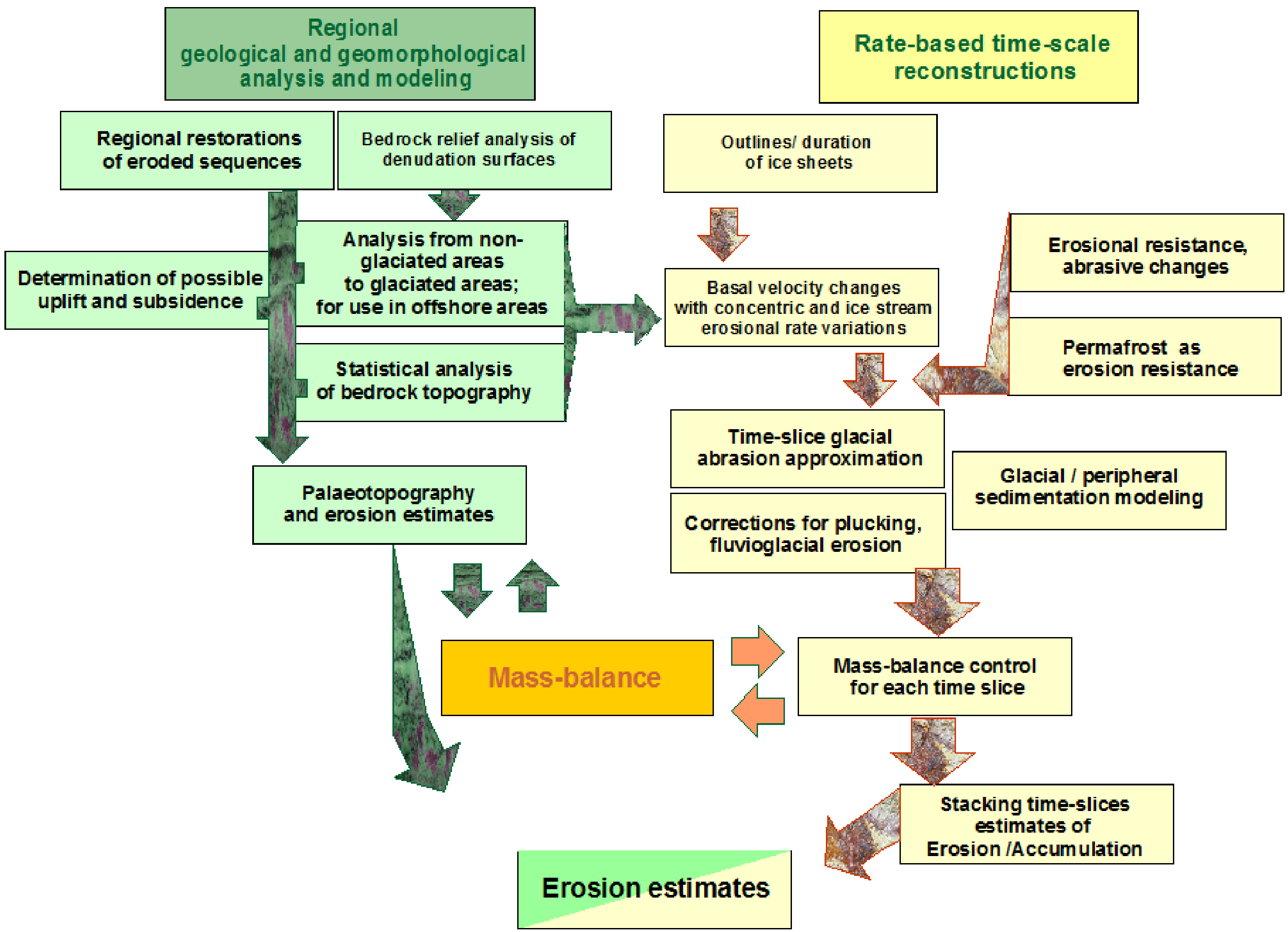
The isostatic effects of glaciers, glacial erosion/deposition are calculated. The Earth rheology (elastic lithosphere thickness and asthenosphere viscosity) is found from high resolution modelling of the rebound after the last glaciation. Based on this rheology it is shown that the tilting of the reservoirs in the western Barents Sea could be significant, up to 2m/km

Neogene and Paleogene erosion


Regional geological and geomorphological analysis and modeling
Rate-based time-scale reconstructions
Regional restorations of eroded sequences
Bedrock relief analysis of denudation surfaces
Outlines/ duration of ice sheets
Determination of possible uplift and subsidence
Analysis from non-glaciated areas to glaciated areas; for use in offshore areas
Statistical analysis of bedrock topography
Basal velocity changes with concentric and ice stream erosional rate variations
Erosional resistance, abrasive changes
Permafrost as erosion resistance
Time-slice glacial abrasion approximation
Corrections for plucking, fluvioglacial erosion
Glacial / peripheral sedimentation modeling
Palaeotopography and erosion estimates
Mass-balance
Mass-balance control for each time slice
Stacking time-slices estimates of Erosion /Accumulation
Erosion estimates

Erosion estimates uncertainties

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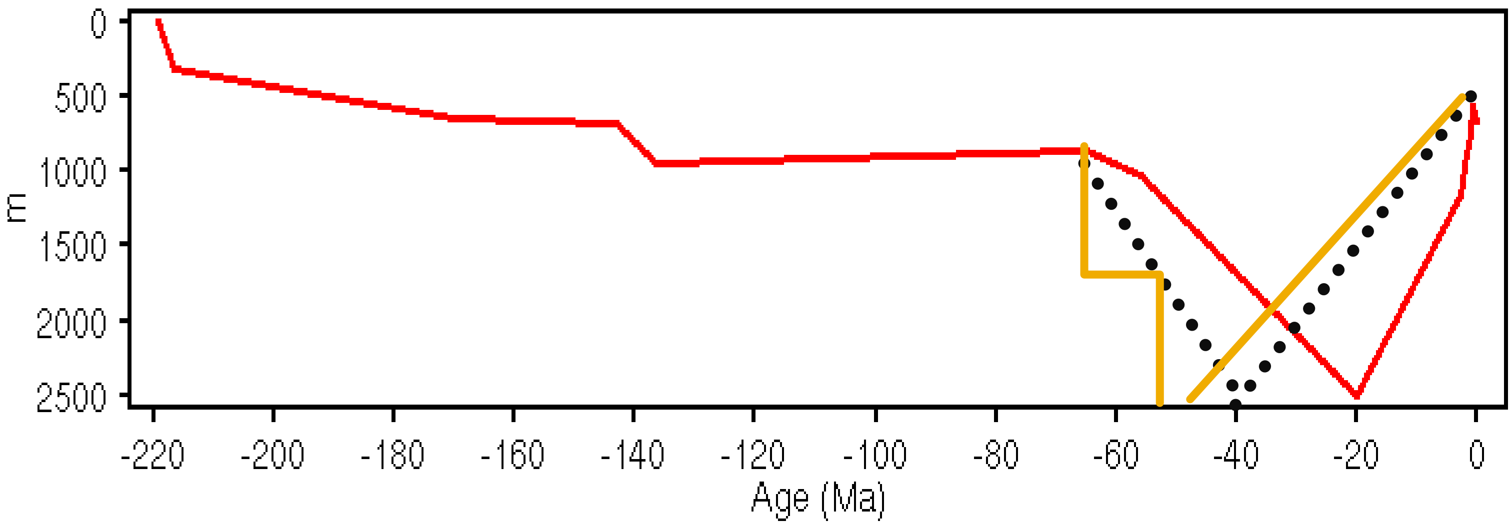
Observed vitrinite reflectance

Time of max burial

Stratigraphy within missing section

Thermal conductivities of the missing section

Timing of Max burial?



Modelling of 2D transects

Modeling of 2D sections

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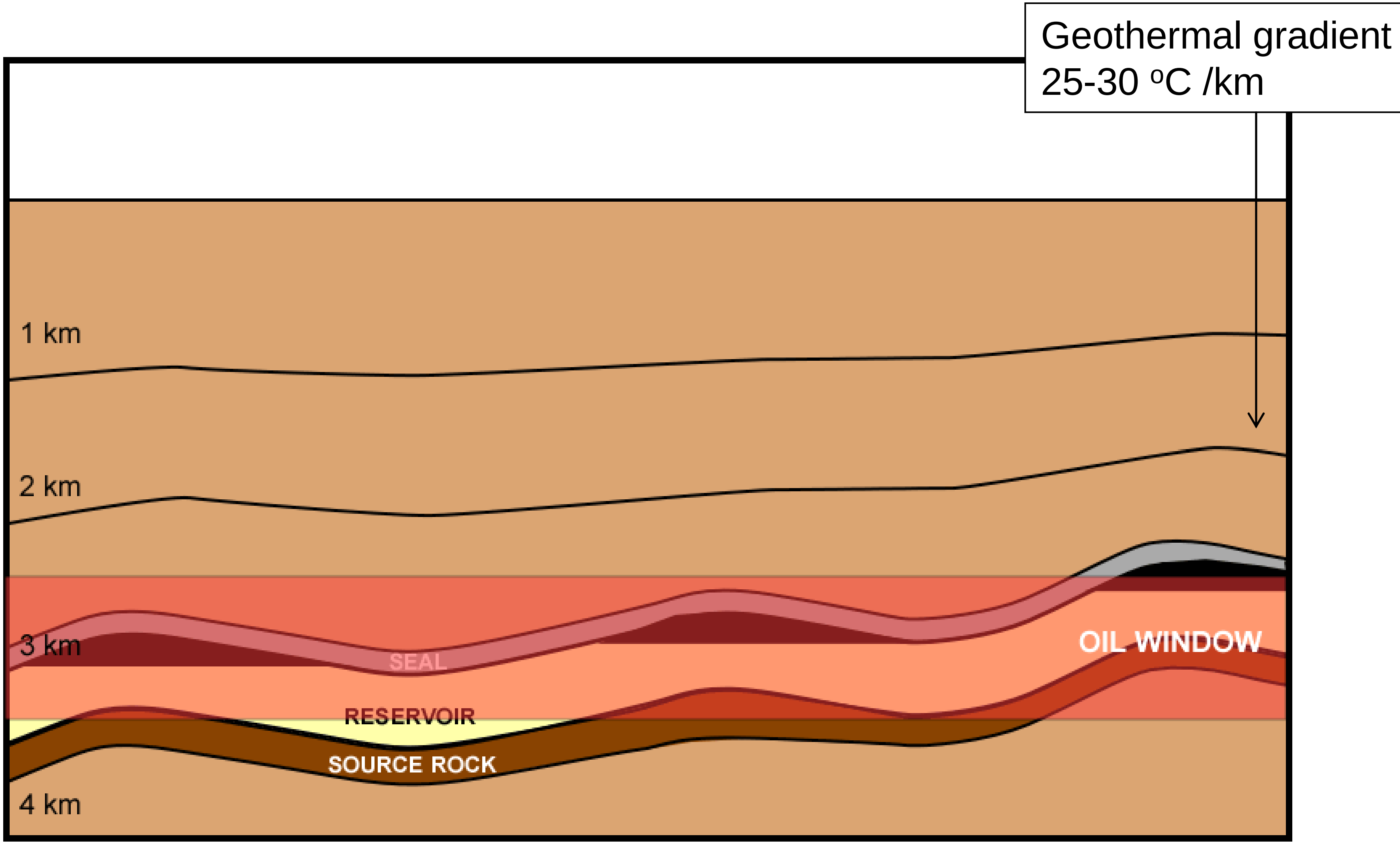
Aim:

temperature and maturity effects of Plio- Pleistocene glaciations and Neogene erosion

Effects of erosion on petroleum systems



Effects of erosion on petroleum systems

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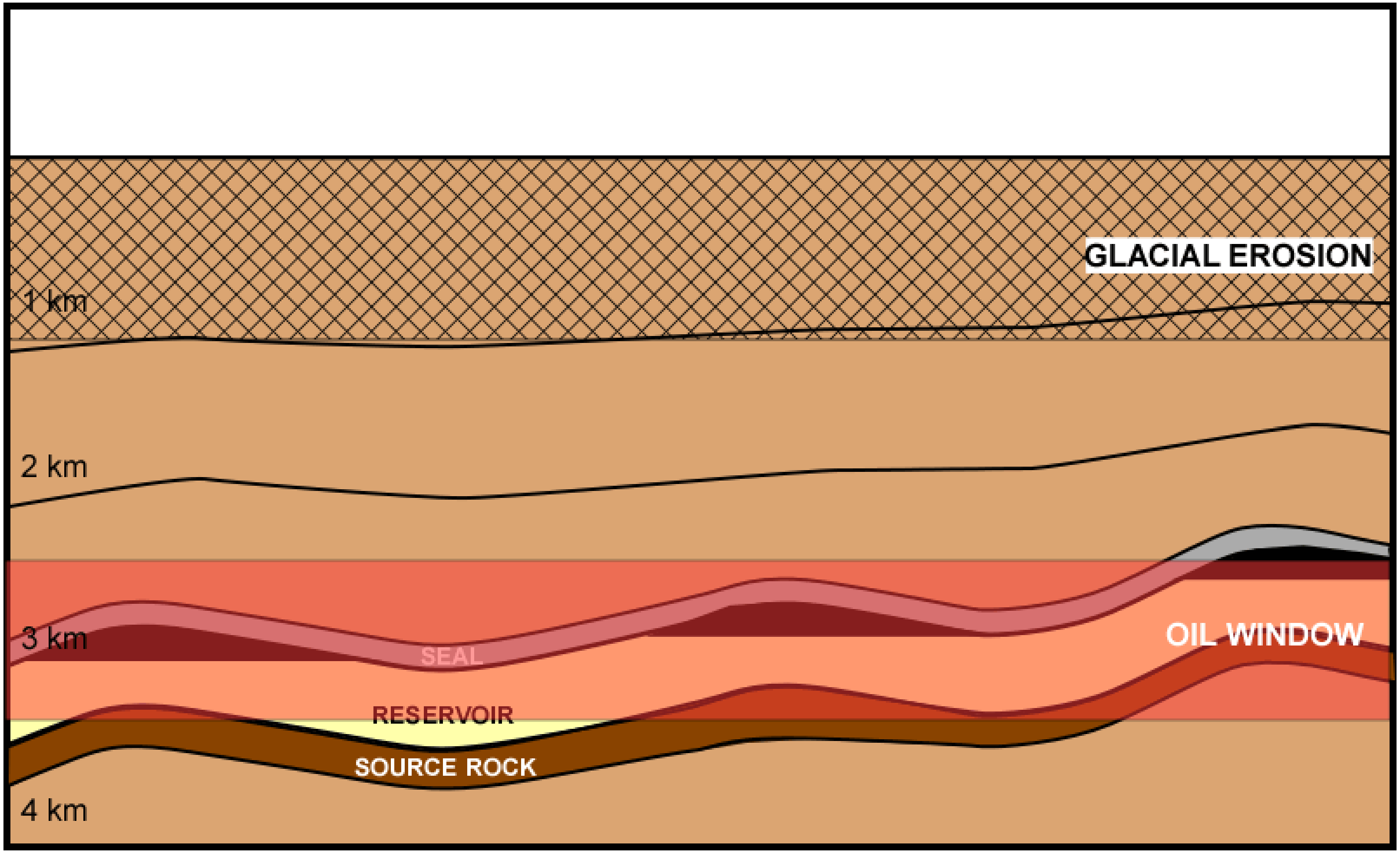
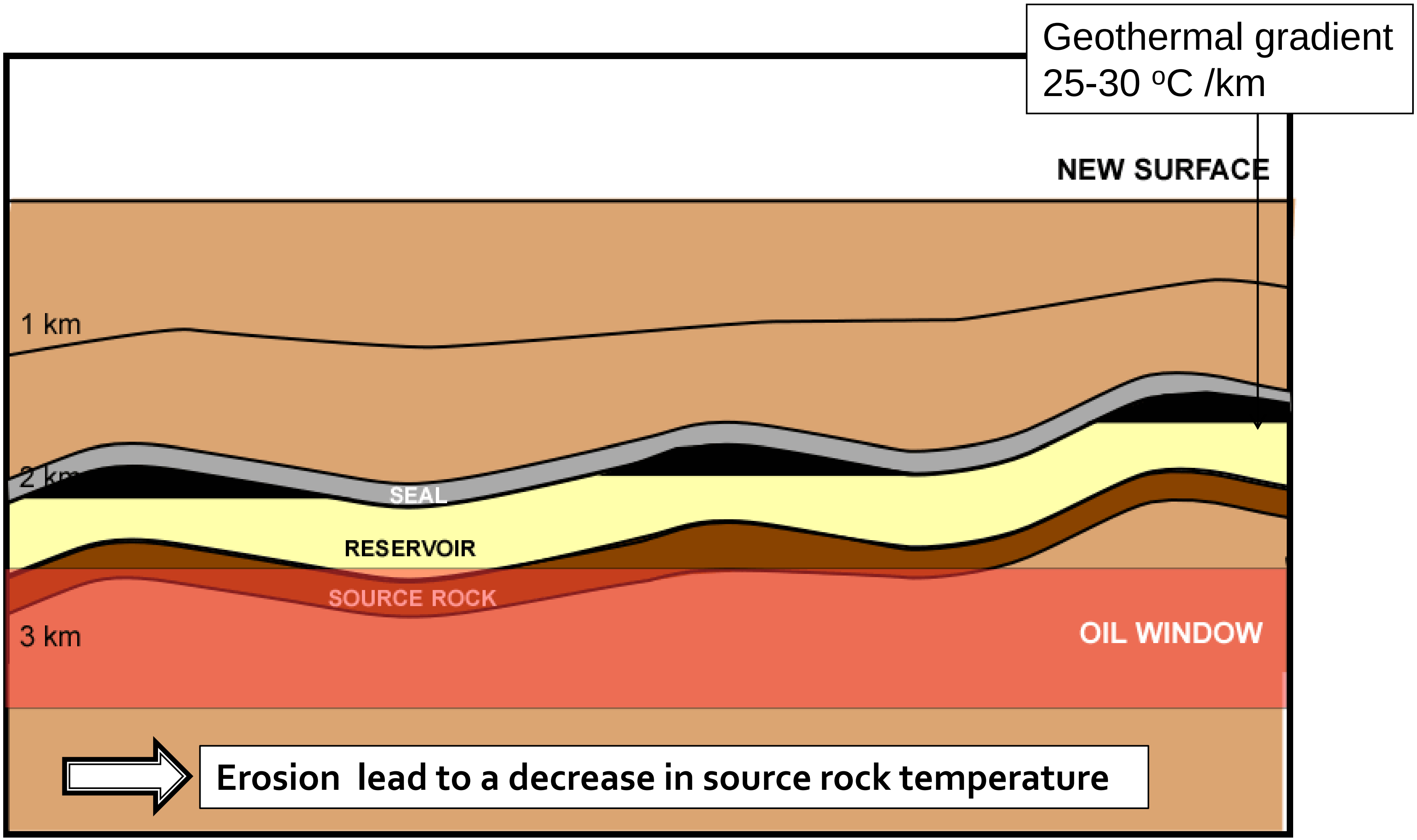
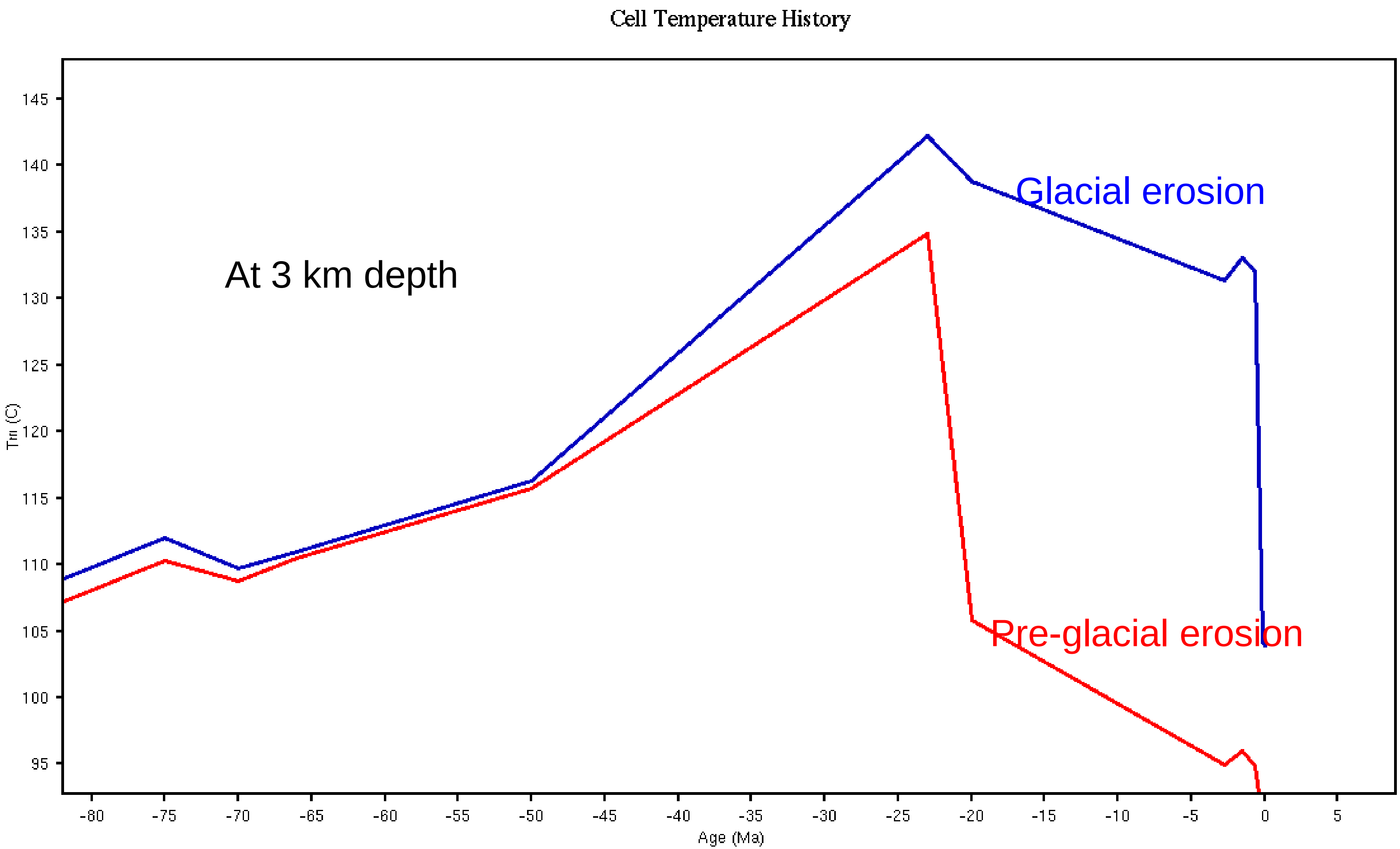


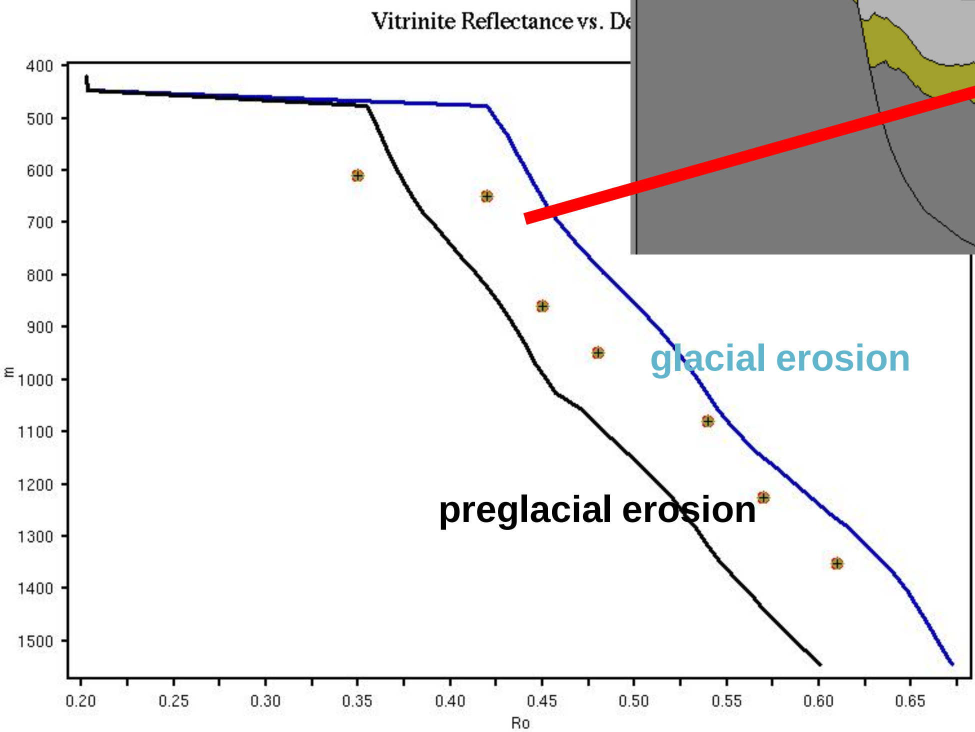
Effects of erosion on petroleum systems

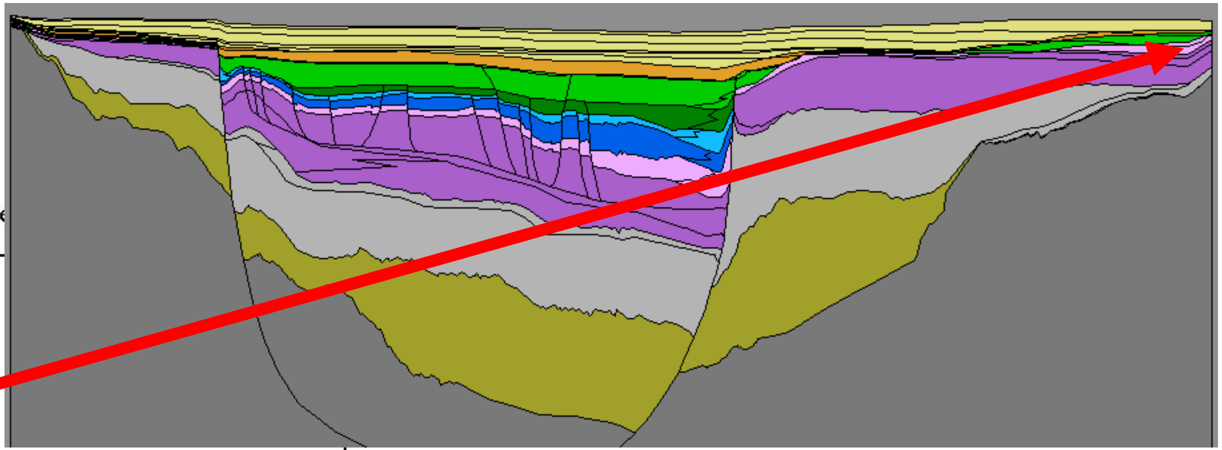


Temperature effect of pre-glacial vs glacial erosion



Vitrinite effect of pre-glacial vs glacial erosion



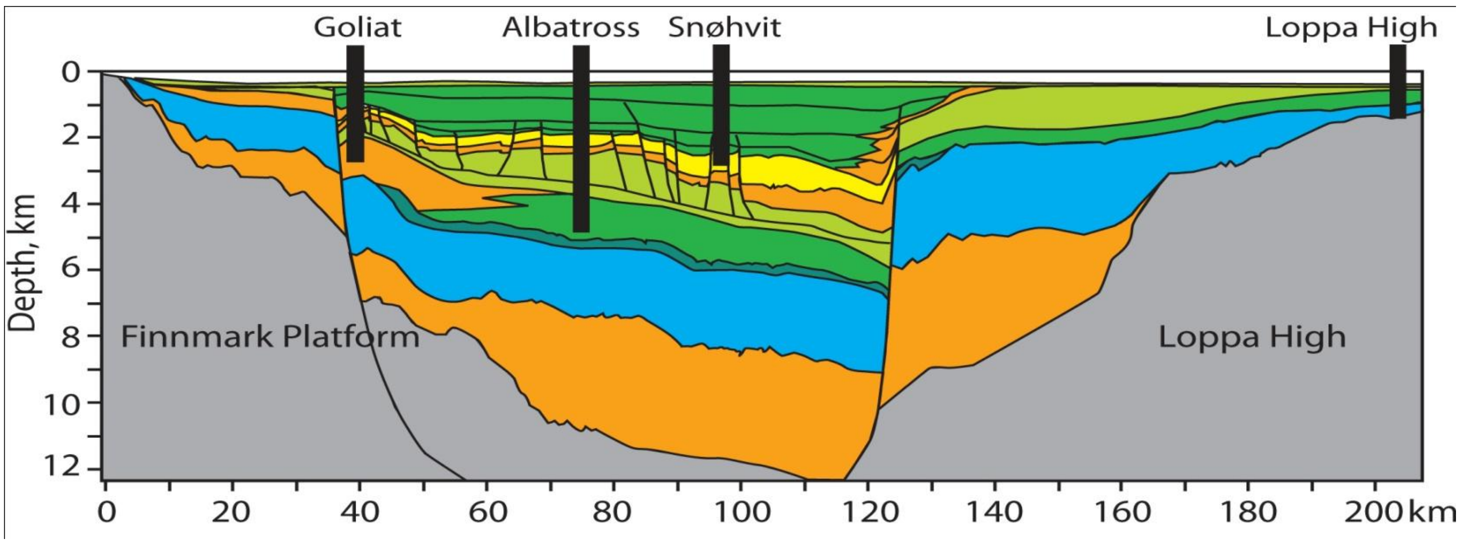


10-15% higher vitrinite reflectance with late erosion

Pre-glacial versus glacial erosion

Prediction of pre-glacial erosion

period	erosion			
2.7- 1.5Ma	200m	250m	300m	350m
1.5- 0.7Ma	300m	350m	350m	400m
0.7- 0Ma	100m	100m	100m	300m



Pre-glacial	**100m**	**150m**	**150m**	**300m**
Total	**700m**	**850m**	**900m**	**1350m**

2D lines

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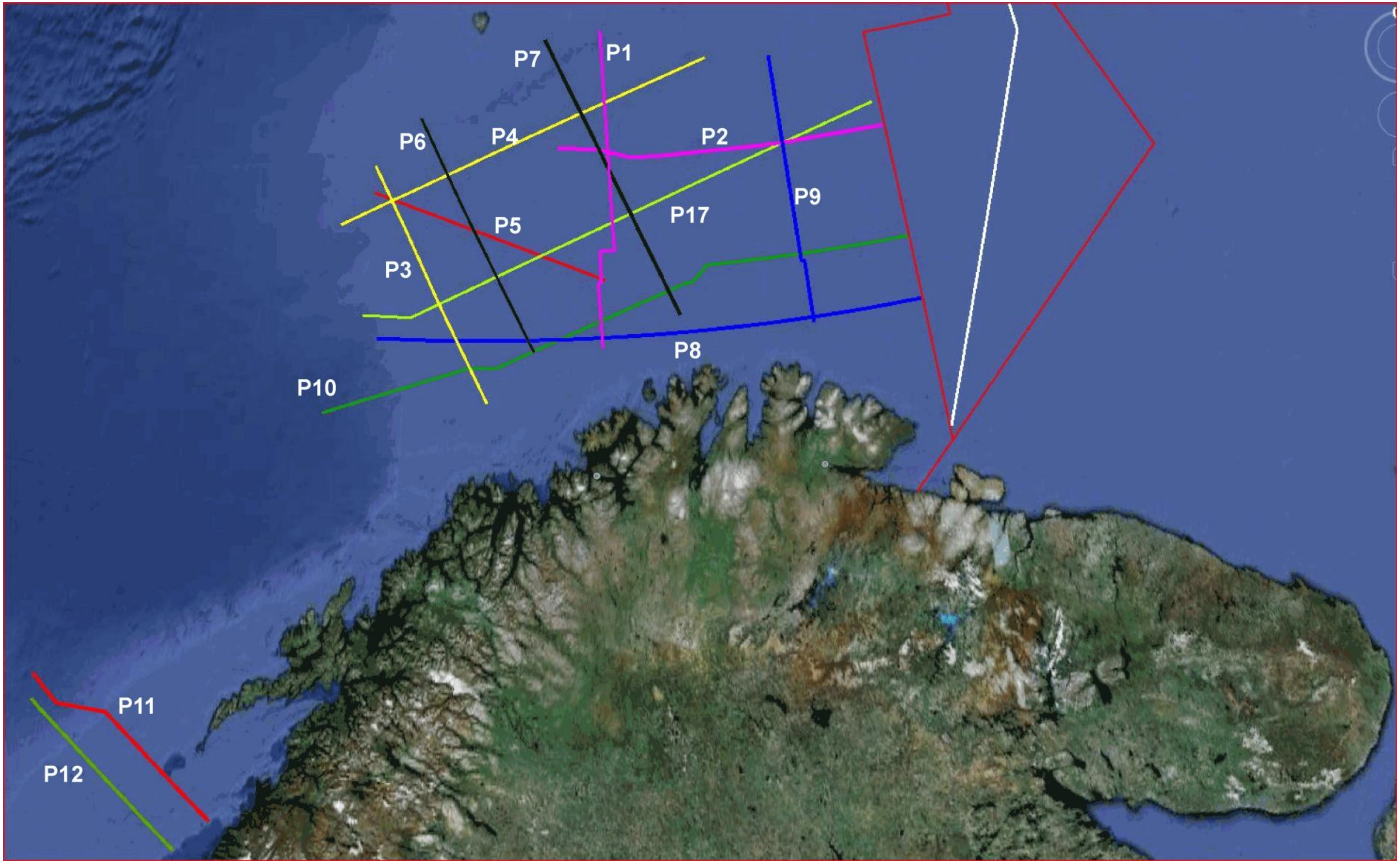
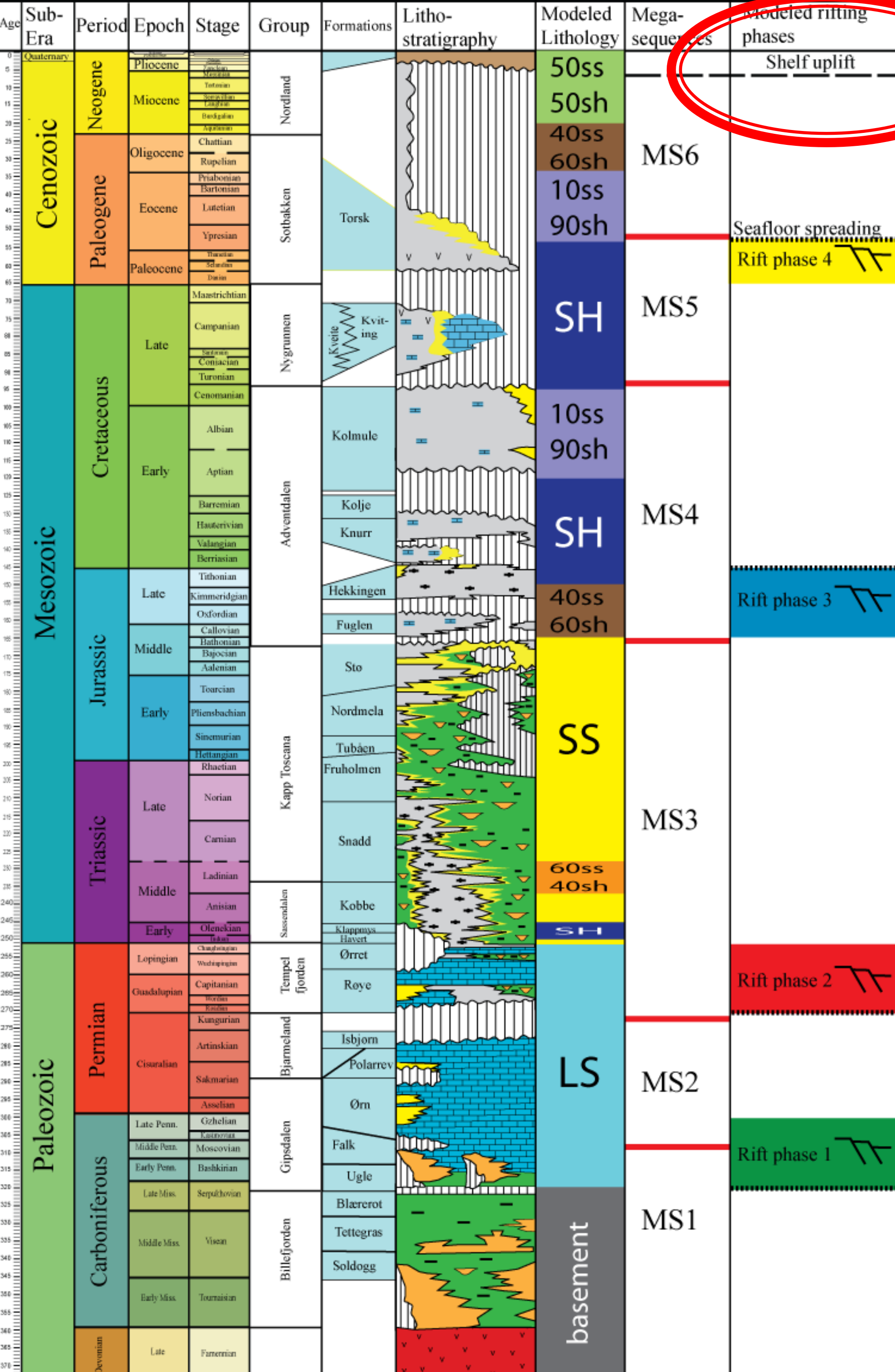




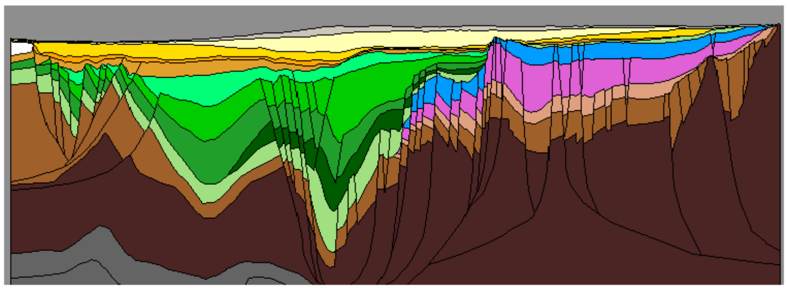
Lithostratigraphic column southwest Barents Sea

(from Clark et al., in review)

BMT – Basin Modelling Toolbox

TECTONOR

- An advanced 2D basin modelling system :
  - Reconstruction of the basin evolution
  - Fault restoration
  - Chemical compaction
  - Isostatic deflections (with flexure)
  - Lithospheric thinning (with necking)
  - Magmatic intrusions
  - User guided salt movements
  - Temperature/maturity effects



Conclusion-2

Vitrinite reflectance gives us the opportunity to constrain the Neogene erosion