Geometric Characterisation of Clastic Intrusion Complexes Adjacent to a Deep-Water Slope Channel: a 3D Seismic Case Study from Offshore Norway*

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Abstract

The North Sea Basin contains some of the most intensively studied examples of large-scale clastic intrusions associated with producing deep-water sandbodies. To-date, however, most studies have focused on the seismic expression, stratigraphic distribution and general geometry of the intrusions, in addition to the impact of intrusions on the reservoir geometry and production. In this study, 3D seismic data is utilised to propose a novel model for the growth of large-scale clastic dykes. Plots of the size of clastic dykes along the length of the a 15 km long deep-water channel indicate that they attain a maximum height of 110 m above and extend up to 1.8 km laterally away from the channel. The dykes are neither continuous nor of the same size along the length of the channel; pronounced along-strike ‘maxima’ and ‘minima’ in injection size are observed which serve to compartmentalise the channel margin dykes into ‘segments’ which individually are ca. 0.5-1.5 km in length. These variations in dyke size are reminiscent of displacement-length (D-L) plots for large normal and reverse faults which have grown via a process of linkage of individual, initially isolated segments. Based on this geometric similarity, a model for clastic dyke development is proposed whereby individual dykes form at ‘seed points’ and then propagate vertically and laterally. Hydrofractures and the associated clastic dykes then propagate radially away from these seed points to eventually fully or partially coalesce along-strike. This study indicates that 3D seismic data provides a useful method to investigate the geometric evolution of large-scale clastic dykes adjacent to deep-water sandbodies. In addition, the clastic injections mapped in this study indicate strong modification of the original reservoir geometry which may require complex production methods to exploit any contained hydrocarbons.

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Data: StatoilHydro

Software: SMT

Rationale I - Conceptual

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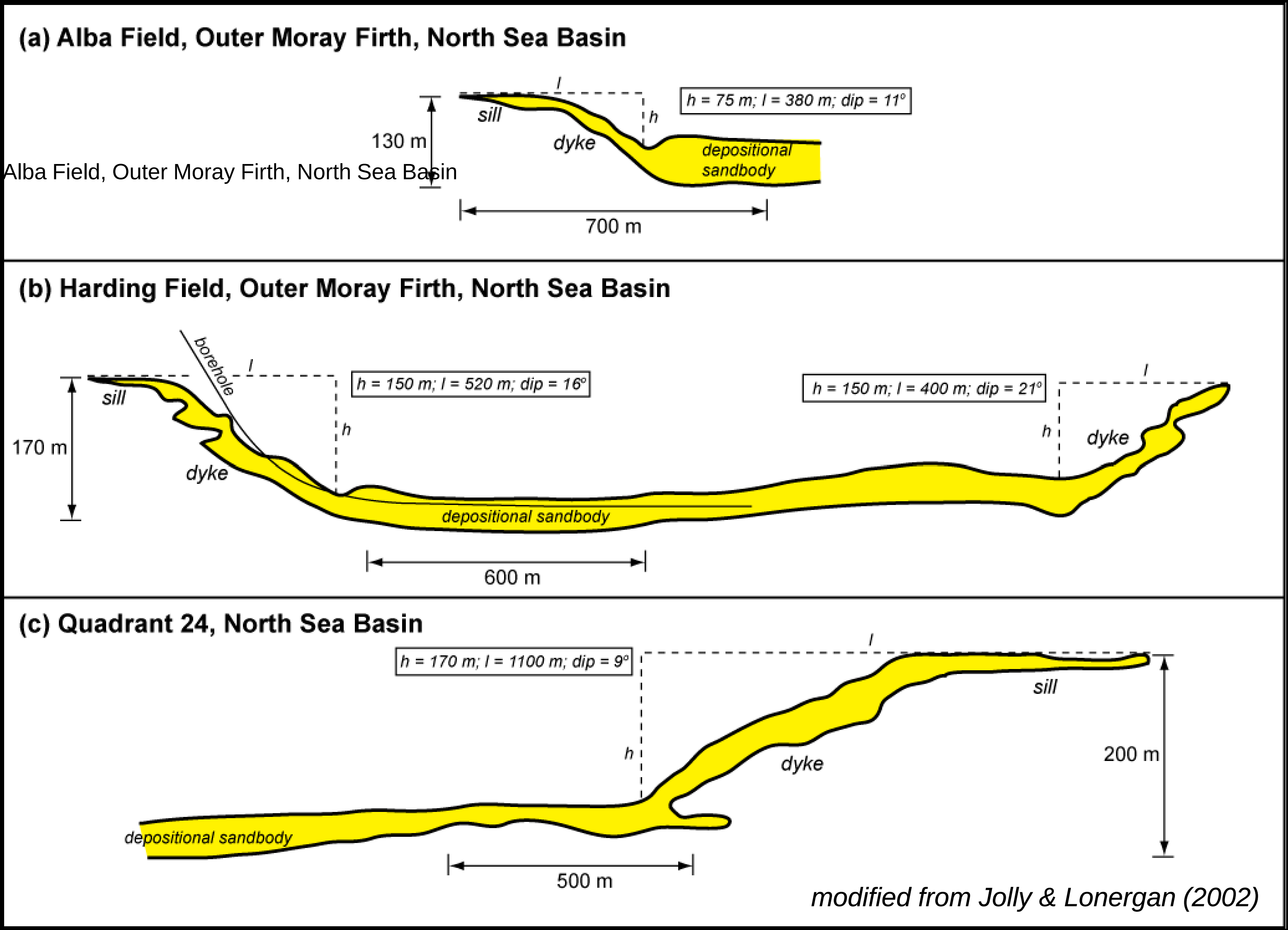
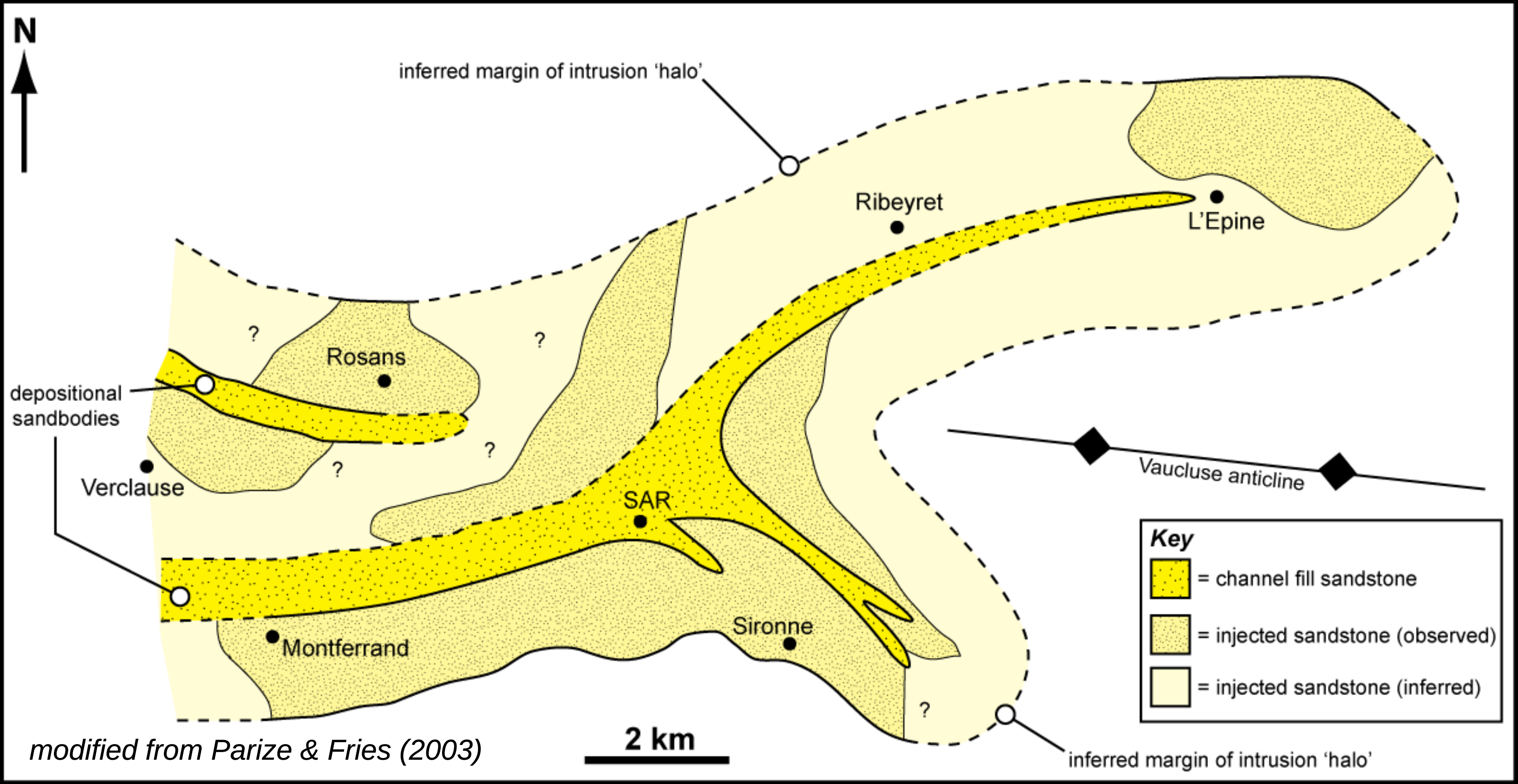
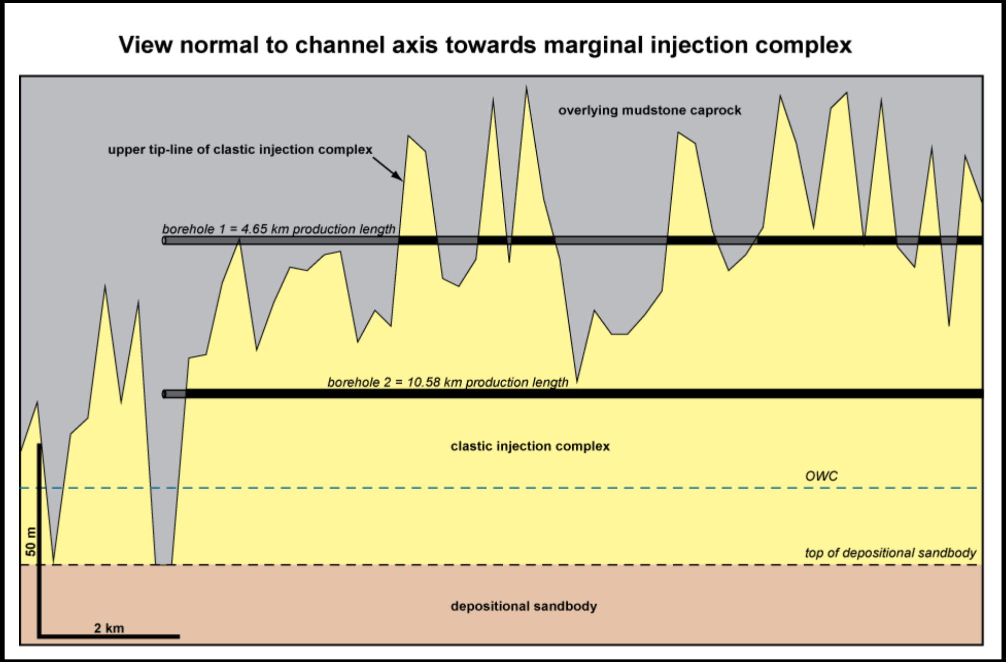
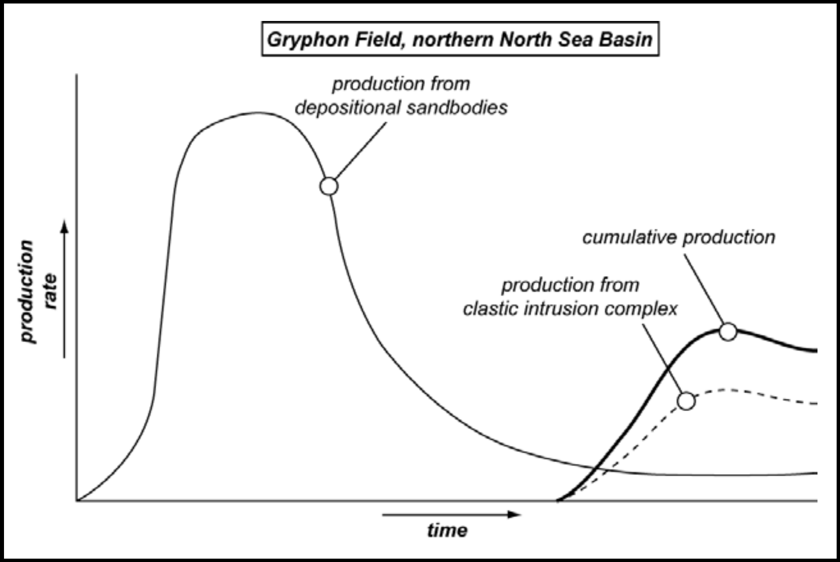


Rationale I - Conceptual



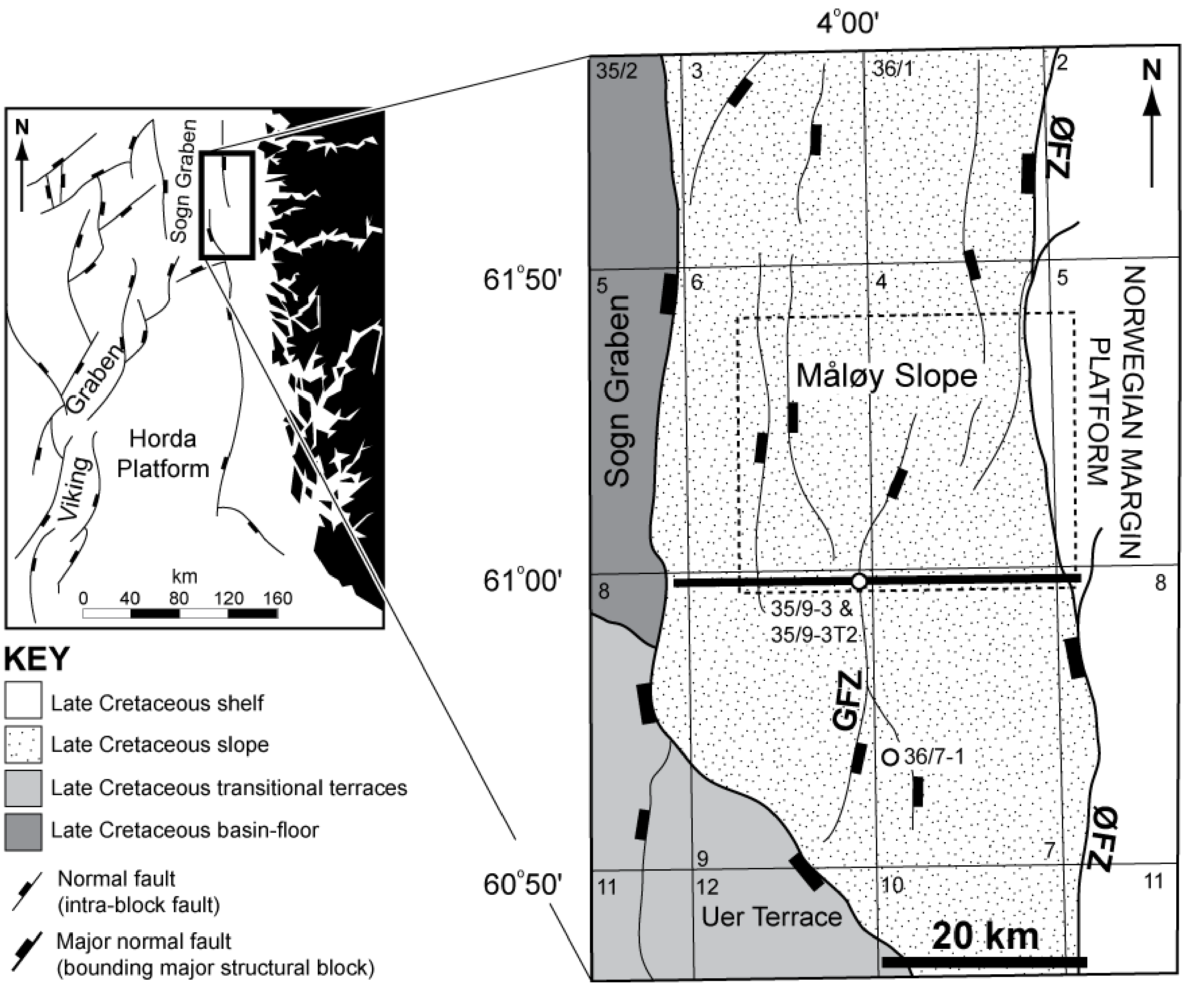
Rationale II - Economic





modified from Templeton et al. (2008)

Tectono-stratigraphic setting I



modified from Jackson et al. (2008)

- Northern North Sea Basin
- Located on a westwards-dipping slope
- Underlain by a Late Jurassic age rift
- 3D seismic and well data available

Tectono-stratigraphic setting II

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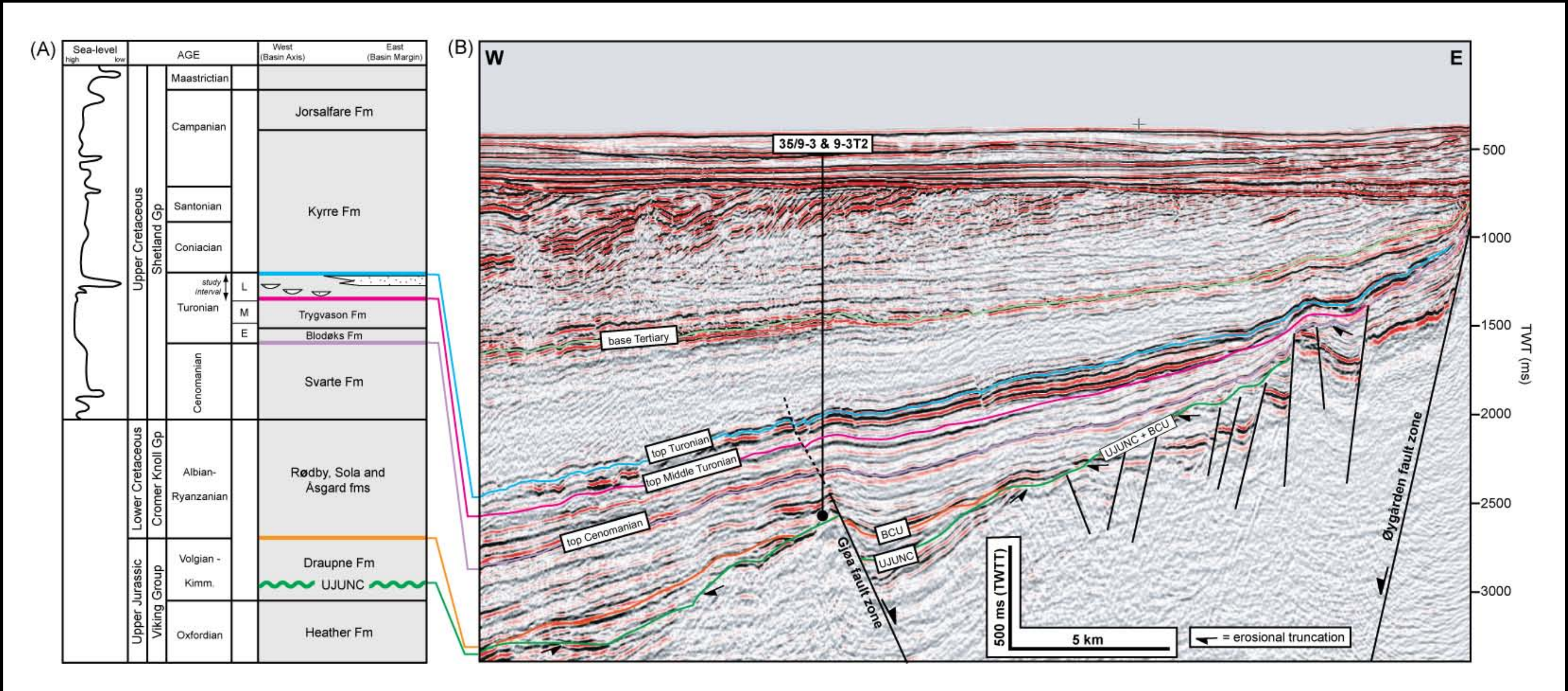

modified from Jackson et al. (2008)

- Located on a westwards-dipping slope
- Mudstone-dominated Cretaceous succession
- Late Cretaceous, sand-rich turbidite systems
- Depositional systems expressed as amplitude anomalies

Depositional (source) systems

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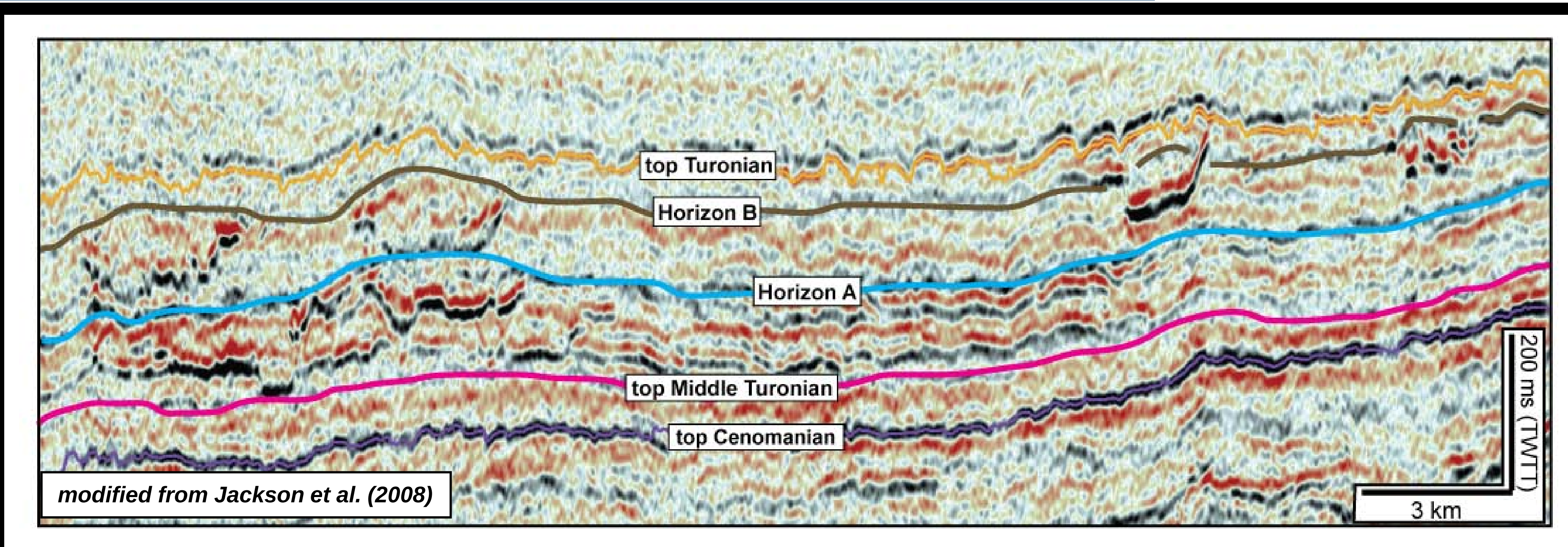

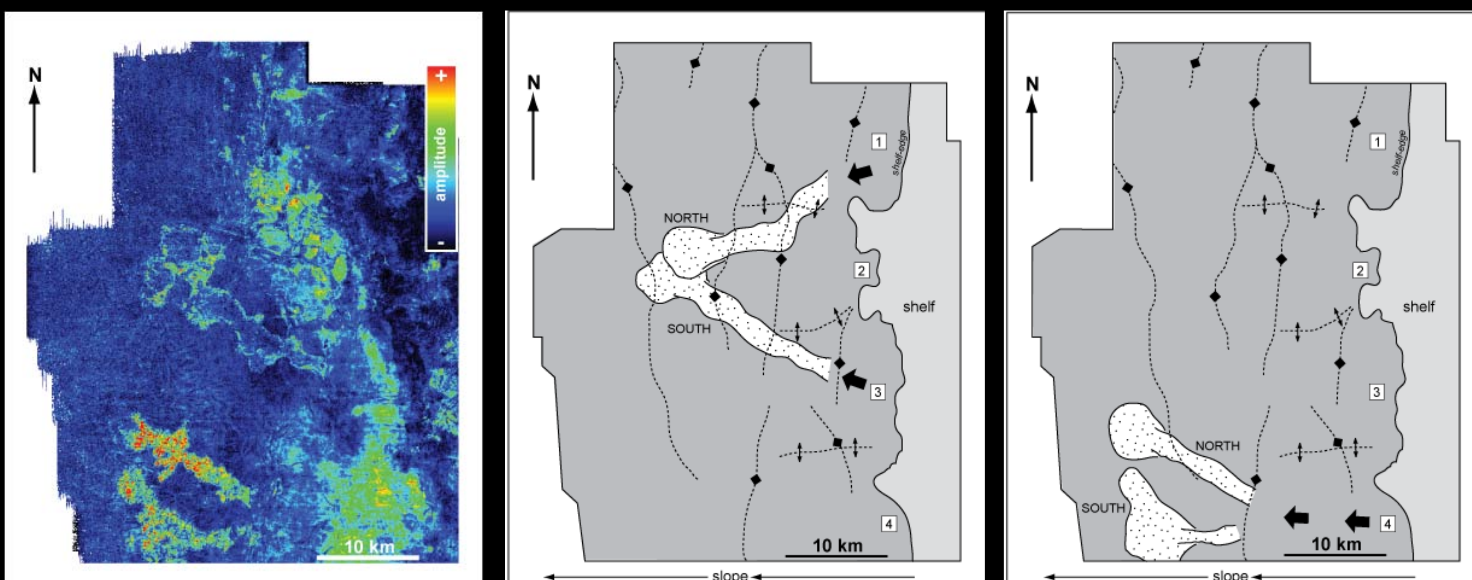

- Numerous levels of channel and channel-complex development
- Associated with shelf-edge canyons
- Note discordant (and concordant) amplitude anomalies

Clastic intrusions I

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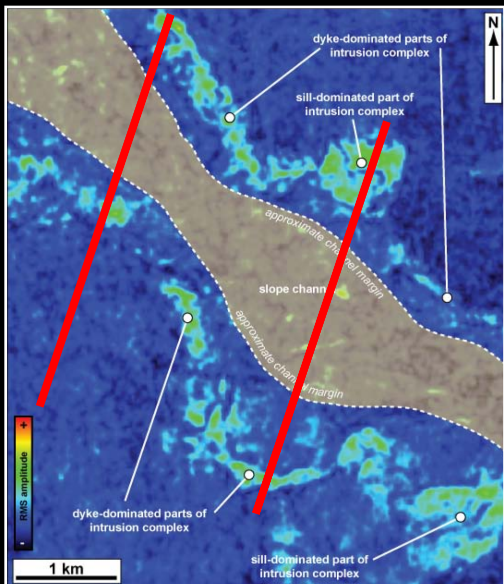
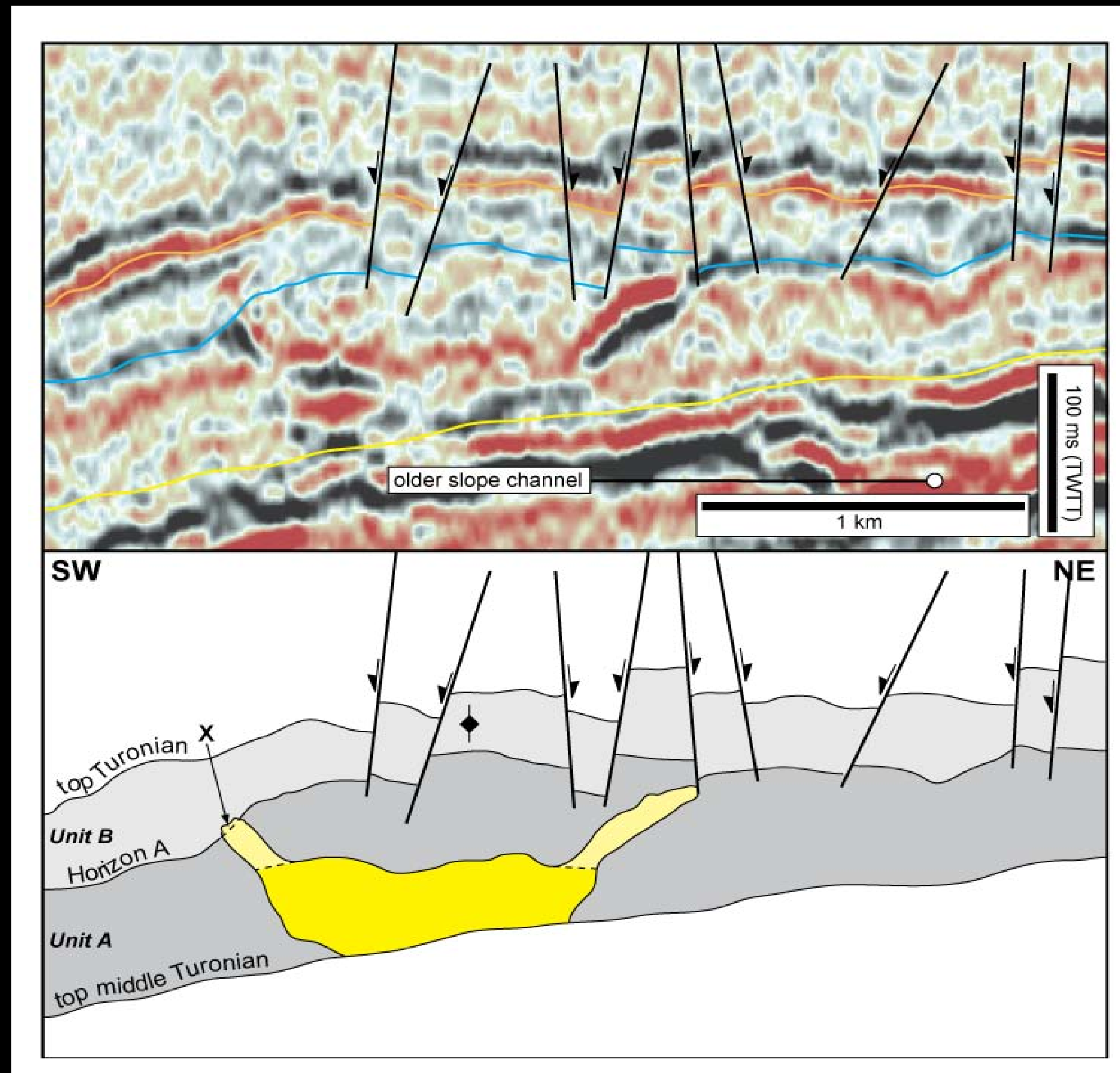


- ‘Ribbon-like’ and ‘pod-like’ amplitude anomalies observed in plan-view which flank the entire 15 km length of the slope channel

- Three key types of intrusions observed:

  - Dykes lacking terminal sills
  - Dykes with terminal sills
  - Transgressive sills

- Note the upward termination of the intrusions



Clastic intrusions II

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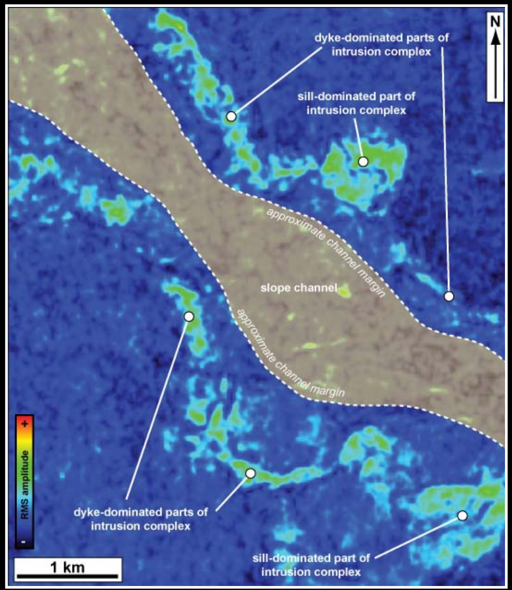

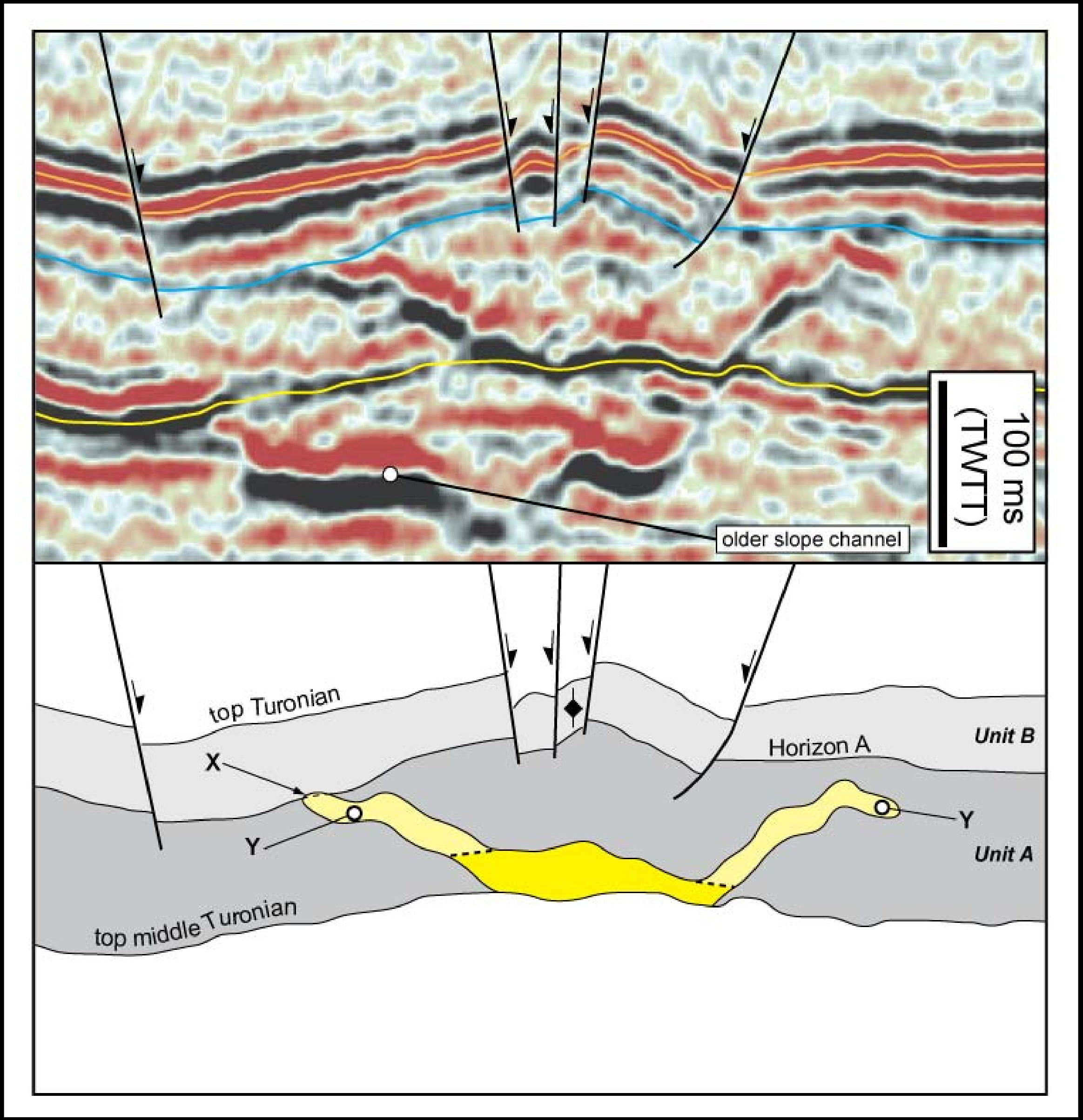

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Clastic intrusions III

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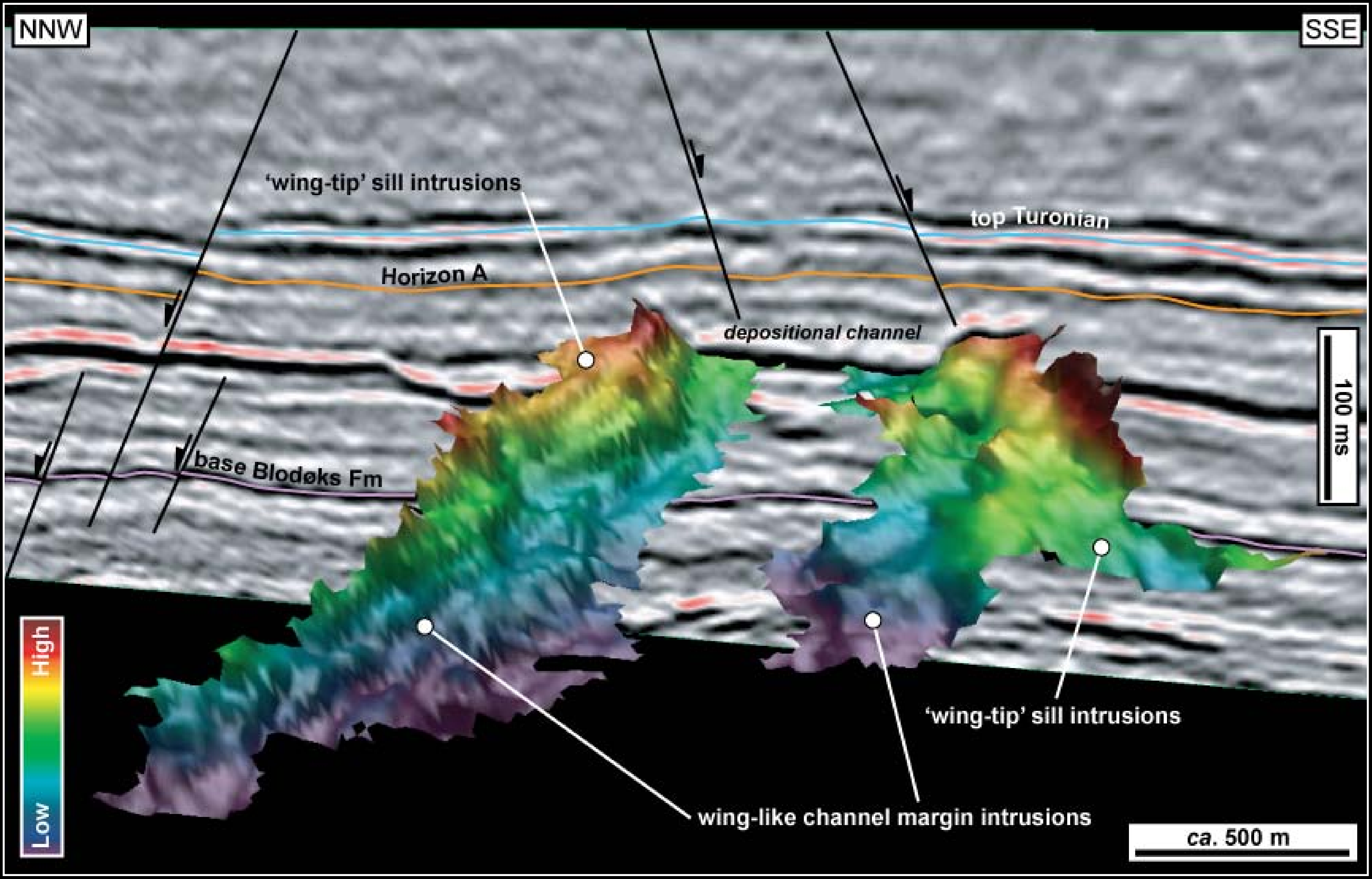

modified from Jackson (2007)

Quantitative analysis - methodology

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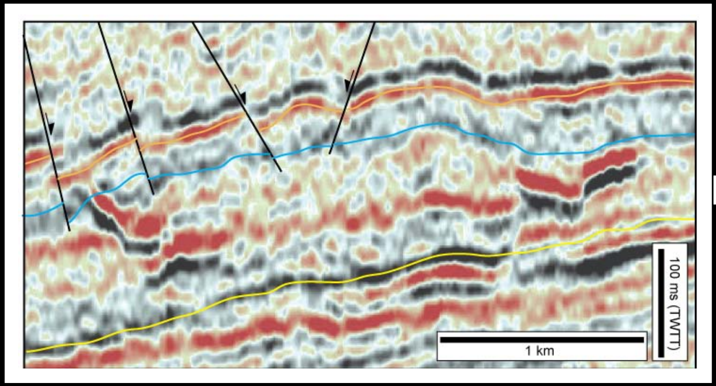
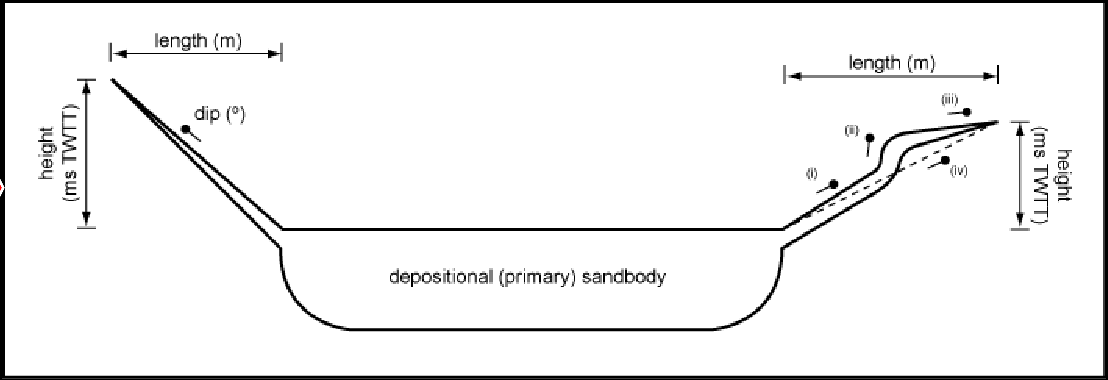
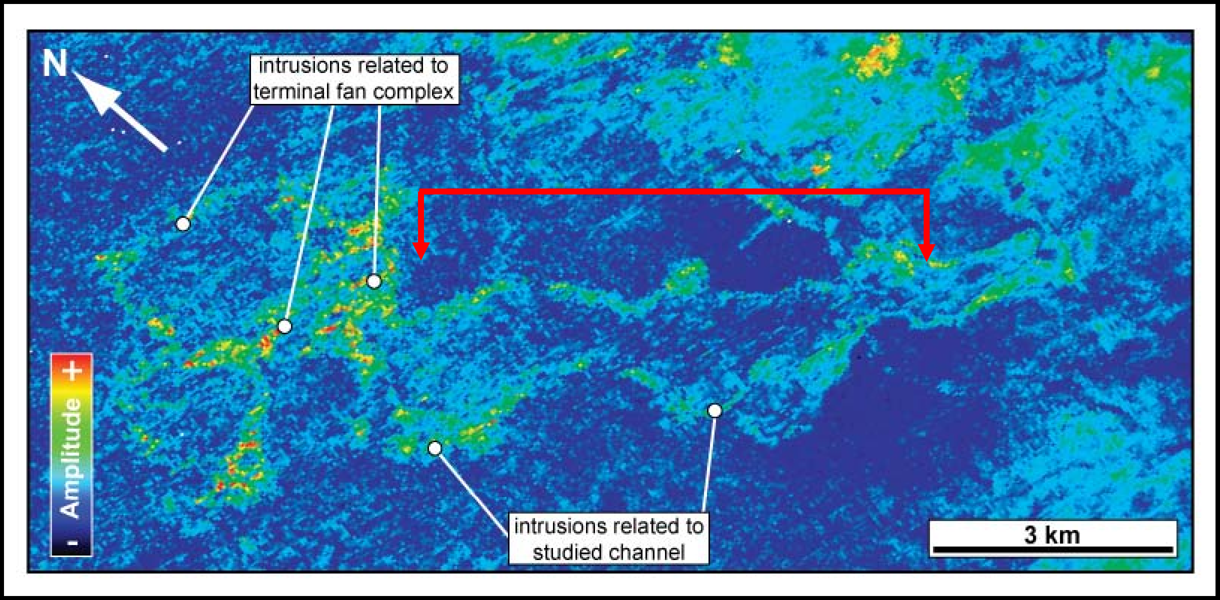


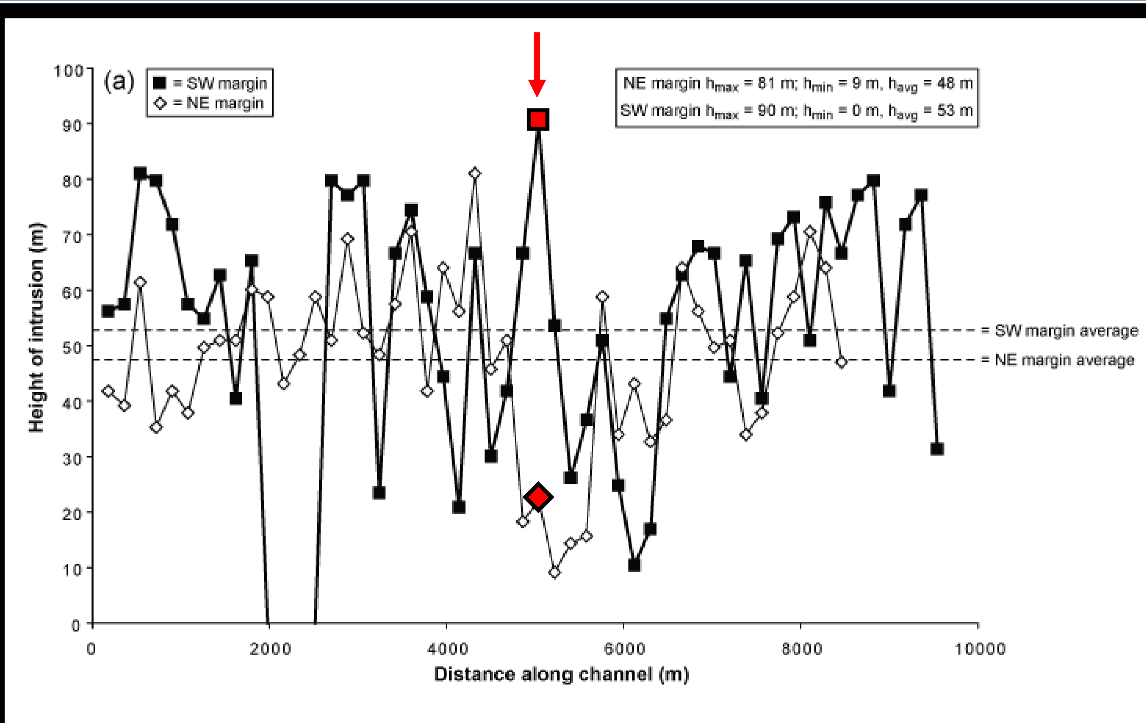


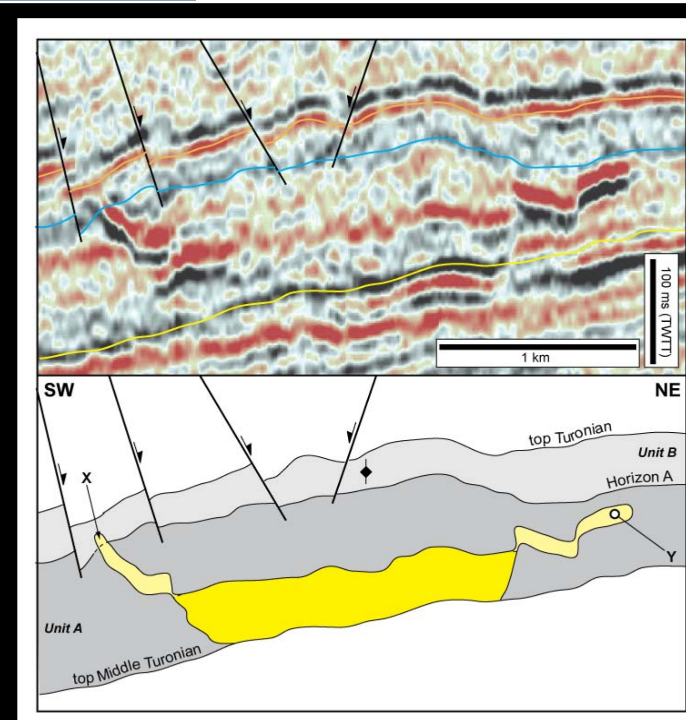
- Three key geometric parameters were recorded:
  - Height (m)
  - Length (m)
  - Dip ( )
- Analysis performed on serial 2D sections spaced 180 m apart along a 9.5 km length of the channel
- Note that all relevant values were depth-converted

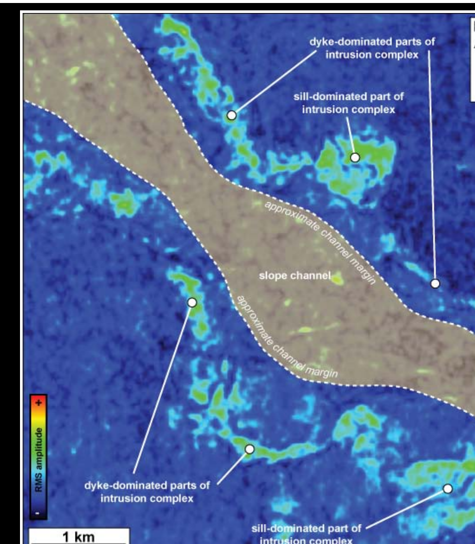


Well	Kyrre Fm top (m)	Kyrre Fm base (m)	Kyrre Fm thickness (m)	Kyrre Fm top (ms TWTT)	Kyrre Fm base (ms TWTT)	Thickness (ms TWTT)	Interval velocity (ms m^{-1})
36/1-2	1335	2213	878	1410	2110	700	2509
35/3-2	1655	2864	1209	1710	2610	900	2687
35/3-1	1720	2962	1242	1730	2670	940	2643

Results I – Intrusion height



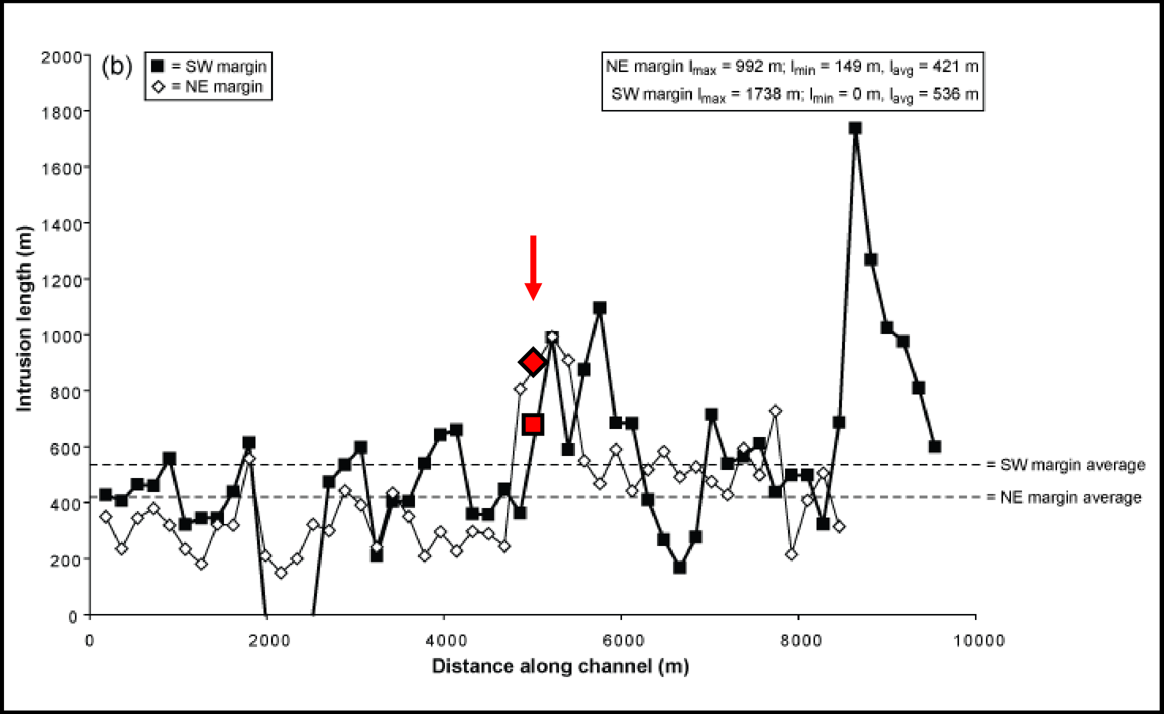


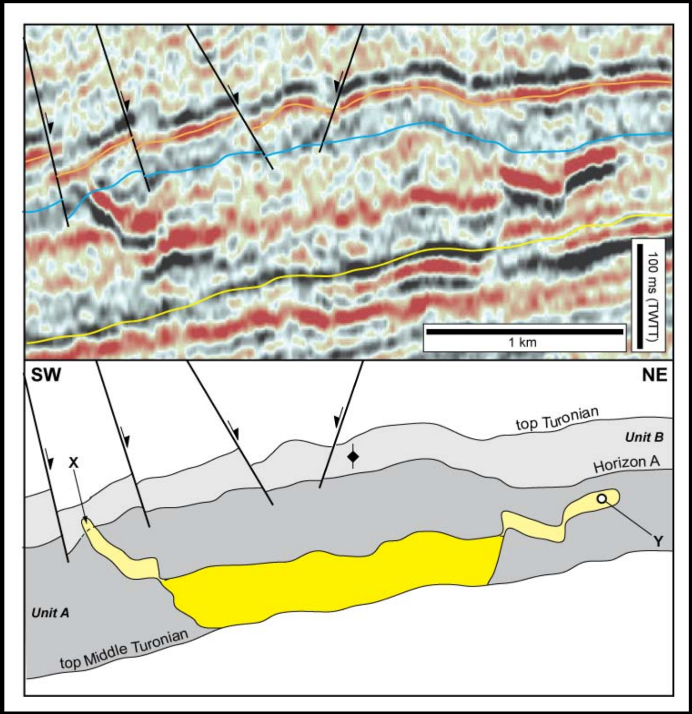


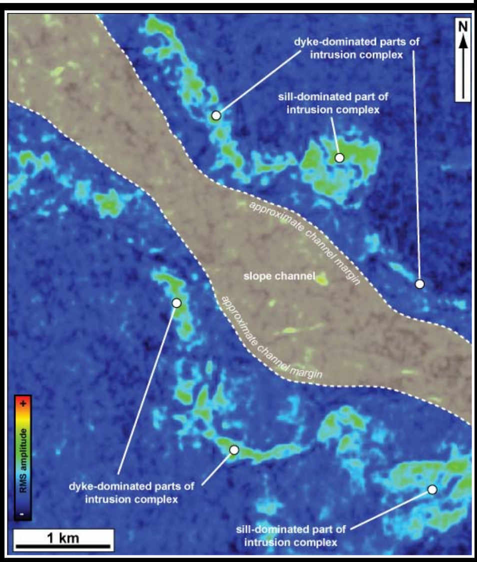
Height variability:

- *NE margin*: h$_{max}$ (81 m), h$_{min}$ (9 m), h$_{avg}$ (48 m)
- *SW margin*: h$_{max}$ (90 m), h$_{min}$ (0 m), h$_{avg}$ (53 m)
- High-frequency (100 m-scale) variability superimposed on larger-scale (km-scale) variability

Results II – Intrusion length







Length variability:

- *NE margin*: l_{max} (992 m), l_{min} (149 m), l_{avg} (421 m)
- *SW margin*: l_{max} (1738 m), l_{min} (0 m), l_{avg} (536 m)

Results III – Intrusion dip

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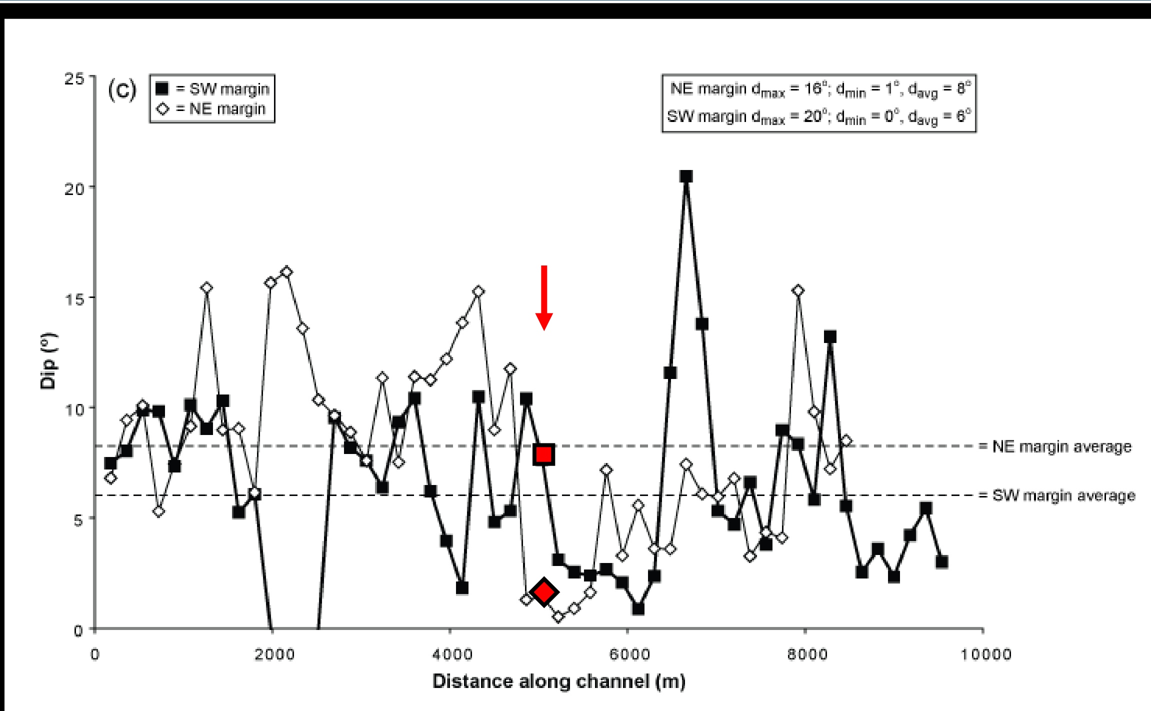
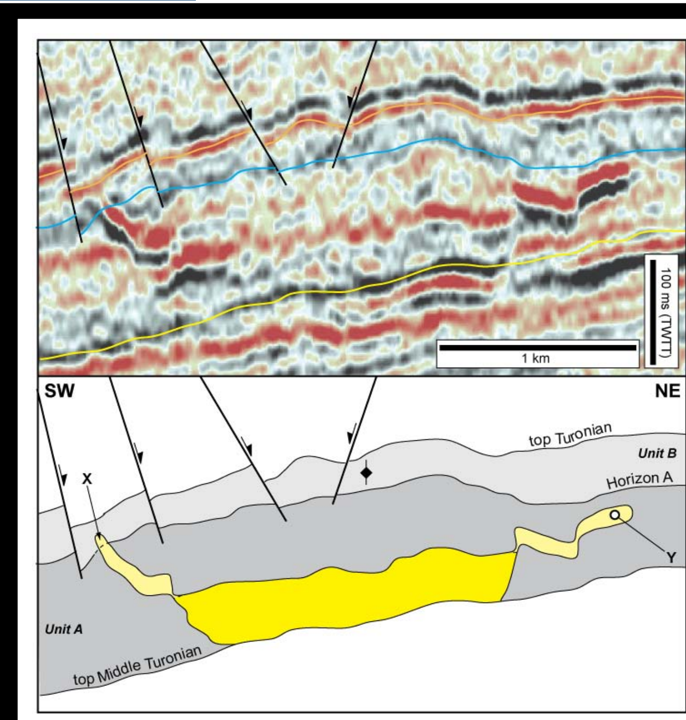
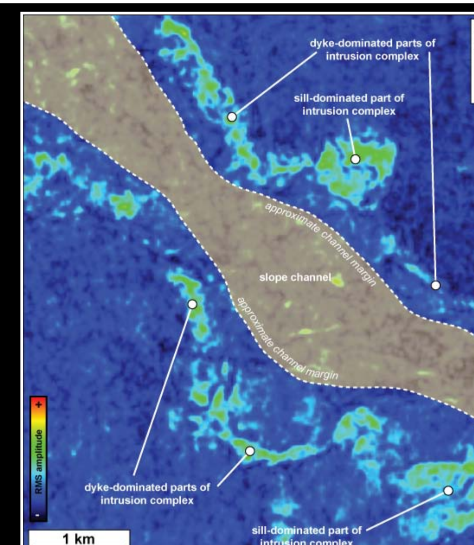




Dip variability:

- *NE margin*: d_{max} (16), d_{min} (1), d_{avg} (8)
- *SW margin*: d_{max} (20), d_{min} (0), d_{avg} (6)



Relationship between geometric parameters

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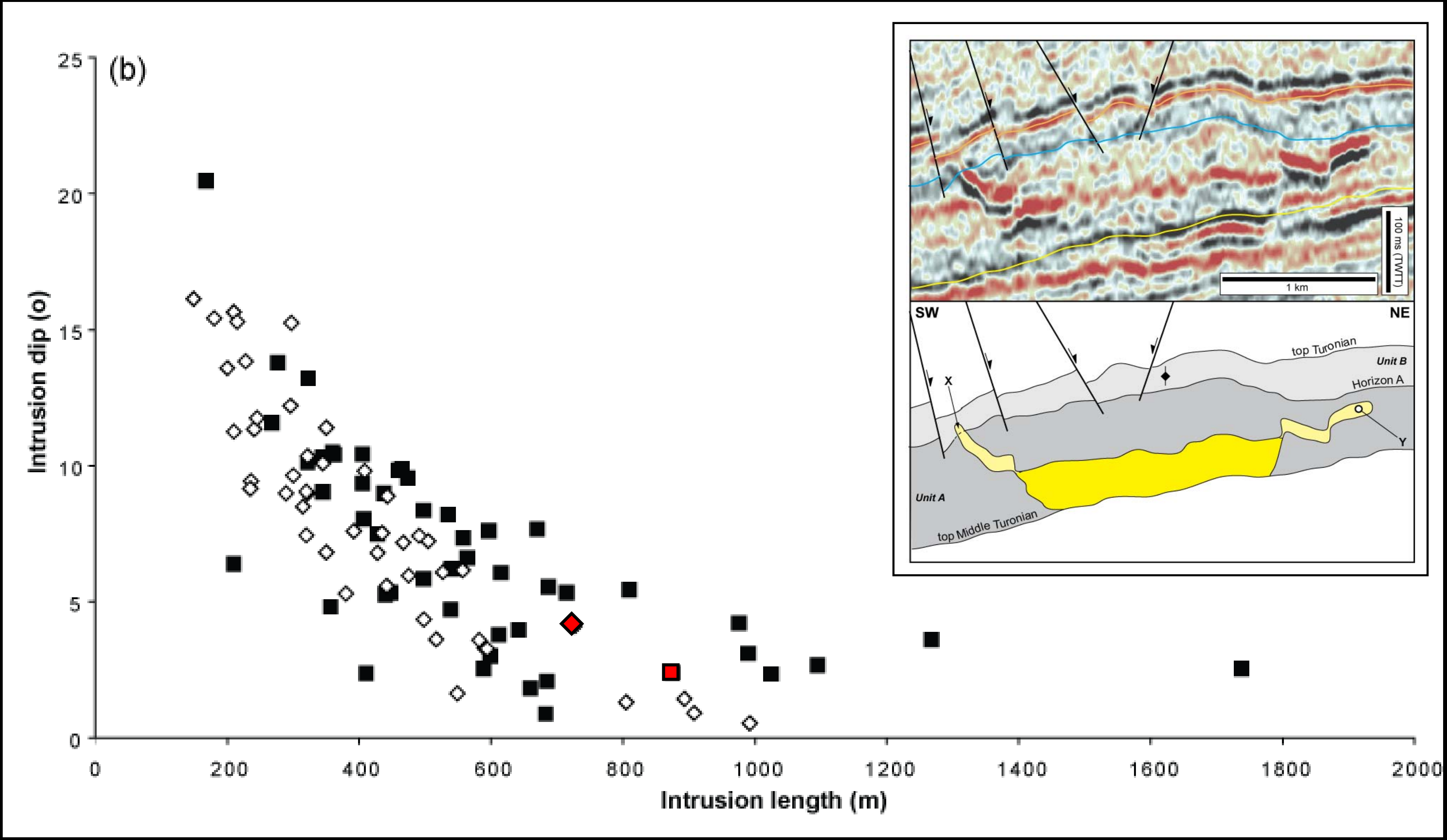
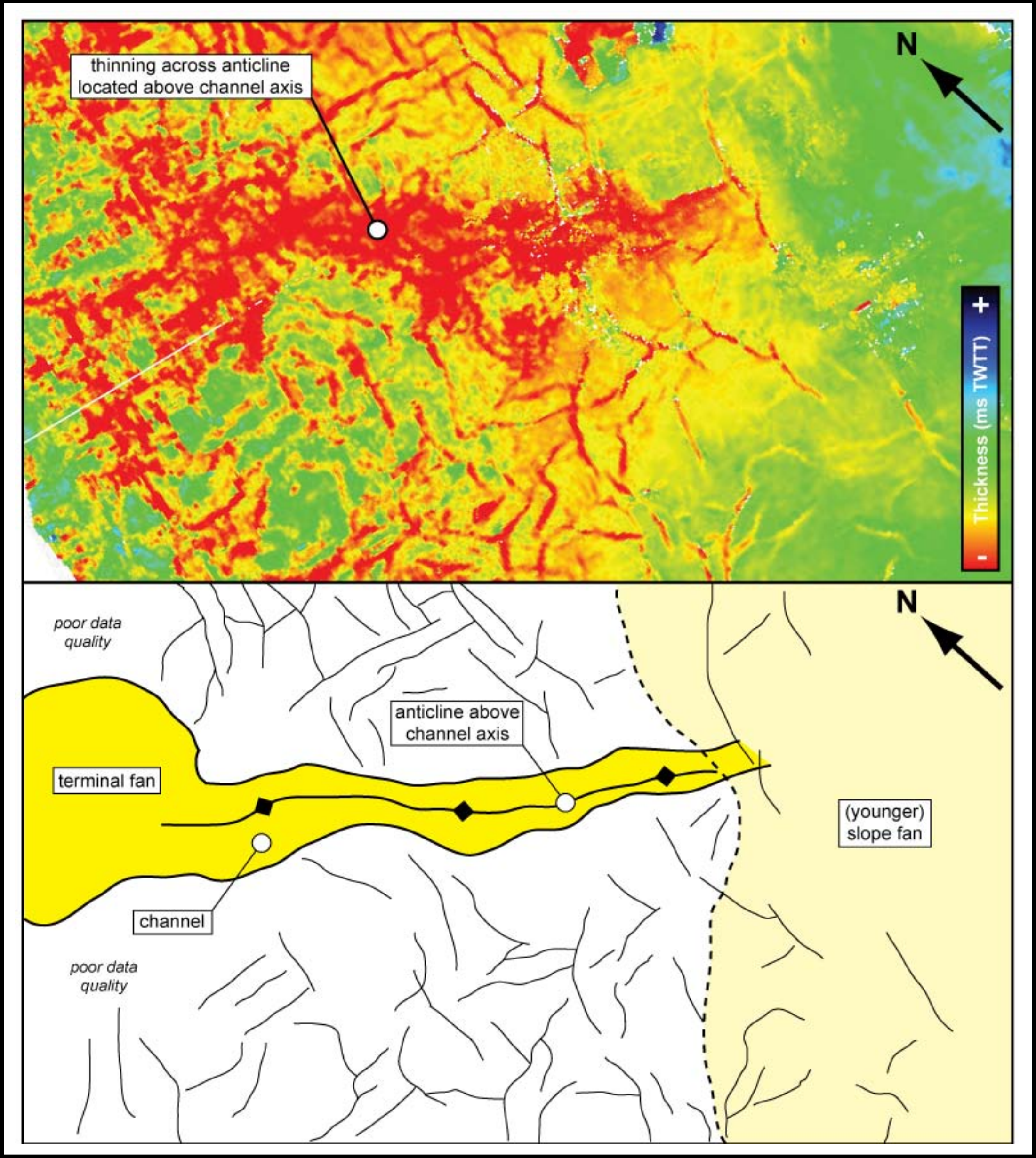
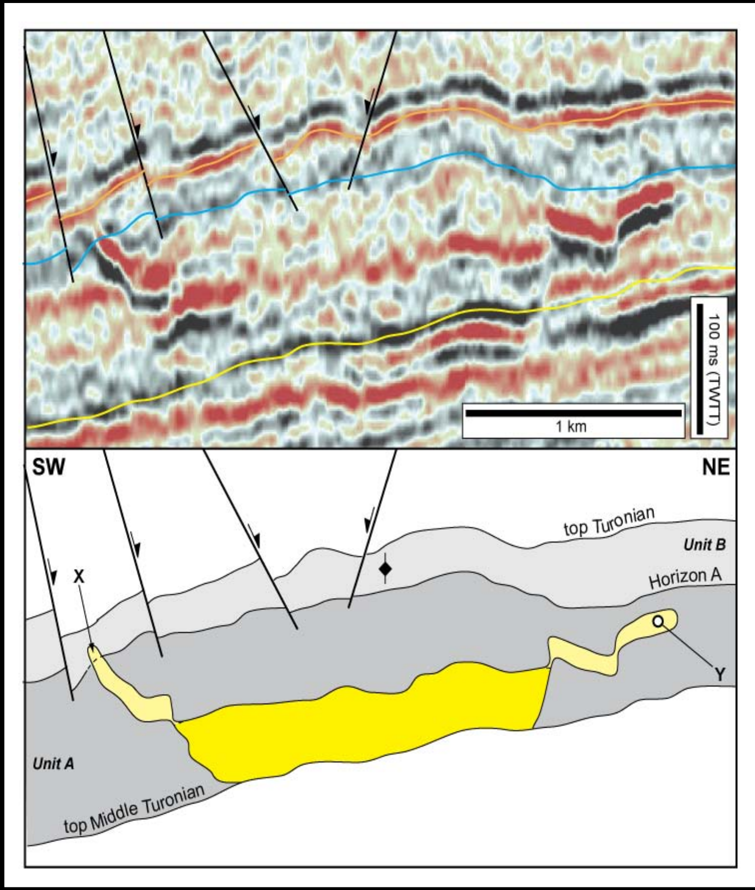


Other observations





- Low-relief anticline developed above and along the length of the slope channel
- Thinning of Unit B stratigraphy over slope channel
- Low-angle onlap locally observed at or just above Horizon A
- Interpreted to be related to differential compaction during early burial

Summary of key observations

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- Sand-rich **depositional** bodies are developed within the Kyrre Fm

- Relatively **low-angle** (<8) intrusion complexes are best-developed at the channel **margins**

- Intrusion are developed along the **entire length** of the associated channel

- Evidence for **differential compaction** during **early burial** of the channel

Conceptual model I

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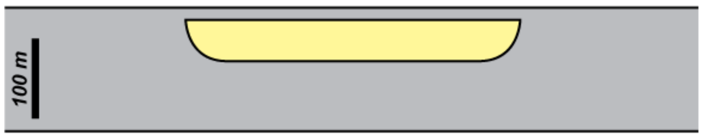
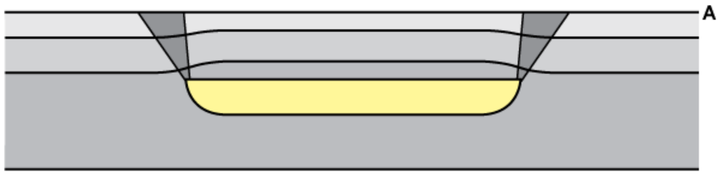
Stage 1 - deposition and early burial



Key processes

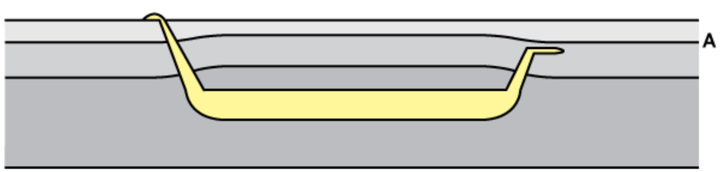
- deposition of sand-rich slope channel
- early burial and encasement in low-permeability mudstone

Stage 2 - ongoing burial



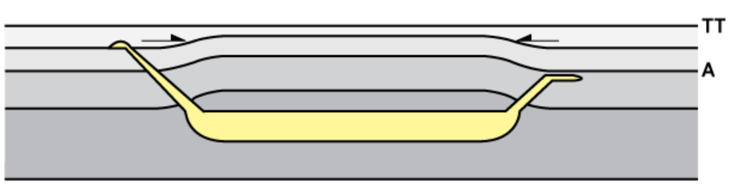
- ongoing burial
- initial stages of differential compaction of channel and related mudstones
- development of high stresses and related fractures at channel margins due to differential compaction

Stage 3 - remobilisation and injection



- ongoing burial, differential compaction and fracture development
- remobilisation, injection and development of clastic intrusions
- development of clastic extrusions?

Stage 4 - post-injection burial



- ongoing burial and differential compaction
- flattening and reduction in dip of clastic intrusions

- Overpressure ‘primer’?
- Relationship between intrusion depth, stress state and dip of intrusion complex?
- Exact mechanism of injection ‘triggering’?

Conceptual model II

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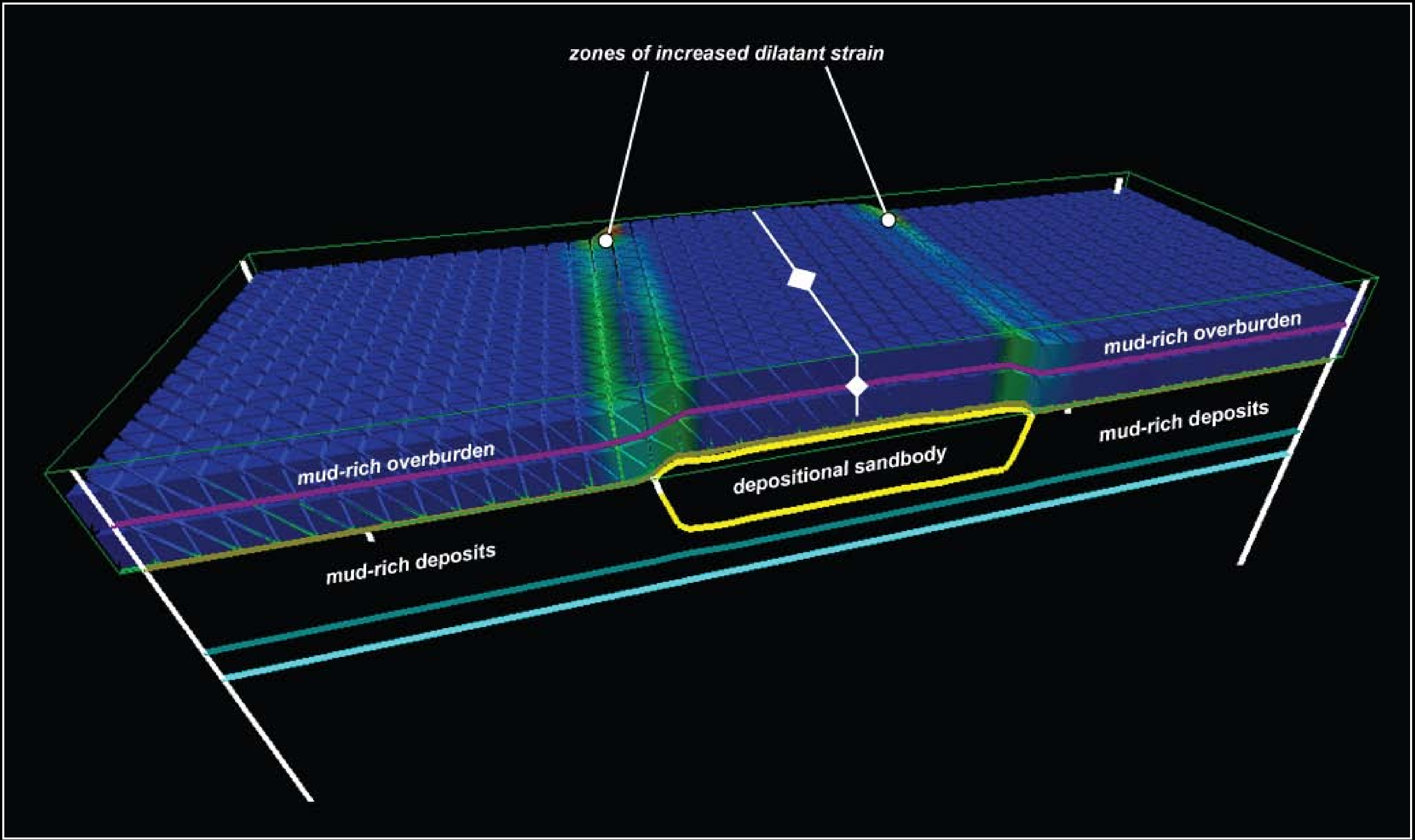

Conclusions and Implications I

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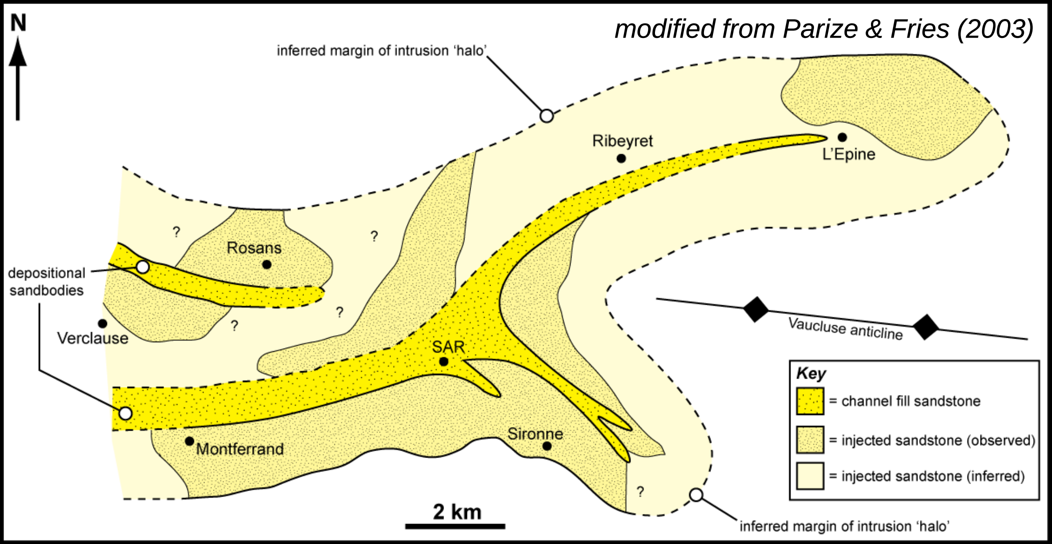
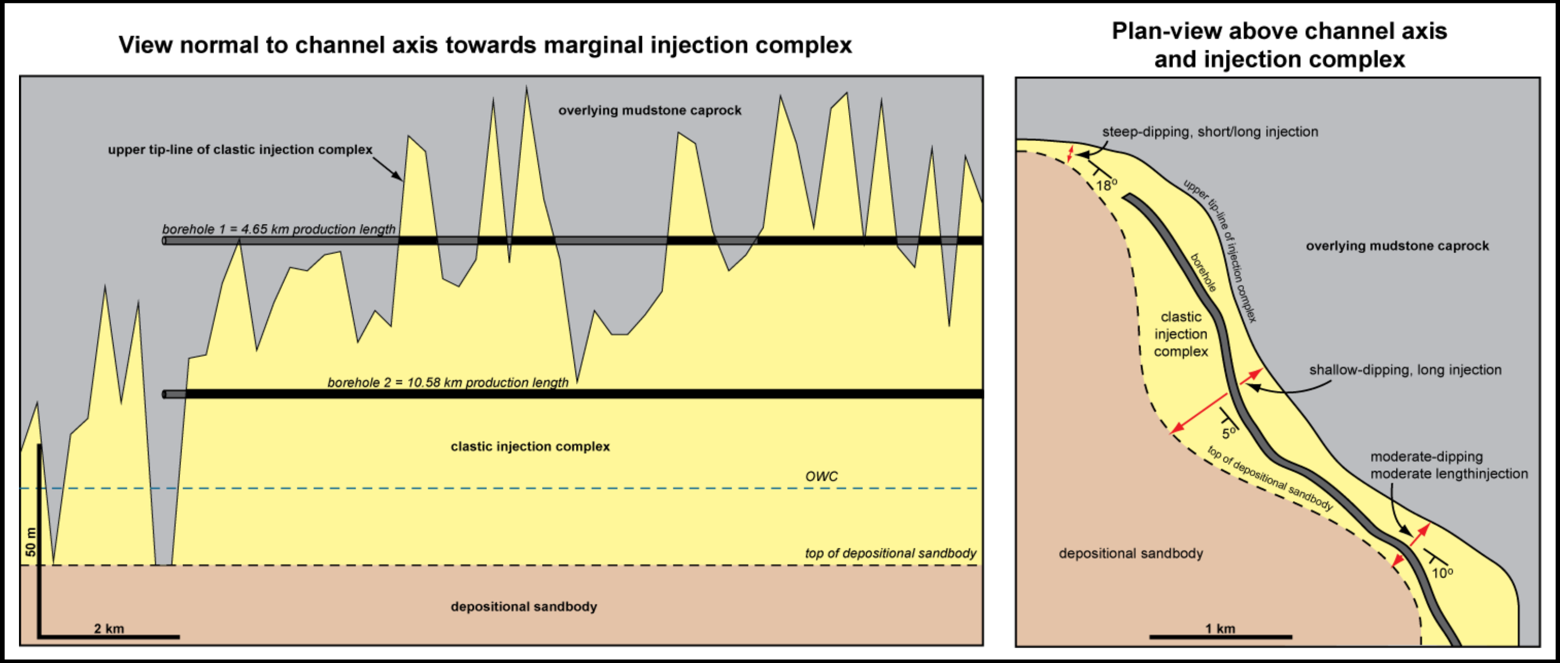
- Sandbodies on the Måløy Slope have been subjected to large-scale remobilisation and injection
- Intrusions are geometrically more variable than suggested by previous studies - some outcrop observations are supported by this analysis
- Injection is interpreted have formed during early burial (<150 m) in response to differential compaction-related stresses
- Pronounced variability in geometry is observed along individual intrusion complexes – minor variability between complexes
- Major implications for the exploration and production of hydrocarbons from intrusion complexes

Conclusions and Implications II





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