Milking the Goat: Revised Reservoir Characterisation of the Åre Formation, Heidrun Field, Offshore Mid-Norway*

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Abstract

The Jurassic reservoirs of the Heidrun Field, offshore Mid-Norway, have so far produced over 114 MSm3 of oil. The oil recovery of the fluviodeltaic (Rhaetian-Sinemurian) Åre Formation is the lowest among the reservoir formations, which makes this an important stratigraphic interval when it comes to remaining reserves and IOR potential. In order to address challenges related to stratigraphic correlation and detailed reservoir modelling, a major core and wireline log based reservoir characterisation study of the Åre Formation has been performed. Main results from this study include a new facies analysis and a revised stratigraphic reservoir zonation. This new stratigraphic framework defines seven main zones, reflecting an overall transgressive development of the formation; from non-marine coastal plain in the lowermost part (Åre 1-2), marginal-marine lower delta plain in the middle (Åre 3-5) and tidally-dominated estuarine and open marine in the uppermost part (Åre 6-7). These reservoir zones represent packages of genetically linked facies, bounded by field-wide, correlateable candidate flooding surfaces. Based on this constrained stratigraphic framework, better and more accurate predictions of the distribution and geometry of hydrocarbon bearing facies can be made.

The implementation of the new reservoir zonation was completed in 2007. All the 90 wells with Åre Formation stratigraphy have been re-interpreted, and the new stratigraphic framework has been applied in a recent update of the full-field geological model. This reservoir zonation scheme has proven to be more robust than previous models and has provided a good platform for improved stratigraphic control during drilling operations. Long-term benefits would also include more precise production forecast, better drainage strategies and well solutions.

Milking the goat;
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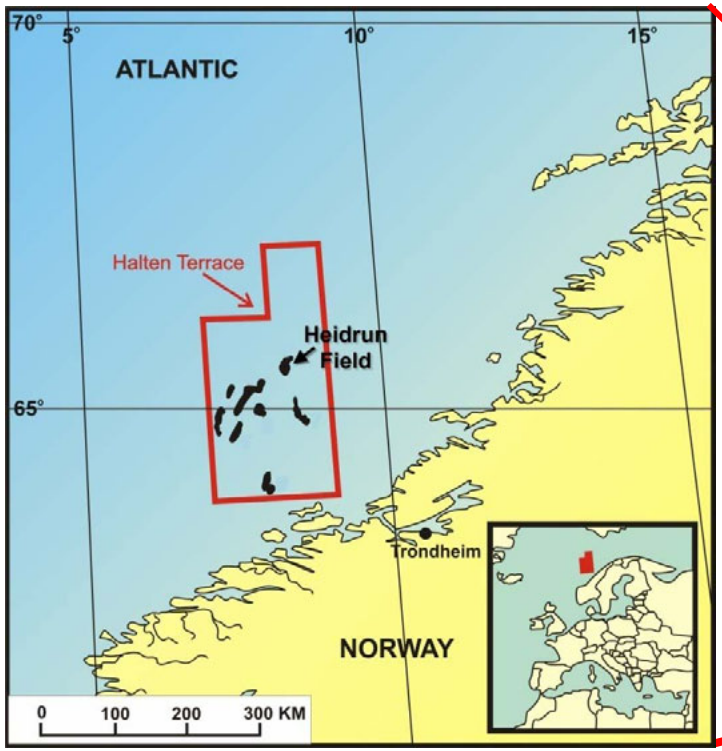
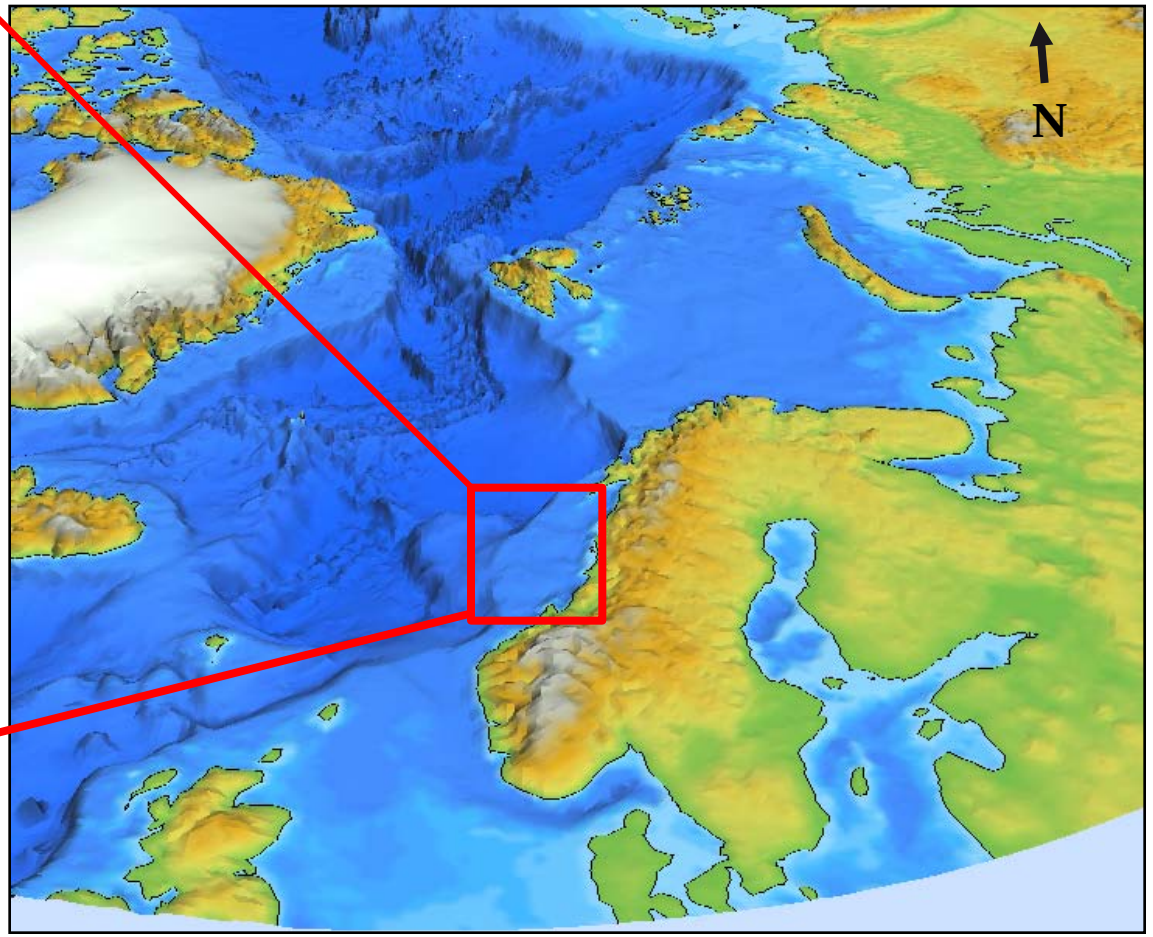
Heidrun Field Offshore Norway





- The Heidrun Field is located 350 km offshore mid-Norway

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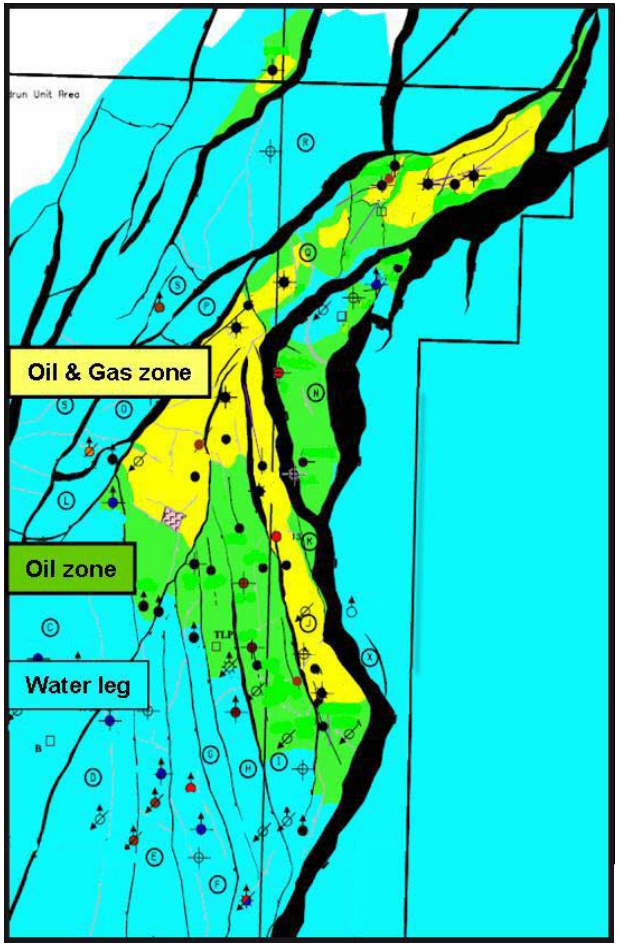
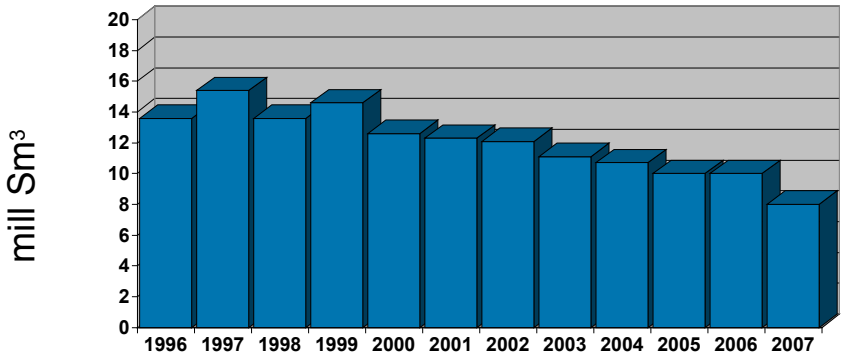
Heidrun Field Offshore Norway - Milking the goat



- According to the mythology: Heidrun is the goat which supports fallen warriors with mead in the kingdom of the dead Vikings.
- The stream of mead from Heidrun's udder is supposed to be never-ending.
- Our Heidrun is a mature field, being on stream since 1995 producing oil and gas.
- Intensively faulted structure and heterogeneous reservoirs → problematic to place drilling targets.
- The production is declining, and the main challenge is to efficiently drain the remaining reserves.



Gross production of Sm^3 oil, gas & condensate

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Heidrun Field Offshore Norway

- Floating concrete tension leg platform, installed over a subsea template with 56 well slots, and additional 5 subsea templates.
- Heidrun has per June 2008 produced over 124 M Sm^3 (ca 780 M bbl) of oil out of 186 M Sm^3 (ca 1 170 M bbl) recoverable reserves.
- <u>Remaining reserves:</u>
~64,1 M Sm^3 (ca 400 M bbl) oil
~30,7 G Sm^3 (ca 190 G scf) gas
- <u>Production rates (2008)</u>:
~15 000 Sm^3 (ca 94000 bbl) oil/day
~6,2 G Sm^3 (ca 40 G scf) gas/day

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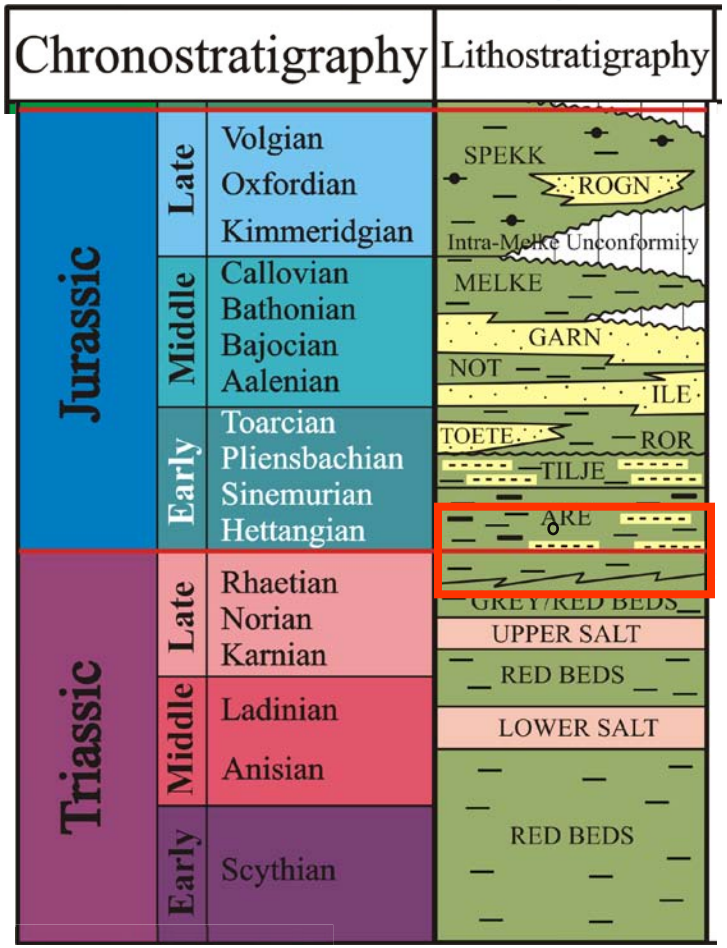
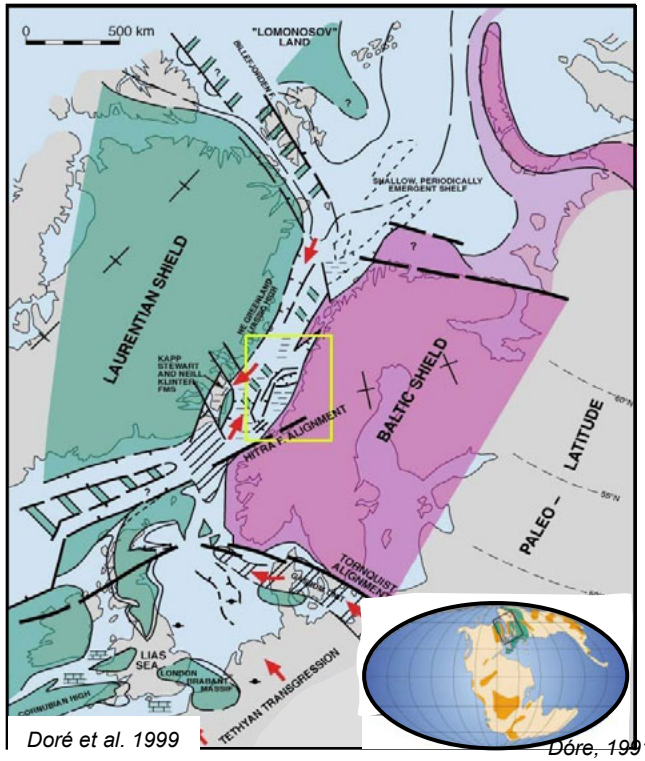
Reservoir Stratigraphy - Jurassic Halten Terrace



Brockbank and Hanssen, 2004

- The Åre Formation: ~500 m thick heterogeneous fluviodeltaic succession
- The oil recovery of the Åre Formation is the lowest among the reservoir formations, which makes this an important interval when it comes to remaining reserves and IOR potential



Doré et al. 1999

Dore, 1991

- The Lower Jurassic deposition on the Halten Terrace occurred in a coast-parallel (NE-SW) rift generated basin.

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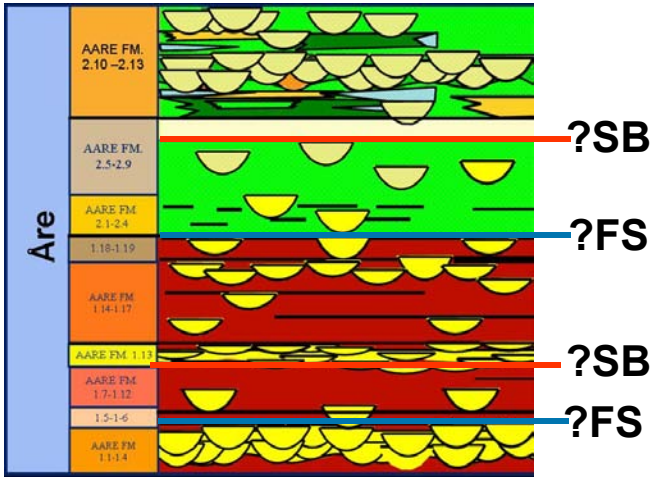
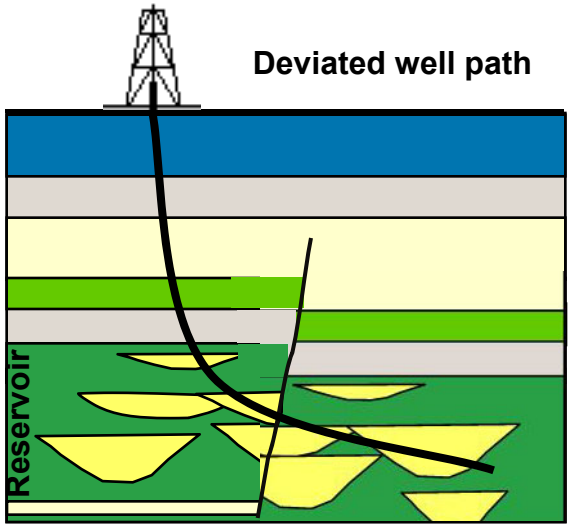
Challenges in sedimentological/stratigraphic concepts





Åre Fm. reservoir challenges:

- Few marker beds identified
- Large uncertainties in lateral facies trends
- Poor biostratigraphic resolution

- A high number of deviated wells – often trough faults → resulting challenges:
  - interpreting well results
  - defining and hitting drilling targets

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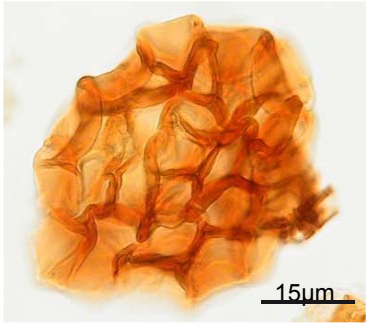
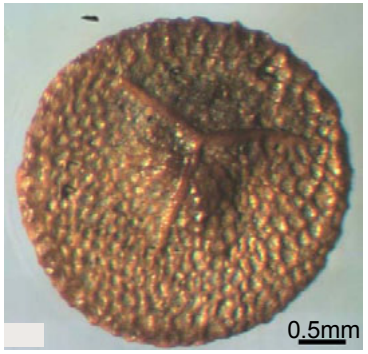
Review of sedimentological/stratigraphic concepts



Acritarchs
(Pediastrella heidrunii)



Megaspores
(N. hoplithicus)

The Åre study: 2003 - 2008

- Objective: improved sedimentological understanding and robust stratigraphic framework
- Re-description of all existing core material: 1362 m
- Biostratigraphic studies
- Review of database: 90 wells with Åre stratigraphy→ new stratigraphic model suggested and revised reservoir zonation and facies interpretation implemented

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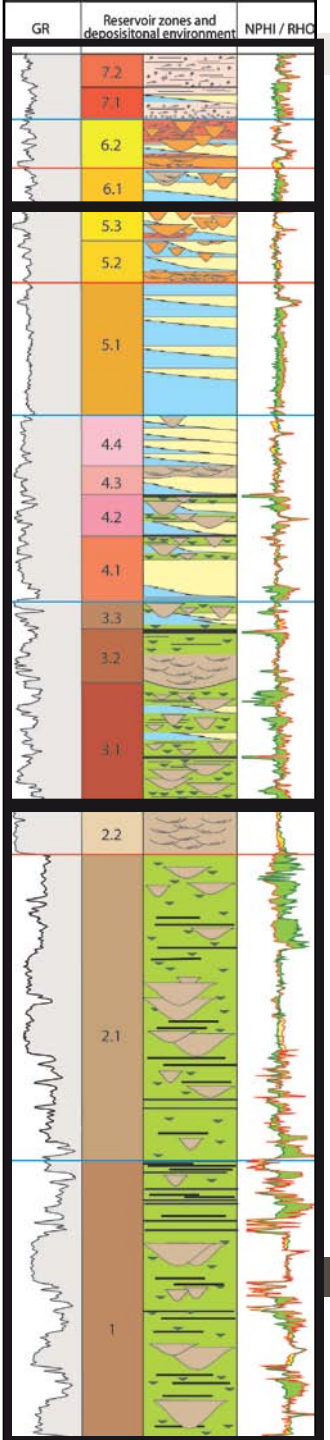


New solution: Revised Reservoir Stratigraphy

• The new stratigraphic framework defines seven main zones reflecting an overall transgressive development of the Åre Formation:

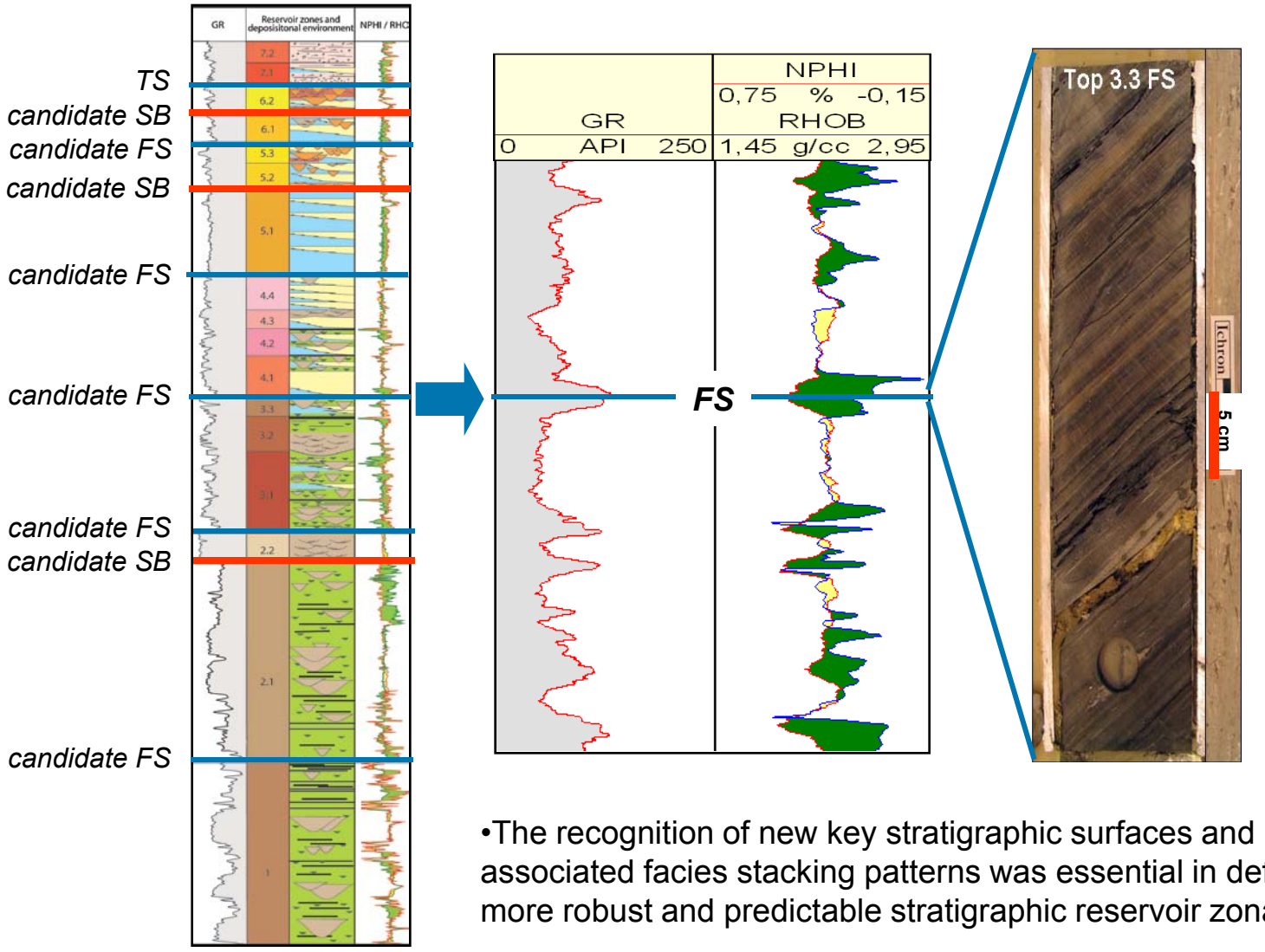
- Åre 1-2: Non-marine coastal plain

- Åre 3-5: Marginal-marine lower delta plain

- Åre 6-7: Estuarine and open marine

• These zones represent packages of genetically linked facies, bounded by field-wide, correlateable key surfaces.

New solution: Revised Reservoir Stratigraphy



•The recognition of new key stratigraphic surfaces and associated facies stacking patterns was essential in defining a more robust and predictable stratigraphic reservoir zonation.

TS = Transgressive surface
FS = Flooding surface
SB = Sequence boundary

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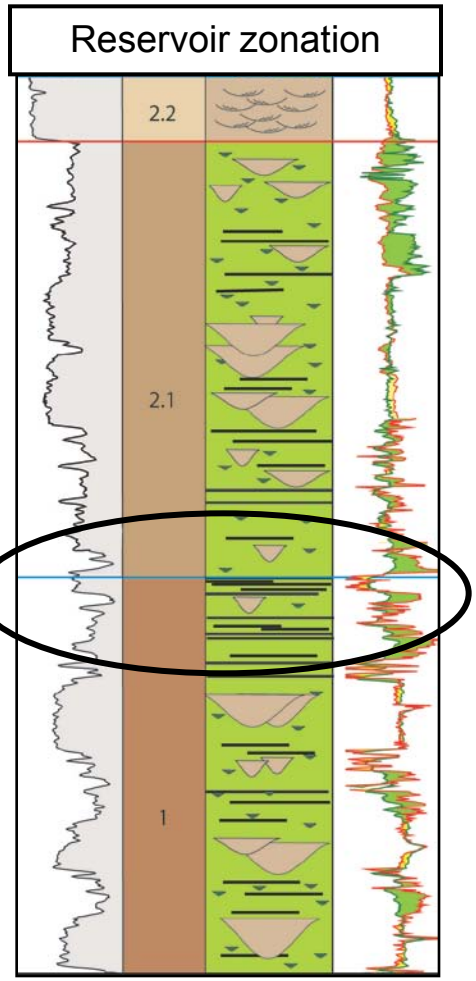
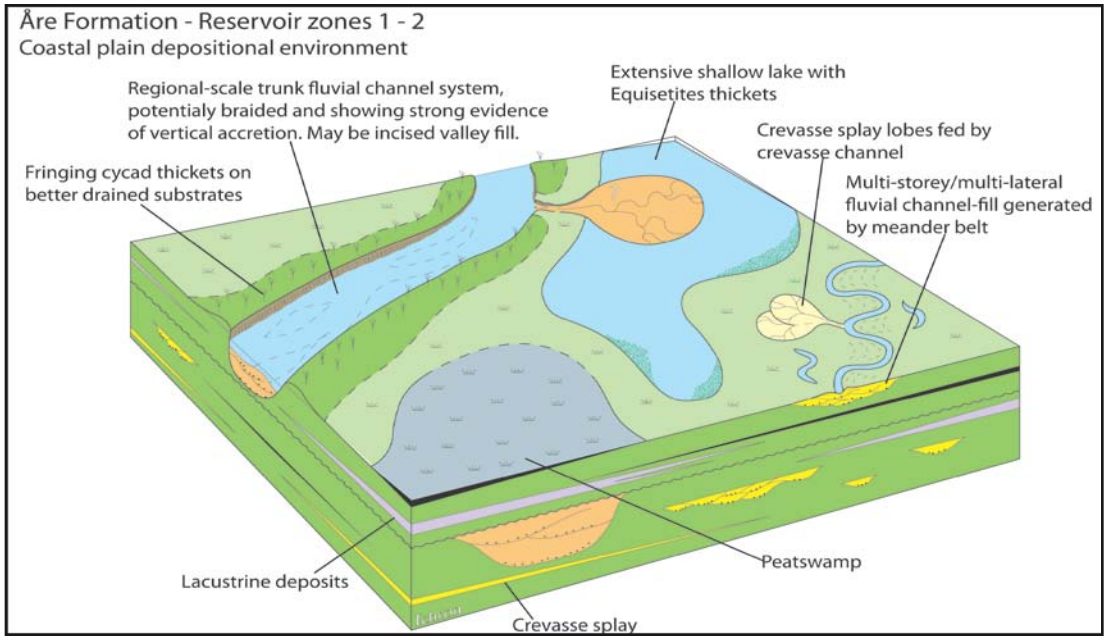
Åre 1 & 2: Fluvial dominated reservoir



- Coastal plain setting; single- to multi-storey fluvial channels enchased in muddy floodplain fines.
- Few marker beds → correlative interval of coal seams.



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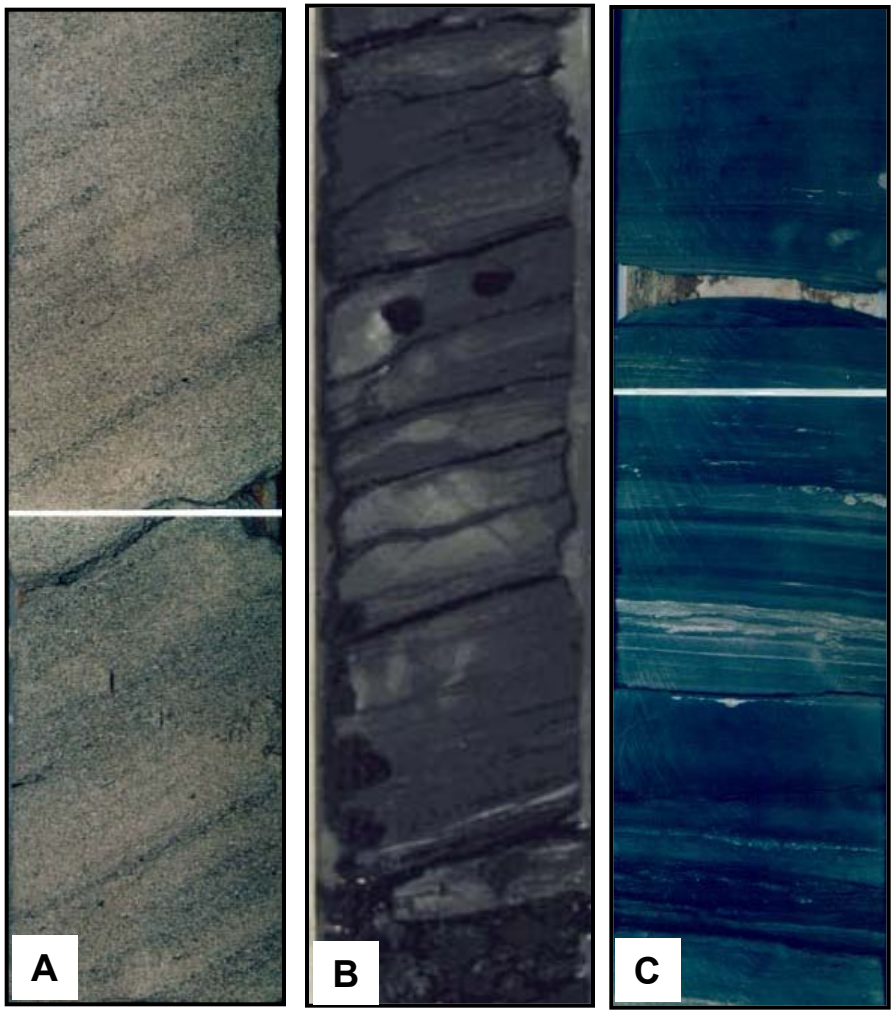
Åre 1 & 2: Fluvial dominated reservoir



A) FLUVIAL CHANNEL SANDSTONE

- Fine to medium grained sandstone

- Low-angle cross-stratification

- Micaceous and carbonaceous drapes

- Sharp base, rooted top

B) PEAT SWAMP COAL

- Carbonaceous debris incorporated within carbonaceous siltstones and vitreous coals

- Pedogenic mottling, rooting

C) LACUSTRINE MUDSTONE

- Laminated organic rich mudstones

- Rooting and pedogenic mottling

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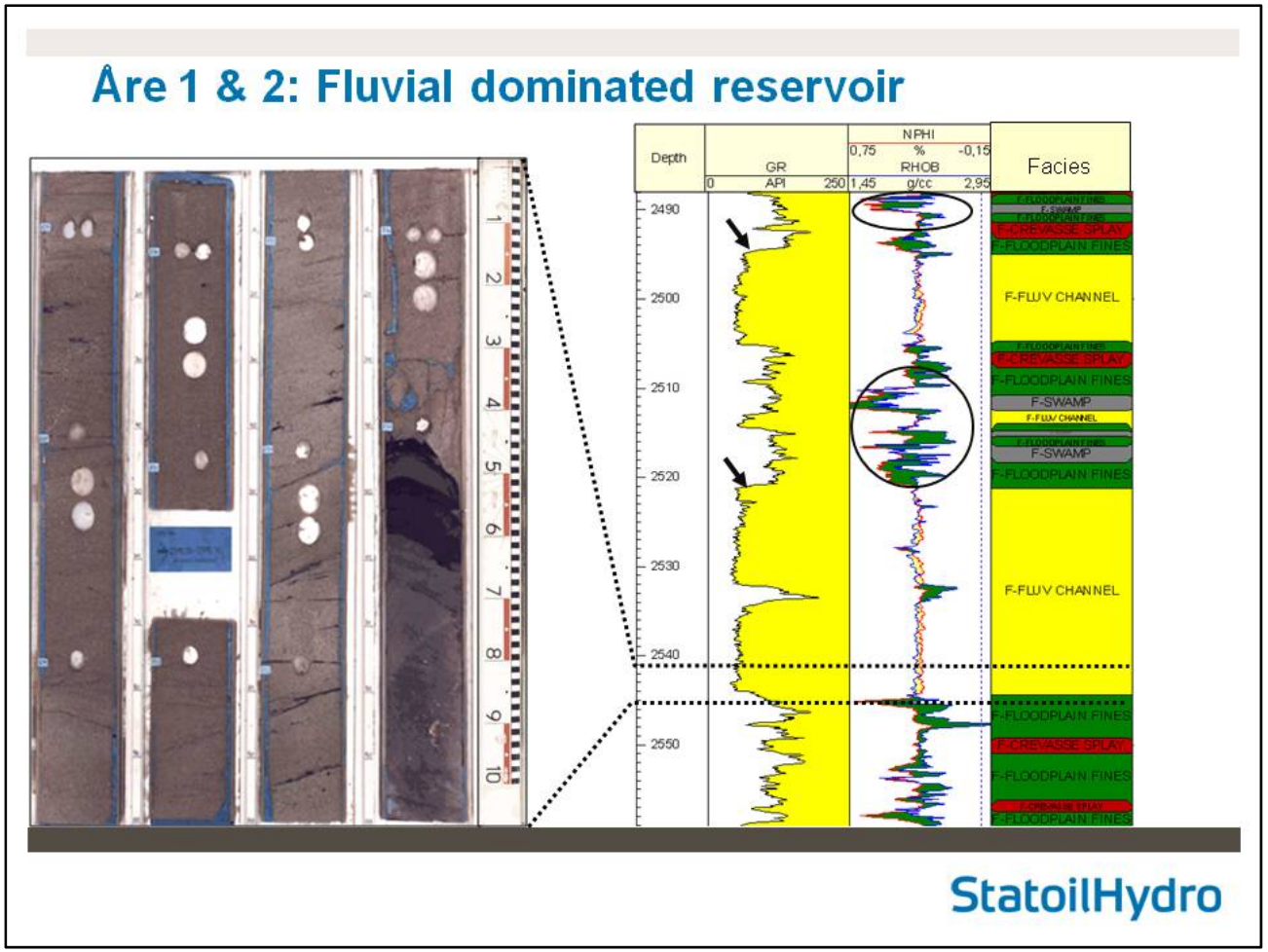
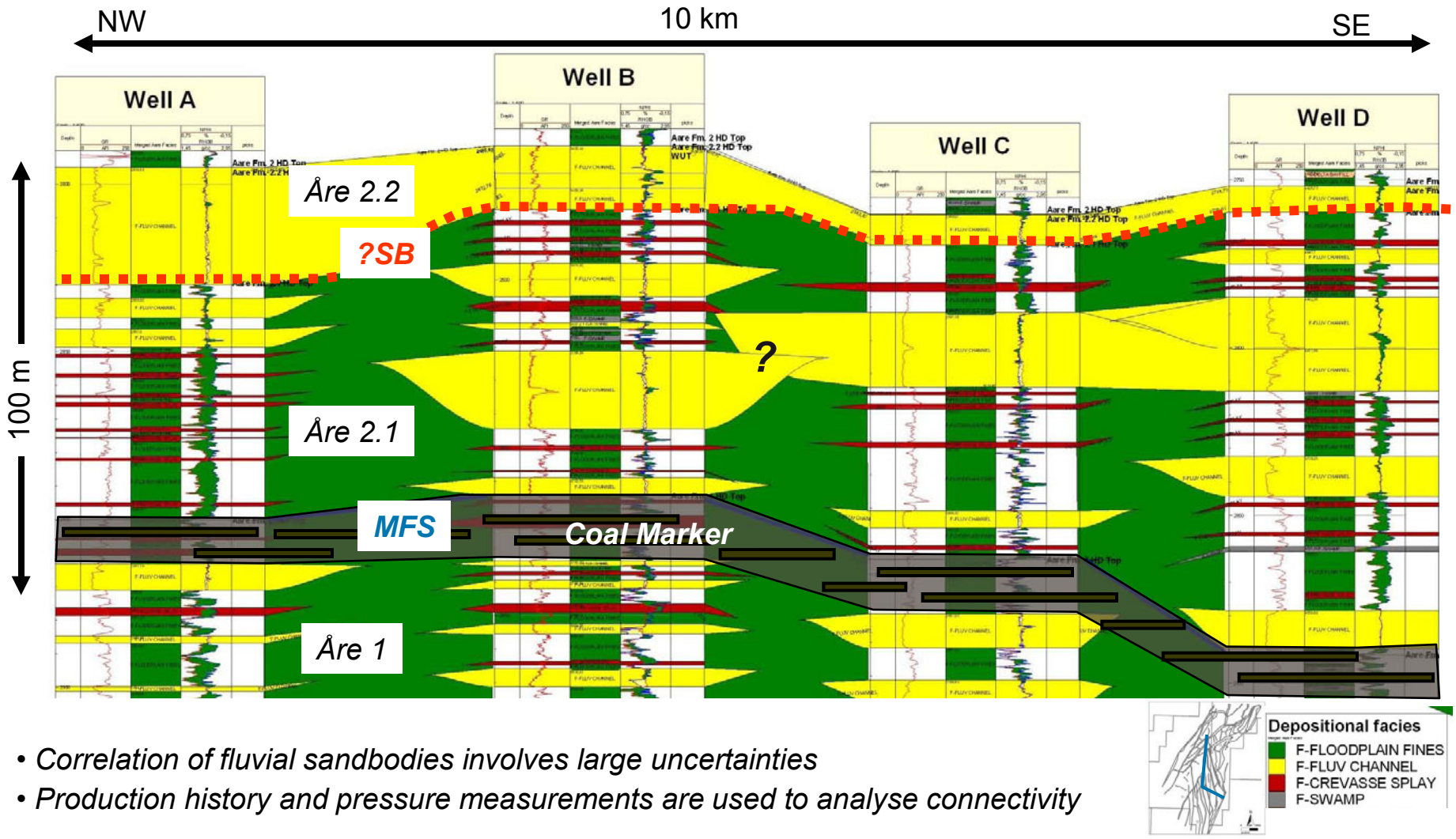


Notes by Presenter:

- 10 – 30 m thick channel sandstones. Sharp base, blocky, abrupt top
- Coal abundance suggests a highly vegetated floodplain representing a stable substrate relatively resistant to fluvial erosion
- Restricted, low-mobility fluvial channels characterised by vertical stacking → anastomosing fluvial system.

Åre 1 & 2: Fluvial dominated reservoir



- *Correlation of fluvial sandbodies involves large uncertainties*
- *Production history and pressure measurements are used to analyse connectivity*

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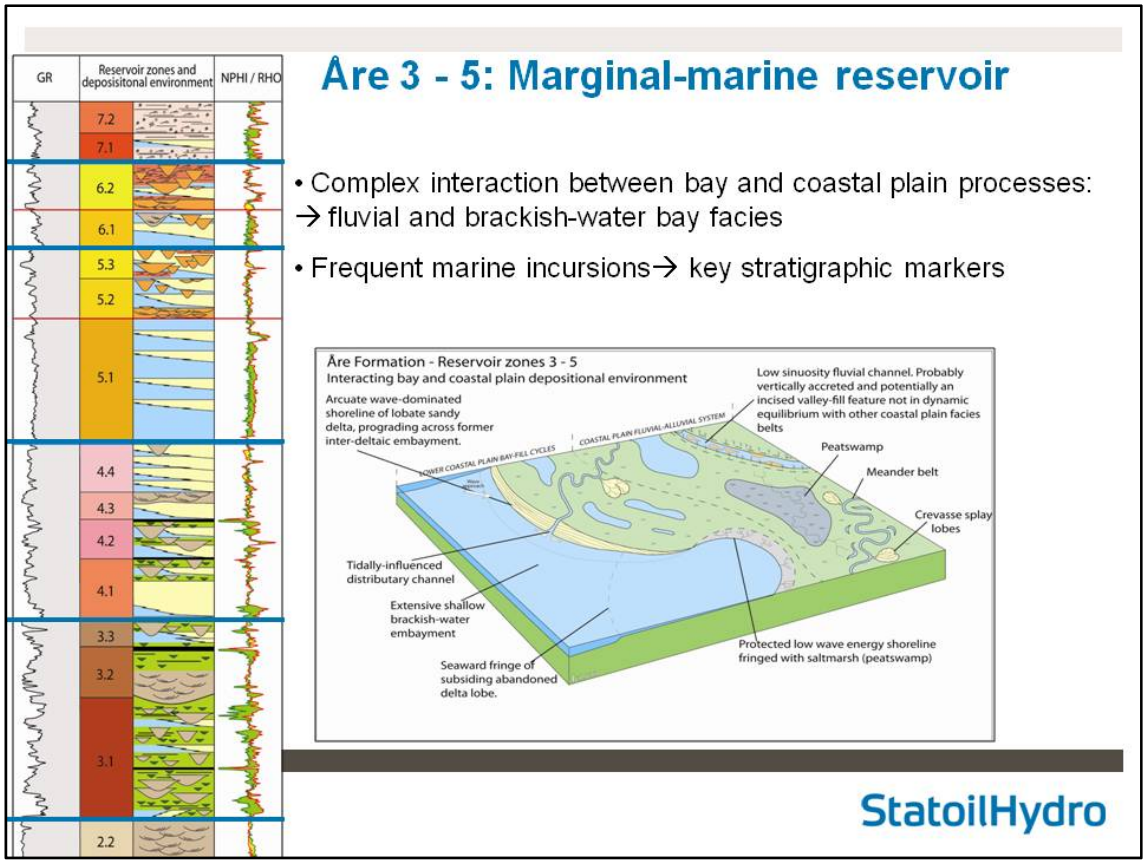


Notes by Presenter:

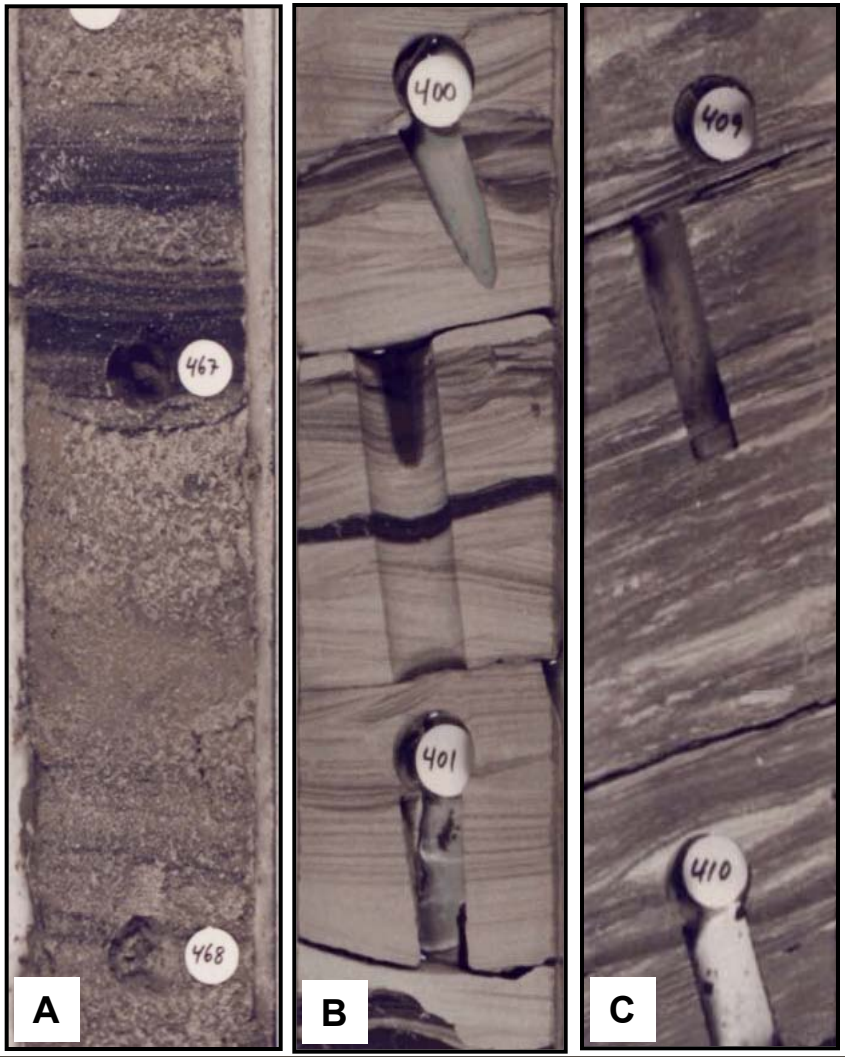
• As we move further up in the strategraphy, the Åre reservoir zones 3 , 4 & 5, are characterised by marginal-marine reservoir rocks.

• This part of Åre represents a Complex interaction between coastal plain and lower delta plain processes:

• Typical depositional elements include distributary channels, entering and depositing delta lobes within shallow and brackish water embayments.

Frequent marine incursions during deposition of this part of Åre resulted in many key stratigraphic surfaces- as field-wide candidate flooding surfaces –

Åre 3 - 5: Marginal-marine reservoir



A) DISTRIBUTARY CHANNEL

- *Medium/coarse gr. cross-stratified sandstones*
- *Current ripples*
- *Locally capped by peat swamp coal*

B) BAY MARGIN SHOREFACE

- *Wave rippled/micro hummocky cross-stratified sandstones and heteroliths*

C) BAY FLOOR MUDS

- *Micaceous siltstones- pinstripes of sand*
- *Wave ripple cross-lamination and micro hummocks may occur*
- *Synaresis cracks*
- *Brackish-water trace fossils:* Planolites montanus, Arenicolites carbonarius

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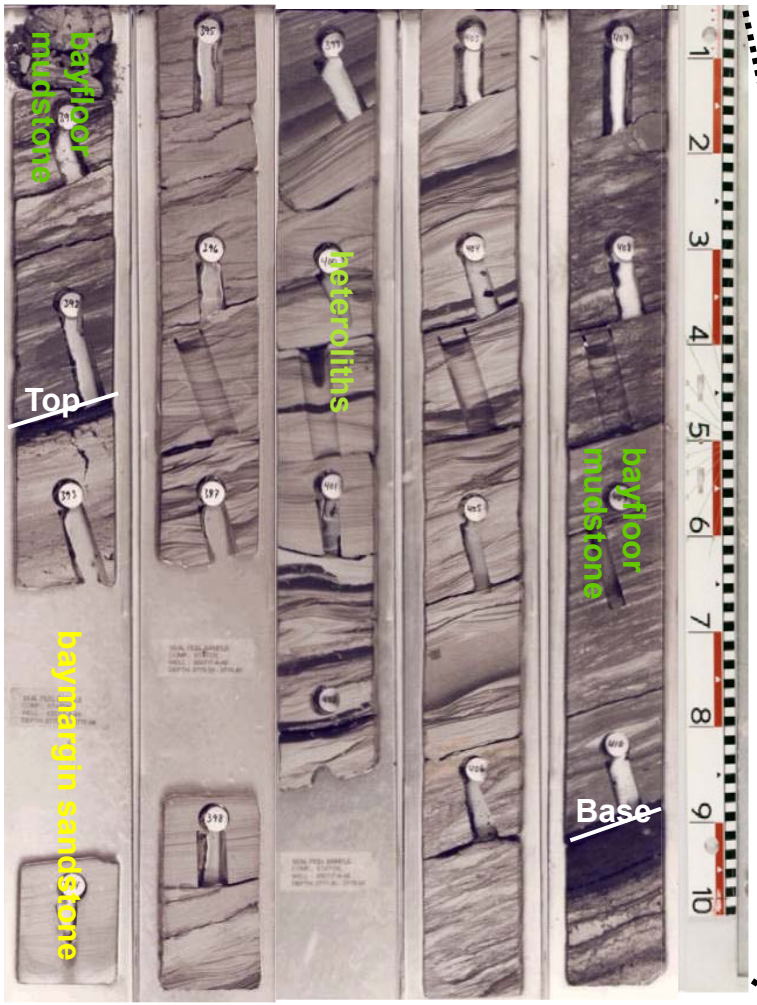
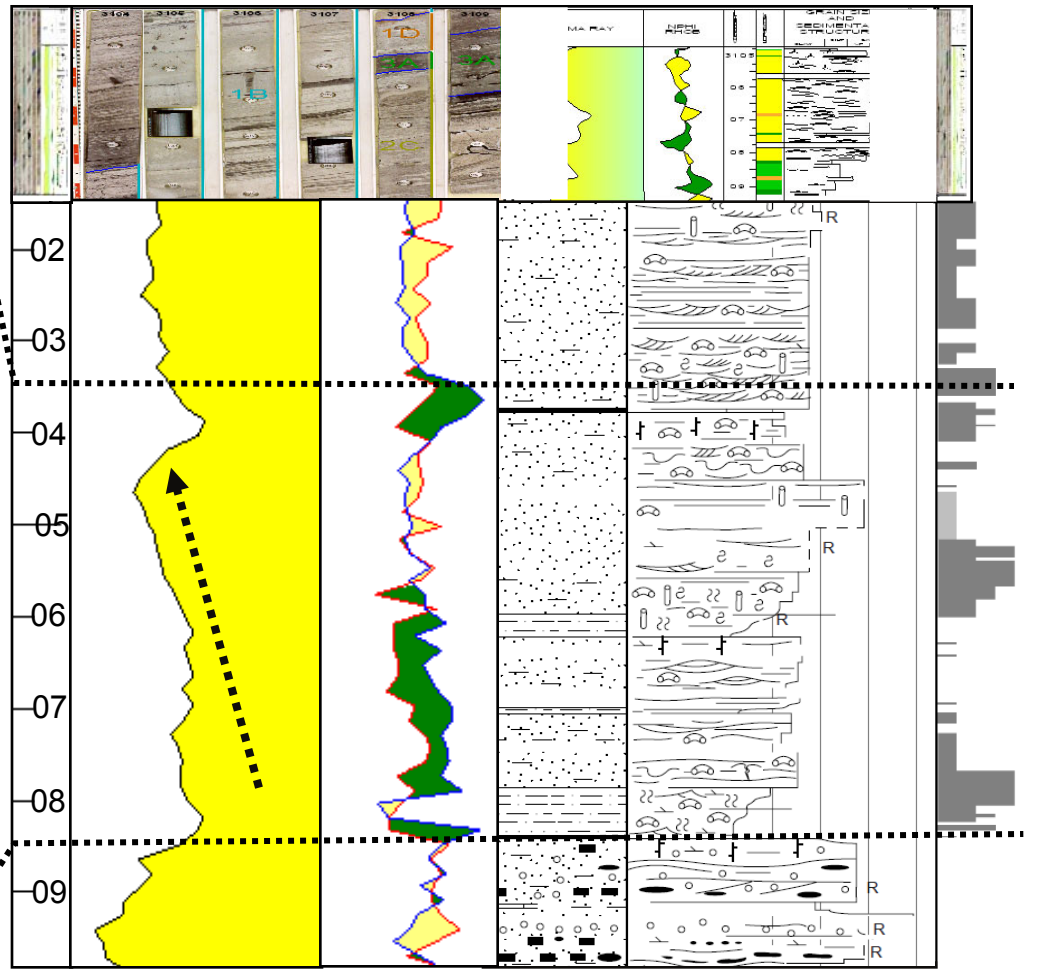
Åre 3 - 5: Marginal-marine reservoir





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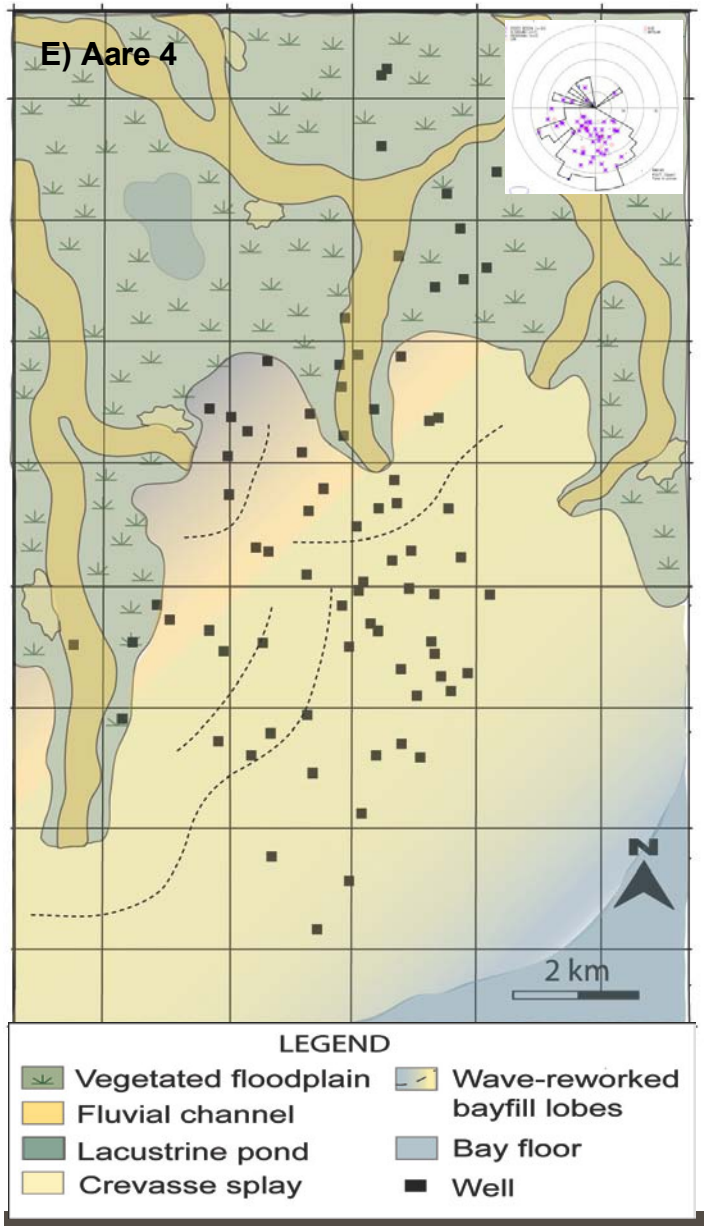

Åre 3 - 5: Marginal-marine reservoir

- Palaeogeographic maps show complex and rapid shifts of the palaeocoastline
- These maps represent best guess scenarios, but constitute the most realistic geological models available at this time
- The definition of facies architecture and 3D understanding of the reservoir forms an important basis for discussion and direct input to reservoir modelling and well planning

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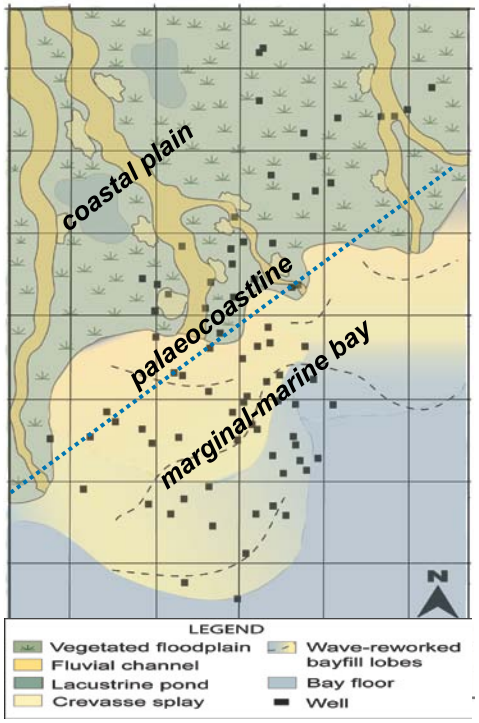
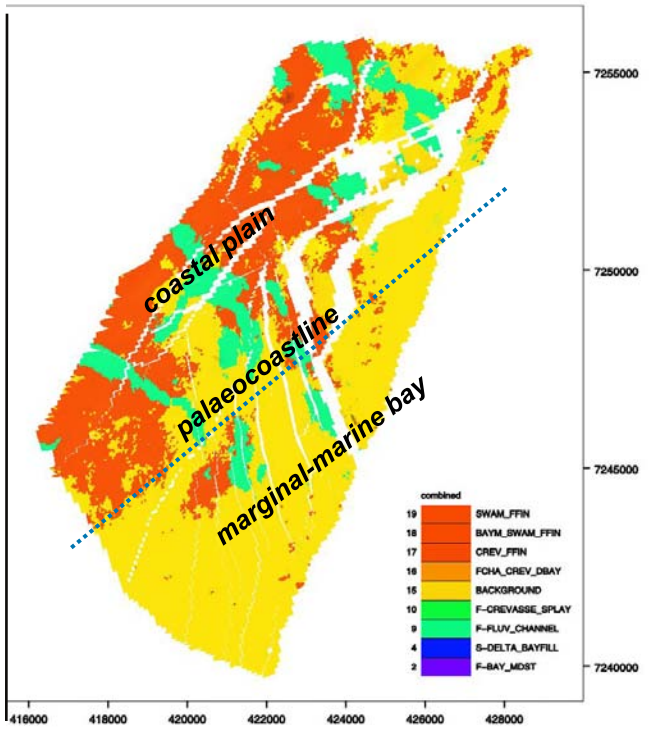
Application & benefits of Åre reservoir characterisation



Palaeogeographic map base Åre 3.3



Geological model base Åre 3.3

Reservoir modelling

- A robust stratigraphic framework
- Choose the correct strategies and simplifications in modelling
- Improve the control on distribution of petrophysical properties

  → Resulting in a more deterministic and geologically confident reservoir model

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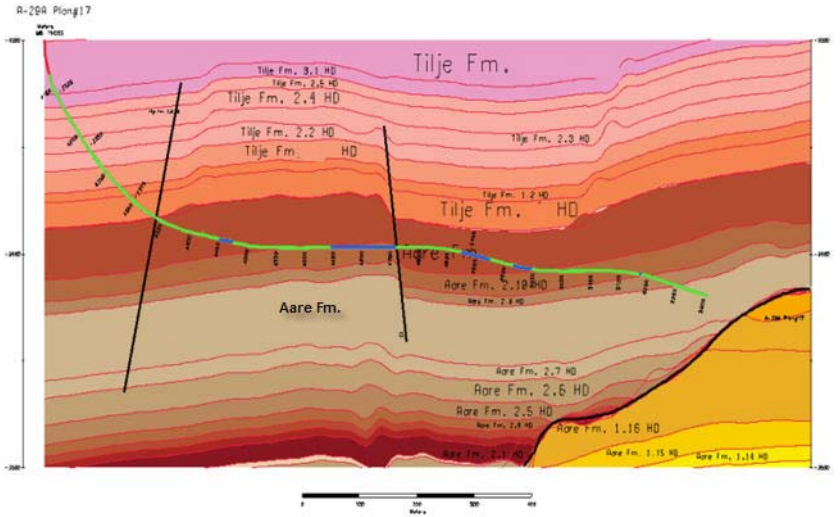
Application & benefits of Åre reservoir characterisation

Well targeting & drainage strategies

- Robust stratigraphic framework enables an improved stratigraphic control during drilling and reduces the risk when placing targets.



Multidisciplinary communication

- Firmly defined sedimentological and stratigraphic concepts and their implications in terms of reservoir drainage are now easier to communicate to all disciplines in the subsurface team.

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Conclusions

- A review and reinterpretation of the complex fluviodeltaic Åre Fm. in the Heidrun Field has resulted in:
  - a robust and predictable stratigraphic framework
  - a simplified strategy for building geological reservoir models
  - good platform for improved stratigraphic control during drilling operations
  - enhanced comprehension of production data
  - more precise production forecast and improved basis for reservoir management decisions
- In other words; all the necessary tools we need to extend the life length of the Heidrun Field

Selected References

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