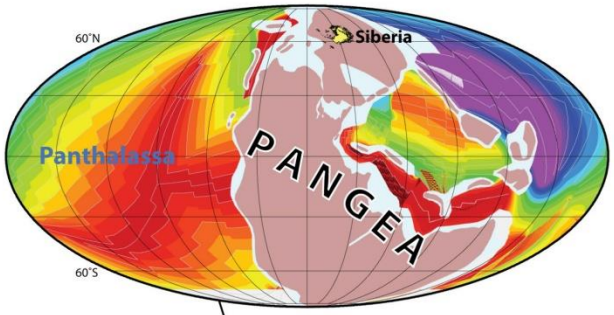
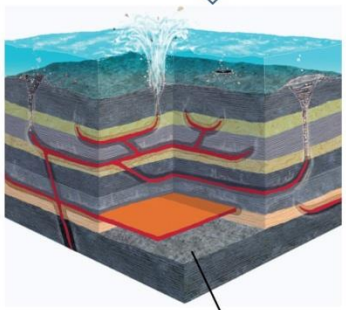
# CEED VISION: Develop an Earth model that explains how mantle processes drive plate tectonics and trigger massive volcanism and associated environmental and climate changes throughout Earth history

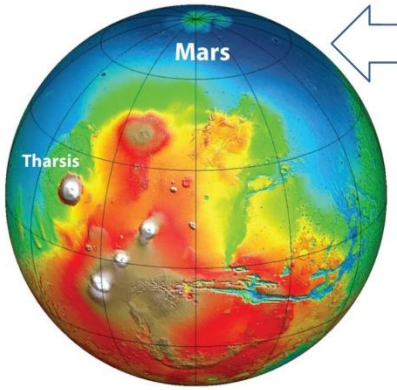
**Dynamic Earth**: Build a consistent global plate tectonic model for the past 1100 Ma

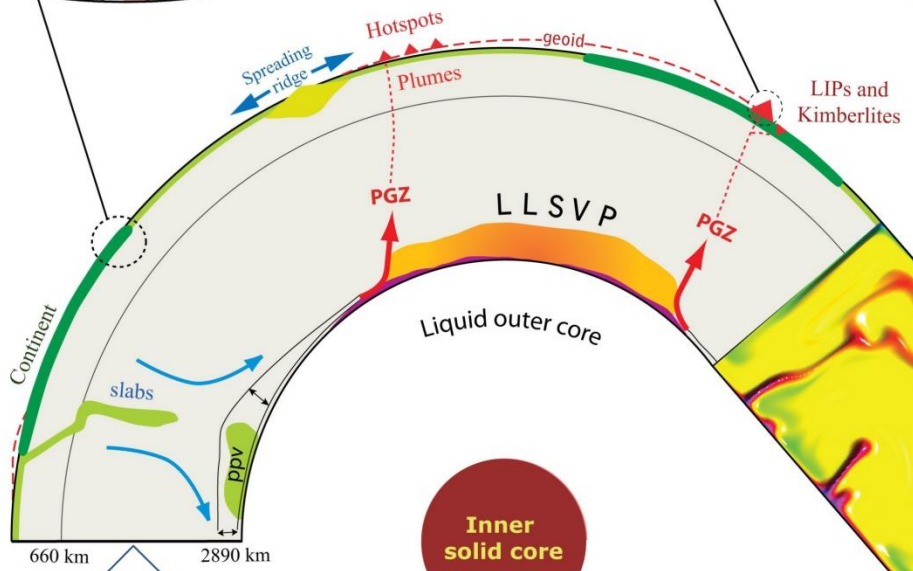
**Earth Crises**: Understand the role of voluminous volcanism on global climate changes and extinctions

**Earth and Beyond:** Understand similarities and differences between the Earth and the other terrestrial planets






**Virtual Earth**: Develop tools and databases that integrate plate reconstructions with geodynamic and climate modeling

**Deep Earth**: Understand the link between the surface and the deep mantle

**CEED VISION:** Develop an Earth model that explains how mantle processes drive plate tectonics and trigger massive volcanism and associated environmental and climate changes throughout Earth history

CEED
The Centre for Earth Evolution and Dynamics

= Synergies among a variety of science disciplines

Geology
Geophysics
Physics & Mineral Physics
Mathematics
Chemistry
Palaeoclimatology
Palaeontology
Tectonics
Palaeomagnetism
Geodynamics
Seismology
Computational and Atmospheric science

**CEED VISION:** Develop an Earth model that explains how mantle processes drive plate tectonics and trigger massive volcanism and associated environmental and climate changes throughout Earth history

CEED
The Centre for Earth Evolution and Dynamics

## Studies the Earth

- From core to atmosphere
- From local to global
- From the present to geological past (1 billion year)

**CEED VISION:** Develop an Earth model that explains how mantle processes drive plate tectonics and trigger massive volcanism and associated environmental and climate changes throughout Earth history

CEED
The Centre for Earth Evolution and Dynamics

## Studies the Earth

- From core to atmosphere
- From local to global
- From the present to geological past (1 billion year)

Distance from basic to applied research can be short…

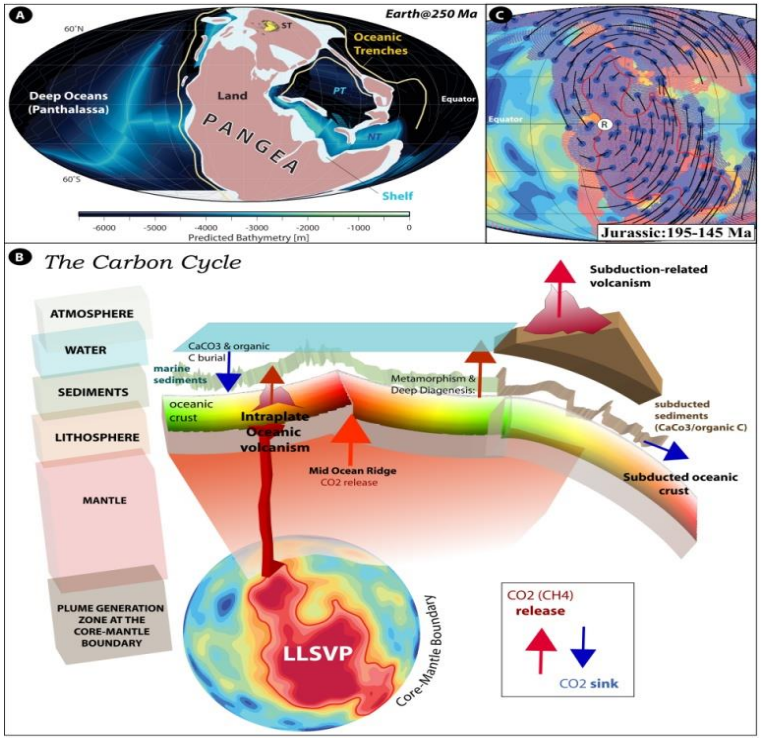
Applications of fundamental knowledge (process understanding) in integrated basin studies/petroleum exploration:

- Plate reconstructions/paleogeography (source-to-sink/provenance)
- Linking deep and shallow processes
- Sedimentary basins – formation and evolution
- Vertical motion and temperature histories
- Implications for petroleum systems
- Magmatism - effects on basins and petroleum systems

# CEED DYNAMIC EARTH
## PLATE MOTIONS AND EARTH HISTORY

Carmen Gaina

**Sub-theme 1:** Supercontinents, Palaeogeography and Biogeography
**Sub-theme 2:** Wilson Kickoff: Passive Margins and Break-up
**Sub-theme 3**: Continents adrift and oceanic basin formation, TPW & climate changes
**Sub-theme 4:** Terminal Wilson: Subduction and Collision



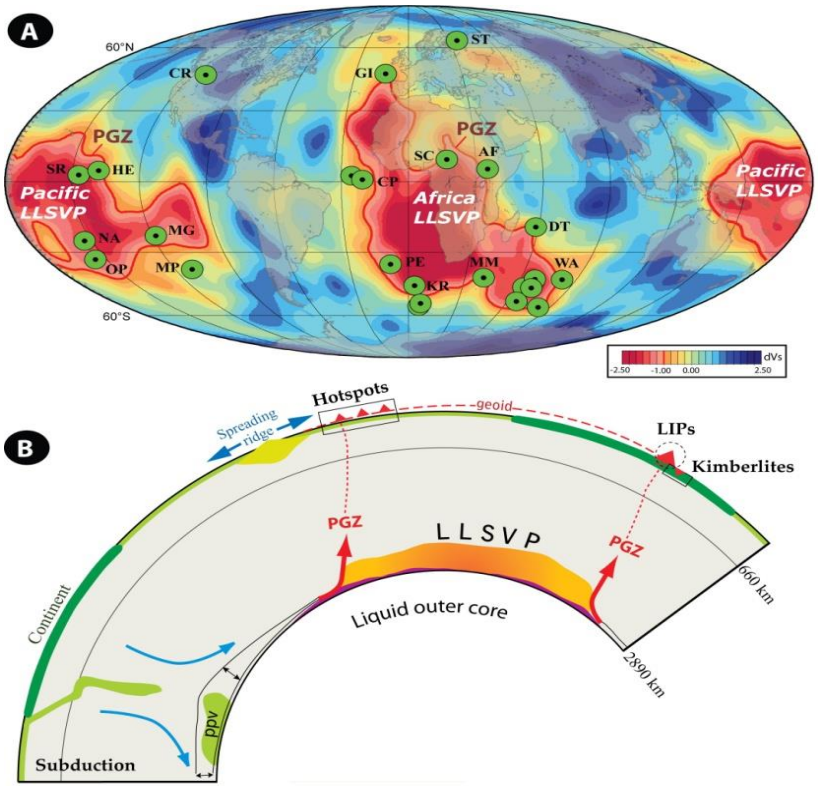

**Mission:** To explore the link between the lithosphere and the convecting mantle and quantify how palaeogeography and TPW have influenced the climate system.

**Main Hypothesis:** Motion of tectonic plates is closely related to mantle dynamics and the mantle-lithospheric dynamics drives major changes in Earth's life.

# CEED DEEP EARTH
## MATERIALS, STRUCTURE AND DYNAMICS

Reidar Trønnes

**Sub-theme 1:** Absolute Reference Frames and links to the Deep Mantle
**Sub-theme 2:** Composition, Mineral Physics and Origin of the LLSVPs
**Sub-theme 3:** Plumes from the Margins of the LLSVPs: Toward a Geodynamic Model



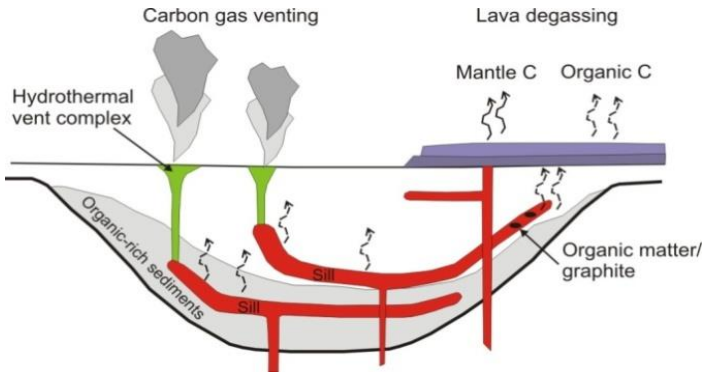

**Mission:** To develop a model that links surface volcanism with processes in the deep mantle

**Main Hypothesis:** Mantle plumes from the edges of the stable LLSVPs explain the surface distribution of most hotspots, LIPs and kimberlites.

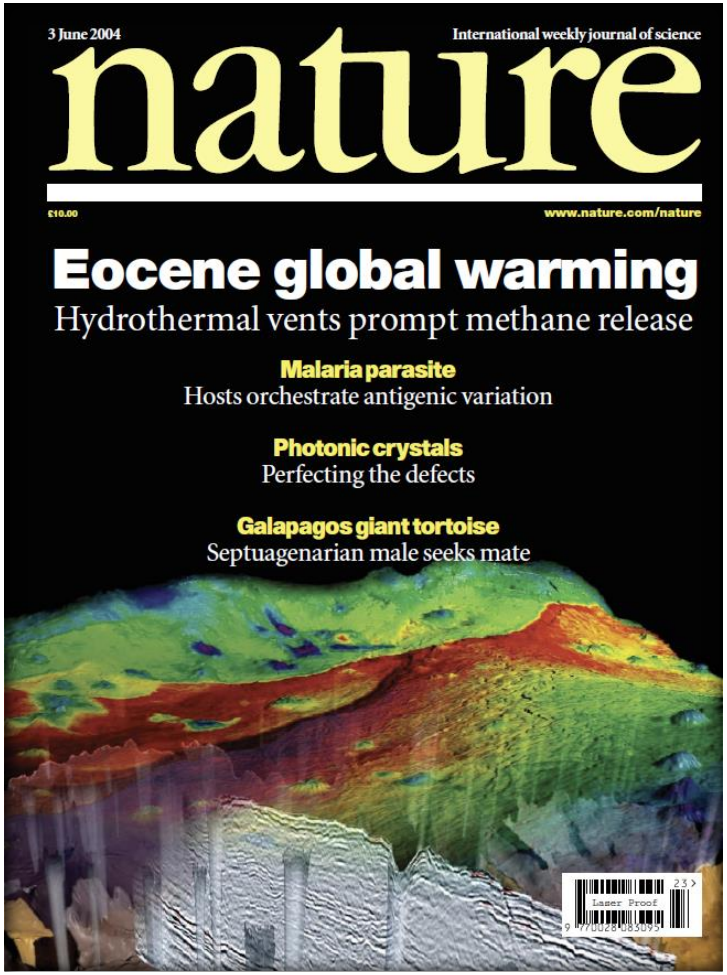
# CEED EARTH CRISES
## LIPS, MASS EXTINCTIONS AND ENVIRONMENTAL CHANGES

Henrik Svensen

**Sub-theme 1:** Large Igneous Provinces and Global Warming
**Sub-theme 2:** Emplacement Environment and Killer Mechanisms
**Sub-theme 3:** Geochemical Cycles and Paleoenviroment




CROSS-SECTION THROUGH A LIP VOLCANIC BASIN.
Different types of solid Earth degassing are shown.




**Mission:** To understand the role of voluminous intrusive and extrusive volcanism on rapid global climate change and mass extinction in Earth history.

**Main Hypothesis:** LIPs have caused most of the mass extinctions and major climate changes of Phanerozoic times.

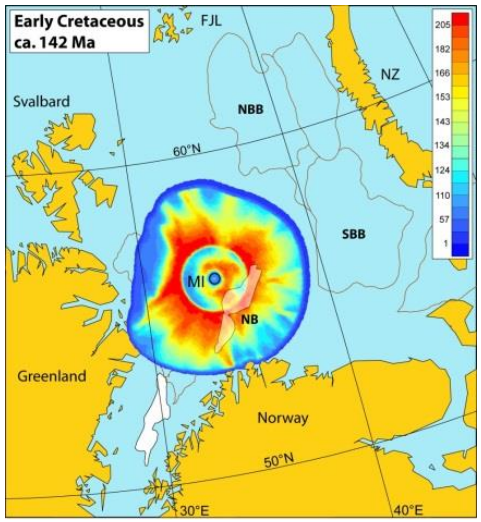
CEED EARTH AND BEYOND
COMPARATIVE PLANETOLOGY

Stephanie C. Werner

**Sub-theme 1:** Planetary time-scales, Surface ages, Impact cratering and Cratering Statistics
**Sub-theme 2:** Crustal Processes and Planetary Evolution

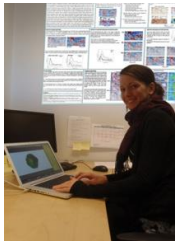
**Mission:** To understand similarities and differences between the Earth and the other terrestrial planets

**Main hypothesis:** The dynamics of Earth and planets can be understood within the same framework, but with different parameters.



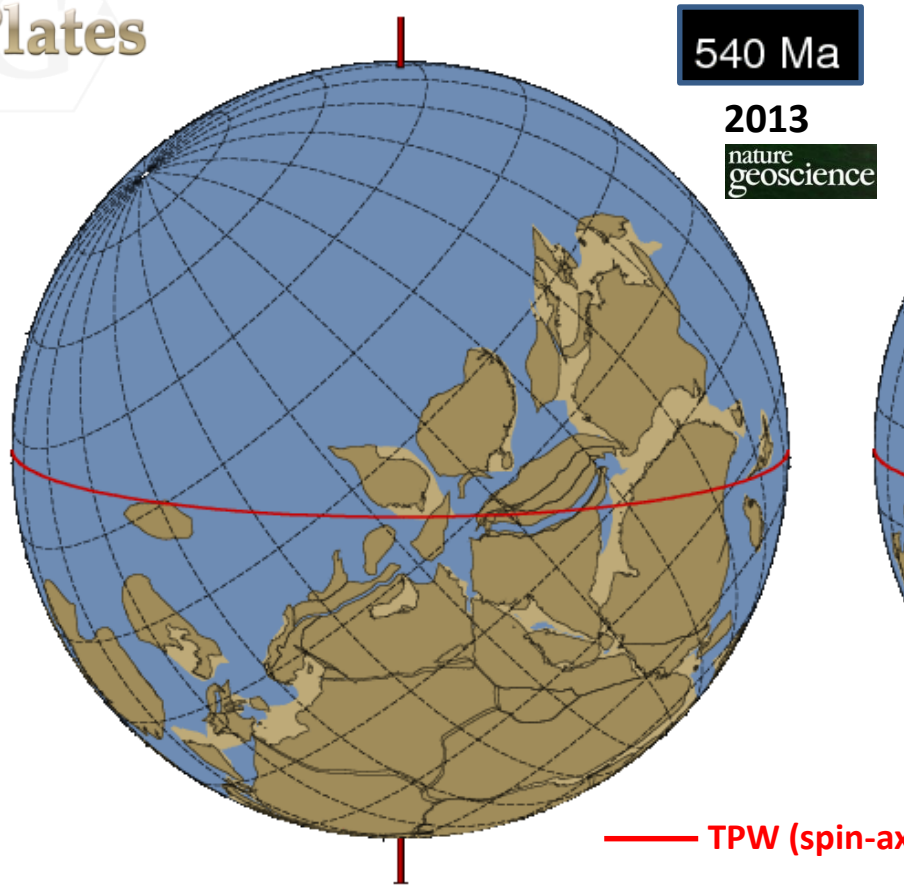

# CEED EARTH MODELING
## NUMERICAL MODELS OF EARTH DYNAMICS

Abigail Bull-Aller

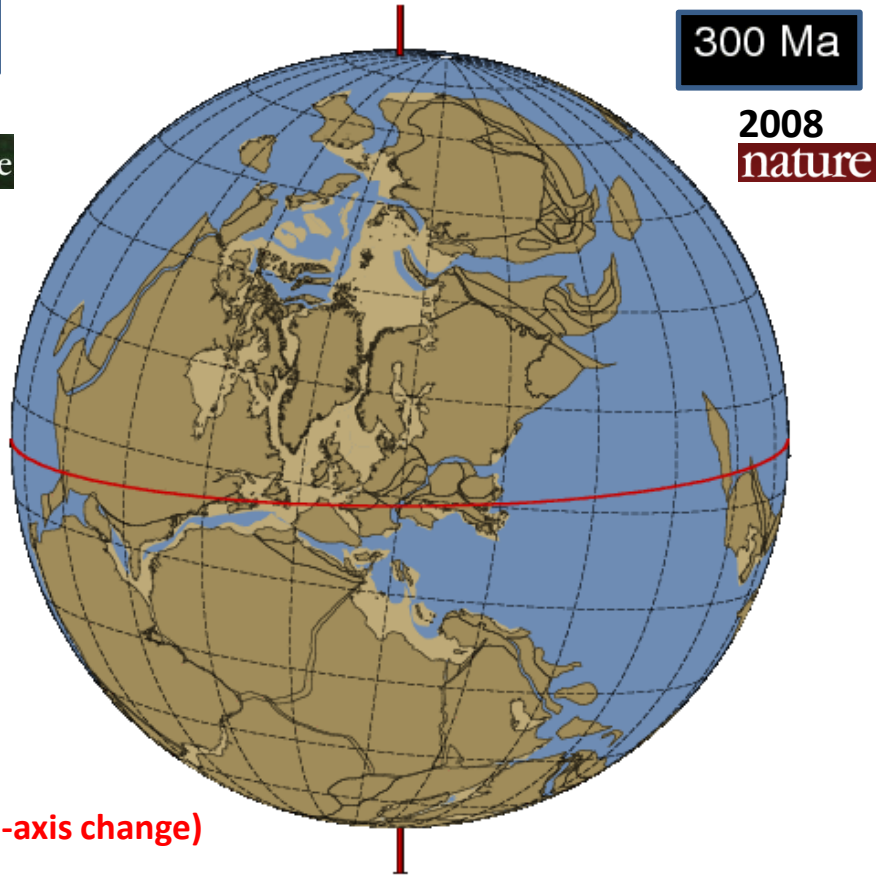


**Sub-theme 1:** Integrating Plate Reconstructions with Numerical Models (GPlates)
**Sub-theme 2:** Novel Numerical Techniques for problems in Geodynamics
**Sub-theme 3:** Massively Parallel Simulations

GPlates




2013
nature geoscience




2008
nature

TPW (spin-axis change)

# CEED EARTH LABORATORY

## IVAR GIÆVER GEOMAGNETIC LABORATORY

Pavel Doubrovine

VISION: Establish a national laboratory to serve the geomagnetic community by providing free-of-charge access to state-of-the-art facilities and scientific and technical expertise

- Encourage Norwegian and foreign researchers to visit and use the laboratory infrastructure
- Explore fundamental questions at the frontiers of modern geomagnetism
- Provide the necessary tools to maintain and strengthen the University of Oslo as an internationally leading center for plate dynamics and palaeogeography
- Develop links to other science and engineering research disciplines
- Institute geomagnetism as a scientific discipline for frontier research and education at the University of Oslo and strengthen this discipline at our partner institutions.

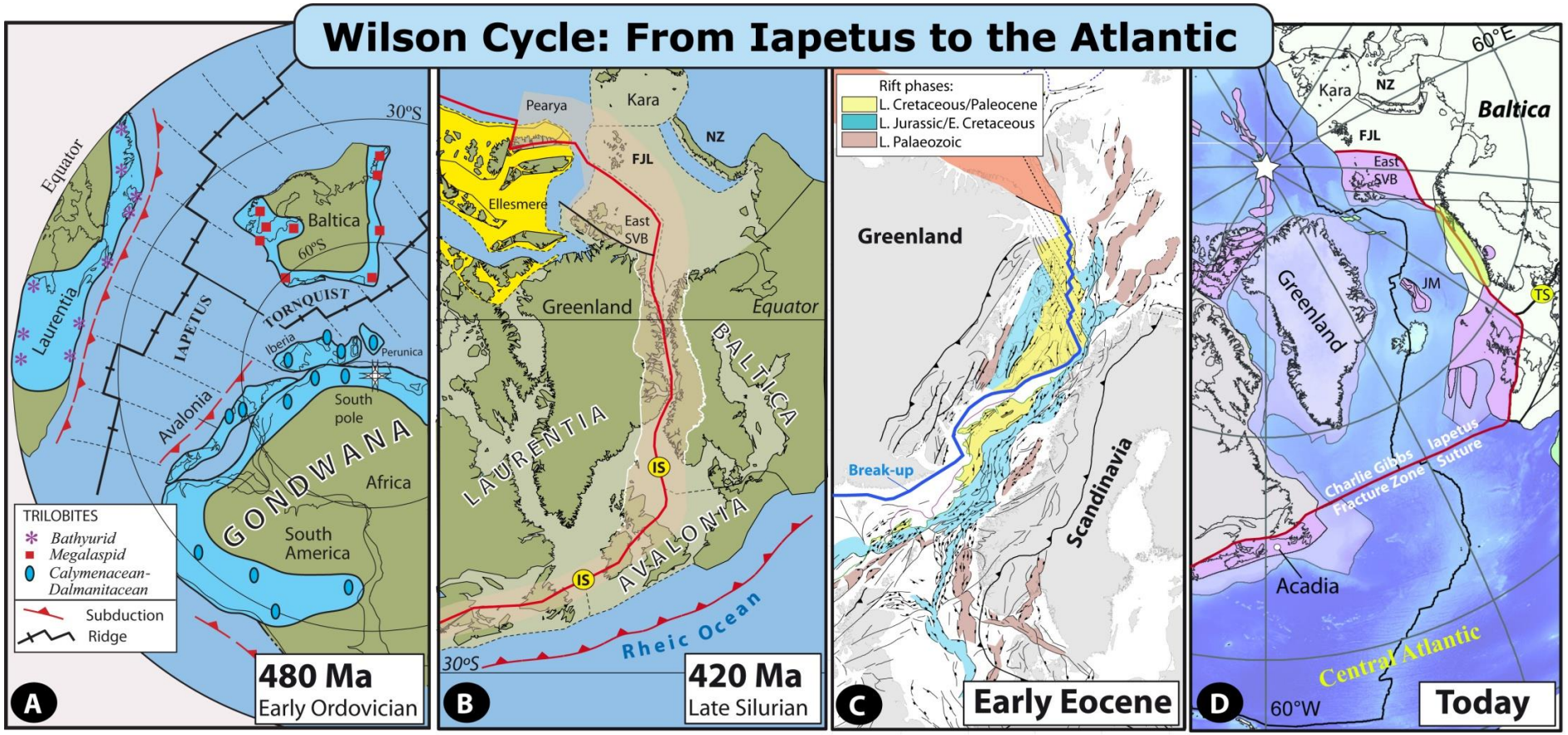
# CEED INDUSTRY

Sverre Planke

In addition to the Centre of Excellence funding from NRC we receive additional funding from the European Research Council (ERC), NRC and the petroleum industry.

The most petroleum relevant projects focus on:

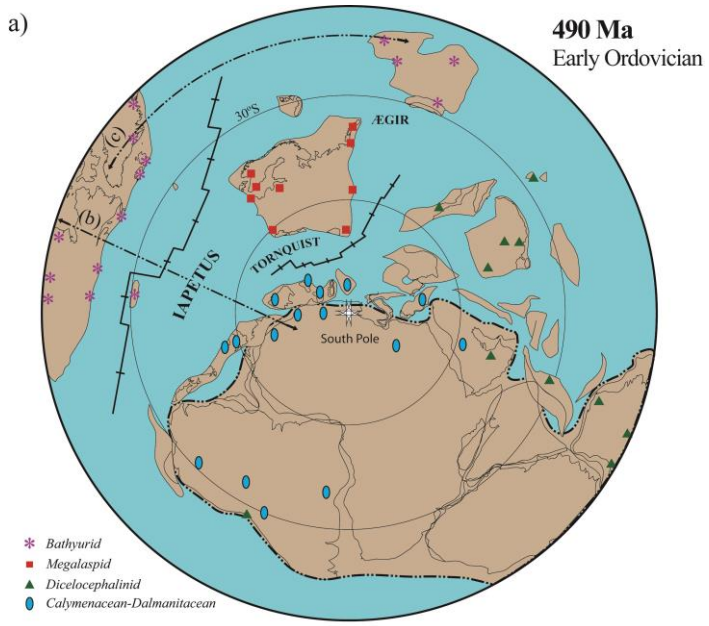
- Plate reconstructions/paleogeography (source-to-sink/provenance)
- Linking deep and shallow processes
- Sedimentary basins – formation and evolution
- Vertical motion and temperature histories
- Implications for petroleum systems
- Magmatism - effects on basins and petroleum systems

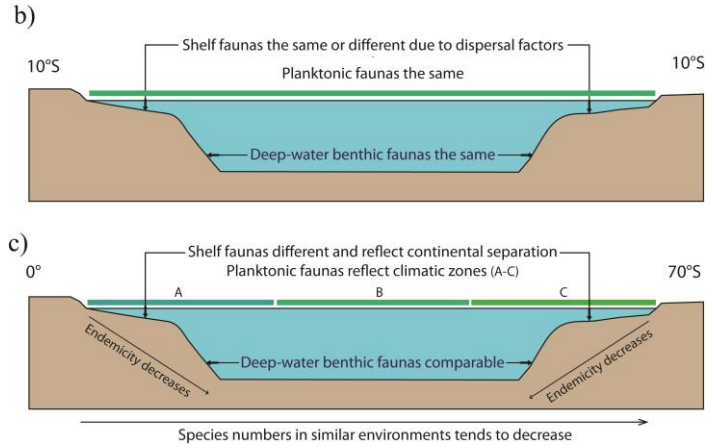


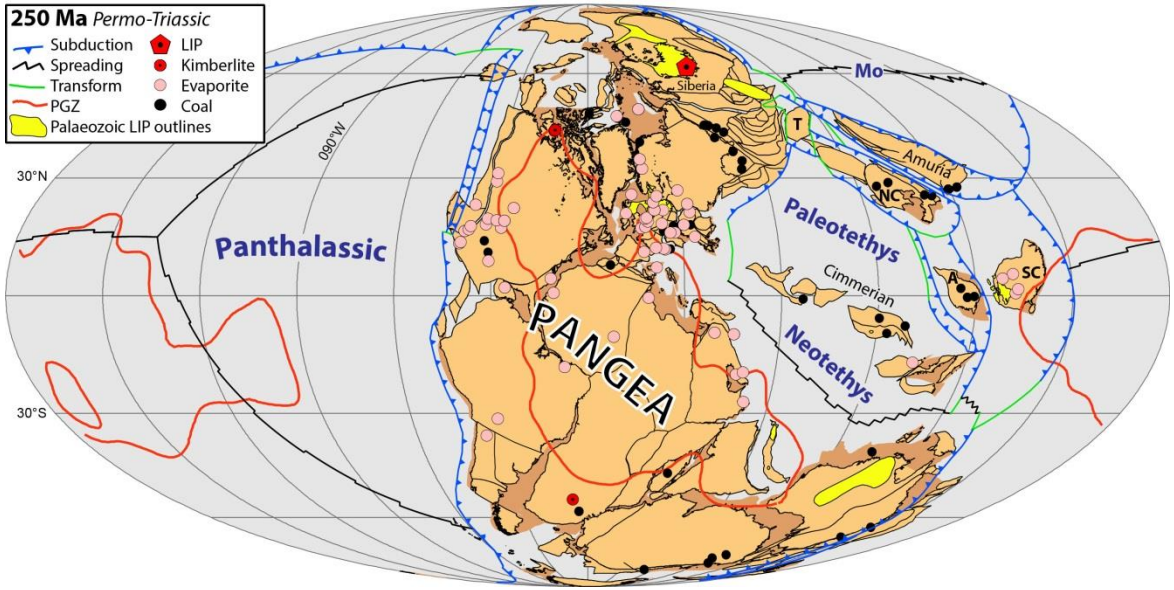

## Plate reconstructions/paleogeography

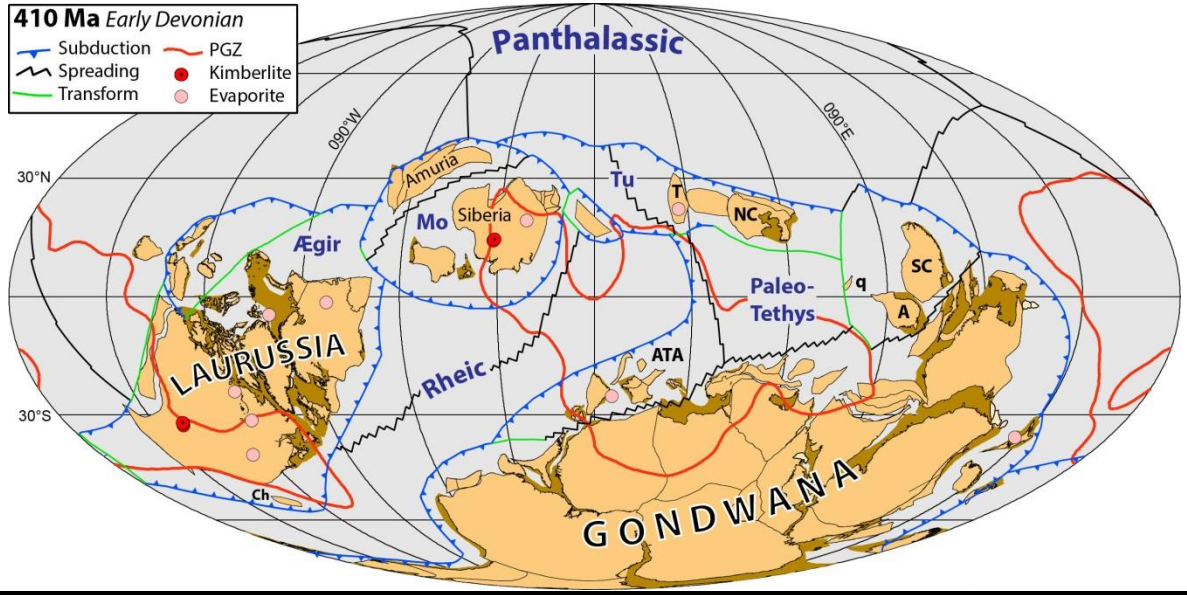
- Regional tectonic evolution
- Source-to-sink (provenance)

# Book @ Cambridge University Press: Earth History and Paleogeography *(Torsvik & Cocks 2016)*

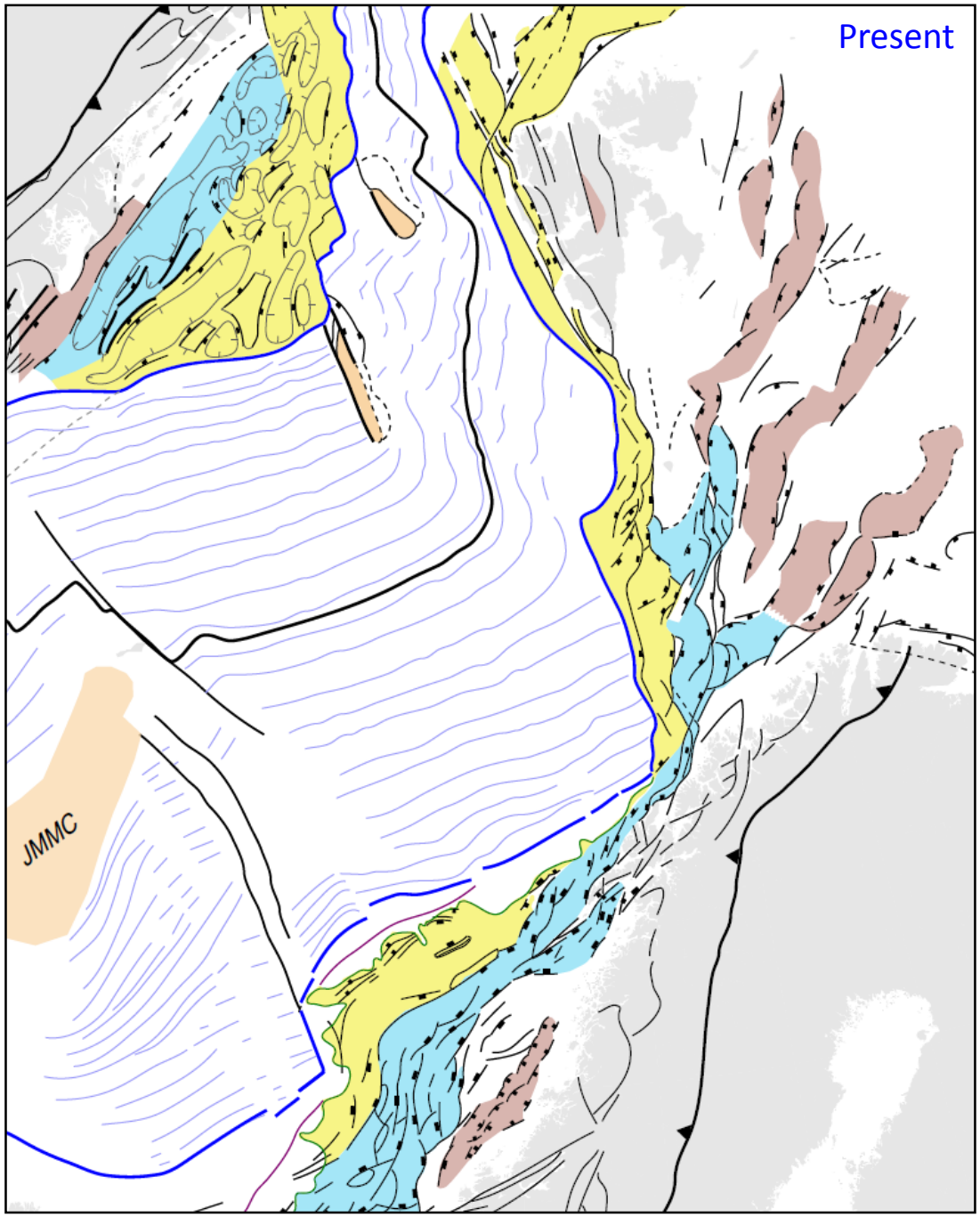


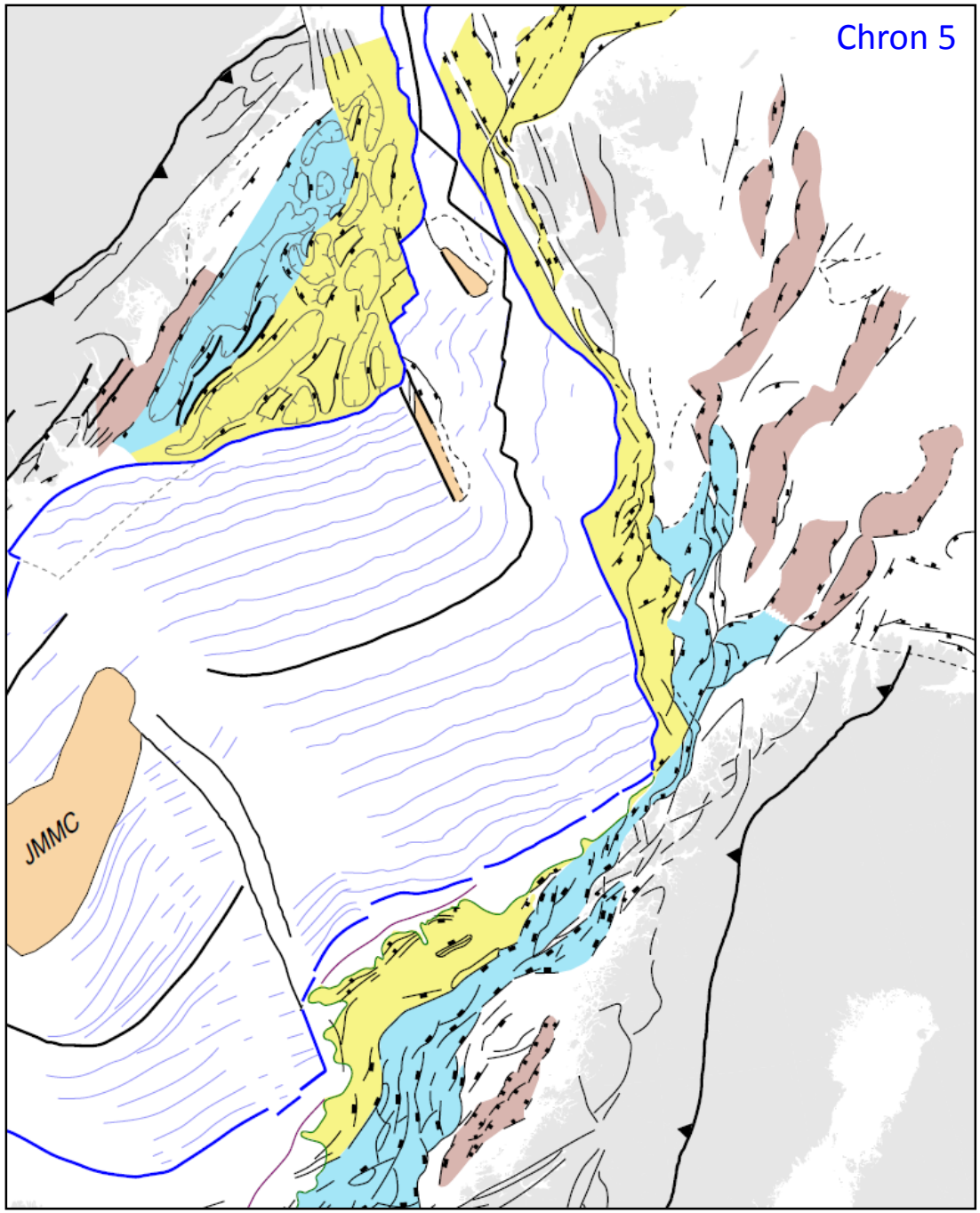



# Plate tectonic reconstructions

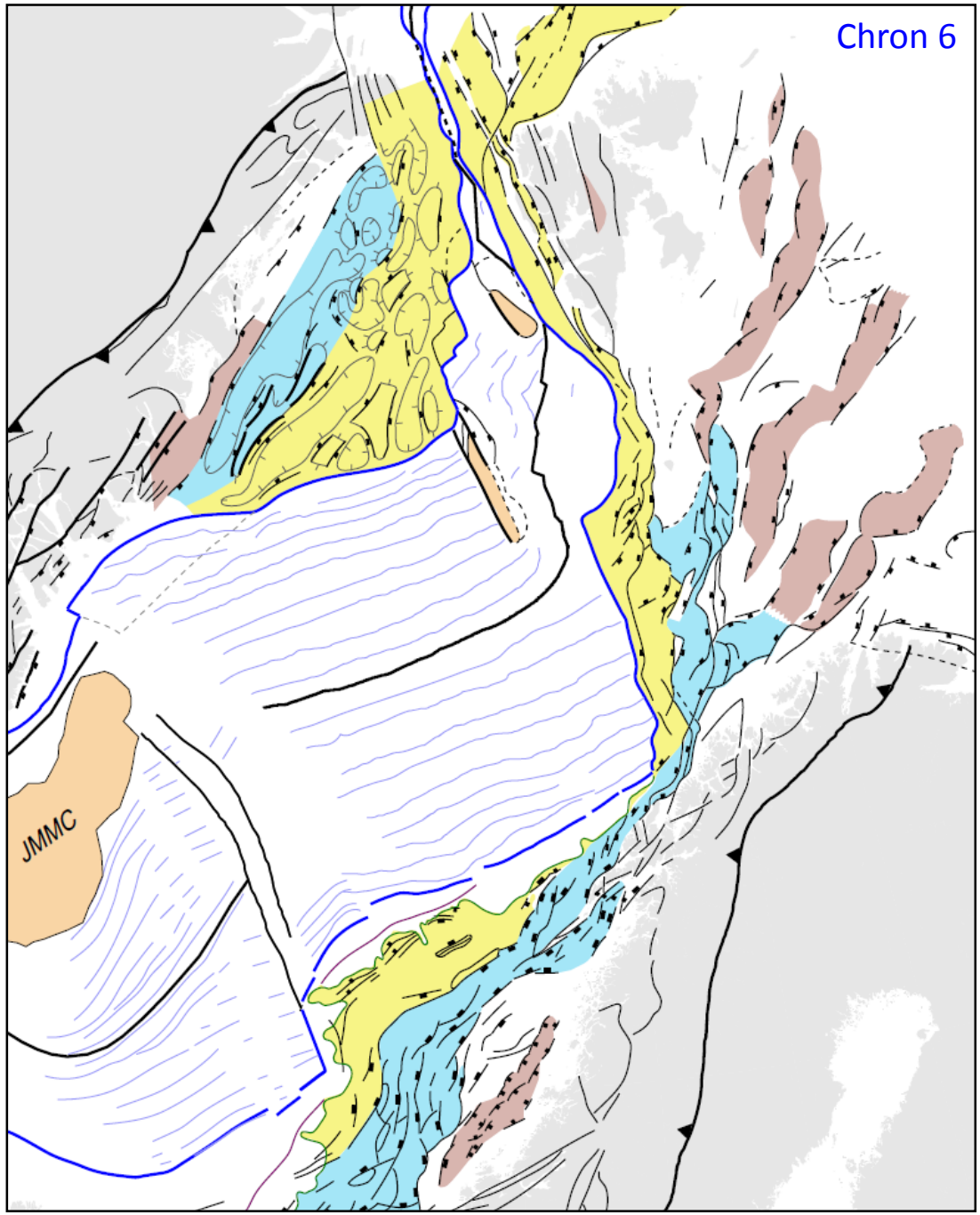



Rift phases:
- Late Cretaceous - Paleocene
- Late Jurassic - Early Cretaceous
- Late Paleozoic

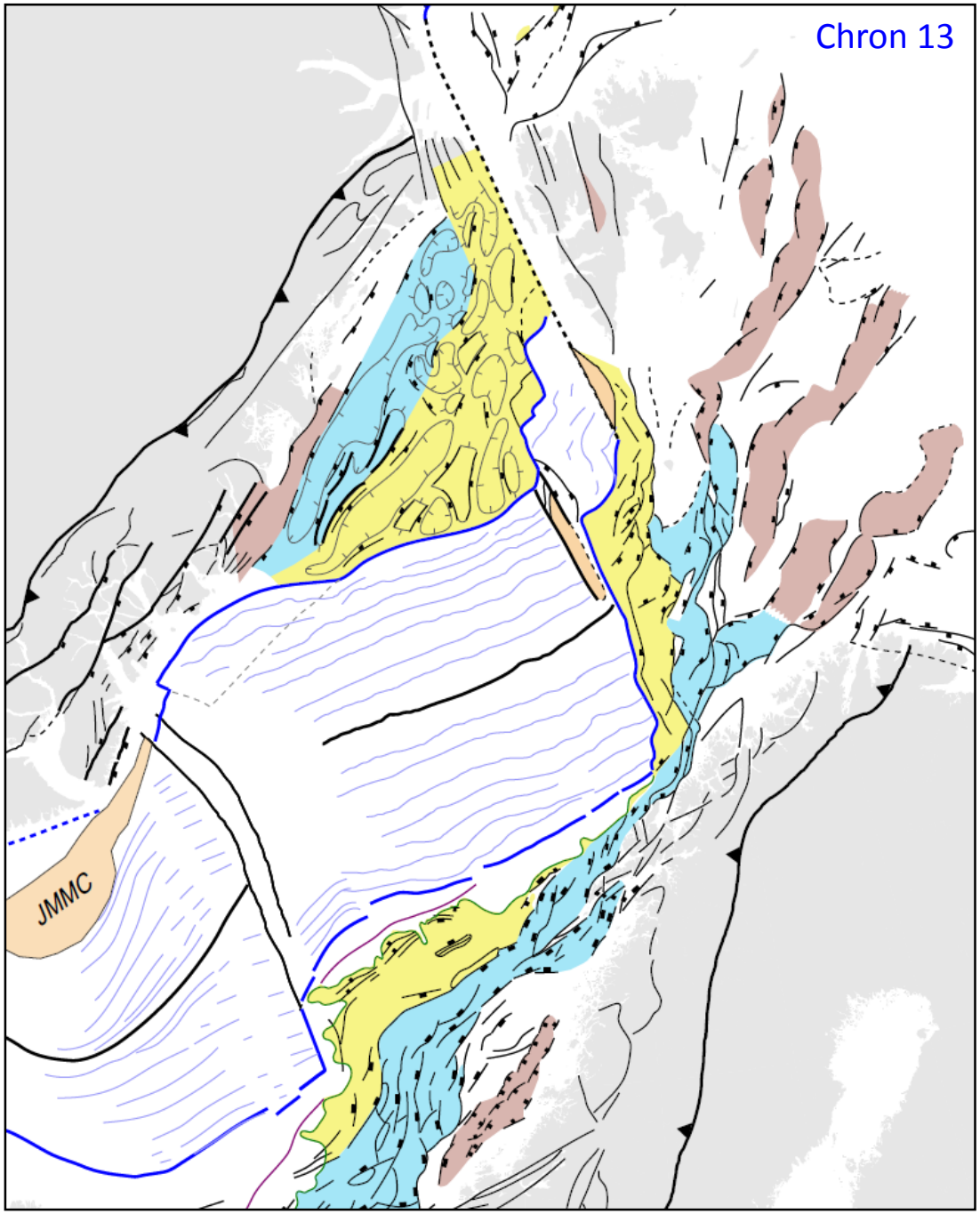
Faleide et al. (2010)



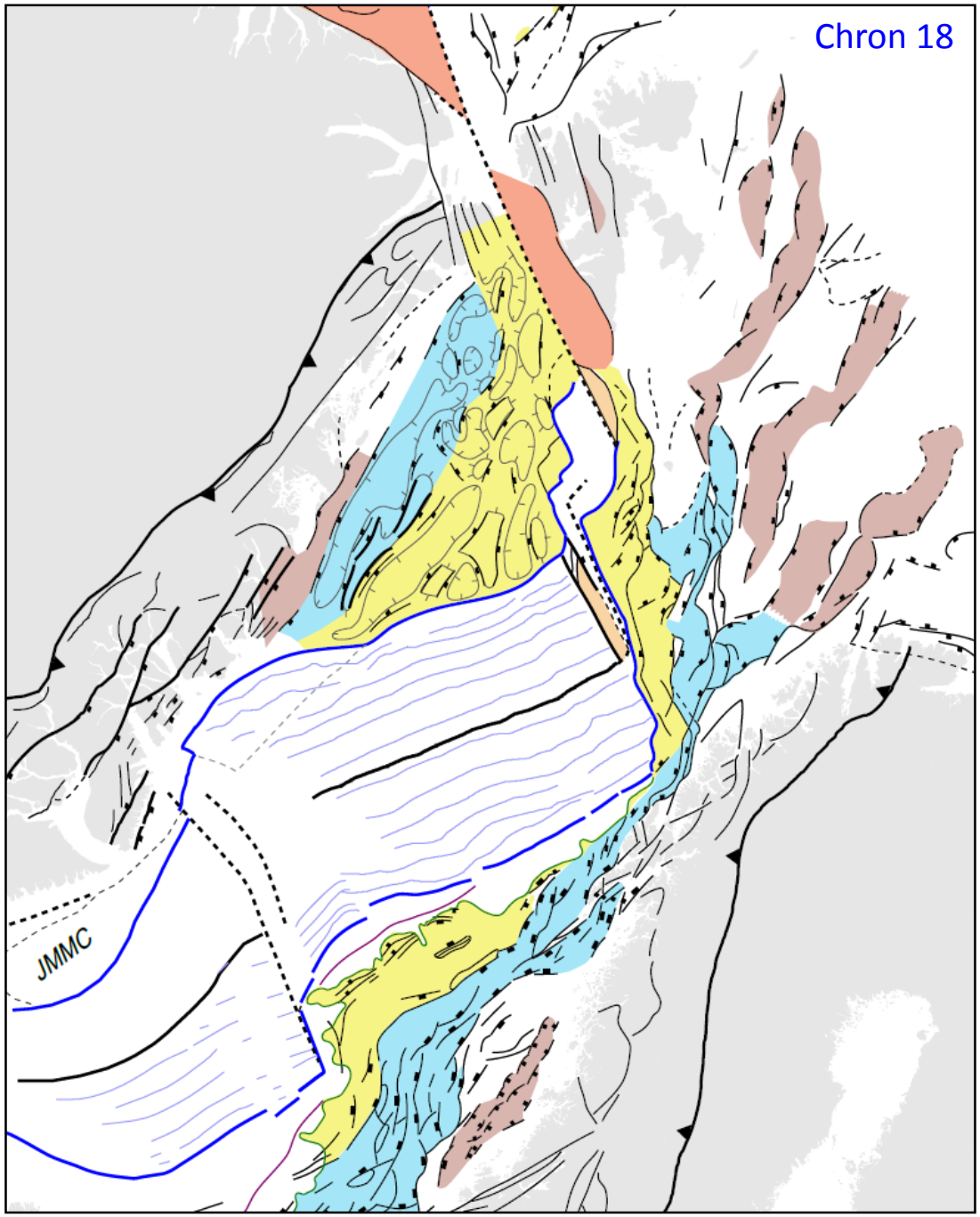

Faleide et al. (2010)




Faleide et al. (2010)



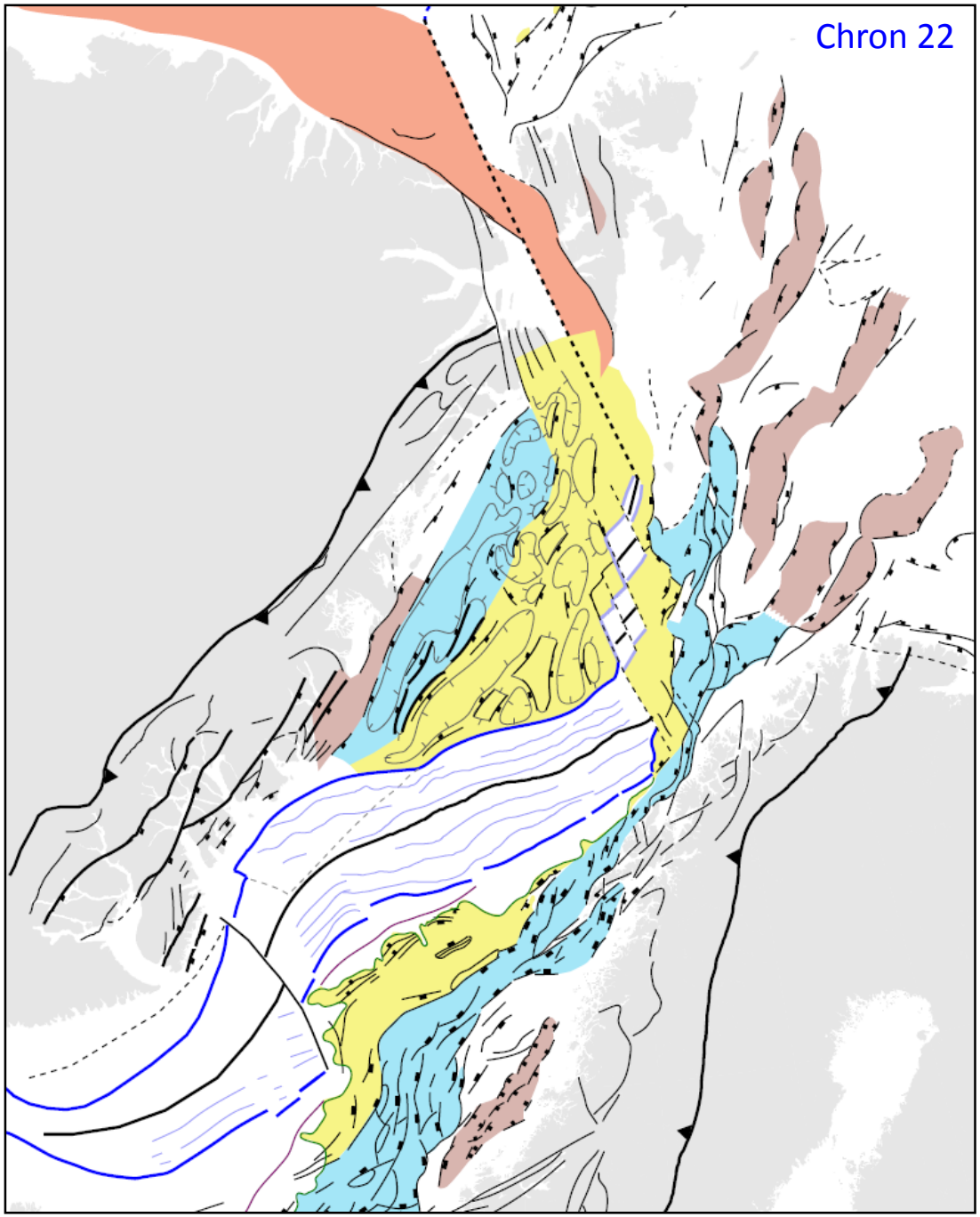

Faleide et al. (2010)



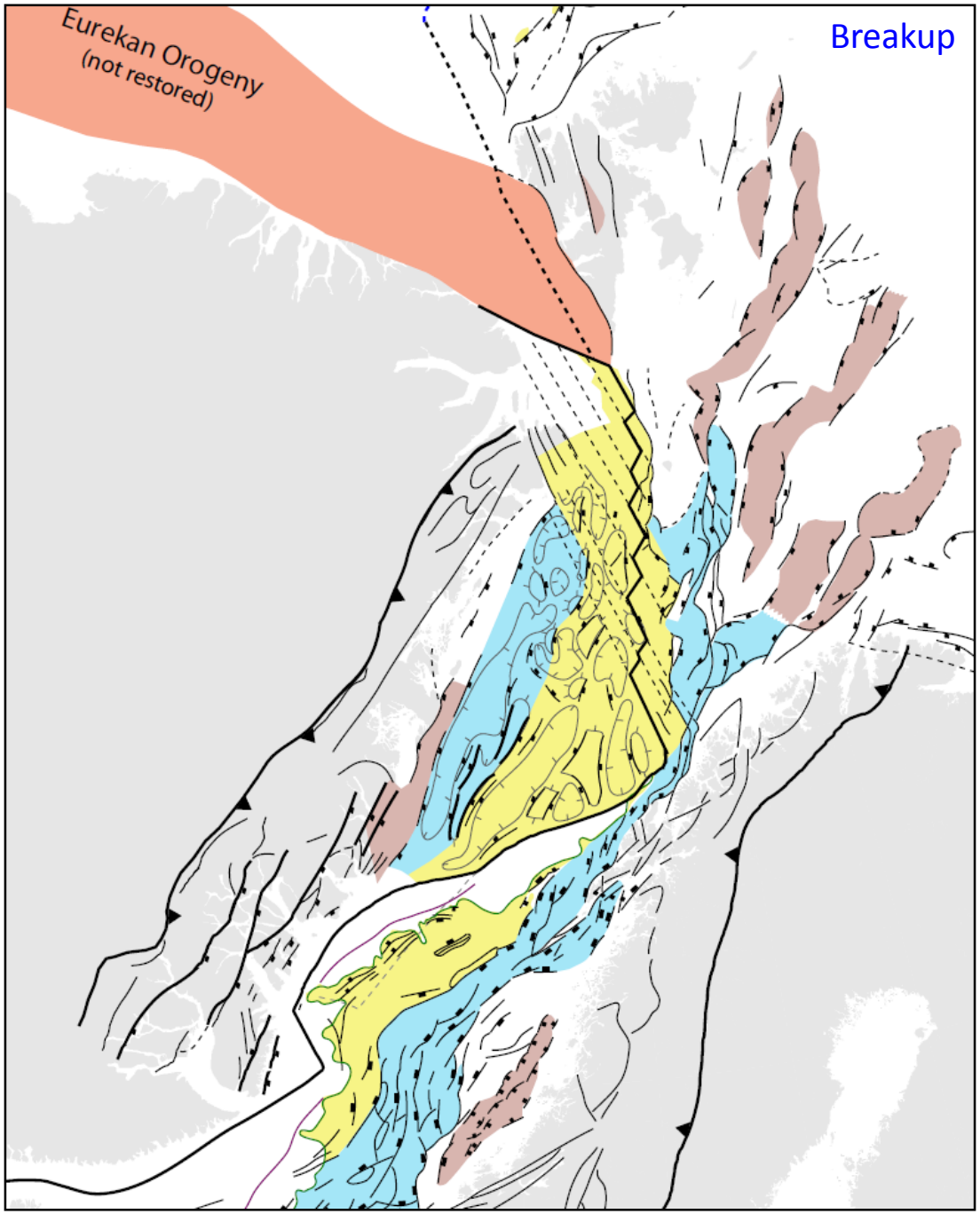

Rift phases:

- Late Cretaceous - Paleocene
- Late Jurassic - Early Cretaceous
- Late Paleozoic

Faleide et al. (2010)




Faleide et al. (2010)

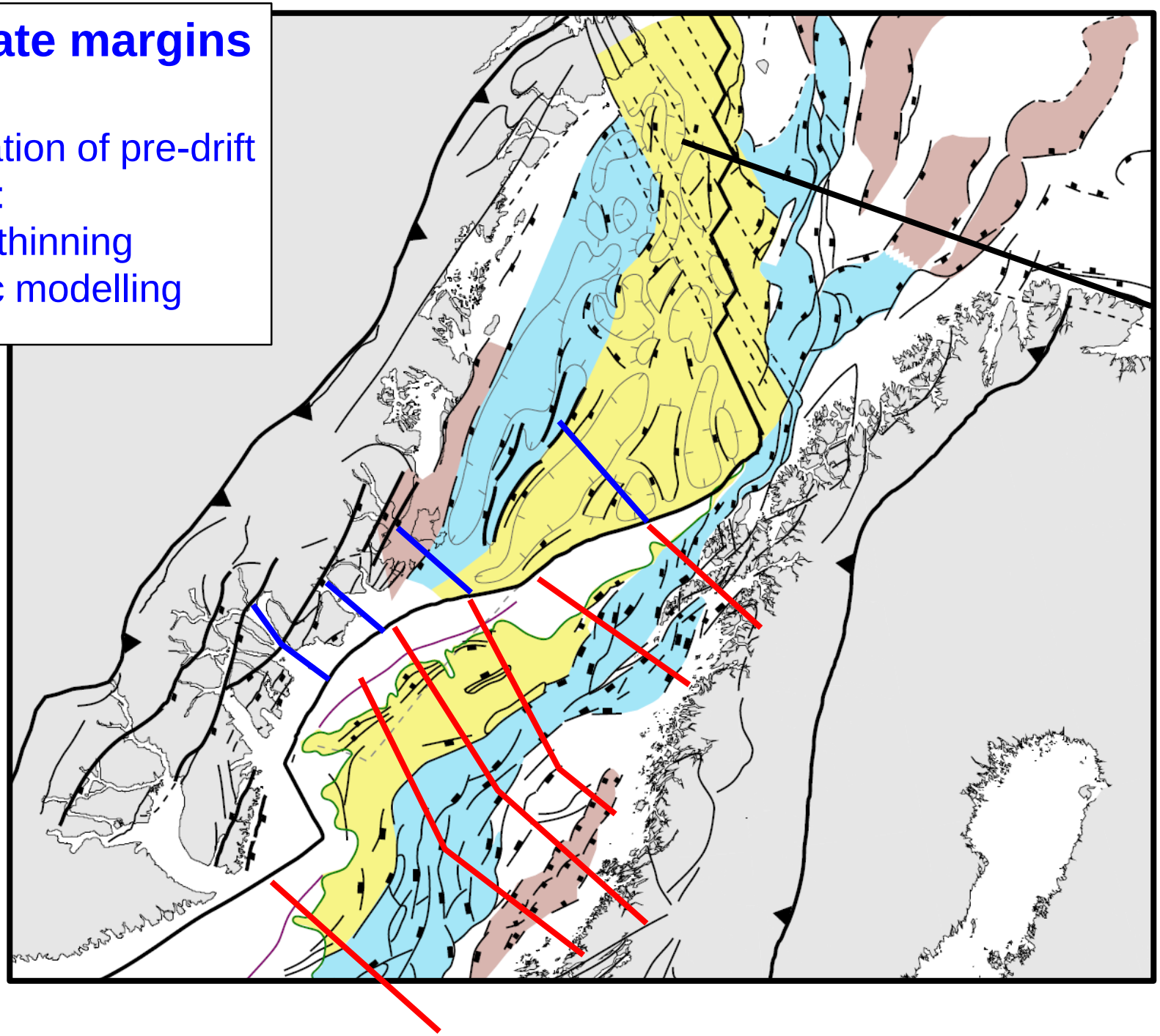



Faleide et al. (2010)

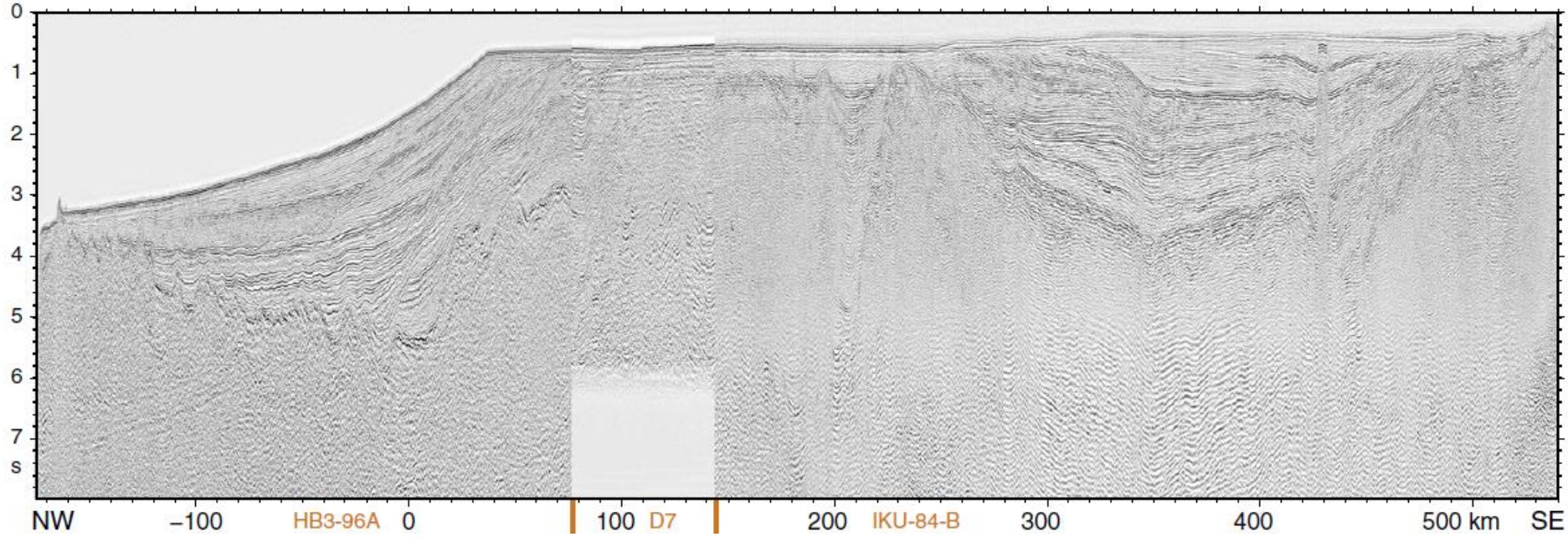
# Conjugate margins

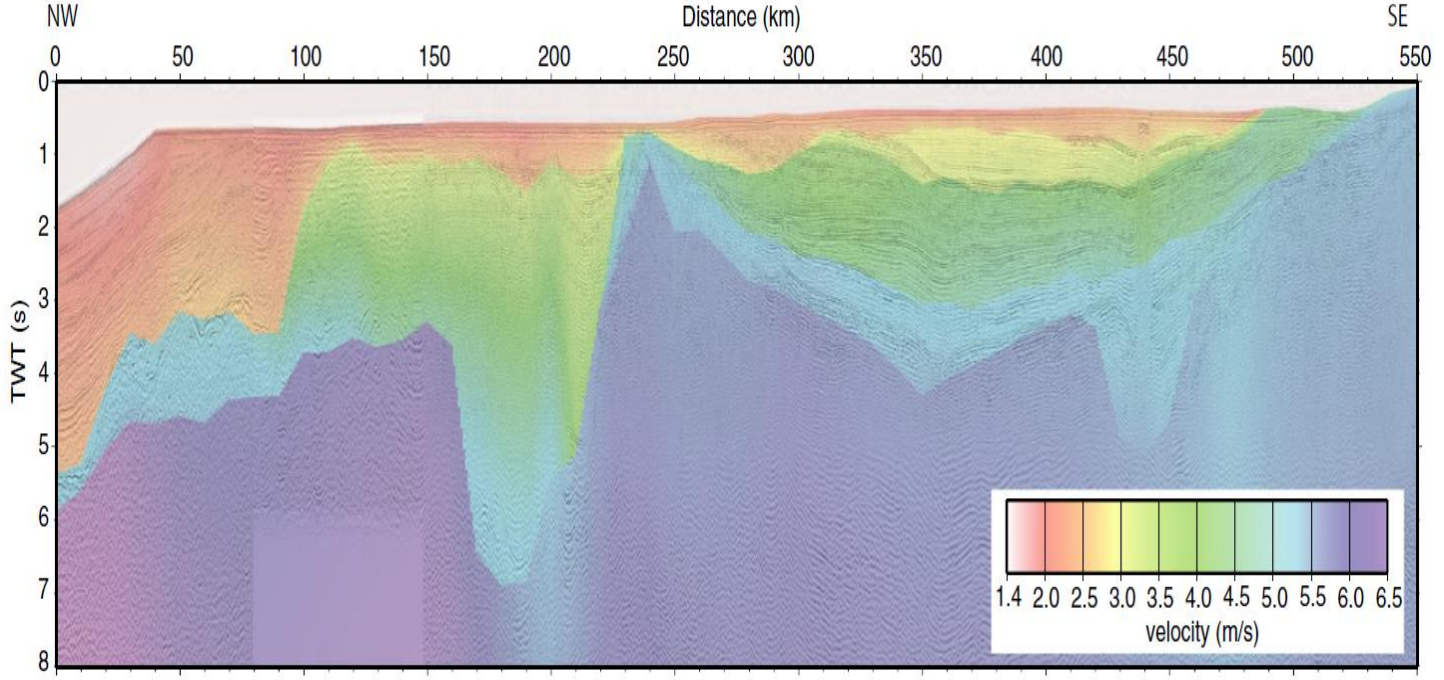
Quantification of pre-drift extension:

- Crustal thinning
- Tectonic modelling



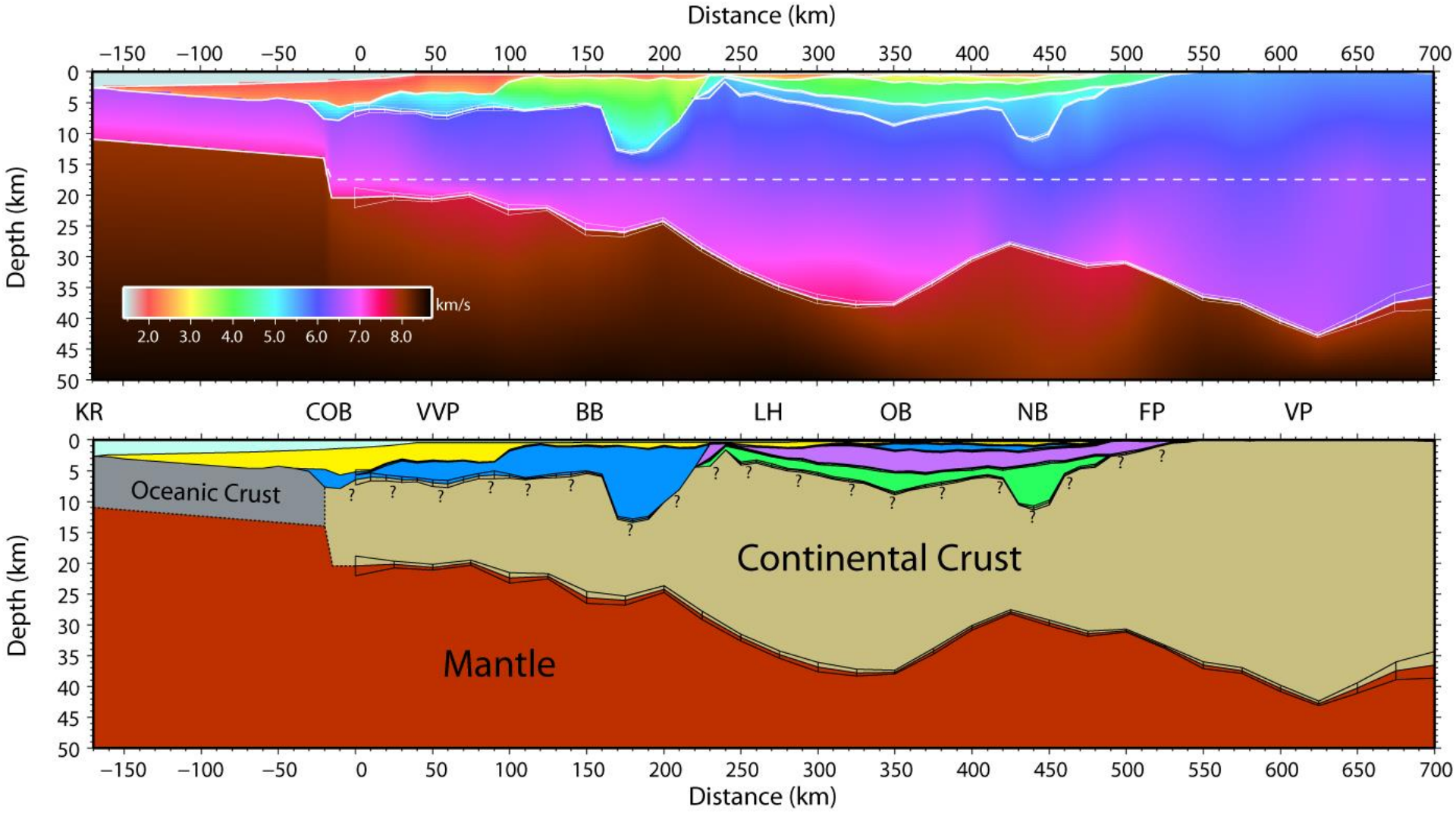
Faleide et al. (2010)



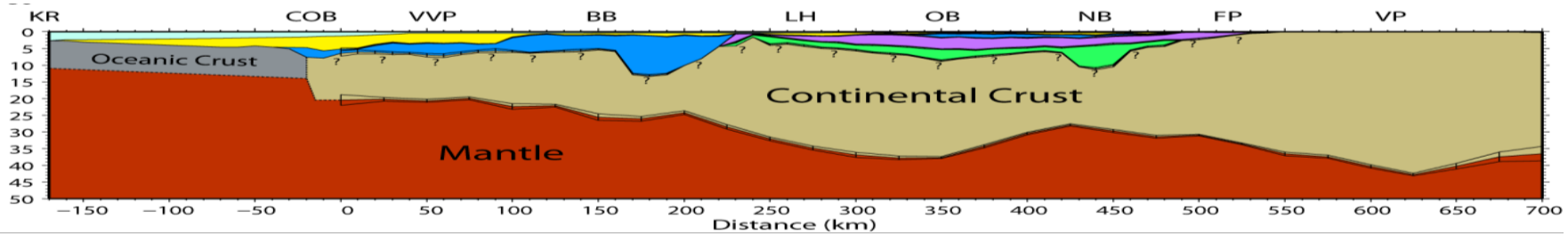

Clark et al. (2013a)

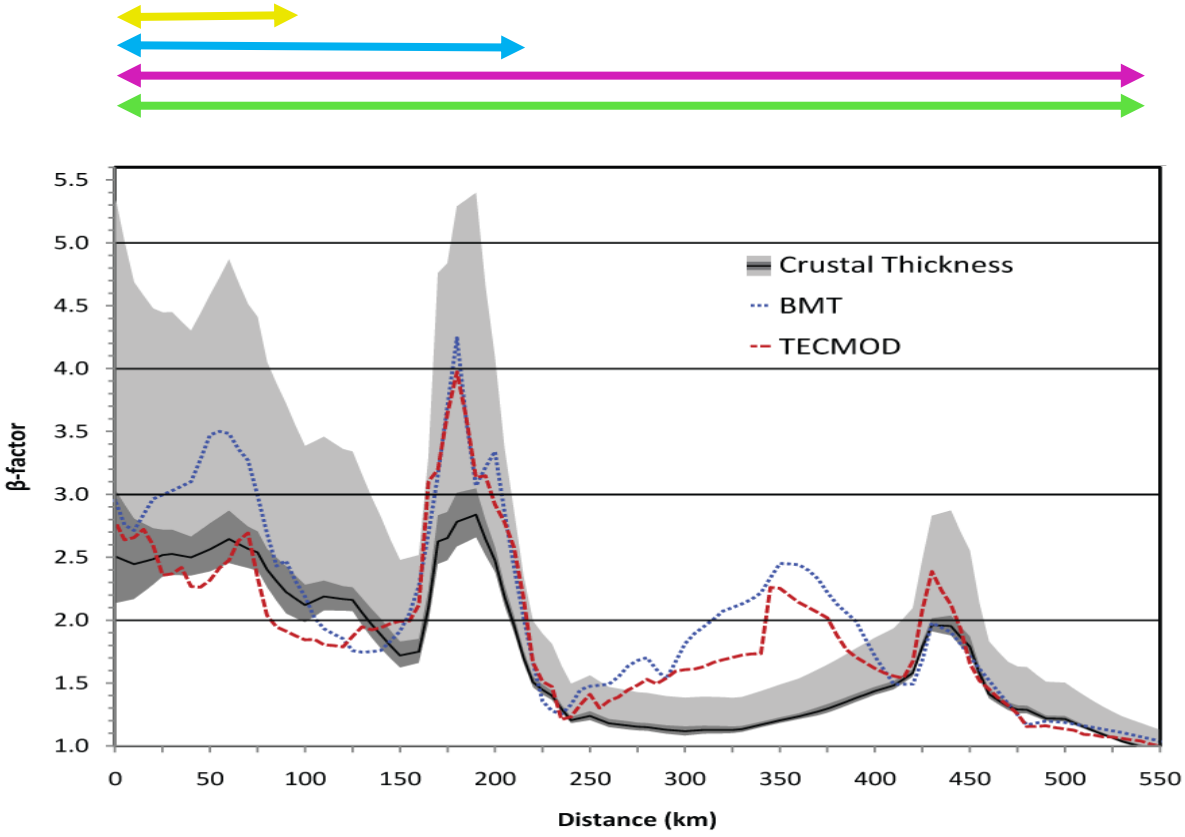
# Crustal-scale model of PETROBAR-07




Clark et al. (2013a)

# Stretching/thinning Factors

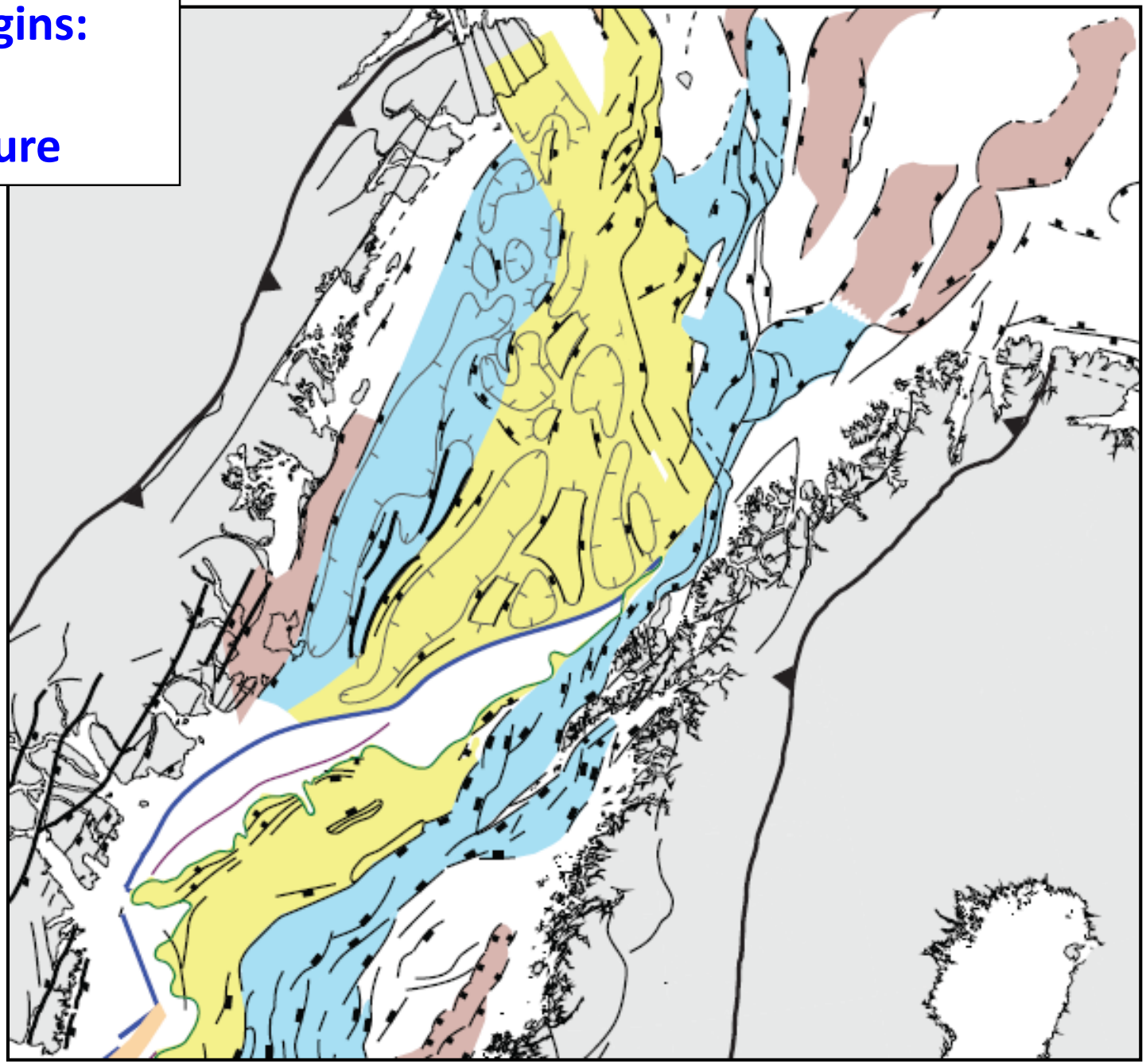



Average beta of 1.7±0.1, with 227± 16 km total extension

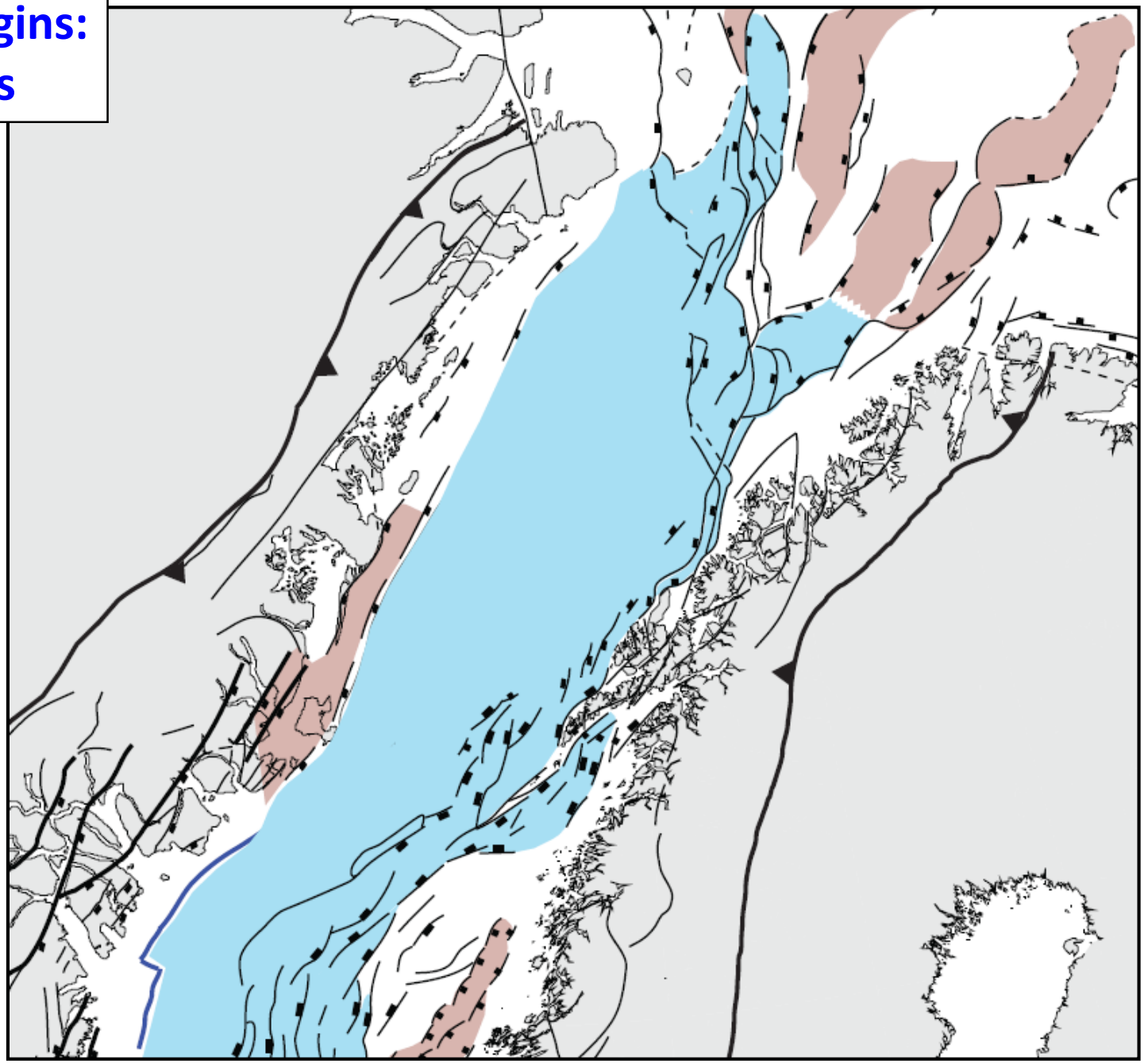
Clark et al. (2013b)

# Conjugate margins: Pre-drift basin architecture



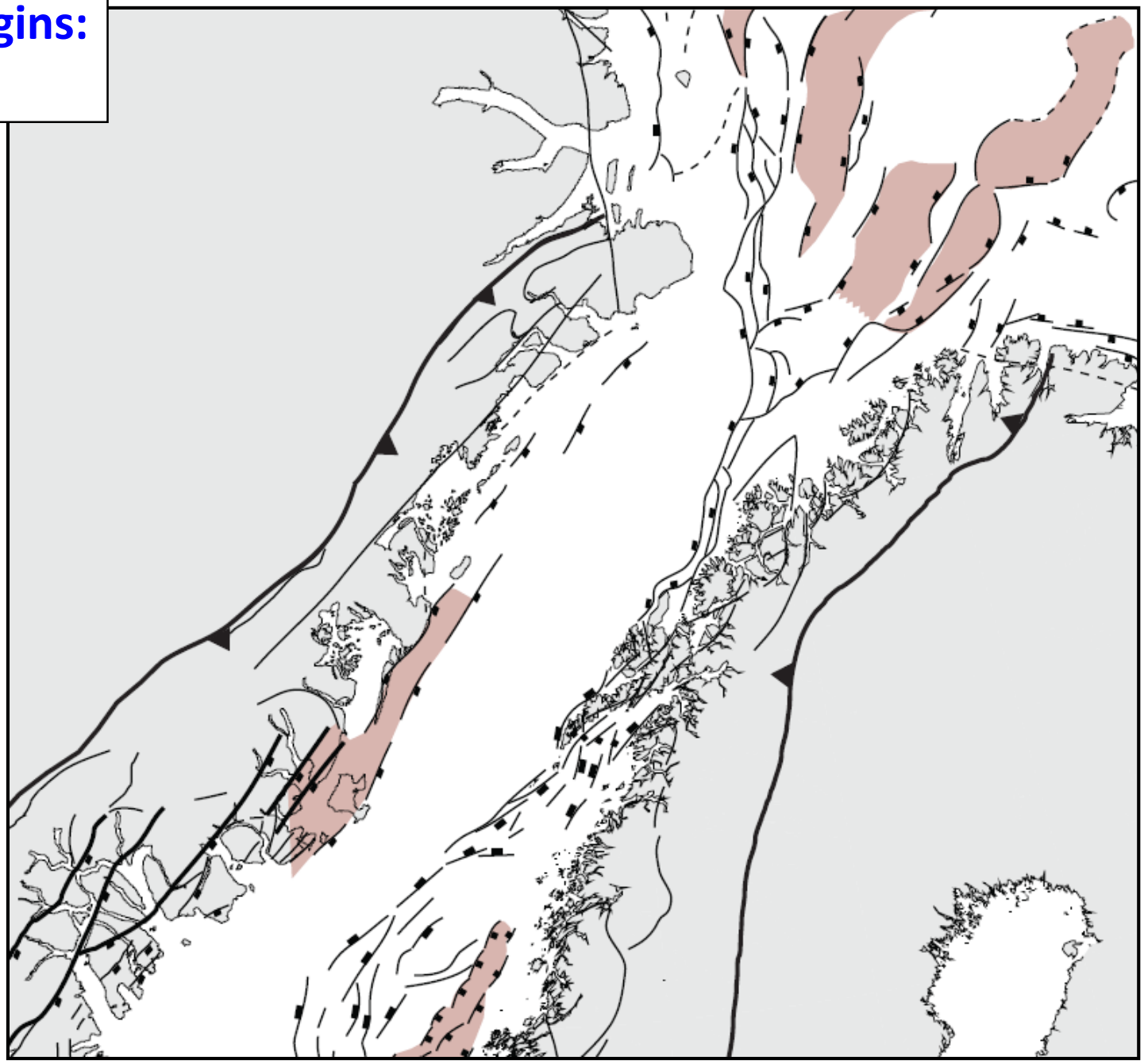
Faleide et al. (2010)

# Conjugate margins: Mid-Cretaceous



Faleide et al.

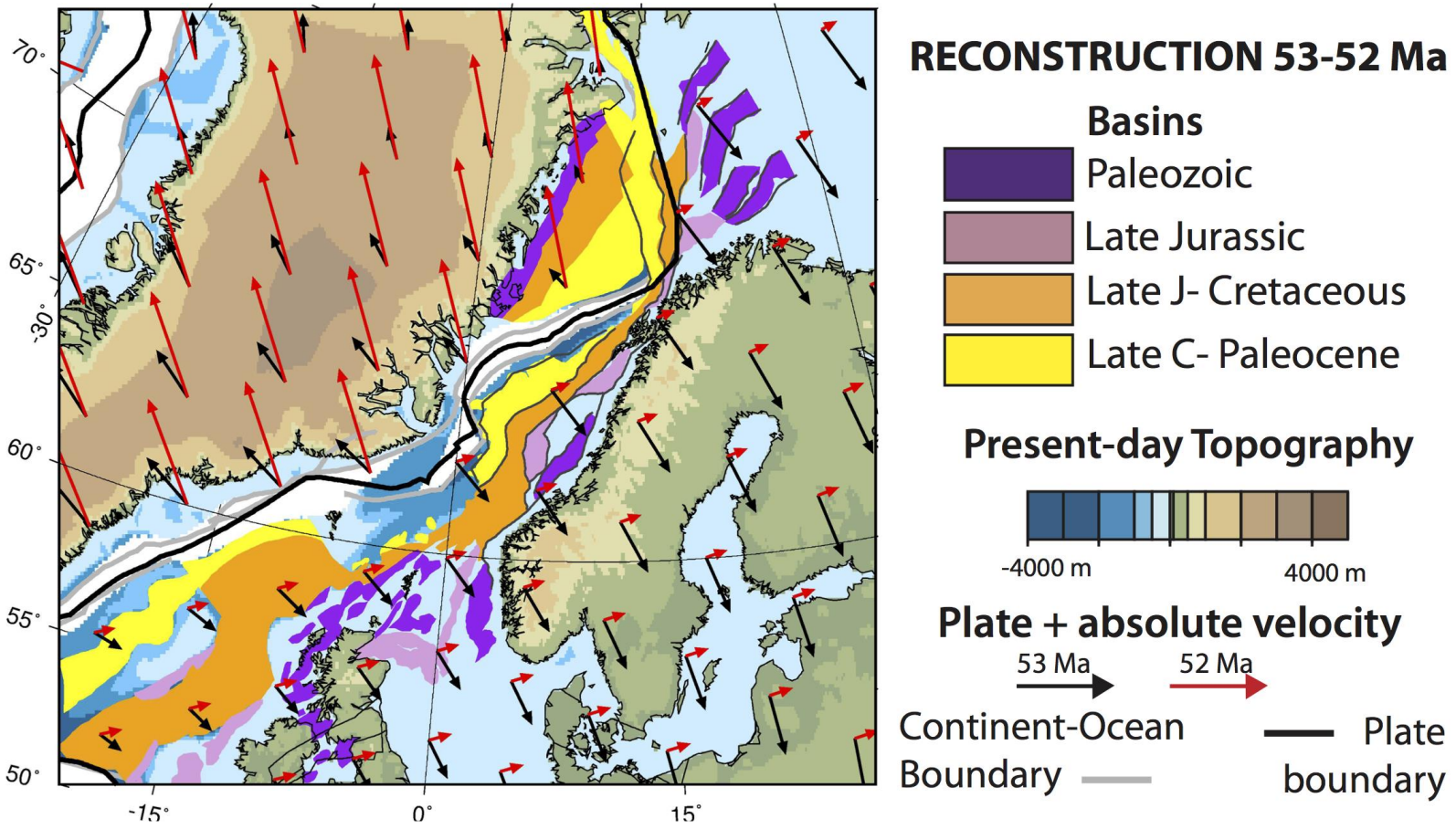
# Conjugate margins: Mid-Jurassic



Faleide et al.

*VISTA postdoc: Grace Shephard*

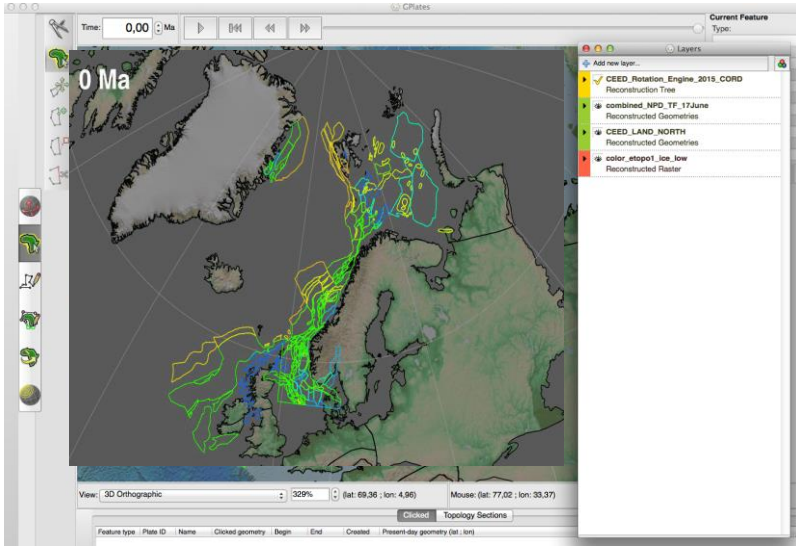
# **DEFMOD**:
*Def*ormation *mod*elling of the North Atlantic and Arctic
(May 2016-2018)




g.e.shephard@geo.uio.no **http://www.vista.no/c63739/project/vis.html?tid=66589**

# DEFMOD:
*Def*ormation *mod*elling of the North Atlantic and Arctic

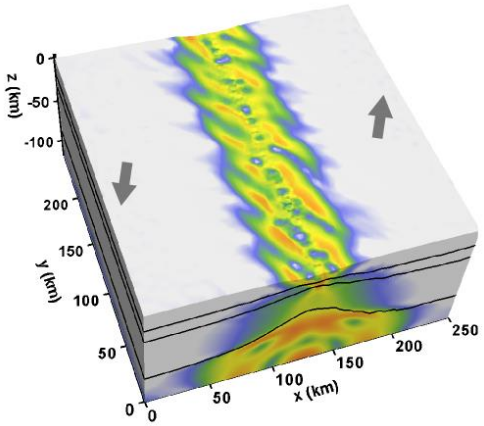
*VISTA postdoc: Grace Shephard*



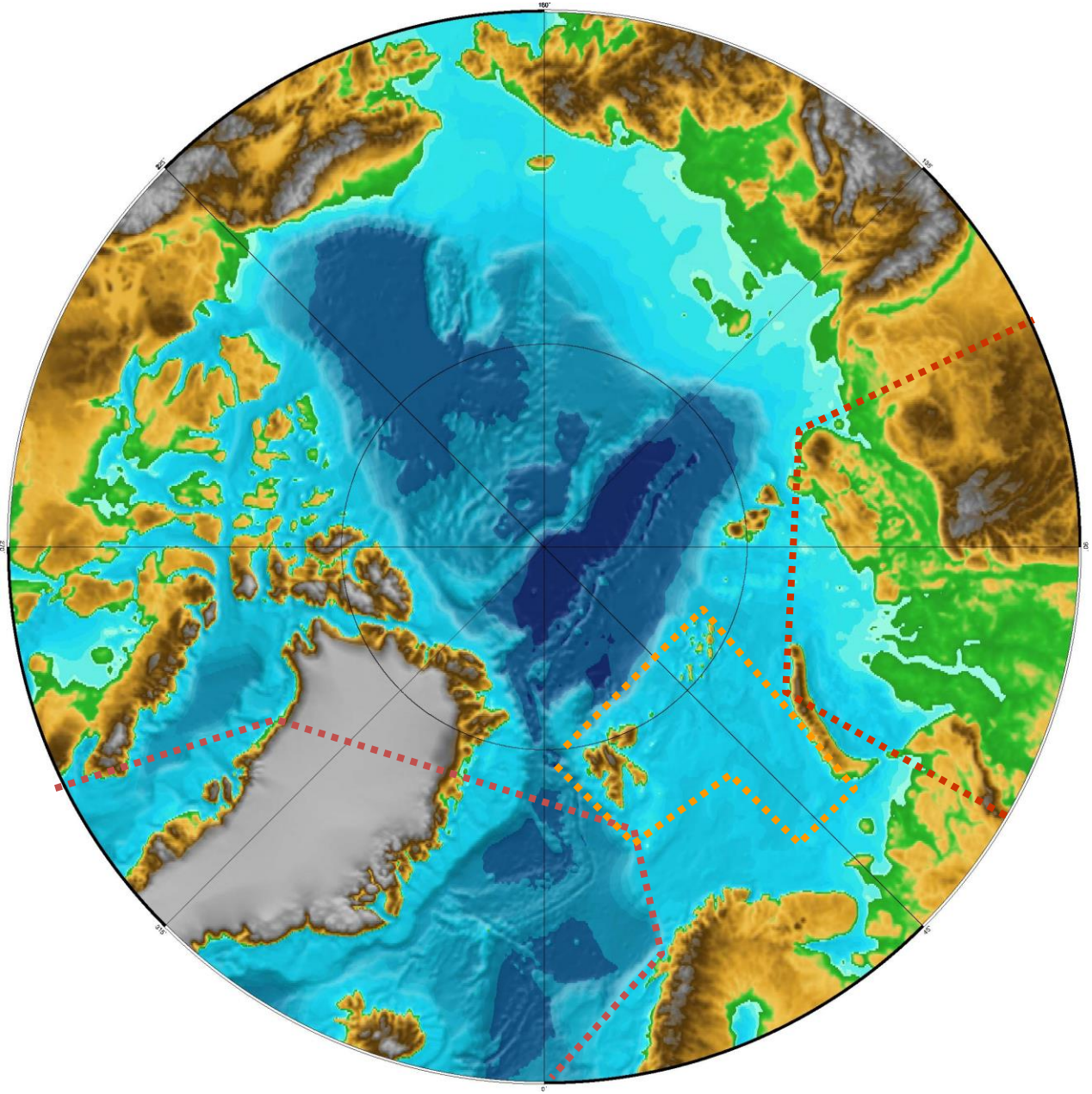

GPlates

- **4 work main packages:**
  - **Basin-scale reviews**
    - North Atlantic (+ Labrador/Baffin)
    - Ellesmere
    - Laptev (and beyong)
  - **Time and spatial constraints**
    - Cenozoic
    - Mesozoic and Paleozoic
    - Crustal thickness, stretching etc
  - **Tectonic models and iterations**
    - Plate reconstruction in GPlates
  - **Geodynamic models**
    - 2D and 3D lithospheric models (SLIM3D, SULEC, CitcomS)
    - Paleogeographic maps

Collaborations with
NGU (Trondheim)
GFZ (Potsdam)
BGR (Hamburg)




g.e.shephard@geo.uio.no **http://www.vista.no/c63739/project/vis.html?tid=66589**



# Hypothesis

***Arctic LIP volcanism had a major impact on the NCS petroleum systems***

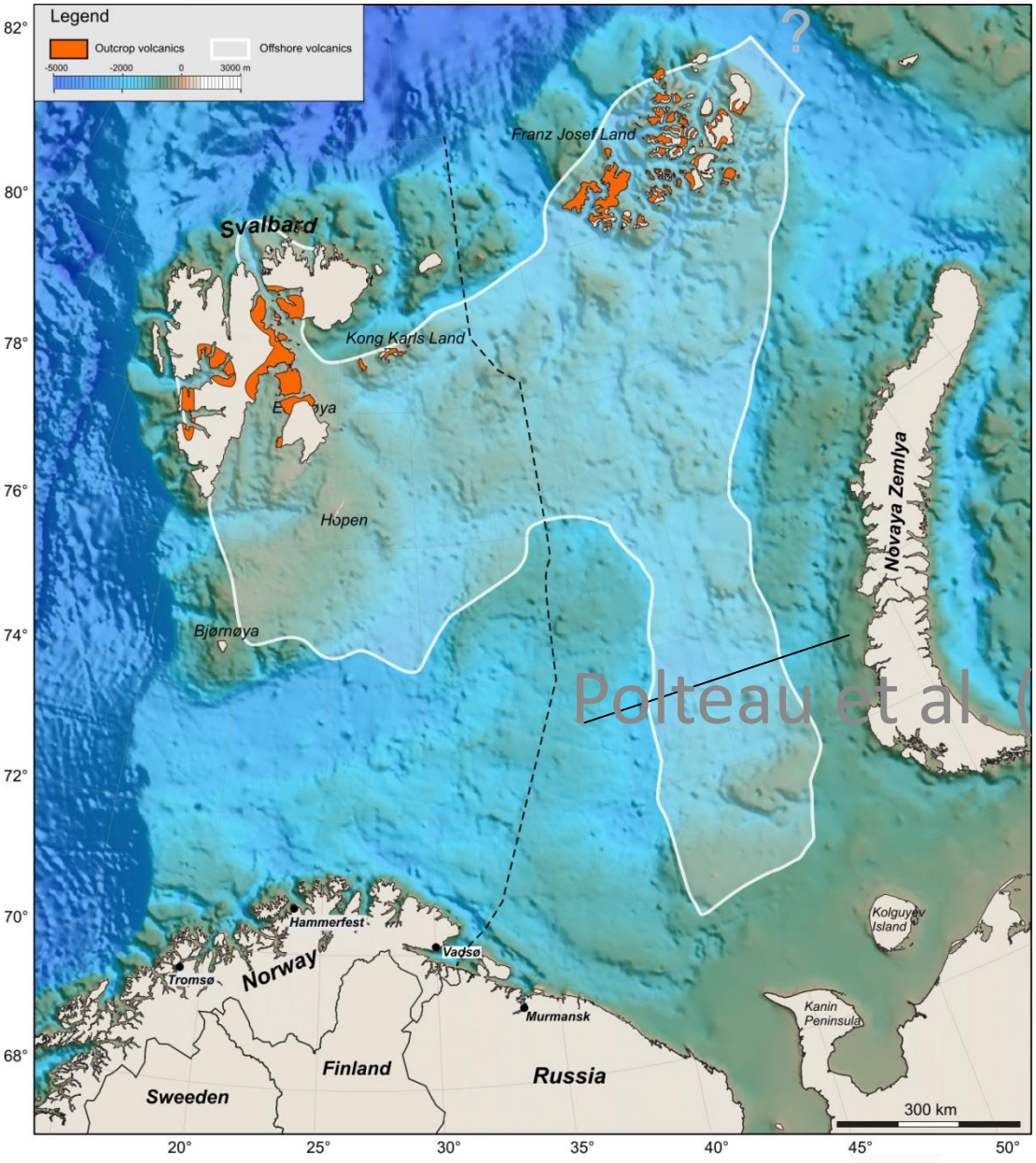
---

**North Atlantic Igneous Province (Paleogene)**

**High-Arctic LIP (Early + Late Cretaceous)**

**Siberian Traps (End-Permian)**

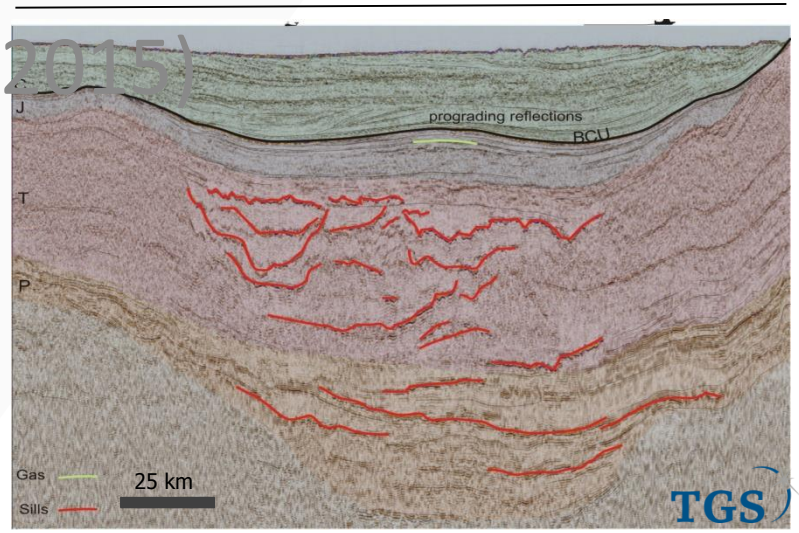
# Barents Sea LIP Sill Complexes




Polteau et al. (2015)

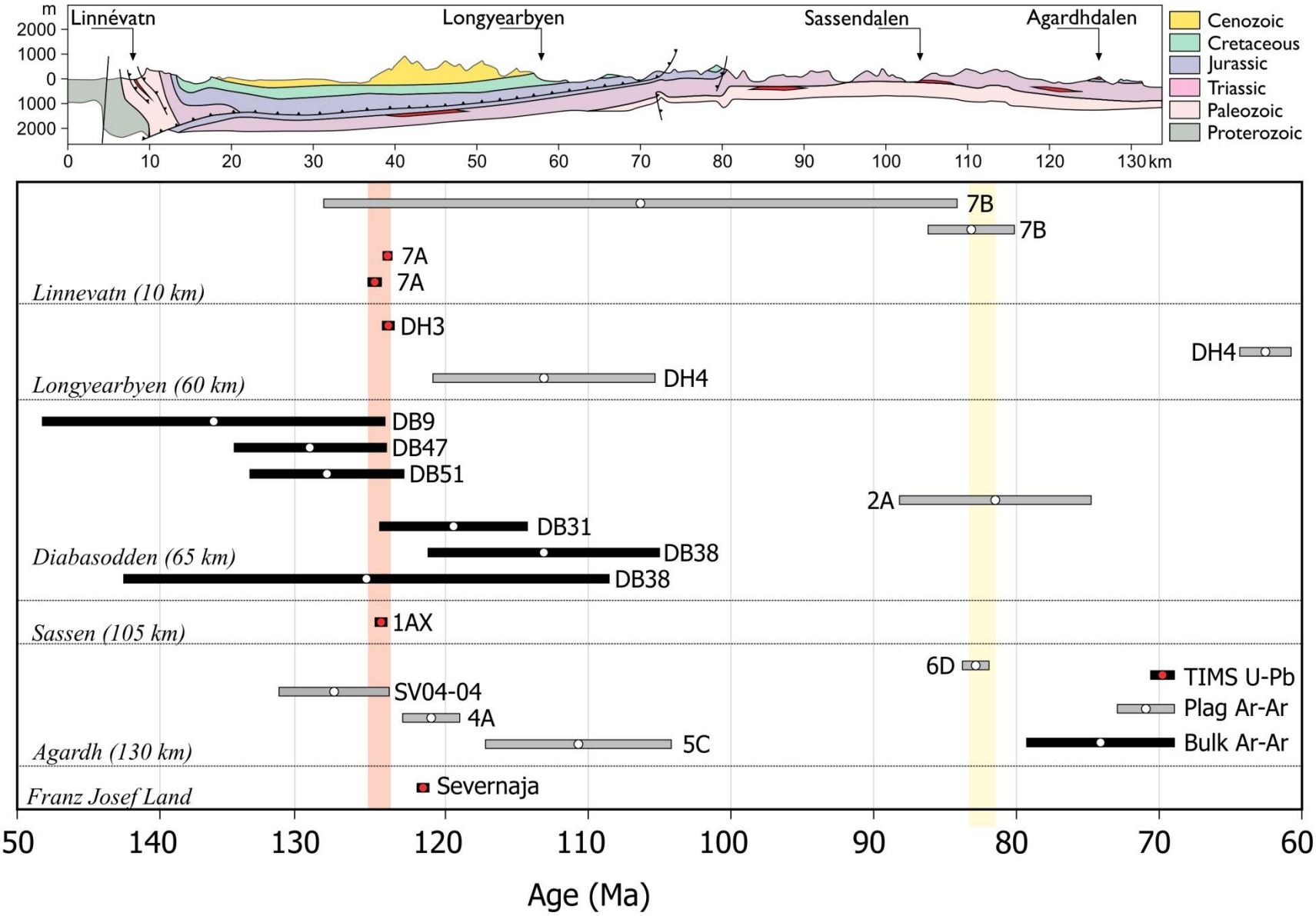
## Mapped by seismic and magnetic data

- E Barents Sea > 150,000 km$^2$
- Total: 700,000 km$^2$
- Intruding Permo-Triassic organic-rich successions
- Underly giant gas fields (e.g. Stockman)



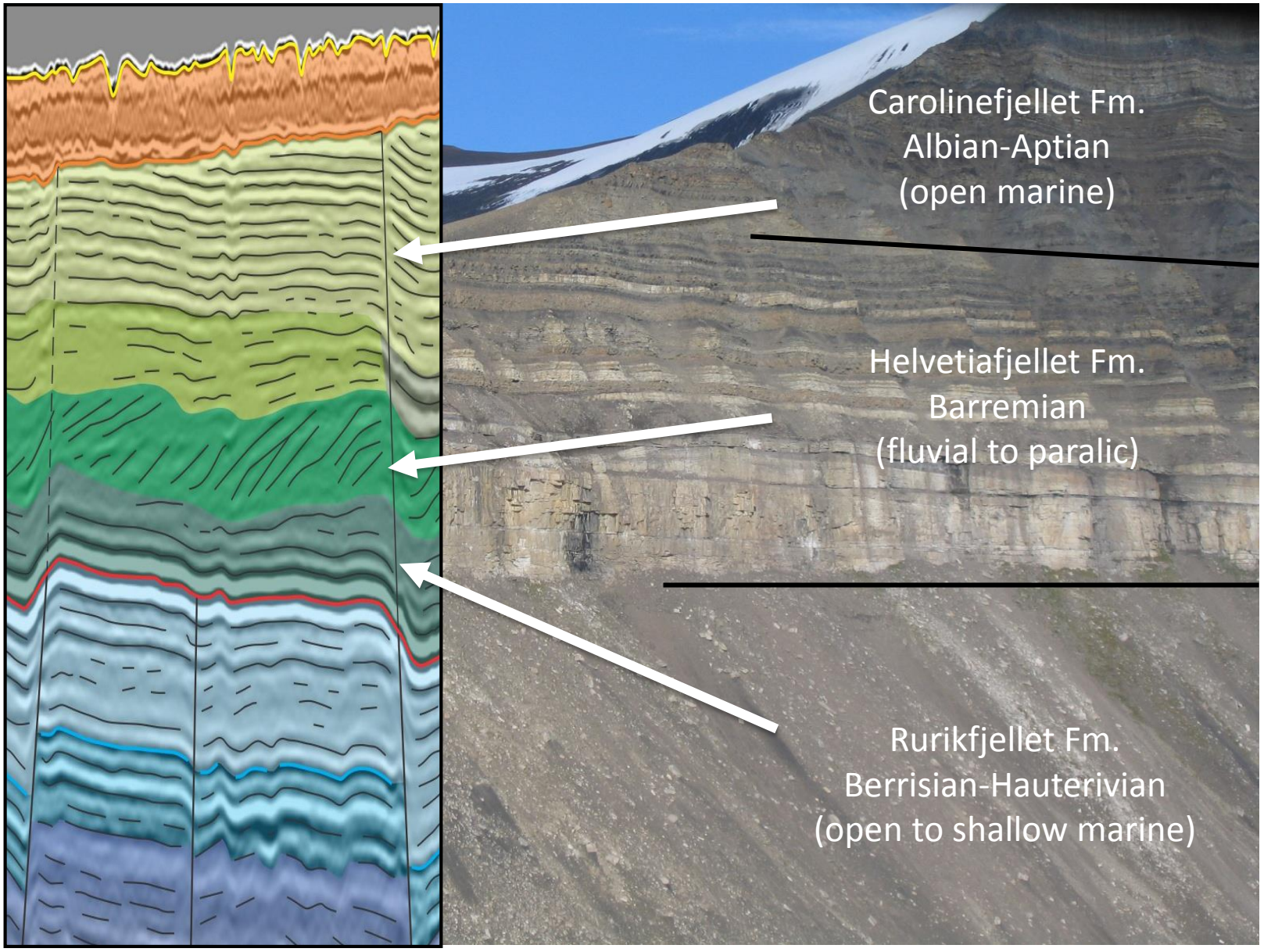

Polteau et al. (2015)

# HALIP Geochronology

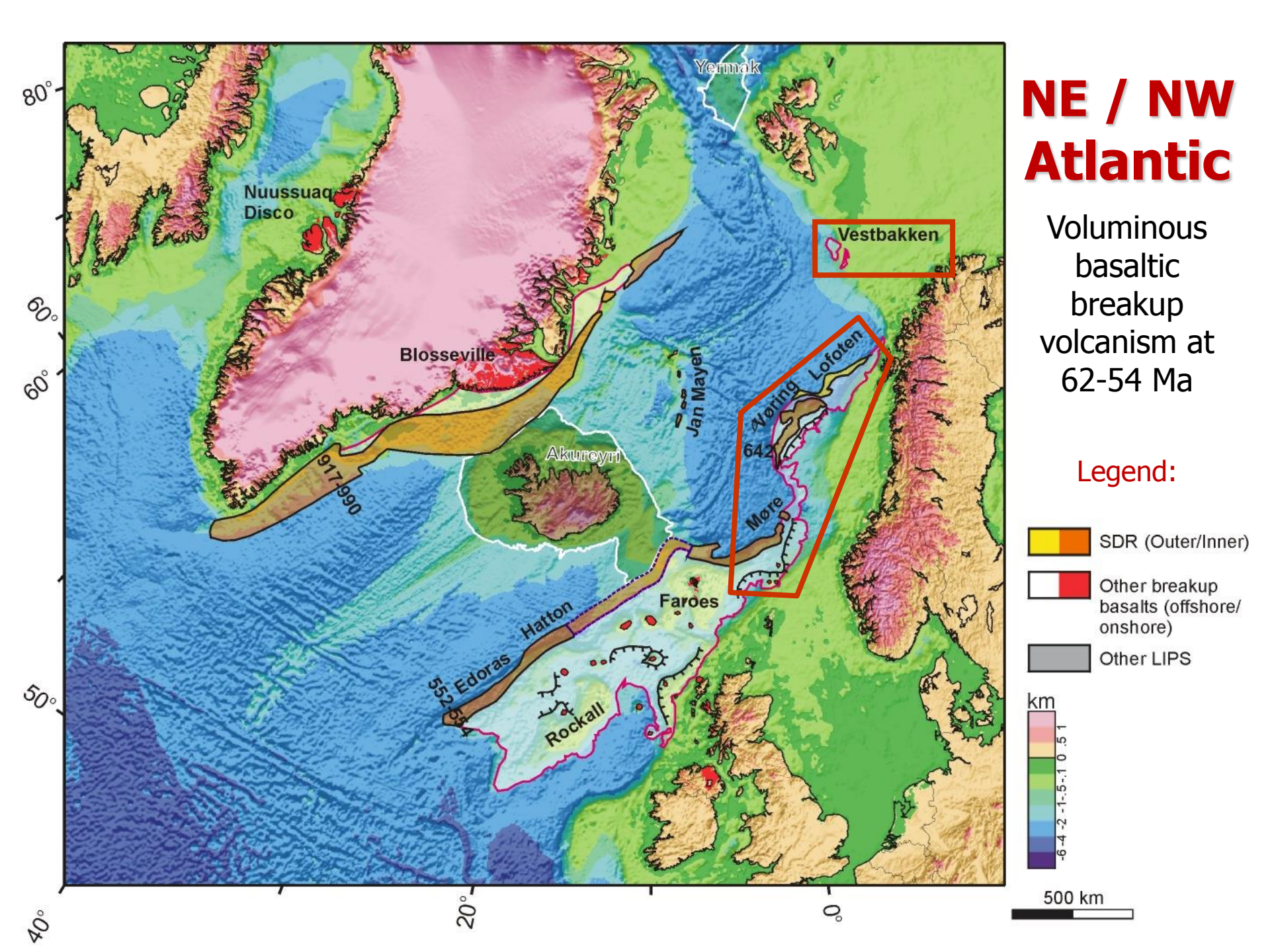



Polteau et al. (2015)

# Svalbard | Early Cretaceous

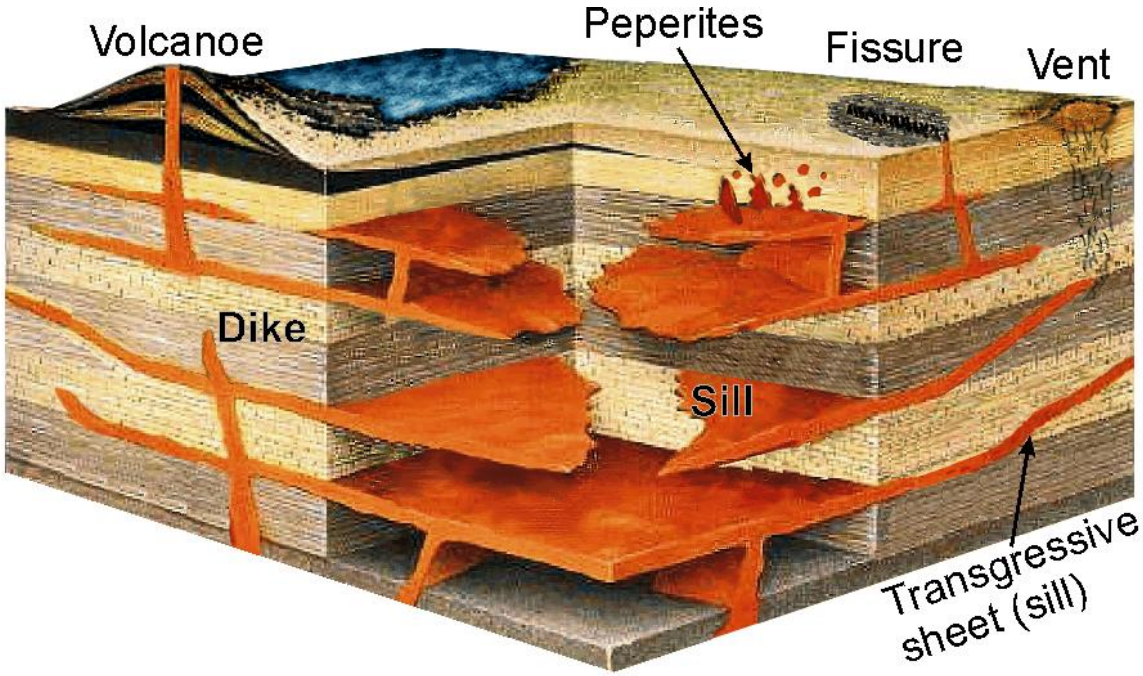



Thompsonbreen, E Spitsbergen | Glørstad-Clark, Midtkandal et al. (2010)


NE / NW Atlantic
Voluminous basaltic breakup volcanism at 62-54 Ma
Legend:
SDR (Outer/Inner)
Other breakup basalts (offshore/ onshore)
Other LIPS
km
6 4 2 1 .5 .1 0 .5 1
500 km
Yermak
Nuussuaq
Disco
Vestbakken
Blosseville
Jan Mayen
Lofoten
Vøring
64
Akureyri
917-990
Møre
Faroes
Hatton
552-564
Edoras
Rockall
80°
60°
60°
50°
40°
20°
0°

# Volcanic Basins

-- sedimentary basins with a significant amount of **primary deposited volcanic rocks**




## Petroleum Implications

### Emplacement

**Maturation**: Increased hydrocarbon maturation in maturation aureole

**Migration**: Enhanced hydrothermal circulation and generation of migration pathways

**Traps**: Lifting and deformation of the overburden possibly forming traps

### Post-Emplacement

**Migration**: Re-use of fracture systems. Barriers and compartmentalization (sills, dikes, hydrothermal vent complexes and aureoles)

**Traps**: Differential compaction

**Seals:** Tuff

Planke et al.

# Volcanism in Sedimentary Basins

1995
1996
1997
1998 IAVCEI
1999
2000
2001
2002 LASI I
2003
2004
2005
2006 LASI II
2007
2008 LASI III
2009
2010 LASI IV
2011
2012 LASI V
2013
2014
2015
2016 Book

**Passive Margin Research Group, U. Oslo**
- Seismic imaging and interpretation
- E Greenland field work

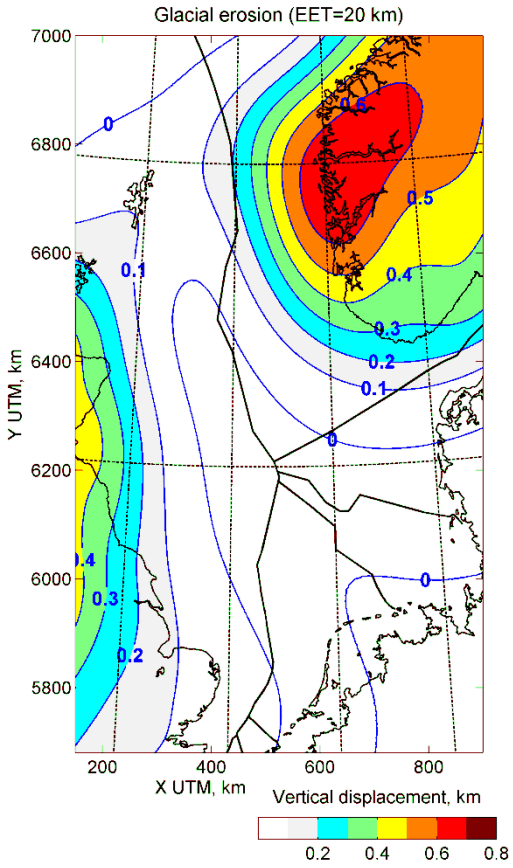
**Petroleum Implications of Sill Intrusions (VBPR, UiO, TGS)**
- Seismic imaging and interpretation
- Karoo field work (vents, aureoles, sills)
- Numerical modeling

**NFR projects (PGP & collaborators)**
- PGP (2003-2013)
- Sill emplacement (2004-2007)
- Hydrothermal venting (2004-2007)
- Aureole processes (2007-2010)
- Climate implications (2007-2011)

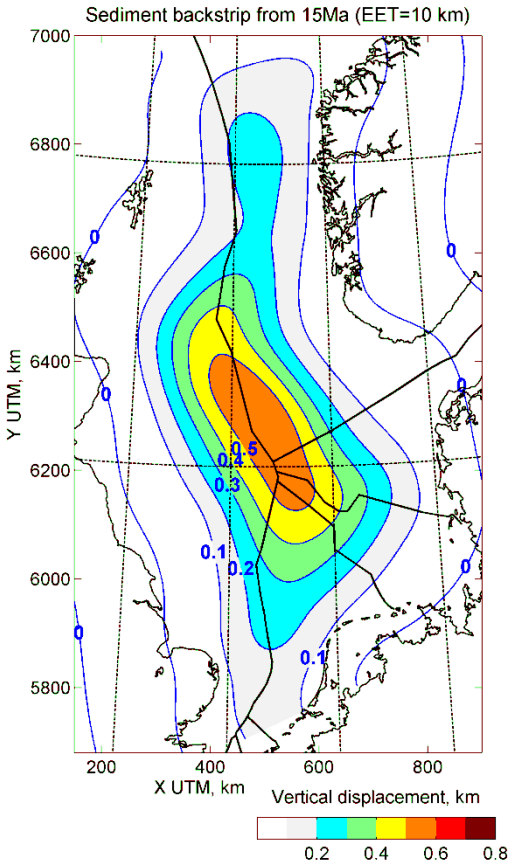
*Karoo, Siberia, Greenland, Azerbaijan, Java, Argentina (Brazil)*

**NFR and industry projects (CEED & collaborators)**
- CEED (2013-2023)
- Siberia projects – EPIC/PeTrArc (2012-2016)
- VMAPP (2013-2016)
- DIPS/MIMES (2015-2018)

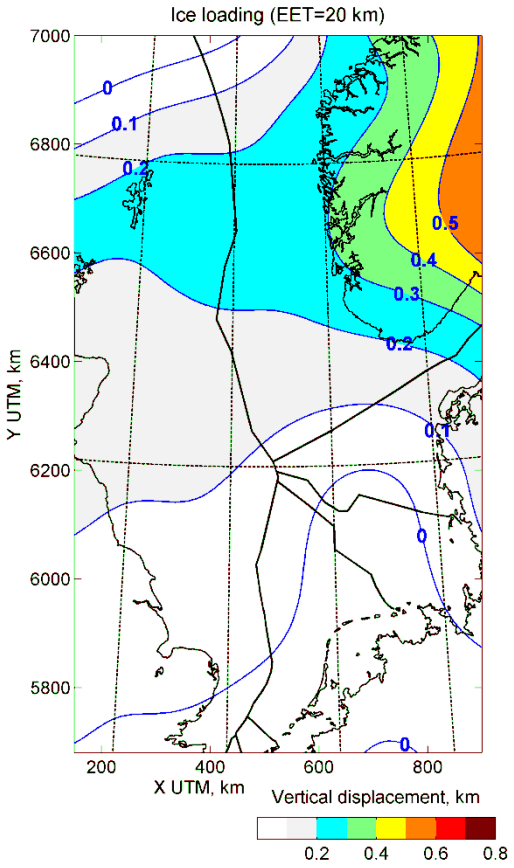
# Vertical motion of basement: sources of differential motion




Onshore erosion (glacial carving) unloading



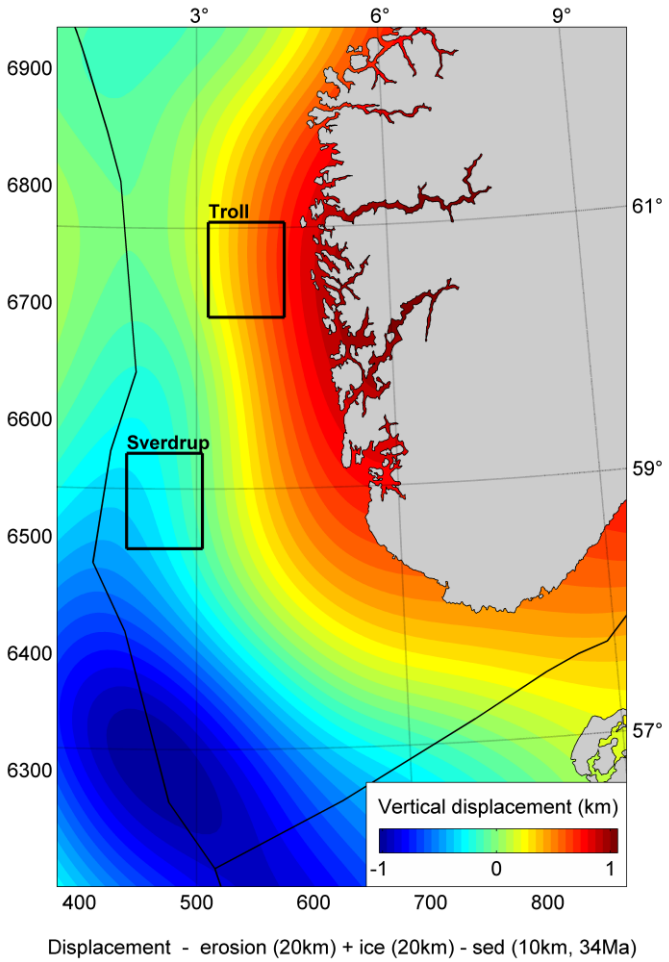

Accumulated sediments loading




Ice sheet loading/unloading

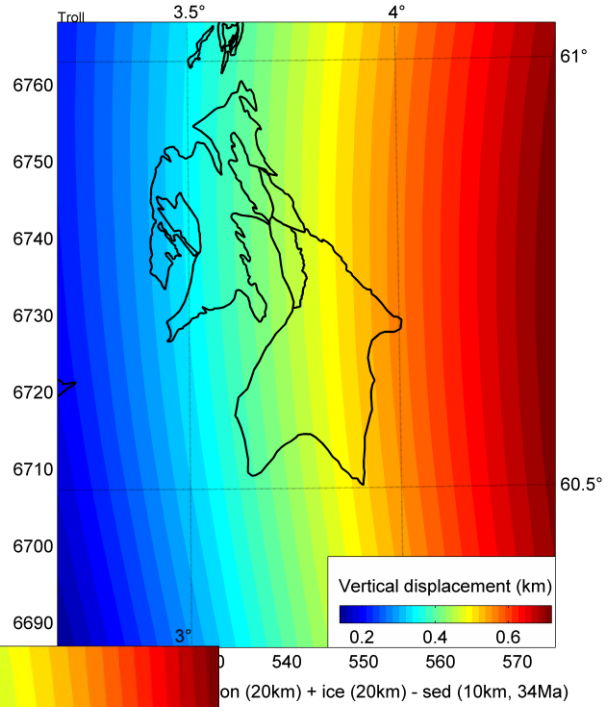
Medvedev et al.

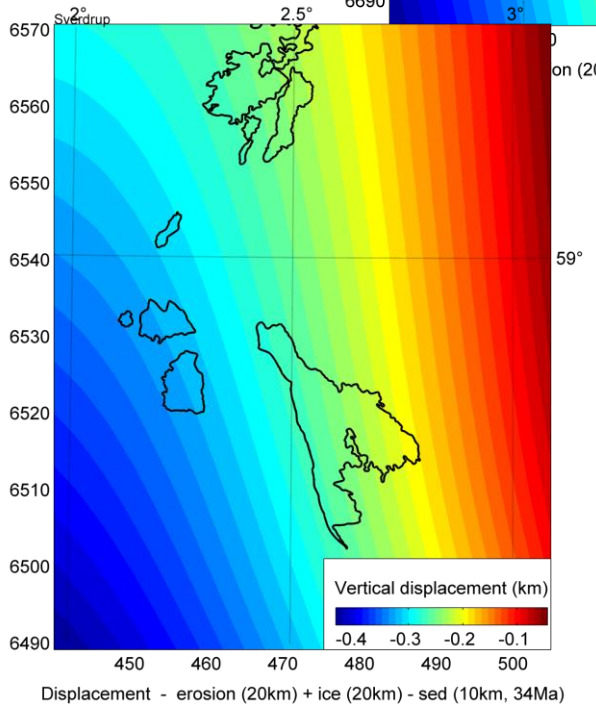
# Vertical motion of basement: zoom-in to particular discoveries




Total displacement

Troll




Sverdrup

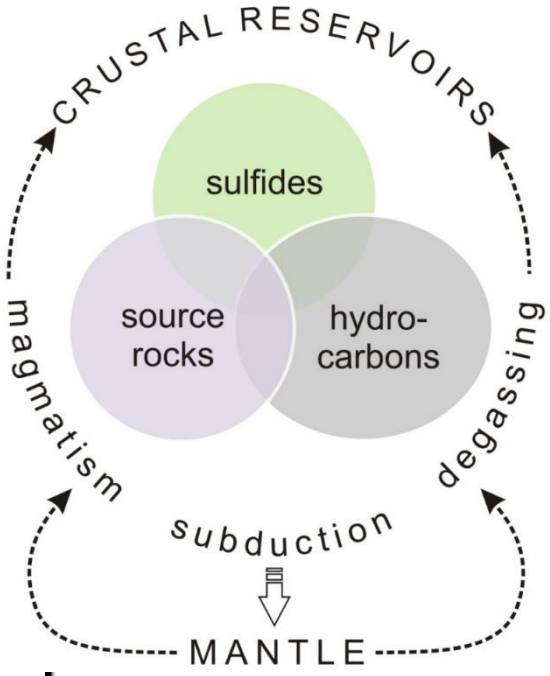
Medvedev et al.

# When? The 4th dimension – TIME

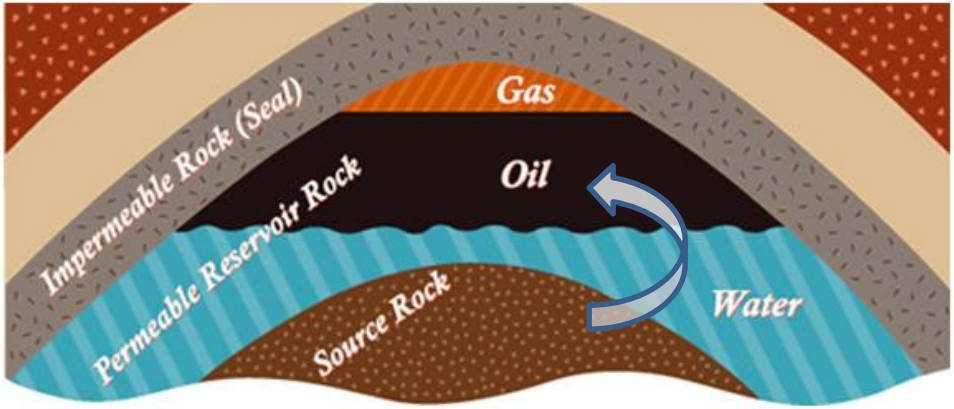
## New Technology – Geochemistry

**Radiometric ages for earth processes important to hydrocarbon generation**

- **Dating source rocks for oil and gas**
- **Dating oil and gas migration**




**Conventional**




**Unconventional**

Stein, 2014


CHRONOS – 2012-2017

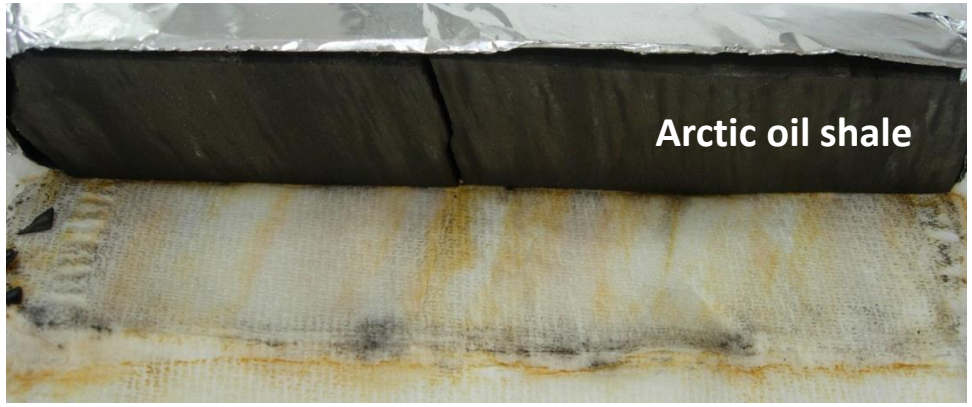
Chronology and Correlations in Absolute Time

Holly Stein & Judith Hannah, Project Leaders

## Tiny Tutorial

- Radiometric dating method is Re-Os (rhenium-osmium)
- Re and Os reside in organic material and sulfides
- Dating kerogen, bitumen, migrated oil using Re-Os in a geologic context


**WORKING MEDIA for Re-Os**



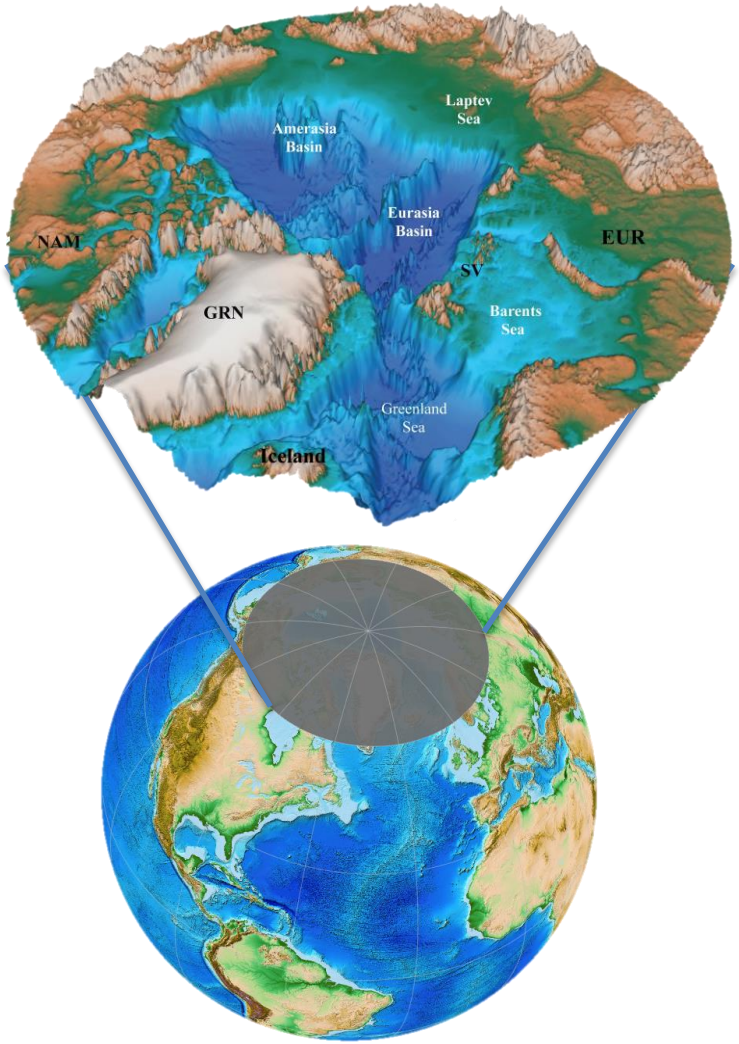

**shale-pyrite**


# Arctic tectonics and basin evolution

- Local, Regional and Global Perspective
- Geological Time
  → 4D model for Arctic's evolution

- Understand **Passive Margin Formation** *Norwegian-Greenland Sea, Barents Sea* and the formation and evolution of **Geo-resources**

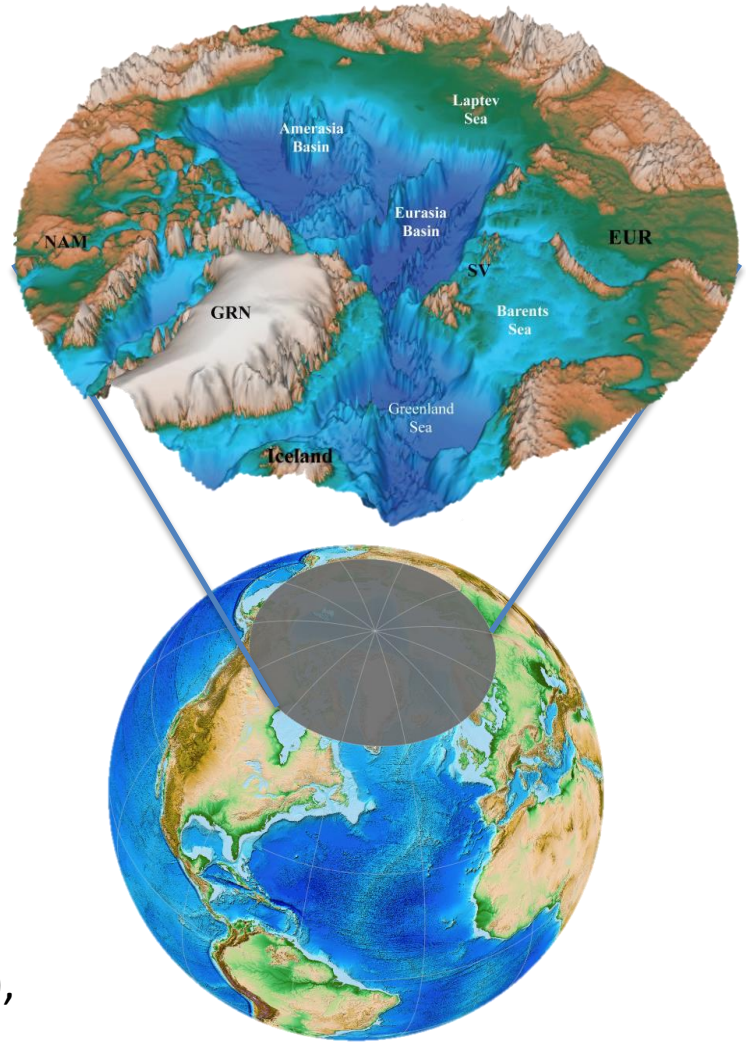
- Understand **Climate Evolution** – Oceanic gateways – *Fram Strait* Volcanism – *High Arctic Large Igneous Province (including Svalbard and Northern Barents Sea)*



# Arctic tectonics and basin evolution

The Arctic (and Circum-Arctic) region is an important puzzle piece (1/6$^{th}$) in Earth's Evolution that may hold the answers to KEY questions regarding

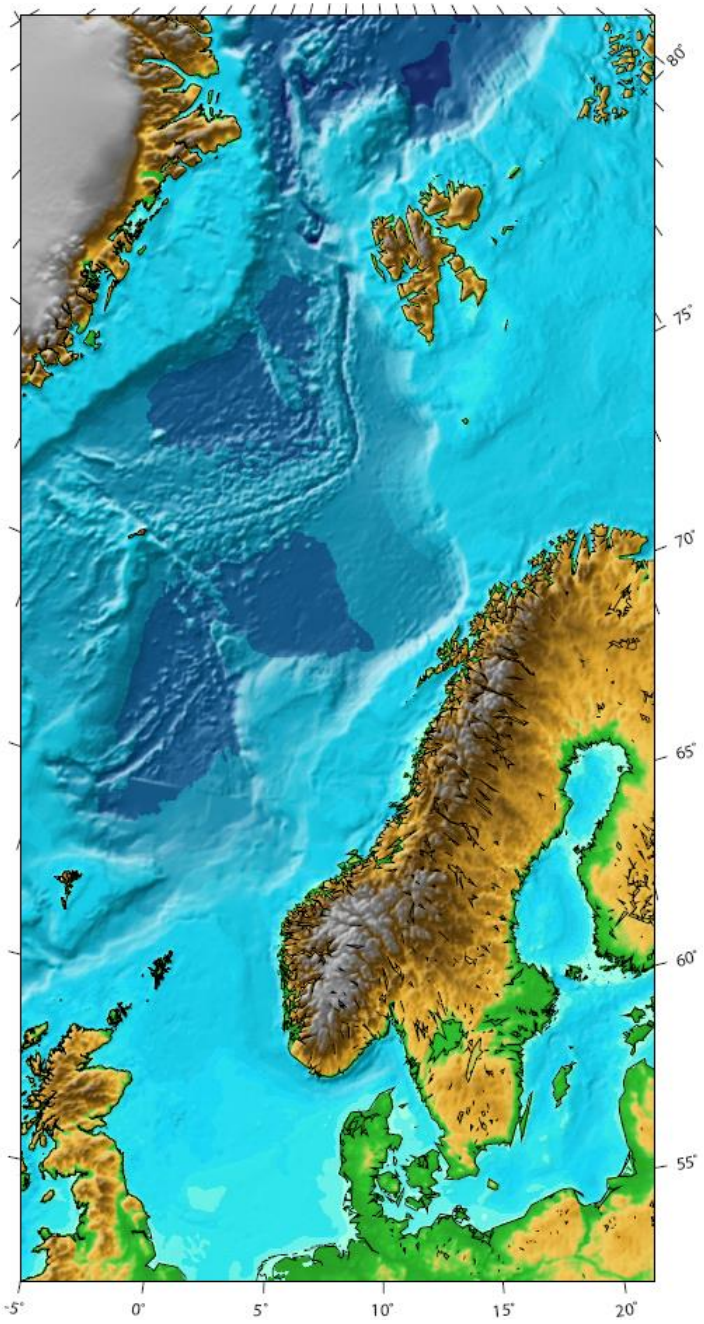
- mantle-crust interactions
- volcanism and climate change




Existent CEED projects relevant to Polar Research (RCN, Industry, ERC):
4D Arctic, BarMod, BarPz, BarN-S2S, CHRONOS, OMNIS, Beyond Plate Tectonics

Department of Geosciences, UiO also part of:
CALE (Circum-Arctic Lithosphere Evolution)
ARCEx (Research Centre for Arctic Petroleum Exploration),
TeMAR (Tectonic Map of the Arctic) +++

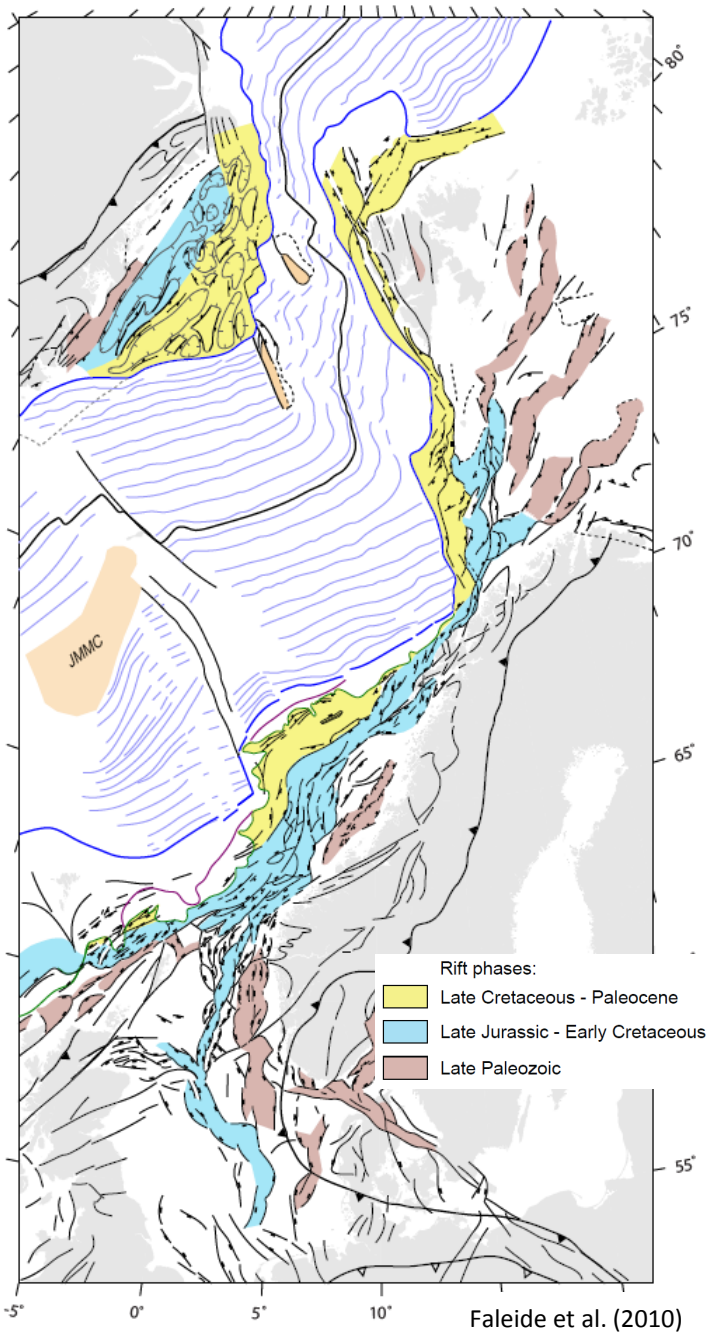
**UiO: Department of Geosciences** – involved in many petroleum relevant research projects




ARCEx
BarMod
BarPz
BarN-S2S
TriasNorth
LoCrA
+++

OMNIS

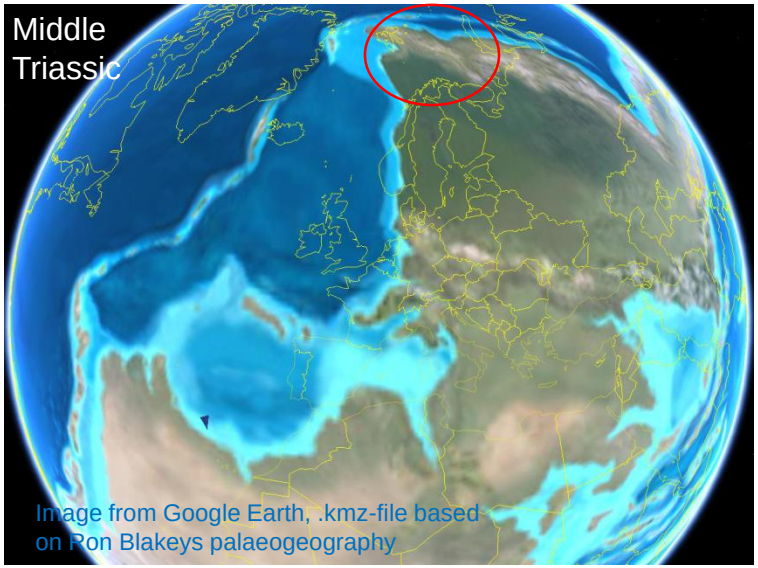
MultiRift



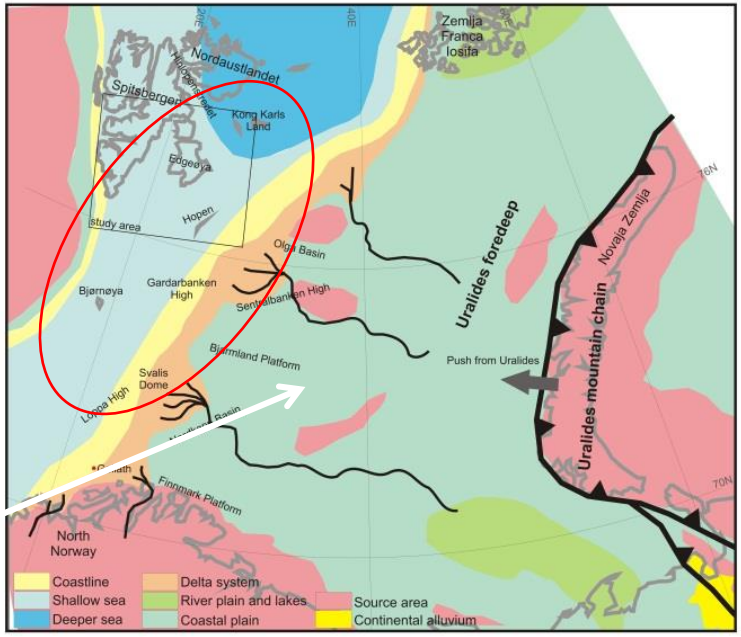

Faleide et al. (2010)

# TRIAS NORTH PROJECT

**Objectives**: Integrate onshore and offshore datasets to improve the understanding of basin development and tectonic activity of the Triassic Barents Shelf




- **Depositional systems** of the migrating shelf,
- **Clinoform migration** across sags and upwarps/highs,
- **Growth faulting** in the distribution of reservoir sandstones,
- **Sandstone quality**; provenance, routing and diagenesis
- **Stress** configurations as driver

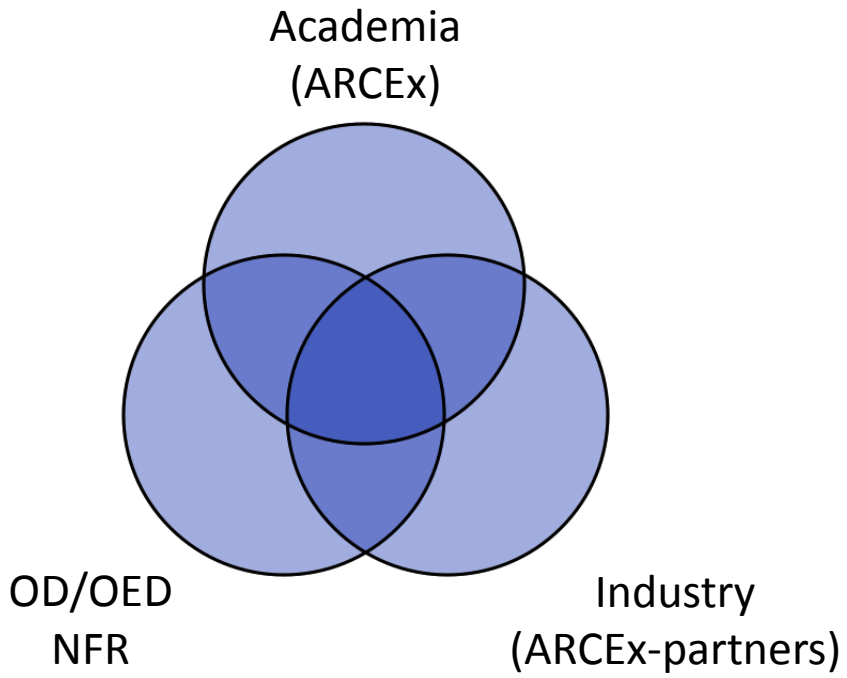



How did this foreland basin fill in?
What controlled infill patterns?
Can we establish sediment routing?
What do we see in seismics?

Braathen et al. 2012

## Collaboration between academia – industry - authorities

- Sharing of roles
- Complementarity
- Synergies
- Expectations




- We are not exploring for oil/gas directly, but we provide knowledge that the companies can use in their exploration

- Short distance from basic to applied research

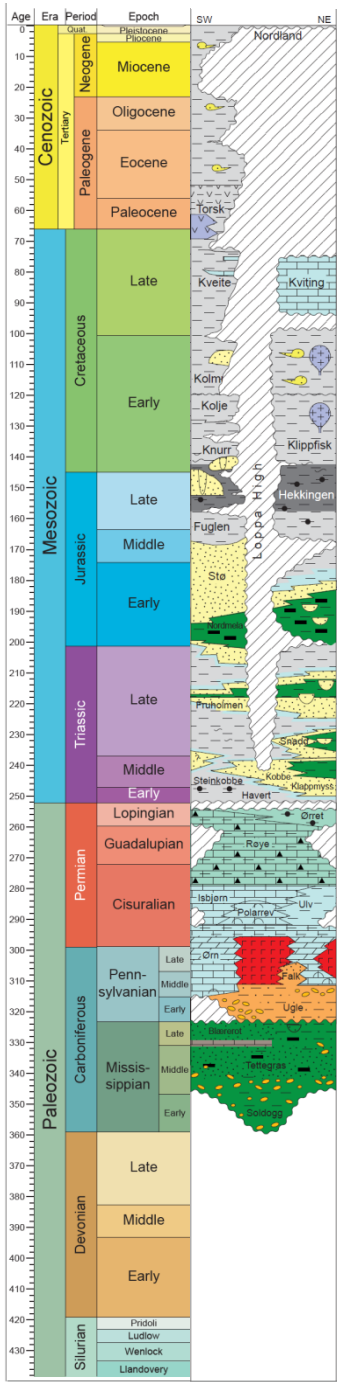
# Petroleum systems – play models – risking

- Source rock(s)
- Reservoir rock(s)
- Traps (structural - stratigraphic)
- Caprock - seal

- Burial history – temperature history
- Maturation – hydrocarbon generation – migration – charge of traps
- Reservoir quality

- Timing of trap formation (e.g. contraction)
- Reactivation of faults – fracture of seal – leakage

- Regional geology
- Paleogeography – plate reconstructions
- Depositional systems – from source to sink
- Uplift/erosion




# Main geological events affecting the western-central Barents Sea:

- Basement
- Multiple rift phases
- Regional subsidence
- Contraction/inversion
- Regional uplift/erosion

www.nhm2.uio.no/norlex

ARCEx

# $CO_2$ storage group – Geosciences UiO

## FME – SUCCESS

Reservoir modelling
Geomechanical response to $CO_2$ injection
Mineral-$CO_2$ interaction kinetics
Fluid phase equilibria / fluid properties in $CO_2$-rich systems

## CO2Seal

Regional seals Southern North Sea:
seismic mapping, sedimentology,
geomechanics/structural geology

## SSC-Ramore

Seal reactivity & geomechanics,
coupled reactive transport

## BarRock

Geomechanics and rock physics, seals
capabilities in up-lifted basins

## $CO_2$ storage potential in Skagerrak

Seismic mapping CO2 storage plays,
reservoir models
Injectivity proposal

## Inject

Operations
Injectivity, case histories

## Min-Gro (EU)
## DeltaMin (EU/PGP)

PGP cooperation

## NORDICCS

Nordic CCS centre

## LYB CO2 Pilot

## $CO_2$ Field Laboratory - Hurum

UiO : Department of Geosciences
University of Oslo

Department of Geosciences (Industrial Liaison + CEED) will invite the industry to a meeting in the spring 2016

- Review of ongoing petroleum relevant research
- Propose topics for potential new projects

**Thank you!**