Walk fast  Walk alone

Walk far  Walk together

Quote by Sissel Eriksen, NPD

16th of May 2017

Opportunities and Challenges in the Barents Sea

by

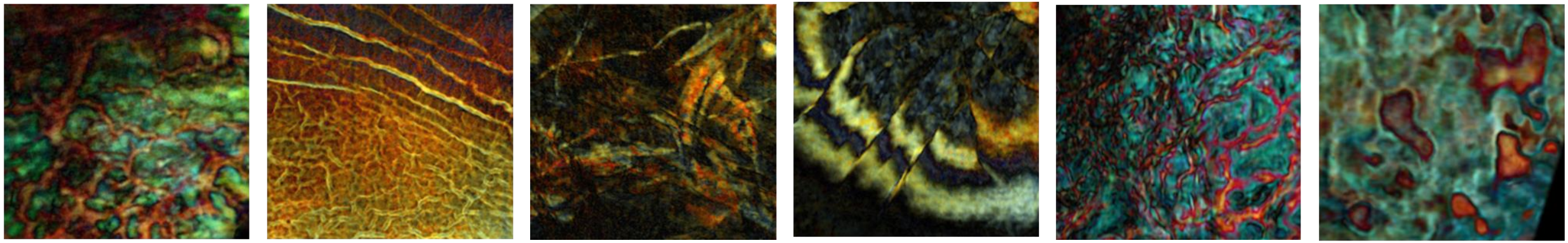
Sidsel Lindsø,

Explorationist // Founder of ExploCrowd

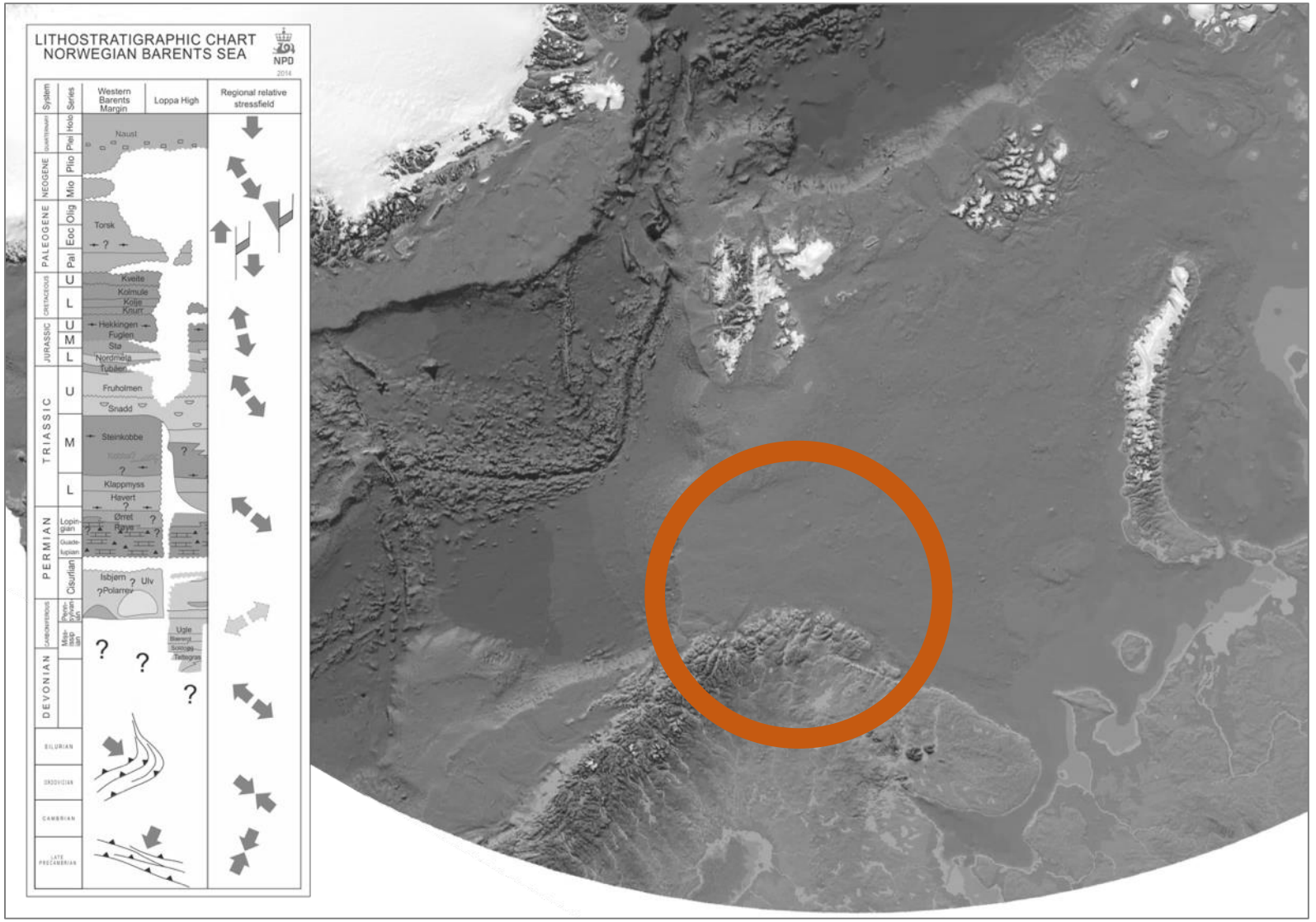
for

FORCE

June 2nd, 2017



Structure of Presentation



Glaciations and Neotectonics

Paleogene and Neogene Uplift and Erosion

Opening of Atlantic Ocean

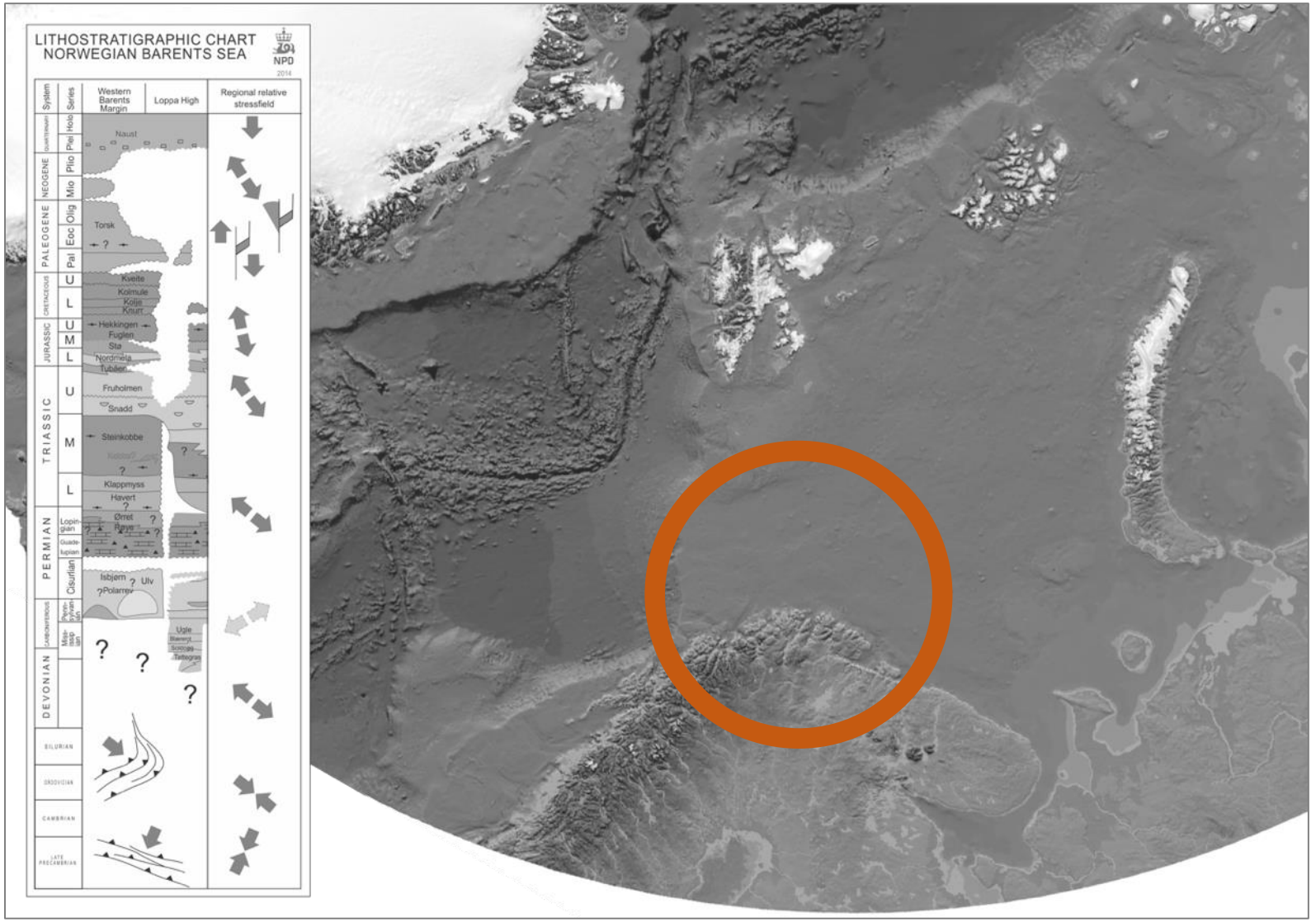
Spitsbergen Orogeny

Uralian Orogeny

Caledonian Orogeny

Timanide Orogeny

Structure of Presentation



Geopolitics

Exploration History

Plate Tectonic Framework

Paleozoic Grabens and Evaporites: why are they important?

Opportunities and Challenges in the Eastern Barents Sea

Opportunities and Challenges in the Central Barents Sea

Opportunities and Challenges in the Western Barents Sea

GEOPOLITICS

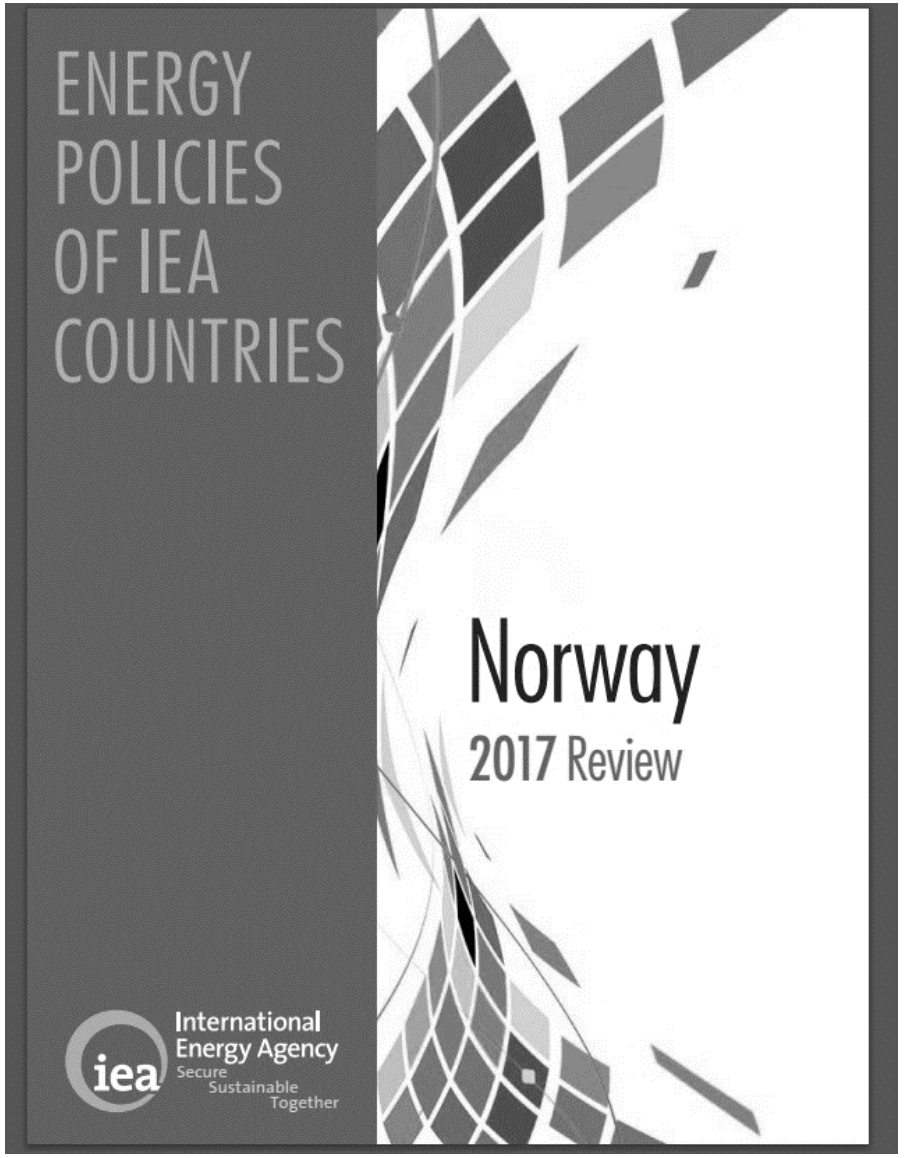
Geopolitics

Predictable and Efficient Energy Supply

Nuclear?

Geopolitics

Fresh IEA report



Key recommendations

The government of Norway should:

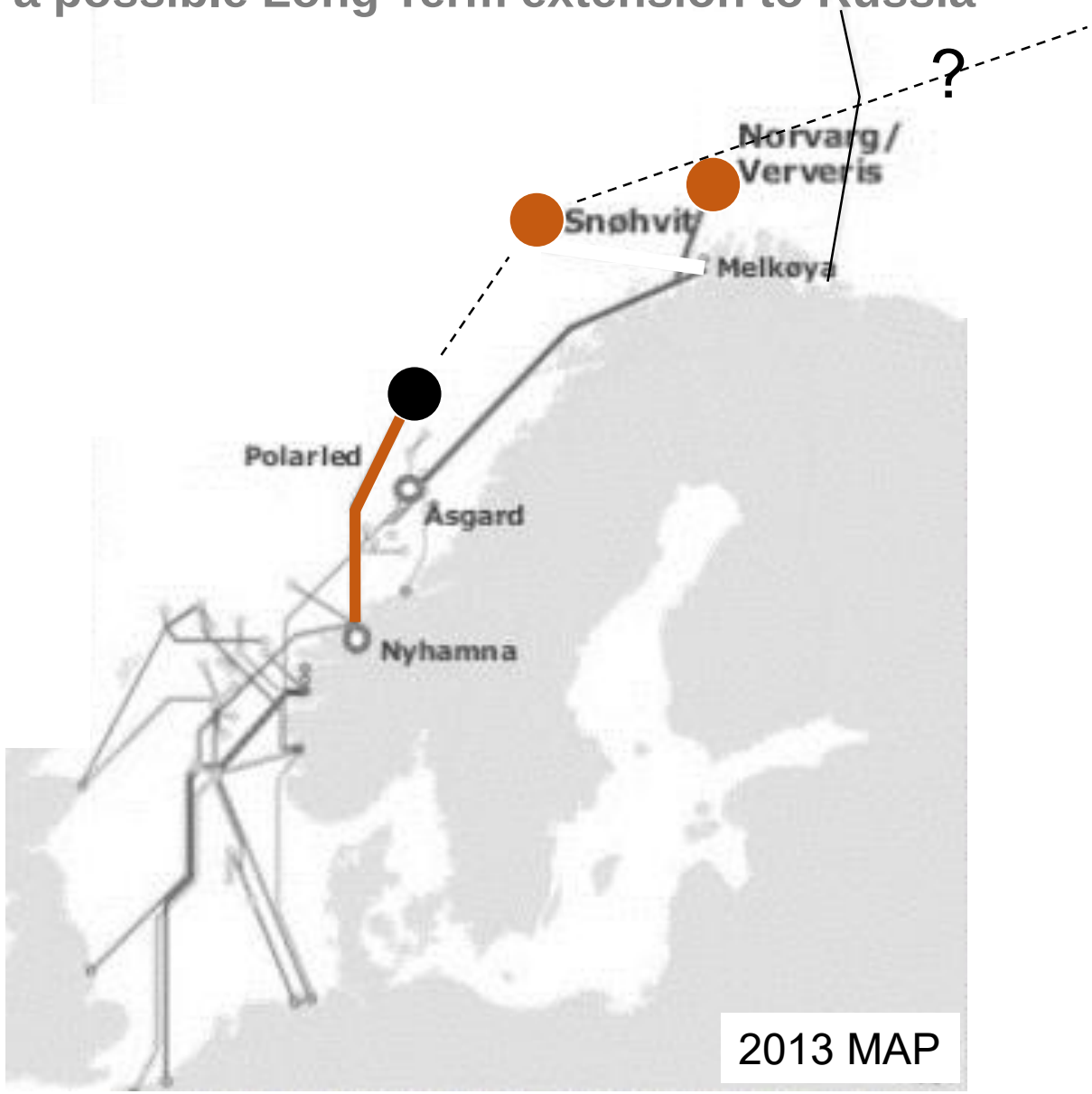
- ☐ Stimulate further increases in oil and gas production from safe and environmentally sustainable operations and consider measures to prepare for a future with lower oil and gas revenues.
- ☐ Continue to support further harmonisation and integration within the Nordic electricity market, facilitate an increase in cross-border connections and demand-side measures to this end, and take measures to encourage market-based investments in low-carbon power generation.
- ☐ Develop a strategy to meet the 2030 and 2050 climate change targets.

Secure
Sustainable
Together

Geopolitics

Gassled and Polarled – and a possible Long Term extension to Russia

130 TCF Shtokman Gas



UK infrastructure based on gas supply

Geopolitics

Nord Stream 2

Financial Investors

uniper · OMV · wintershall BASF Gruppe · ENGIE by people for people

Supplying natural gas to Europe

The Nord Stream 2 pipeline will transport natural gas into the European Union to enhance security of supply, support climate goals and strengthen the internal energy market.

The EU needs to import more gas

Domestic gas production is set to halve in the next two decades, as ageing assets are retired and hard-to-reach North Sea resources become uneconomic. The EU will need to import more gas and will need additional infrastructure to transport these imports. Nord Stream 2 together with other suppliers and supply routes (such as LNG) will meet these requirements – the share between them will be decided by the market.

Russia's geographic proximity, plentiful gas reserves and history of reliable supply make it a natural partner for a new gas transportation route that can enhance gas security.

Natural gas is a lower-carbon fuel

Demand for natural gas is predicted to continue. Natural gas is a lower-carbon fuel that can replace other fossil fuels in the energy mix and deliver a reliable output to complement intermittent renewable energy.

Today, the EU energy mix is still heavily reliant on coal, which produces about twice as much CO_2 as natural gas, and oil, which has 25 percent higher emissions.

https://www.nord-stream2.com/project/rationale/

Geopolitics

BALTIC PIPE: new gas transmission pipeline, connecting Norway, Denmark and Poland

"Baltic Pipe is a potential new gas pipeline that would provide Denmark and Poland with a direct acces to Norway's gas fields"

https://en.energinet.dk/Infrastructure-Projects/Projektliste/BalticPipe

PROJECT OF COMMON INTEREST

The Baltic Pipe project has been included on EU's list of important infrastructure projects – so-called Projects of Common Interest (PCI) – which are deemed essential to the integration of the European energy networks. As a result, the project has been granted EU funds to perform a feasibility study. Find an abstract of the feasibility study here.

Learn more about PCI

Co-financed by the European Union
Connecting Europe Facility

"WIN-WIN FOR BOTH DENMARK AND POLAND

A feasibility study has shown that both Denmark and Poland are poised to gain from Baltic Pipe:

In Denmark, the massive volumes of gas transported from Norway to Poland through Baltic Pipe would create optimal conditions for a significant drop in transport tariffs for the Danish gas transmission system, which in turn would benefit Danish consumers and businesses. At the same time, Denmark's direct access to Norway's gas fields would also improve Denmark's security of supply and increase competition in the gas market.

Similarly to other Central and Eastern European countries, Poland is dependent on gas from Russia. Baltic Pipe, in conjunction with a newly constructed Polish receiving station for liquid gas (LNG), will give Poland and its neighbour's access to alternative sources of supply which in turn would improve security of supply.

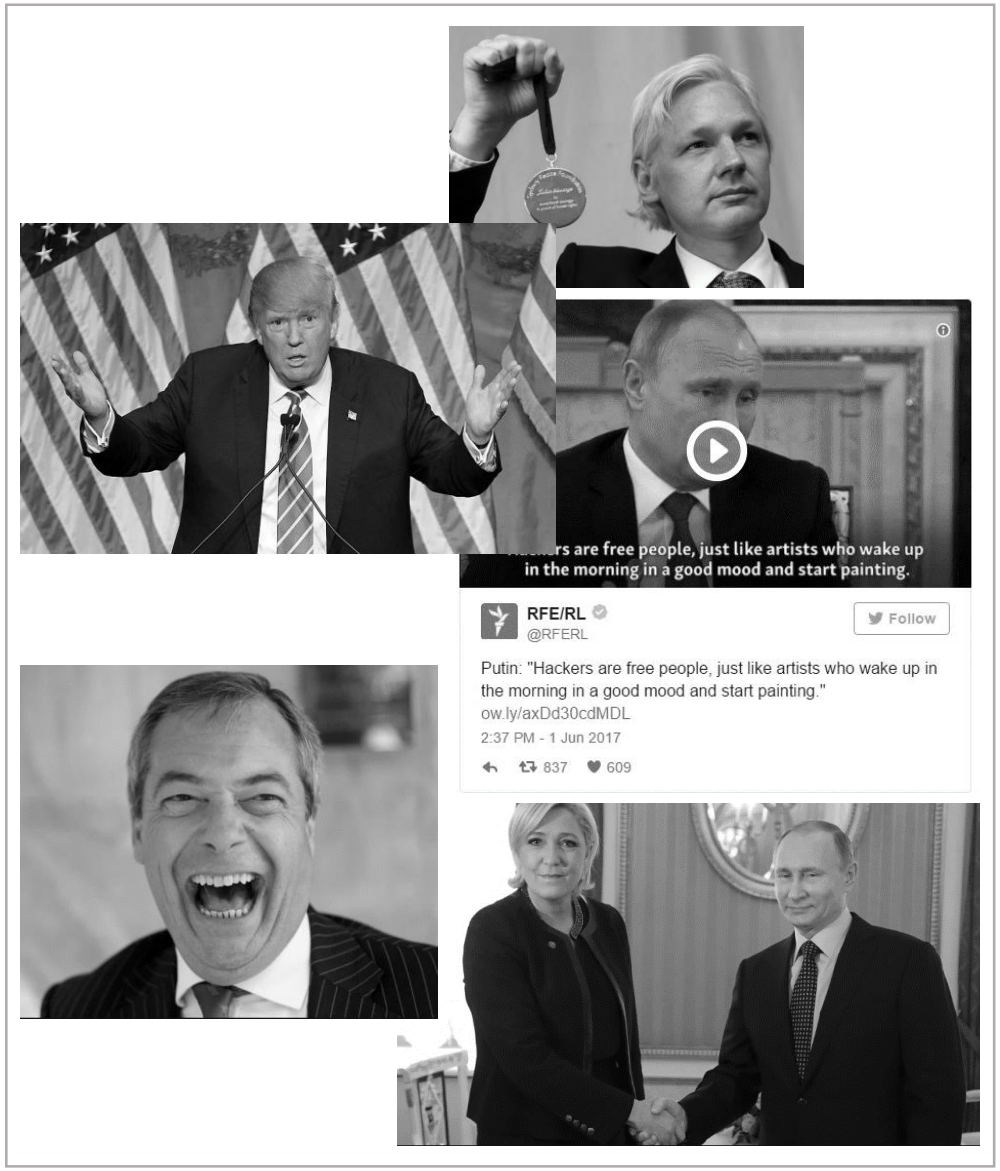
IMPORTANT EUROPEAN PROJECT

EU has included Baltic Pipe on its list of key infrastructure projects that are of common interest to Europe – also known as "PCI projects". This is due to the essential role Baltic Pipe could play in contributing to the development of Europe's internal market for gas, and the fortification of EU's security of supply." *https://en.energinet.dk/Infrastructure-Projects/Projektliste/BalticPipe*

New slide included after June 2nd presentation

Geopolitics

Looking for predictability?

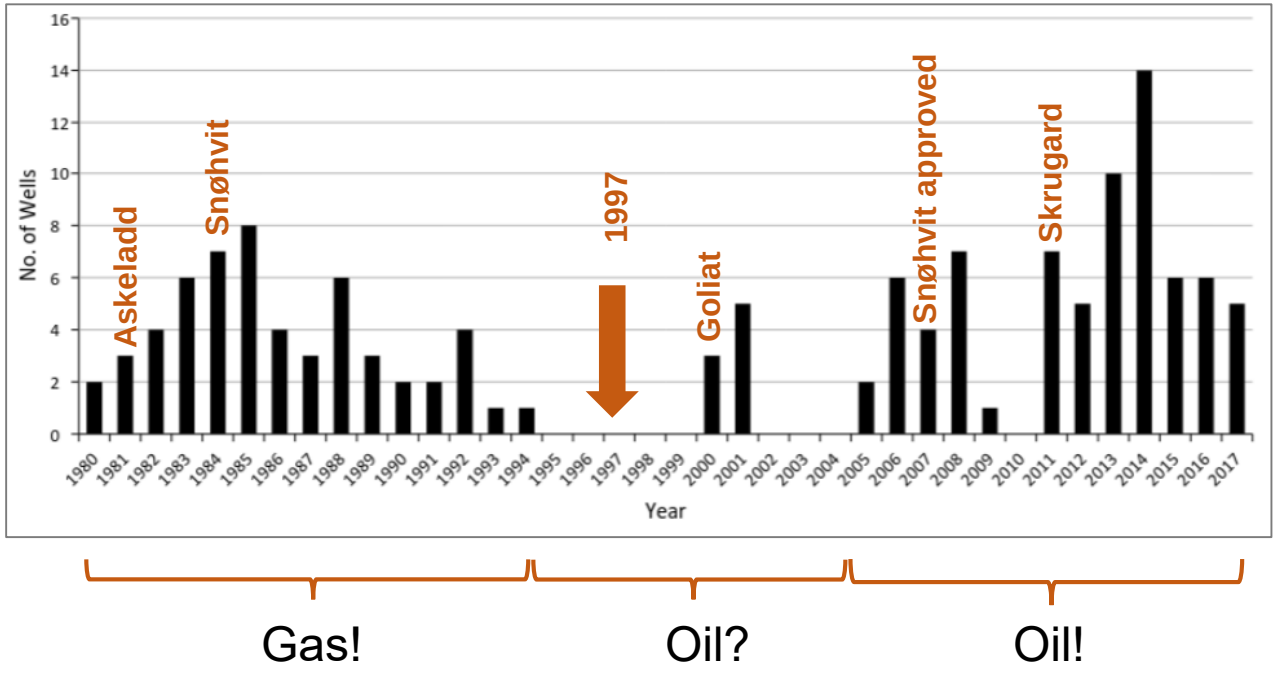


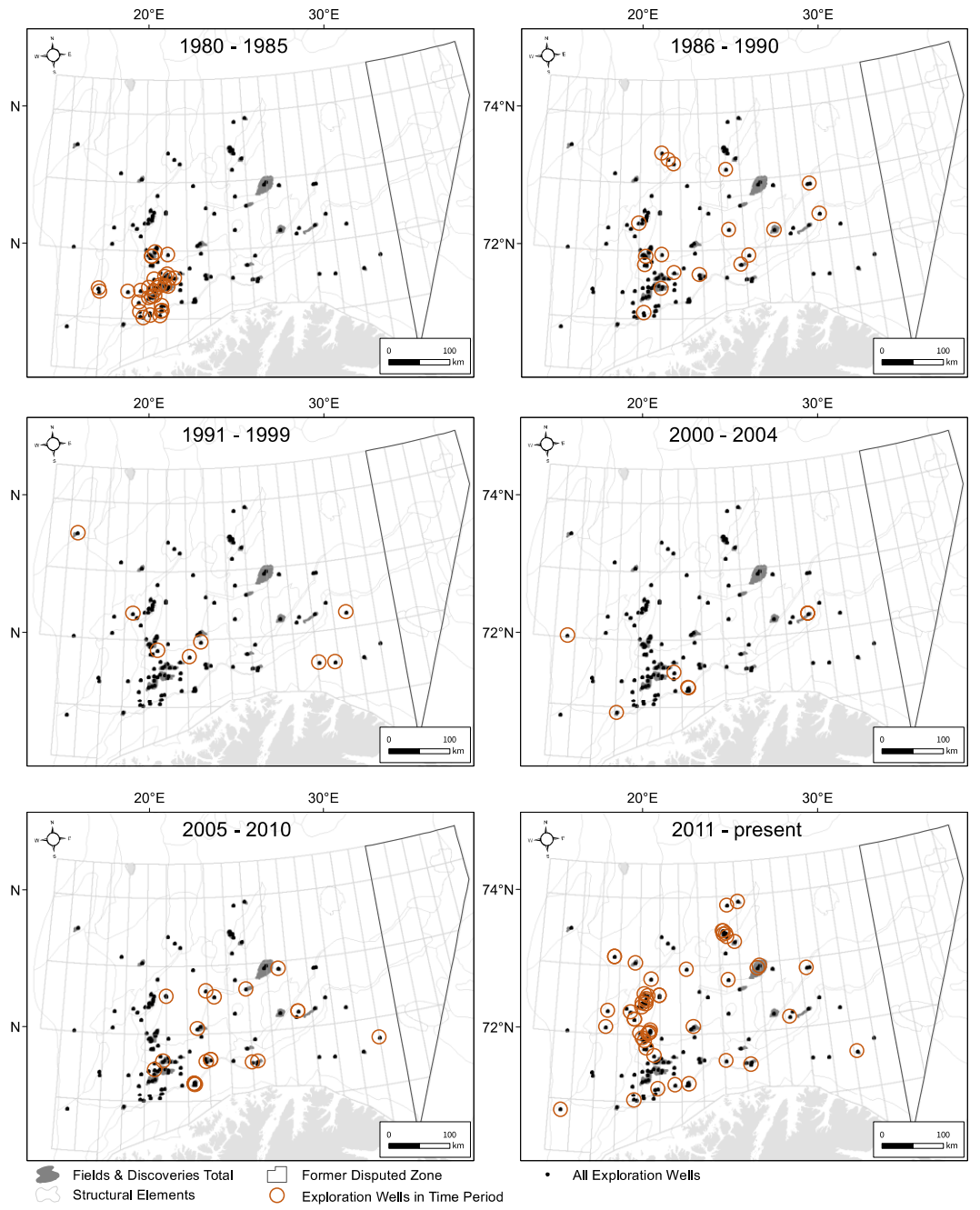
or

EXPLORATION HISTORY

Exploration History

Nearly four Decades of Exploration



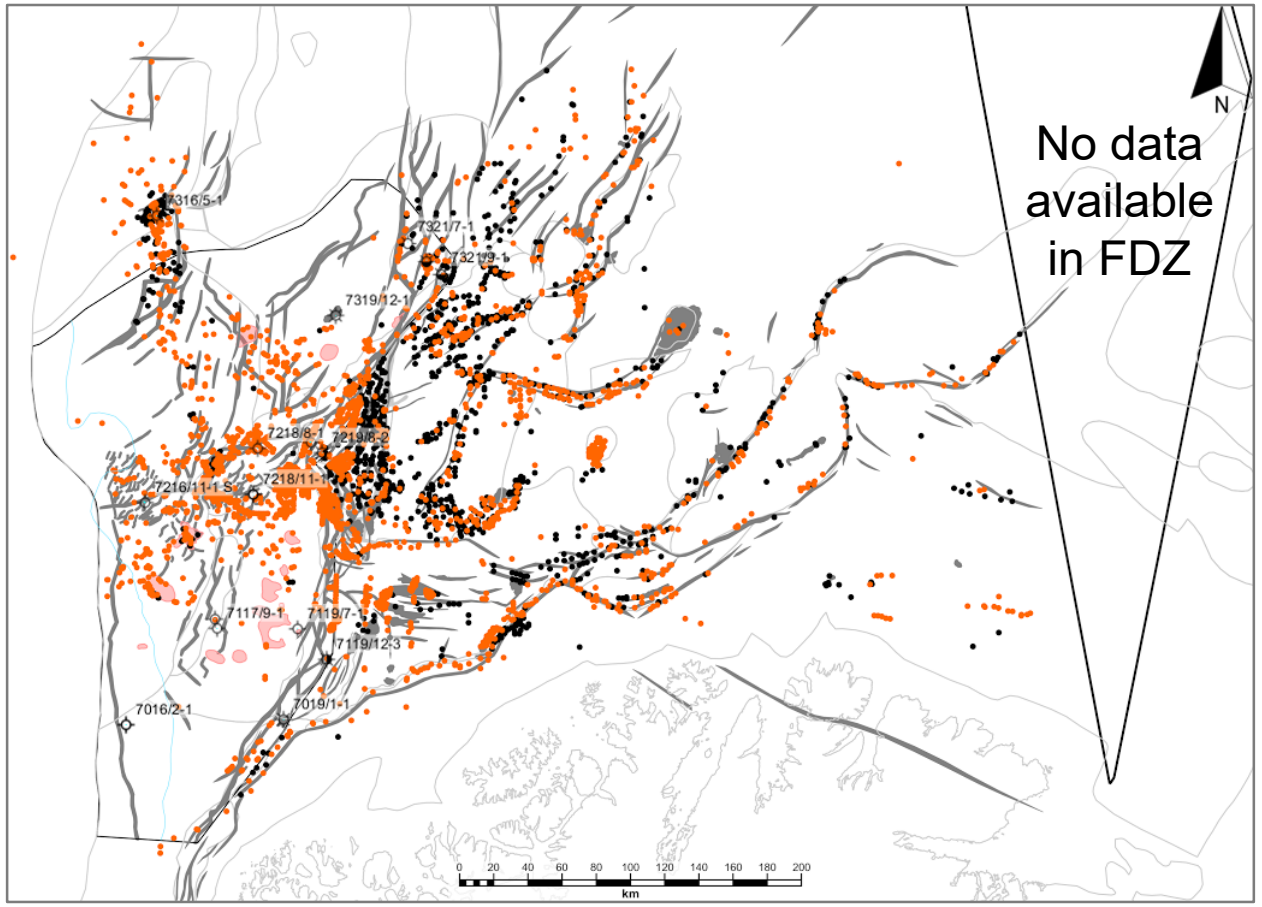


Exploration History

Source Rock Indications on Regional Scale

Main Source Rocks

- **Upper Cretaceous Albian-Turonian**
- **Lower Cretaceous Aptian**
- **Upper Jurassic Hekkingen**
- Steinkobbe?
- Permian?



Observed HC indications in seismic data: East versus West

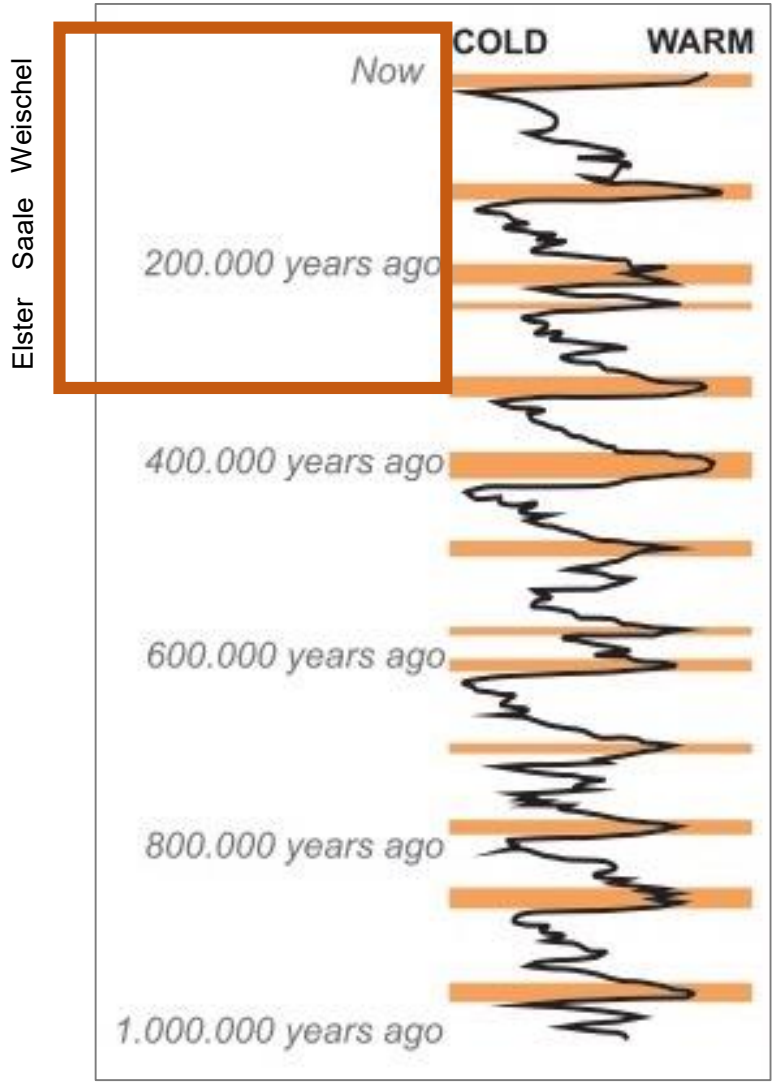
Vadakkepuliyambatta et al. (2013)

Main Source Rocks

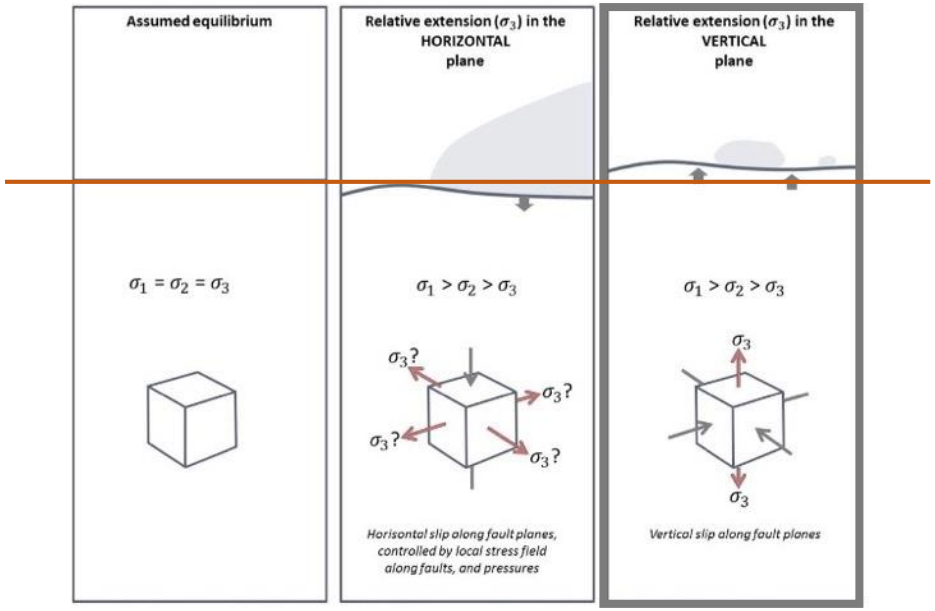
- *(Hekkingen immature)*
- Triassic restricted basins?
- Triassic regional?
- **Permian**
- Carboniferous?
- Devonian?

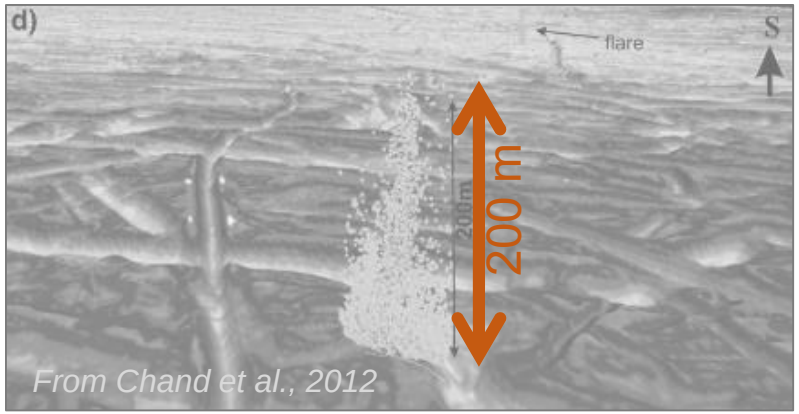
Exploration History

Challenges in the West



Fault leakage expected during every interglacial cycle

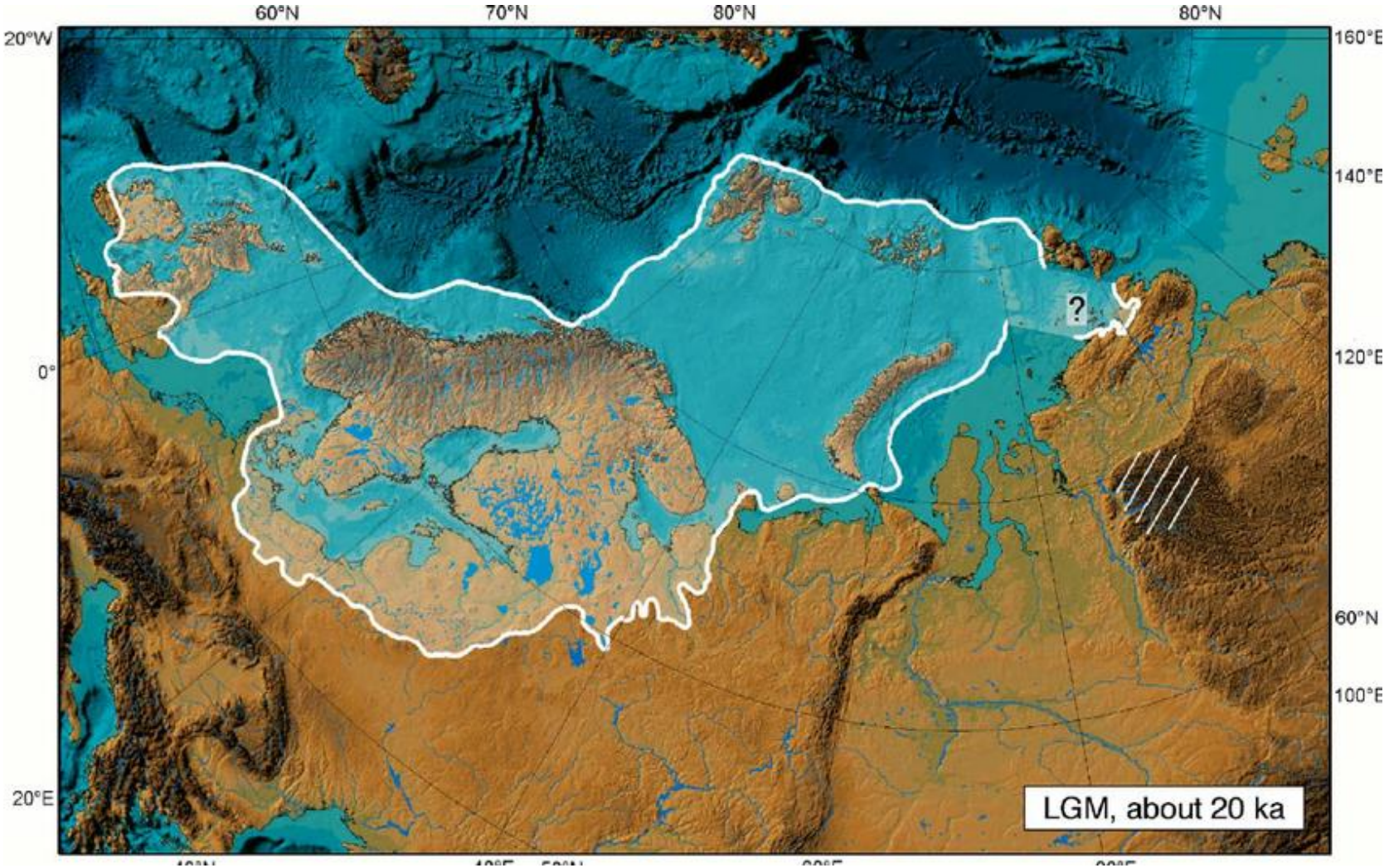




Present day fault leakage where major fault systems intersect

Exploration History

Impact of Glaciations and Interglaciations extends far south of Barents Sea

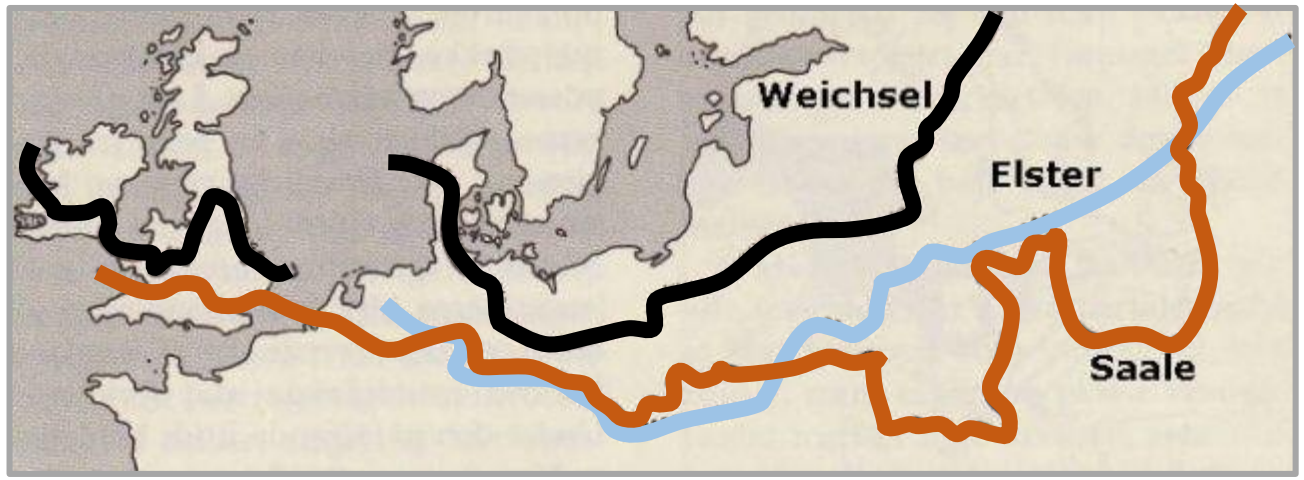


Reconstruction of the Eurasian ice sheet at the last glacial Weischel maximum

https://www.researchgate.net/figure/235703913_fig16_Fig-16-A-reconstruction-of-the-Eurasian-ice-sheets-at-the-Late-Weichselian-glacial

Exploration History

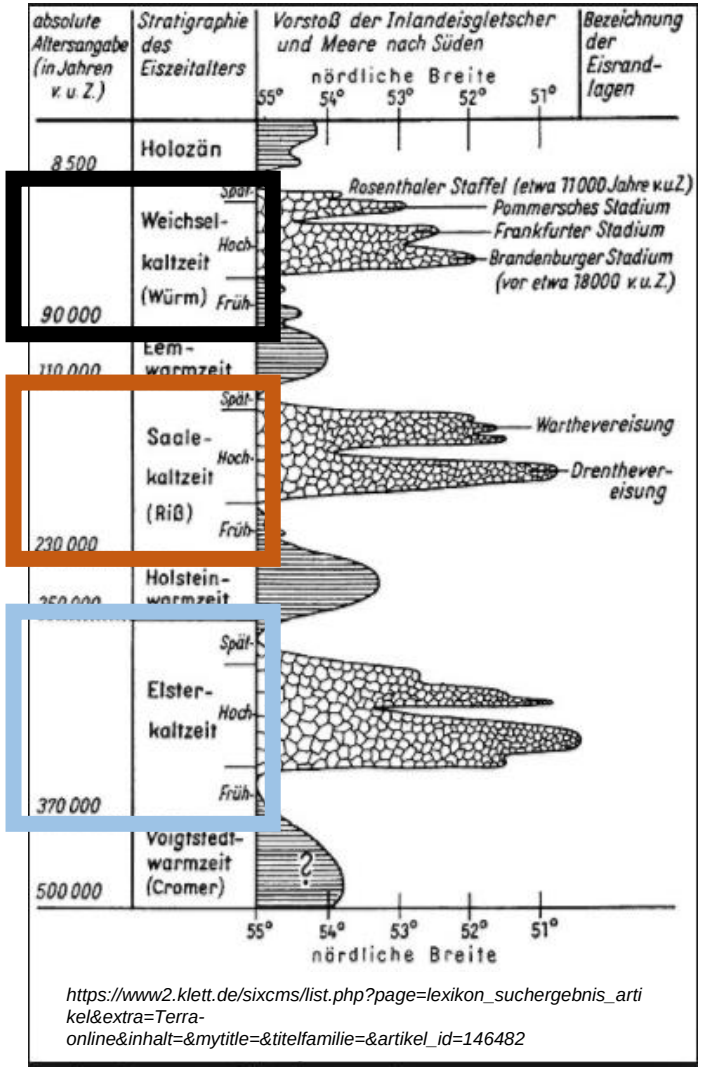
Impact of Glaciations and Interglaciations extends far south of Barents Sea



The rest of the NCS was also covered by ice sheets during the last three glaciations, including Utsira High, so why is there HC leakage in one place and not the other?

Is it due to the thin or absent Paleogene and Neogene sections in places?

Or could there be more to it that we don't yet understand?



https://www2.klett.de/sixcms/list.php?page=lexikon_suchergebnis_artikel&extra=Terra-online&inhalt=&mytitle=&titelfamilie=&artikel_id=146482

http://geocenter.dk/xpdf/geoviden-2-2005.pdf

Exploration History

Can it really be that bad?

- Hekkingen Fm oil from Bjørnøya Basin migrated into Johan Castberg*
- Oil from Tromsø Basin in Filicudi?
- Possible oil shows in Pingvin well?

Ref: (Olaf Thiessen, Statoil, NCS Recent Discoveries Conference, May 11th 2016)

An overview map illustrating the main findings and reasons for failures in the Western Barents Sea.

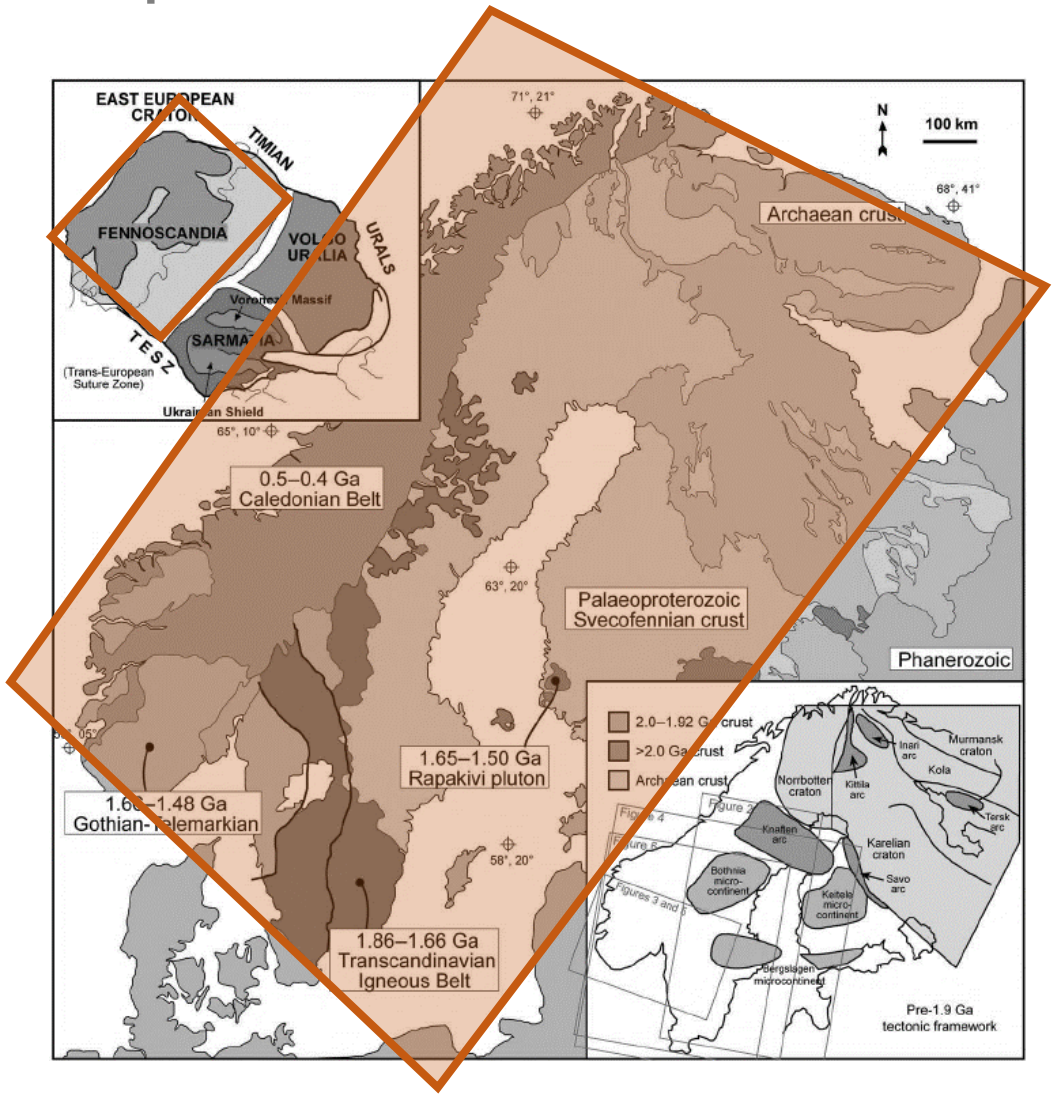
The oil that has migrated into the Johan Castberg area appears to come from Bjørnøya Basin.

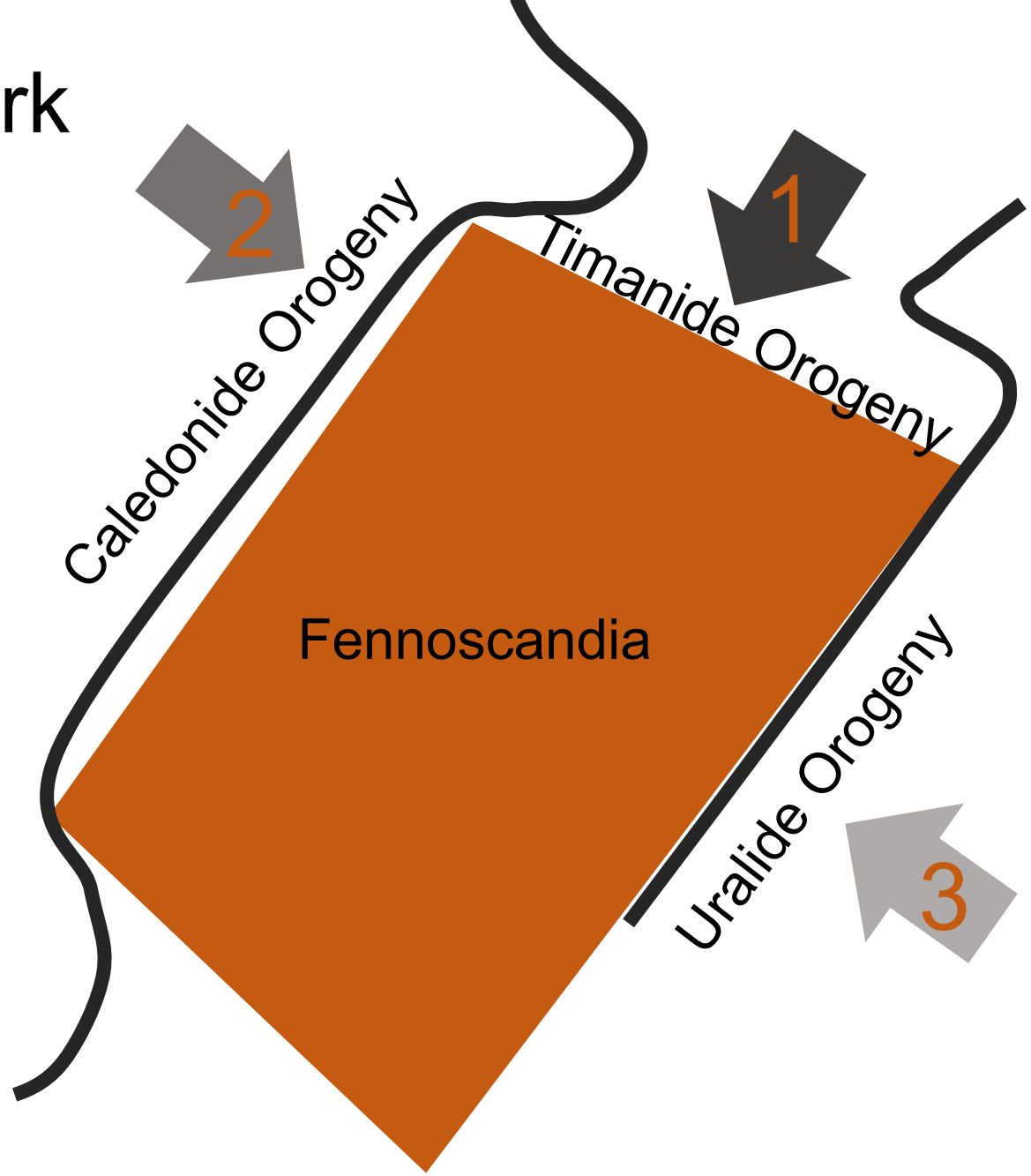
But which area does the Filicudi oil come from? From the south? And if so, which source rock is the primary source rock for the oil found in the discovery?

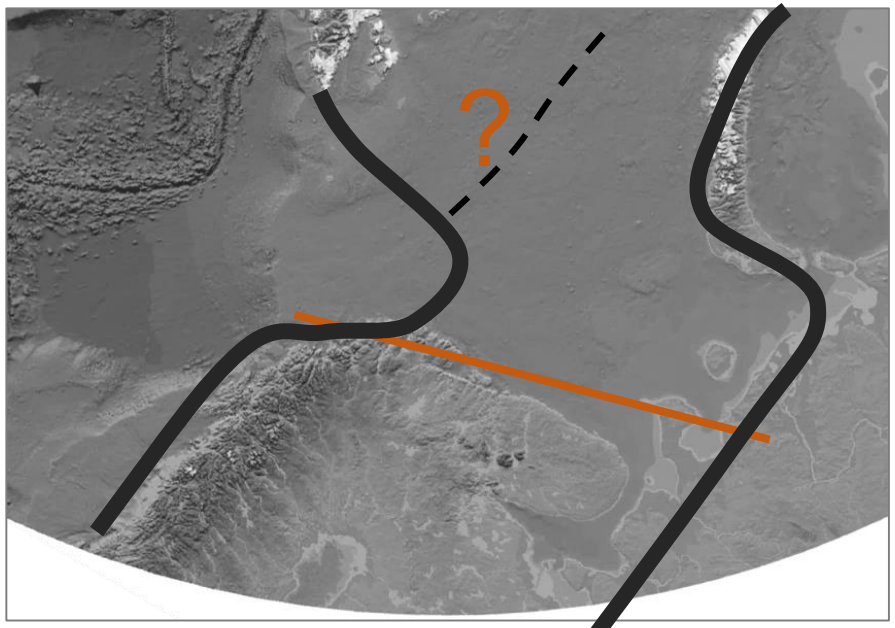
PLATE TECTONIC FRAMEWORK

Plate Tectonic Framework

Simplified






?

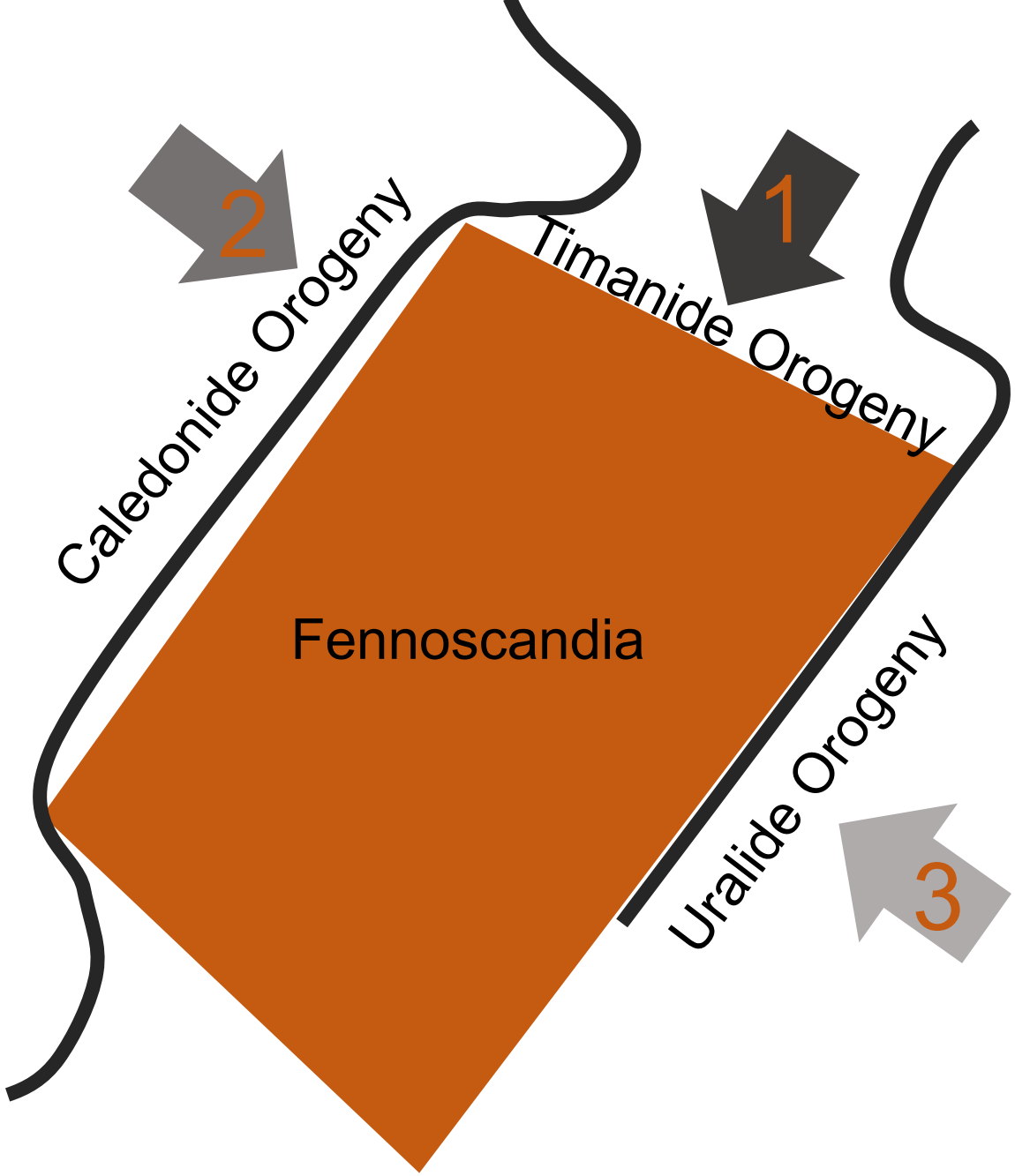
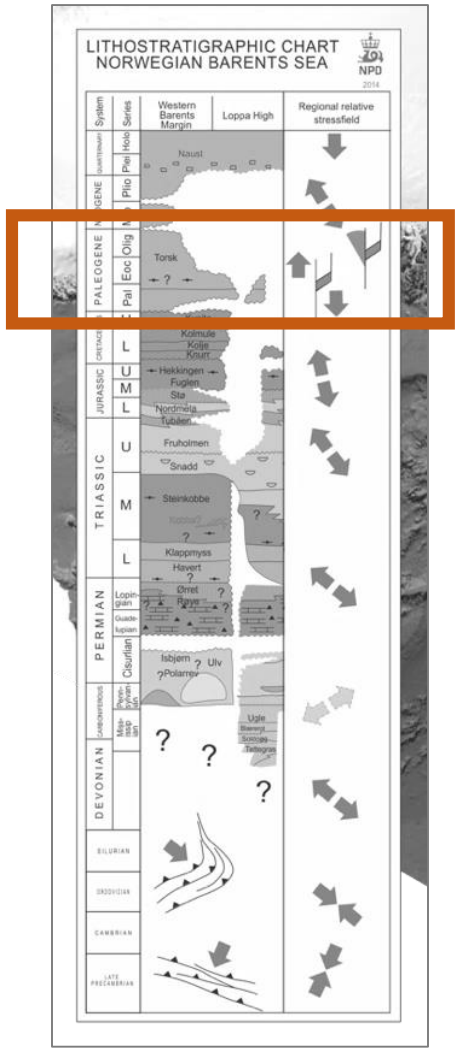
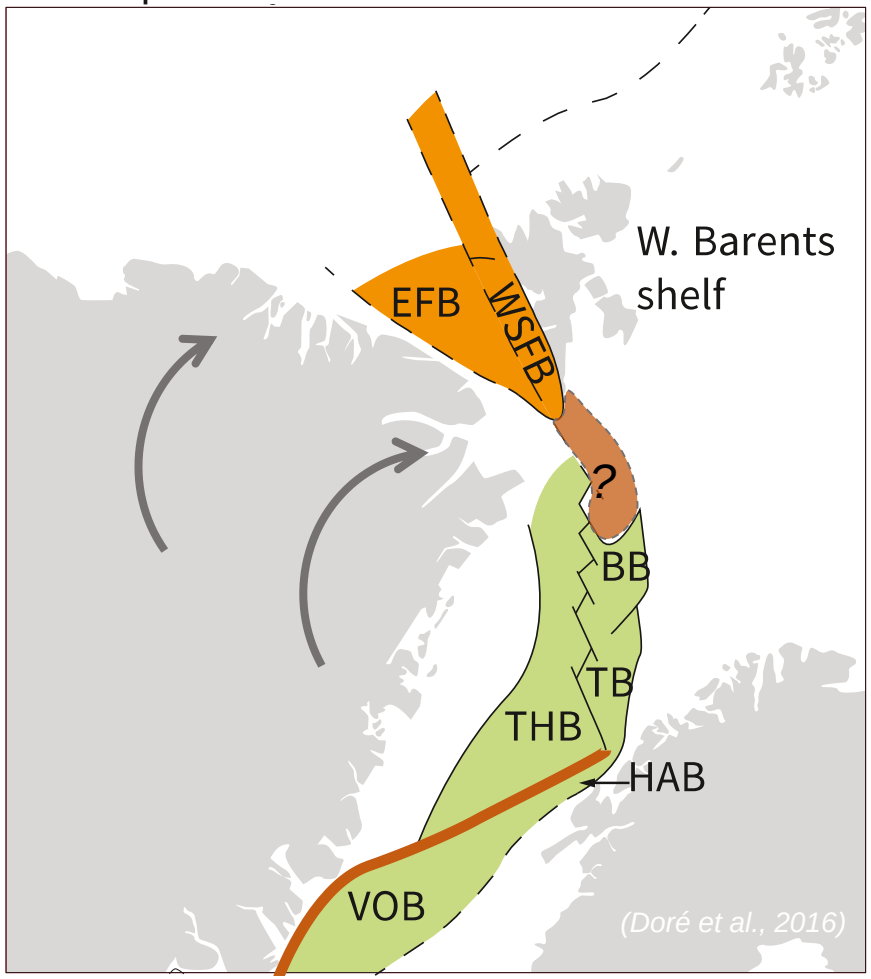

2
1
Caledonide Orogeny
Timanide Orogeny
Fennoscandia
Uralide Orogeny
3

Plate Tectonic Framework

Paleocene Atlantic Opening and Spitsbergen Orogeny



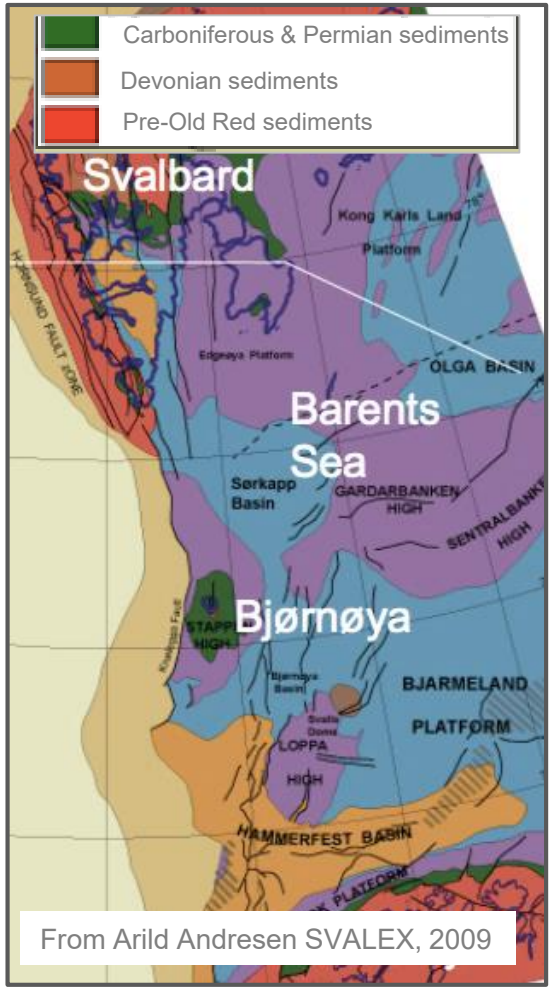
Breakup



Ocean floor
Micro continent
Orogen
Cenozoic basin
Cretaceous basin
Active or incipient spreading ridge

Possible extension of the Spitsbergen Orogeny to include Stappen High?

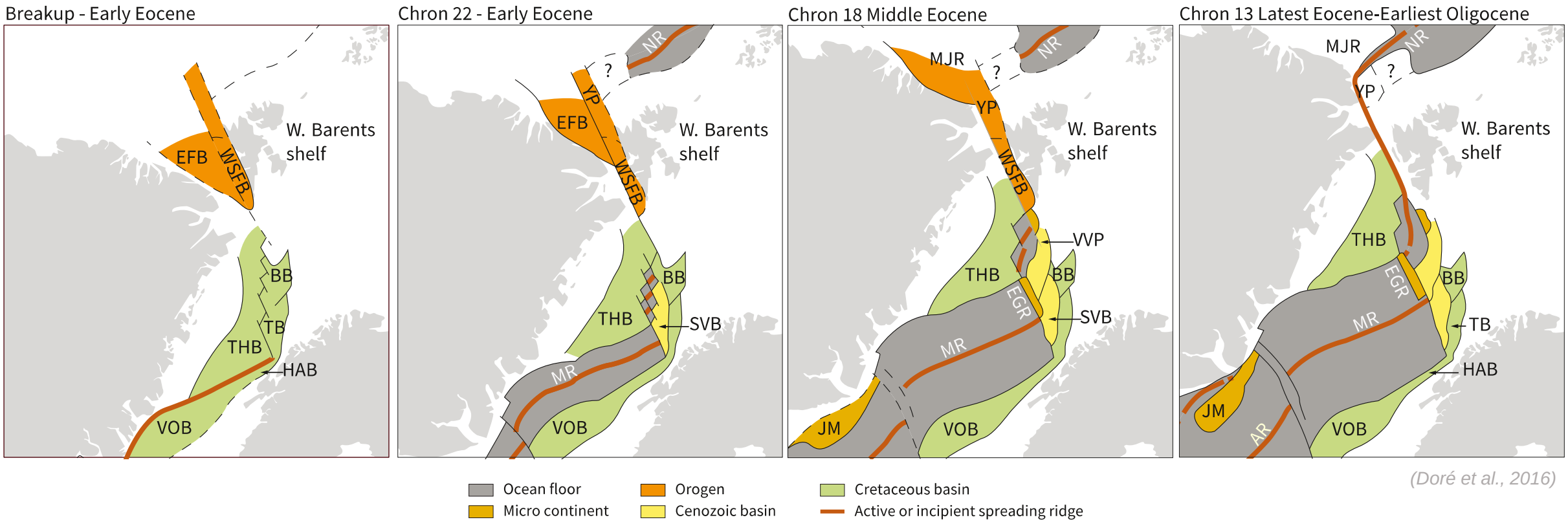
Implications for magnitude of maximum burial and estimated uplift and erosion in the Stappen High area, if this is correct.



From Arild Andresen SVALEX, 2009

Plate Tectonic Framework

Eocene Atlantic Opening

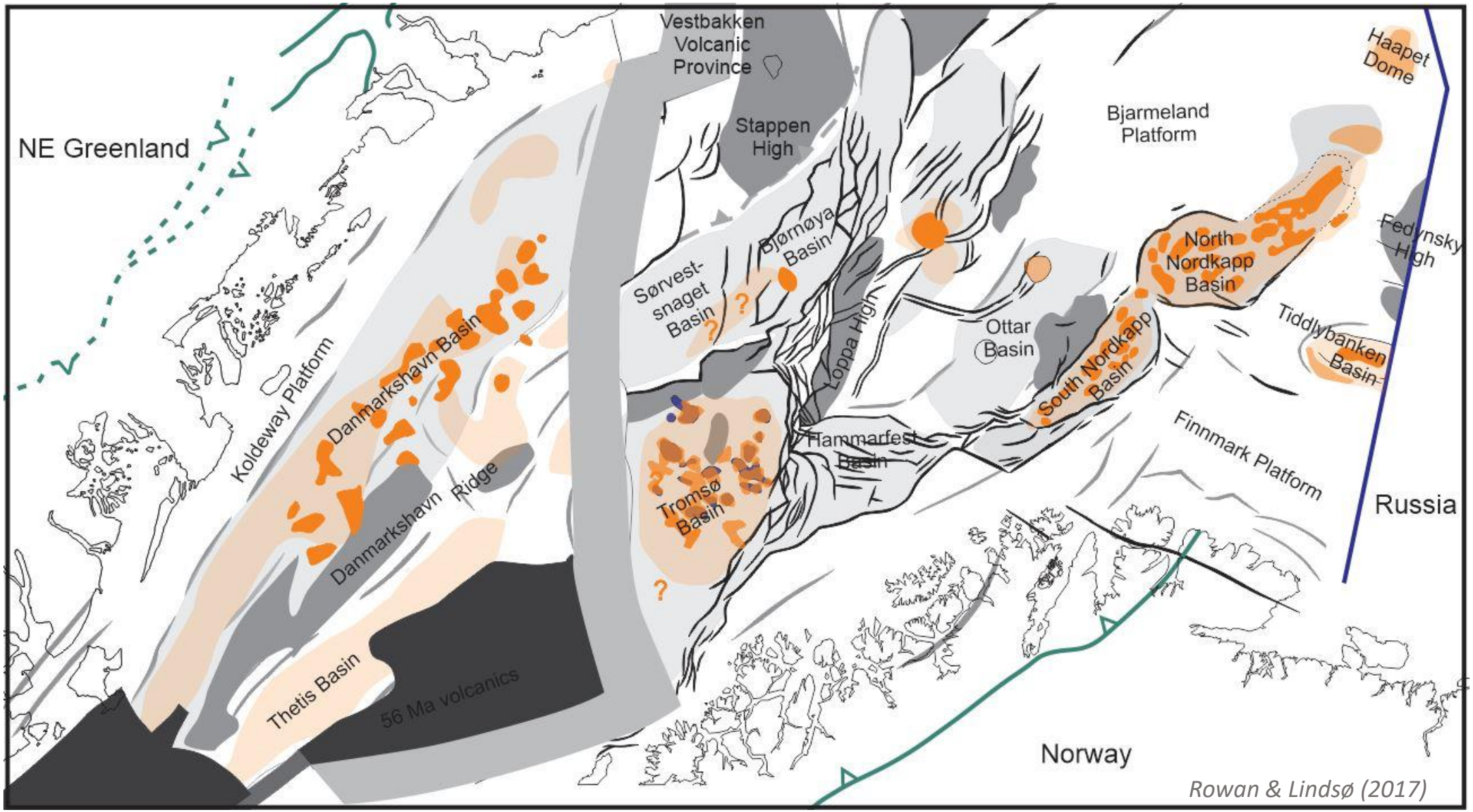


(Doré et al., 2016)

PALEOZOIC GRABENS AND EVAPORITES

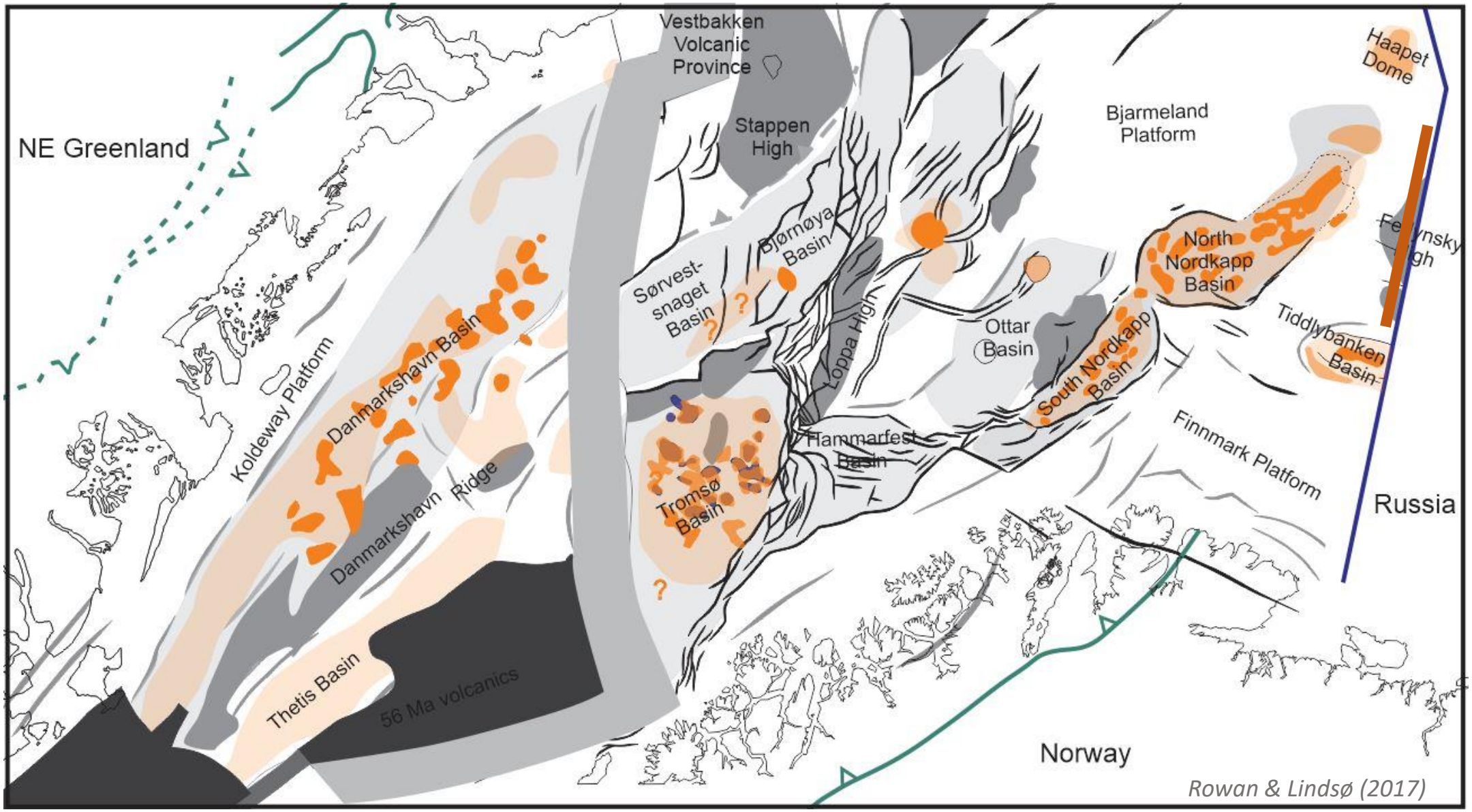
Why are they important?

Paleozoic Grabens and Evaporites



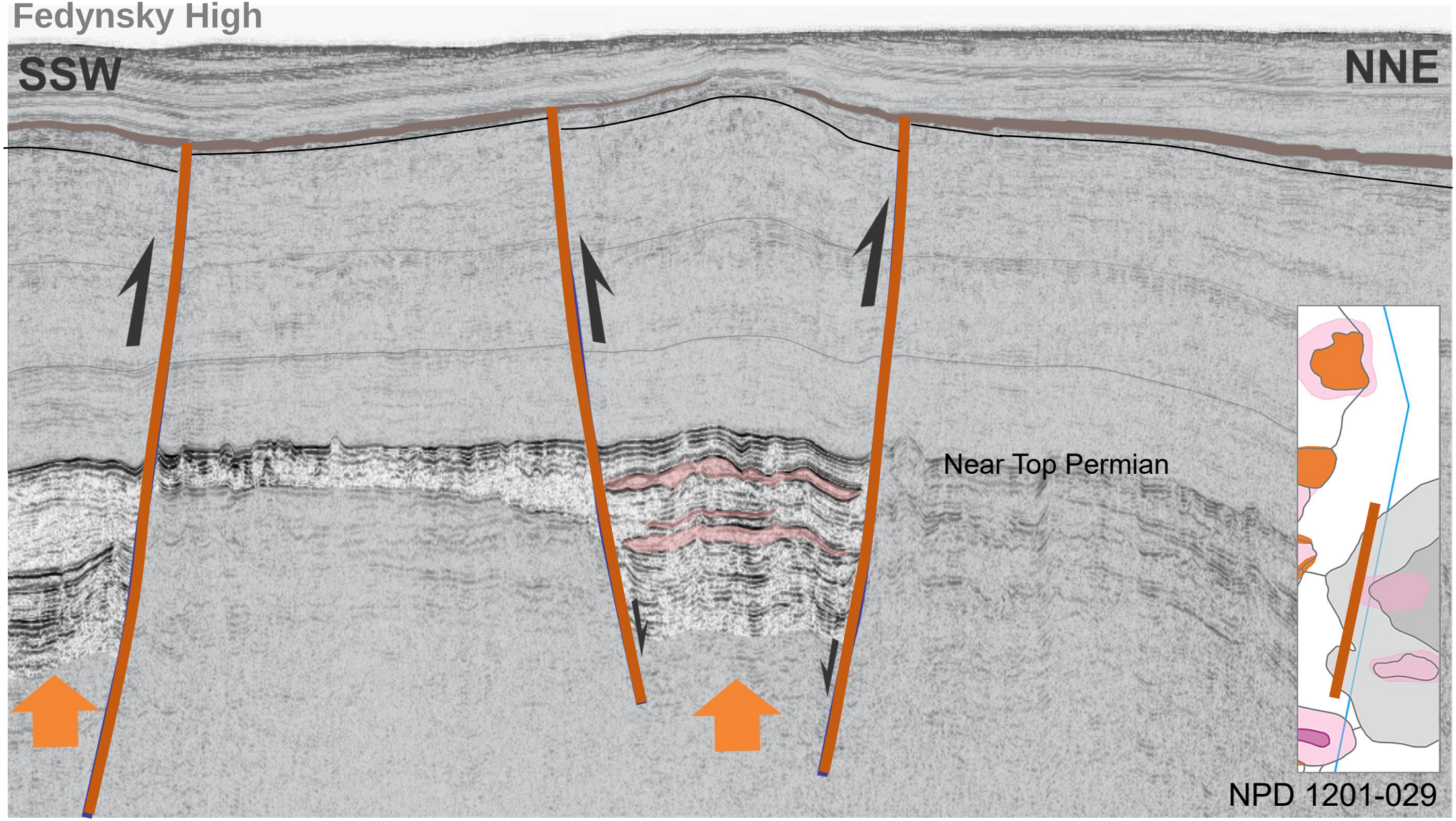
Rowan & Lindsø (2017)

Paleozoic Grabens and Evaporites



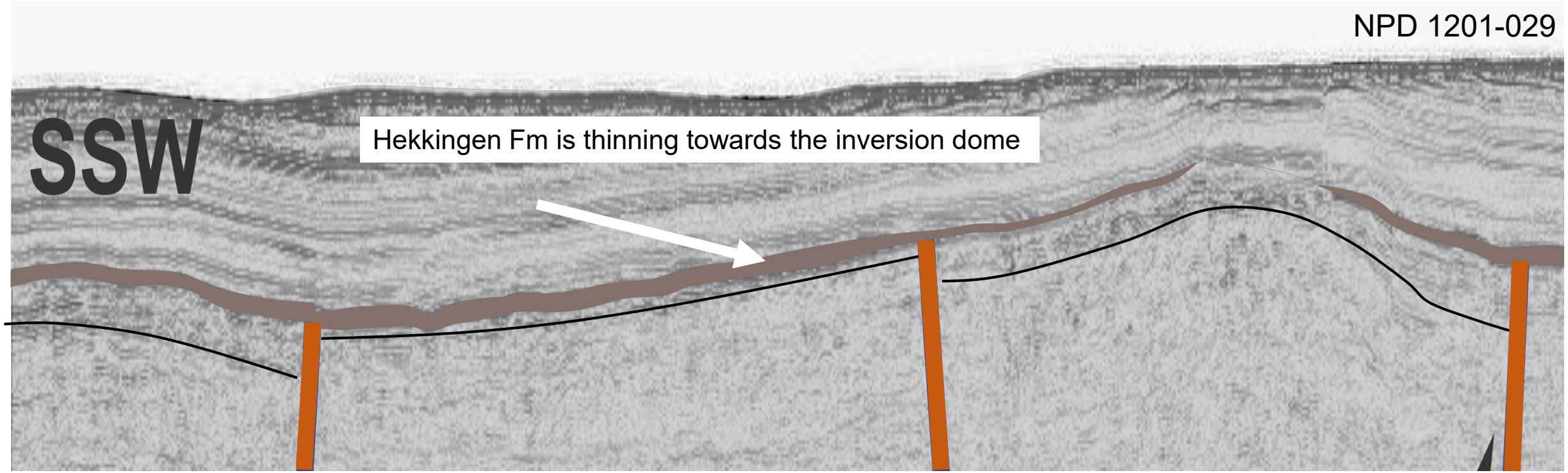
Rowan & Lindsø (2017)

Paleozoic Grabens and Evaporites



Paleozoic Grabens and Evaporites

Fedynsky High

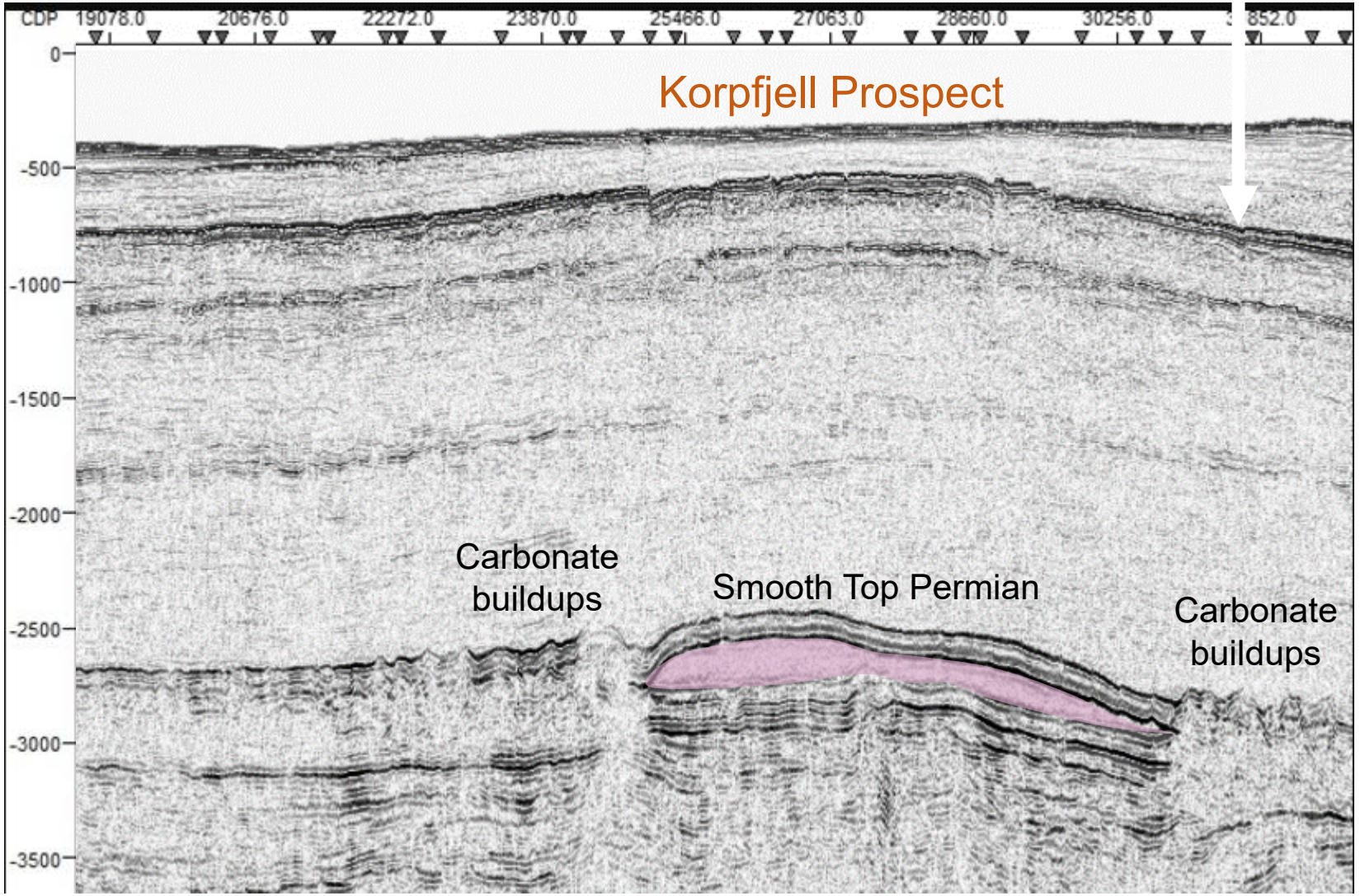


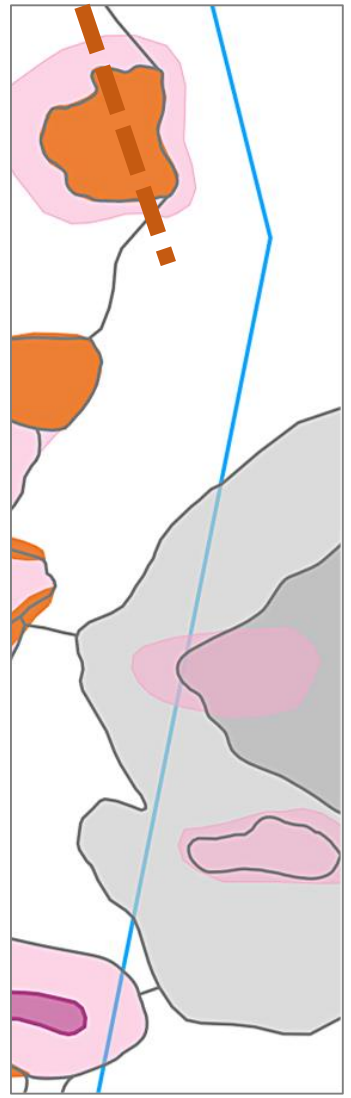
Where is the reservoir preserved?

Paleozoic Grabens and Evaporites

Haapet Dome

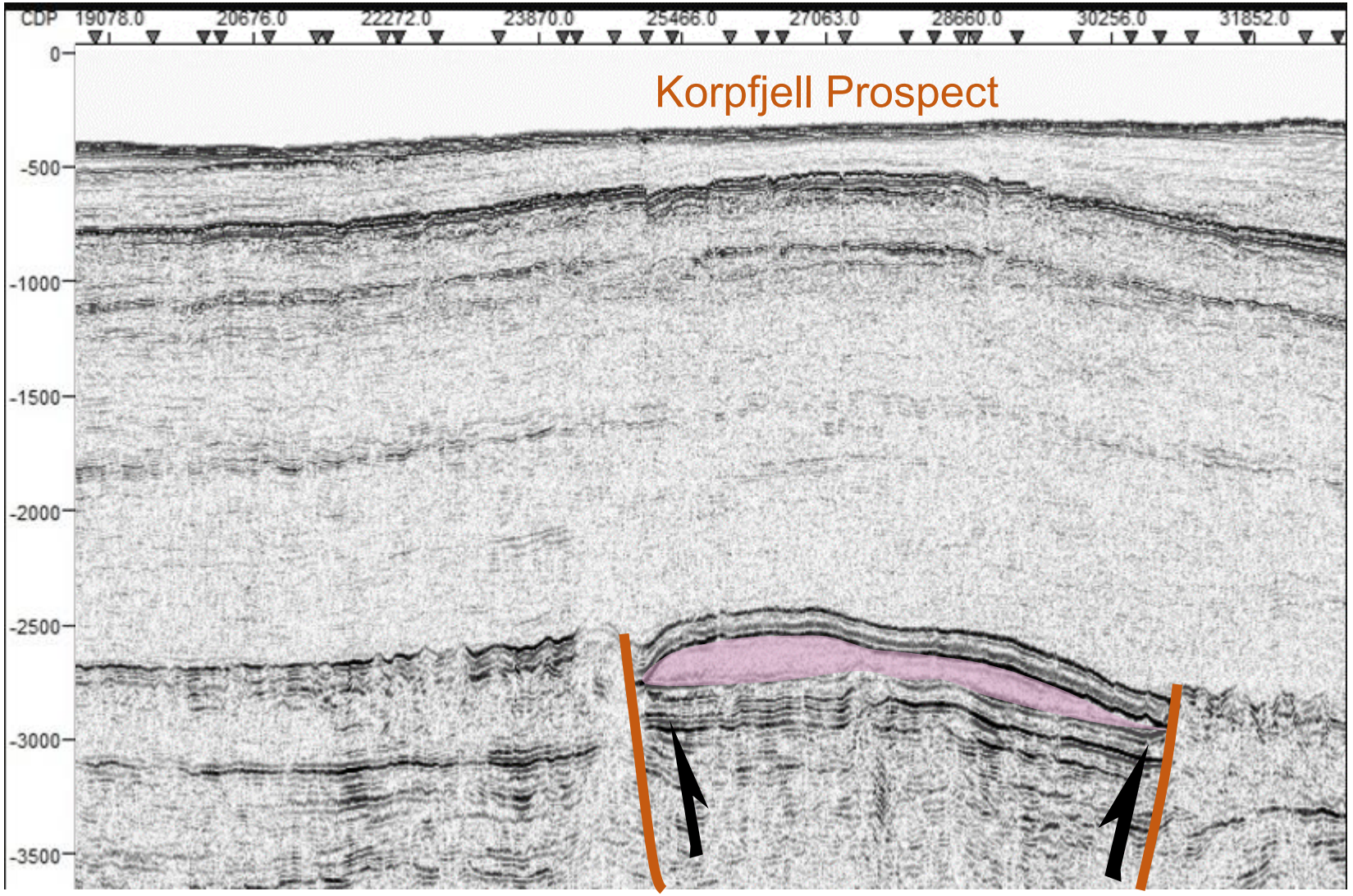
Hekkingen Fm is thinning towards the inversion dome

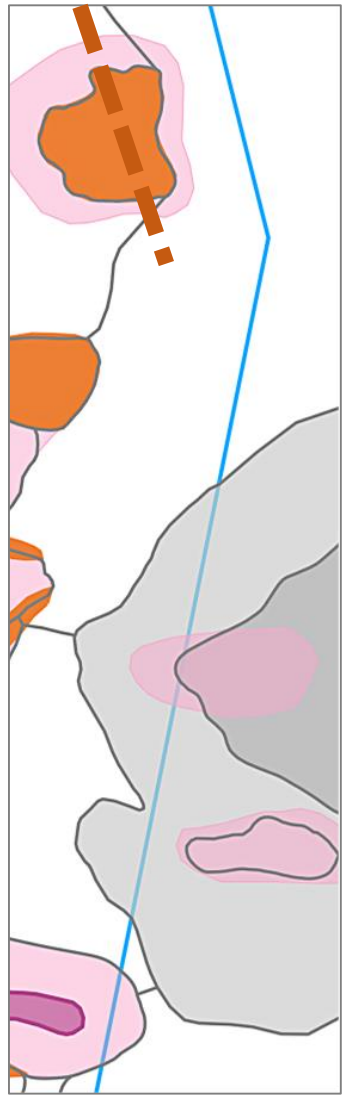




Paleozoic Grabens and Evaporites

Haapet Dome

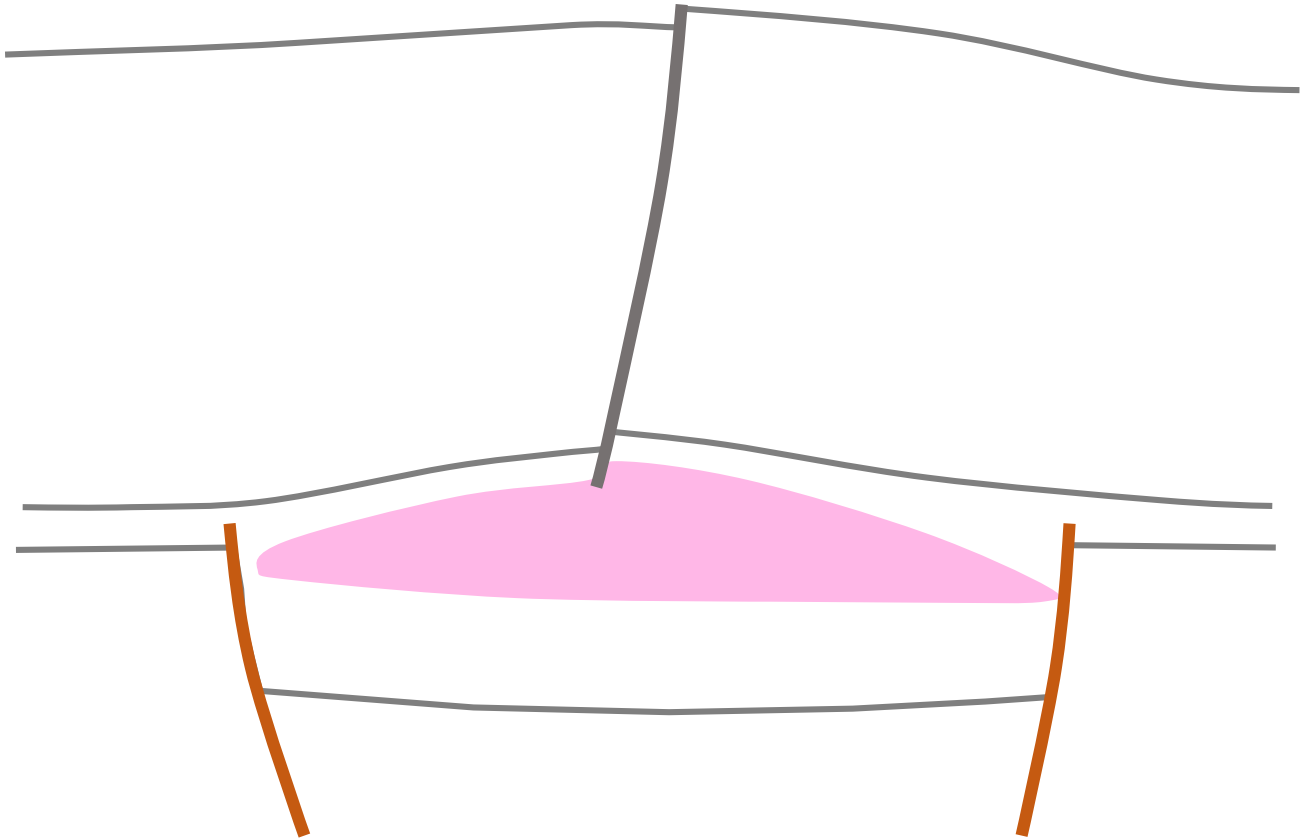


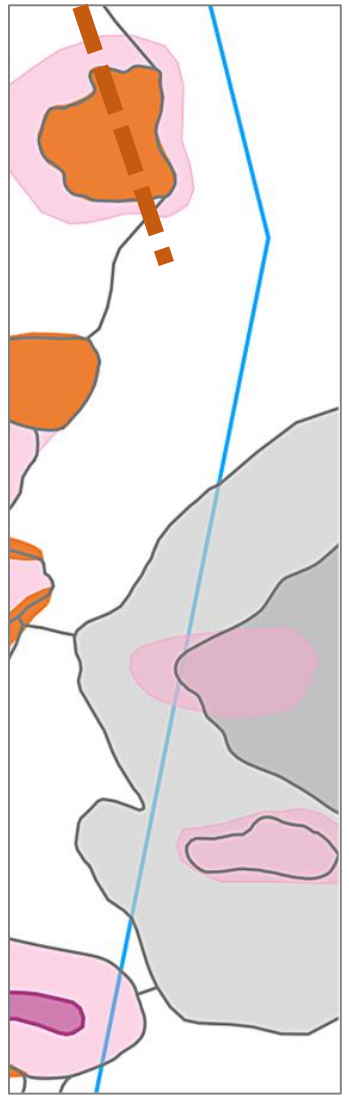


Inverted Paleozoic Graben

Paleozoic Grabens and Evaporites

Haapet Dome



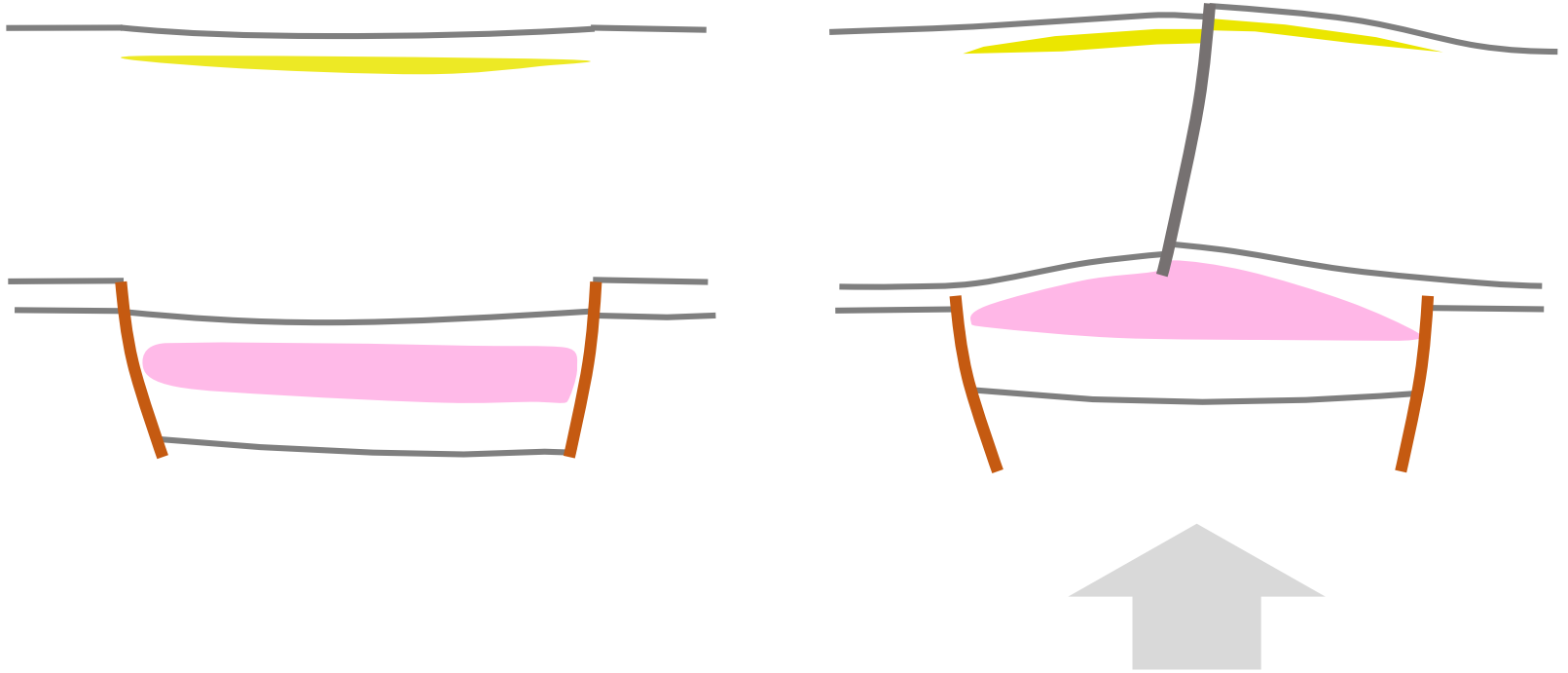


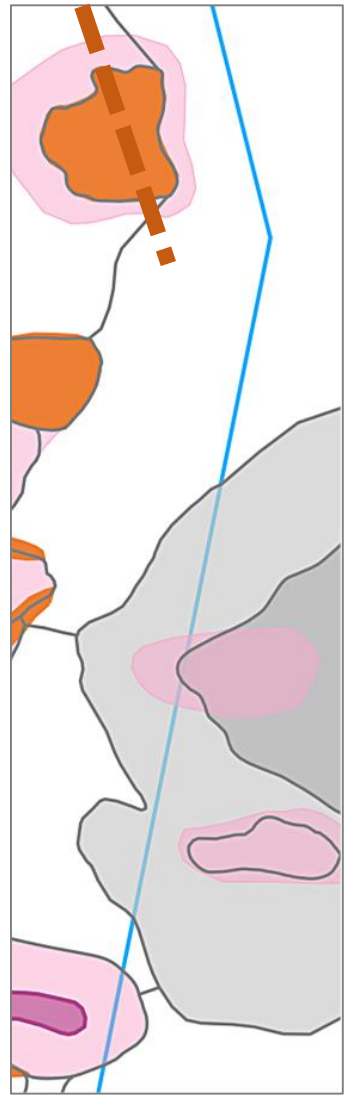
Chasing the assumption that the salt has 'actively generated' the dome (Triassic)

NO RESERVOIR

Paleozoic Grabens and Evaporites

Haapet Dome





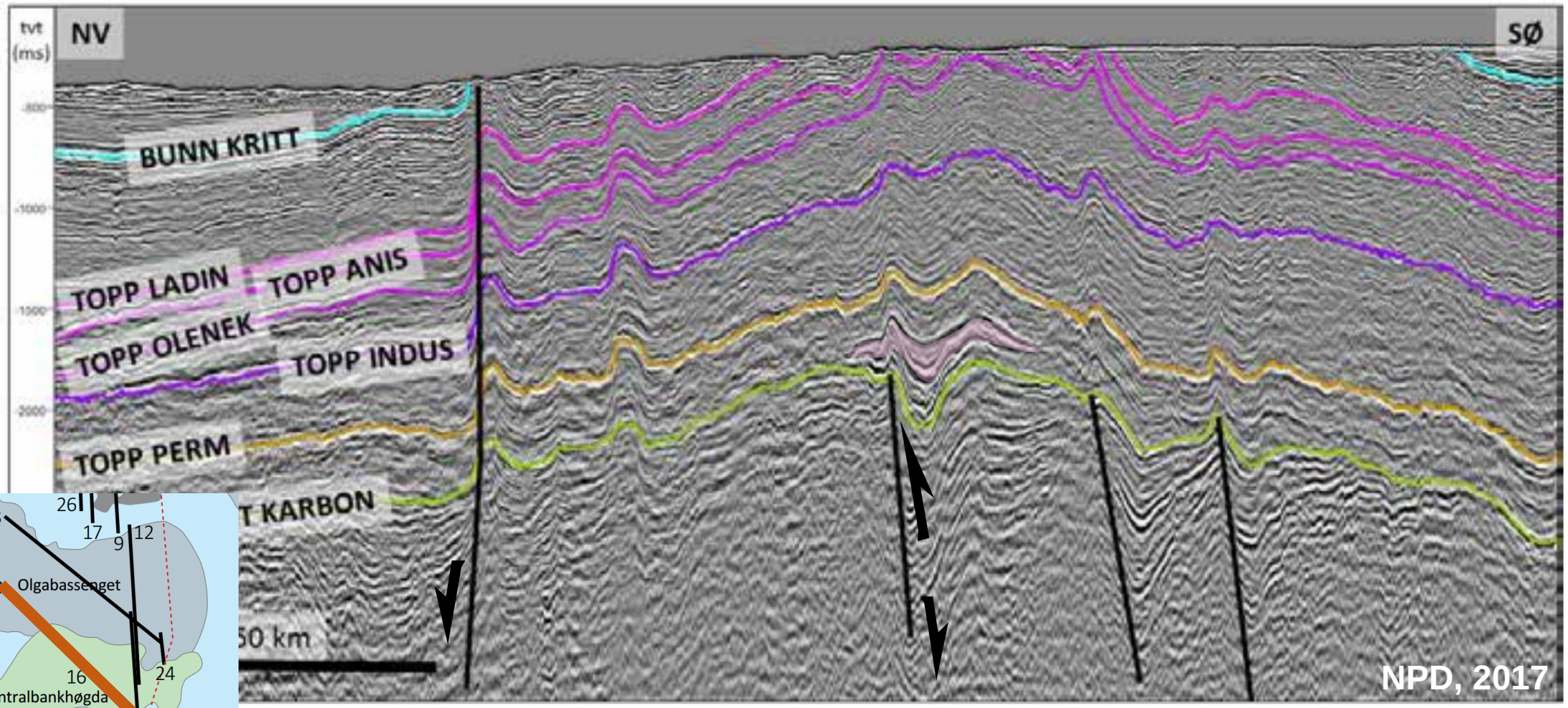
Hypothesis: inverted graben structure and perfect timing:

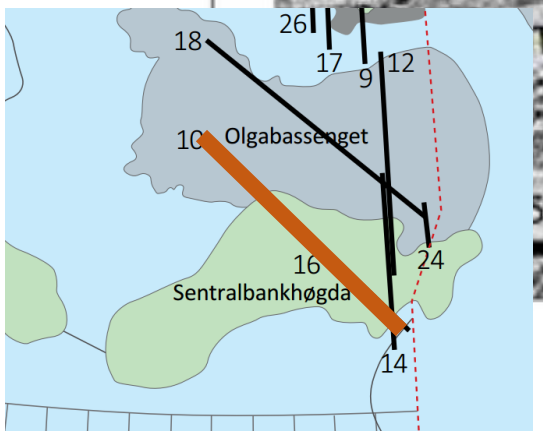
RESERVOIR PRESENT

(check this with spectral decompositon)

Paleozoic Grabens and Evaporites

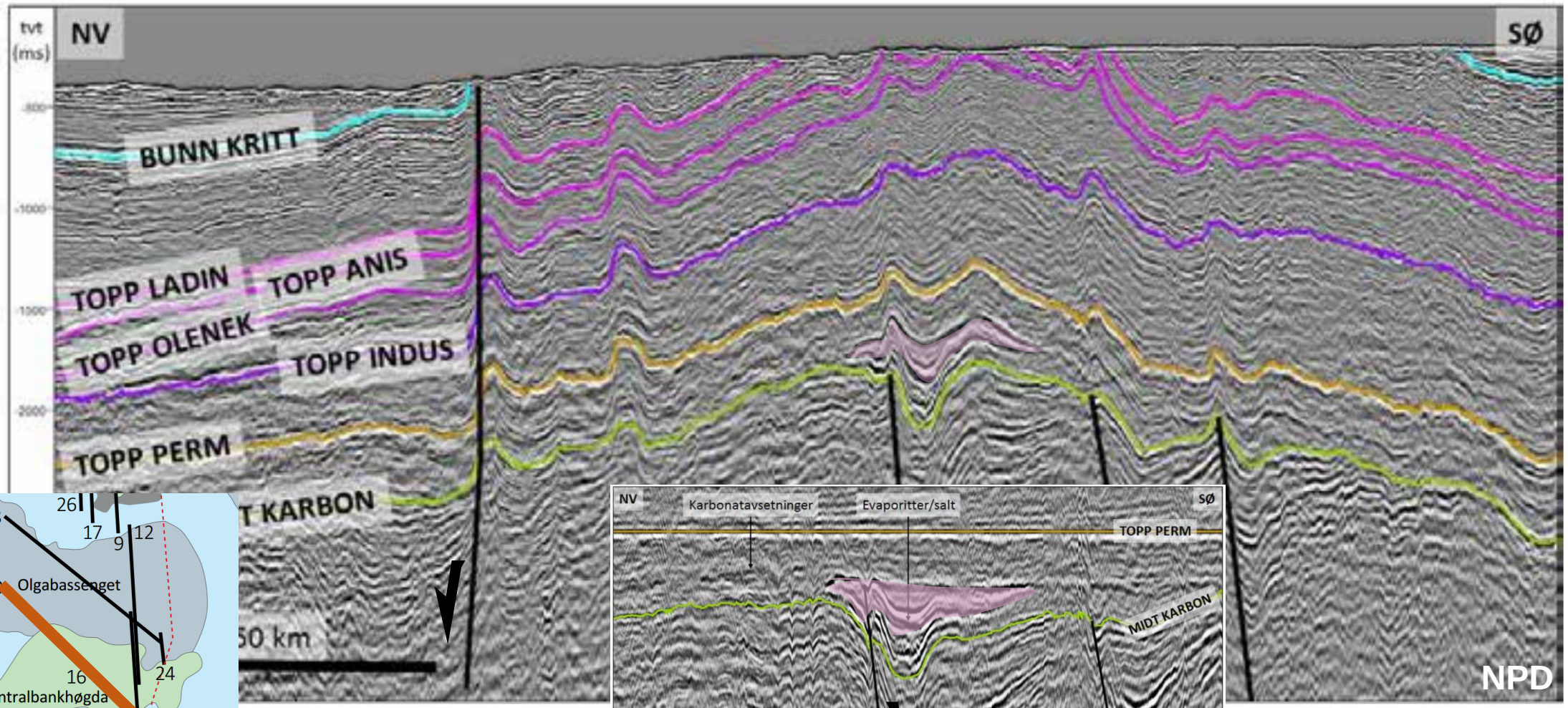
Barents Sea North

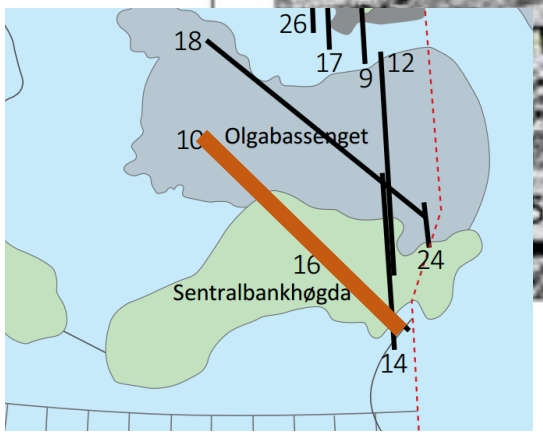




Paleozoic Grabens and Evaporites

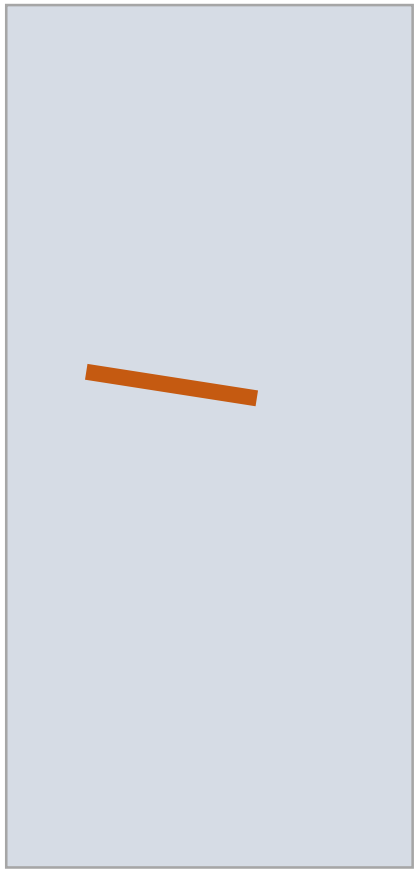
Haapet Dome

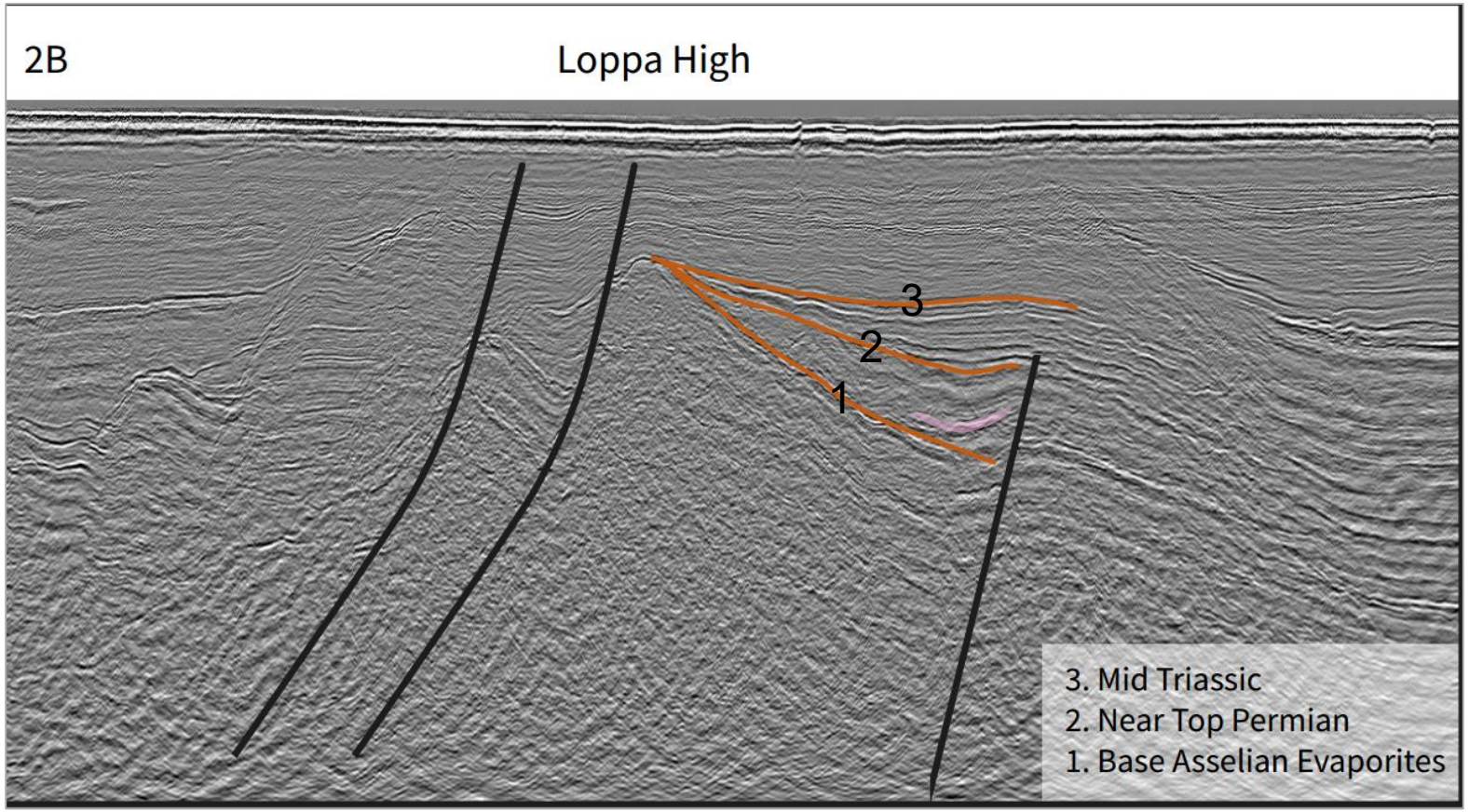




Paleozoic Grabens and Evaporites

Loppa High





BUT WHY ALL THAT SALT?

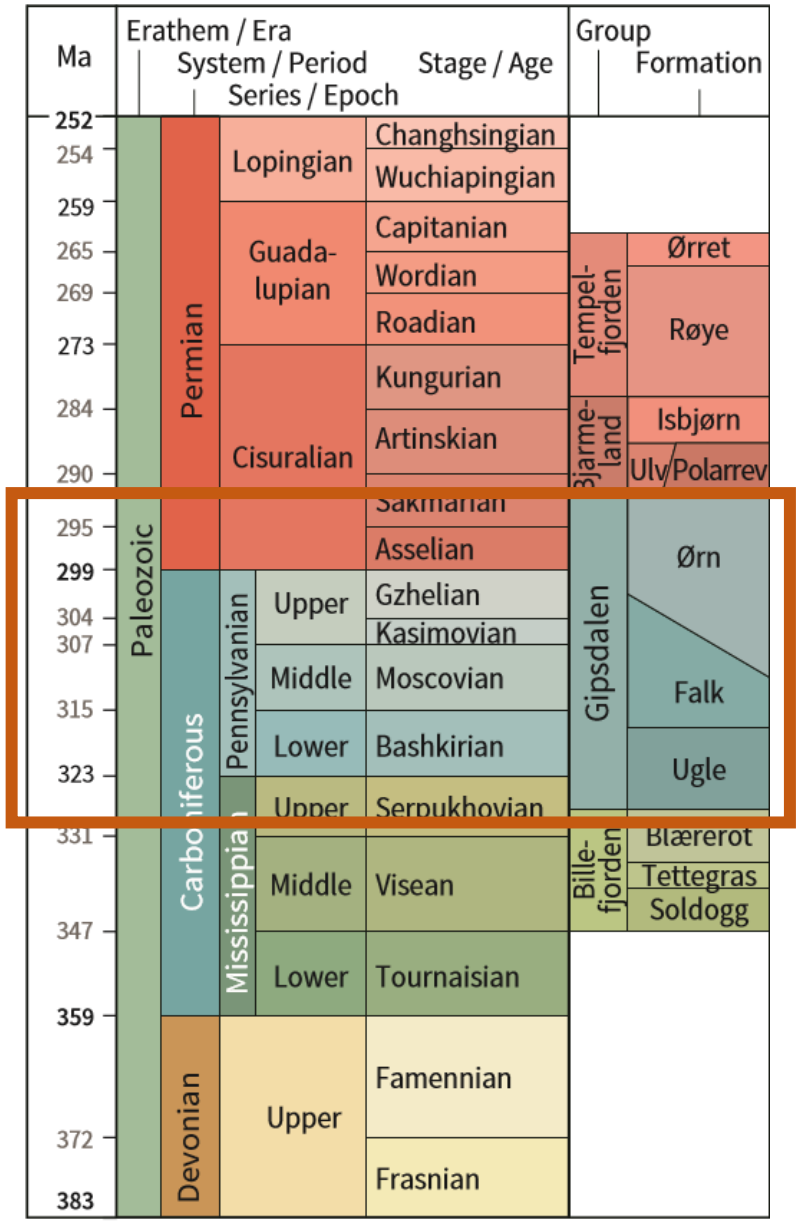
Opportunities in Central Barents Sea

Carboniferous to Permian Carbonates and Evaporites

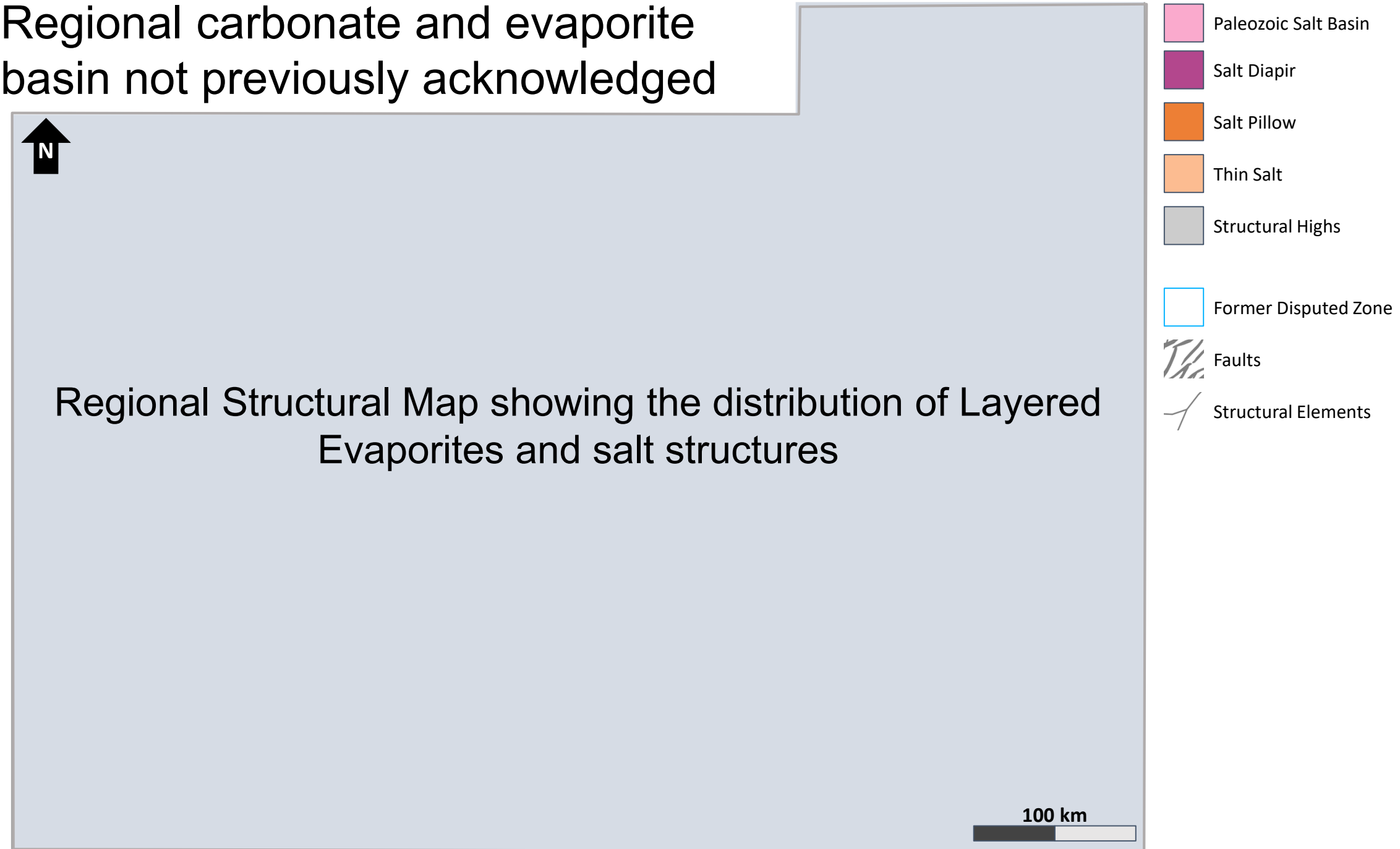
Gipsdalen Group Carbonates, evaporite seals and source rock

Co-existing source rock and reservoir

Boltonbreen, Wordiekammen Formation, Tyrellfjellet Member, *Palaeoaplysina* buildups

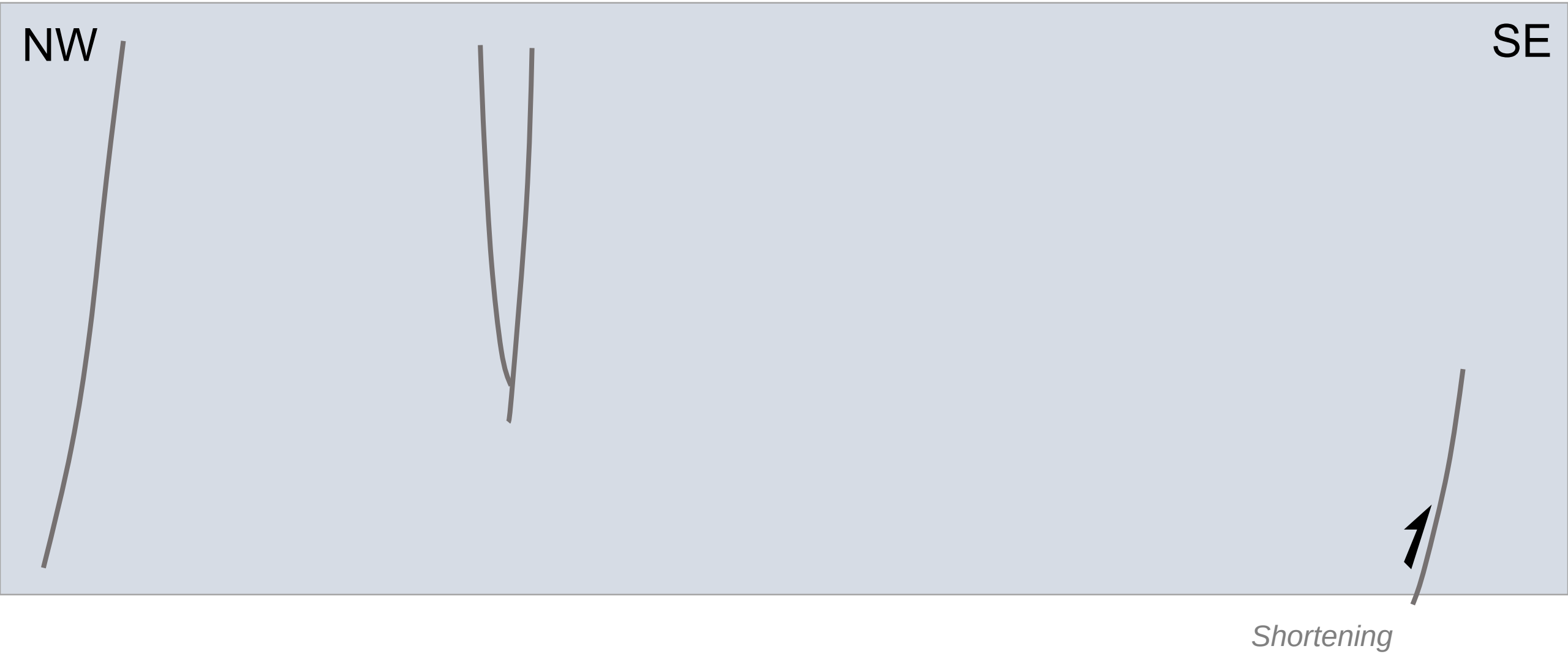


Regional carbonate and evaporite basin not previously acknowledged



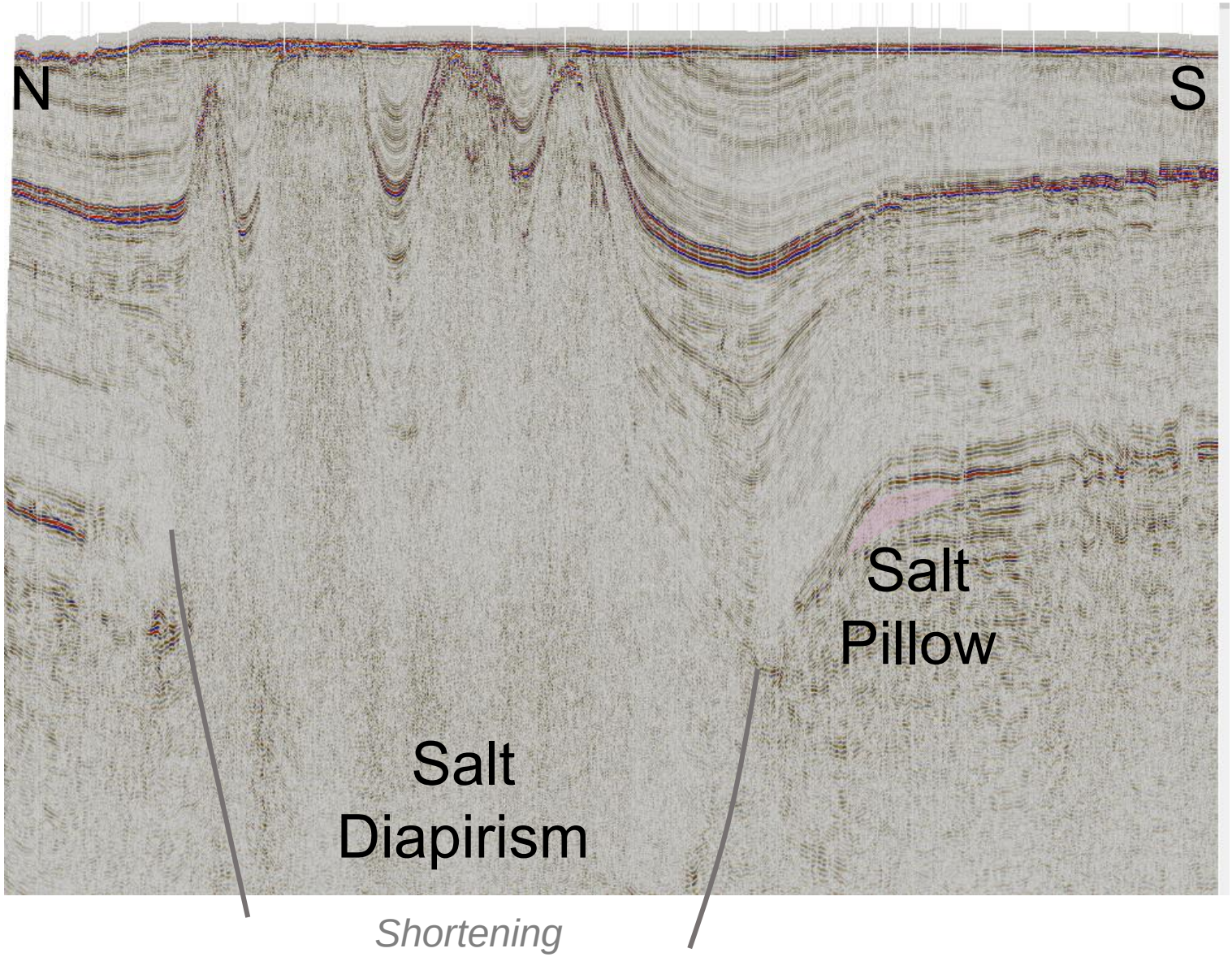
Paleozoic Grabens and Evaporites

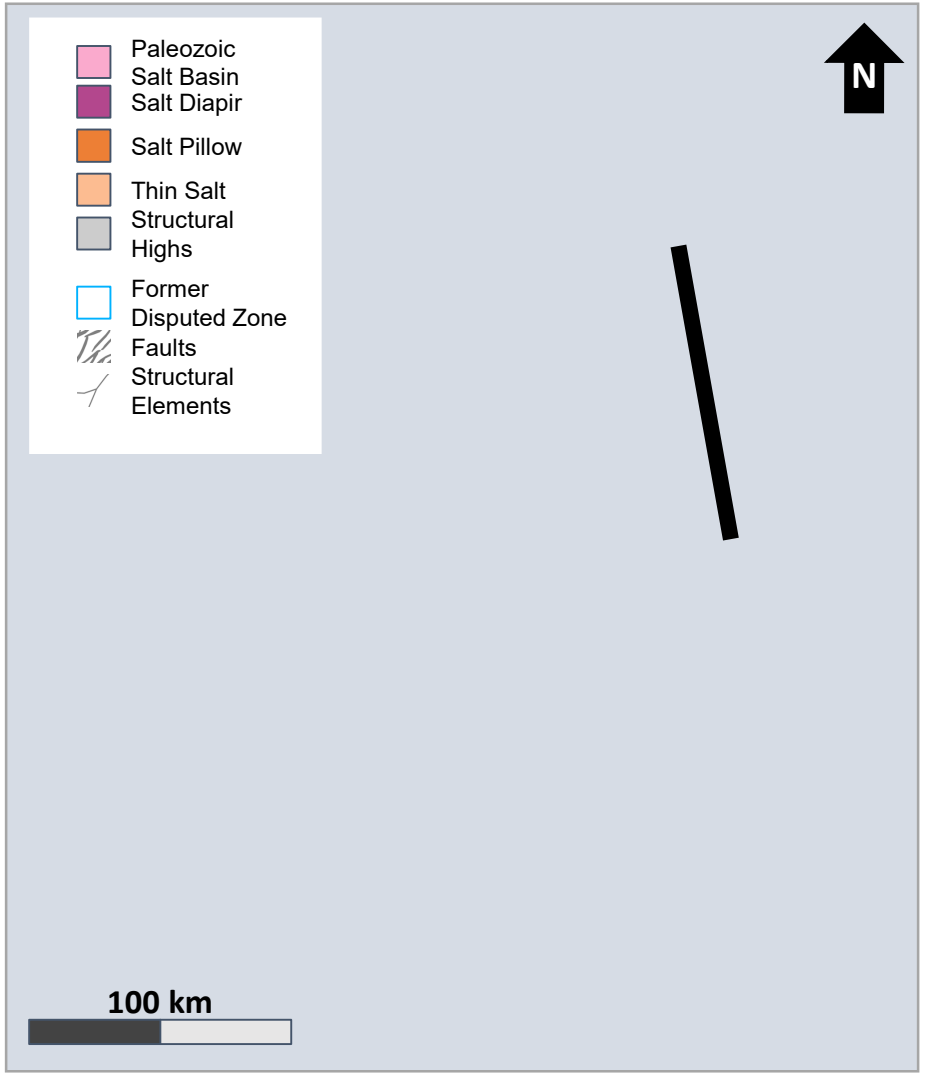
Loppa High



Paleozoic Grabens and Evaporites

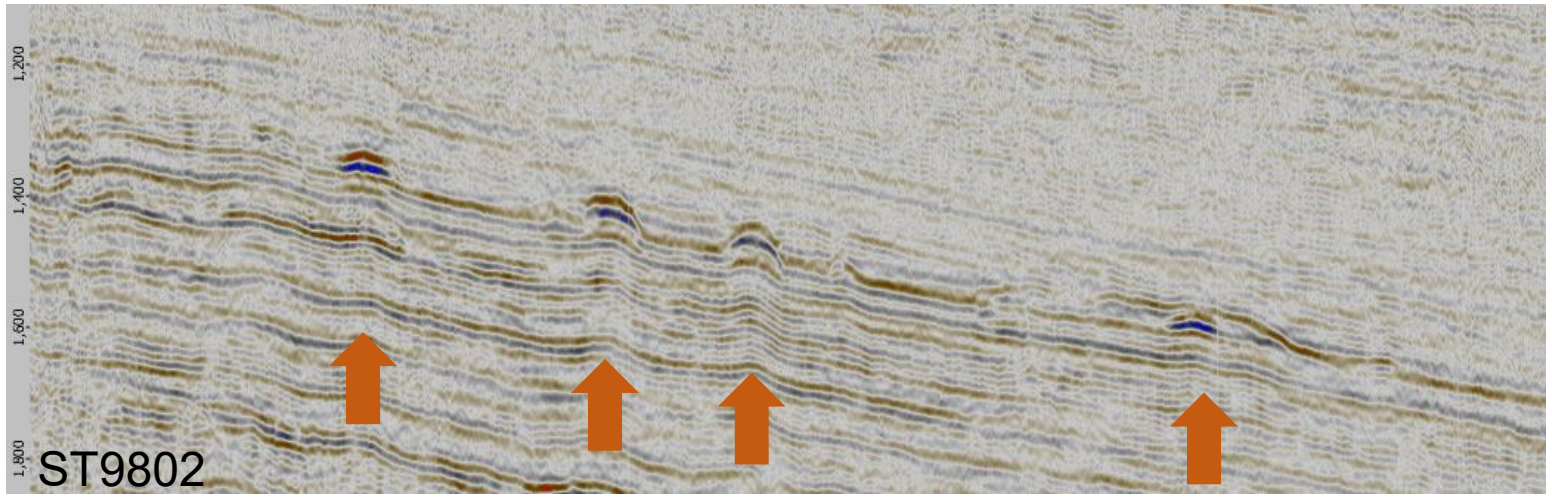
Nordkapp Basin

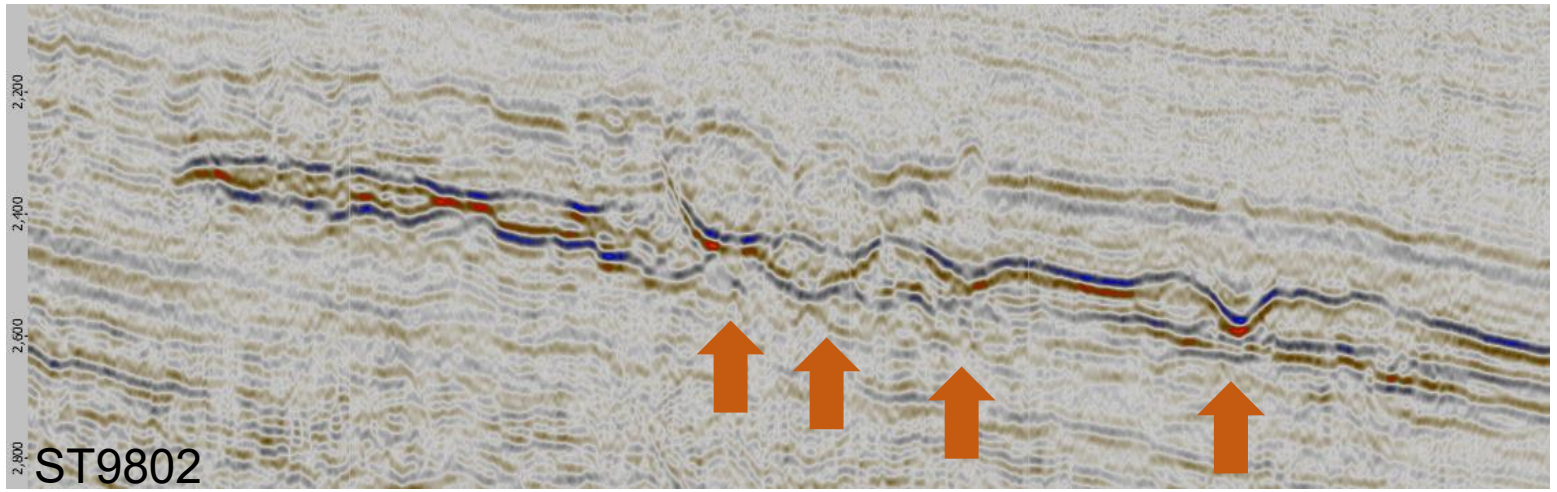


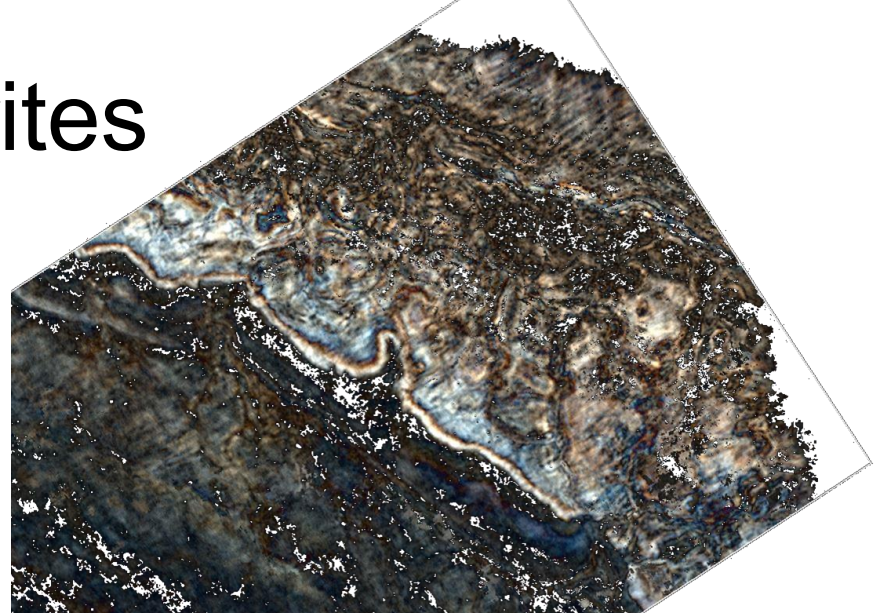


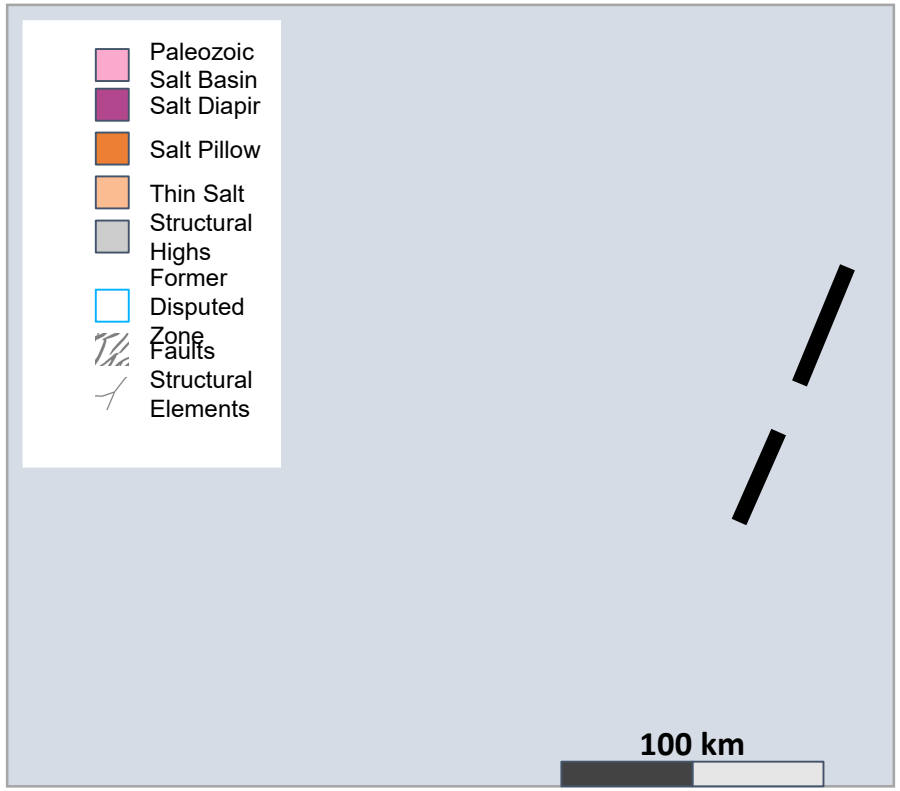
Paleozoic Grabens and Evaporites

Reef Types Observed in Seismic Data + Pinch-out

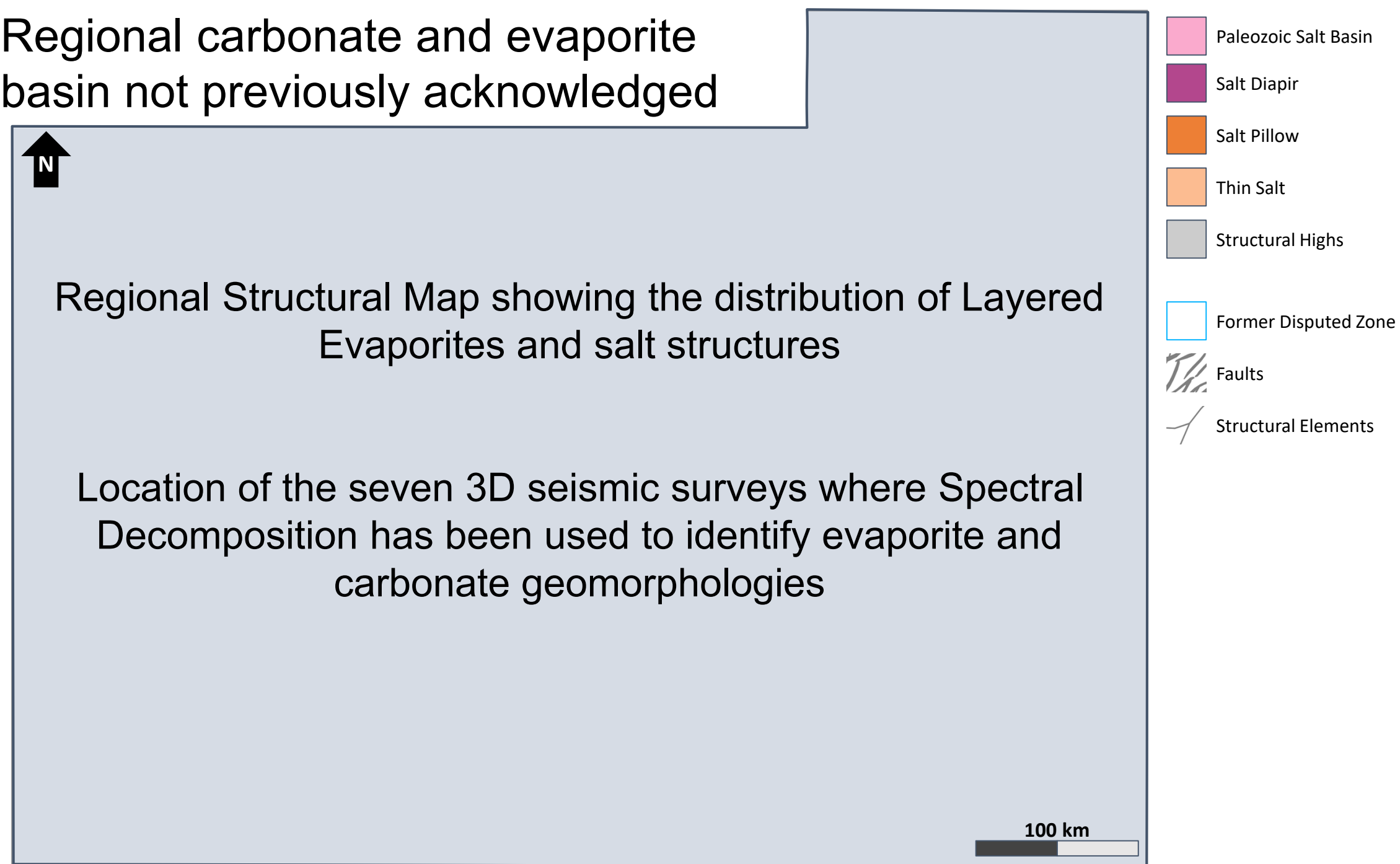




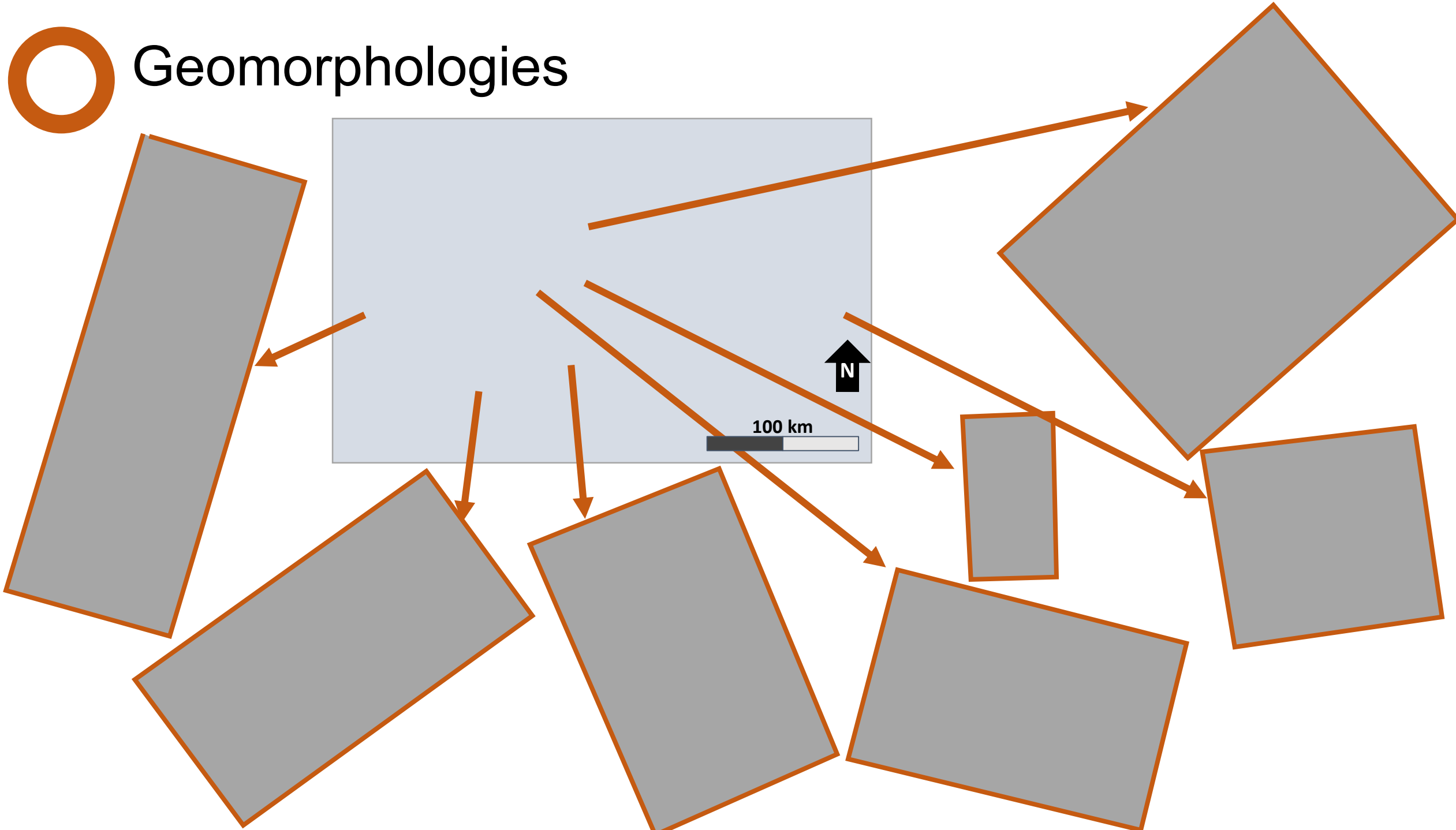




Regional carbonate and evaporite basin not previously acknowledged

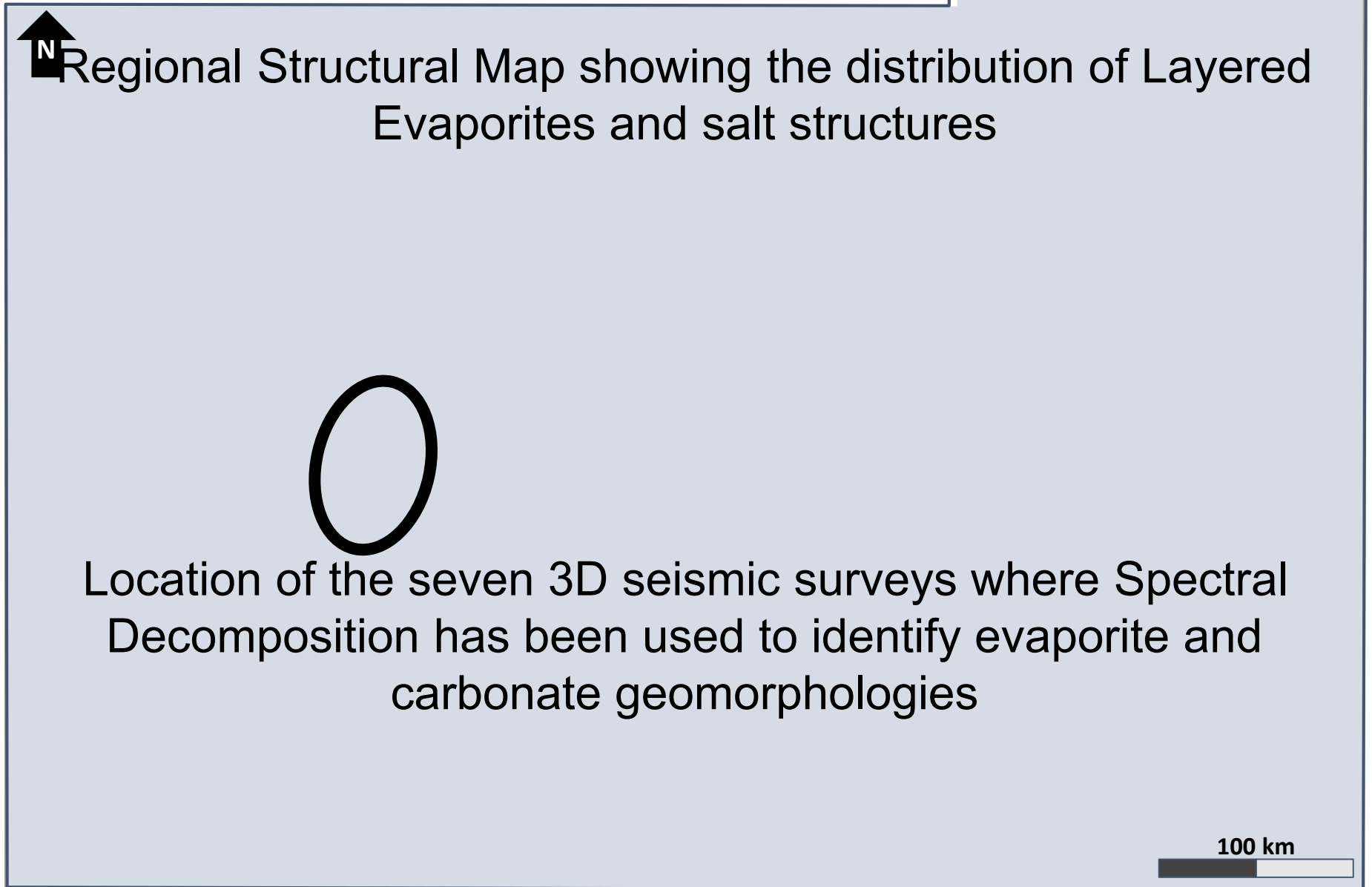


Geomorphologies



Geomorphologies

Loppa High



Paleozoic Salt Basin

Salt Diapir

Salt Pillow

Thin Salt

Structural Highs

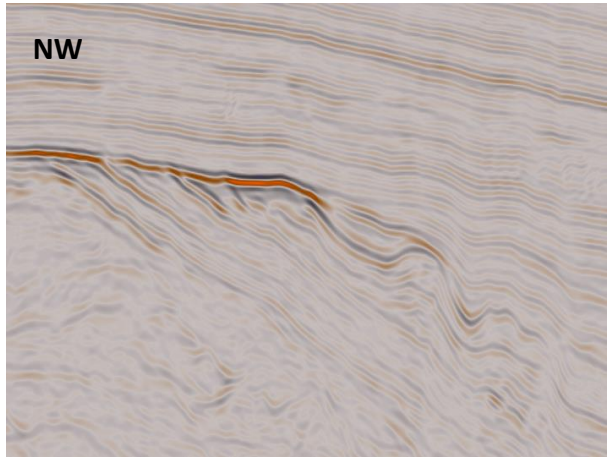
Former Disputed Zone

Faults

Structural Elements

Geomorphologies

Loppa High



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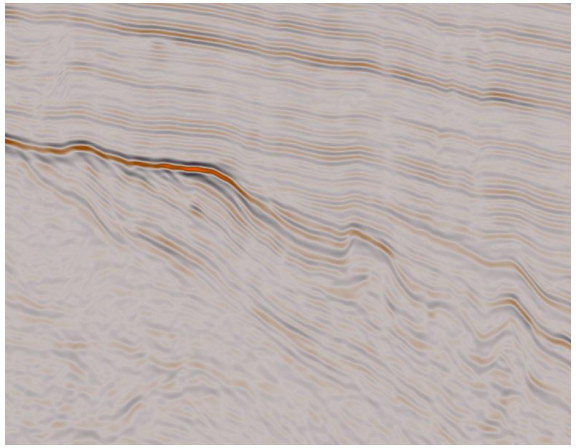

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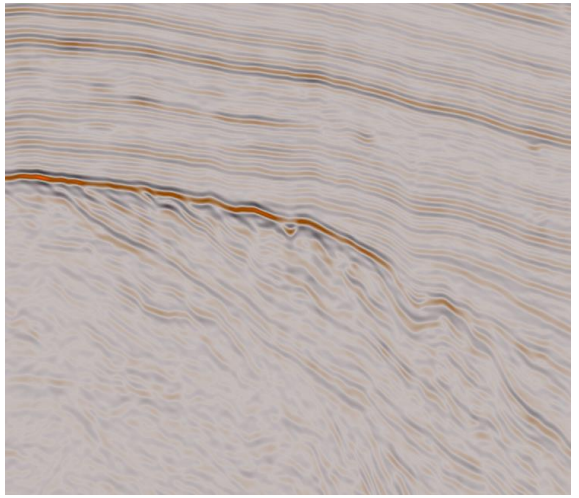

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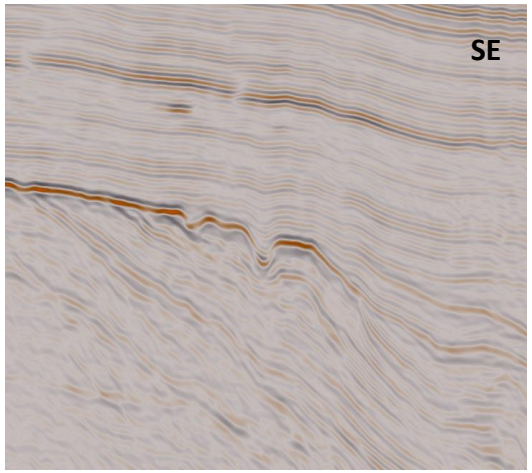

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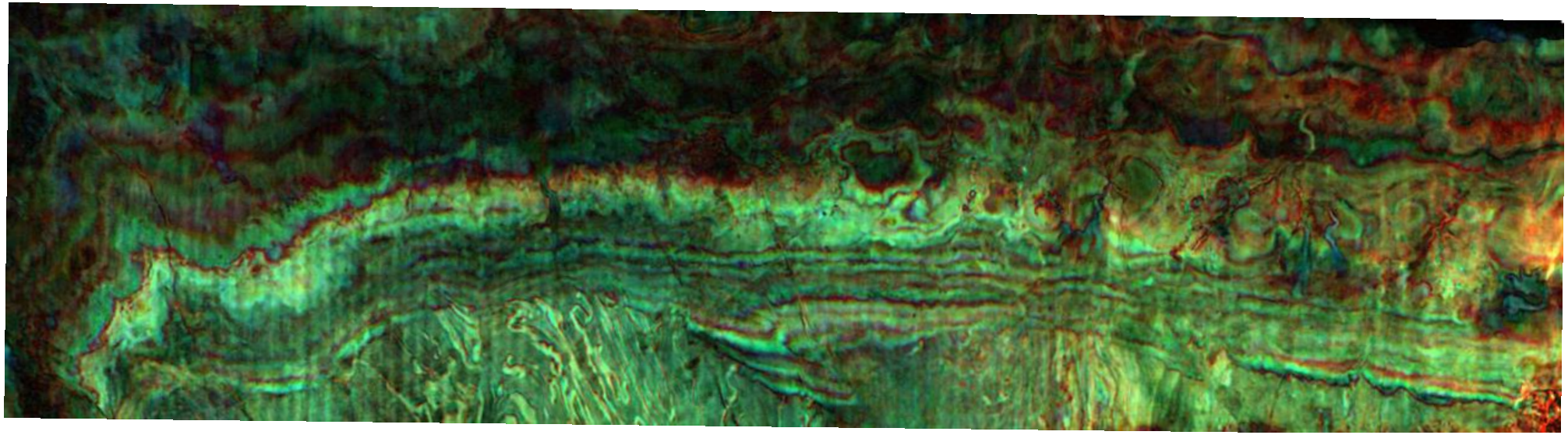


10 km

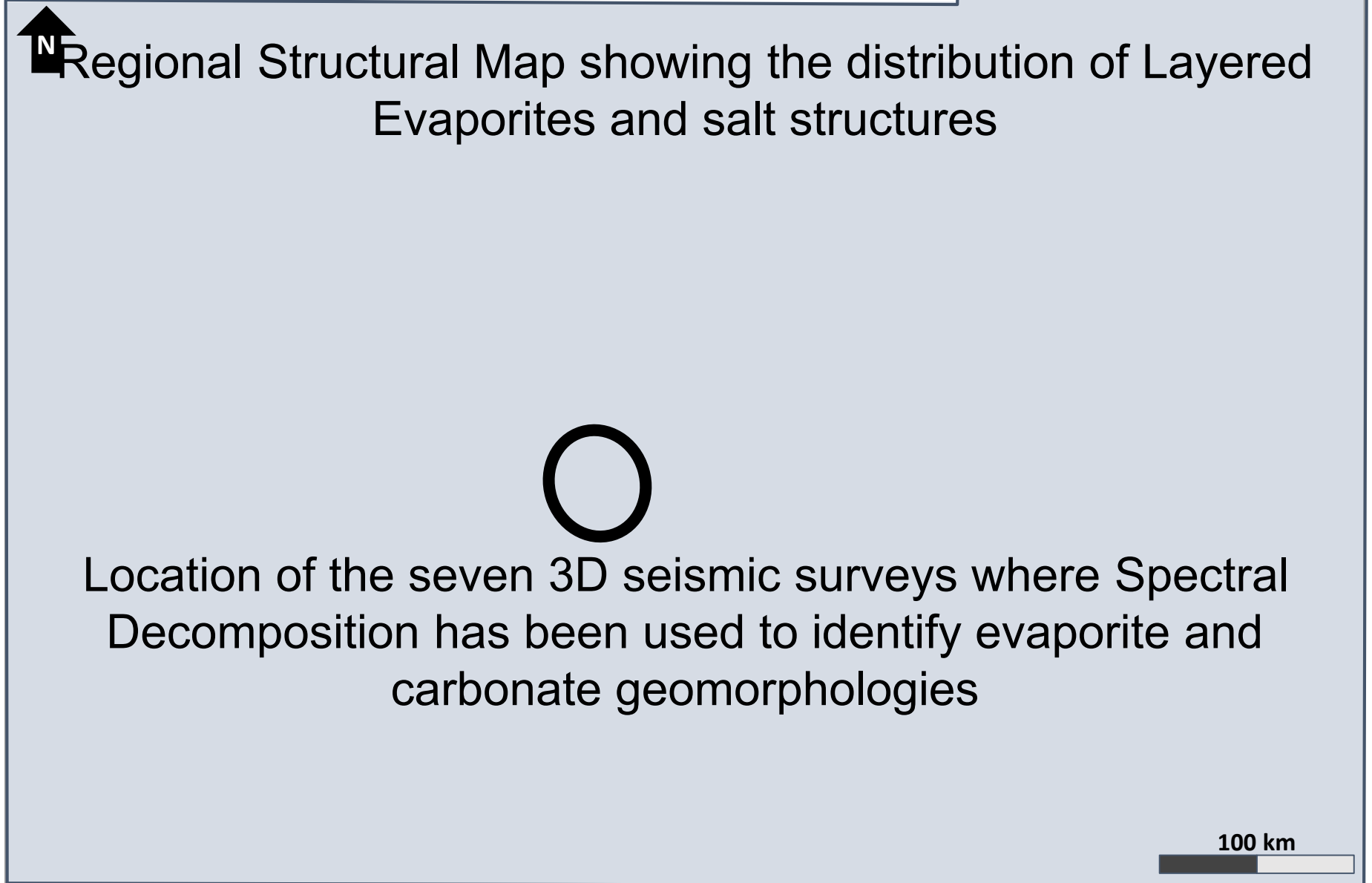
N

Frequency Decomposition (Constant Q)

RGB - 10/27/45 Hz

Geomorphologies

Samson Dome



Paleozoic Salt Basin

Salt Diapir

Salt Pillow

Thin Salt

Structural Highs

Former Disputed Zone

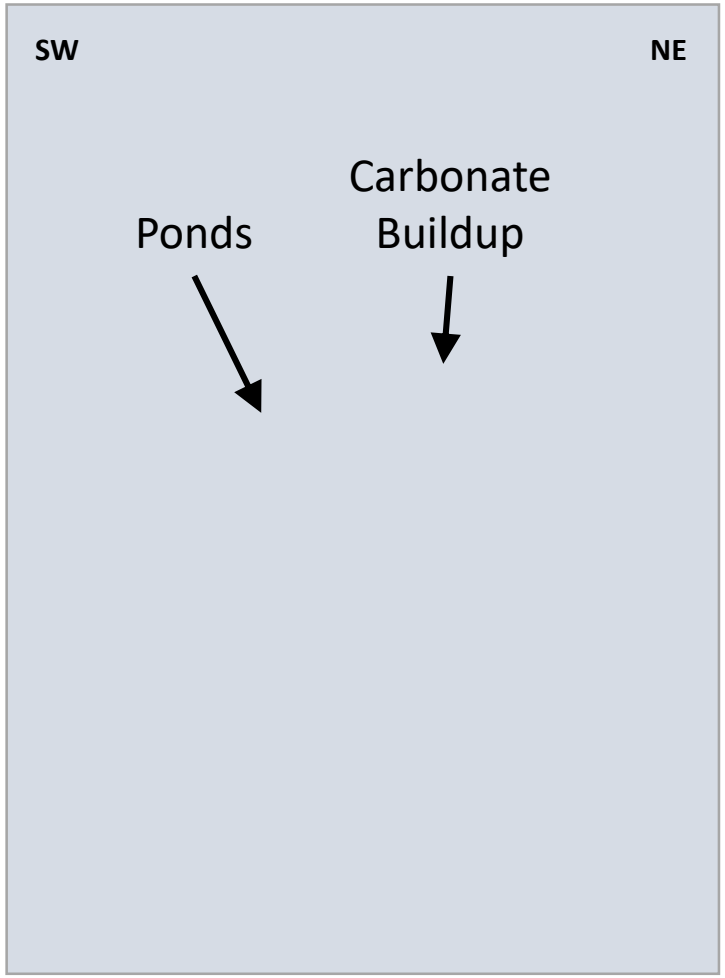
Faults

Structural Elements

Geomorphologies

Samson Dome

Top Asselian Carbonates and Evaporites



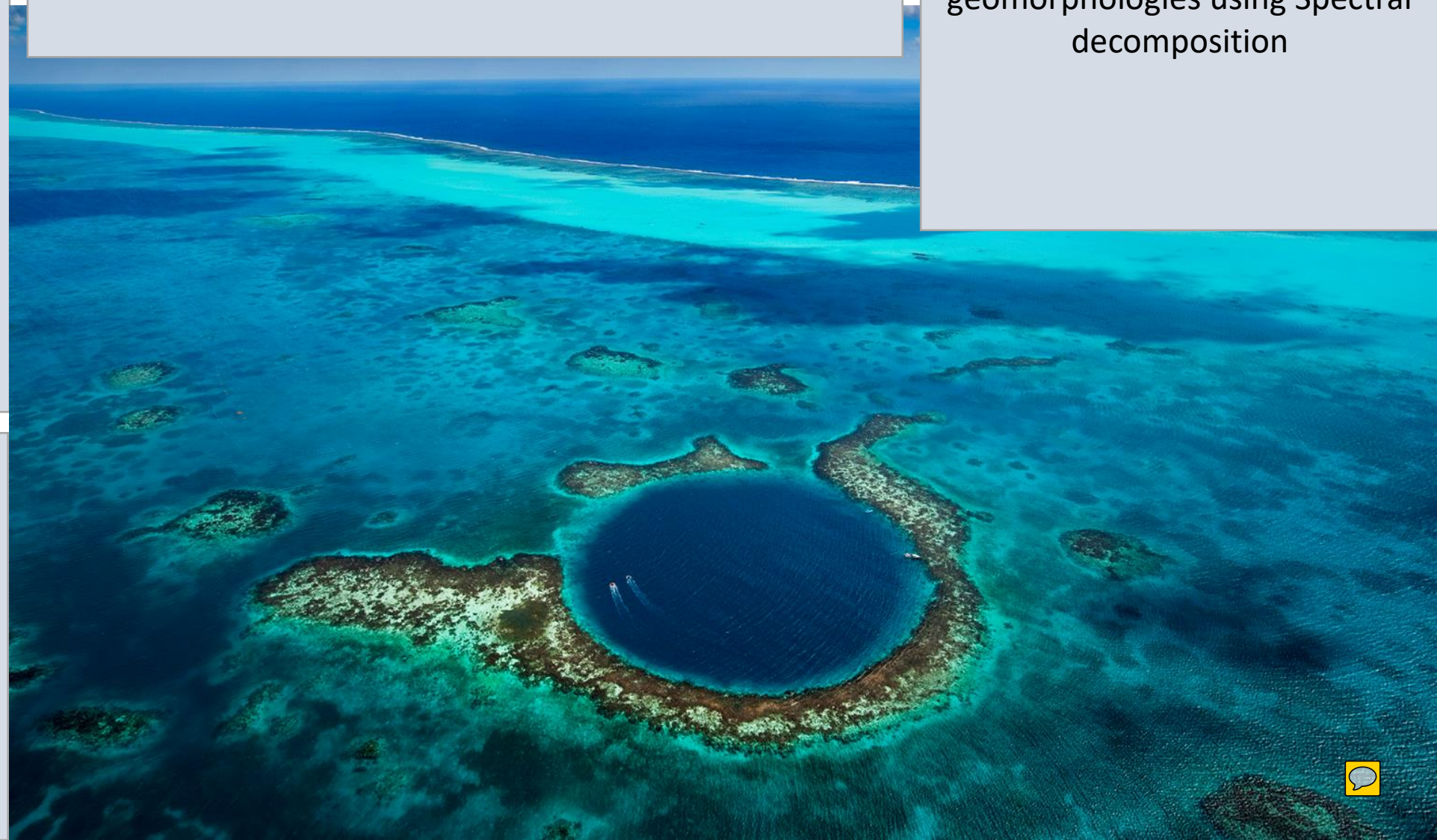
Frequency Decomposition (Constant Q)

RGB - 14/24/37 Hz

Visualisation of carbonate geomorphologies using Spectral decomposition

Visualisation of carbonate geomorphologies using Spectral decomposition

Visualisation of carbonate geomorphologies using Spectral decomposition

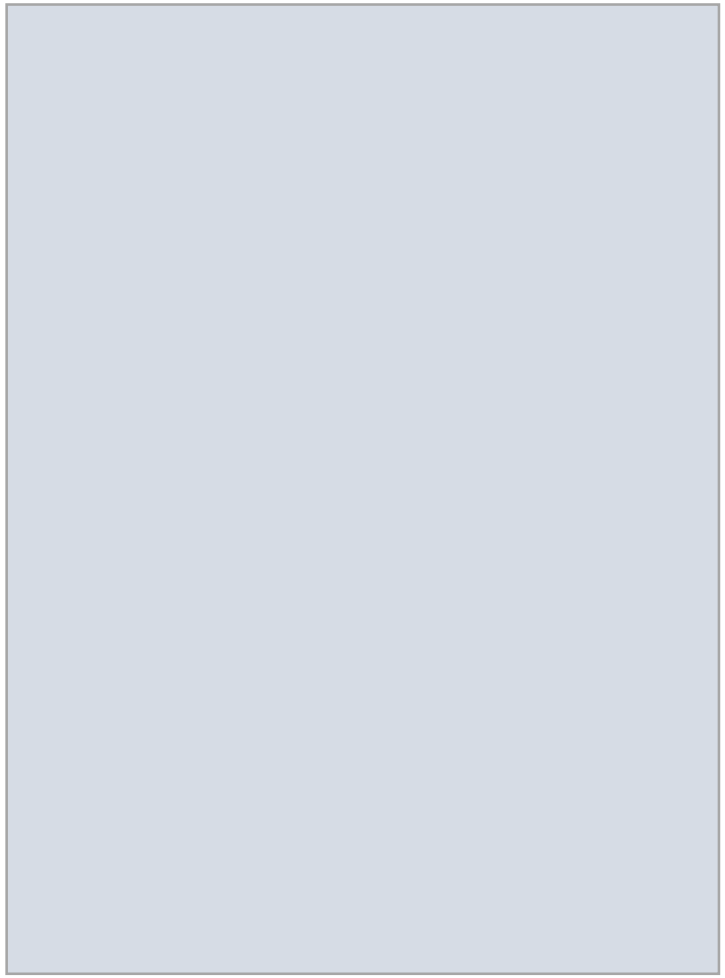


Visualisation of carbonate geomorphologies using Spectral decomposition

Geomorphologies

Samson Dome

Top Bjarmeland Group

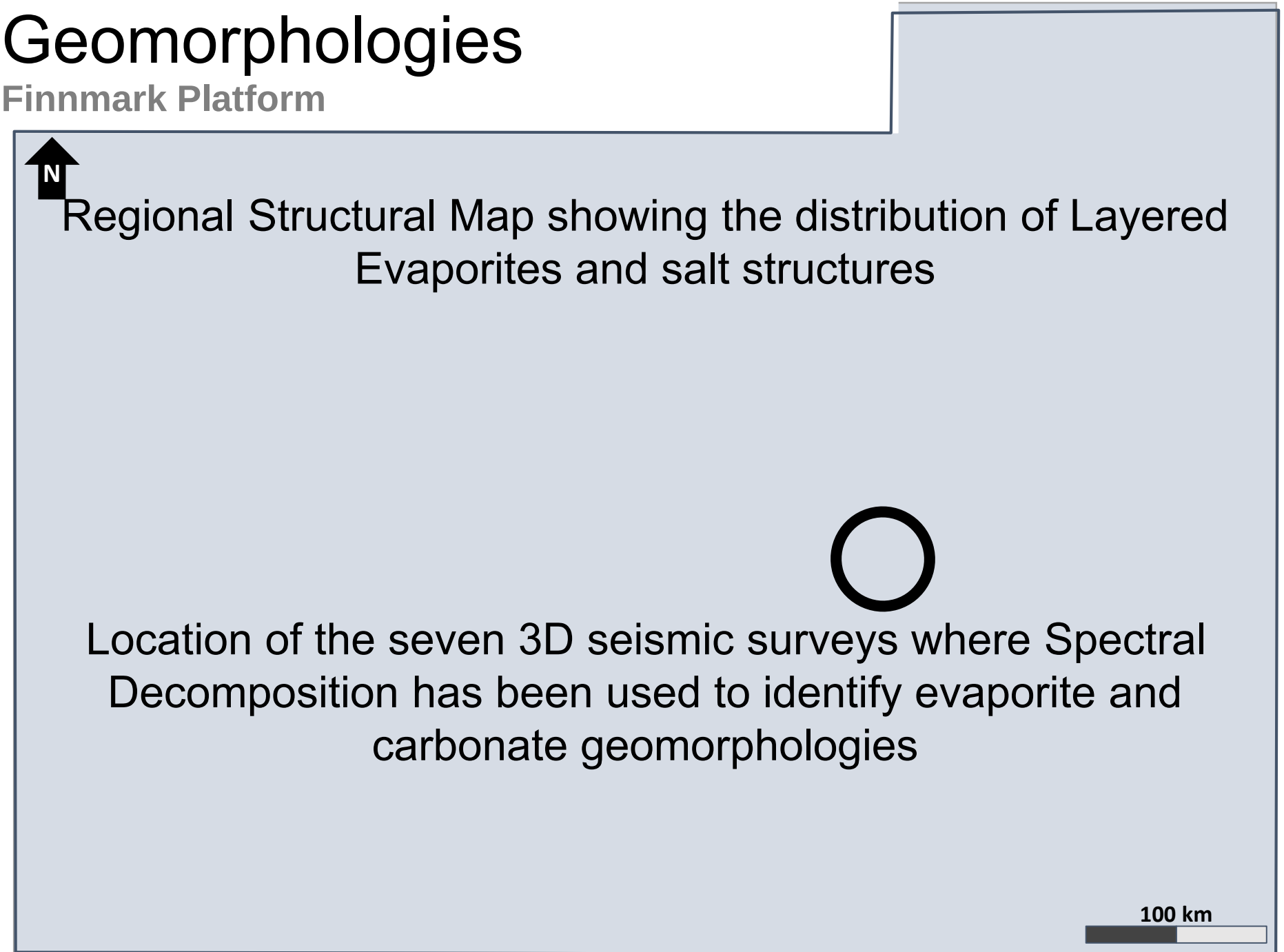


Frequency Decomposition (Constant Q)

RGB - 14/24/37 Hz

Geomorphologies

Finnmark Platform



Paleozoic Salt Basin

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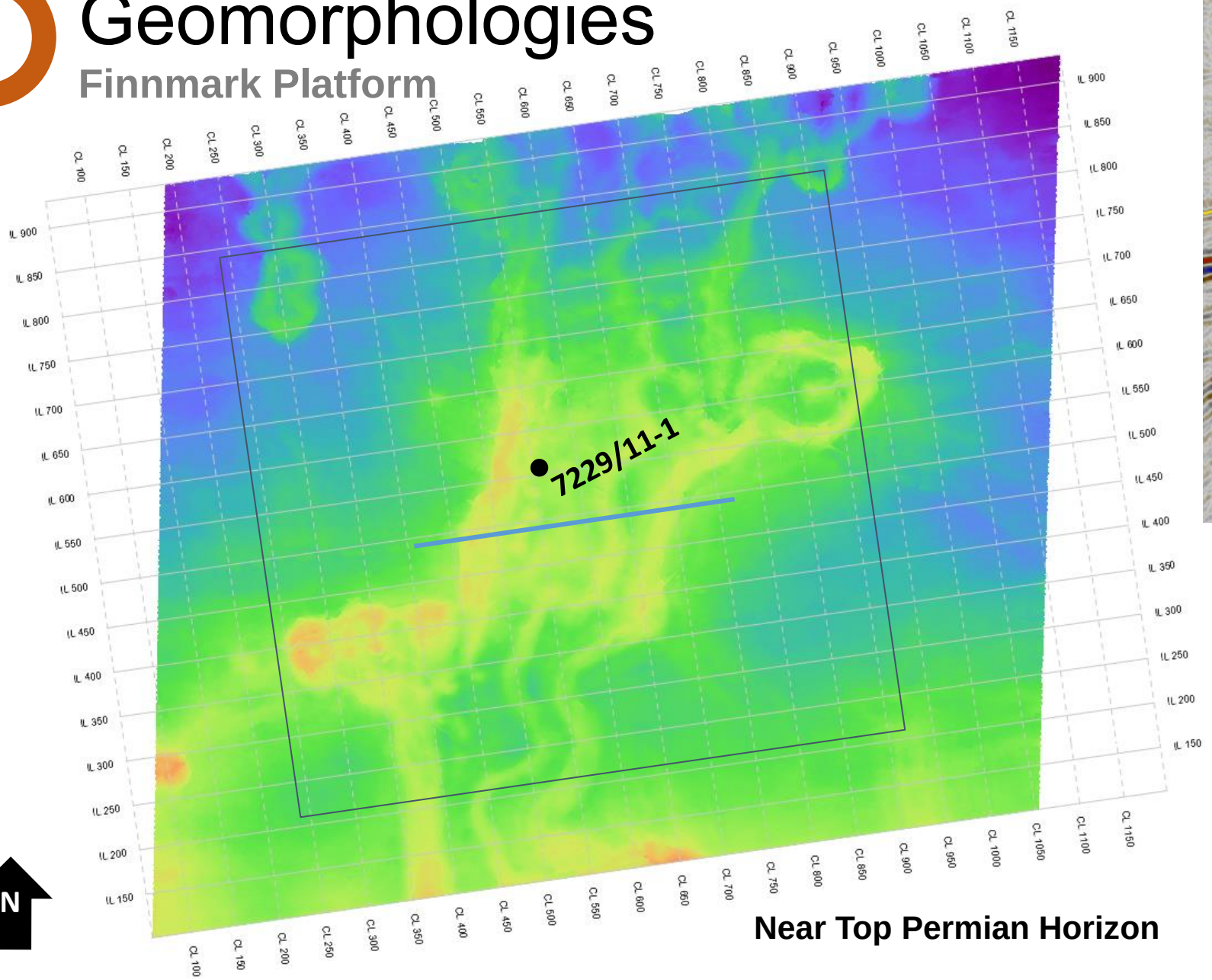
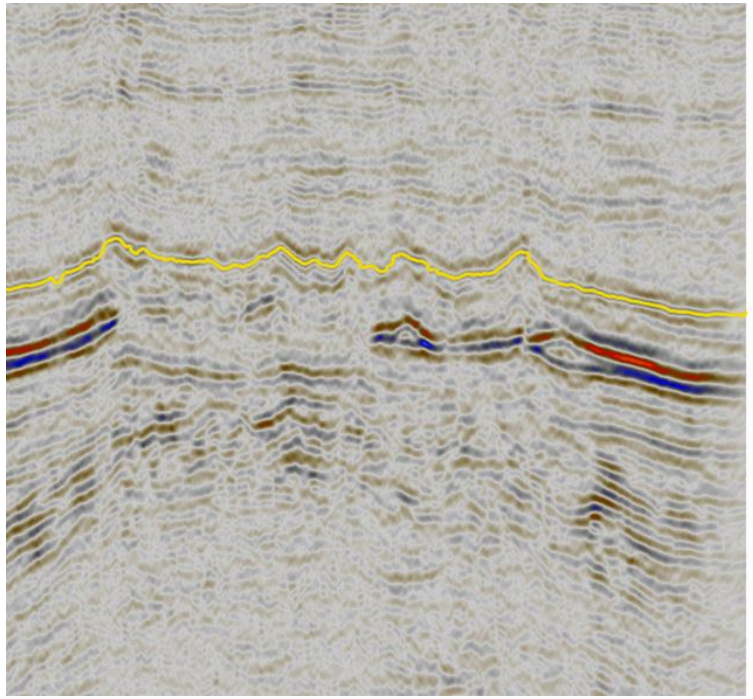
Structural Elements

Geomorphologies

Finnmark Platform

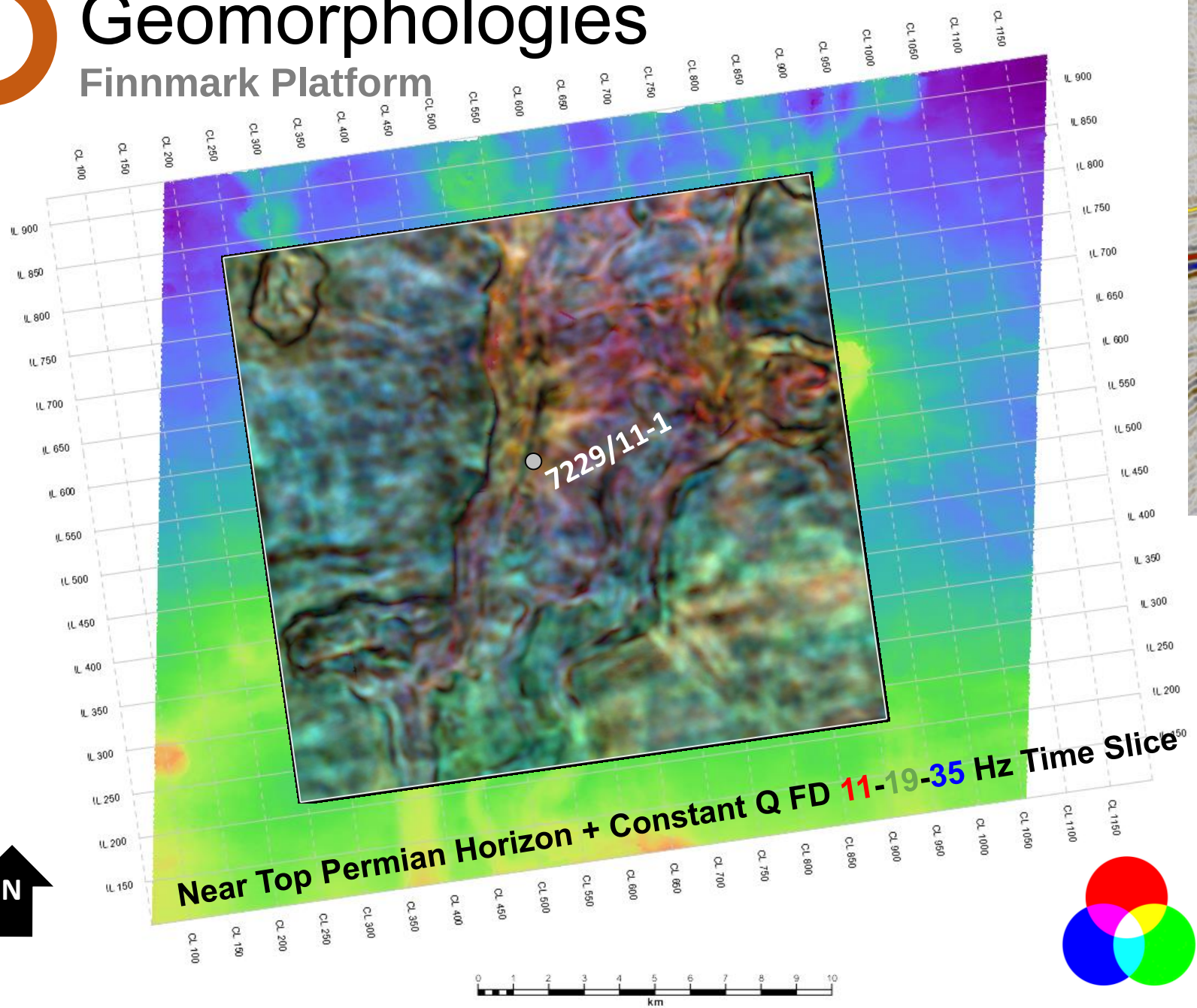


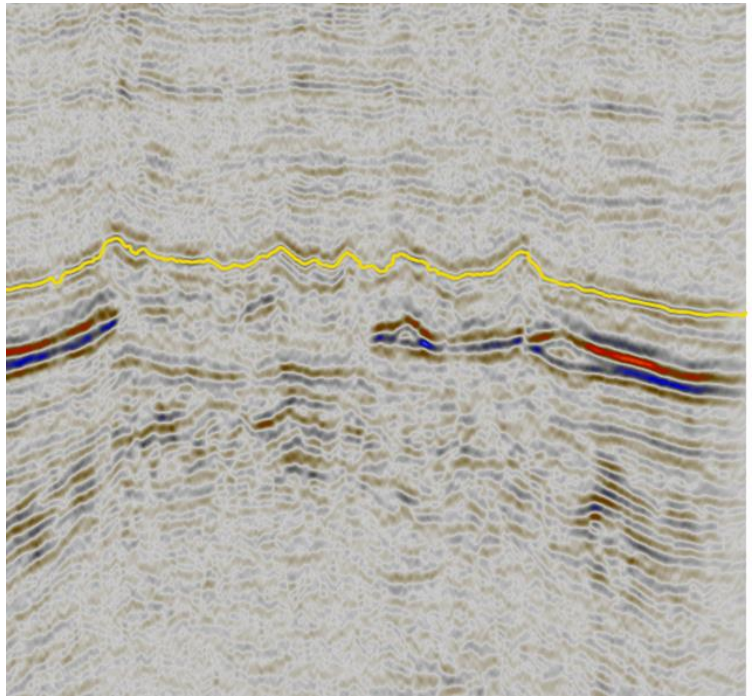
Near Top Permian Horizon



Geomorphologies

Finnmark Platform





Visualisation of carbonate geomorphologies using Spectral decomposition

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Visualisation of carbonate geomorphologies using Spectral decomposition

Summary on Evaporites and Carbonates

- Carboniferous and Permian carbonates and evaporites with seismic scale carbonate buildups are widely distributed in the southern Barents Sea, strongly controlled by Paleozoic structural architecture.

- Paleozoic grabens and structural lows with evaporites / salt have been inverted in Mesozic(?), Paleogene and Neogene, forming traps.

- A working petroleum system is proven.

- Spectral Decomposition is an excellent tool for identifying geomorphologies in really old seismic data – imagine what you can do with new data...

CHALLENGES IN EASTERN BARENTS SEA

Challenges in the Eastern Barents Sea

Source Rocks

PRESENCE AND QUALITY OF SOURCE ROCK

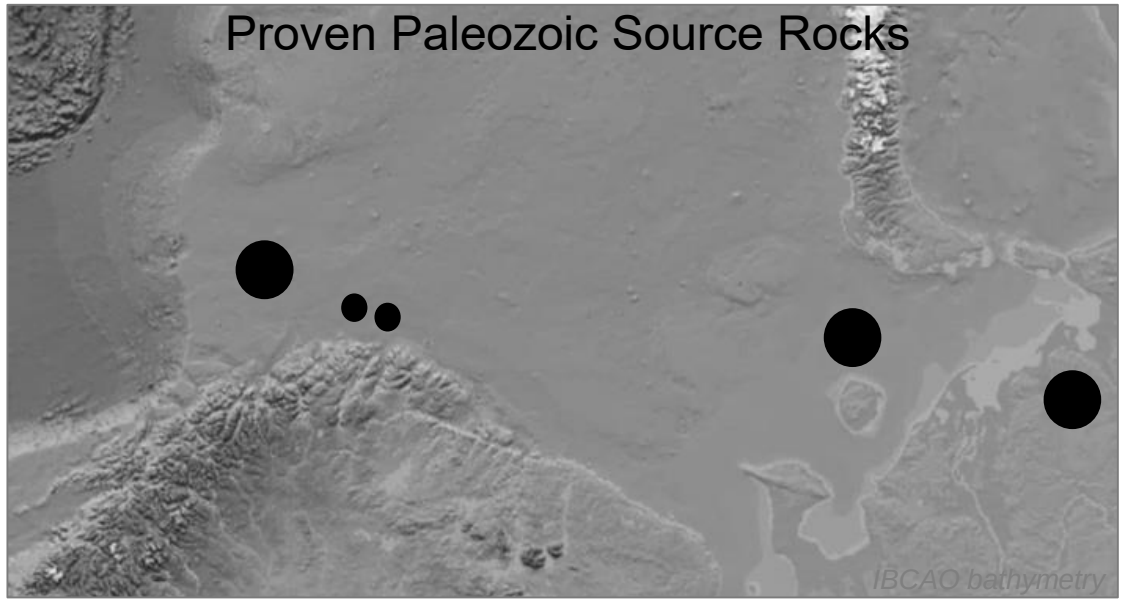
Will it/they have expelled enough hydrocarbons to fill an 800 km2 structure?

Challenges in the Eastern Barents Sea

Source Rocks – Proved versus Possible

Main Source Rocks

- **Upper Cretaceous Albian-Turonian (proved)**
- **Lower Cretaceous Aptian (proved)**
- **Upper Jurassic Hekkingen (proved)**
- **Steinkobbe (proved)**
- **Permian (proved)**



Main Source Rocks

- *(Hekkingen immature)*
- Triassic restricted basins?
- Triassic regional?
- **Permian (proved)**
- Carboniferous? (Ørnen?)
- Devonian? (Ørnen?)

Challenges in the Eastern Barents Sea

Source Rocks

How to efficiently de-risk source rock presence?

Walk fast  Walk alone

Walk far  Walk together

Challenges in the Eastern Barents Sea

Test the Source Rock Presence and Maturity

Collaborate across competitive boundaries to accelerate knowledge building

Challenges in the Eastern Barents Sea

Test the Source Rock Presence and Maturity

PROPOSAL

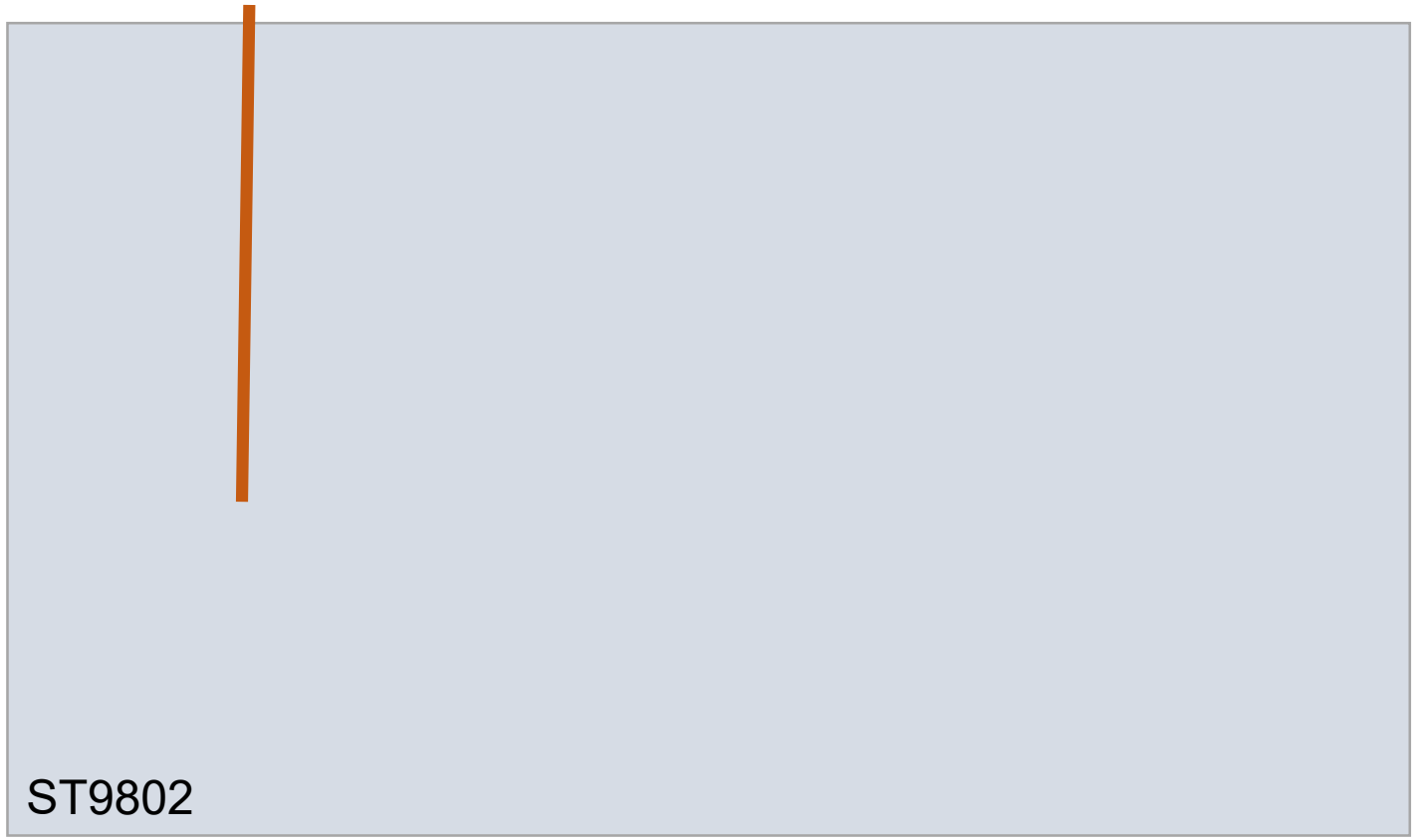
Industry joining forces to drill stratigraphic well(s) to save time and money:
to avoid unnecessary future dry wells testing small traps,
large areas could be de-risked.

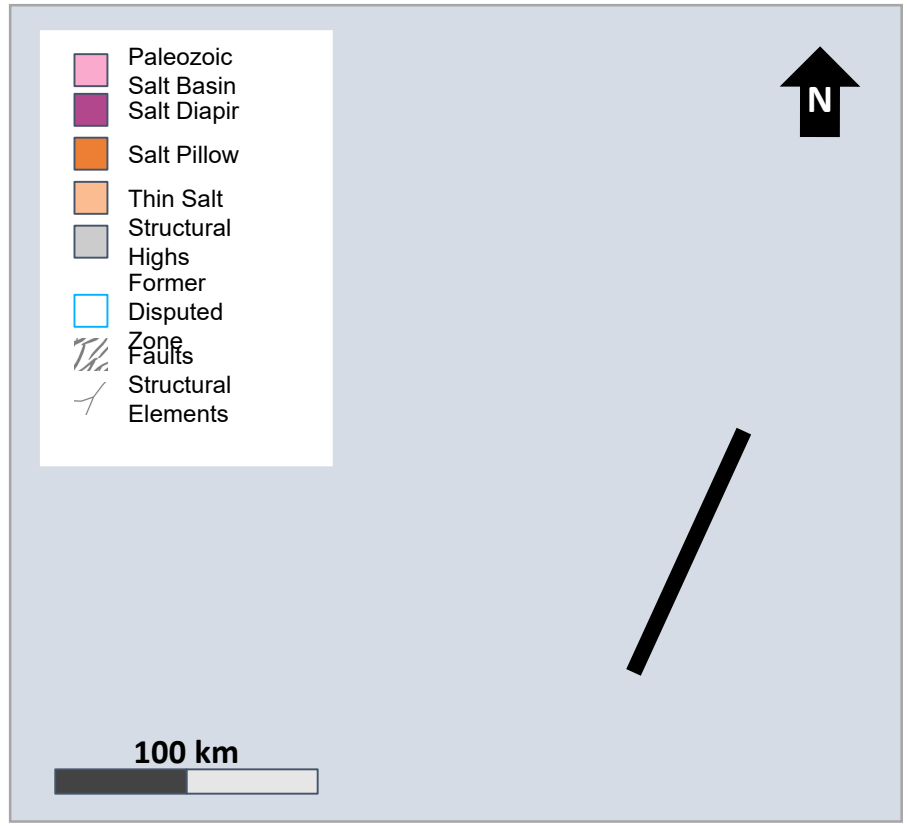
A way to accelerate exploration in frontier areas.

OPPORTUNITIES IN EASTERN BARENTS SEA

Opportunities in the Eastern Barents Sea

Indications of migration from carbonate source rocks associated with evaporites

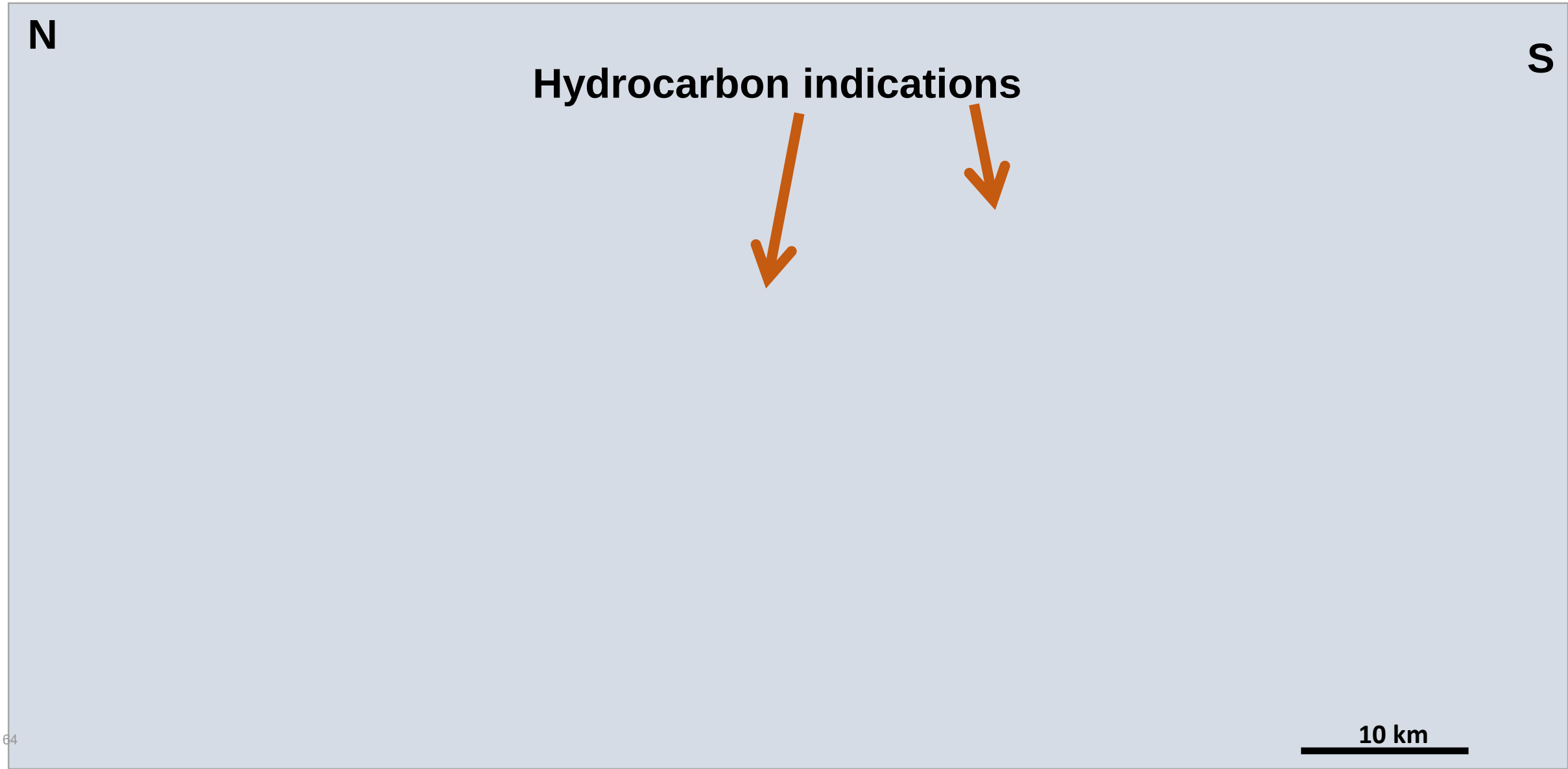




Where did the gas in Ørnen well originate from?

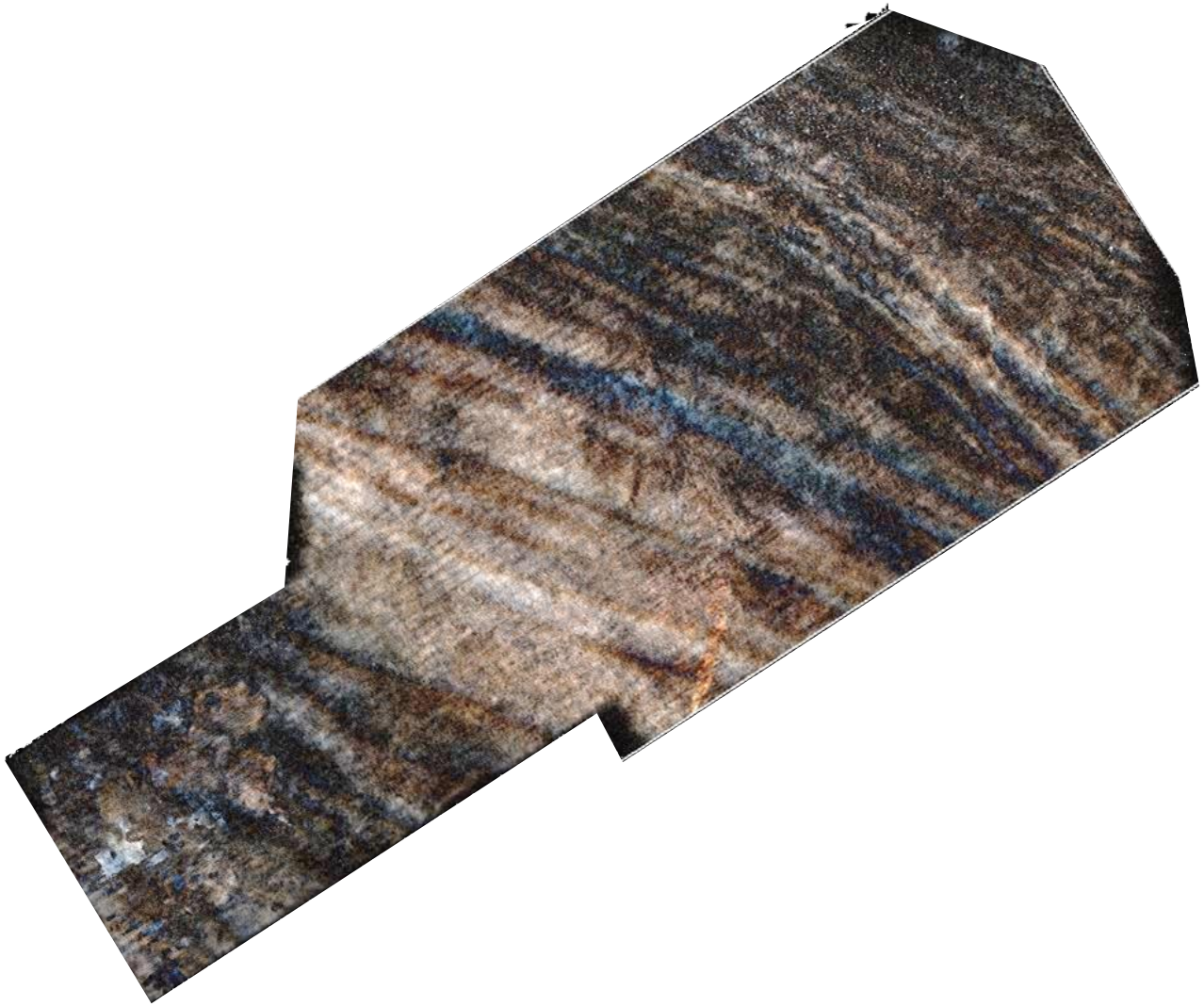
Opportunities in the Eastern Barents Sea

Indications of migration from carbonate source rocks associated with evaporites



Opportunities in the Eastern Barents Sea

Induan Clinoforms from Mainland Norway

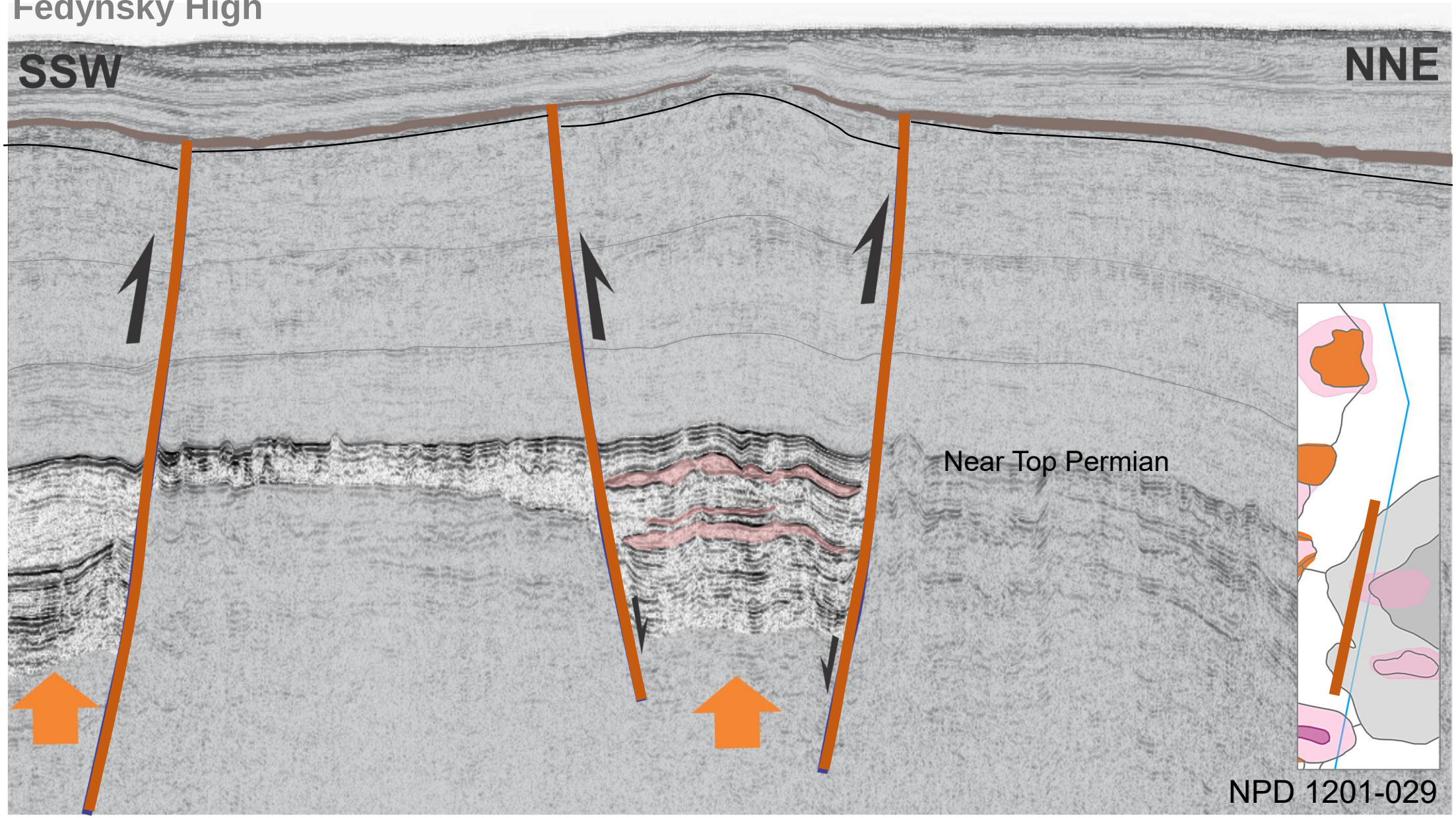


Opportunities in the Eastern Barents Sea

Carnian Channels – But How About Migration?

Opportunities in the Eastern Barents Sea

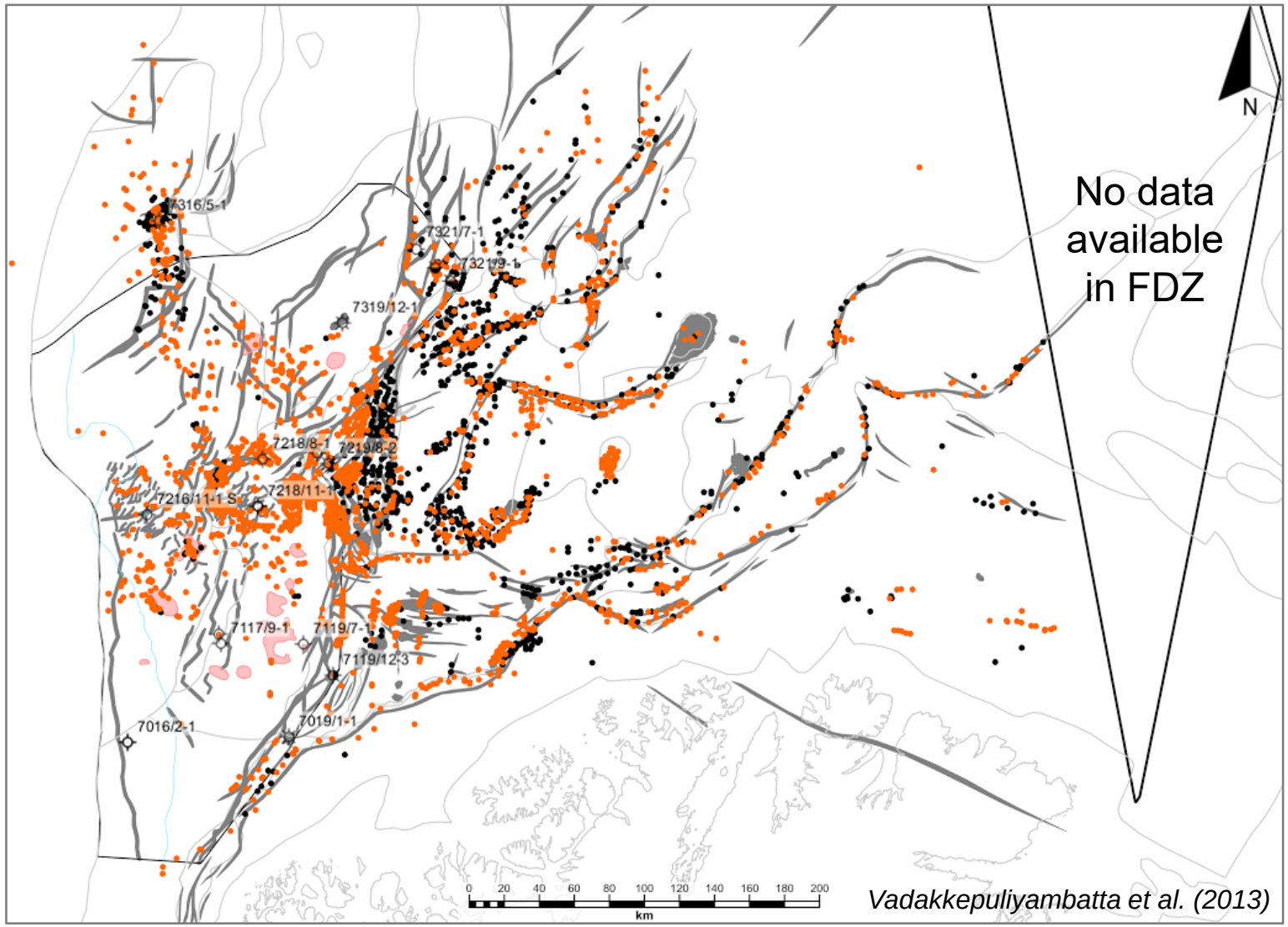
Fedynsky High



CHALLENGES IN CENTRAL BARENTS SEA

Challenges in Central Barents Sea

Trap Size and Migration (just fault related?)



Observed HC indications in seismic data: East versus West

Barely any HC found in Snadd Channels

Challenges in Central Barents Sea

Source Rock

PRESENCE AND QUALITY OF SOURCE ROCK

Hekkingen immature

Triassic volumes questionable (except Steinkobbe in and around Maud Basin)

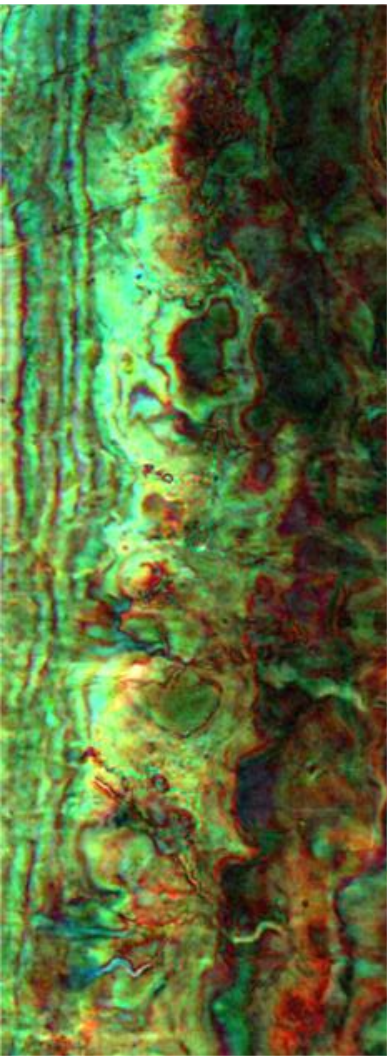
Paleozoic Source Rock overmature and burned out?

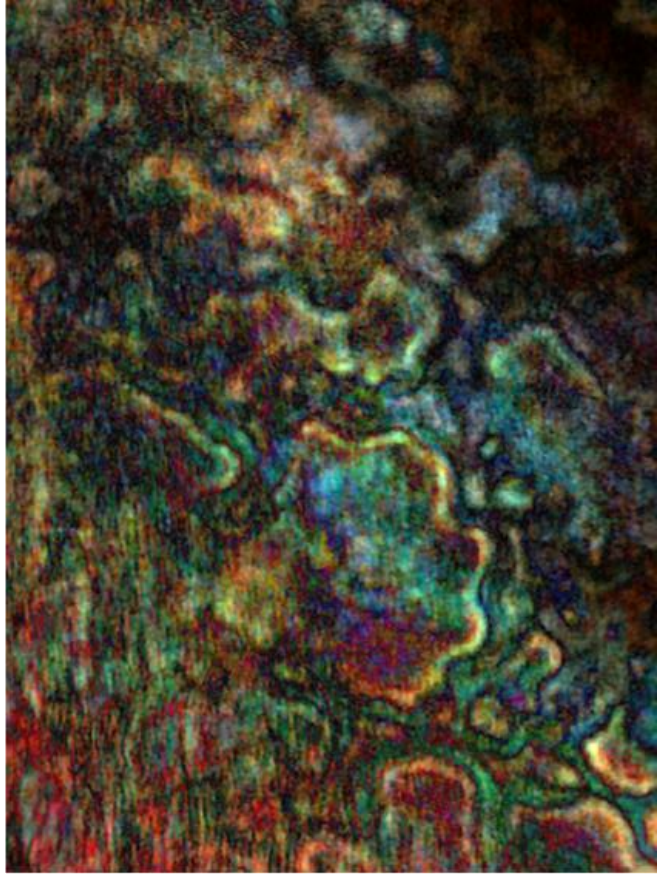
OPPORTUNITIES IN CENTRAL BARENTS SEA

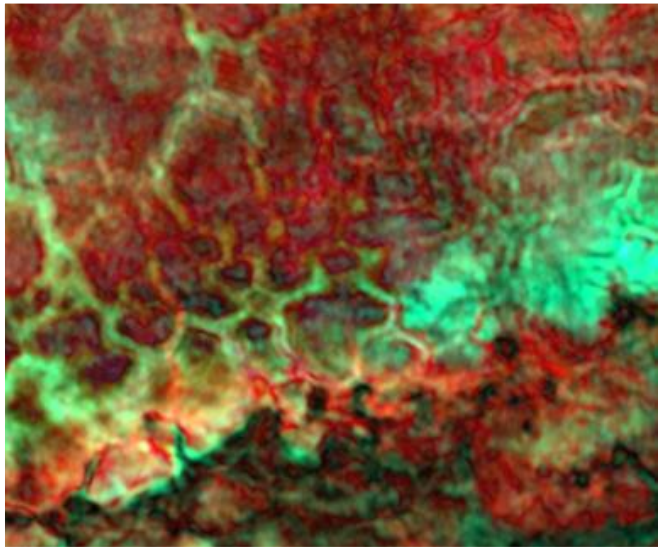
Opportunities in Central Barents Sea

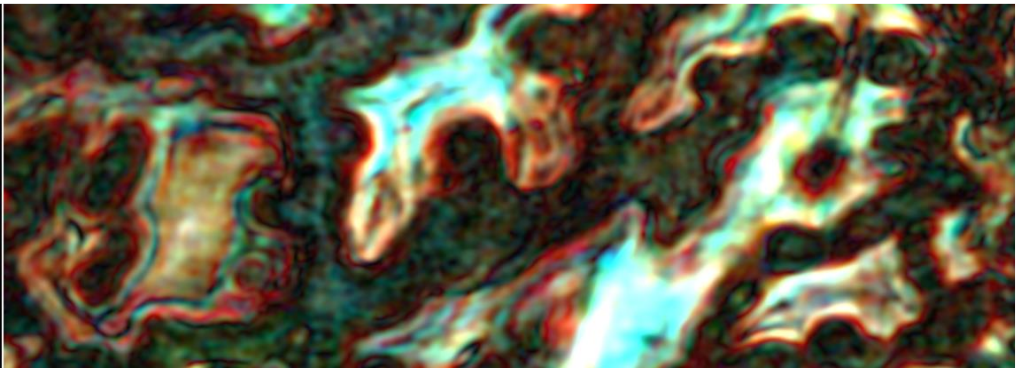
New Knowledge – New Possibilities

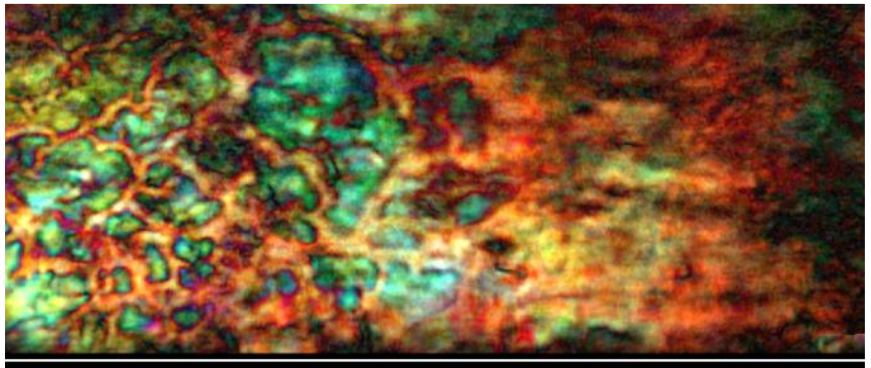
Could Stø Fm work in other places than Wisting?







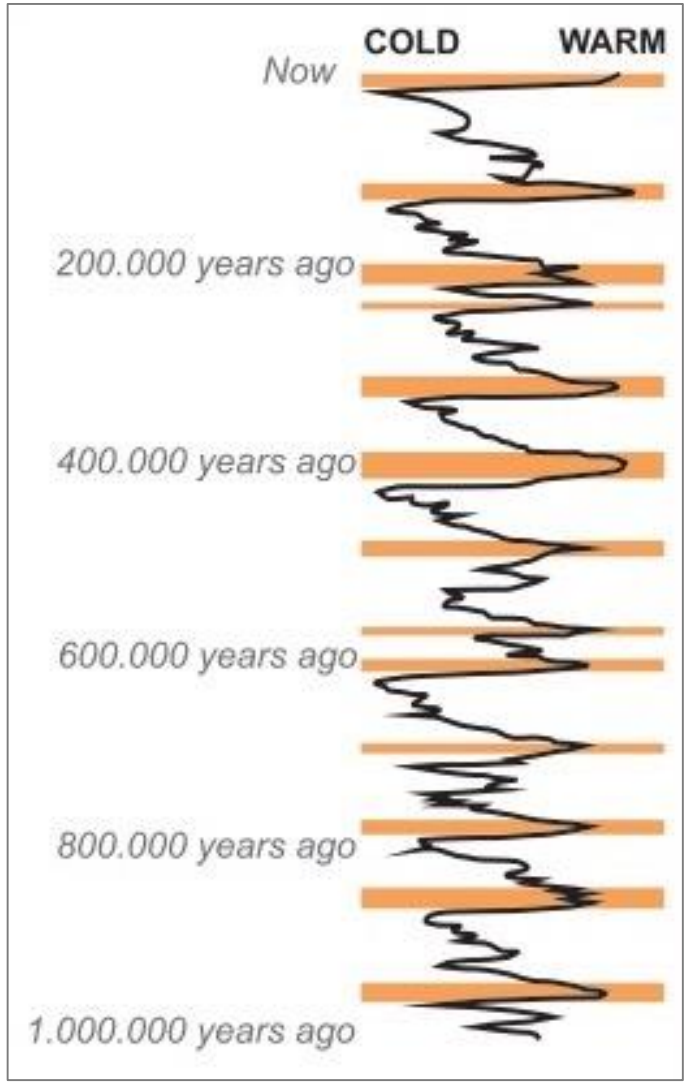


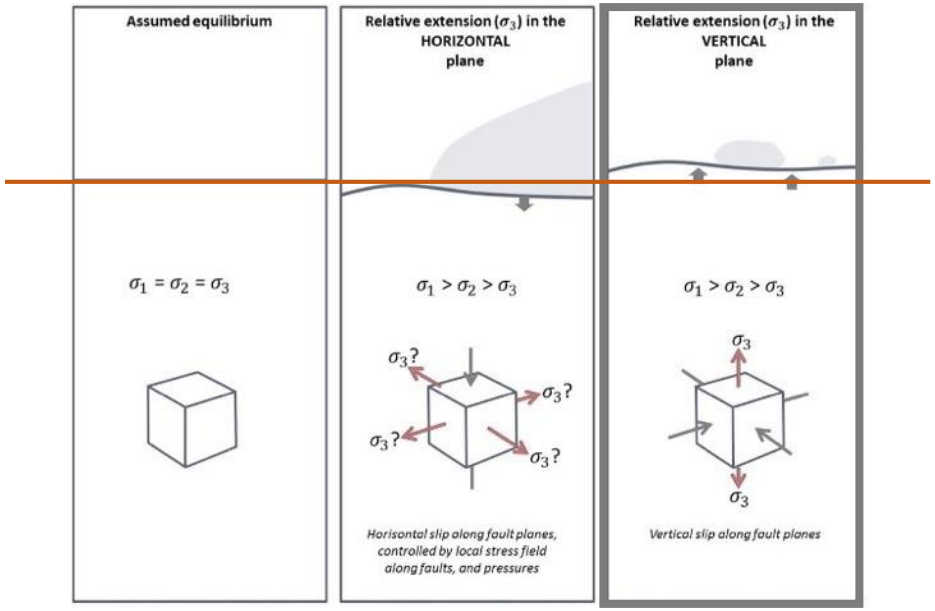


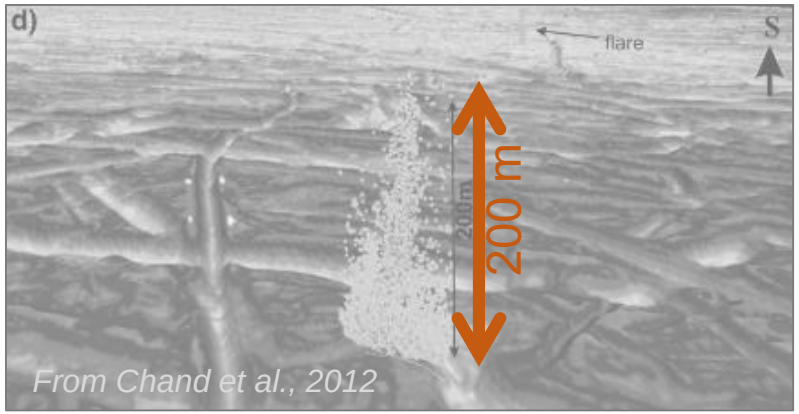
CHALLENGES IN WESTERN BARENTS SEA

Challenges in Western Barents Sea

Retention and Complicated Migration History

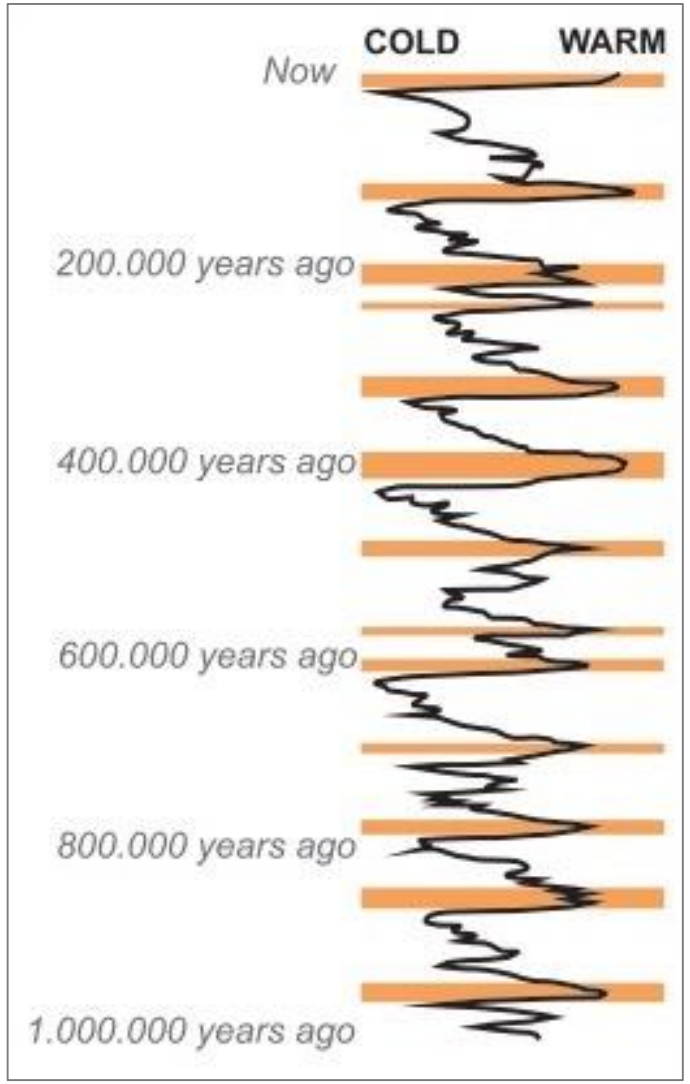


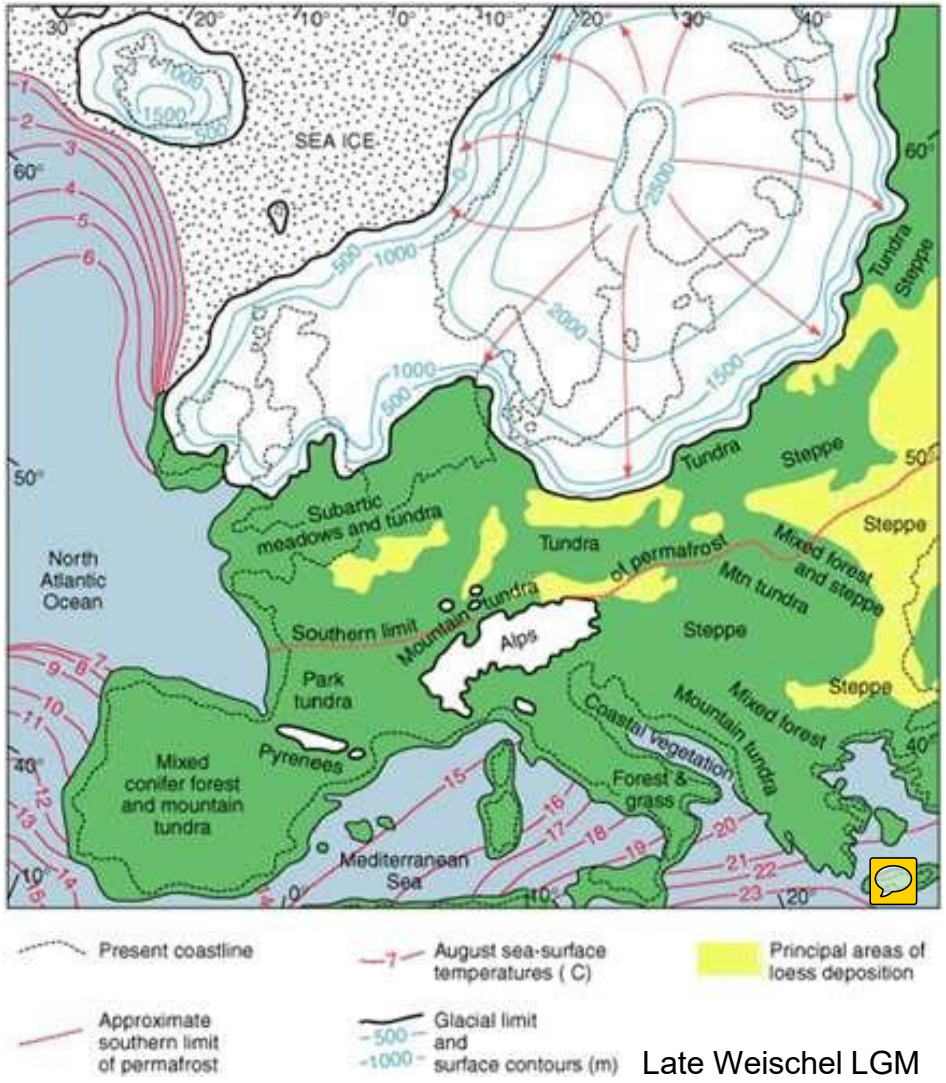




Challenges in Western Barents Sea

Retention and Complicated Migration History



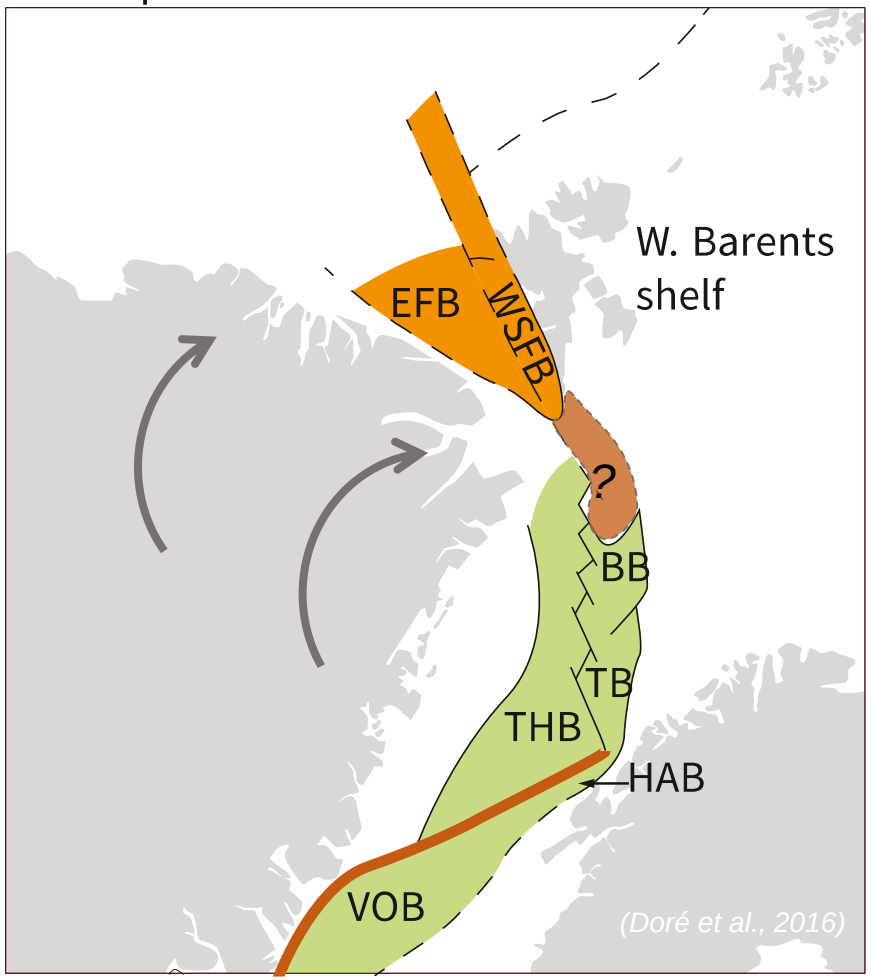


Late Weischel LGM

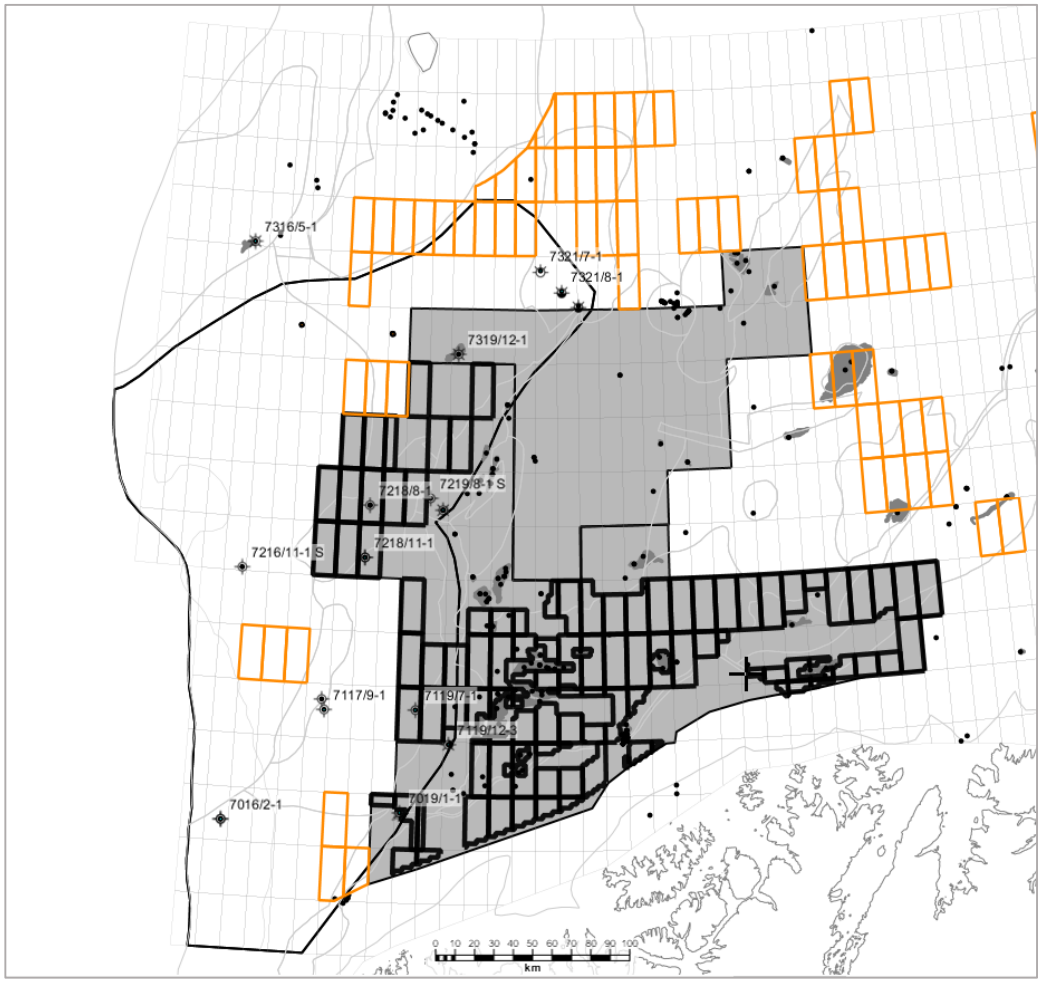
Challenges in Western Barents Sea

Tectonic Uplift and Erosion in the North

Breakup

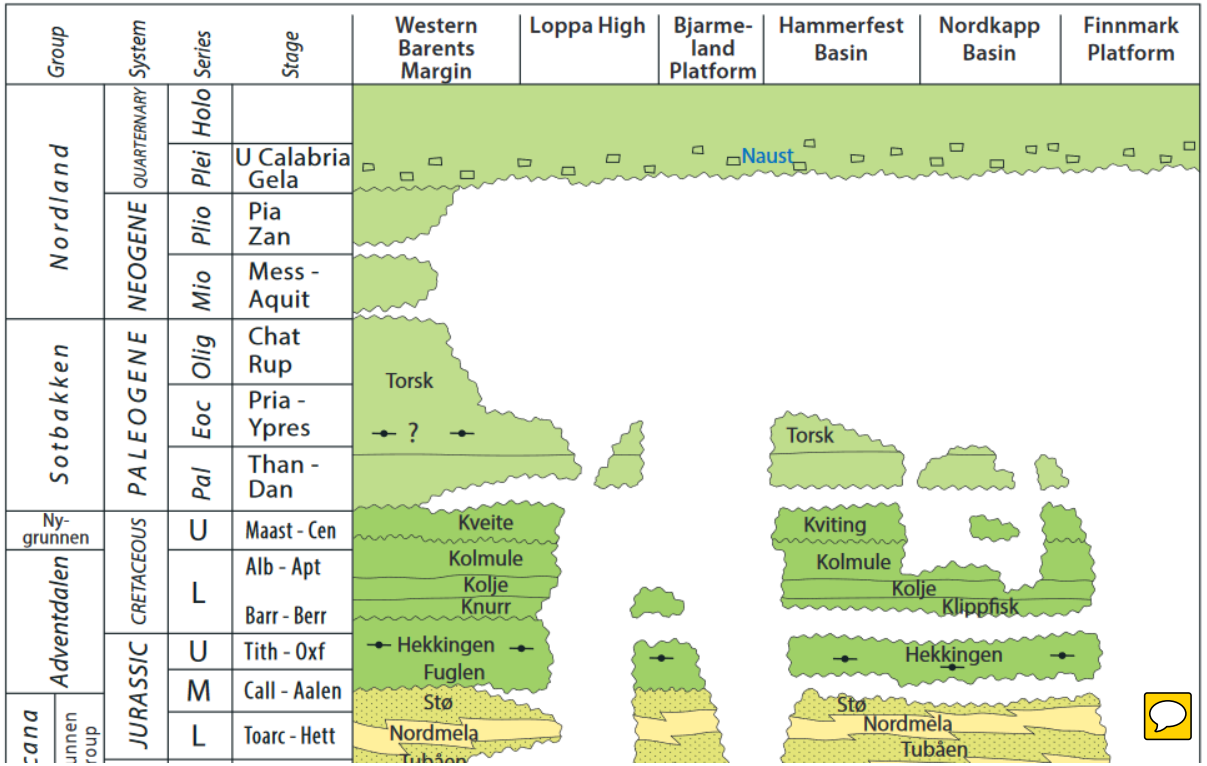


Ocean floor
Micro continent
Orogen
Cenozoic basin
Cretaceous basin
Active or incipient spreading ridge



Challenges in Western Barents Sea

Lithostratigraphy versus Chronostratigraphy



NPD lithostratigraphy published in 1988, based on earliest exploration wells in Barents Sea.

3 wells used for reference & type wells for entire post-Jurassic succession (7119/12-1, 7120/12-1 & 7121/5-1), drilled in Hammerfest Basin & Ringvassøy-Loppa Fault Complex.

No formalised subdivision of the Paleogene succession (Torsk Fm).

Application of Cretaceous lithostratigraphy is subtle, even in the type & reference wells.

Consistency with wells drilled in WBS is highly problematic in the absence of biostratigraphic data, which generates a circular argument and undermines the principle of lithostratigraphy.

Far more intra-formational variation than inter-formational differences.

Solution to the challenge: use a chronostratigraphic approach

Challenges in Western Barents Sea

Lithostratigraphy versus Chronostratigraphy

Wheeler Diagram
Highlighting unconformities observed in wells by detailed Biostrat analysis

+

Cross-diciplinary approach

Petrophysics
Geophysics
Seismic interpretation
Structural geology
Facies analysis
Salt tectonics

OPPORTUNITIES IN WESTERN BARENTS SEA

Opportunities in Western BS

New constraints on deep seismic markers

- Hekkingen Fm oil from Bjørnøya Basin migrated into Johan Castberg*
- Oil from Tromsø Basin in Filicudi?
- Possible oil shows in Pingvin well?

Ref: (Olaf Thiessen, Statoil, NCS Recent Discoveries Conference, May 11th 2016)

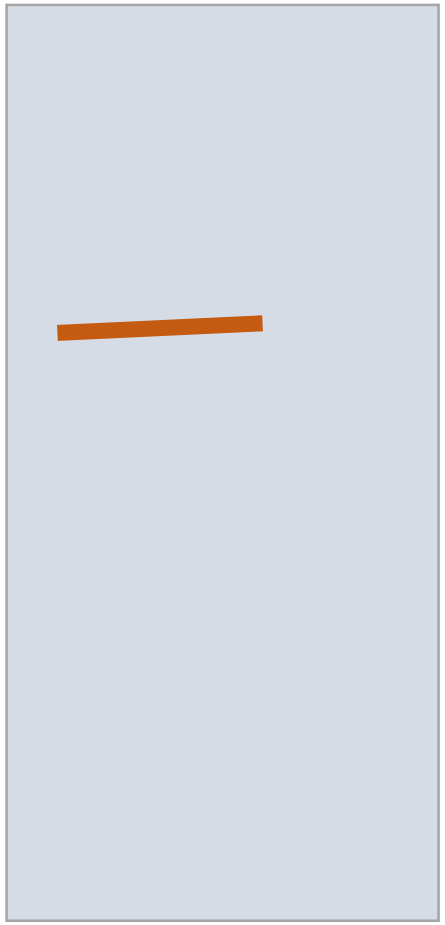
An overview map illustrating the main findings and reasons for failures in the Western Barents Sea.

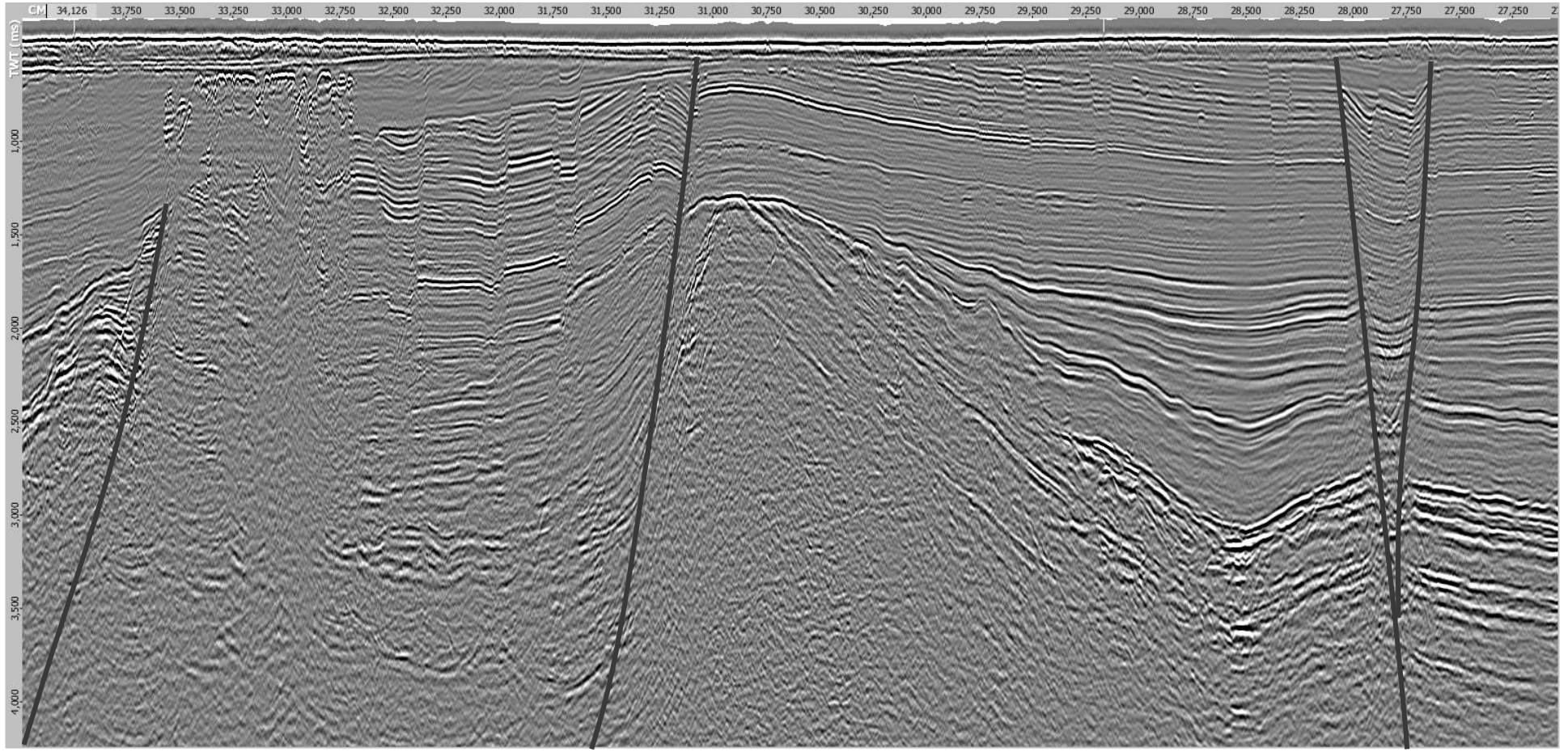
The oil that has migrated into the Johan Castberg area appears to come from Bjørnøya Basin.

But which area does the Filicudi oil come from? From the south? And if so, which source rock is the primary source rock for the oil found in the discovery?

Opportunities in Western Barents Sea

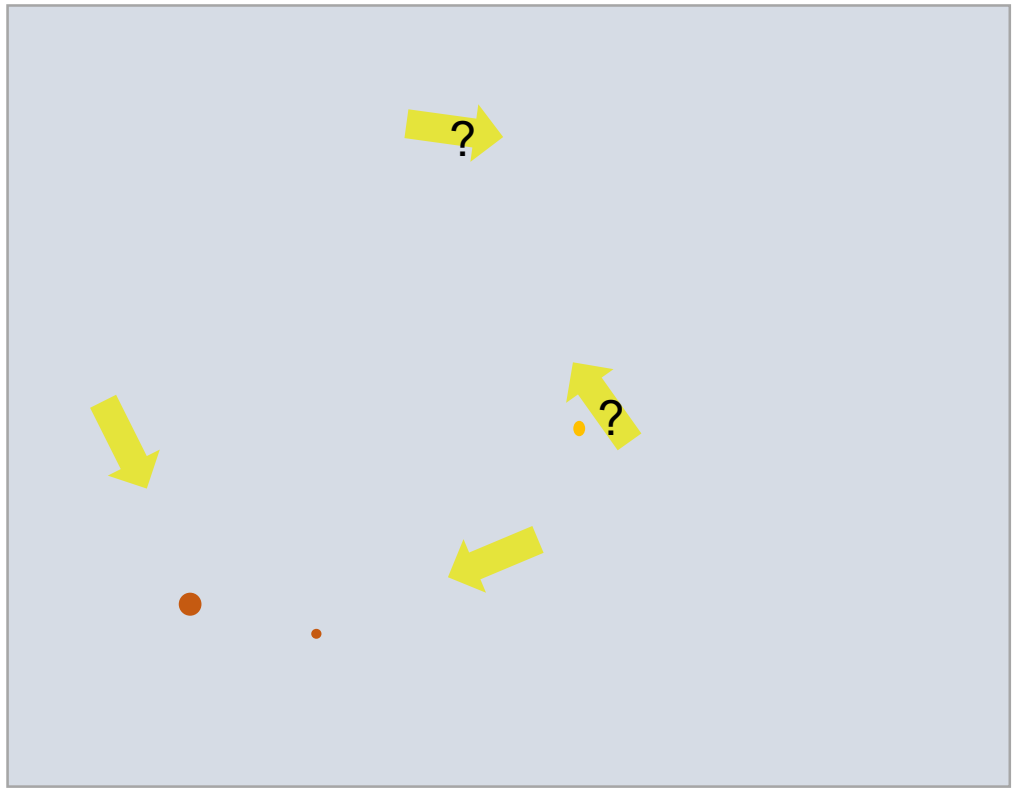
Inversion structures

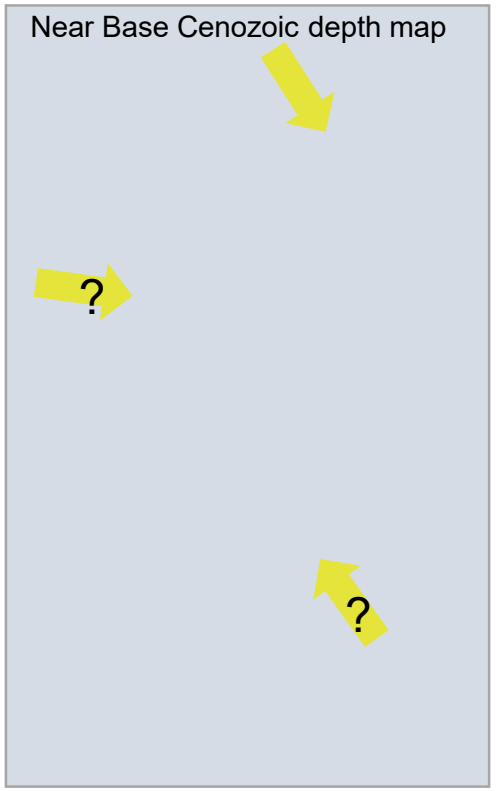


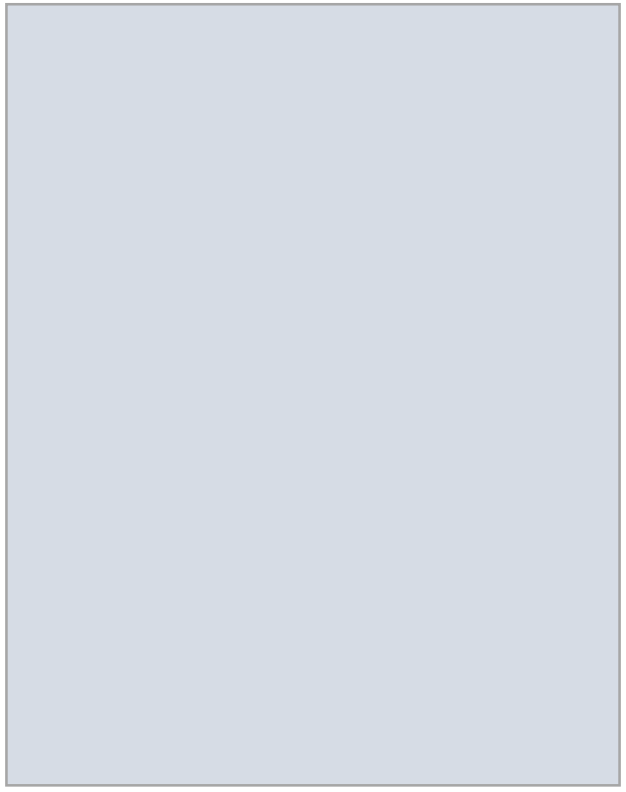


Opportunities in Western Barents Sea

New Play Models







Springar and Nise fm equivalent Late Cretaceous Play in areas close to provenance areas?

Opportunities in Western Barents Sea

A viable oil play?

- New ID of deep markers
- New Velocity Model for Depth Conversion
- New erosion model based on observations from wells and seismic data →

new petroleum system model

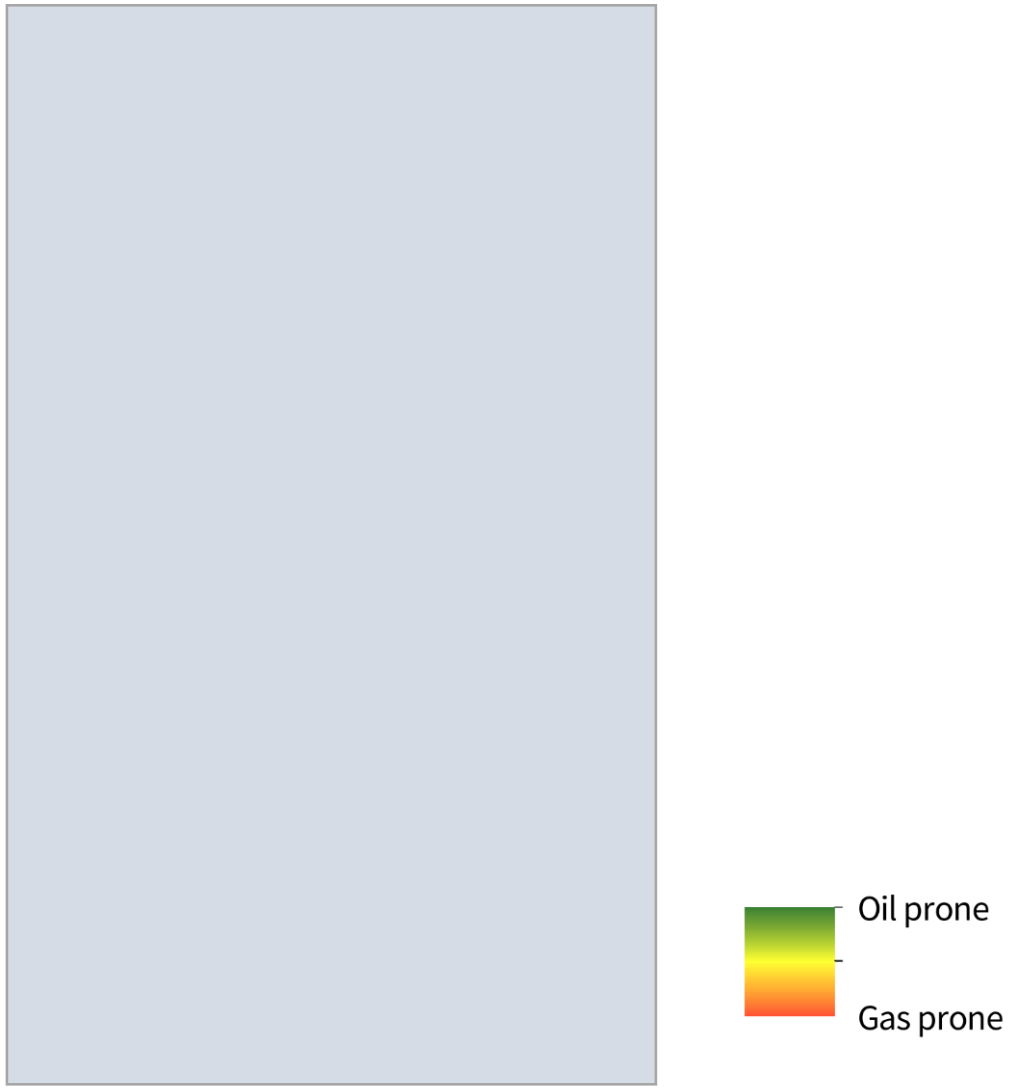
Play fairway maps indicate:

- Low, moderate and high possibility for reservoir presence
- Hydrocarbon expulsion for a given source rock at the time of trap formation
- Retention risk is *not* included

Opportunities in Western Barents Sea

A viable oil play?

Play Fairway Map Example:



SUMMARY

SUMMARY

Main Challenges

- Main challenge for Eastern Barents Sea is presence and quality of source rock
- Main challenge for Central Barents Sea is migration and trap size
- Main challenge for Western Barents Sea is to drill the right wells to efficiently understand the migration history and plays better + tectonic uplift in north area

SUMMARY

Main Opportunities

- Main opportunity for Eastern Barents Sea is proving source rock + possible traps straddling Fedynsky High
- Main opportunity for Central Barents Sea will be included in the Prospect Database
- Main opportunity for Western Barents Sea: big traps and a viable oil plays