The Structural History of the Jan Mayen Micro-Continent (JMMC) and Its Role During the Rift "Jump" Between the Aegir to the Kolbeinsey Ridge*

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Abstract

In 2008 a structural and geological study was initiated in preparation for the first and second Icelandic petroleum exploration license calls in 2009 and 2011. Much research concerning the history of the opening of the North Atlantic has been ongoing using up-to-date information. The results of this study establish a basis for a re-evaluation of the Jan Mayen Ridge (JMR) and its hydrocarbon potential. The last detailed study of the Jan Mayen Ridge (JMR) was conducted in 1985 to 1992 during a joint project between the National Energy Authority of Iceland (NEA) and the Norwegian Petroleum Directorate. This study has the aim to tie in newly acquired data sets such as 2D seismic data acquired between 2001 and 2010, high resolution bathymetry, velocity estimates, seafloor samples, and applicable research in particular concerning the timing of the North Atlantic Opening and the Jan Mayen Fracture Zone. A review of seismic and OBS velocity data were included to tie the model to depth, and estimate possible ties to pre-Tertiary formations, outline the JMR's basement, and especially assist the interpretation of the volcanic formations within the ridge.

Traditionally the ridge has been subdivided into the Main and Southern Ridge Complexes with associated listric and normal extensional fault patterns. The structural model indicates that the JMR itself is subdivided into smaller blocks with small highs and lows that most likely have been activated during the opening of the Aegir Ridge, and were influenced by the Jan Mayen Fracture Zone developments since. The western flank blocks especially show indications of uplift during the Tertiary, due to near complete erosion of the central highs in the Southern Ridge Complex with very thin deep basin sediment covers deposited during post-rift time. It also could be suggested that two failed rift attempts reached into the southeastern and southern part of the Southern Ridge Complex during the early Middle Eocene, and during the transition between Late Eocene and Early Oligocene. Indications for this are not just presented in published work, but also would better explain mapped seaward dipping reflector areal lateral offsets, volcanic intrusive observations, fault mapping with their lateral offset

comparisons on 2D seismic data, OBS velocity data anomalies between the JMR and Iceland, or explain structural features visible on high resolution bathymetry data.

The interpretation of the structural model for formation interval stratigraphic thickness changes also suggest the existence of two paleogeographic lows striking more or less west-east that might have been present at the end of the Cretaceous, prior to the Late Paleozoic initial break-up episode and massive volcanic extrusive and intrusive depositions. These two lows appear to align with the general positioning of the JMMC to the Scoresby Sund located just south of the Liverpool Land high and Jameson Land prospective basin, with indications that pre-Tertiary deposits are still preserved underneath the Tertiary basalt cover, which could explain locally identified pre-Tertiary and sub-basalt unconformities and well-visible layering on more recent 2D seismic data. The newly derived structural model indicates that the JMR itself could be used as a part of the puzzle to better explain the transition from the Aegir Ridge to the Kolbeinsey Ridge during the opening of the North Atlantic between the Middle Eocene up to the Early Miocene. This transition history has implications for the structural history and timing of the ridge segments, and its geothermal influence on the JMR formations during the initial break-up of the North Atlantic and the extensive volcanism during the Late Paleocene to Early Eocene, and especially between the Middle Eocene and Early Miocene.

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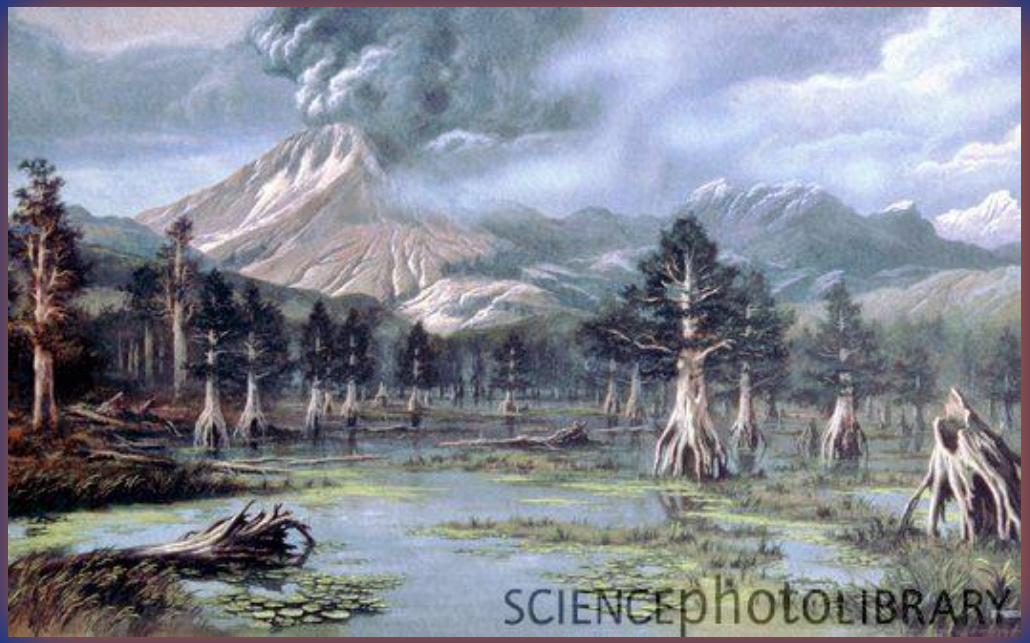
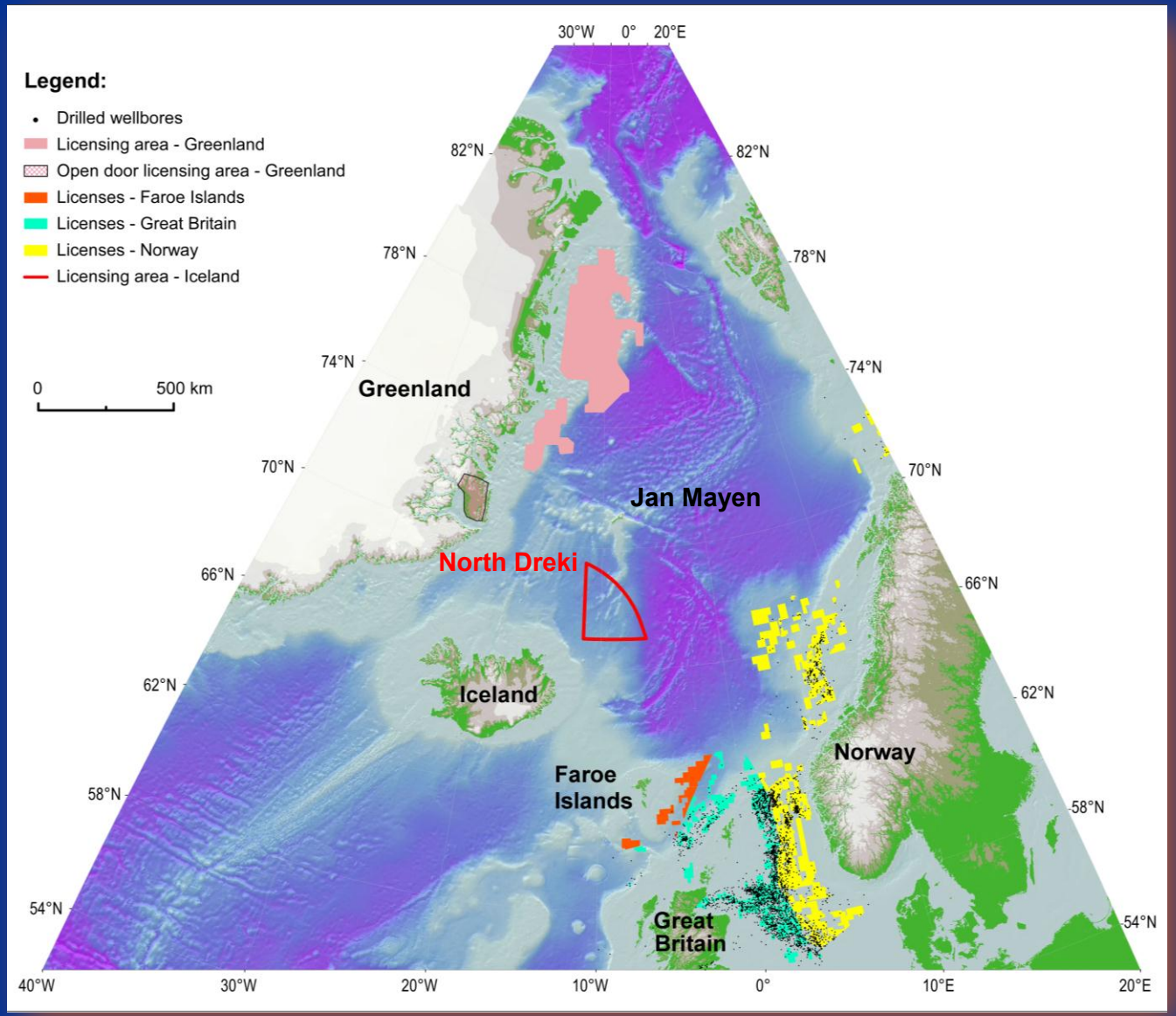


The North Dreki Licensing Area

Location Reference

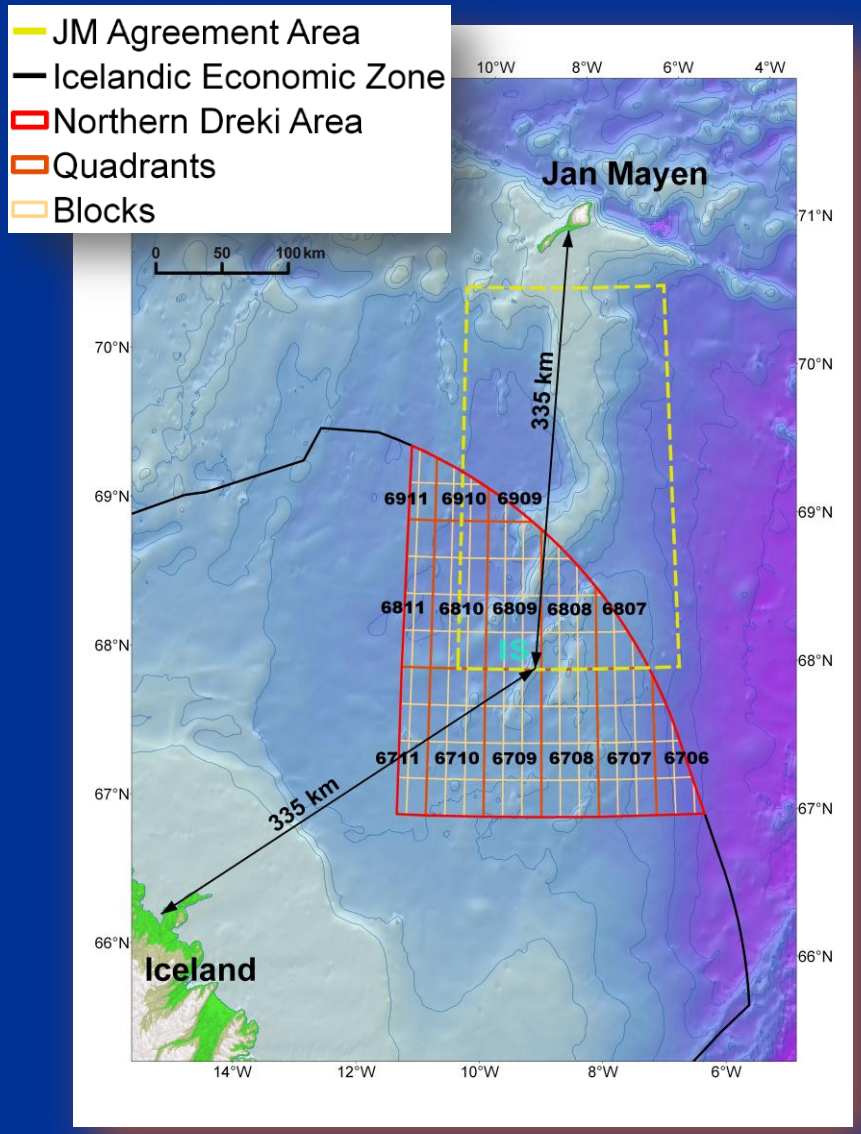
- North Dreki is part of the Jan Mayen Micro-Continent (JMMC) with indications of continental strata and suitable structures
- Similarities to the middle East Greenland coast that is part of Greenland Licensing areas, the Møre- and Vøring Basins at the Norwegian coast, which are proven hydrocarbon provinces.



Second Icelandic Licensing Round

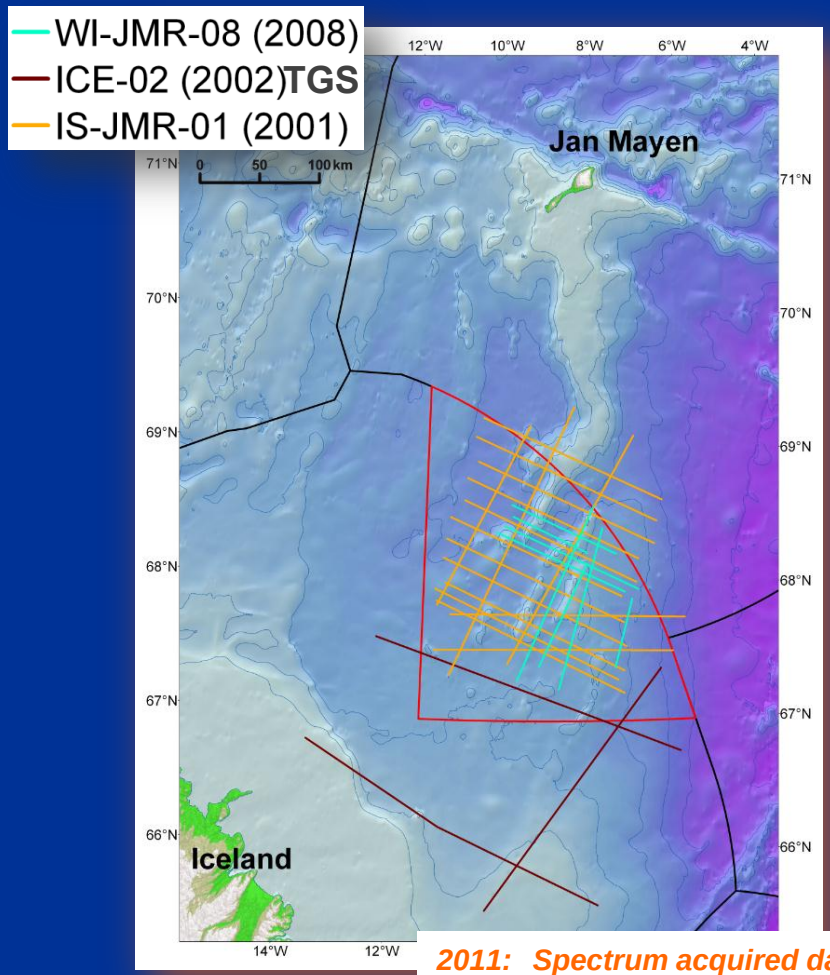
Northern Dreki Area

- Licensing Round is set to open on the 3rd of October 2011
- Application deadline is on the 2nd of April 2012
- Norway (Petoro) has right to participate up to 25% in licenses granted within the Jan Mayen Agreement Area



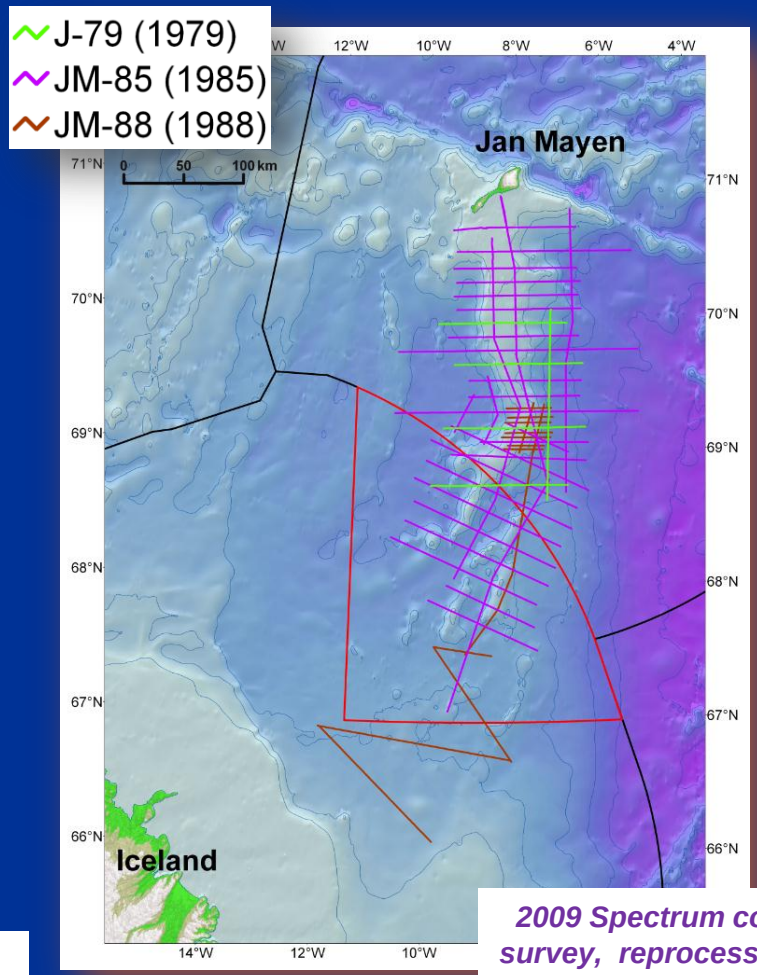
2D Seismic reflection data surveys over the Jan Mayen Area

Commercial Surveys



2011: Spectrum acquired data from CGG Veritas;
2009: CGG Veritas, reprocessed part of the IS-JMS-01 data

NPD-NEA Surveys



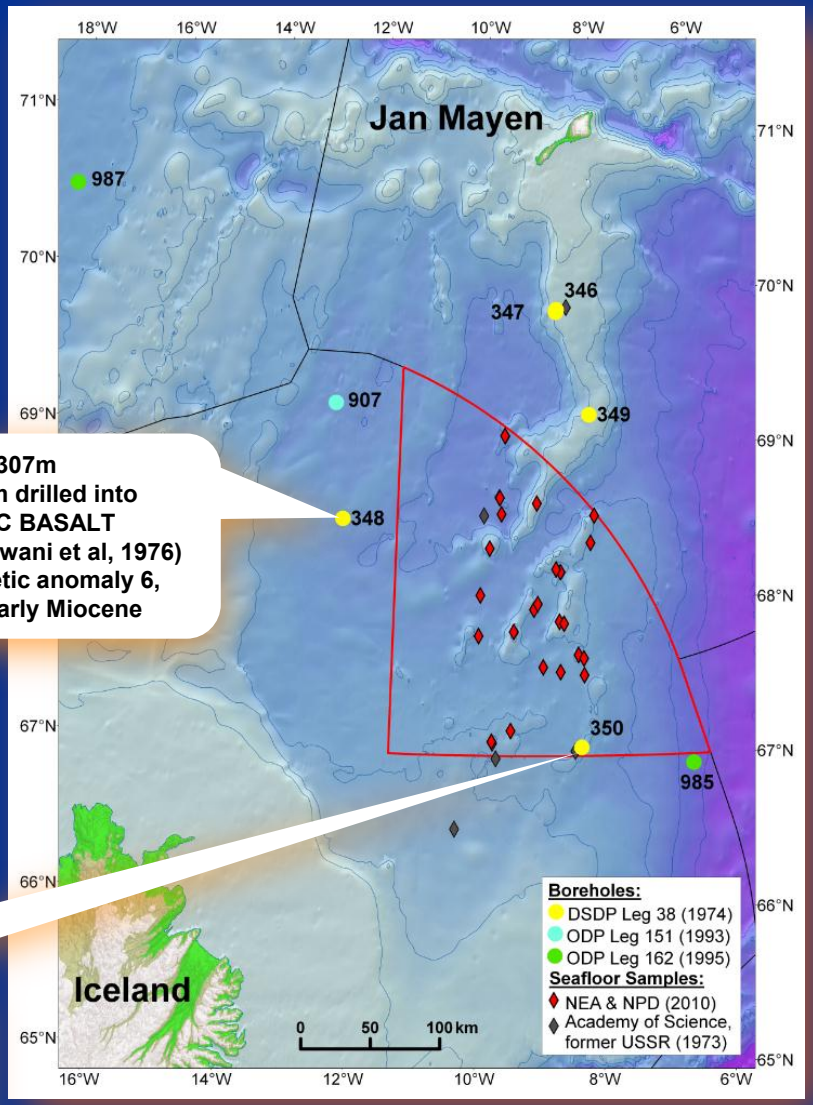
2009 Spectrum commercial survey, reprocessed JM-85 & JM-88 data

Borehole & Seafloor Samples around the Jan Mayen Area

Academic DSDP & ODP Cruises

- 5 wells during Leg 38 in 1974
- 1 well during Leg 151 in 1993
- 2 wells during Leg 162 in 1995

Wells have core analyzed based density and vertical velocity data available that enabled a depth – seismic tie (TWT) to confirm the Top Eocene marker for 3 wells on the Ridge.



TD: 2307m
Fm@TD: 17m drilled into VARIOLITIC BASALT
18.8 ± 1.7Ma (Talwani et al, 1976)
approx. magnetic anomaly 6, around top Early Miocene

TD: 1663m
Fm@TD: 26m drilled into BASALT BRECCIA/DIABASE BASALT
40-44 Ma (Talwani et al, 1976)
approx. magnetic anomaly 19-20, Middle Eocene

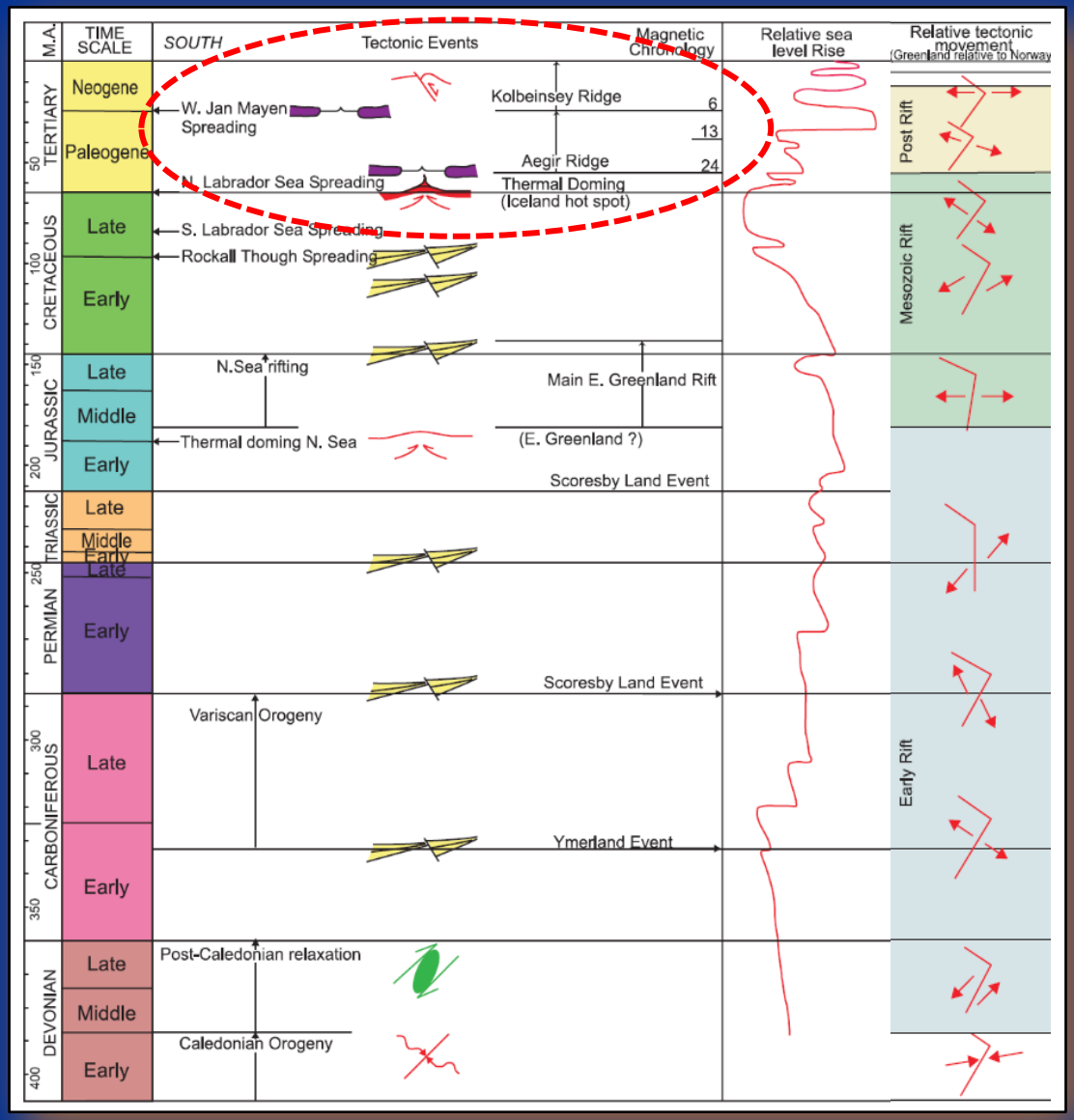
REGIONAL SETTINGS

- TECTONIC MODELS
- STRATIGRAPHY
- ANALOGUES

Tectono-stratigraphic Chart

What to consider for the JMMC ?

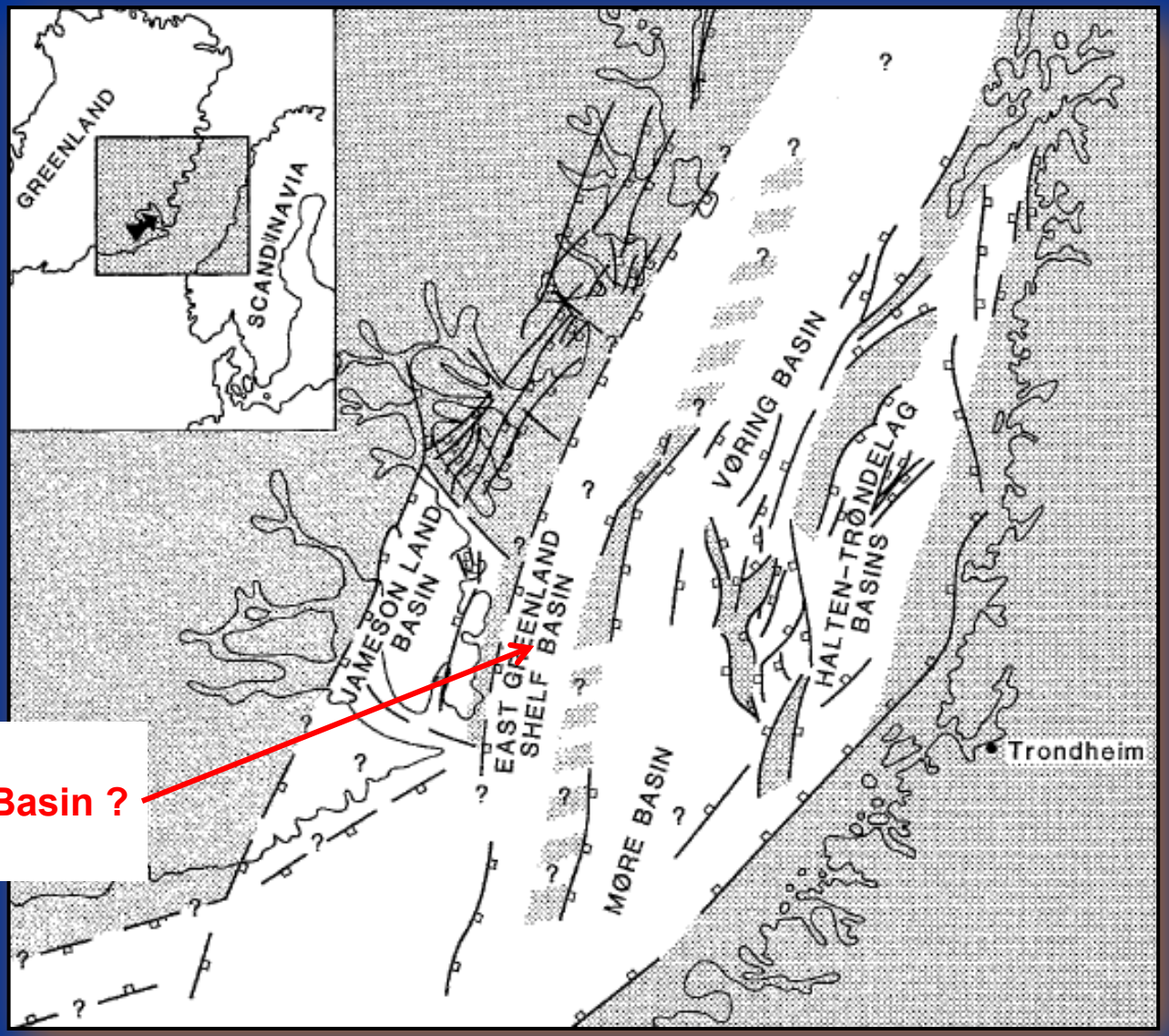
Hamann, N.E. et al, 2005



Early Jurassic Tectonic Map

What to consider for the JMMC ?

G. Dam & F. Surlyk, 1995



Tectonic History of the JMMC

Possible Scenario

- Jan Mayen Micro-Continent
- Major Fault-Fracture Zone
- Possible Major Fault-Fracture Zone
- Active Mid-Oceanic Ridge & Volcanic systems
- Possible Active Mid-Oceanic Ridge
- Extinct Oceanic Ridge or Ridge Segment
- JMR Major Fault
- JMR Late Tertiary Reverse Fault
- General direction of plate motion (Gaina et al, 2009)
- General direction of MOR opening (Gaina et al, 2009)
- Icelandic Hot Spot Location (Gaina et al, 2009)
- Large Paleocene volcanic intrusion (Henriksen et al, 2008)
- Mapped possible extent of Paleocene / Early Eocene Basalt (Henriksen et al, 2008)
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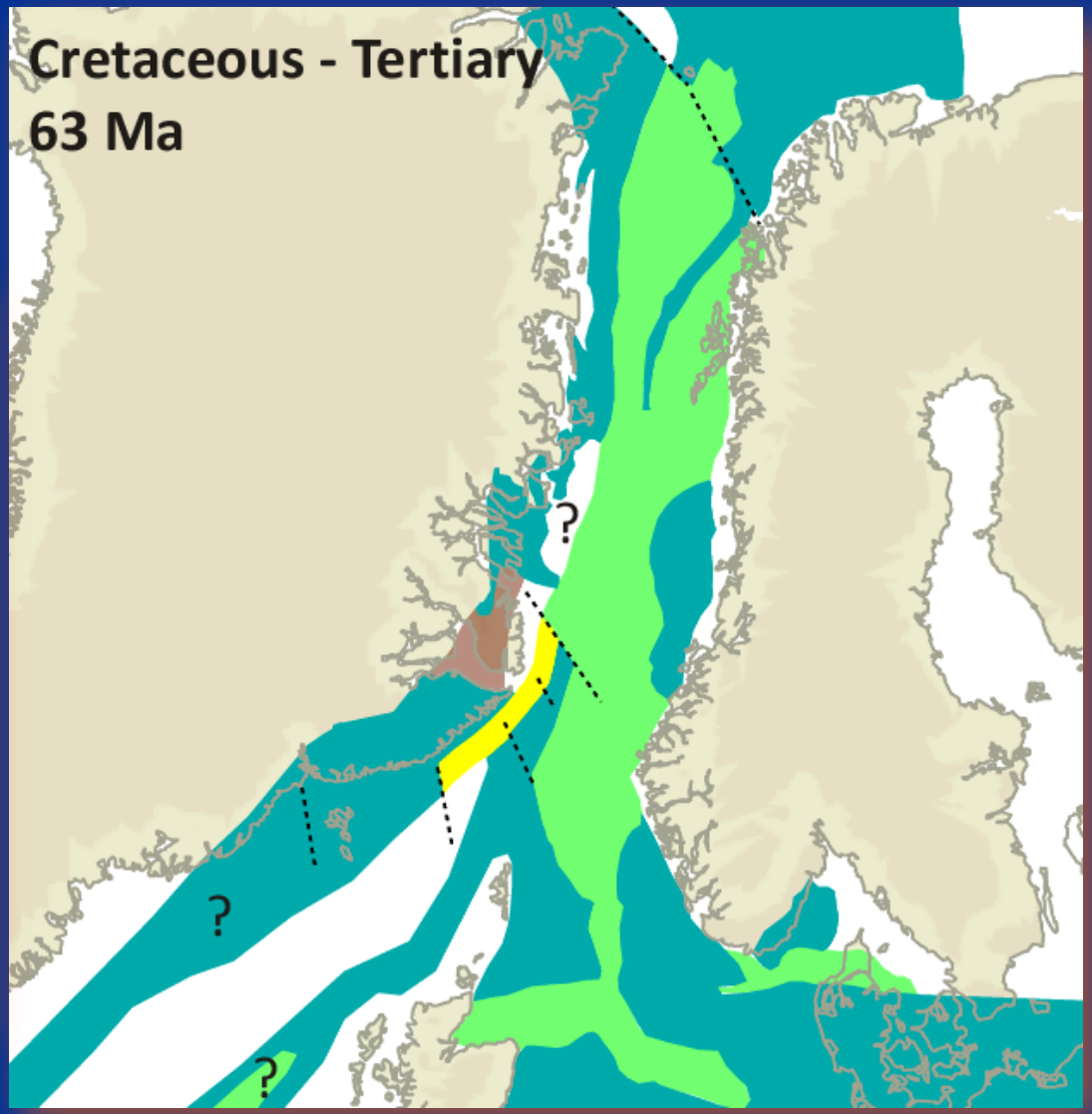
- Late Cretaceous - Possible outline of deep basin areas.
- Late Cretaceous - Possible outline of platform-terrace & high areas.
- East Greenland Paleozoic Basin (Jameson Land) (Henriksen et al, 2008)

Possible oceanic crust time zones:

- ~56 Ma - 49,7 Ma (approximately Anomaly 25-22)
- ~49,7 Ma - 47,9 Ma (approximately Anomaly 22-21)
- ~47,9 Ma - 33,1 Ma (approximately Anomaly 21-13)
- ~33,1 Ma - 20 Ma to 19 Ma (approximately Anomaly 13-6)
- At time interval build up of oceanic floor.



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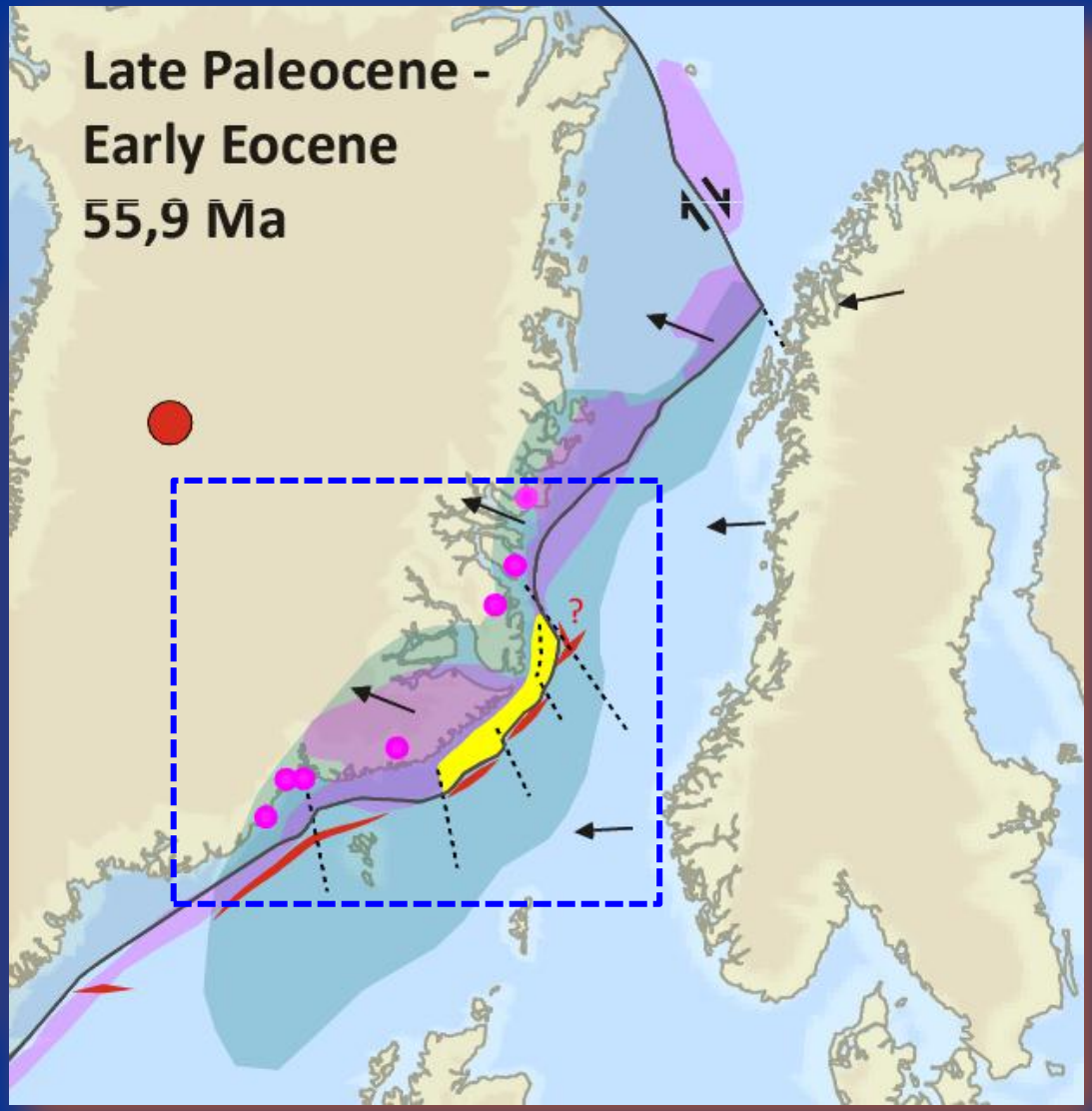

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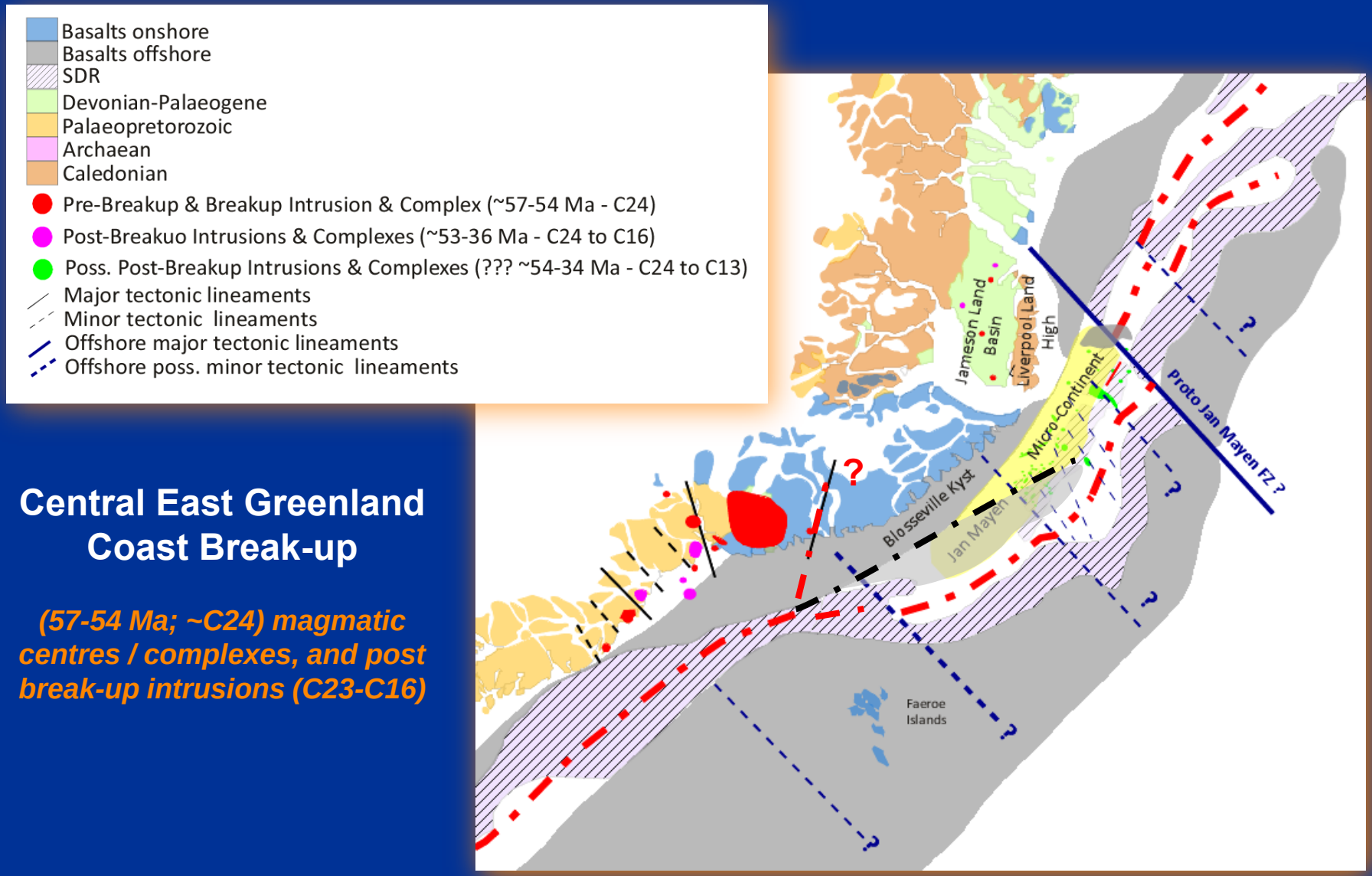

Central East Greenland Coast Break-up

(57-54 Ma; ~C24) magmatic centres / complexes, and post break-up intrusions (C23-C16)

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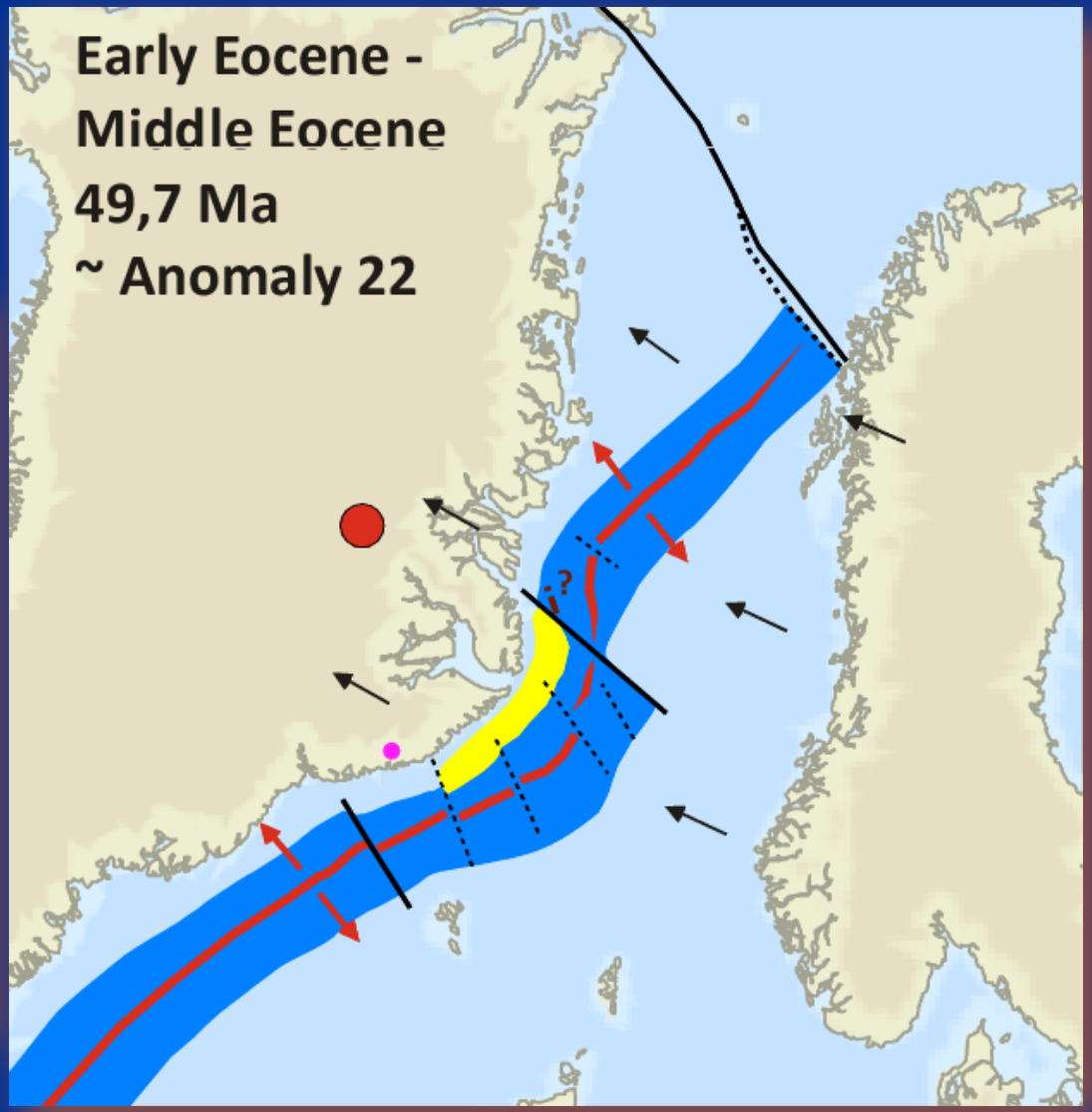

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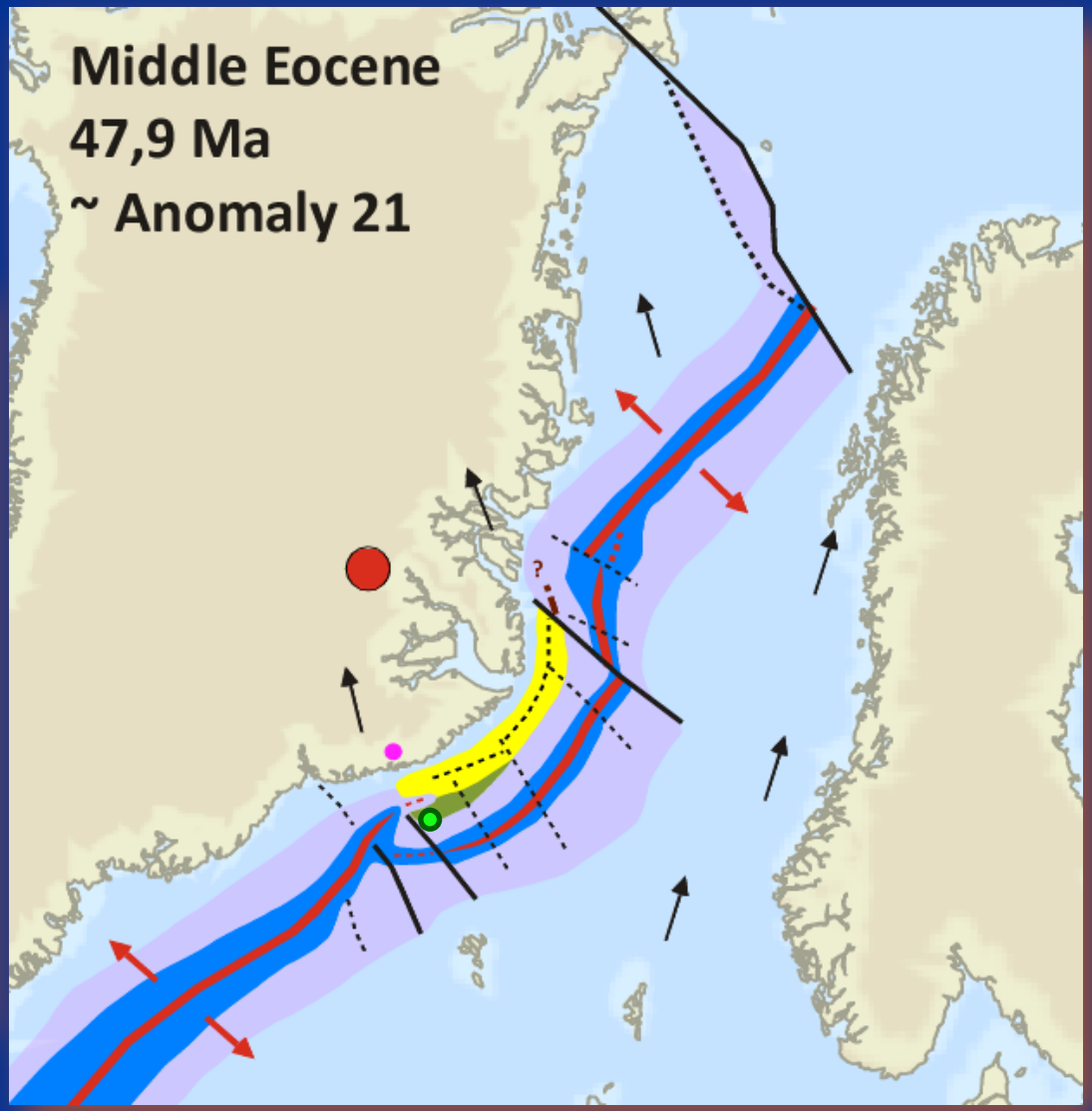

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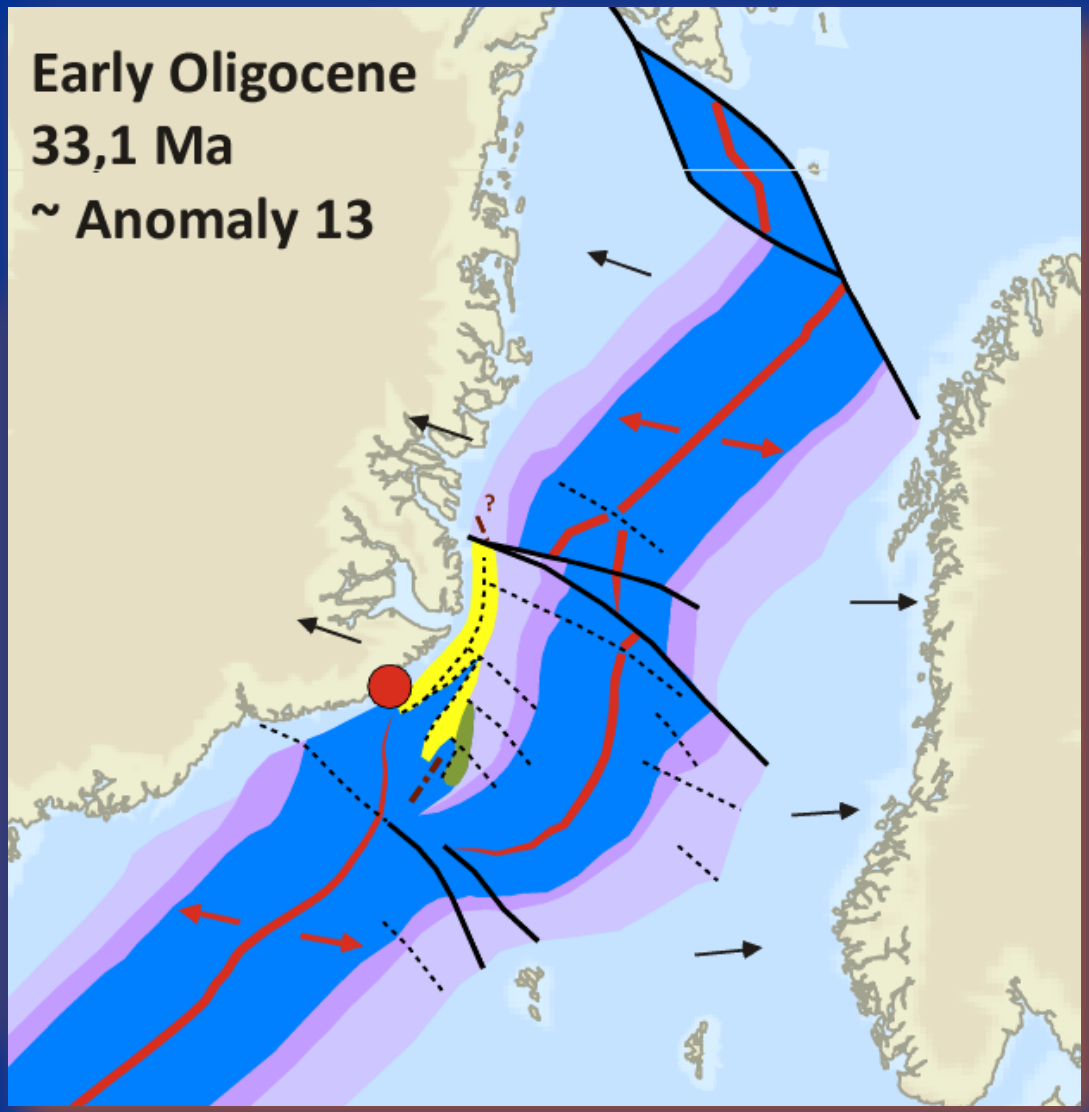

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- General direction of plate motion (Gaina et al, 2009)
- General direction of MOR opening (Gaina et al, 2009)
- Icelandic Hot Spot Location (Gaina et al, 2009)
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- Late Cretaceous - Possible outline of deep basin areas.
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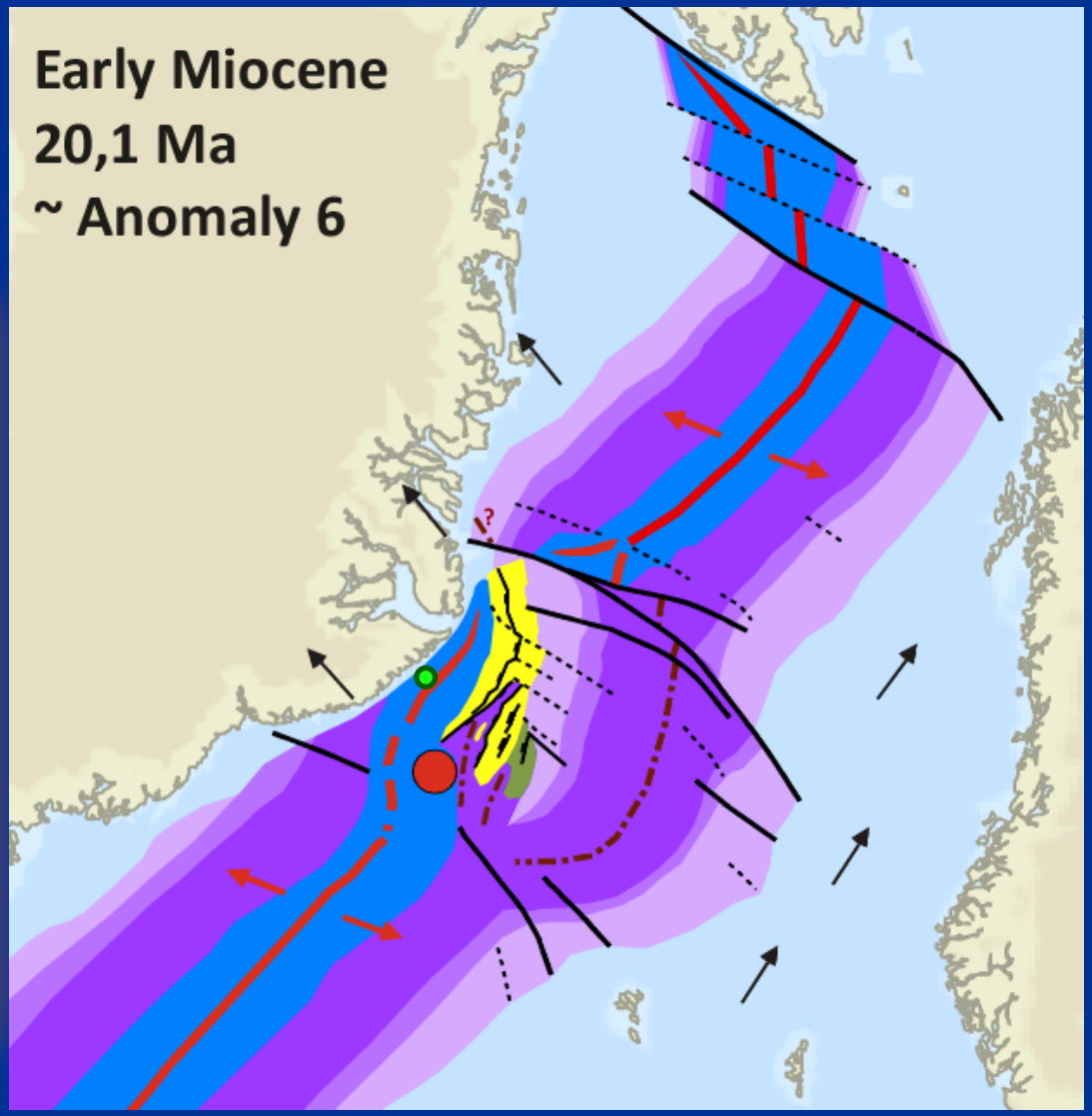
- East Greenland Paleozoic Basin (Jameson Land) (Henriksen et al, 2008)

Possible oceanic crust time zones:

- ~56 Ma - 49,7 Ma (approximately Anomaly 25-22)
- ~49,7 Ma - 47,9 Ma (approximately Anomaly 22-21)
- ~47,9 Ma - 33,1 Ma (approximately Anomaly 21-13)
- ~33,1 Ma - 20 Ma to 19 Ma (approximately Anomaly 13-6)
- At time interval build up of oceanic floor.



Tectonic History of the JMMC

Possible Scenario

- Jan Mayen Micro-Continent & Southern Ridge Complex
- Major Fault-Fracture Zone
- Possible Major Fault-Fracture Zone
- Active Mid-Oceanic Ridge & Volcanic systems
- Possible Active Mid-Oceanic Ridge
- Extinct Oceanic Ridge or Ridge Segment
- JMR Major Fault
- JMR Late Tertiary Reverse Fault
- General direction of plate motion (Gaina et al, 2009)
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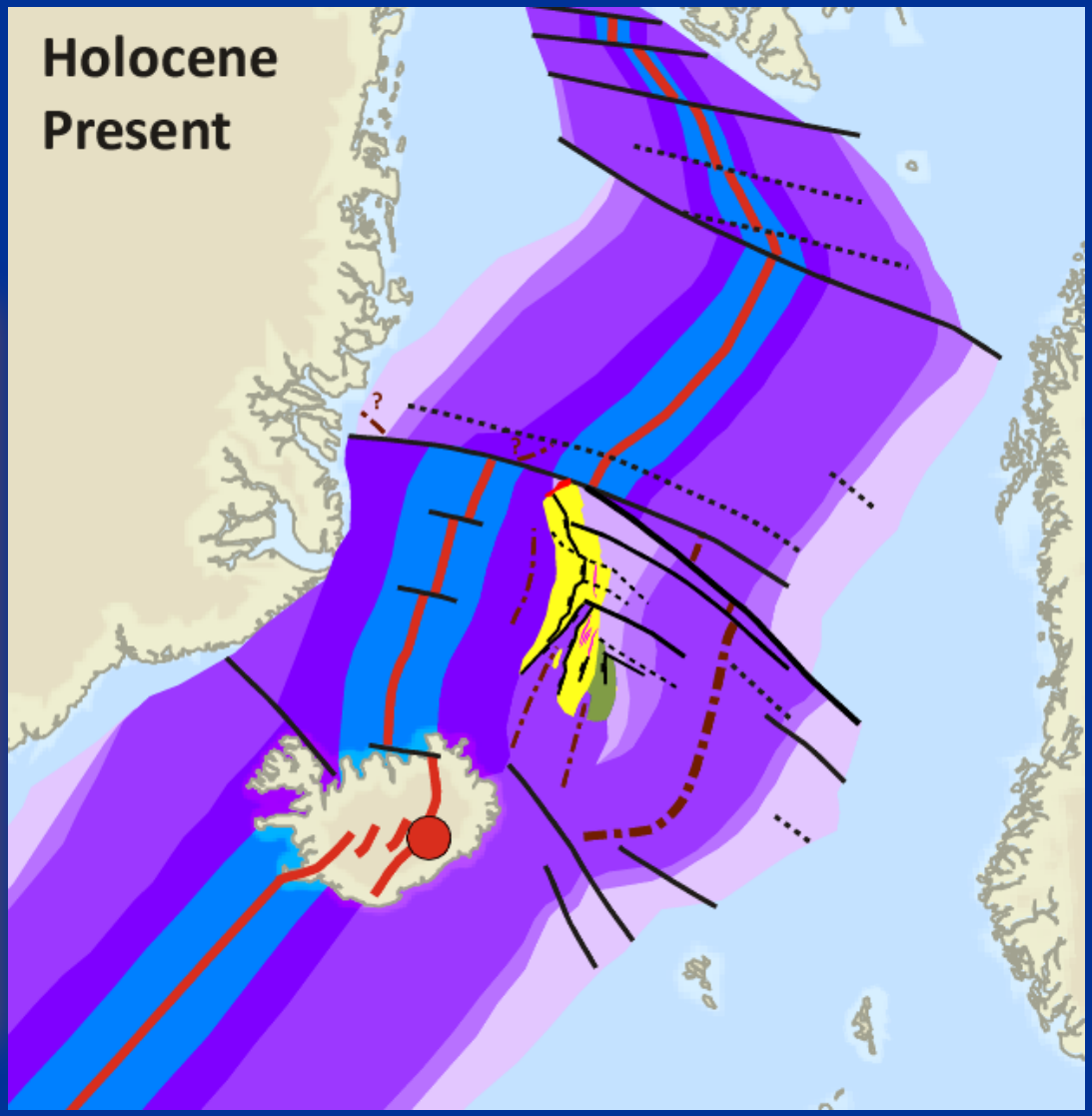
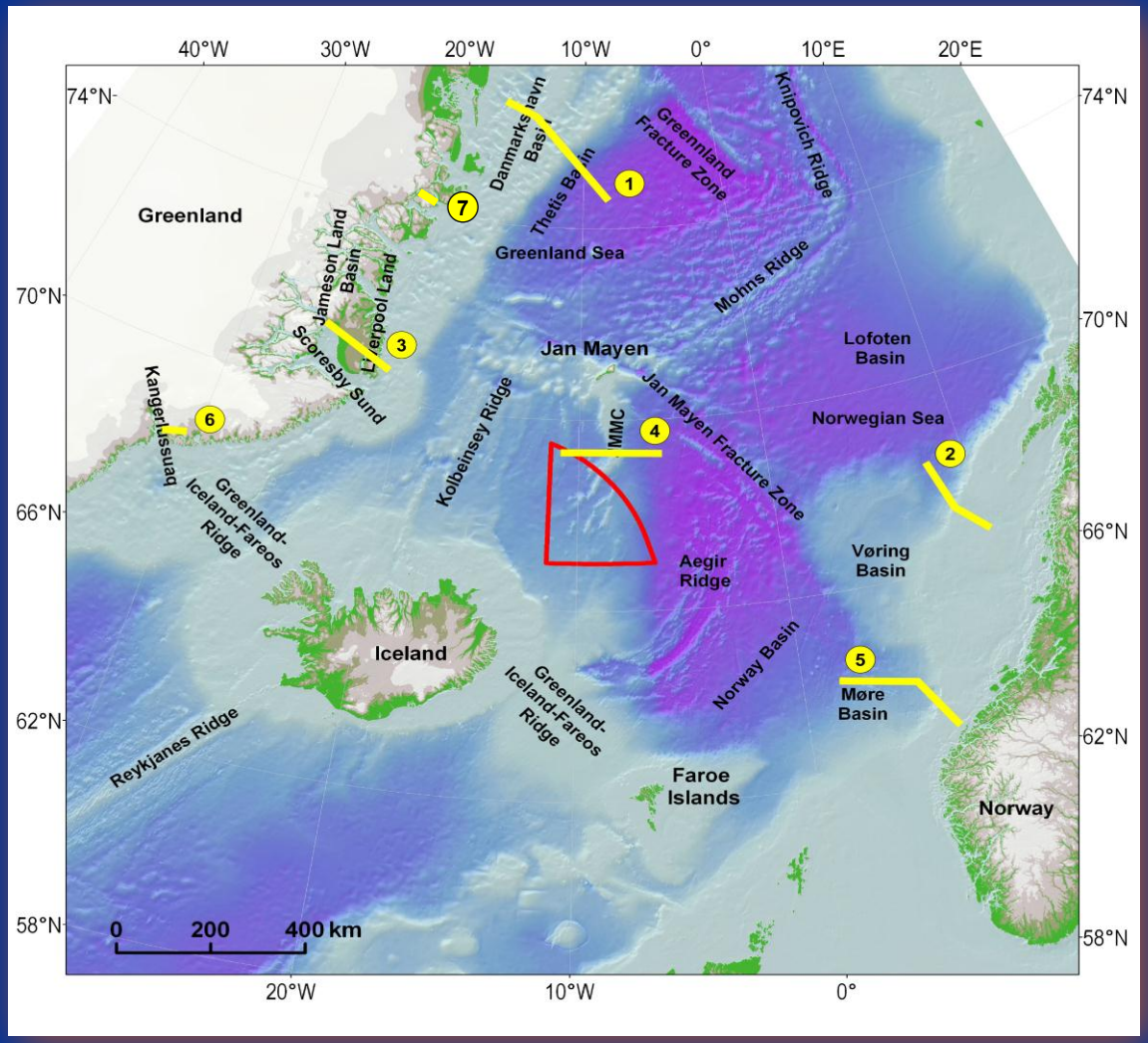


Regional Correlations important for comparison to the history of the JMMC

Collage based on results of recent research publications and observations at the JMMC



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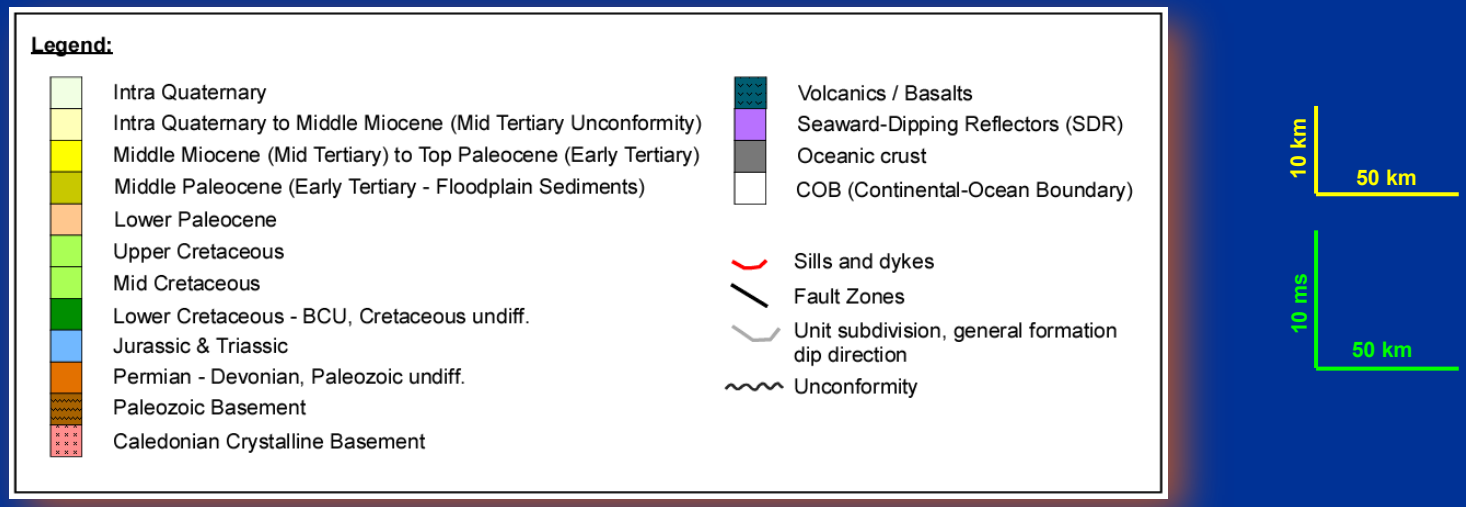

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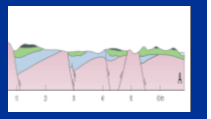
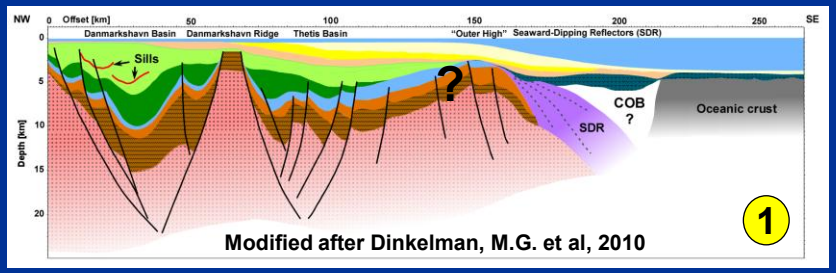
7 Wollaston Foreland



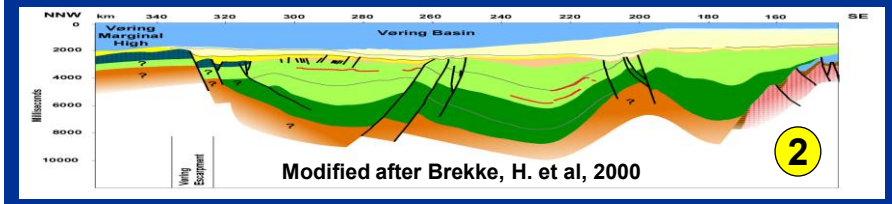
Modified after Henriksen, N. et al, 2009

Danmarkshavn & Thetis Basins



Modified after Dinkelman, M.G. et al, 2010

Vøring Basin



Modified after Brekke, H. et al, 2000

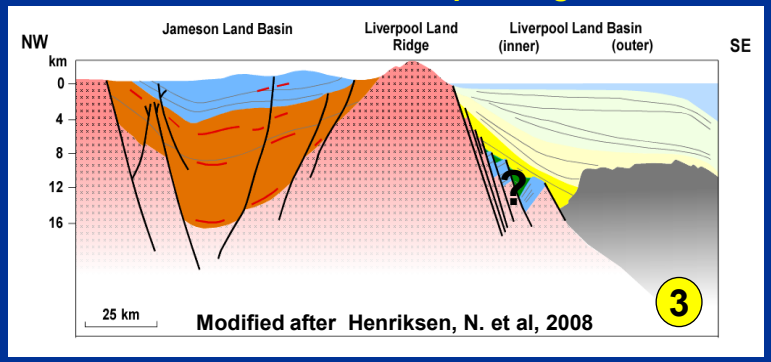
10 km

50 km

10 ms

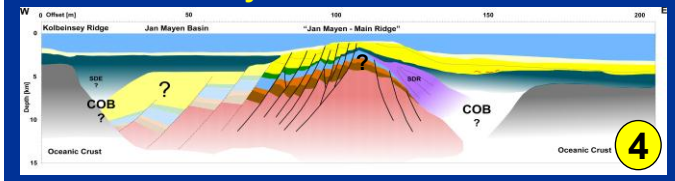
50 km

Jameson Land Basin, Liverpool High & Basin

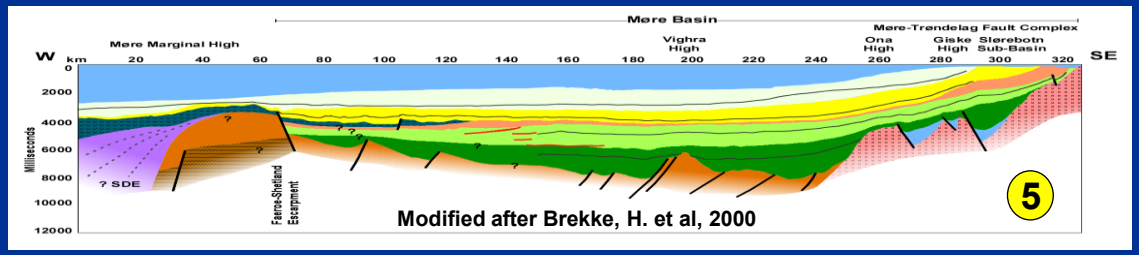


Modified after Henriksen, N. et al, 2008

Jan Mayen Micro-Continent

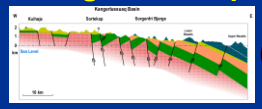


Møre Basin



Modified after Brekke, H. et al, 2000

Kangerlussuaq



6

Modified after Henriksen, N. et al, 2008

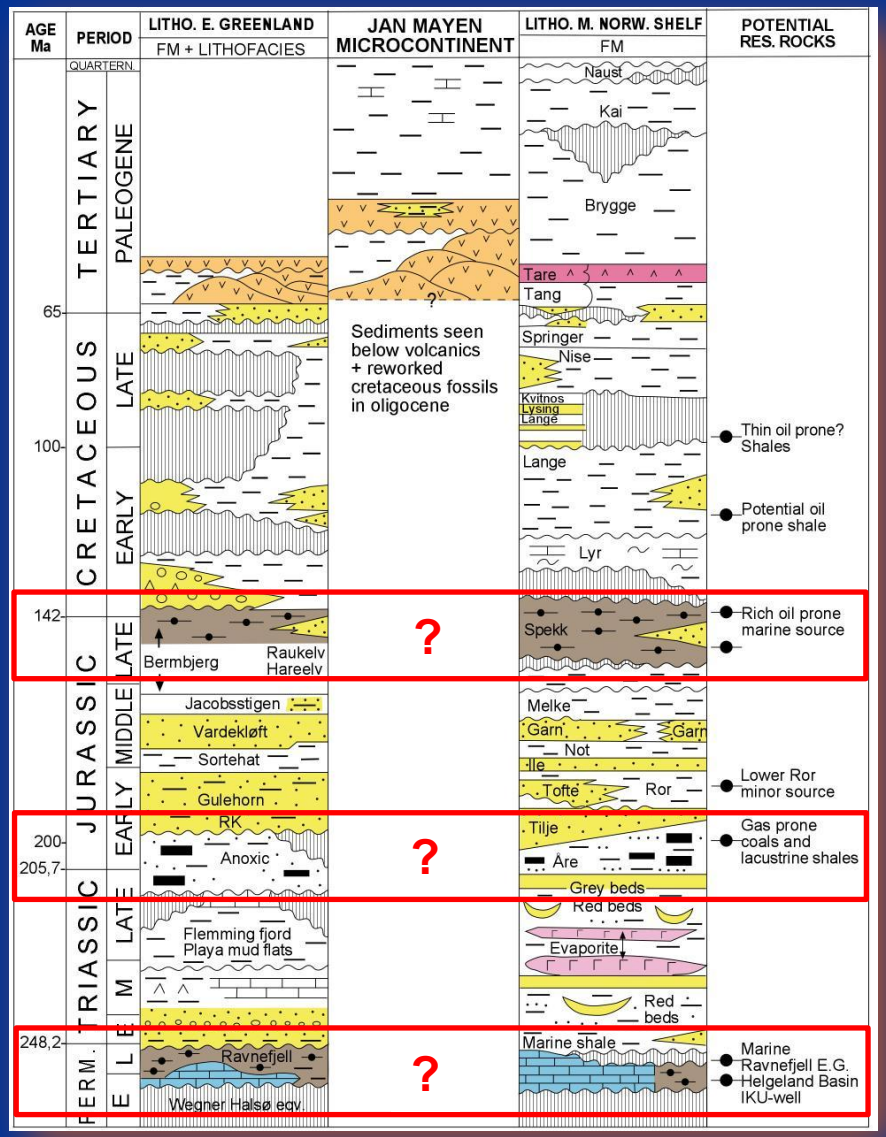
Stratigraphy

Question of Potential Source Rocks

Jameson Land Basin

Mathiesen et al, 2000

- Upper Permian ***Ravnefjell*** Formation:
  - Post-mature, except NW-Region
  - HC-generation began Mid-Cretaceous
  - Main phase, Late Cretaceous – Early Paleocene
- Lower Jurassic ***Kap Stewart*** Formation:
  - Sufficient maturity for Oil exploration in central & southern area of the basin
  - Regionally extensive
  - HC-generation, Paleocene - during and shortly after extrusion of the volcanic rock sequences
- Upper Jurassic **Hareelv** Formation



Sagex (2008)

Jan Mayen Structures

Top Paleocene Structure Map
(Depth Range: 170m – 6100m)

Structural Compartmentalization of the JMMC

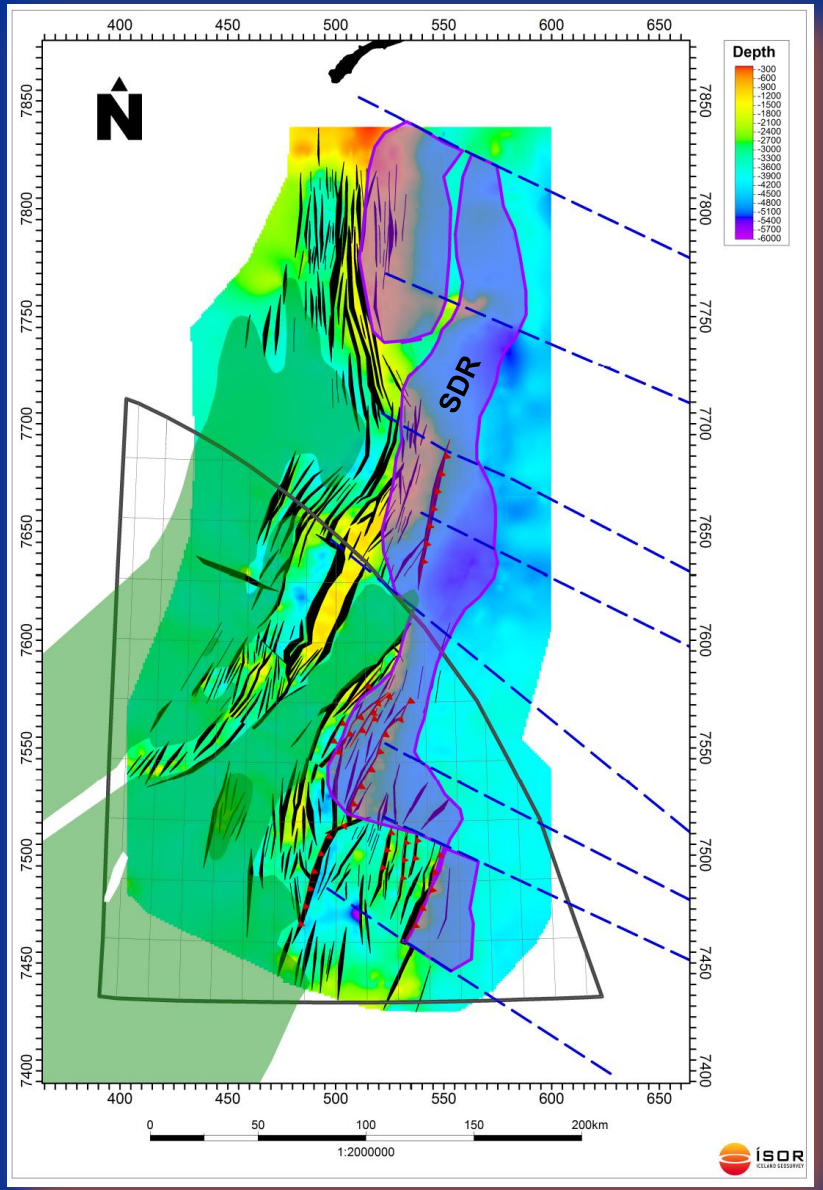
Early to Late Oligocene composite sheet of flat-lying intrusive covering subsided continental crust just before oceanic crust started to form on the Kolbeinsey Ridge and the Iceland Plateau.

SDR (Seaward Dipping Reflectors)

Important Fault / Fractures Zones that influence and subdivide the JMR.

Top Paleocene Faults

Minor reverse faulting visible (poss. since the Middle Miocene parallel the opening of the Kolbeinsey Ridge)

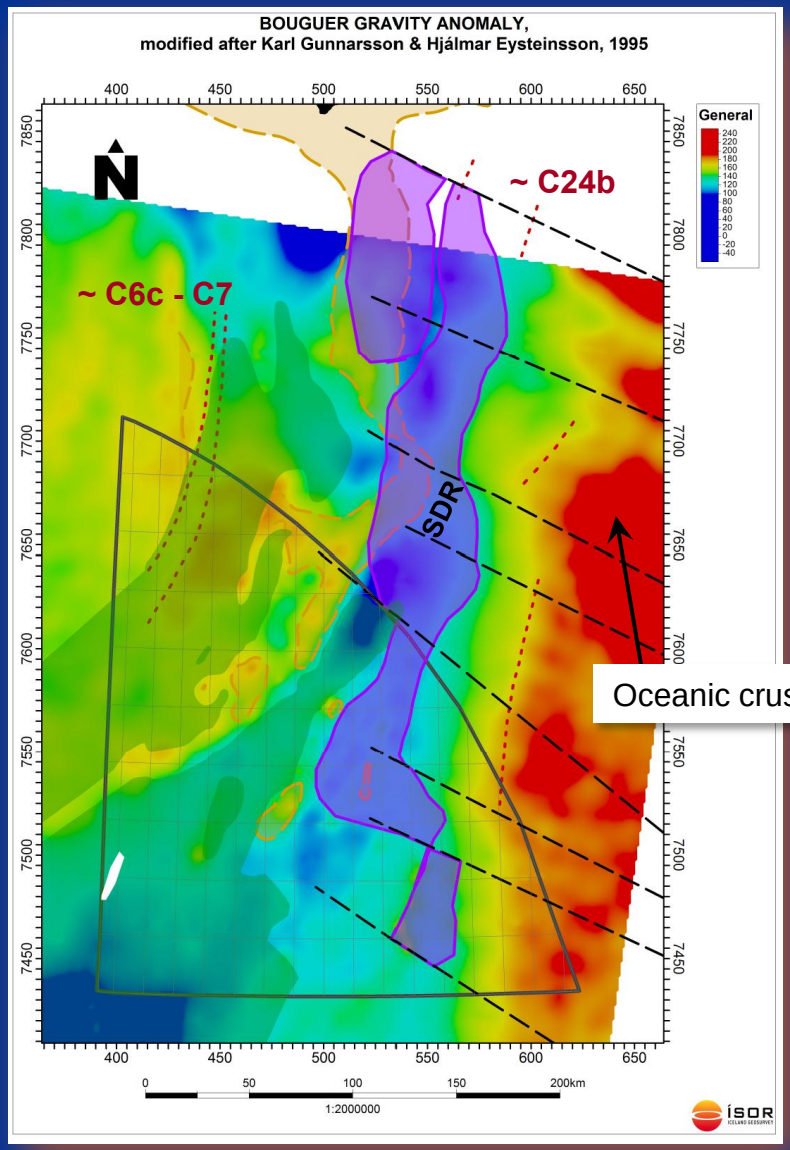


Bouguer Gravity Anomaly (100 to 190 mGal)

(JM-85 Gravity/Magnetic data set modified after Gunnarsson, K. 1995)

Clues to the main structural outlines of JMMC

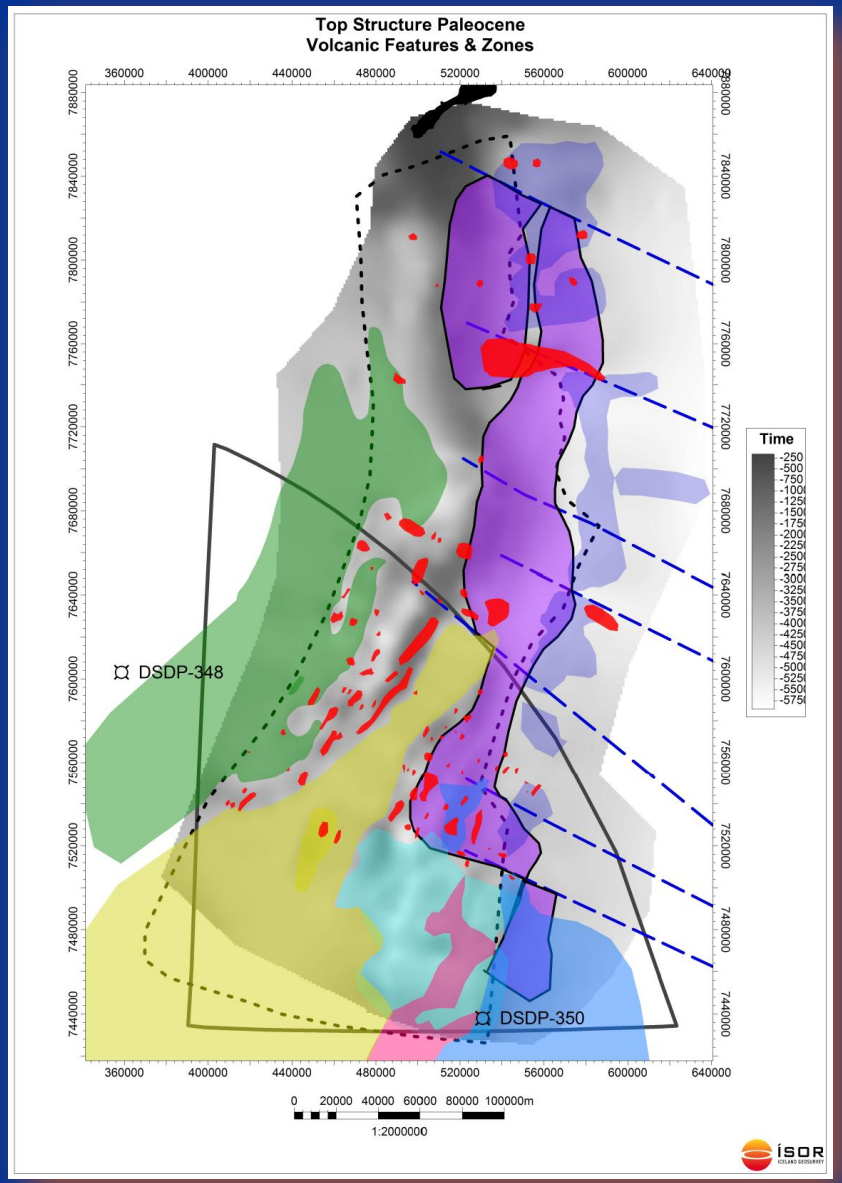
- Early to Late Oligocene composite sheet of flat-lying intrusive covering subsided continental crust just before oceanic crust started to form on the Kolbeinsey Ridge and the Iceland Plateau.
- SDR (Seaward Dipping Reflectors)
- Free Air Gravity >50Gal following the main structural blocks of the JMMC.
- Important Fault / Fractures Zones that influence and subdivide the JMR.



Volcanic Zones of JMMC

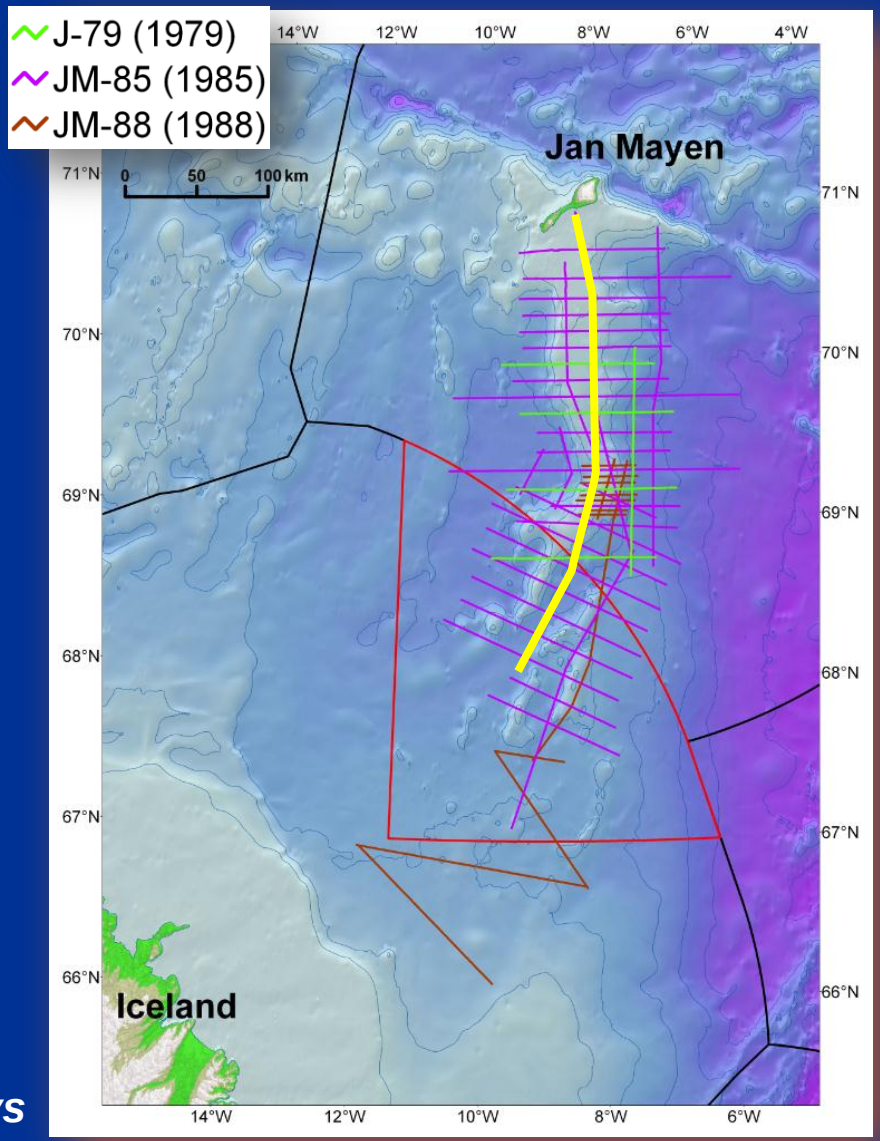
Possible scenario

- SDR (Seaward Dipping Reflectors)
- Poss. post break-up, larger intrusions
- Volcanic complexes poss. just above the top Paleocene marker
- 44-40Ma Anomaly 19-20 Basalt province
- Probably oceanic ridges / transition area
- Possible Rift area between Anomalies 20 & 13
- Jan Mayen Trough shallow intrusions
- Early to Late Oligocene composite sheet of flat-lying intrusive (Anomalies >6)
- Important Fault / Fractures Zones that influence and subdivide the JMR.



Conceptual model – seismic data comparison

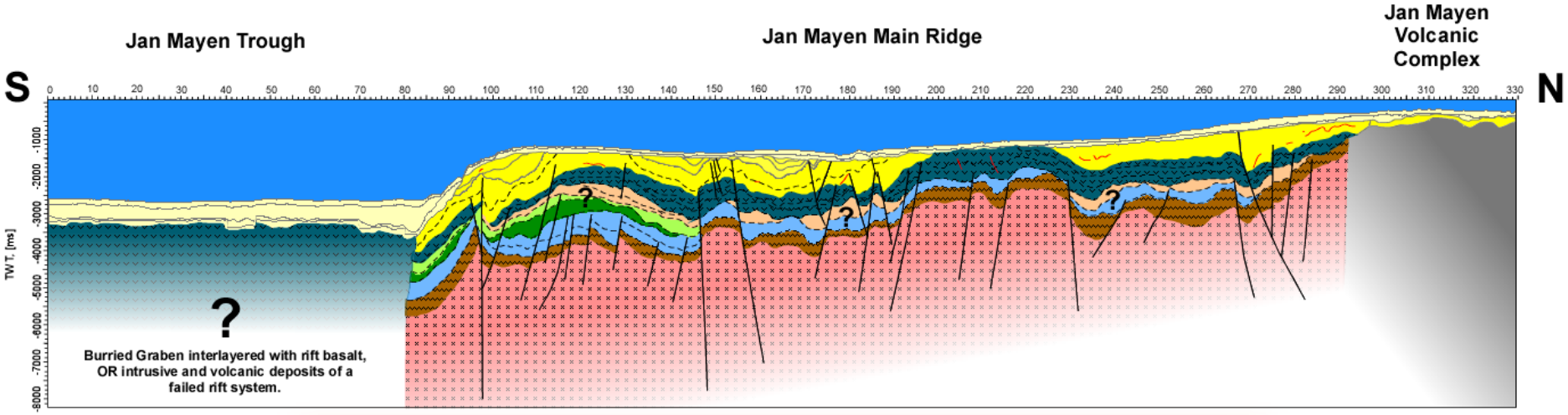
Key line interpretation at the JMMC



NPD-NEA Surveys

Conceptual model – seismic data comparison

Northern edge of the Dreki Licensing Area



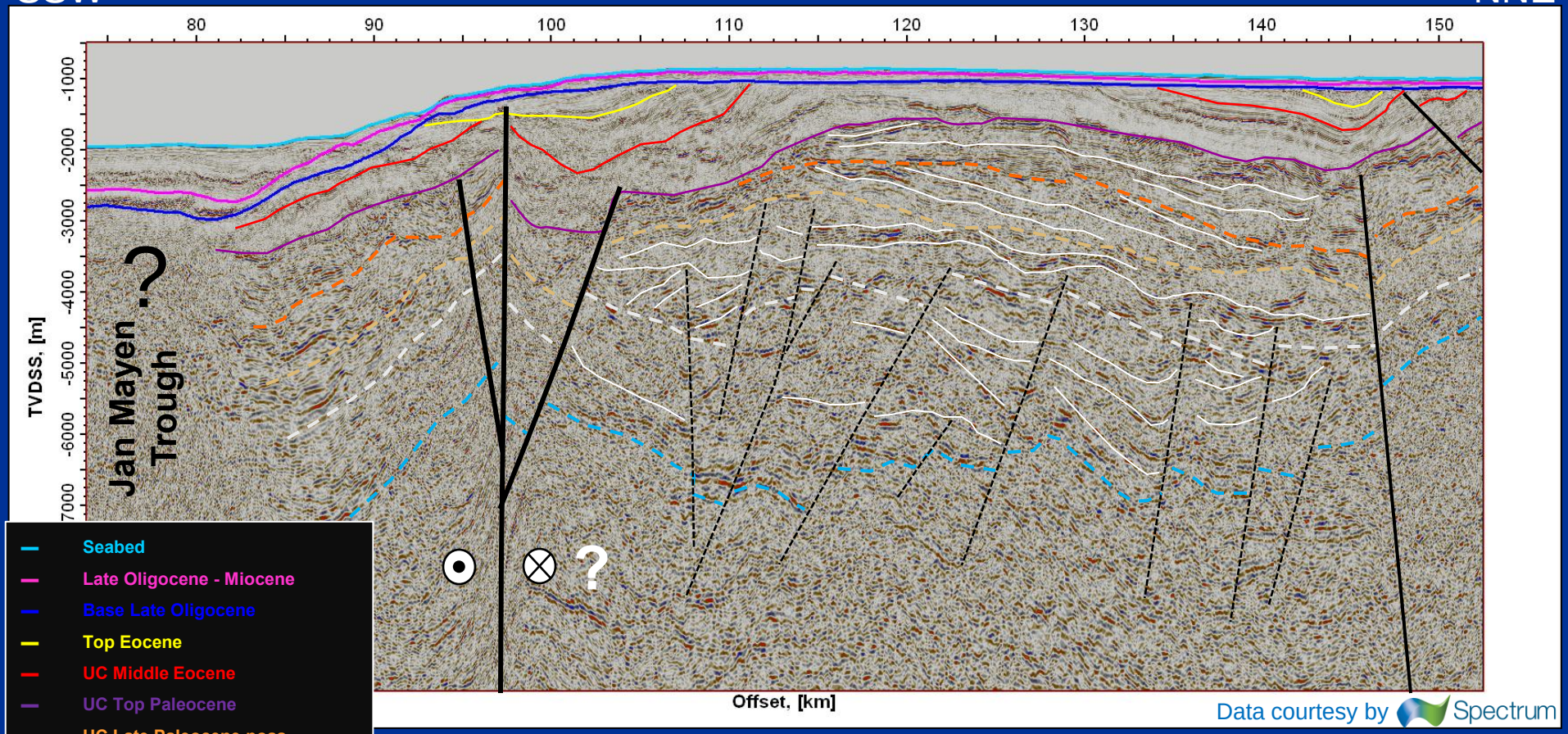
Legend:

- Intra Quaternary
- Intra Quaternary to Middle Miocene (Mid Tertiary Unconformity)
- Middle Miocene (Mid Tertiary) to Top Paleocene (Early Tertiary)
- Middle Paleocene (Early Tertiary - Floodplain Sediments)
- Lower Paleocene
- Upper Cretaceous
- Mid Cretaceous
- Lower Cretaceous - BCU, Cretaceous undiff.
- Jurassic & Triassic
- Permian - Devonian, Paleozoic undiff.
- Paleozoic Basement
- Caledonian Crystalline Basement
- Volcanics / Basalts
- Seaward-Dipping Reflectors (SDR)
- Oceanic crust
- COB (Continental-Ocean Boundary)
- Sills and dykes
- Fault Zones
- Unit subdivision, general formation dip direction
- Unconformity

New 2D Seismic Quality Data = More Possibilities for Data Interpretation

Possible Sub Tertiary unconformities become better visible below the Top Paleocene

SSW NNE



Data courtesy by Spectrum

ORKUSTOFNUN
National Energy Authority

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ICELAND GEOSURVEY

Conceptual model – seismic data comparison

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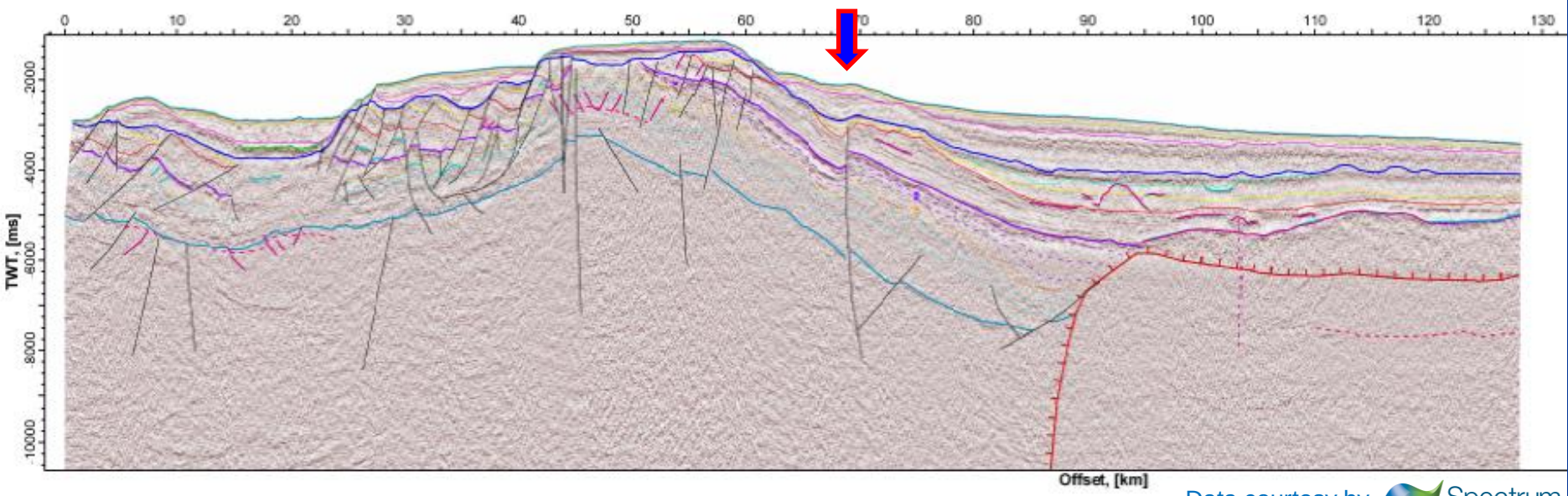

Data courtesy by Spectrum

- Seabed
- UC Late Oligocene - Miocene
- UC Base Late Oligocene
- Top Eocene
- UC Middle Eocene
- UC Top Paleocene
- UC Late Paleocene poss.
- Top Mesozoic poss.
- Top Paleozoic poss. (or actual Basement ???)
- Top Basement poss. (Crystalline ??? deep reflector)

Conceptual model – seismic data comparison

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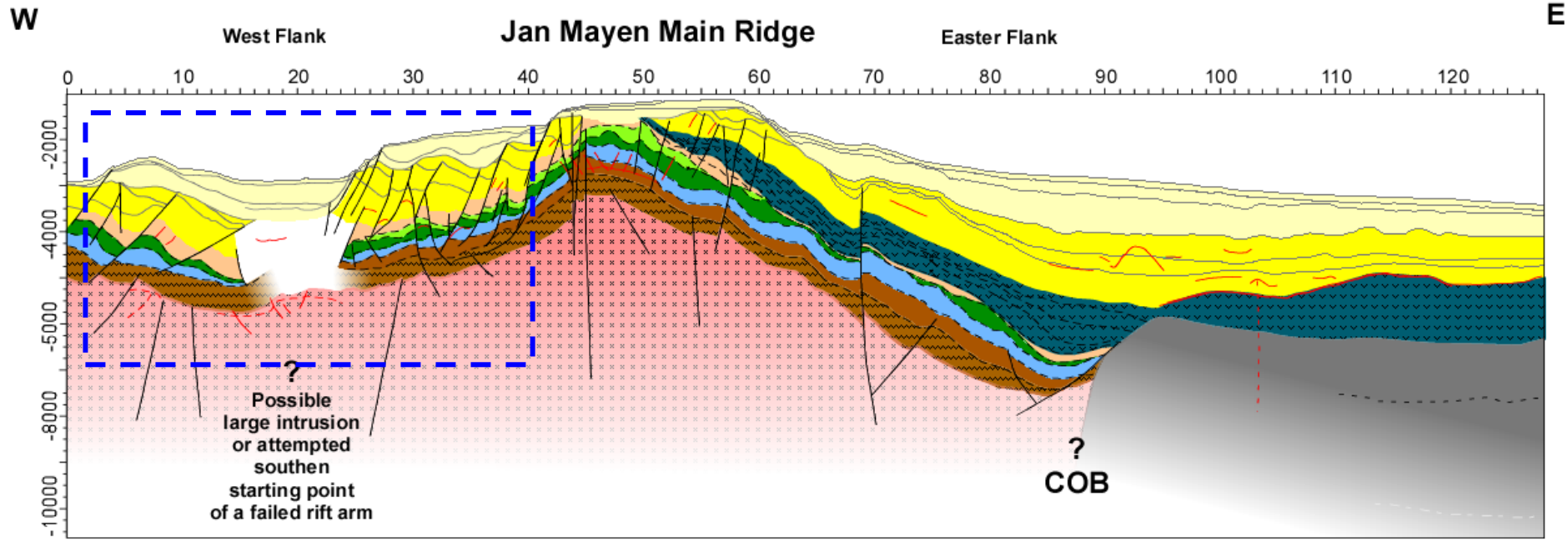

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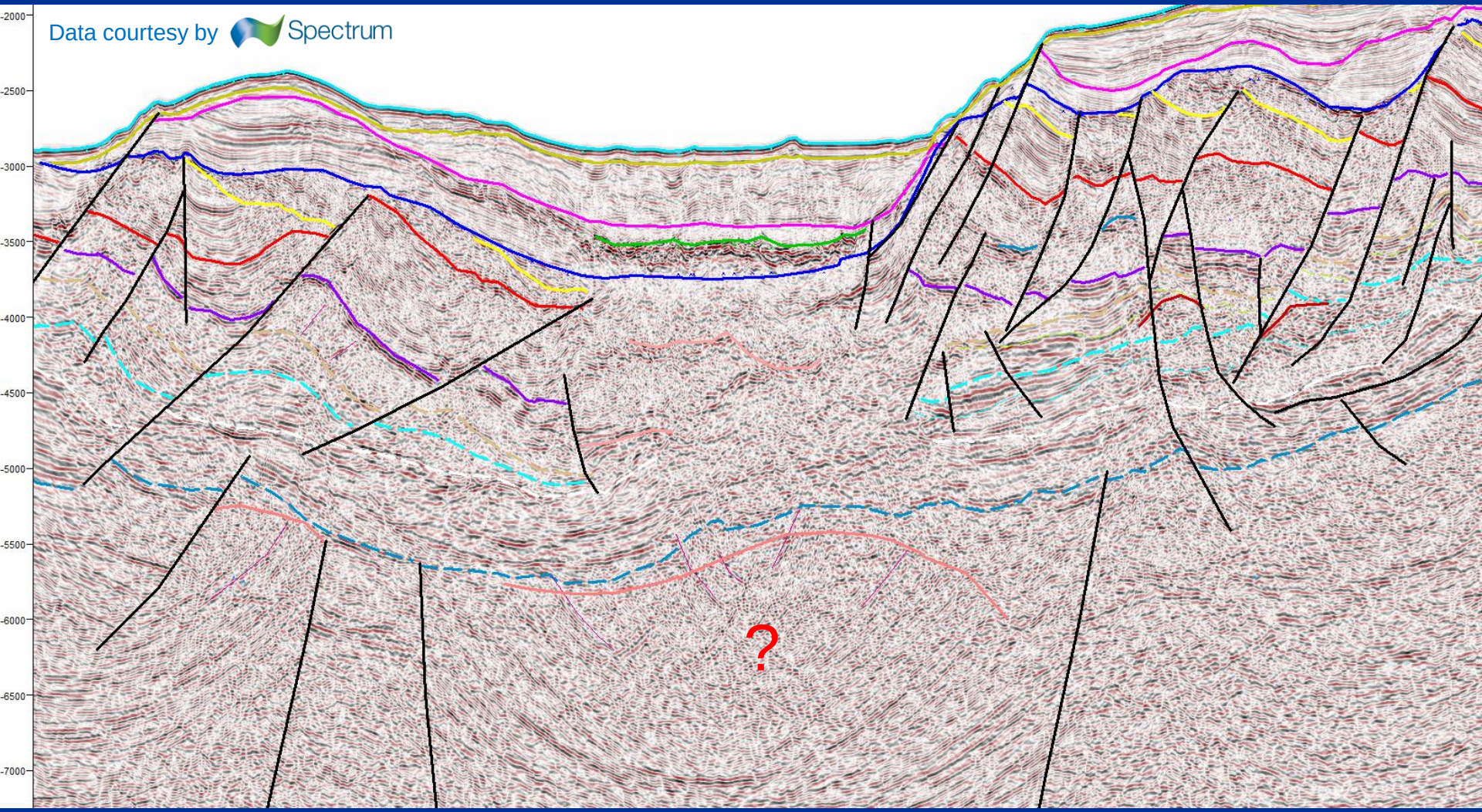
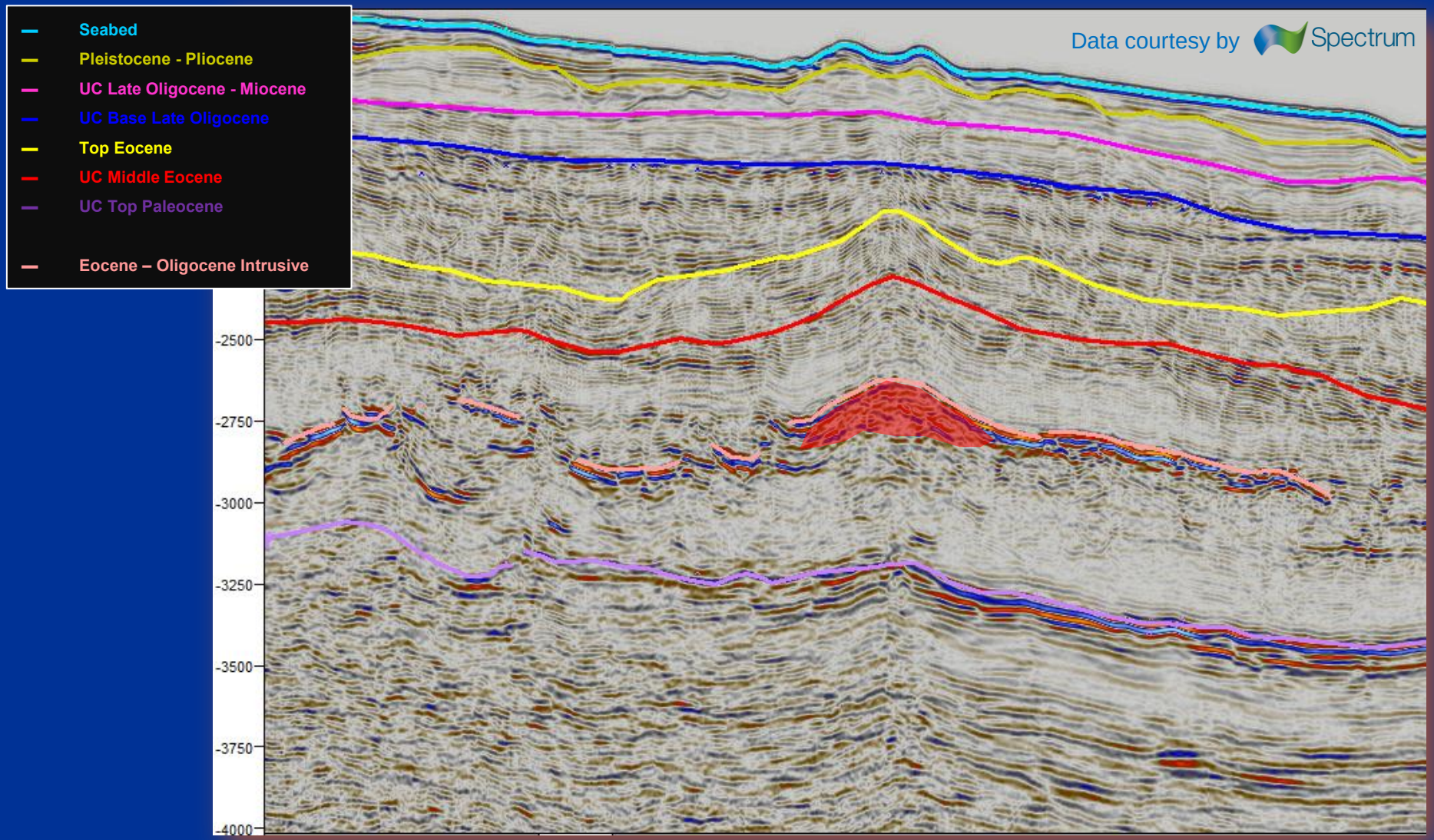


Conceptual model – seismic data comparison – Timing



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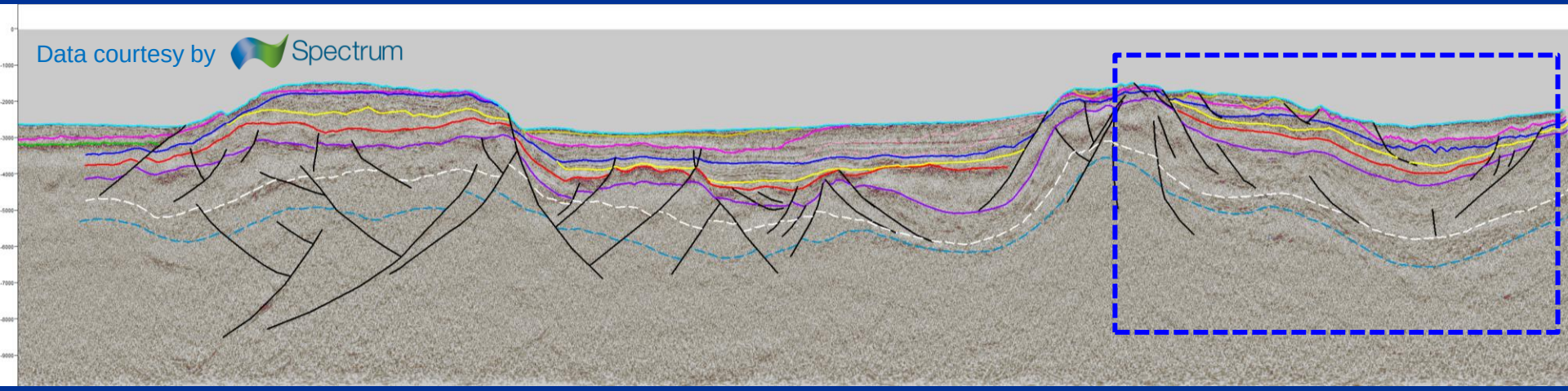

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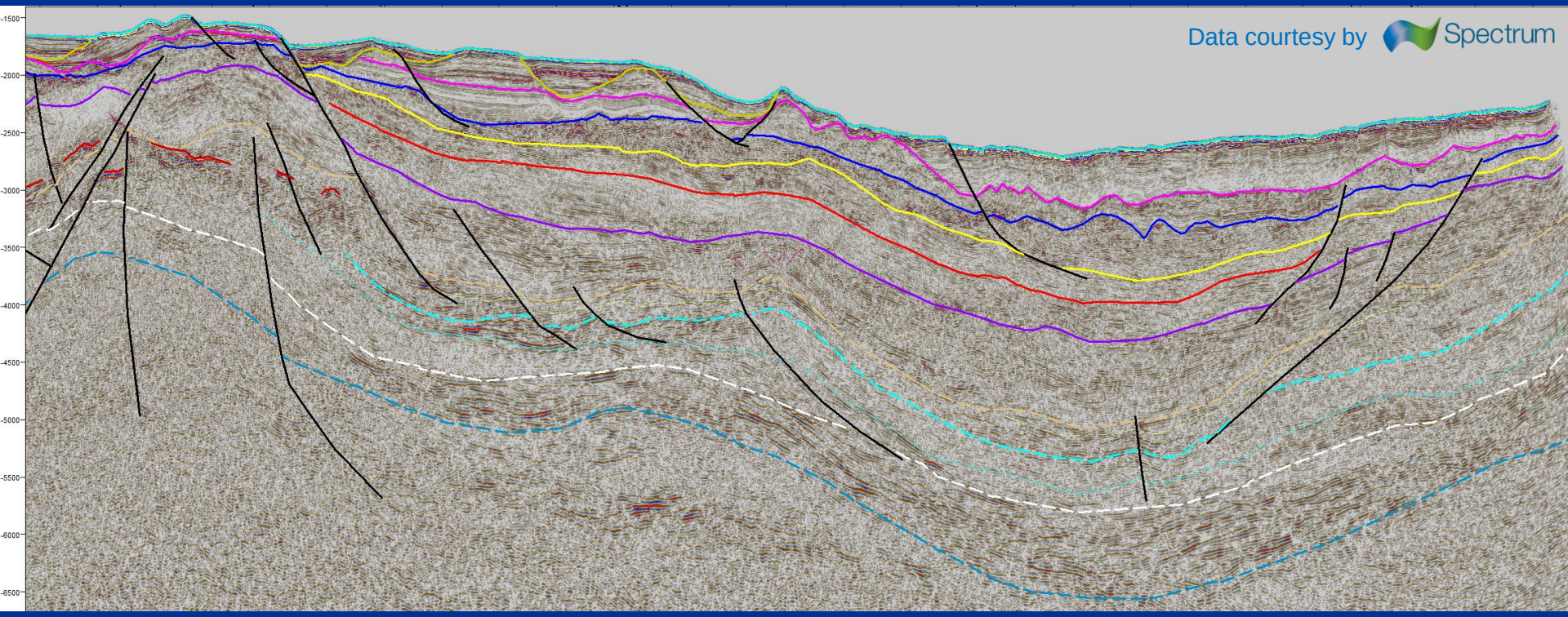

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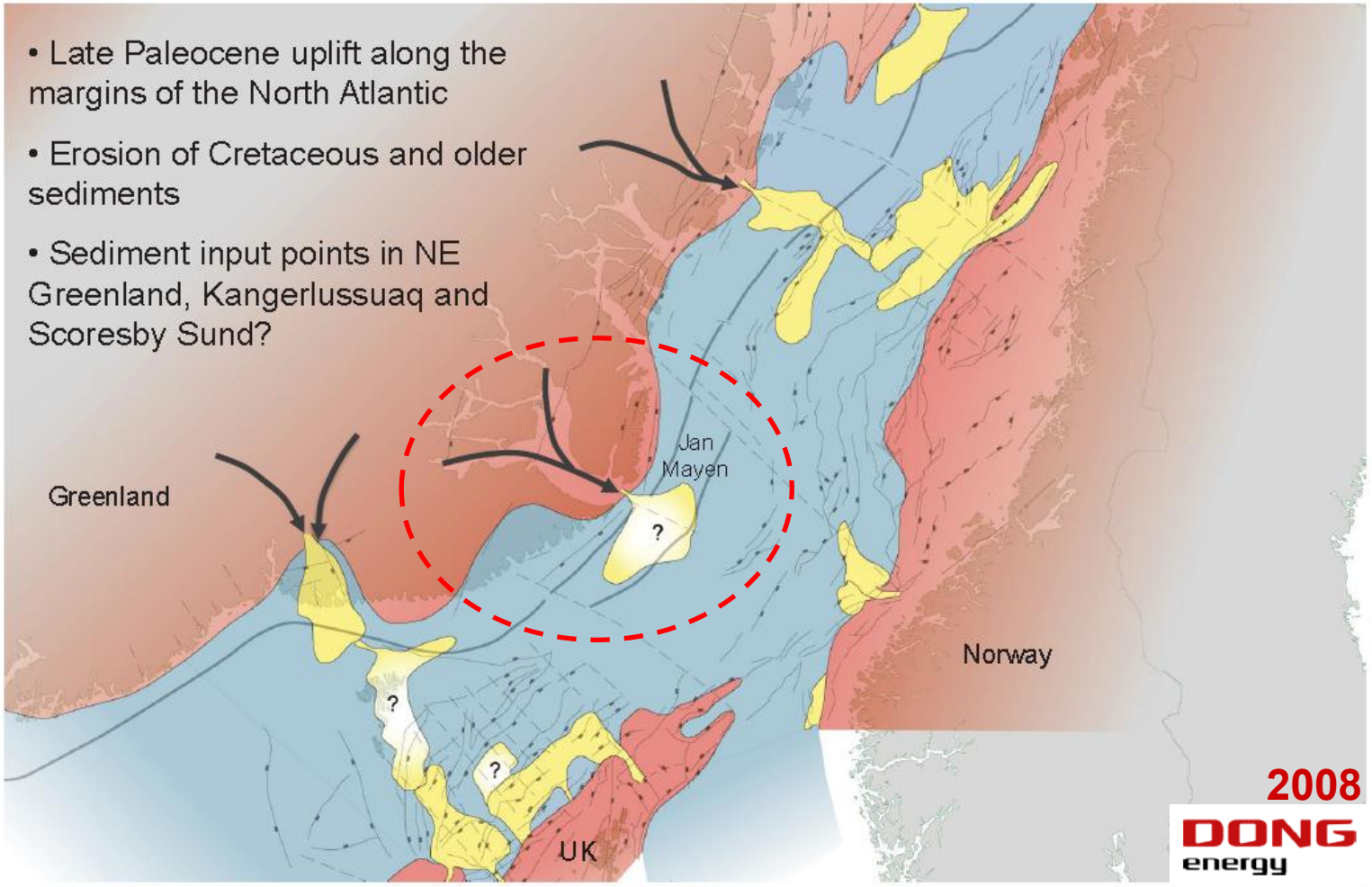
- Top Mesozoic poss. ???
- Top Jurassic poss. ???
- Intrusive

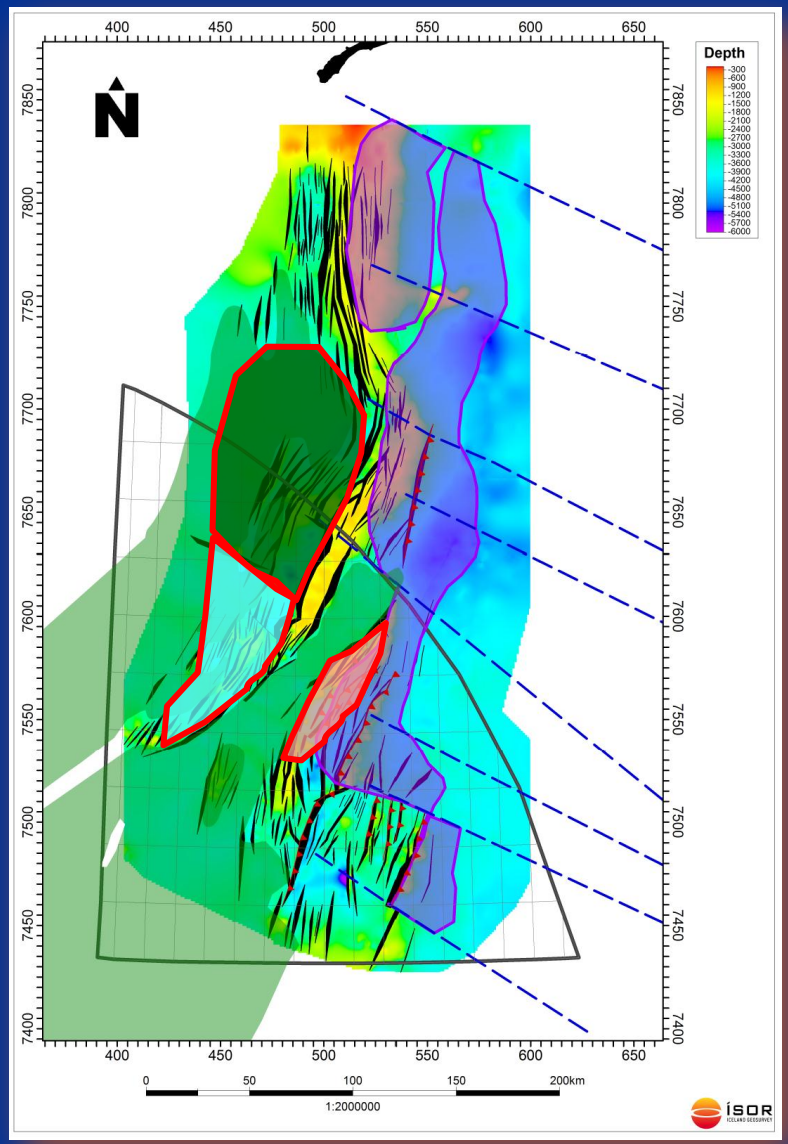
Palaeocene Sediment Input to the Jan Mayen Area?



DONG, First Iceland Exploration Conference, 2008

Mapping risk factors for prospectivity

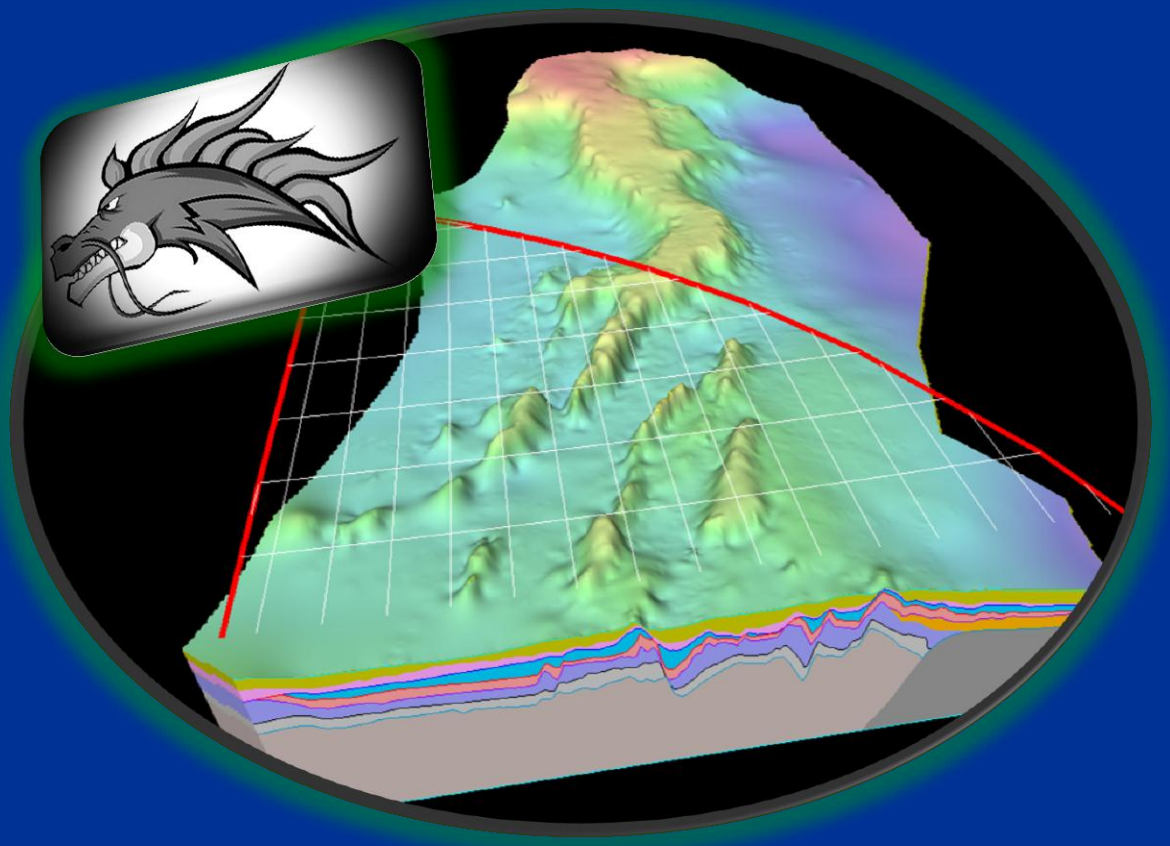
- Data – Interpretation certainty
- Pre-Tertiary Strata – Reservoir & Source
- Post-Paleocene Strata – Reservoir & Seal
- Heat Flow – Maturity of Source Rock
- Structure & Timing – Trap & Seal
- Depth & Location – Accessibility



Hydrocarbon Potential for the Dreki Area

- Best analogue comparison with East Greenland exploration examples and Møre Basin for the Norwegian side.
- Post Paleocene sedimentary rocks of sufficient thickness and age in the ridge flank areas.
- Indications of pre-opening sedimentary strata of possibly Paleozoic, Triassic-Jurassic and maybe Cretaceous age - underneath the west flank areas of the ridge, i.e. Jan Mayen Basin.
- Potential reservoir rocks, focus on locally shallow marine to generally marine deposits, especially submarine fans / turbidite deposits for post Paleocene deposits, and possibly focus on limestone platform to continental deposits for the pre-opening formations.
- Potential traps present, both structural and stratigraphic.
- Hydrocarbon maturation is probably high, more gas prone if sufficient source rocks are present.

Thank you very much for your attention !



Acknowledgements:

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Sigurveig Árnadóttir, Gunnlaugur M. Einarsson, Bjarni Richter at Iceland Geosurvey
Bryndís Bandsdóttir, University of Iceland