Episodic Uplift and Exhumation along Passive Margins in the North Atlantic Domain: Implications for Hydrocarbon Prospectivity*

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Abstract

Our observations demonstrate that the elevated passive margins (EPCMs) around the North Atlantic were formed by episodic, post-rift uplift movements manifested in the high-lying peneplains and characterising the coastal mountains, in the unconformities in the adjacent sedimentary basins, and in accelerated subsidence in the basin centres. Results from West Greenland show that subsidence took place for c. 25 Myr after rifting and breakup in the Paleocene, as predicted by classical rift theory, but this development was reversed by a series of uplift movements (starting at c. 35, 10 and 5 Ma).

East Greenland, Scandinavia, and the Barents Sea seem to have had a similar evolution of post-rift subsidence followed by uplift starting at c. 35 Ma. There was no major fall in sea level at this time; so the subsiding basins must have been inverted by tectonic forces. We speculate that the forces causing this phase were related to the plate boundary reorganisation in the North Atlantic around Chron 13 time. The Cenozoic uplift history of the east Canadian EPCM is poorly known, but the east-west symmetry between Baffin Island and West Greenland and the similarity of landscapes on both sides of Baffin Bay suggest that the Canadian EPCM was also uplifted long after rifting and breakup. The presence of Eocene marine sediments, several hundred metres above sea level on the Canadian margin supports this conjecture.

One feature common to these areas is uplift along the edges of cratons where the thickness of the crust and lithosphere changes substantially over a short distance. It may be that the lateral contrasts in the properties of the stretched and unstretched lithosphere make the margins of the cratons unstable long after rifting. These vertical movements have profound influence on hydrocarbon systems and confront us with questions like: How much section has been removed? When did maximum burial occur? How have migration paths been affected? Has a significant amount of hydrocarbon charge been lost from a breached reservoir during uplift? Such questions become very important, not only in frontier

areas, such as Baffin Bay, where Mesozoic basins are deeply truncated and exposed onshore, but also for the understanding of hydrocarbon systems in more mature areas such as the Barents Sea, where low-angular unconformities represent episodes of deposition and removal of significant sedimentary sections.

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3P ARCTIC

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[3] Exploro Geoservices, Norway

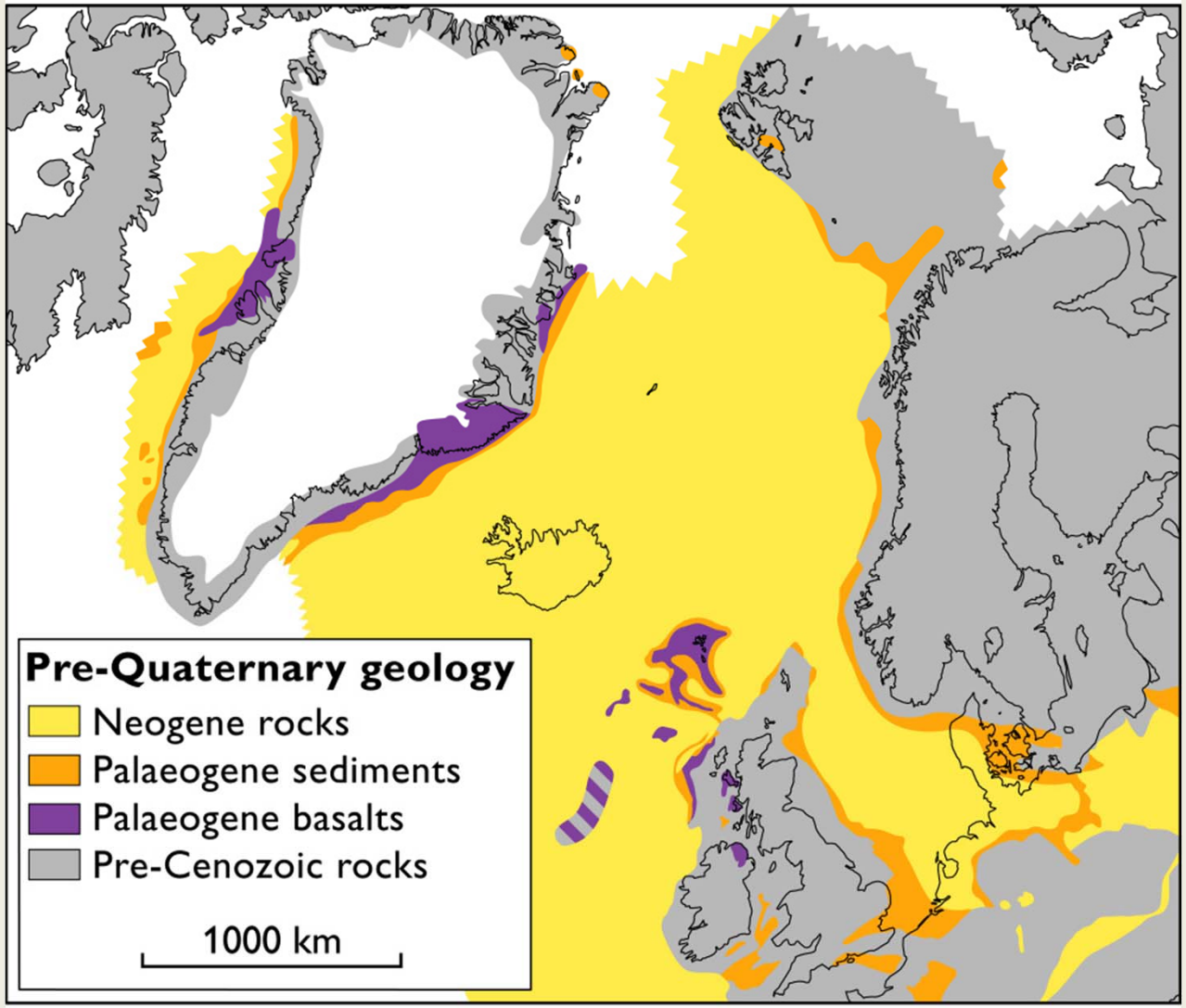
GEUS

GEOTRACK

exploro

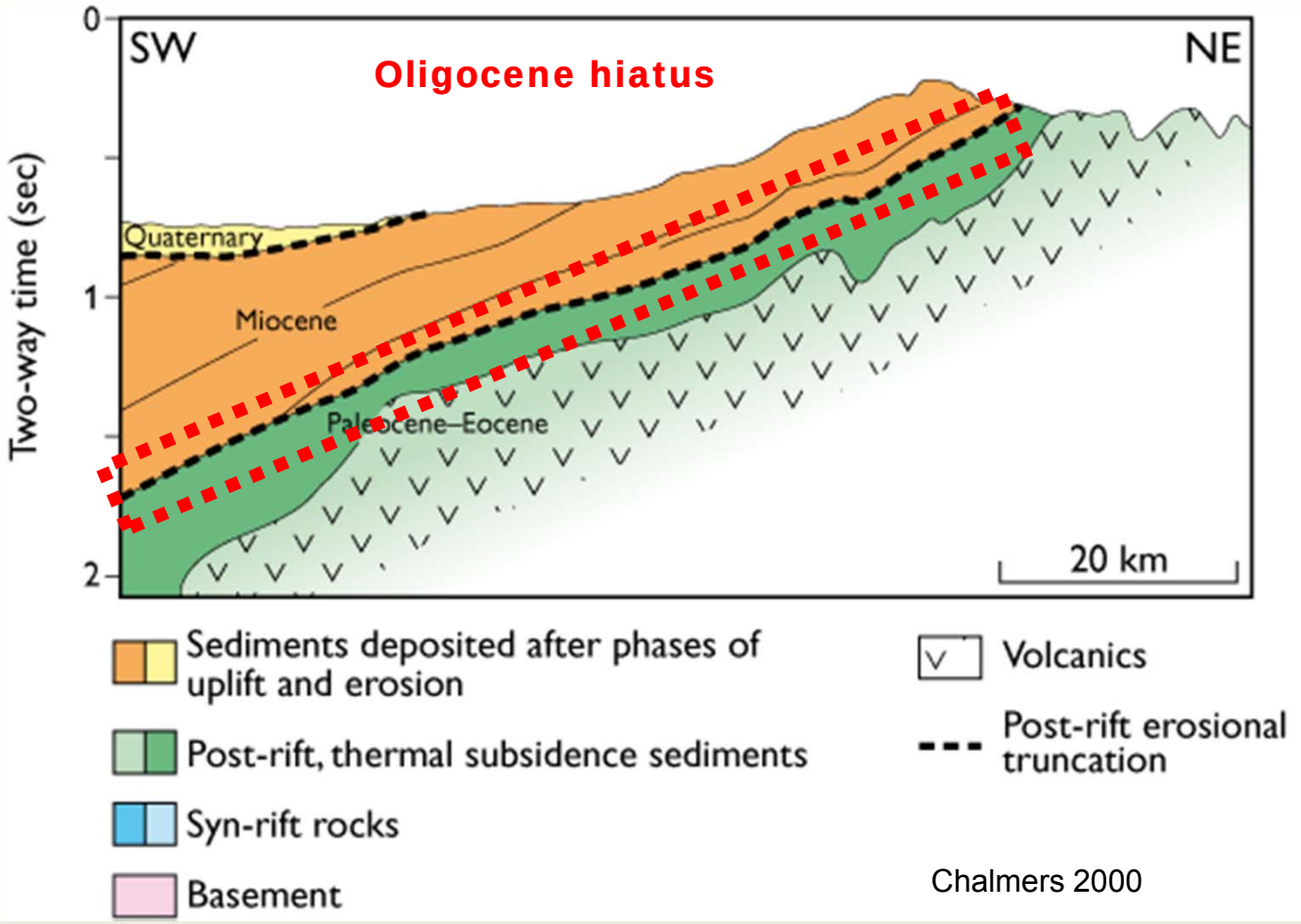
I: Characteristics of elevated, passive continental margins (EPCMs)

Truncated post-rift sequences



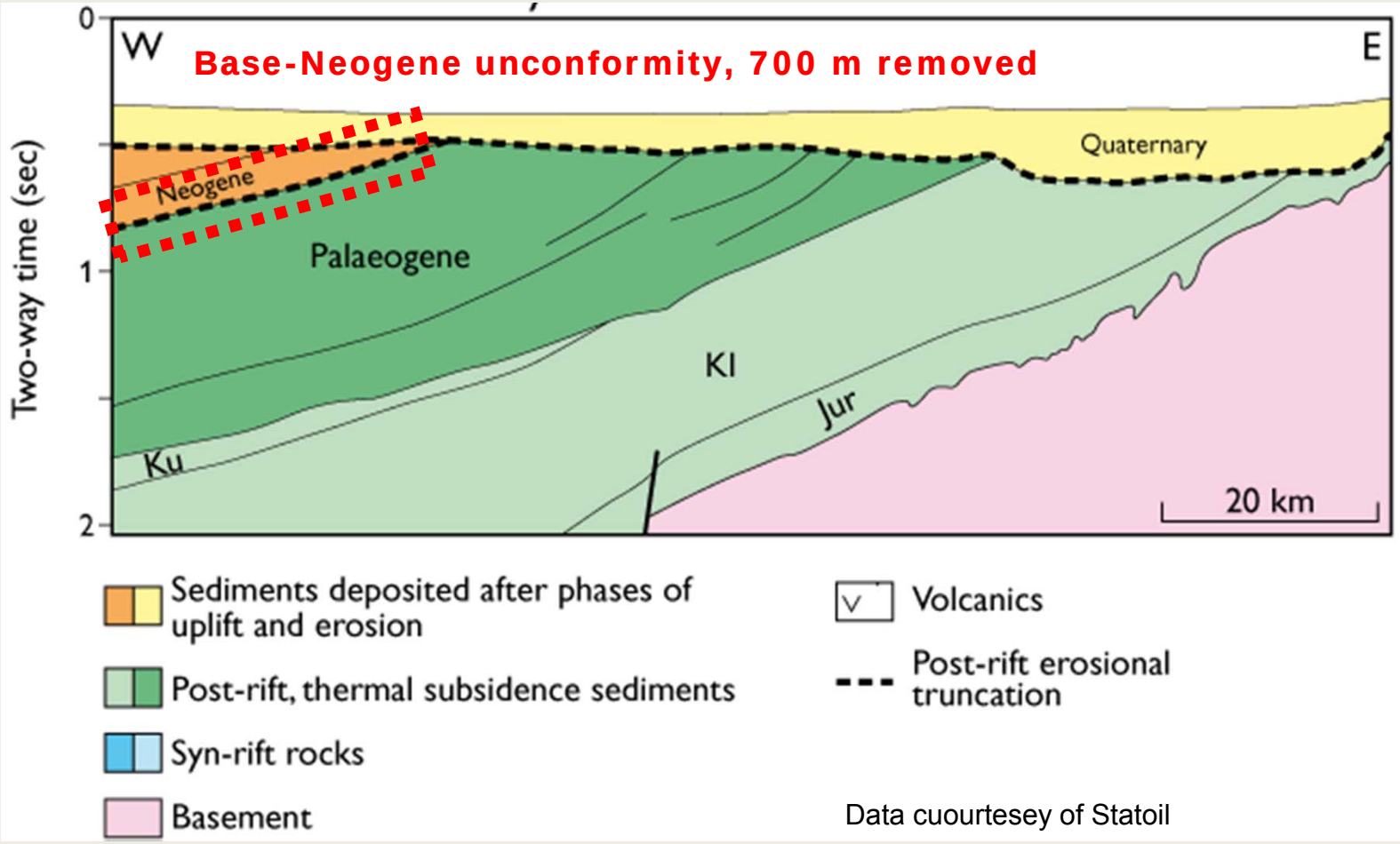
Japsen & Chalmers 2000

Offshore West Greenland, 78° N
Post-rift, erosional truncations



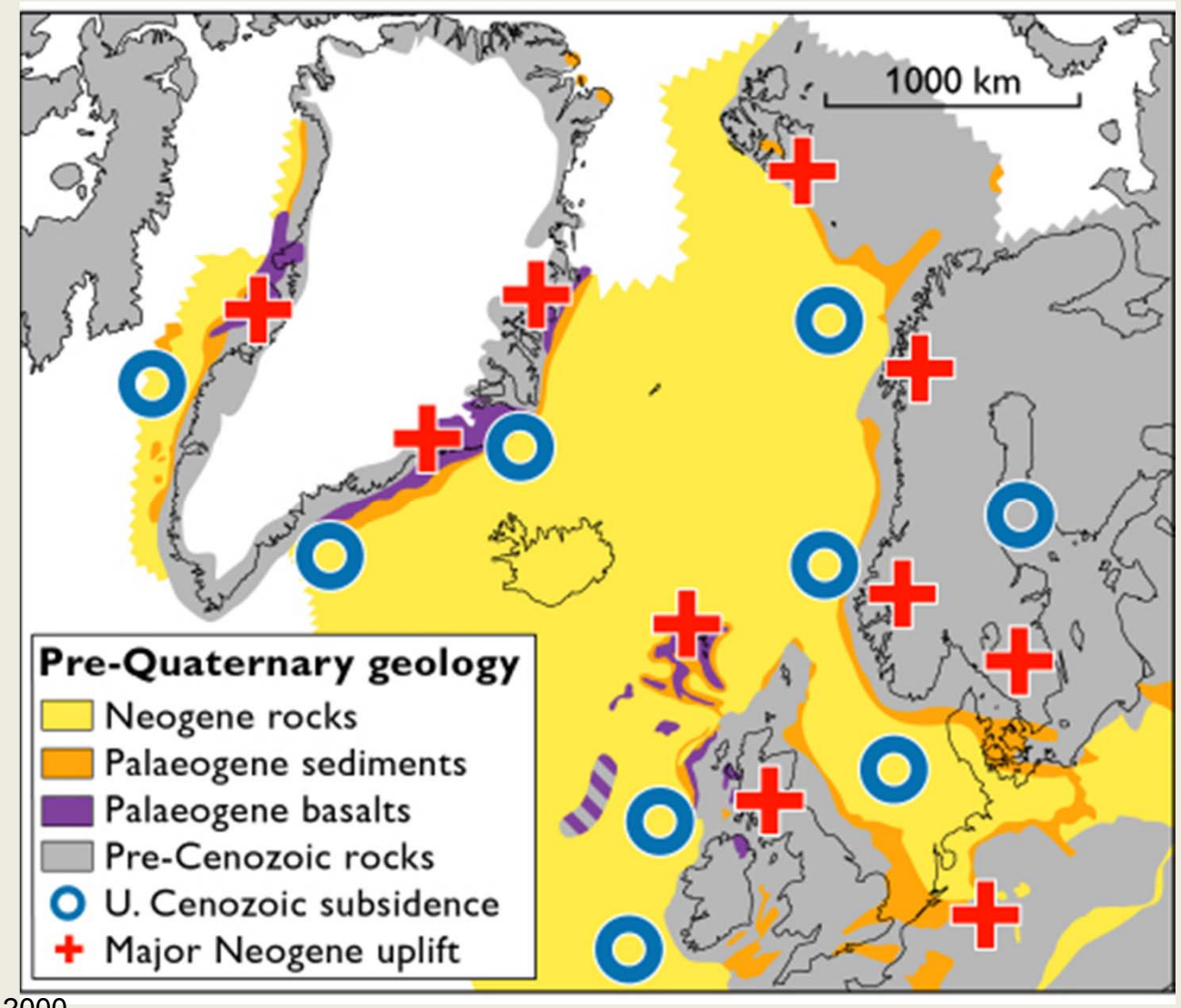
Japsen et al. 2011. *Global Planet. Change*

Offshore south Norway, 59° N
Post-rift, erosional truncations



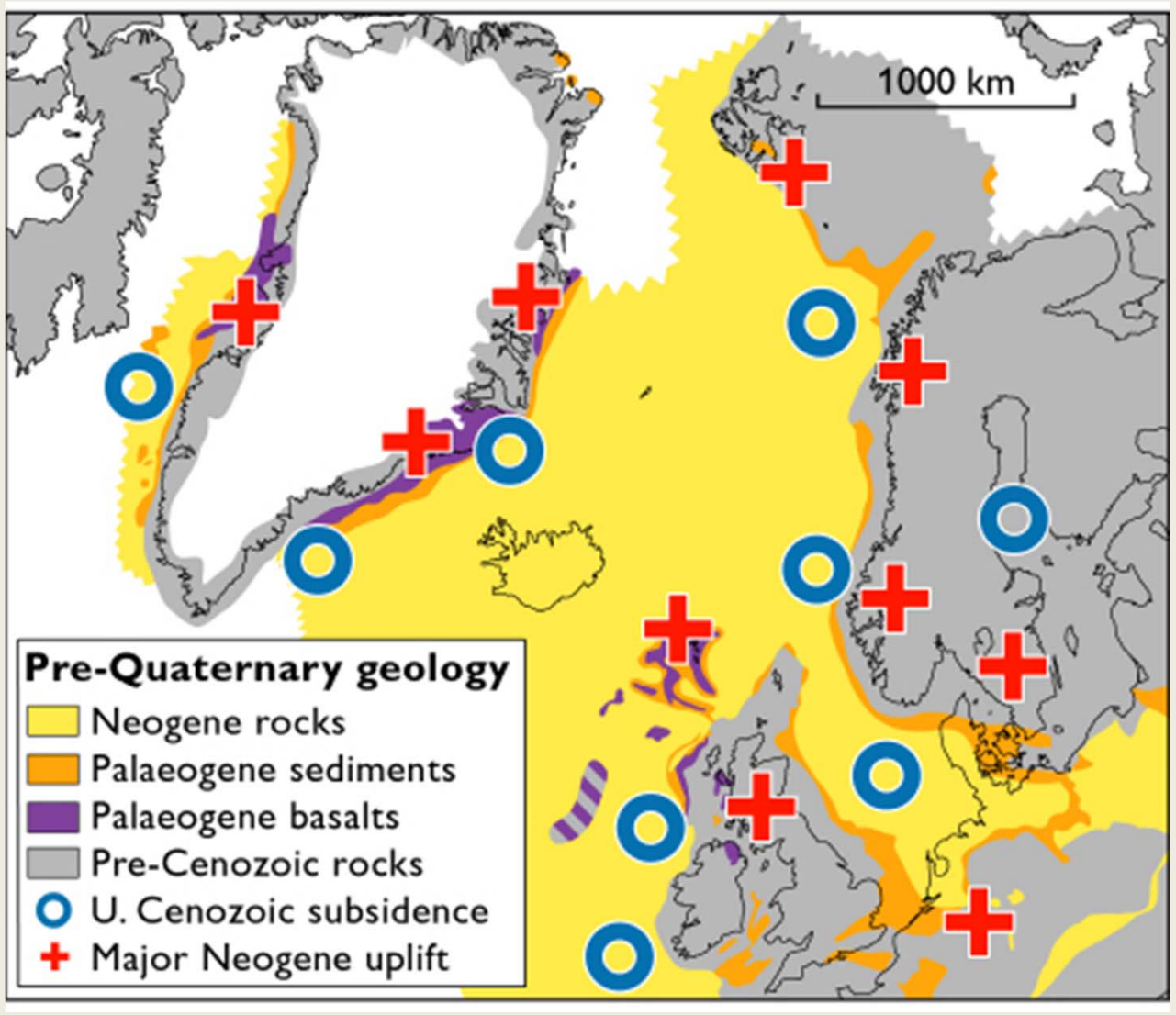
Japsen et al. 2011. *Global Planet. Change*

Late Cenozoic vertical movements



Japsen & Chalmers 2000

Elevated plateaux



Elevated plateaux

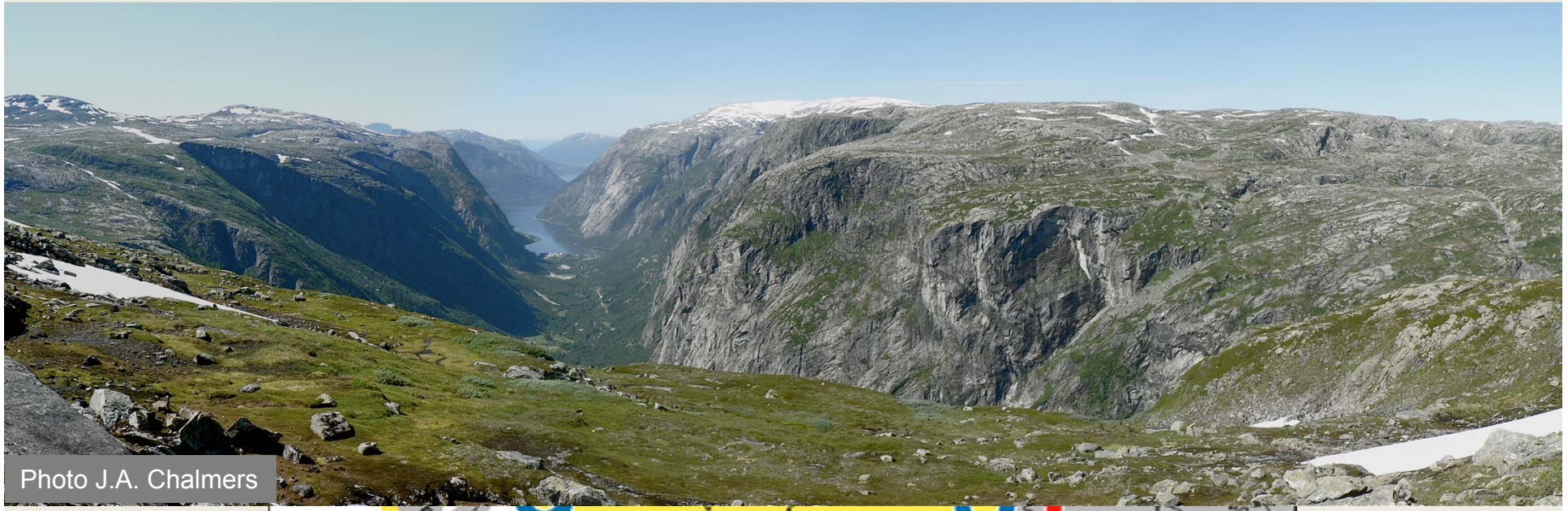
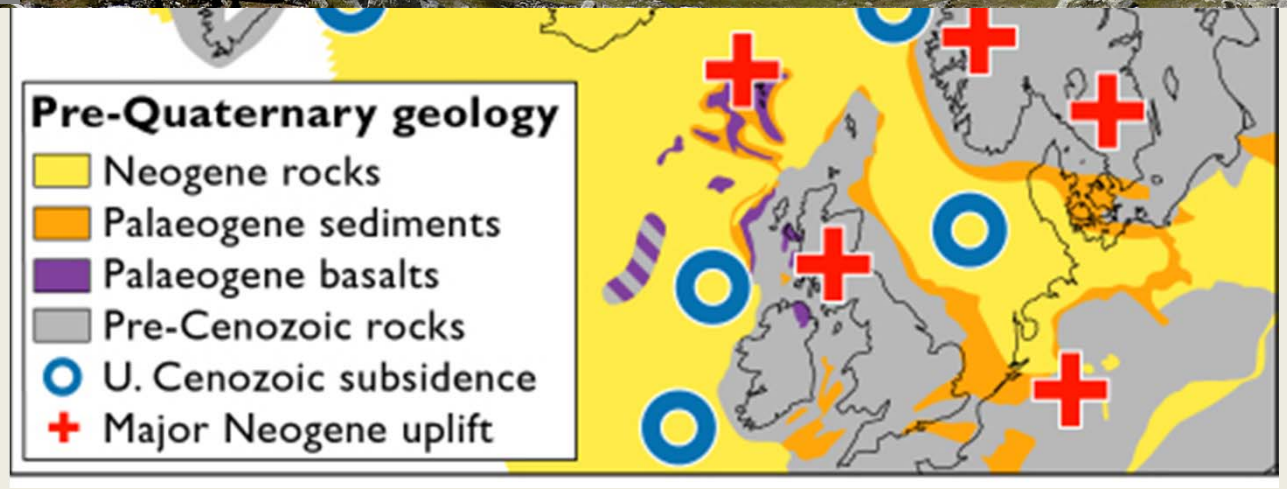
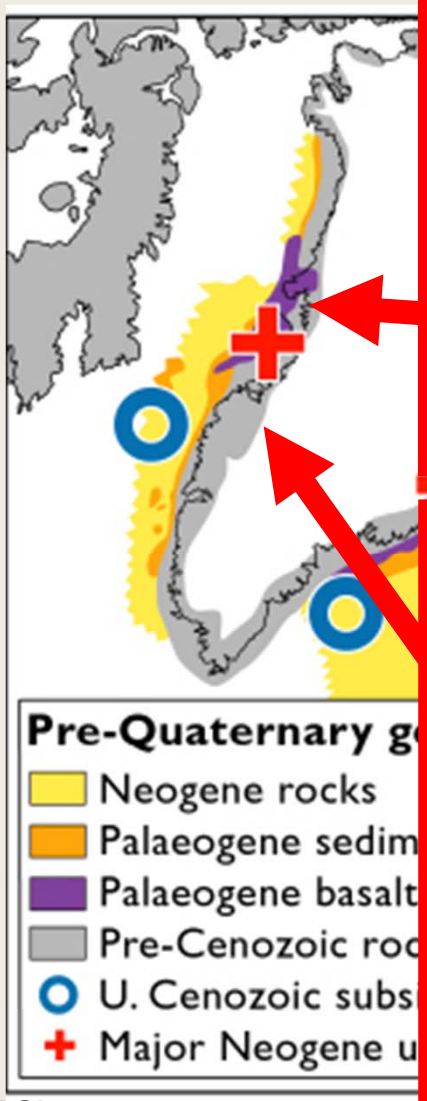
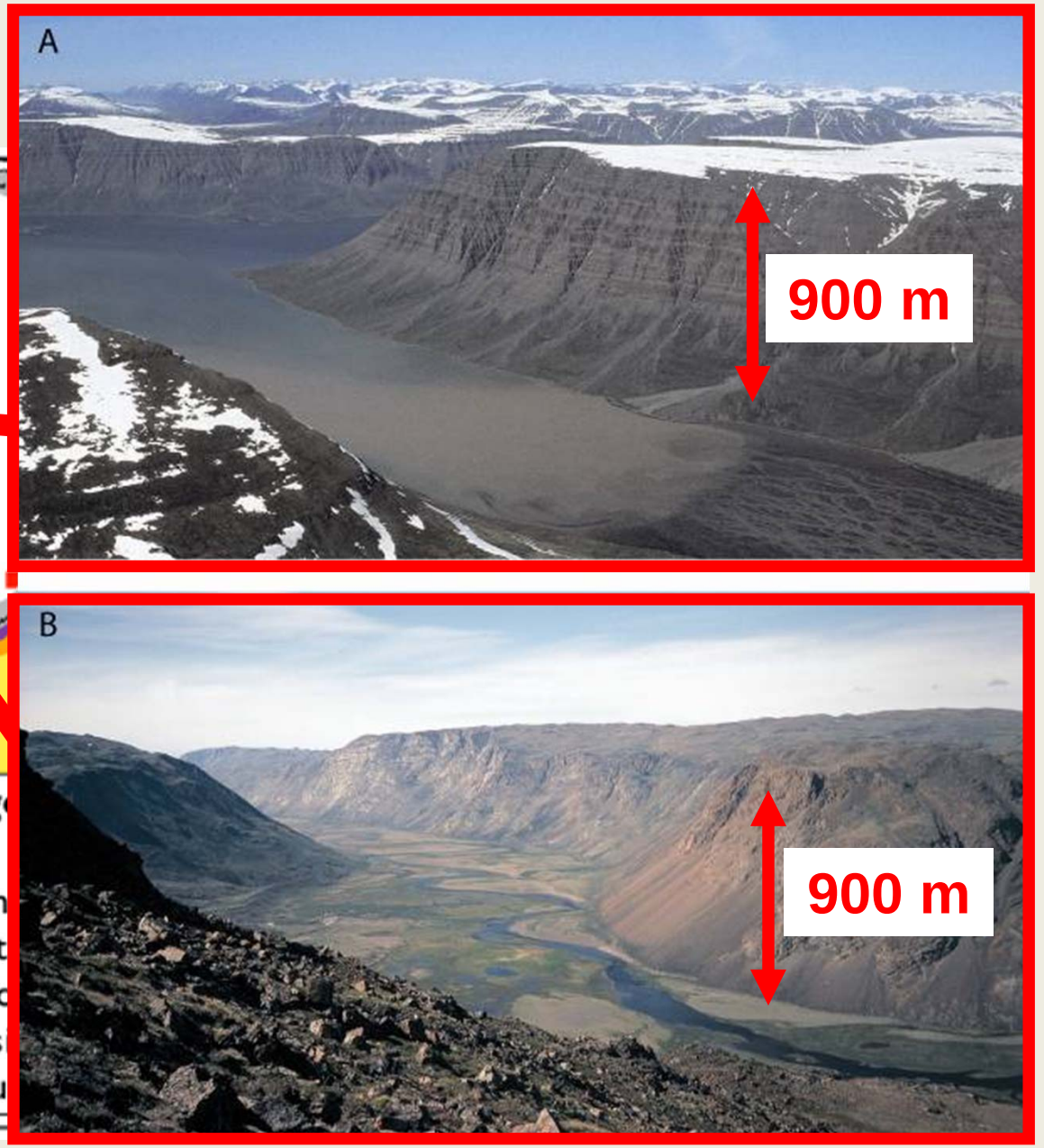


Photo J.A. Chalmers



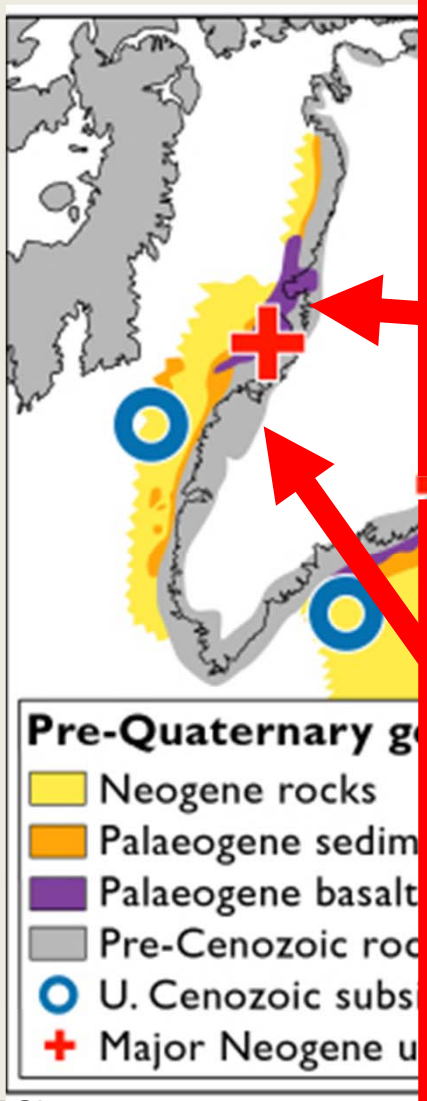
Elevated Plateaux

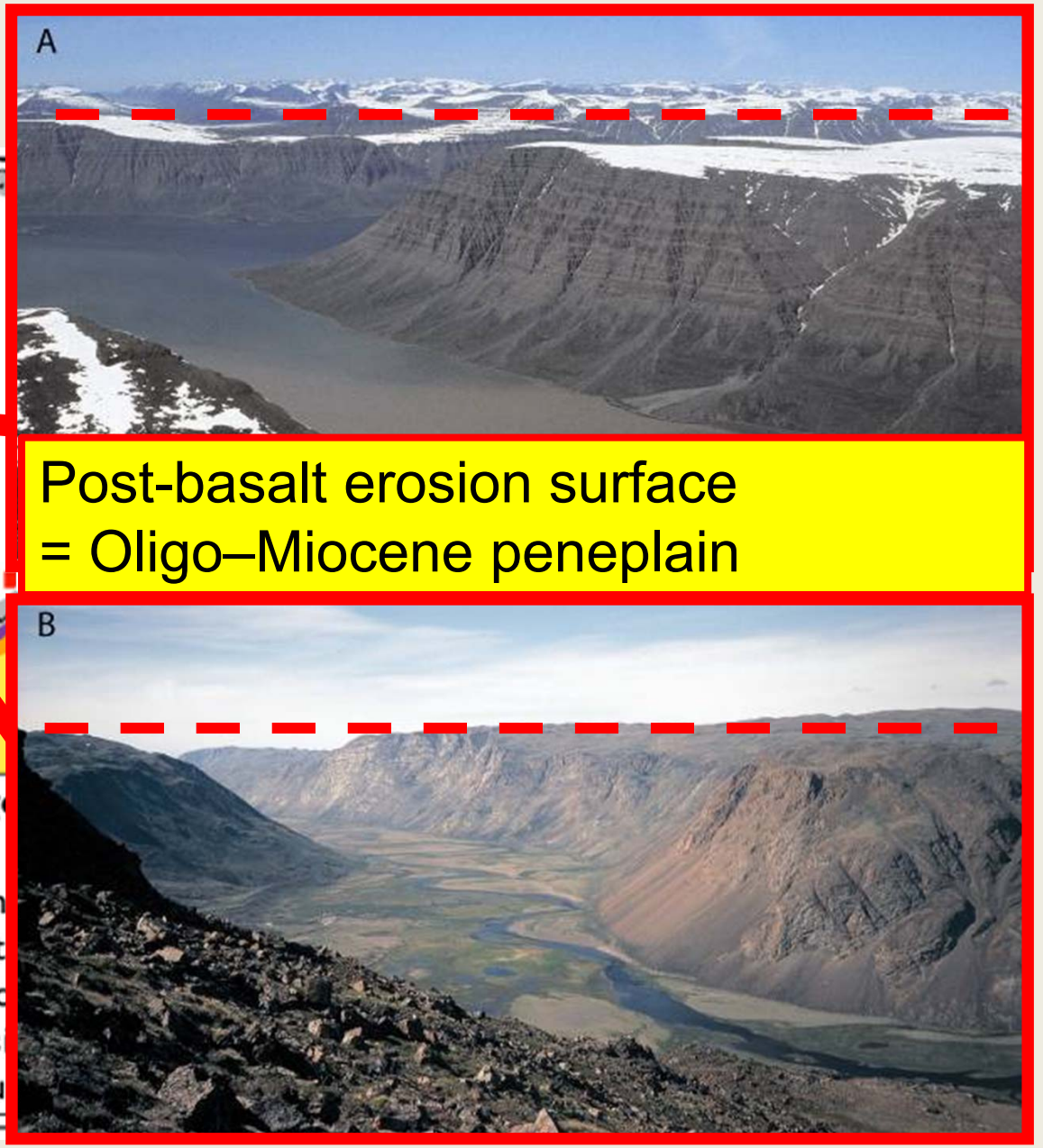




Japsen et al. 2006 *EPSL.*

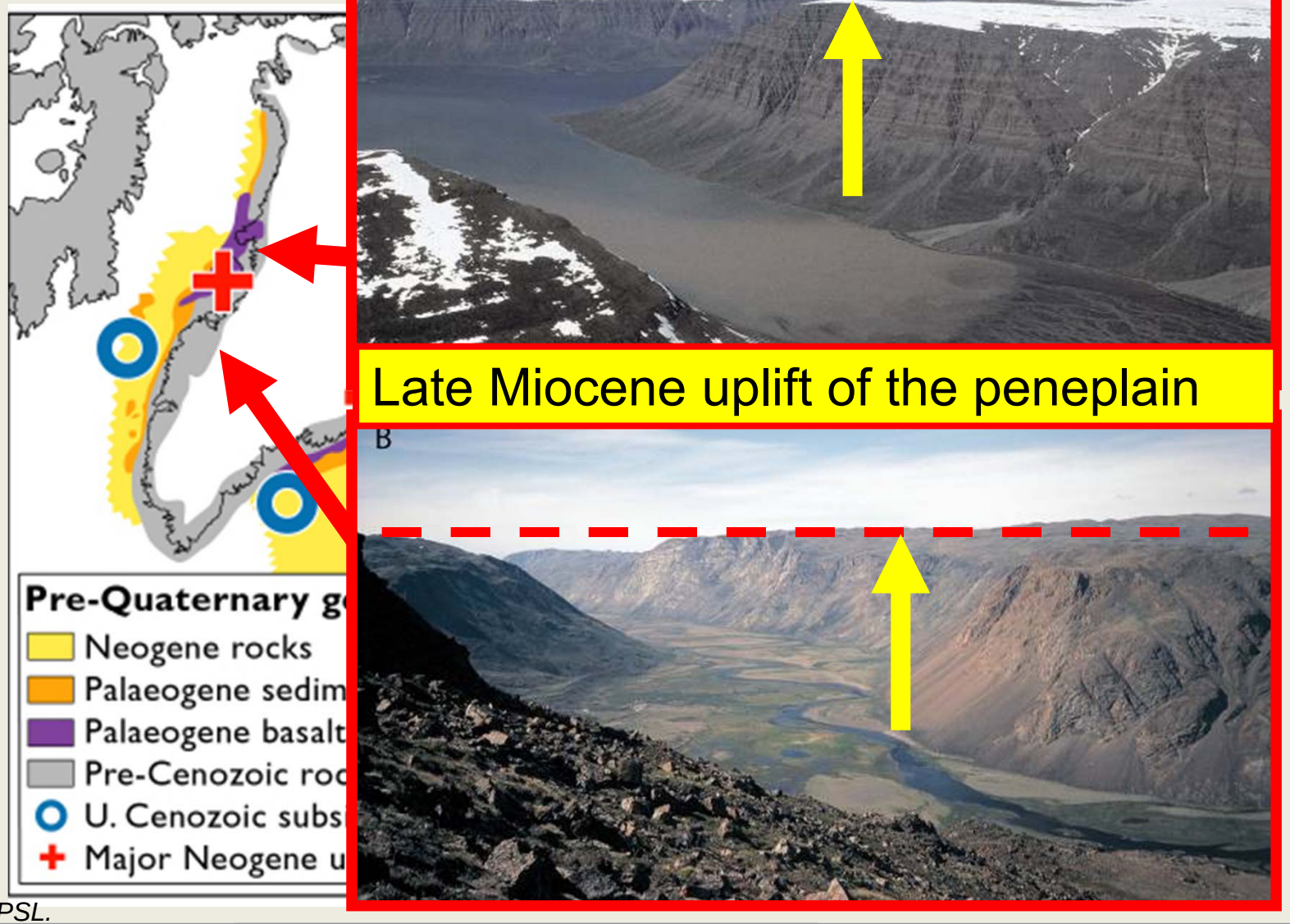
Elevated Plateaux





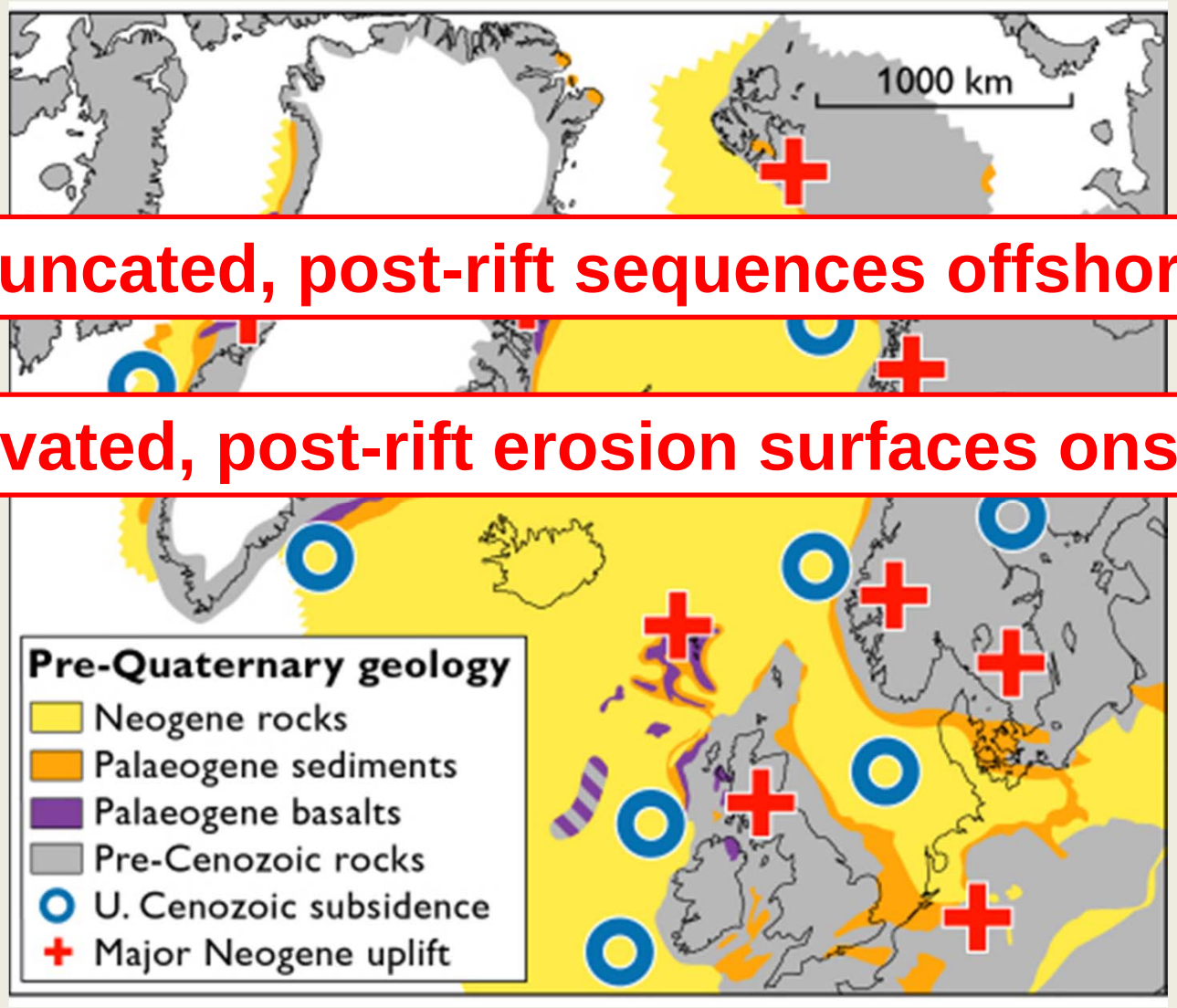
Japsen et al. 2006 *EPSL.*

Elevated Plateaux



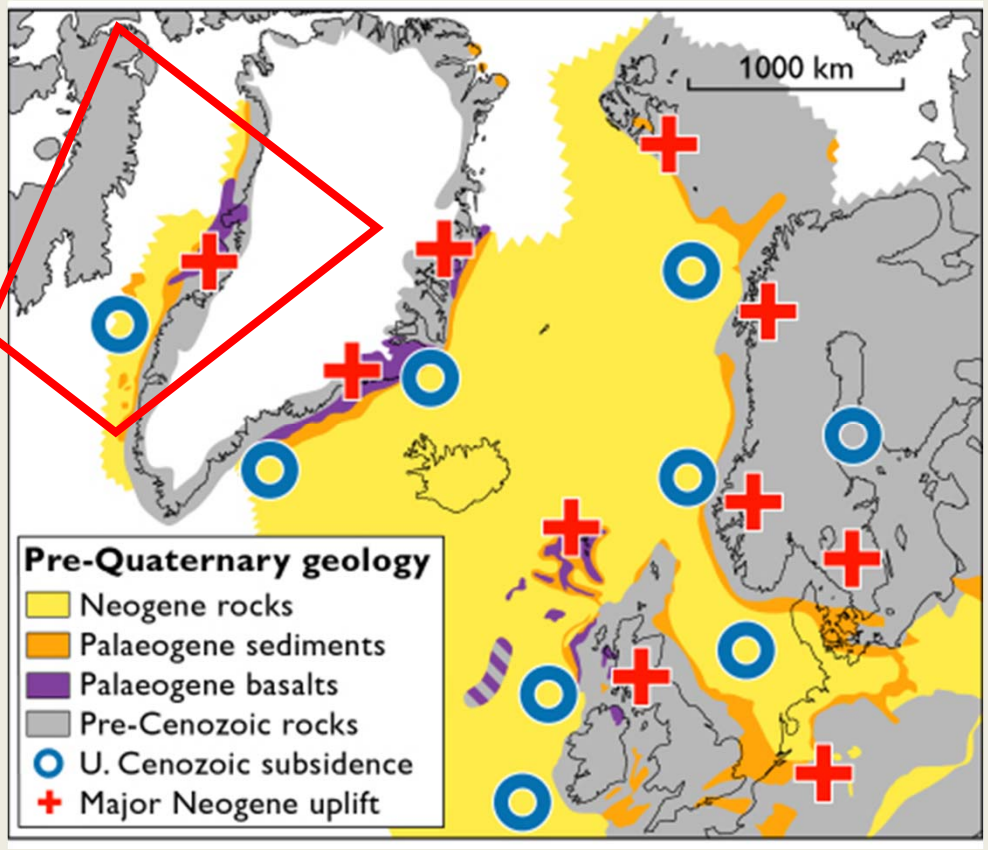
Japsen et al. 2006 *EPSL.*

I: EPCM characteristics

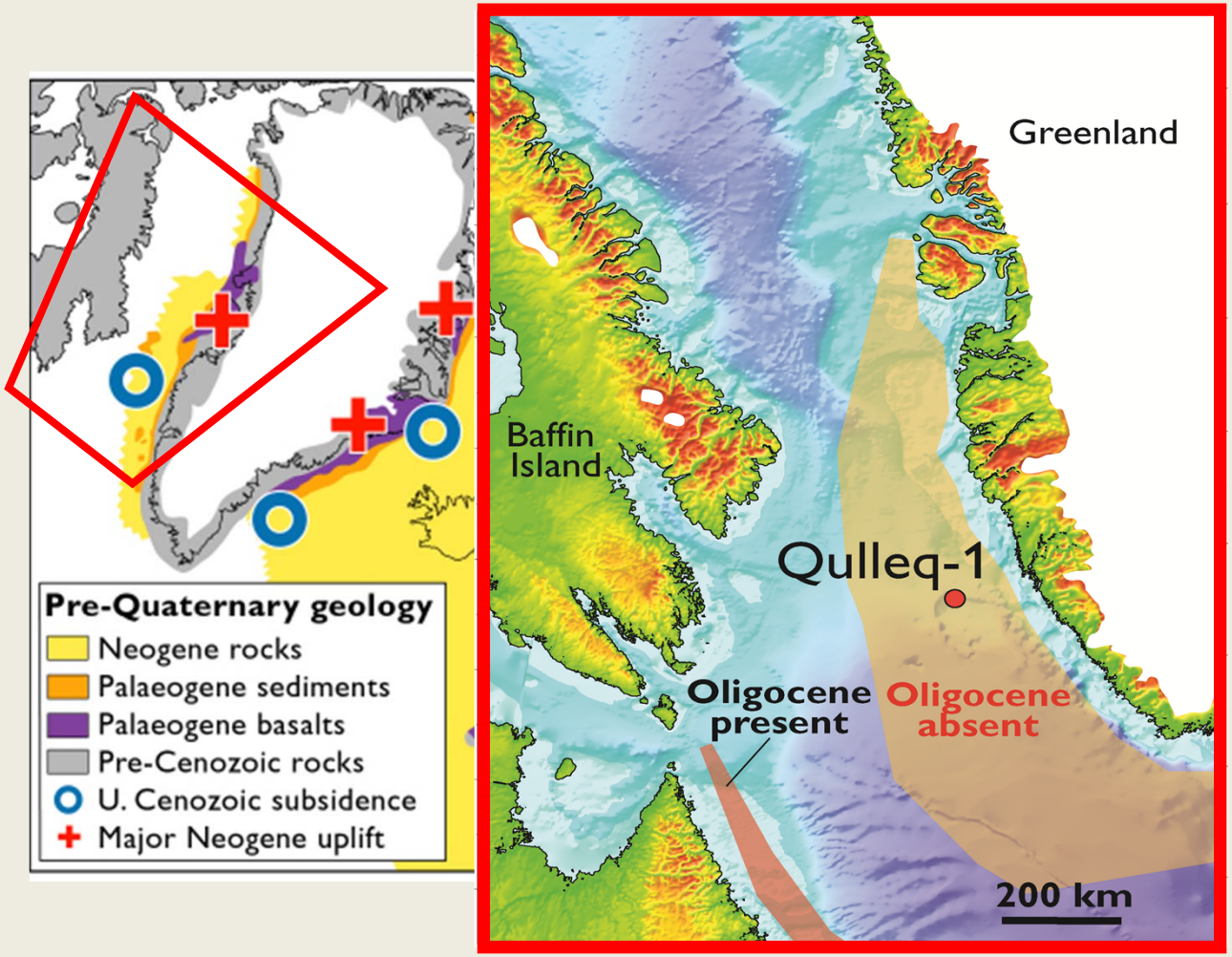


II: North Atlantic cases

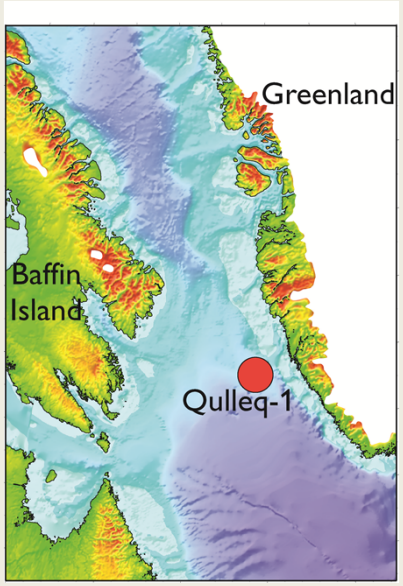
Case A: Greater depth of burial at 35 Ma offshore West Greenland?

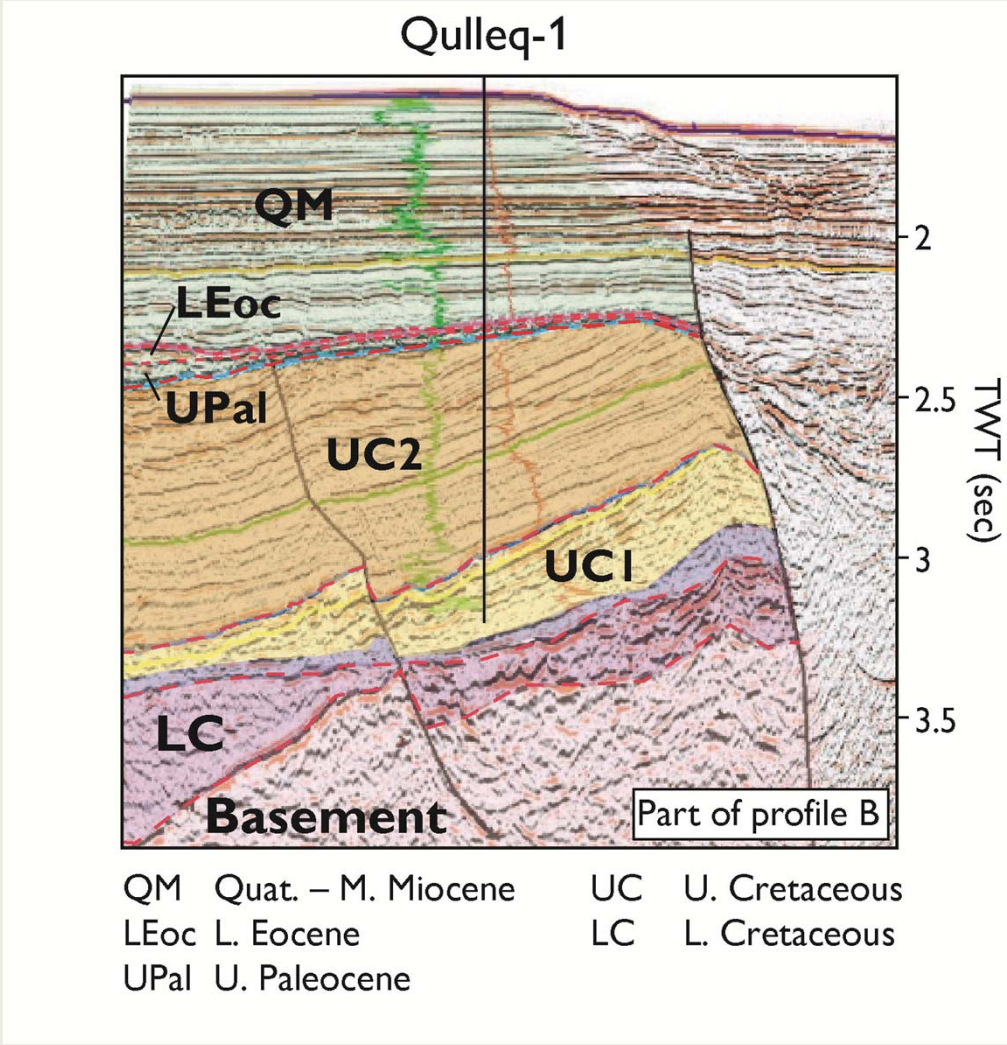


Case A: Greater depth of burial at 35 Ma offshore West Greenland?



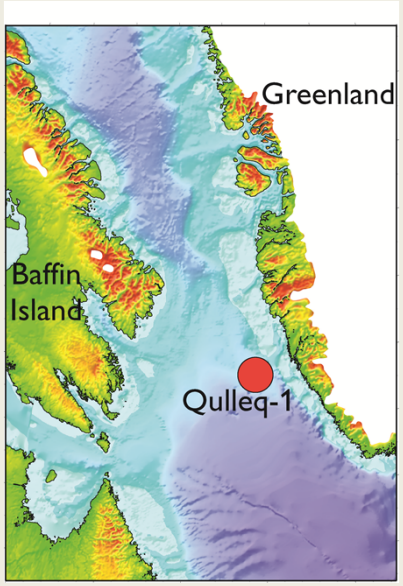
Truncation below Miocene strata

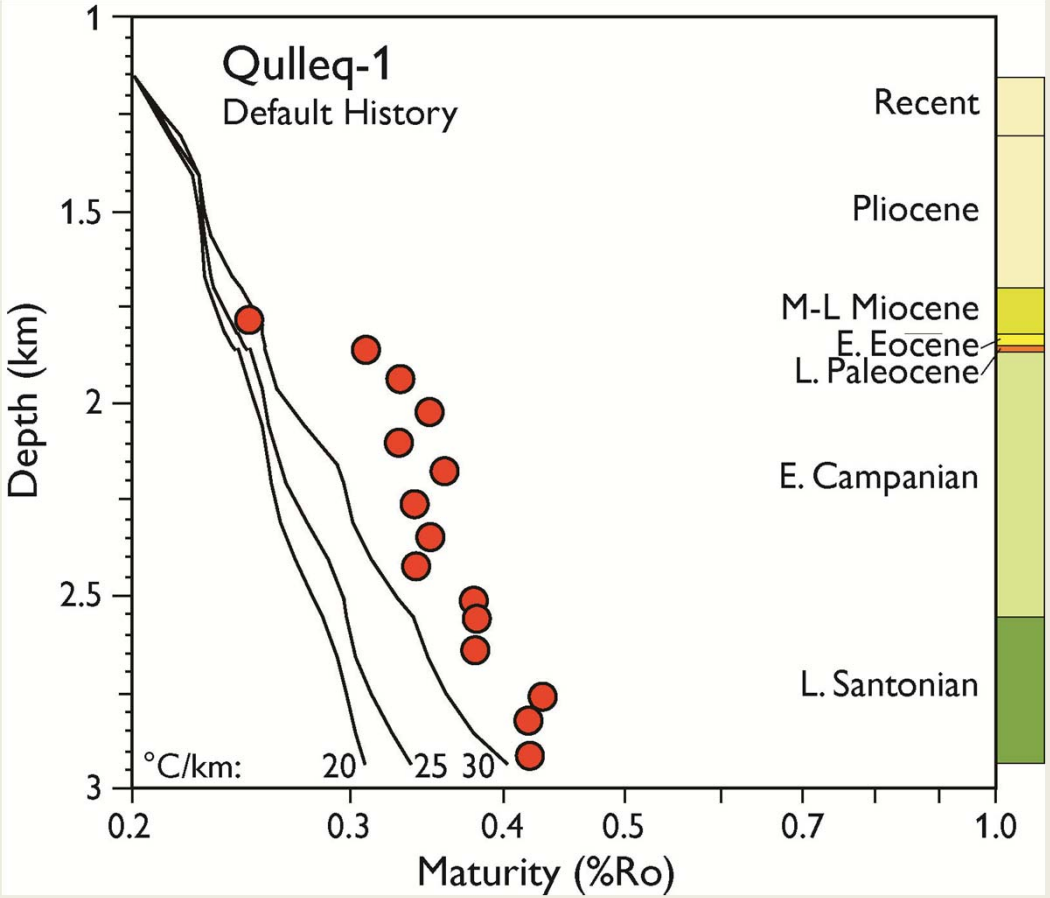




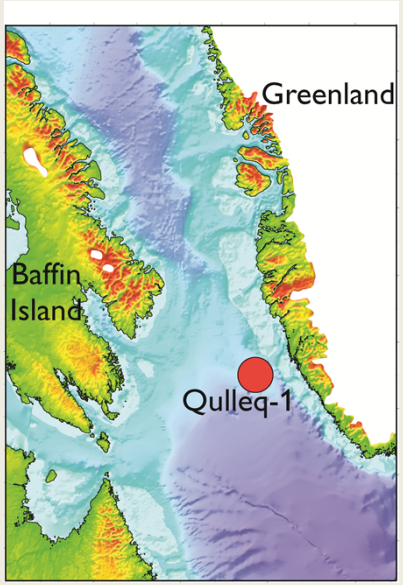
Christiansen et al. 2001

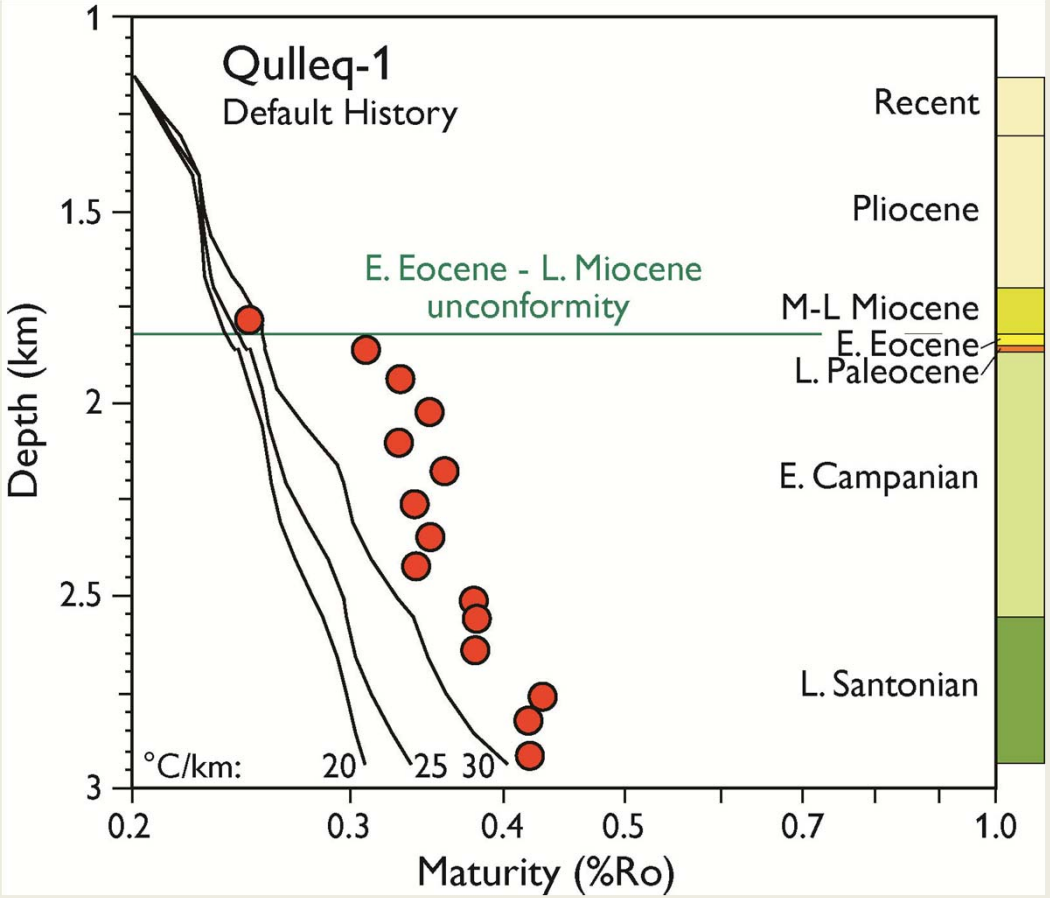
Evidence for deeper burial
VR data plot above default histories





Evidence for deeper burial
VR data jump across unconformity

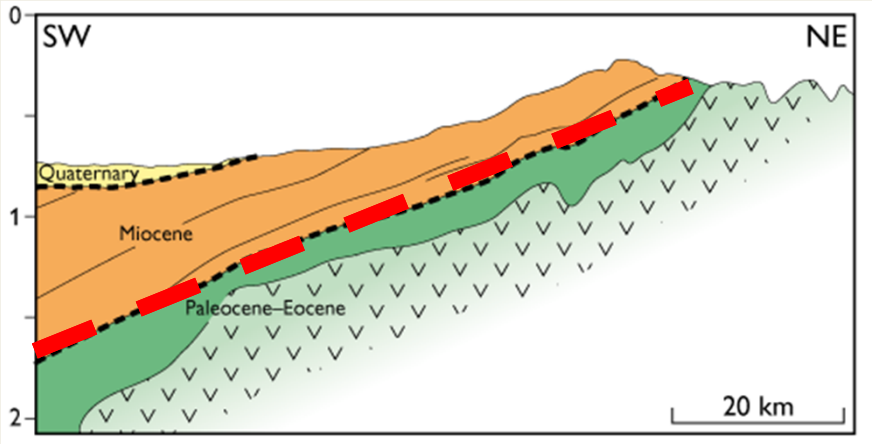




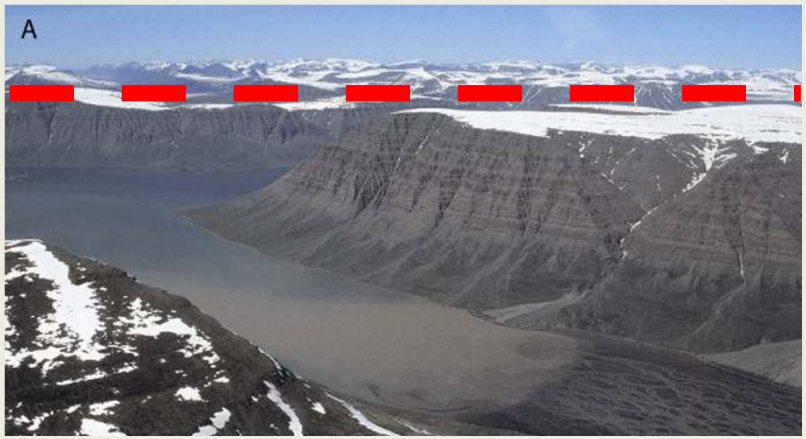
Japsen et al. 2010, *7th PGC*

Offshore – onshore correlation West Greenland

Nuussuaq Basin



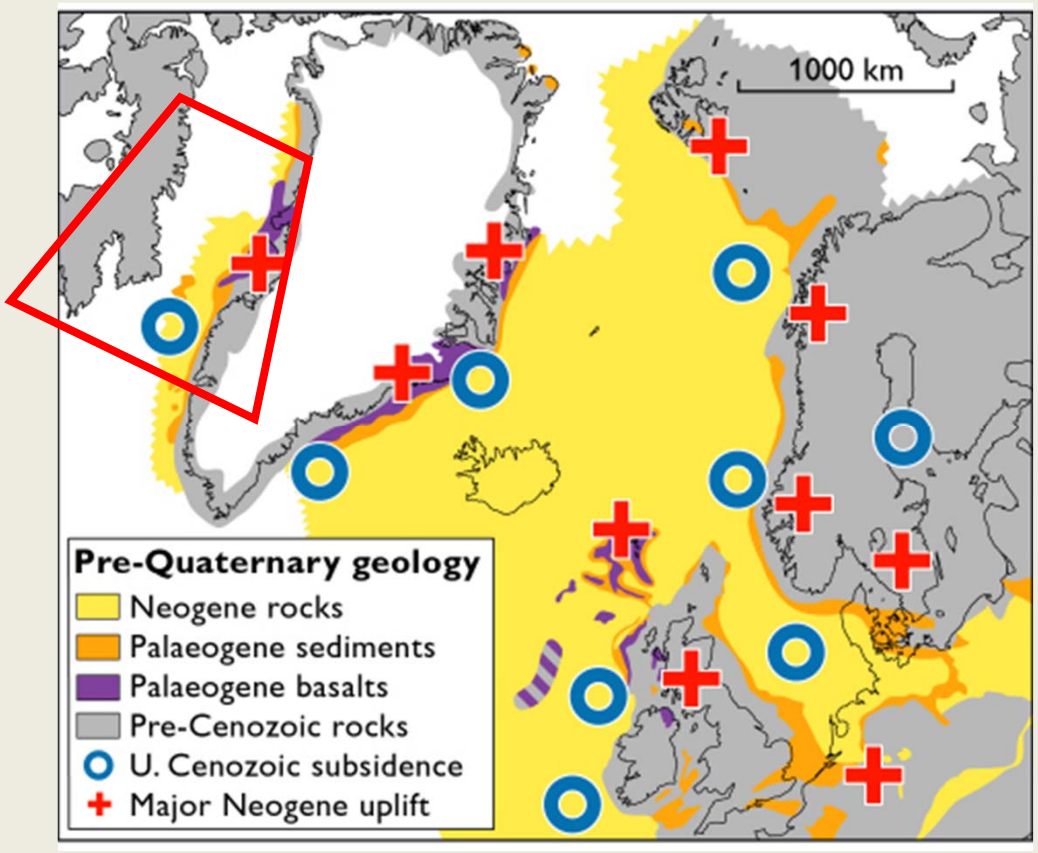
Disko

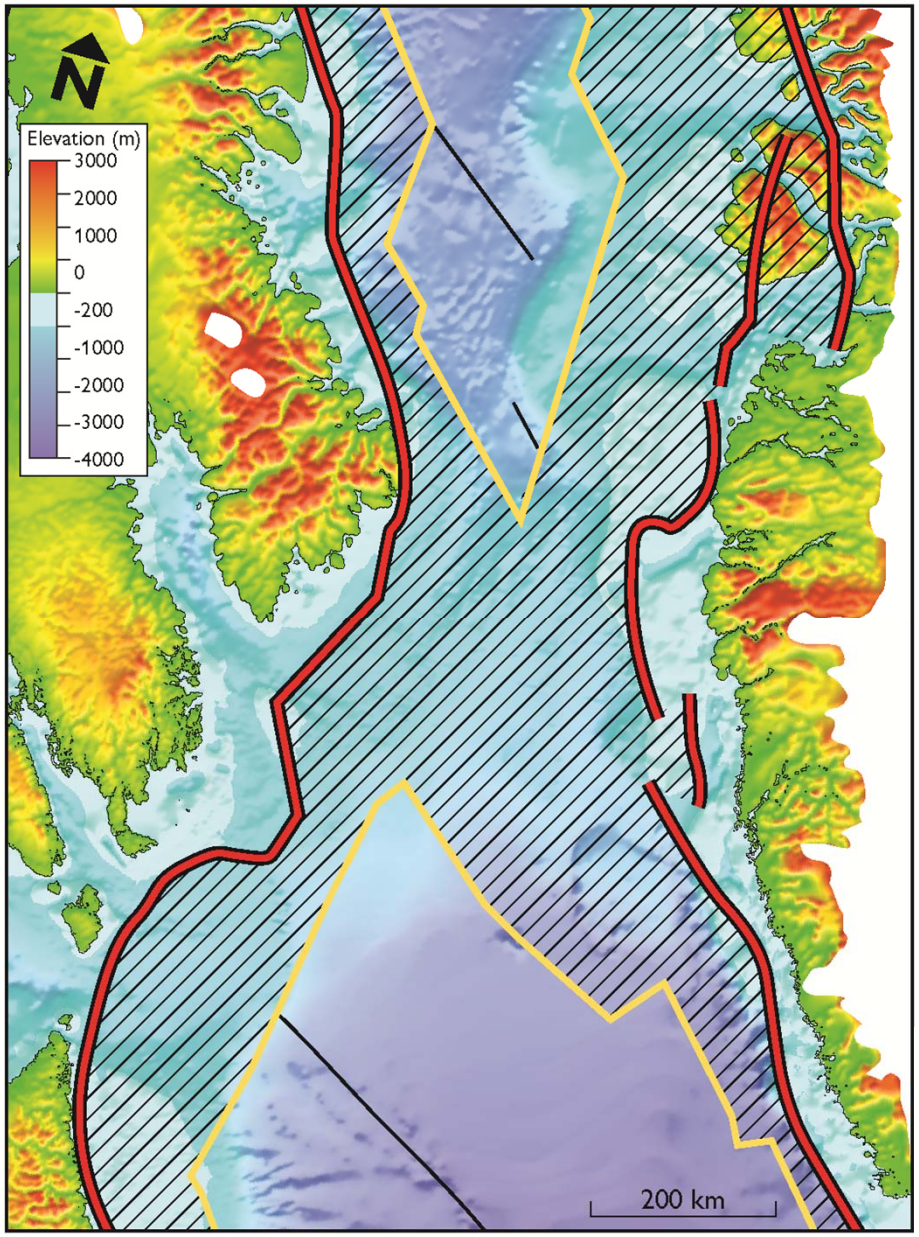


Oligocene hiatus offshore

Post-basalt peneplain onshore

Case B: Neogene uplift of Baffin Island?



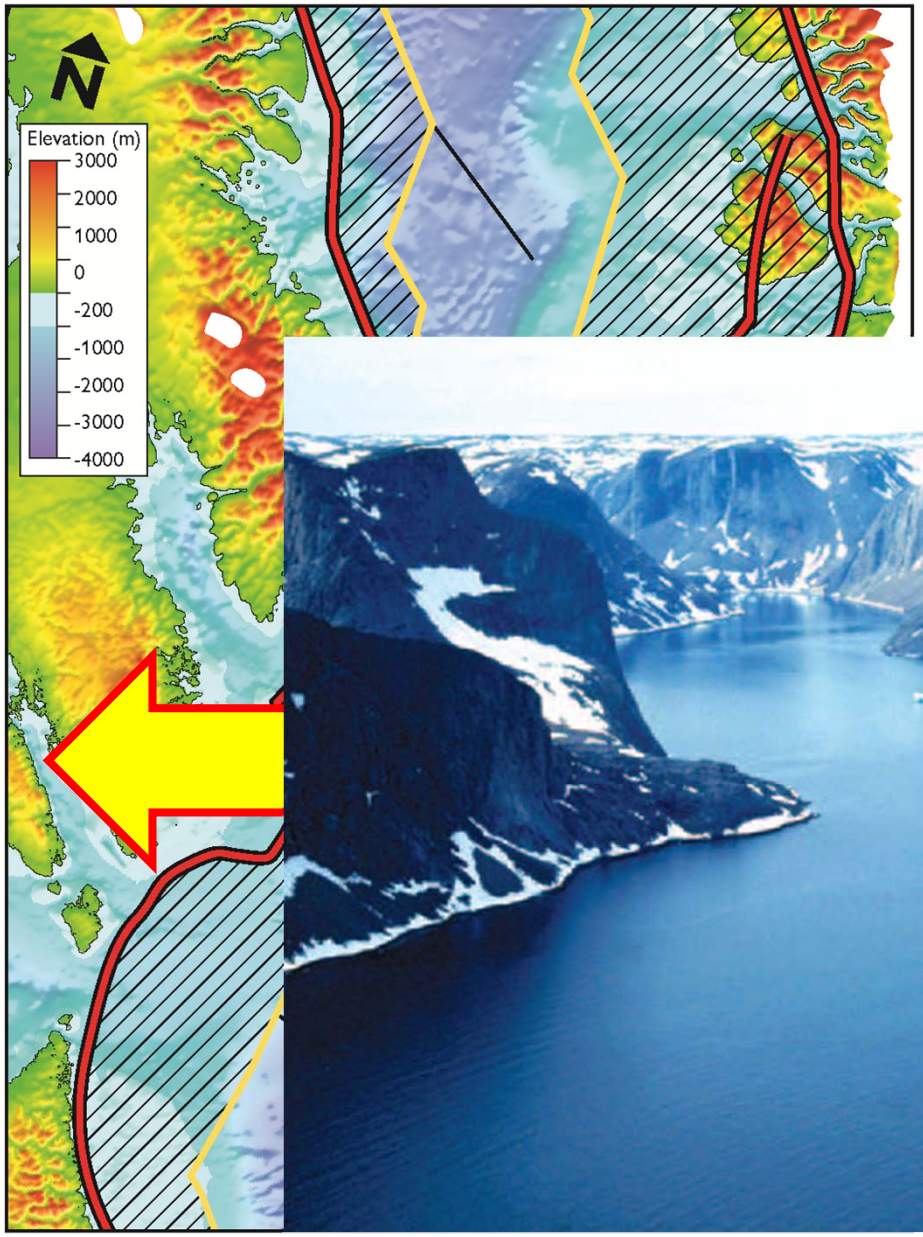


Baffin Island–West Greenland

E-W symmetry
Uplifted cratonic edges

Rifted continental crust
Limit of rifted continental crust
Boundary between oceanic and continental crust
Extinct spreading centre

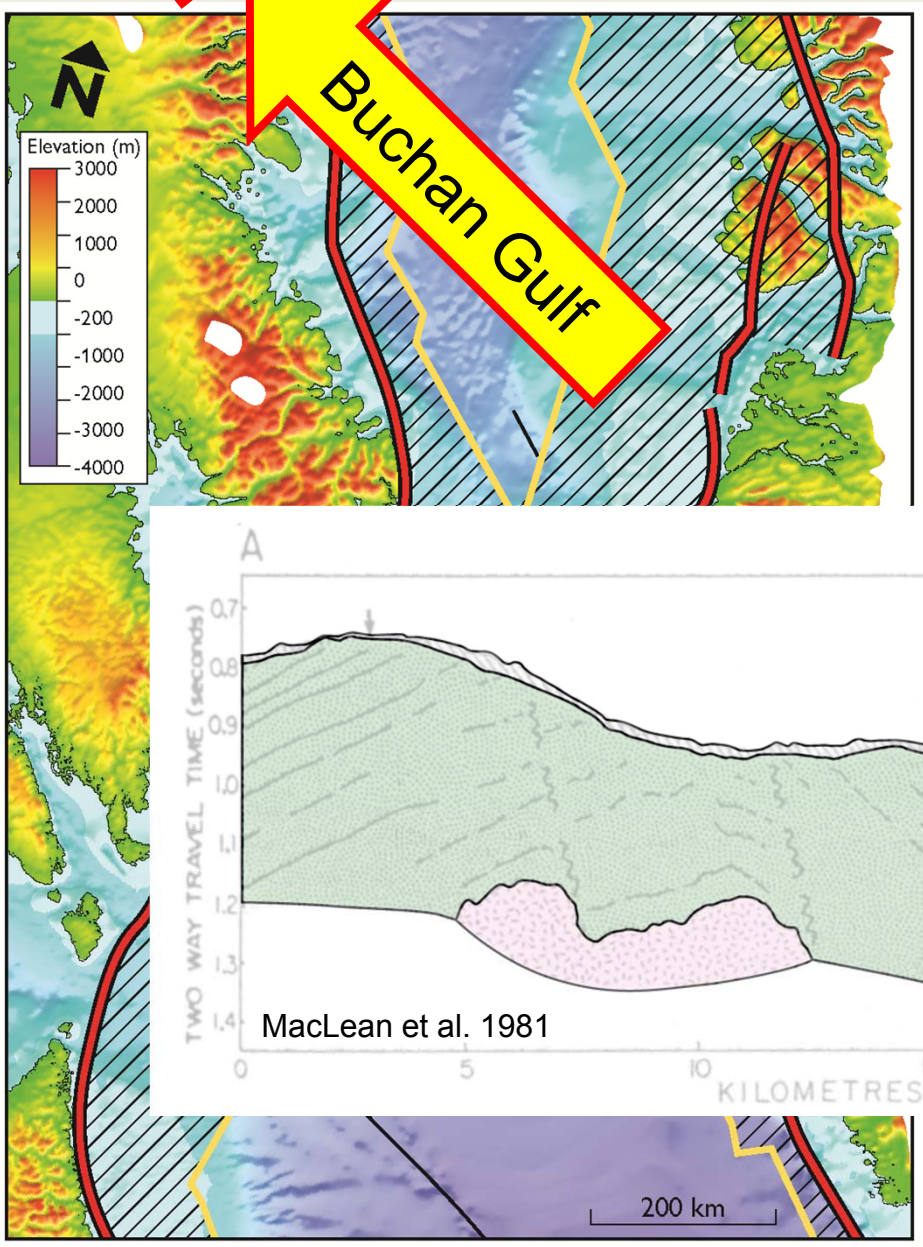
Japsen et al. 2011. *Global Planet Change*



Baffin Island

Pre-glacial peneplains

Klemann 2008

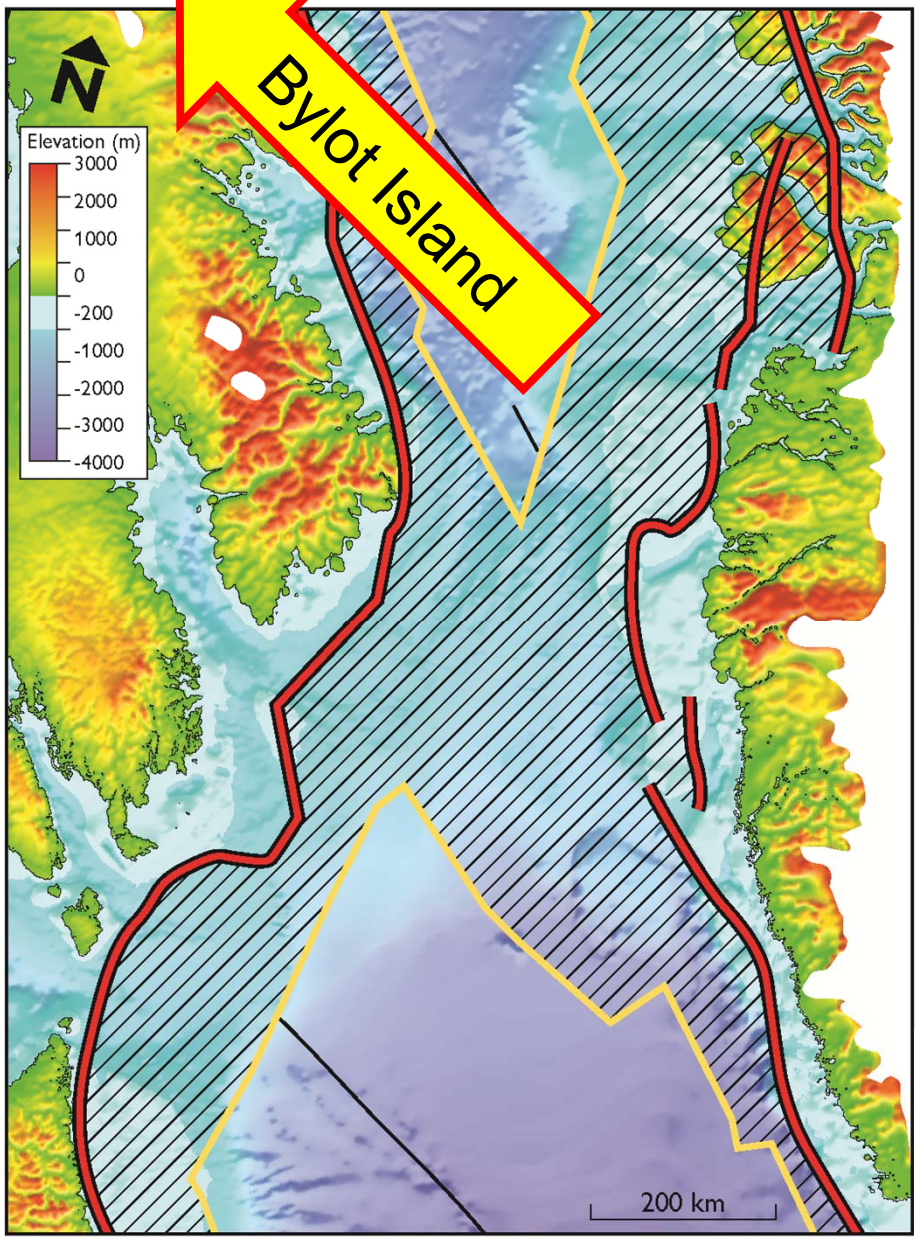


Baffin Island

Truncation of Palaeogene strata towards the coast

MacLean et al. 1981

MacLean et al. 1981



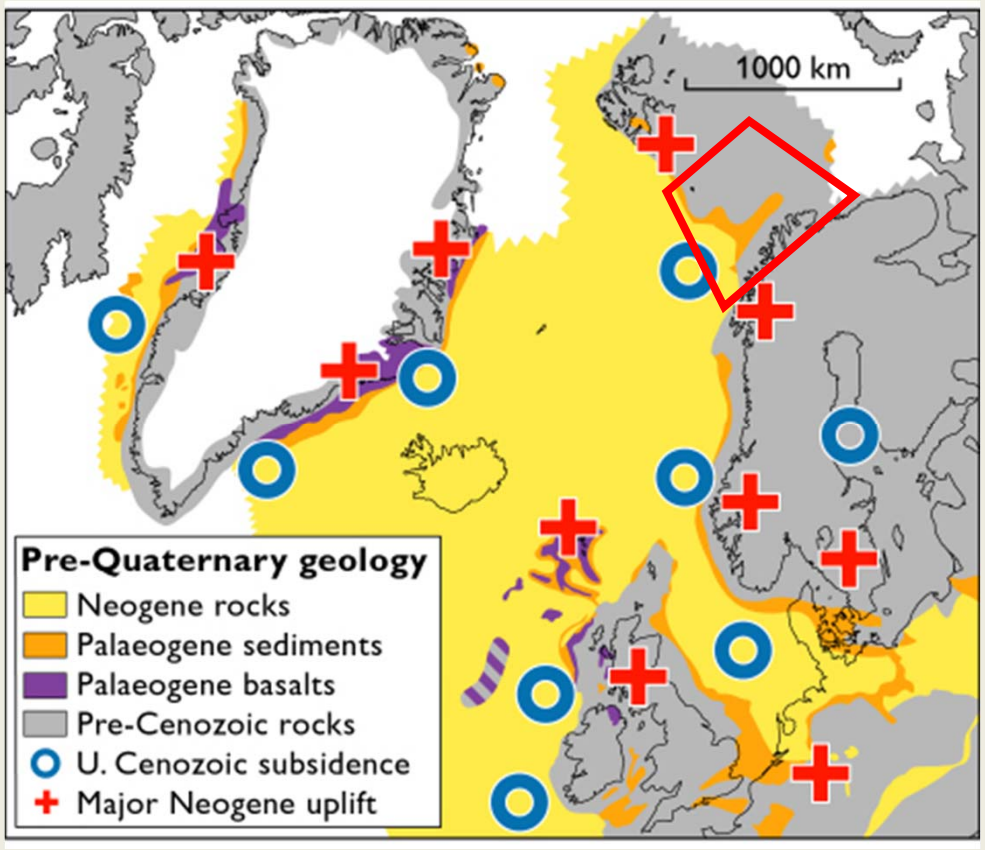
Baffin Island

Lower Eocene marine sediment 600 m above sea level

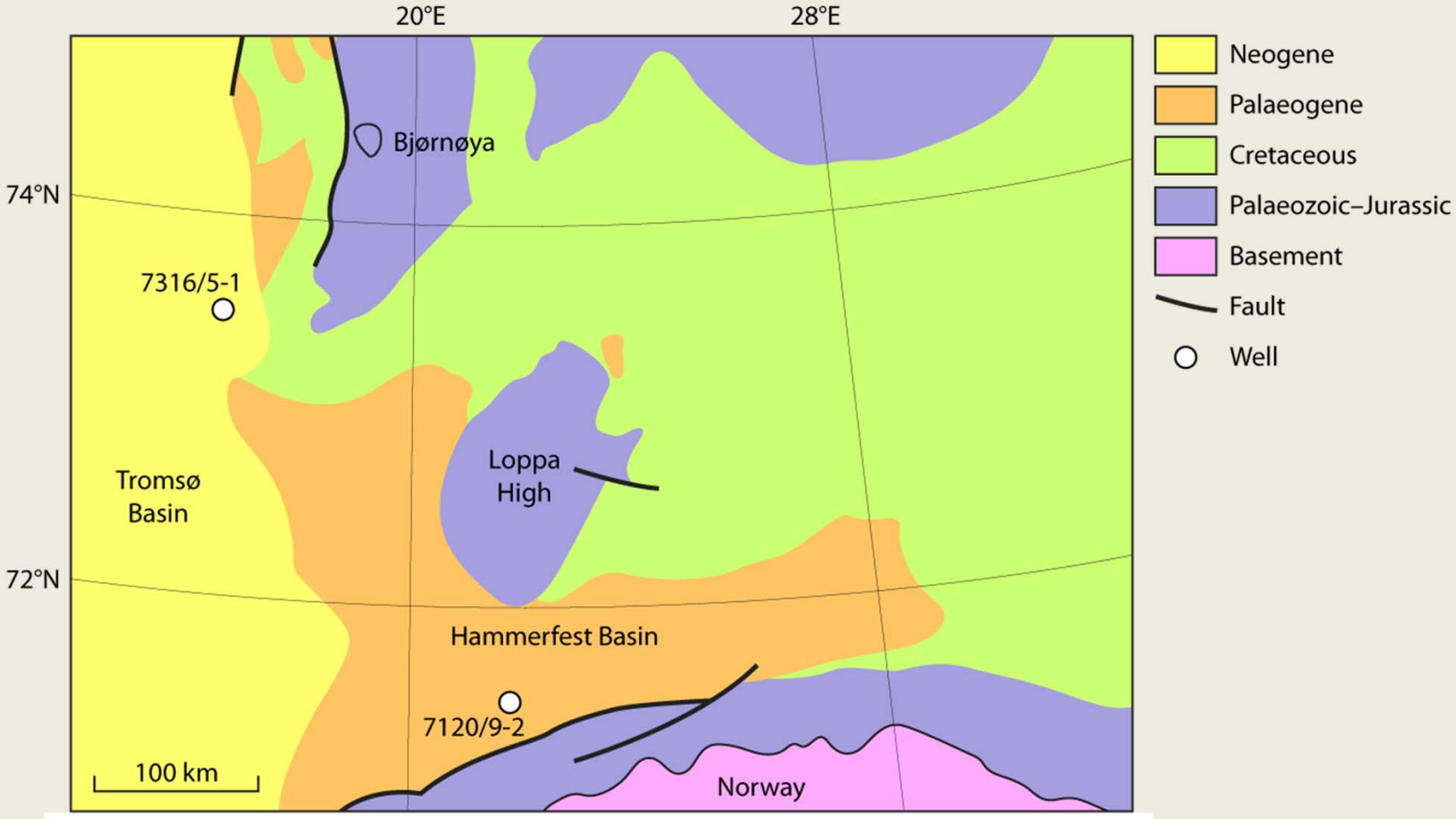
MacLean & Falconer 1979; Miall et al. 1981

Rifted continental crust
Limit of rifted continental crust
Boundary between oceanic and continental crust
Extinct spreading centre

Case C: Exhumation of the Barents Sea

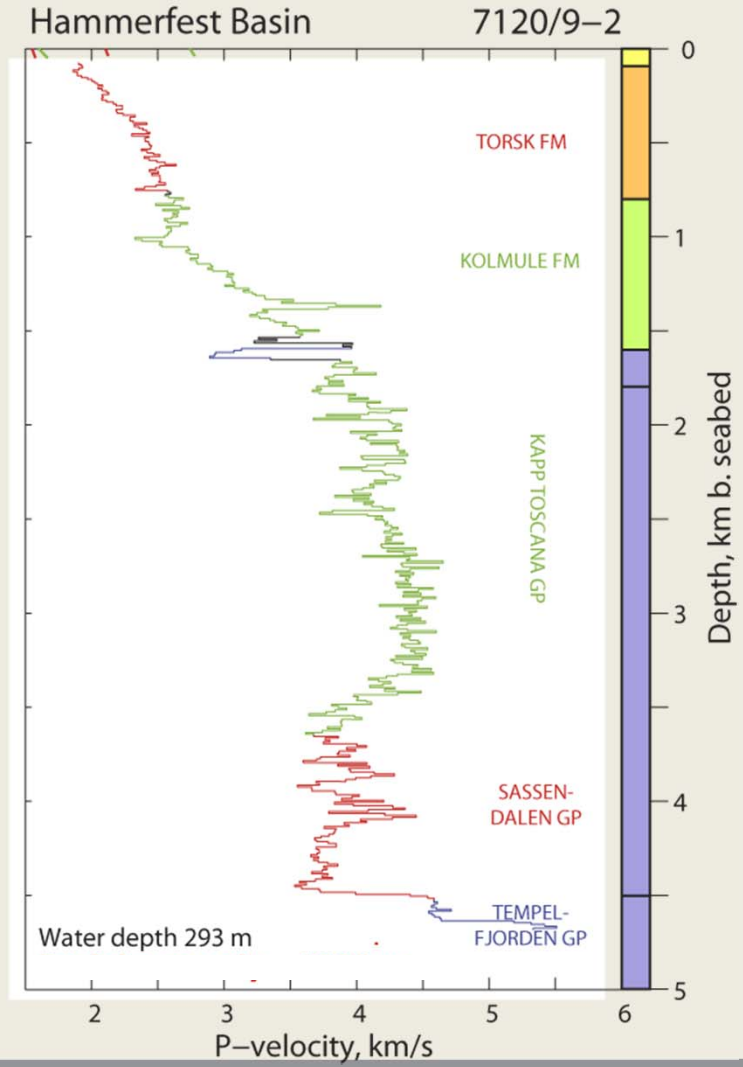


Low-angular, post mid-Eocene unconformity across the Barents Sea



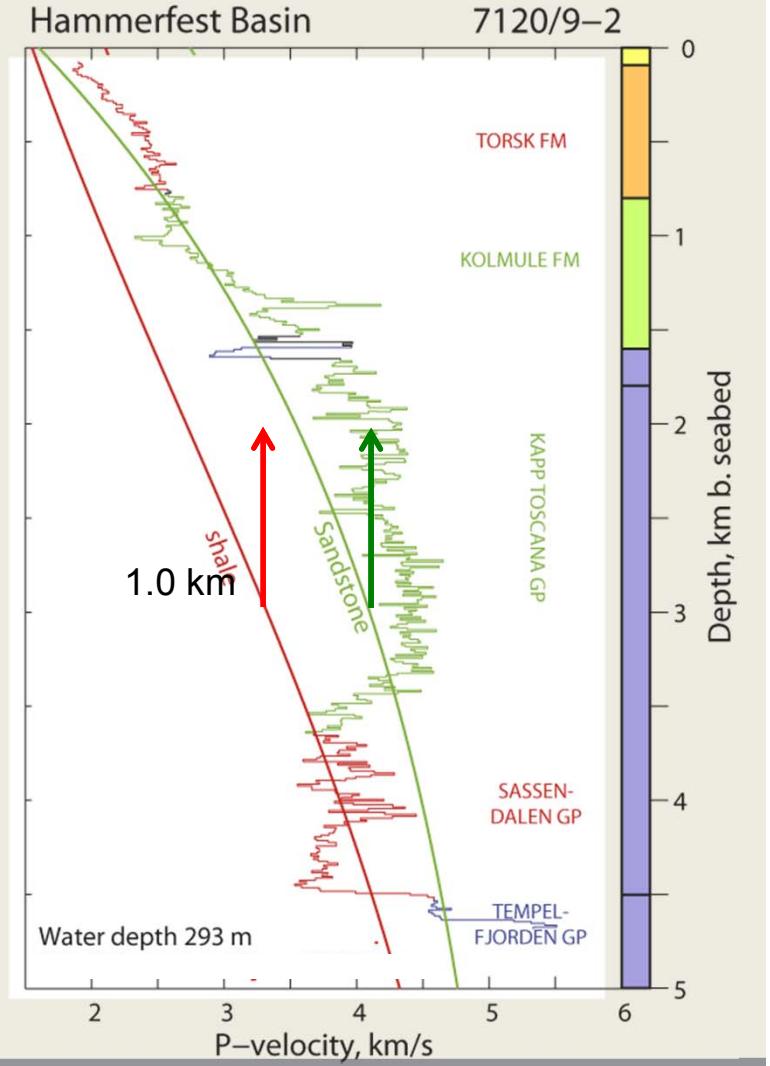
Based on Sigmond 2002, Green & Duddy 2010

Sonic data, shale and sandstone



Neogene
Palaeogene
Cretaceous
Palaeozoic–Jurassic

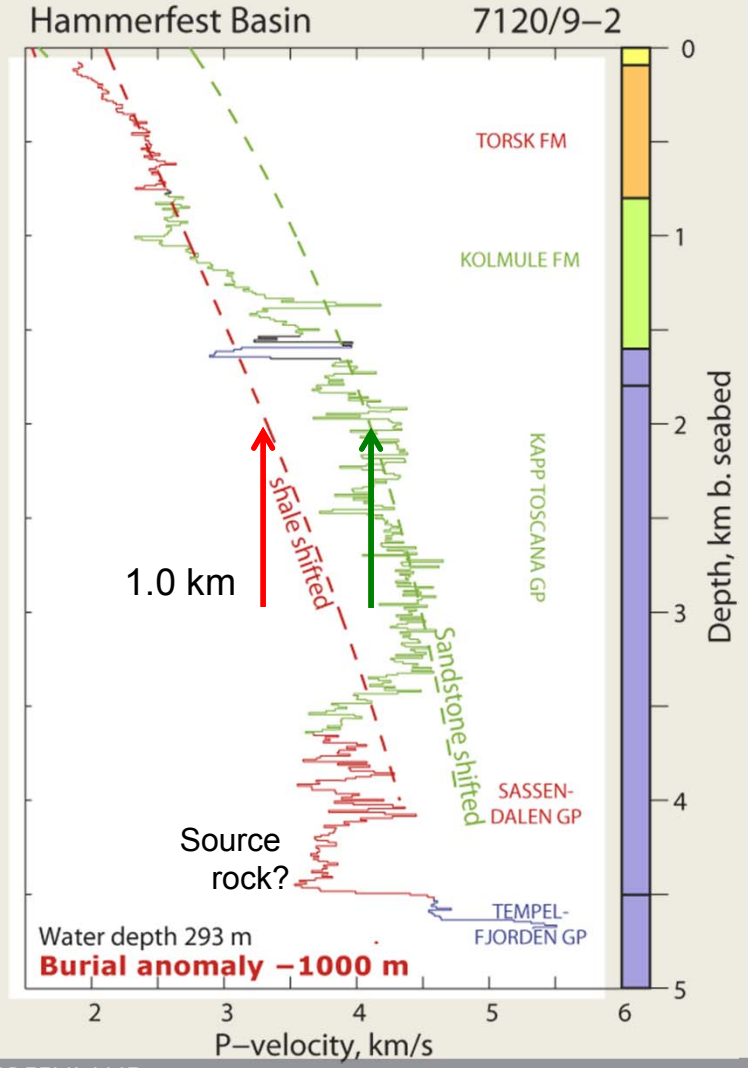
Baselines, shale and sandstone



Neogene
Palaeogene
Cretaceous
Palaeozoic–Jurassic

Baselines for shale/sandstone (Japsen *et al.* 2007)

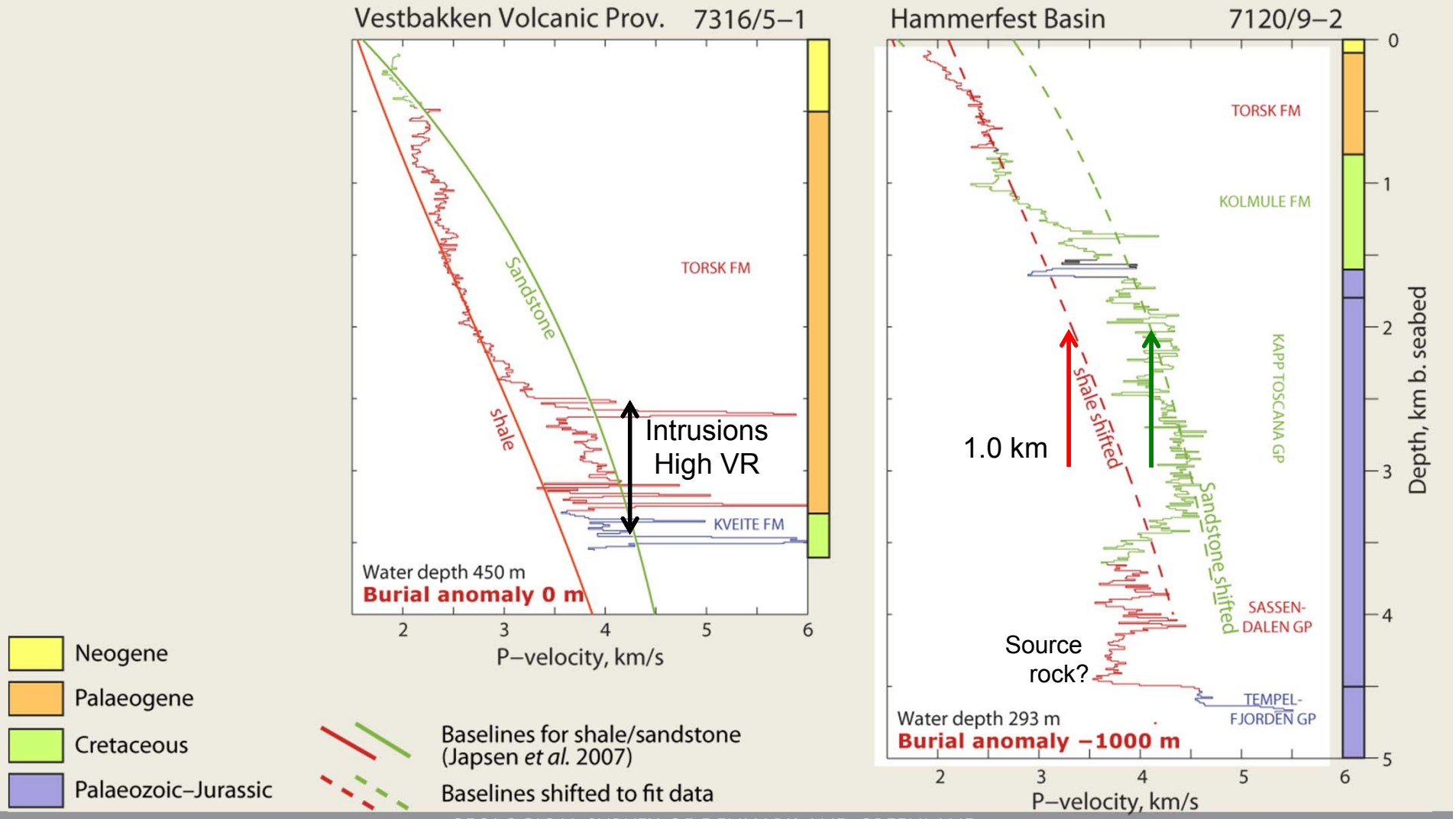
Baselines shifted to fit data



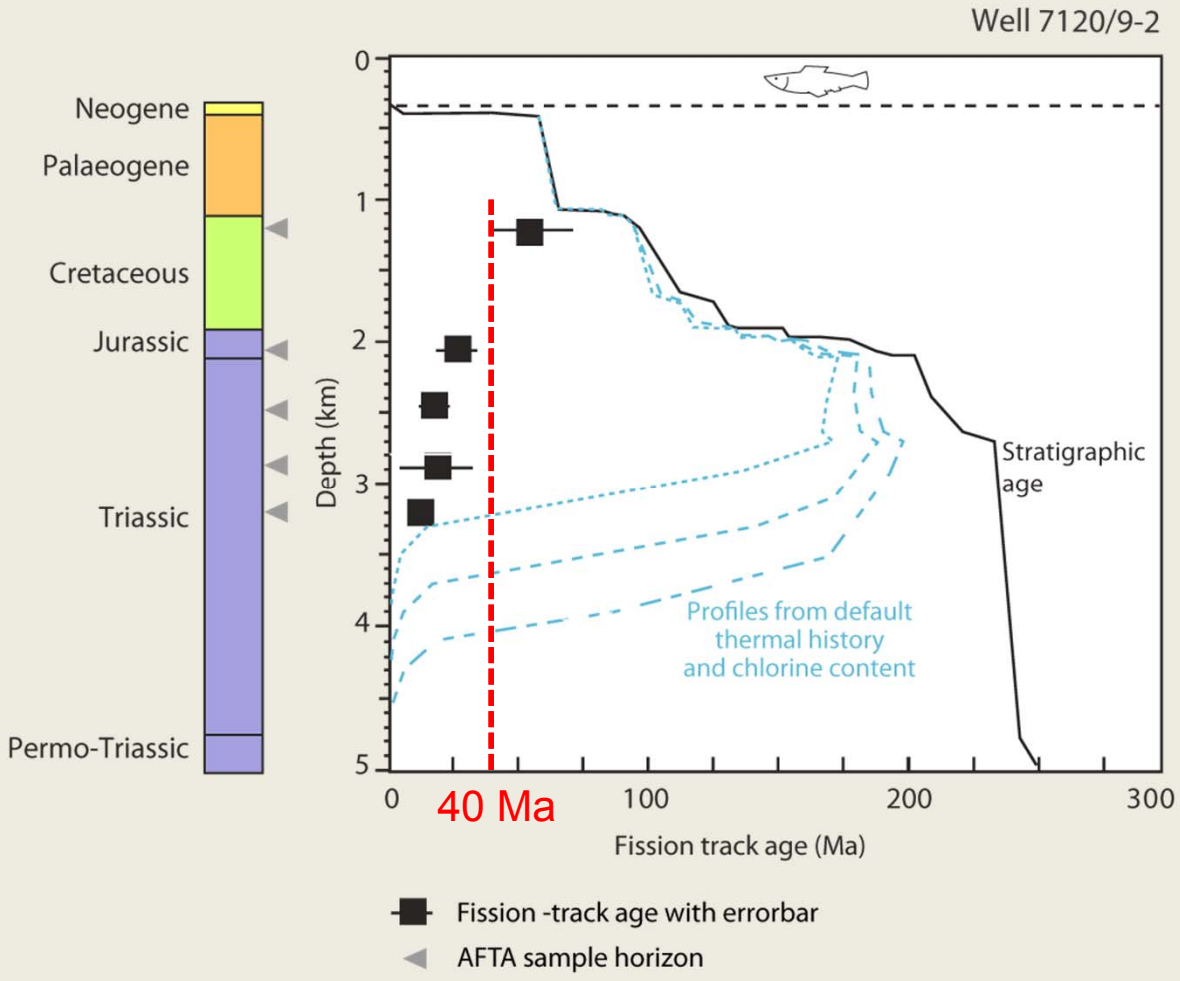
Neogene
Palaeogene
Cretaceous
Palaeozoic–Jurassic

Baselines for shale/sandstone (Japsen *et al.* 2007)
Baselines shifted to fit data

Maximum burial and high VR

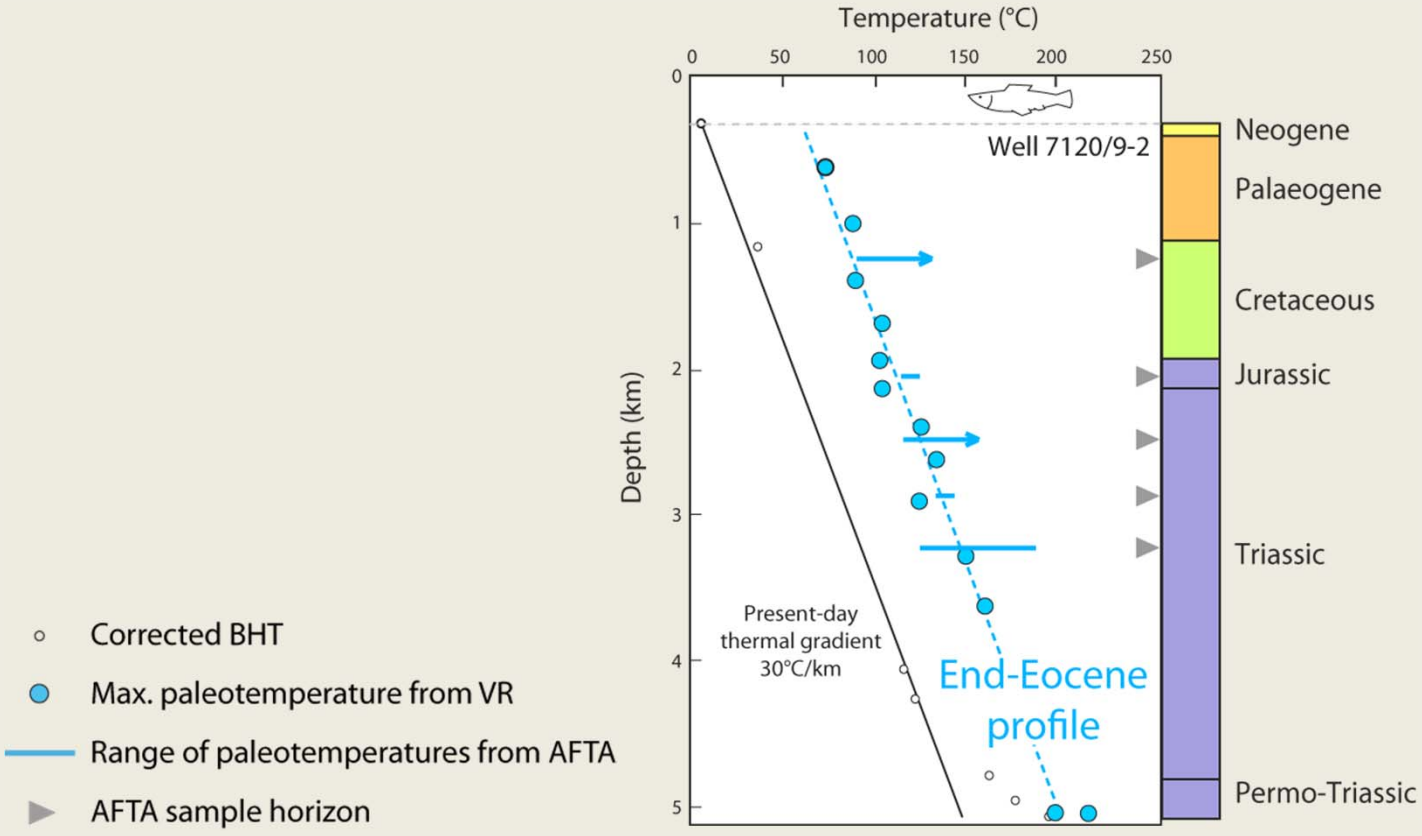


Young AFT ages indicate higher palaeo-temperatures before c. 40 Ma



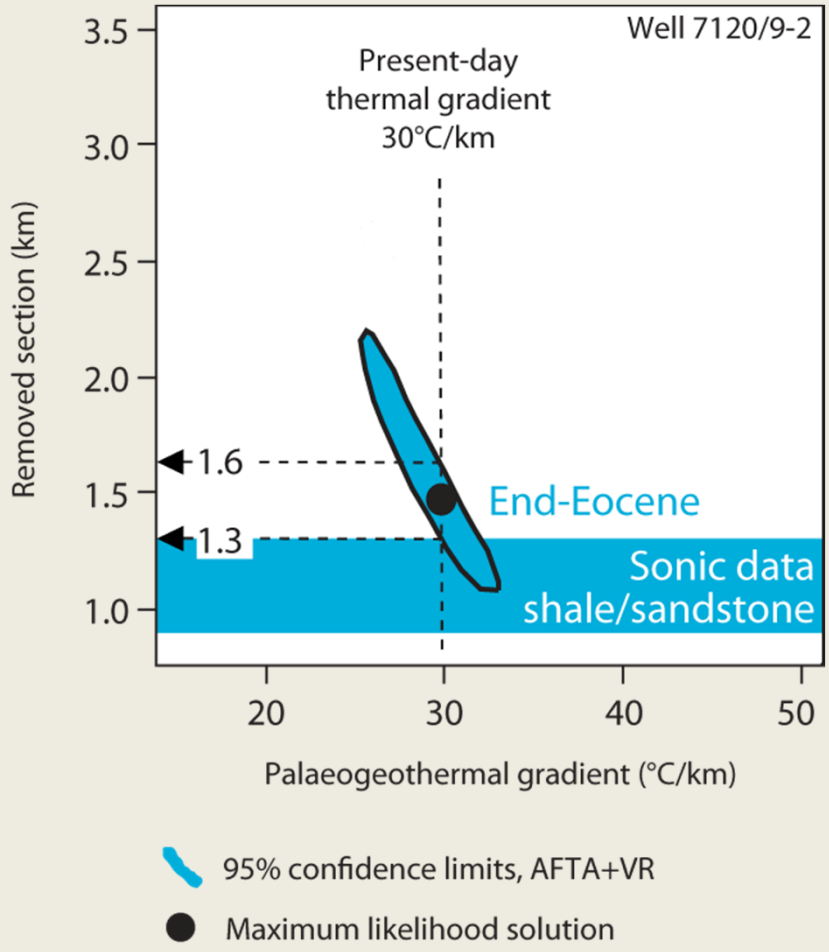
Green & Duddy 2010

Heating due to deeper burial



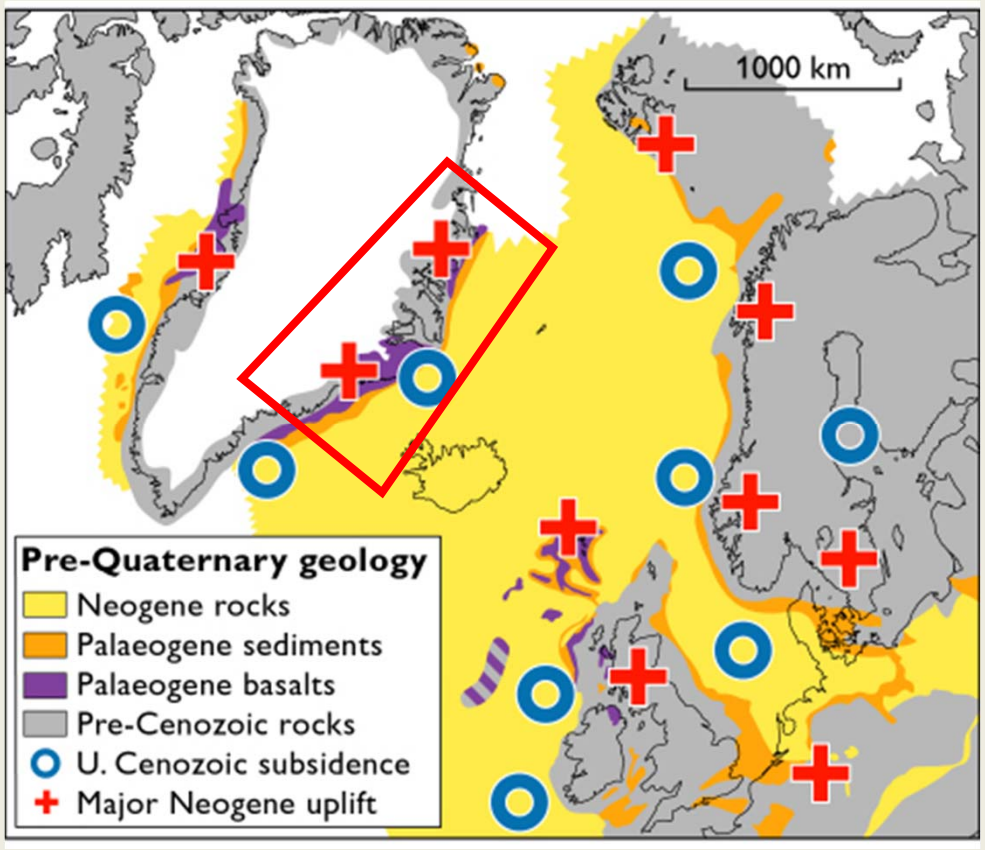
After Green & Duddy 2010

Removed section vs geothermal gradients
15° climate cooling since Eocene



After Green & Duddy 2010

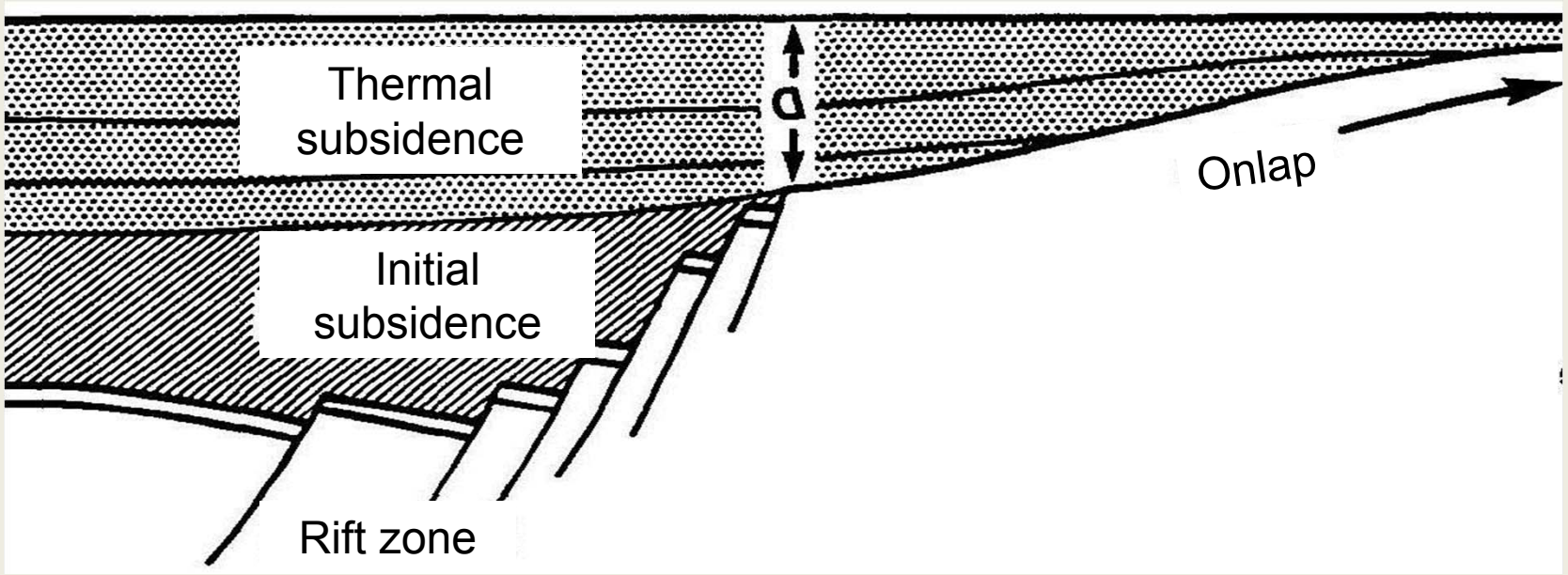
Case D: East Greenland – a classic example of an EPCM formed long after rifting and breakup



III: Conceptual model for post-rift EPCM development

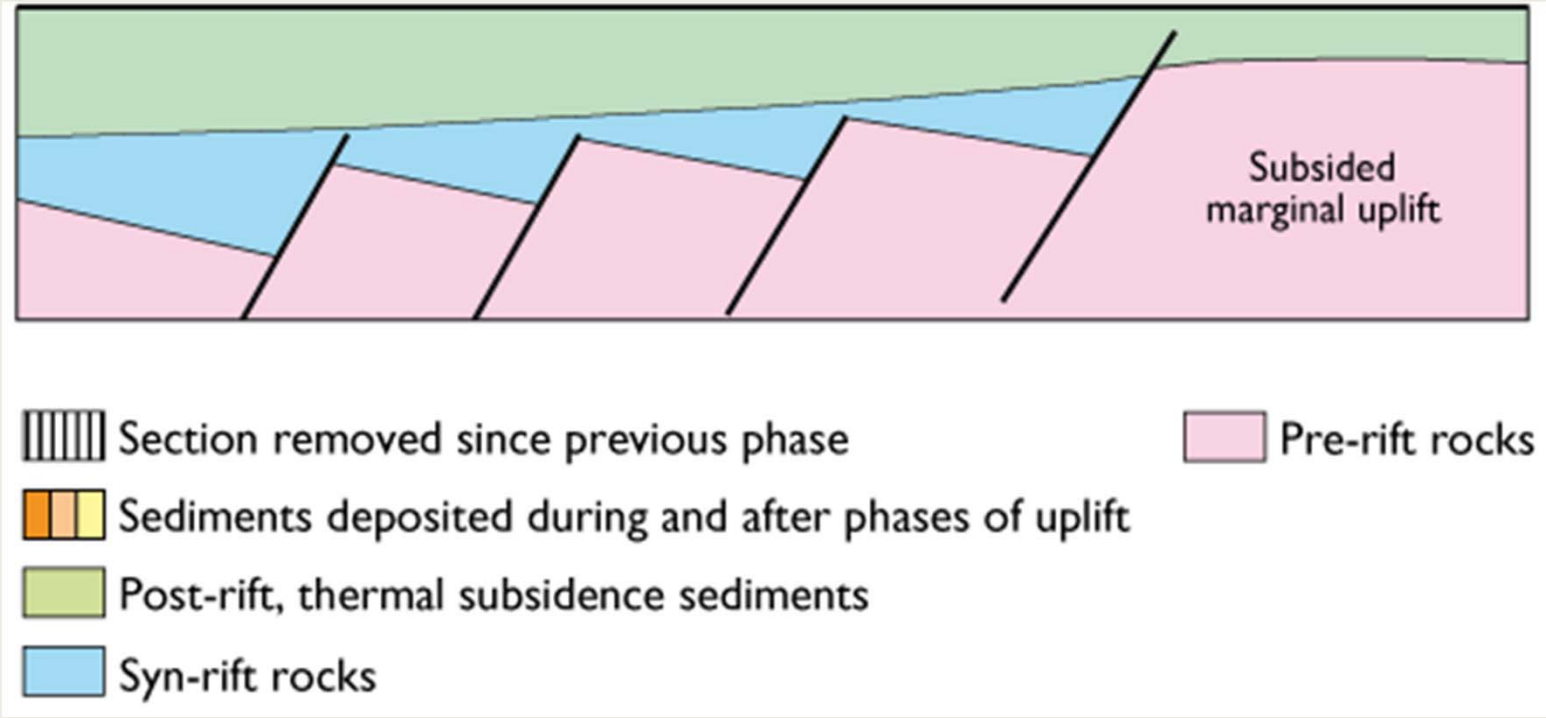
Conceptual model for post-rift EPCM development

Post-rift burial of the rift flank



White & McKenzie 1988

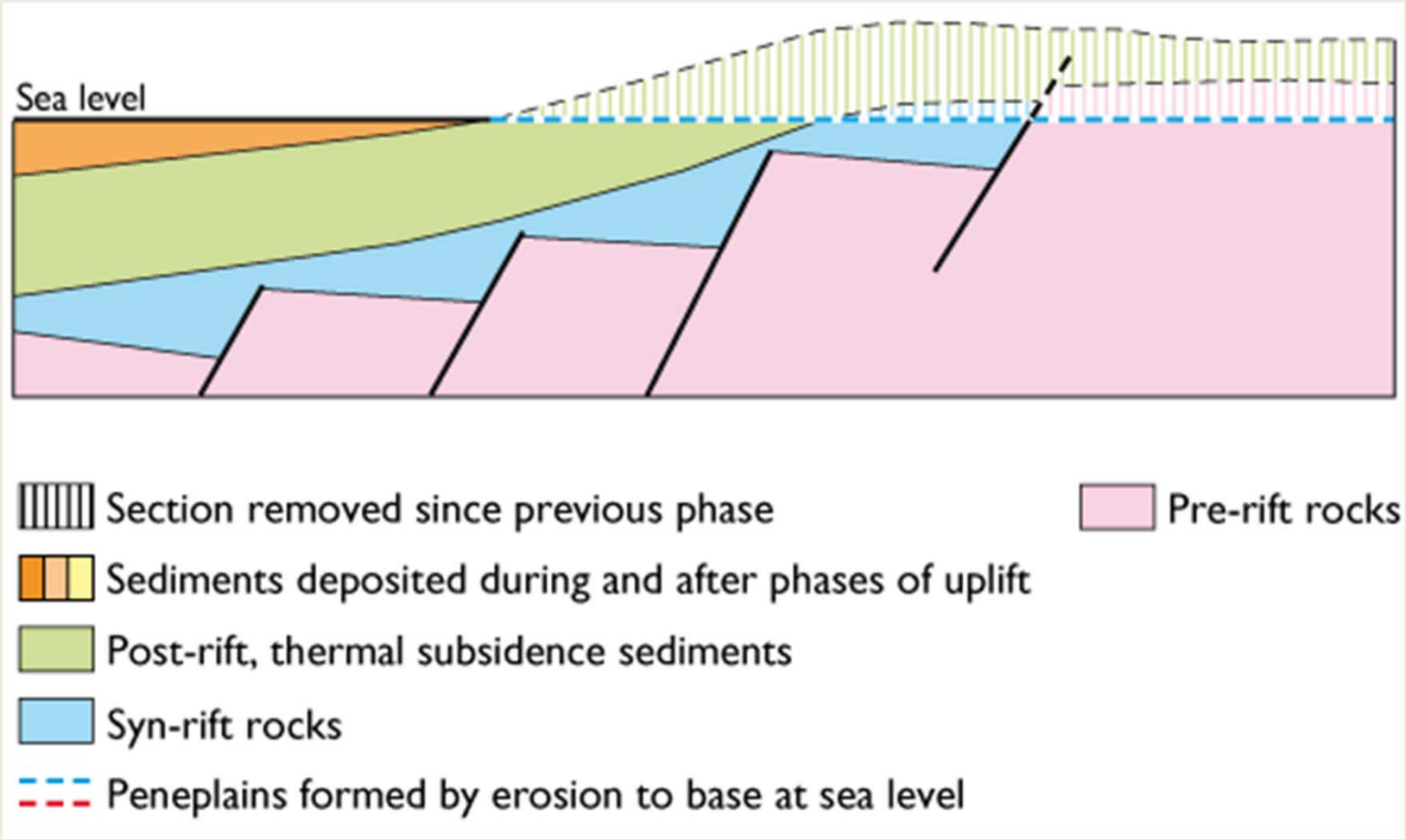
Conceptual model for post-rift EPCM development
Thermal subsidence of rift and margin



Japsen et al. 2011. *Global Planet Change*

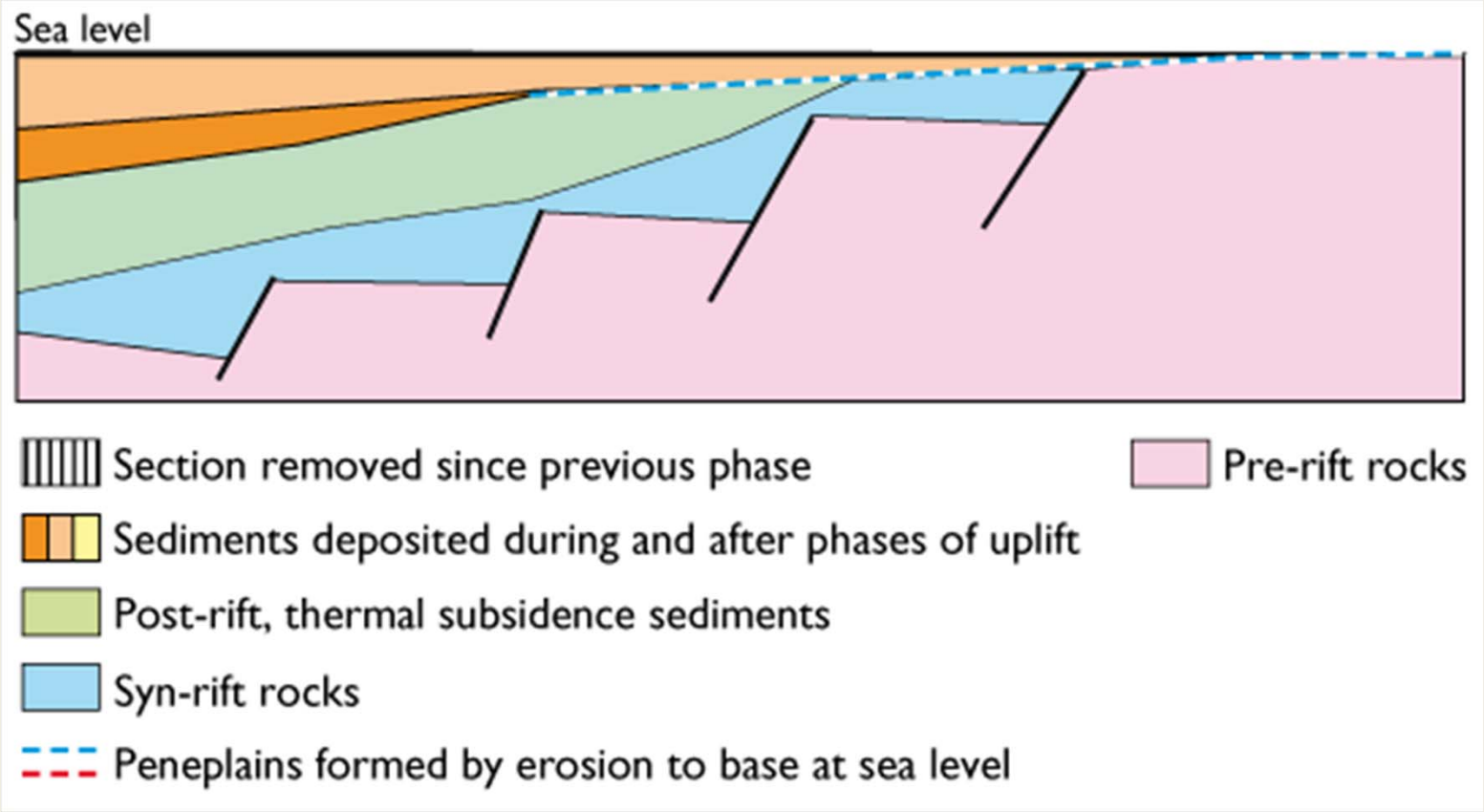
Conceptual model for post-rift EPCM development

First uplift and formation of peneplain



Japsen et al. 2011. *Global Planet Change*

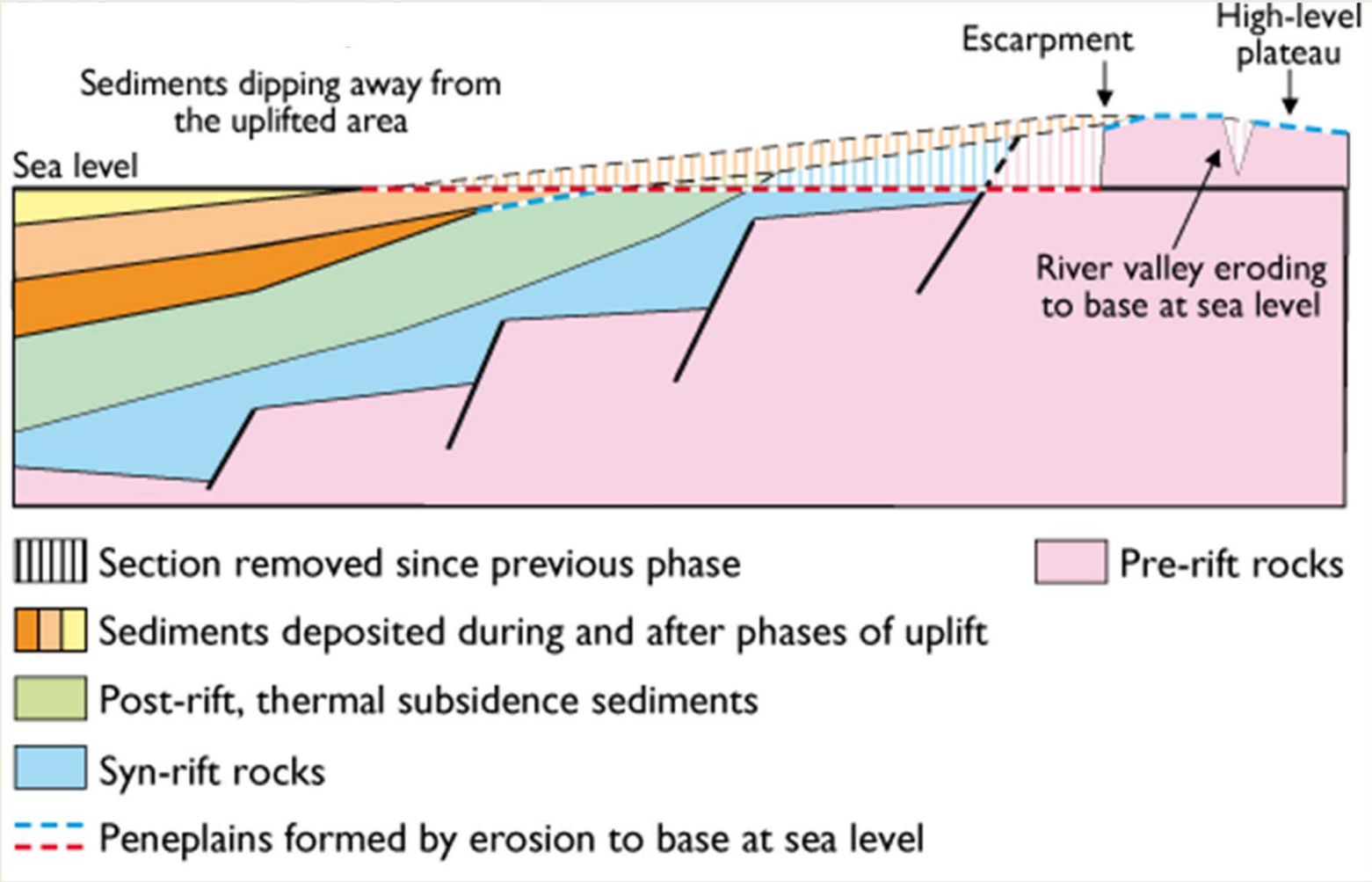
Conceptual model for post-rift EPCM development
Reburial to form low-angle unconformity



Japsen et al. 2011. *Global Planet Change*

Conceptual model for post-rift EPCM development

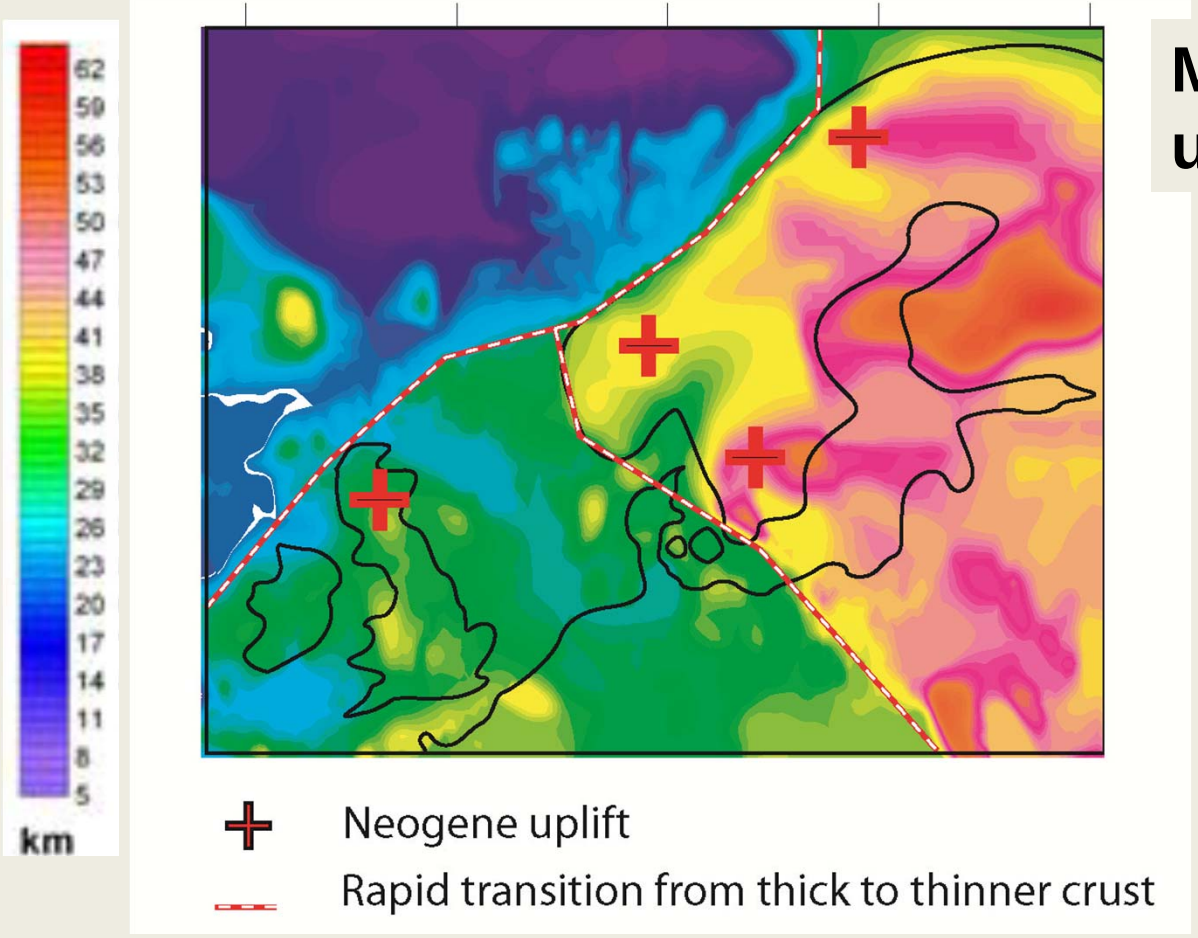
Second uplift to form high-level plateau



Japsen et al. 2011. *Global Planet Change*

IV: So what do we know that can tell us about the driving forces?

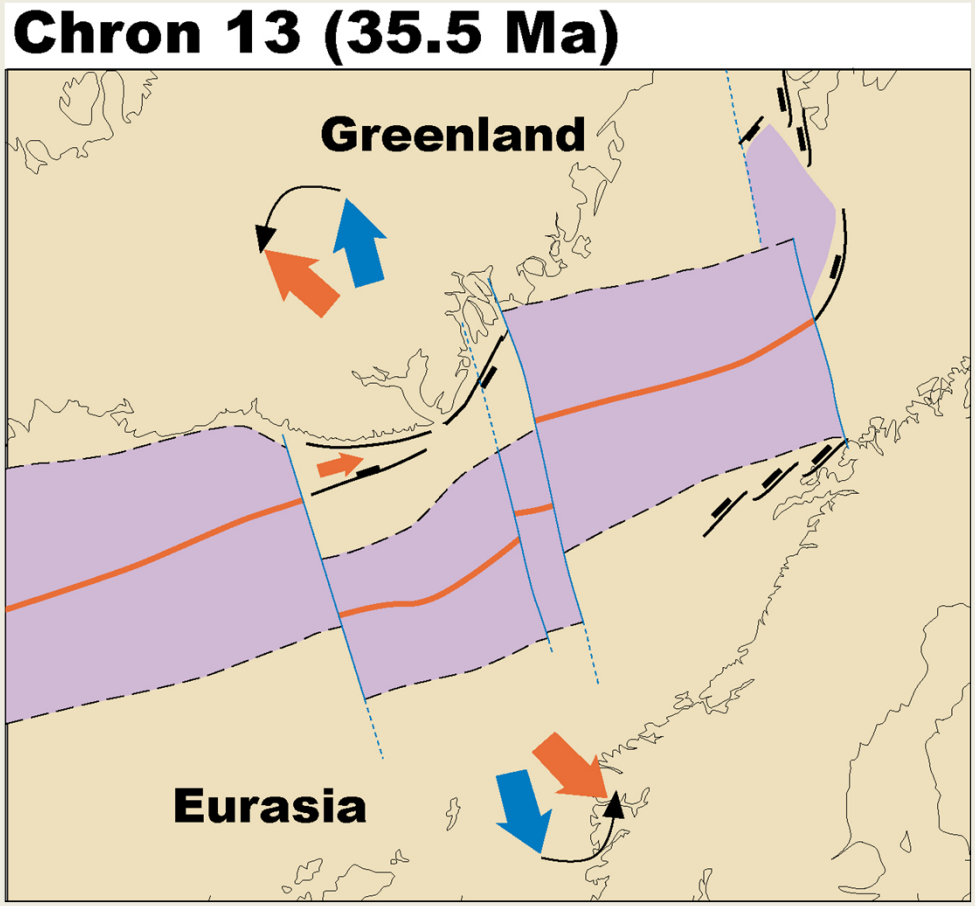
1. EPCMs are located along edges of cratons



Moho depth under NW Europe

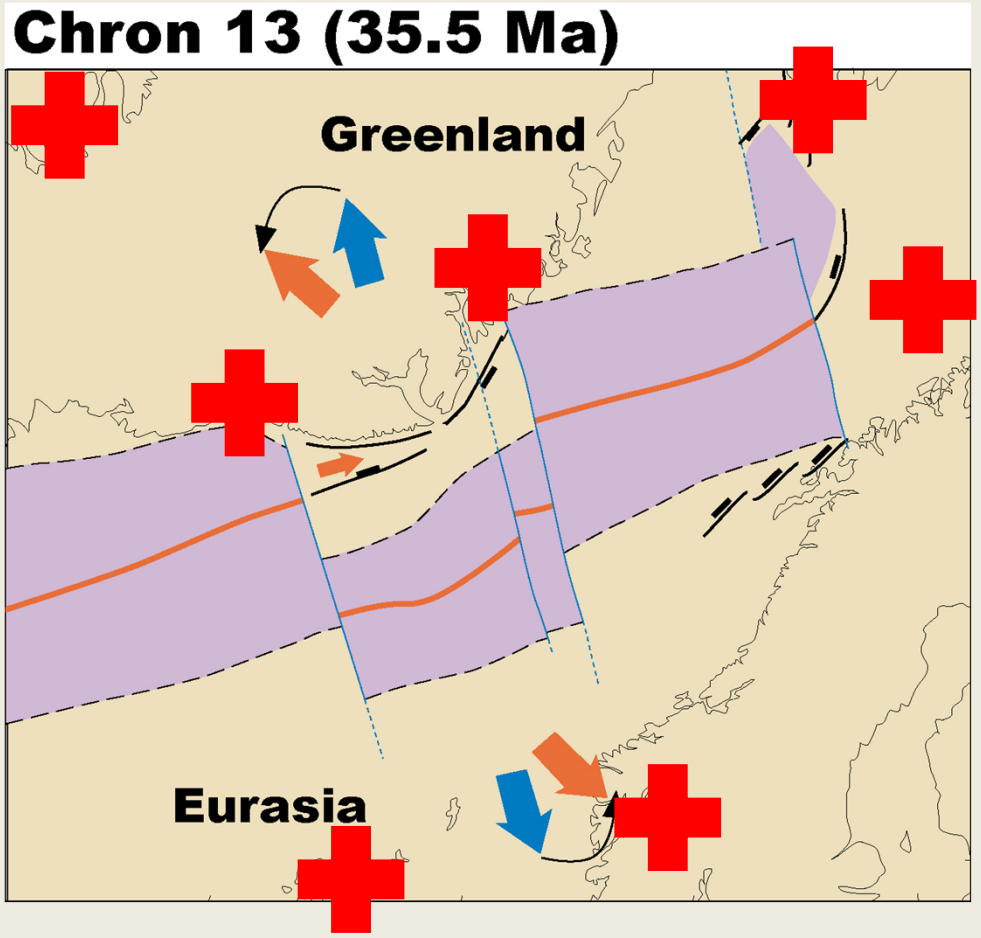
After Tesauro et al. 2008

2. Uplift events along EPCMs correlate with changes in plate motion



After Lundin & Doré 2002

2. Uplift events along EPCMs correlate with changes in plate motion

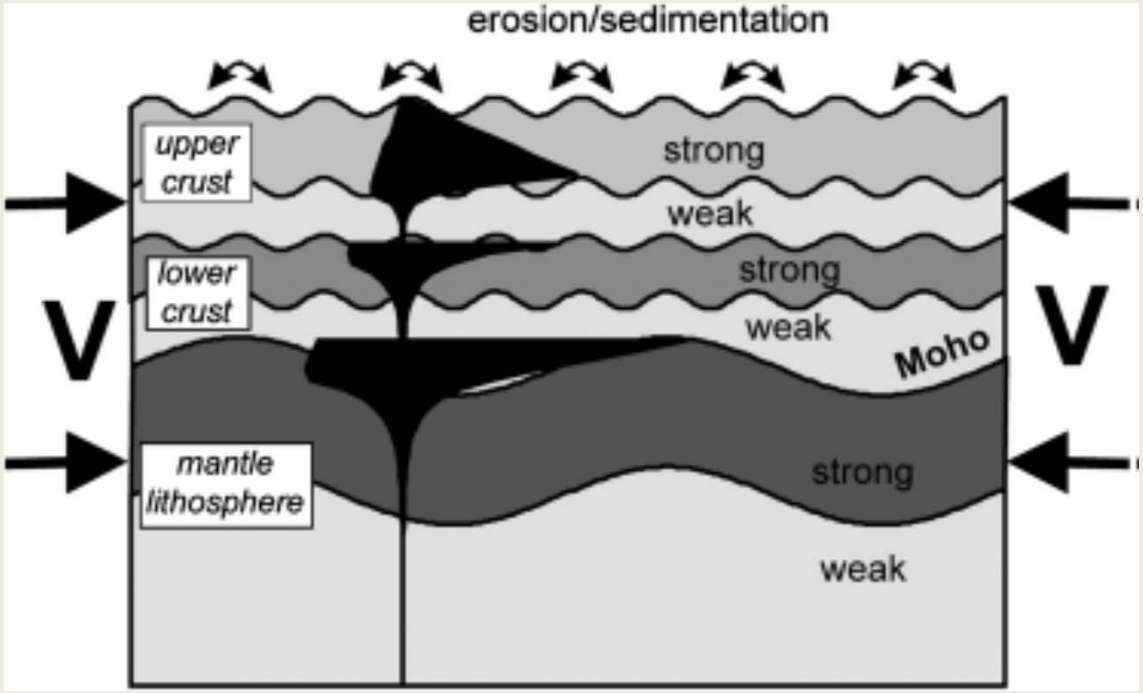


End-Eocene
uplift and exhumation

Green & Duddy 2010
and ongoing studies

After Lundin & Doré 2002

3. Compression may cause lithospheric folding



Burov & Cloetingh, 2010

EPCMs are not rift shoulders

1) EPCMs are not permanent highs and are not related to the rifting process, contrary to widely accepted theories
   -> Variations in post-rift palaeo-geography

2) We propose that EPCMs are expressions of episodic, compression-induced uplift following post-rift burial
   -> Ups and downs in post-rift burial history

3) Initial, post-rift uplift and erosion forms a peneplain; subsequent uplift raises the plateau to its present elevation
   -> Equivalent erosional unconformities offshore

Elevated, passive continental margins are only tops of icebergs: Onshore expressions of episodic, post-rift burial and exhumation