Danish North Sea: An Underexplored System

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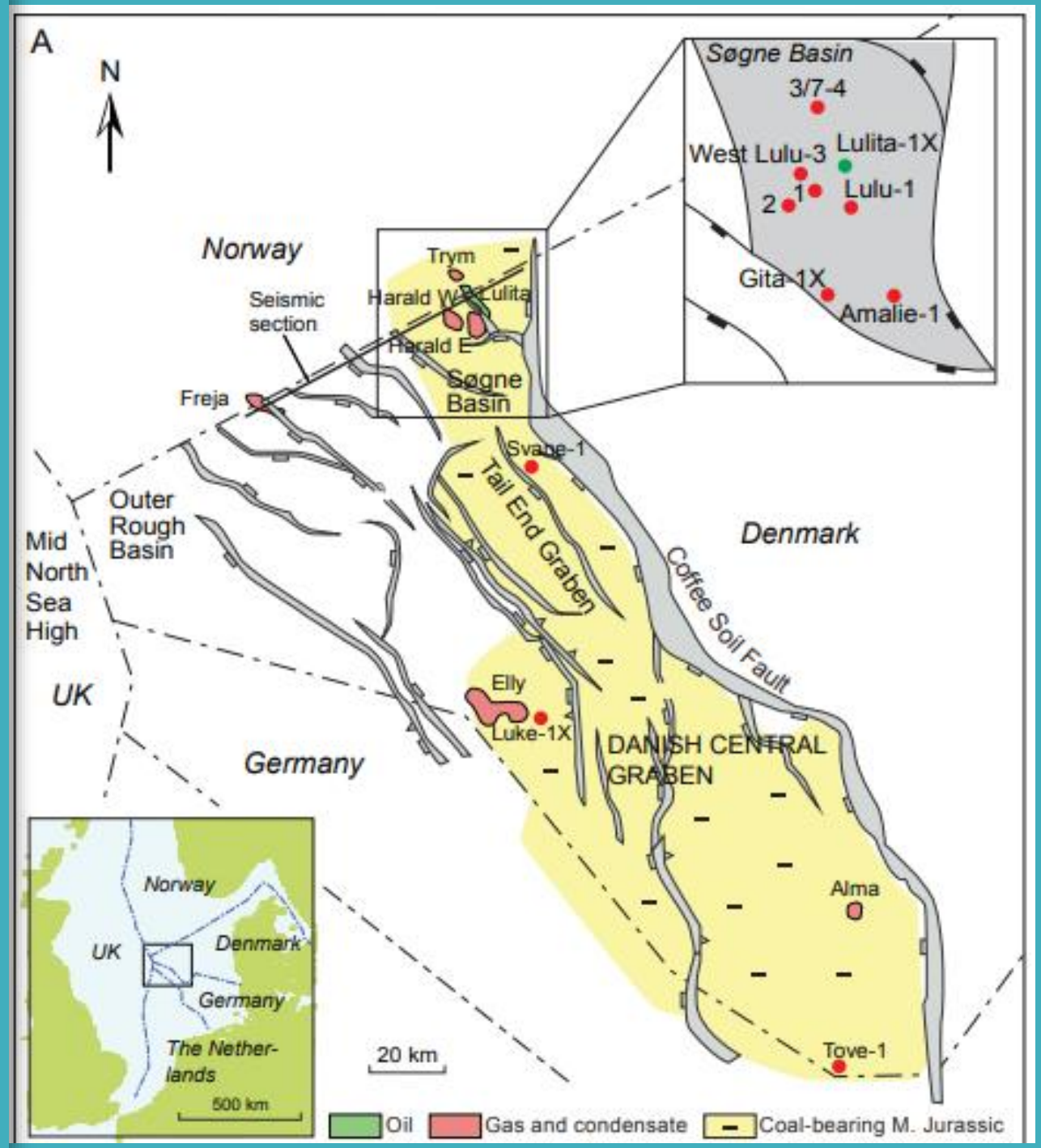
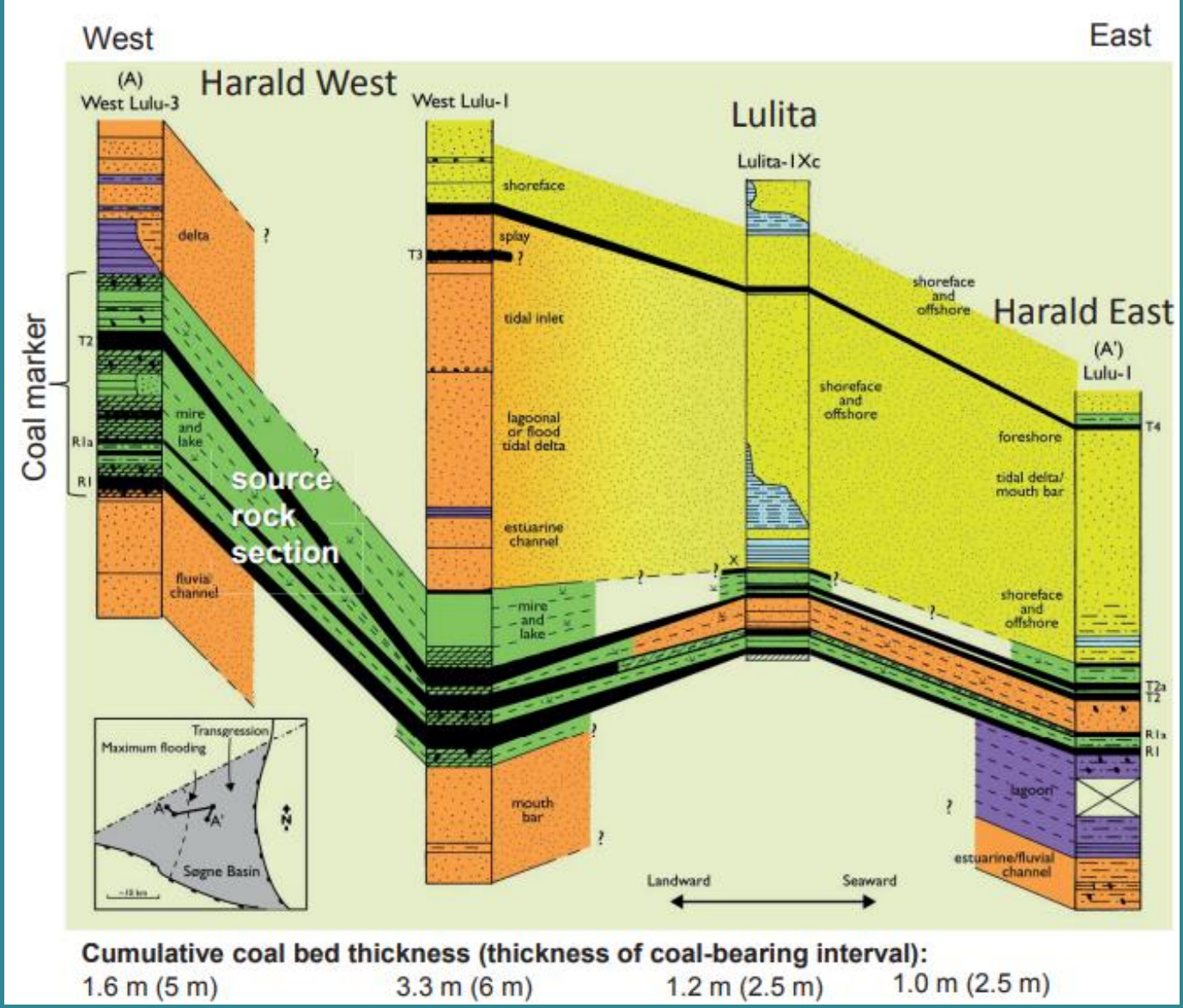
Abstract

- Middle Jurassic petroleum system in Danish Central Graben
- Primary Source rock composed of Upper Jurassic-lowermost Cretaceous marine shales
- Most have been drilled into already
- Further research/discovery of E&P methods needed for additional exploration
- Coaly source rock of Mid Jurassic age creates distinct oils and gases
- Coal bearing unit has regional distribution and can be mapped seismically as the “Coal Marker”

Danish Central Graben

- Triassic and Jurassic sandstones charged from coaly Middle Jurassic source rocks
- In Danish-Norwegian Søgne Basin Harald and Trym fields produce gas/condensate
- Oil produced form the Lulita field
- In UK giant Culzean gas condensate is under development
- Coaly source rock is from Bryne/Lulu Formations (in Denmark)
- Pentland Formation (in UK)
- Sleipner and Hugin Formations (in Norway)





Coal Marker

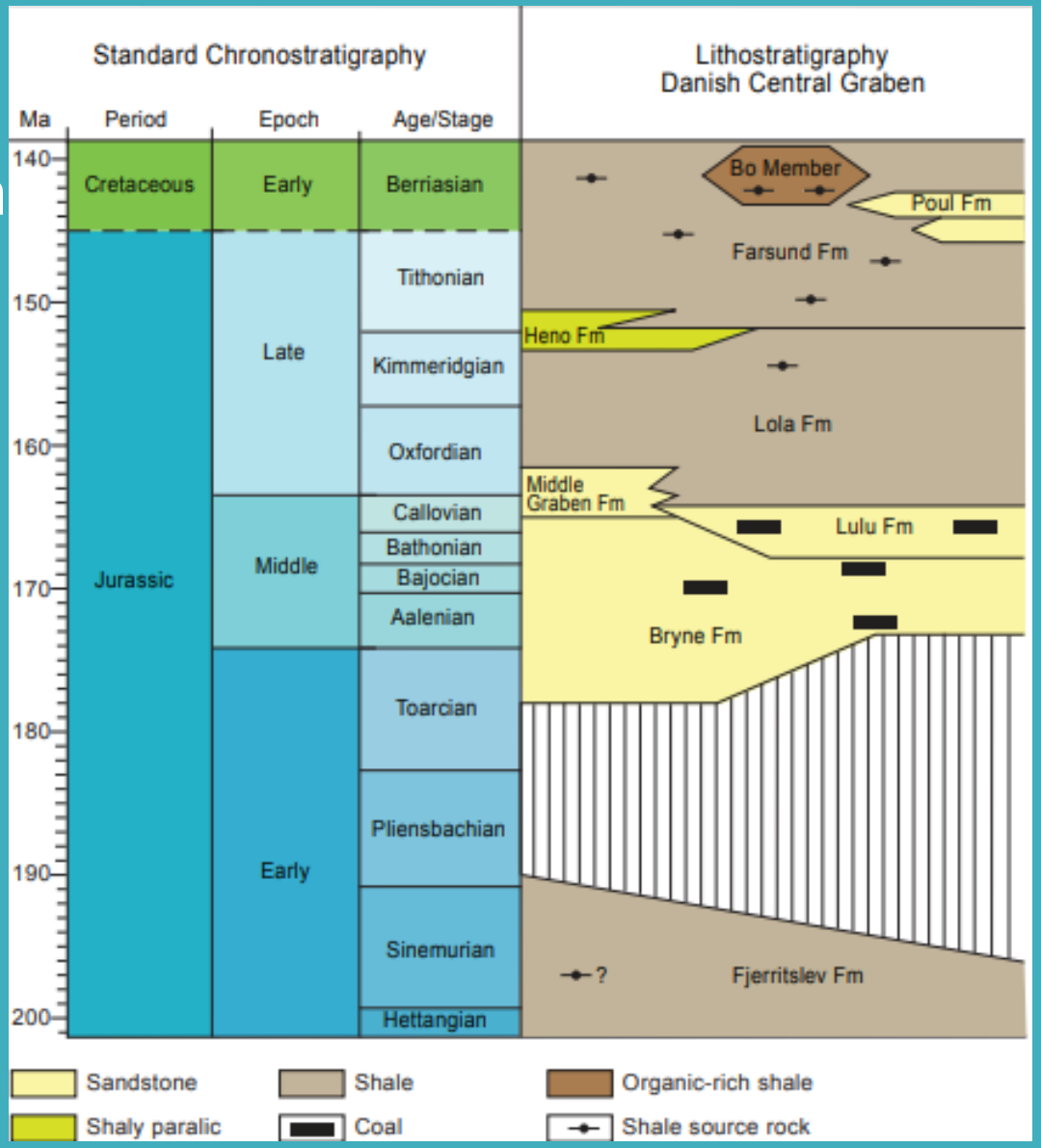
- Coal beds in the Danish Central Graben
- Correlated West-East across 4 well cores
- Starts thicker in the West thins Eastward
- Closer to paleo-shoreline causing more frequent flooding events

Introduction

- Primary source rock in North Sea are Upper Jurassic-lowermost Cretaceous
- Marine shales from Farsund, Mandal, and Kimmeridge Clay formations
- In the DCG source rocks have charged chalk field to create 150k BO and 71k BOE of gas daily
- DCG also has Mid Jurassic coaly-sourced sandstones
- Only been commercially viable in Søgne Basin up till now
- Discovery of Alma, Amalie, Elly, and Svane sandstone reservoirs

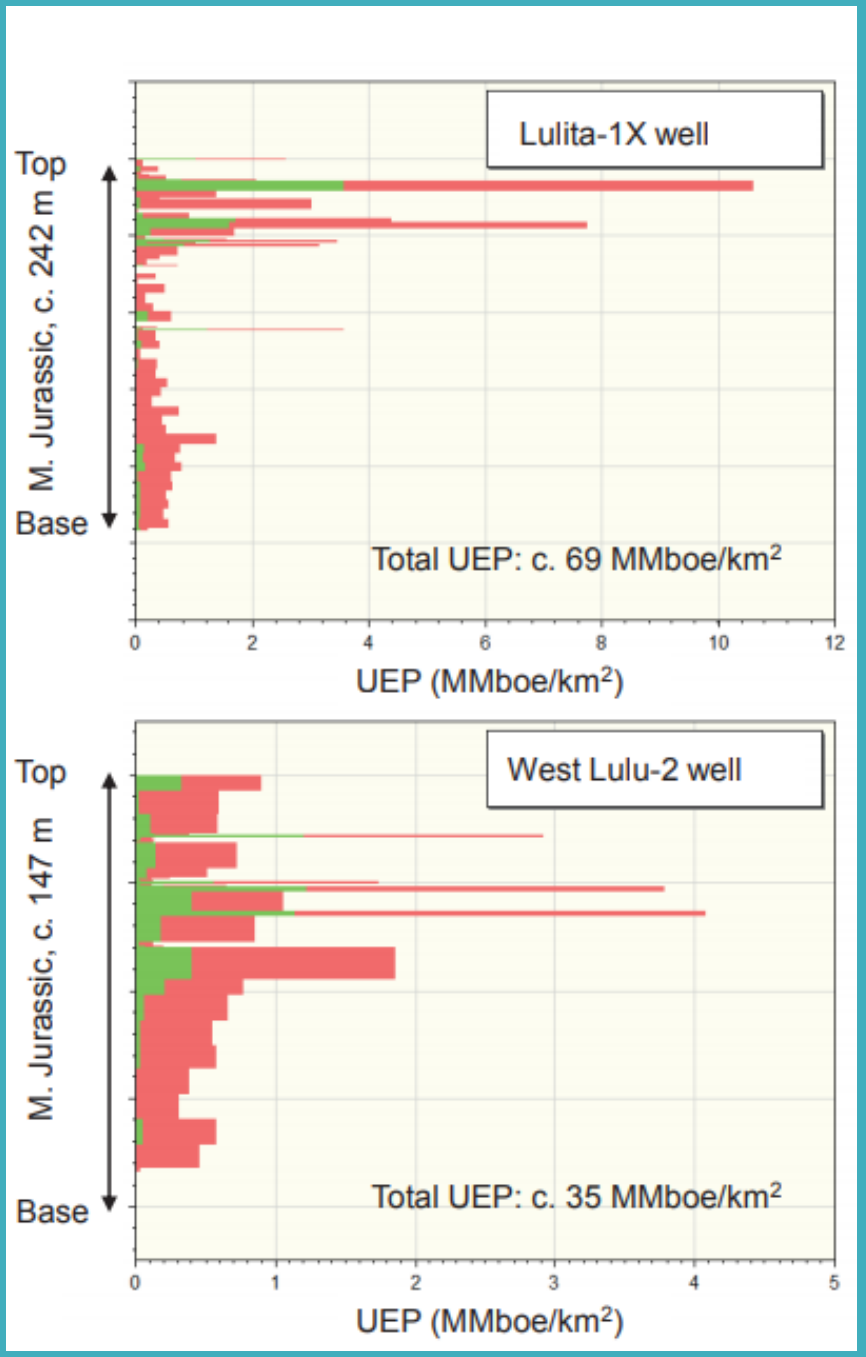
Geologic Setting

- Part of 500km long Central Graben, Southern part of the Jurassic North Sea rift complex
- System of NW-SE trending half grabens and bounded by Coffee Soil Fault to East and Mid North Sea High to the West
- Activity along Coffee Soil Fault caused rifting in the East in Bajocian time, Søgne Basin and Tail End Graben started to subside
- Fluvial sandstones of Bryne overlain by Marine upper part of Lulu with numerous separate coal beds



Source Rock Quality

- Marine shales of DCG have proven economically viable, is there another area which is also viable?
- Cryne and Lulu frmtns divided into coals, coaly shales, and carbonaceous shales (based of WT% TOC)
- ¾ of coal and coaly shale samples had generation potential
- Unlike other coals in N Sea the Mid Jurassic coals are not just gas prone but can produce liquids as well (oil and condensate)\
- Mixing between marine shales and the mid Jurassic coals lead to unique oil/gas signatures



Trym Middle Jurassic sandstones: Gas and oil/condensate.

Harald West Middle Jurassic sandstones: Gas and oil/condensate. API: 46°-48° Average CGR: 80 stb/MMscf. Cretaceous chalk: Terrigenous-influenced marine oil.

Harald East Middle Jurassic sandstones: Oil/gas shows (Lulu-1 well). Cretaceous chalk: Mixed oil/condensate.

Lulita Middle Jurassic sandstones: Waxy oil with gas cap. API: 31°-33°. GOR: 1395-2135 scf/brl .

Amalie-1 Middle Jurassic sandstones: Mixed oil/condensate. L. Cretaceous "Kira sandstones": Mixed oil/condensate.

Gita-1X Middle Jurassic sandstones: Coal-related gas.

Oil families

- 3b(B), Marine
- 4(B-D/E), Marine/Terrigenous
- 5(D/E-B), Terrigenous/(Marine)
- 6(D/E-F), Coaly
- Coal-derived gas

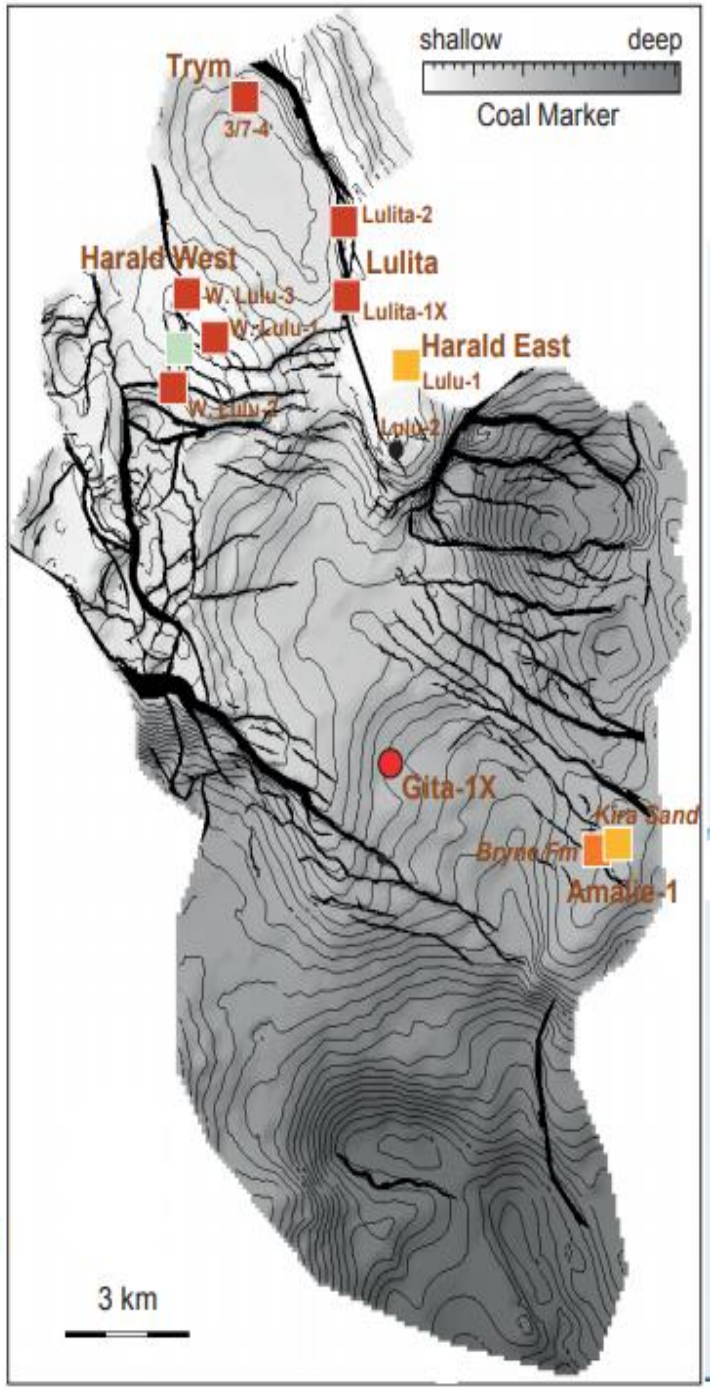
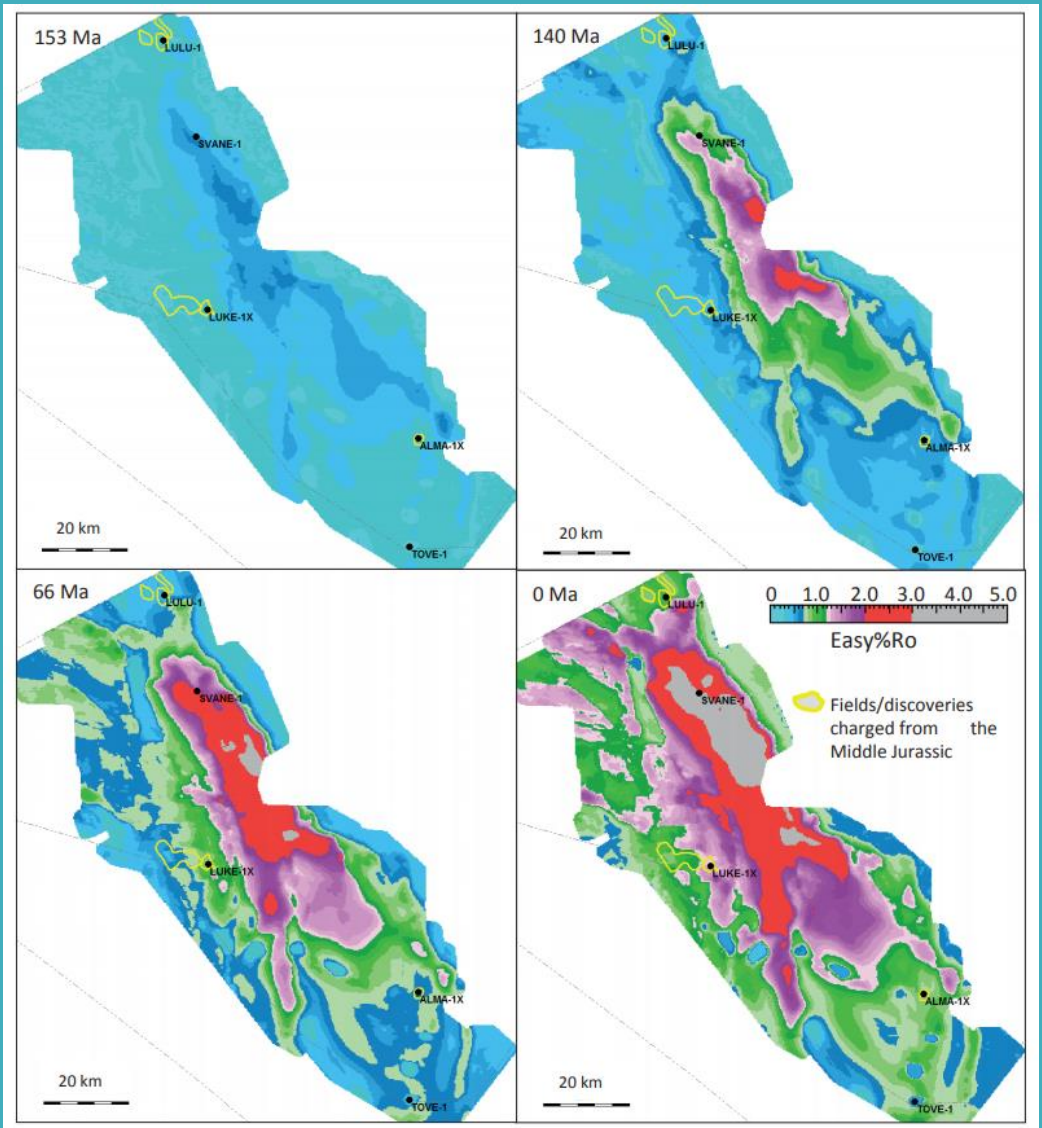


Table 1. Coal-derived oil and gas families in the Danish Central Graben.

HC families (Danish Central Graben)	Source rock type	Geochemical characteristics	Likely source rock unit
Oil family 6(D/E-F)	Coaly source rocks	High Pr/Ph, on average 3.5; strong predominance of C_{29} over C_{27} regular steranes, typically isoSt27/isoSt29 is <0.8; C_{30} steranes <4%; low H35/H34, on average 0.5; heaviest isotopic composition, $\delta^{13}C_{oil}$ on average -26.21‰, $\delta^{13}C_{sat}$ on average -27.00‰	Middle Jurassic coaly Bryne and Lulu Fms
Oil family 5(D/E-B)*	Mixture of terrigenous and marine sources	High Pr/Ph, slight dominance of C_{27} over C_{29} regular steranes; isotopically relatively heavy	Middle Jurassic coaly Bryne/Lulu Fms + minor Upper Jurassic Farsund Fm contribution
Oil family 4(B-D/E)	Mixture of marine and terrigenous source rocks	Relatively high Pr/Ph, on average about 2; dominance of C_{27} over C_{29} regular steranes; C_{30} steranes 5-6%; relatively low H35/H34, on average 0.65; isotopically slightly heavier than marine shale derived oils	Middle Jurassic coaly Bryne/Lulu Fms + some Upper Jurassic contribution, likely lower Farsund Fm and/or Lola Fm
Gas family GasF(Non-A)	Coaly source rocks	Heavier $\delta^{13}C$ methane (> -43‰), ethane, propane and butane isotope values than the oil-associated gas derived from the Upper Jurassic marine shales	Middle Jurassic coaly Bryne and Lulu Fms
Gas family GasF(Non-A/Oil-A)	Mixture of terrigenous and marine sources	Heavier $\delta^{13}C$ methane isotope values than the marine shale-derived gas, but slightly lighter than pure coal-derived gas [GasF(Non-A)]	Middle Jurassic coaly Bryne/Lulu Fms + minor Upper Jurassic Farsund Fm contribution
Gas family GasF(Non-A/?cracked)*	Most likely coaly source rocks	Very heavy $\delta^{13}C$ propane isotope value (-20‰), heavy δD methane (-155‰), high i-butane/n-butane ratio (i/nC4)	Likely high mature Middle Jurassic coaly Bryne and Lulu Fms; potentially cracked gas

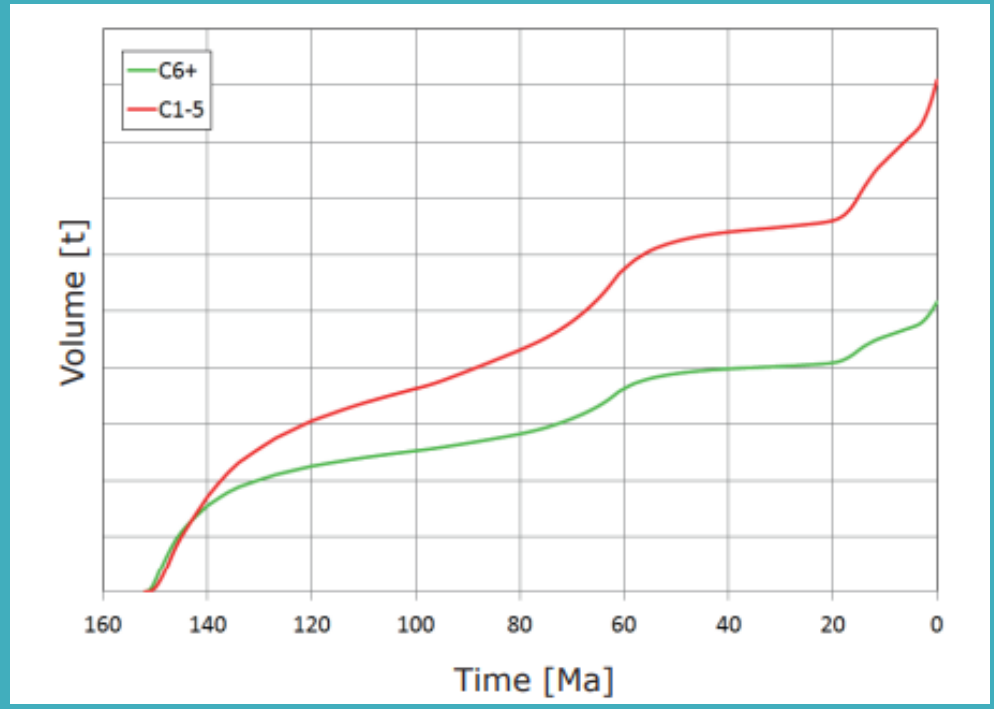
Generation, Expulsion, Migration



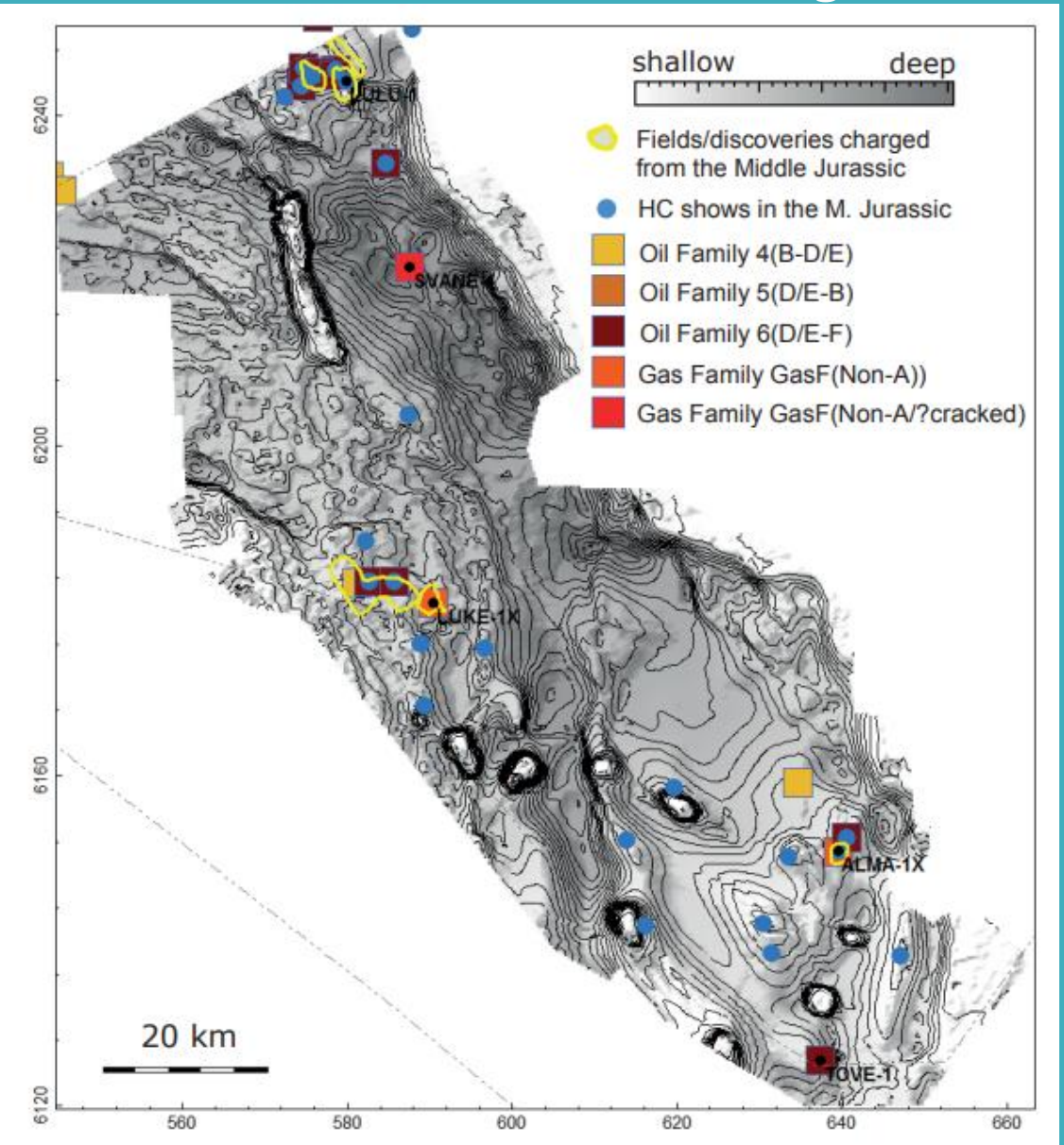
- Mid Jurassic 'Coal Marker' was immature until 153MA
- between 140MA-153MA Tail End Graben became mature enough to expel hydrocarbons
- Deepest part reached dry gas maturity level
- In Cretaceous 140-66MA mature coaly source rocks expanded up basin flanks
- Cenozoic to Present day (66-0MA) entire area became mature
- During this period Tail End Graben became overmature and exhausted its gas potential

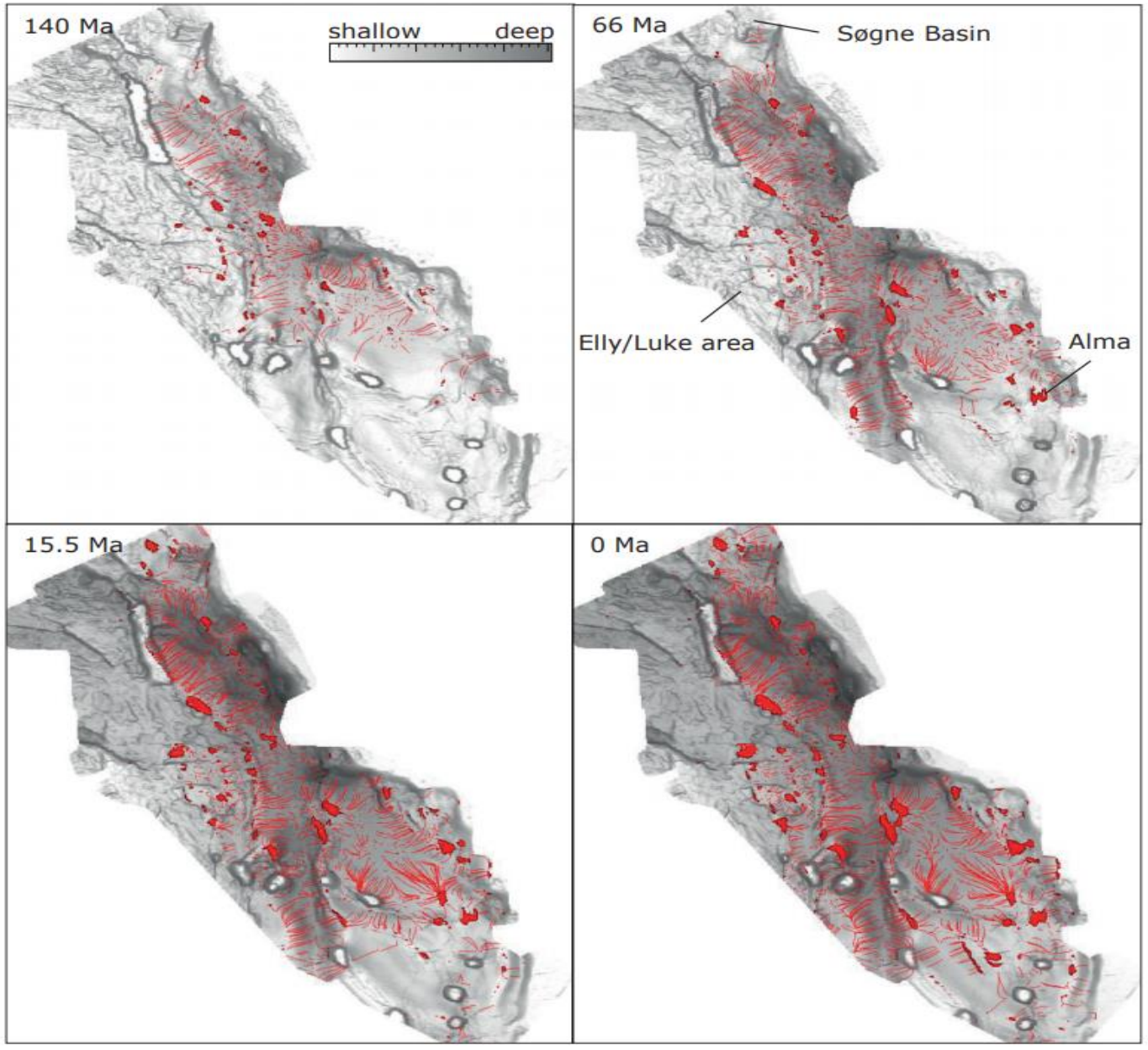
Expulsion Cont'd

- Expulsion began in Late Jurassic for coaly source rocks in deepest part of DCG
- Continuous expansion with hydrocarbon expulsion in Cretaceous
- Low expulsion rates in Paleocene and Late Oligocene, due to chalk being compacted on top
- Expulsion resumed in Miocene to present
- Only on flanks of basin in S W and N
- To this day Coal Marker reaches upwards of 150 degrees Celsius, helps prevent biodegradation



- Map of observed hydrocarbons in Mid Jurassic section
- Distribution of "shows" is regional





- Flow paths and accumulation of Hydrocarbons from coaly source rock over time

Conclusion

- Mid Jur coaly sourced petroleum system has been economic in Danish, UK, and Norwegian N Sea sectors
- Need to explore more widespread conventional plays
- Expulsion from Coal Marker initiated in Late Jurassic in deep Tail End Graben
- Mature coaly source rocks expanded in Cretaceous
- Cenozoic to present etnrie area became mature
- Low expulsion rates in Paleocene and Late Oligocene followed by signicant expulsion