Lithology Distribution in the Zechstein Supergroup and Controls on Rift Structure: Greater South Viking Graben, Northern North Sea

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CGGVeritas

PGS

FORCE Salt Tectonics Seminar
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Salt Deposition

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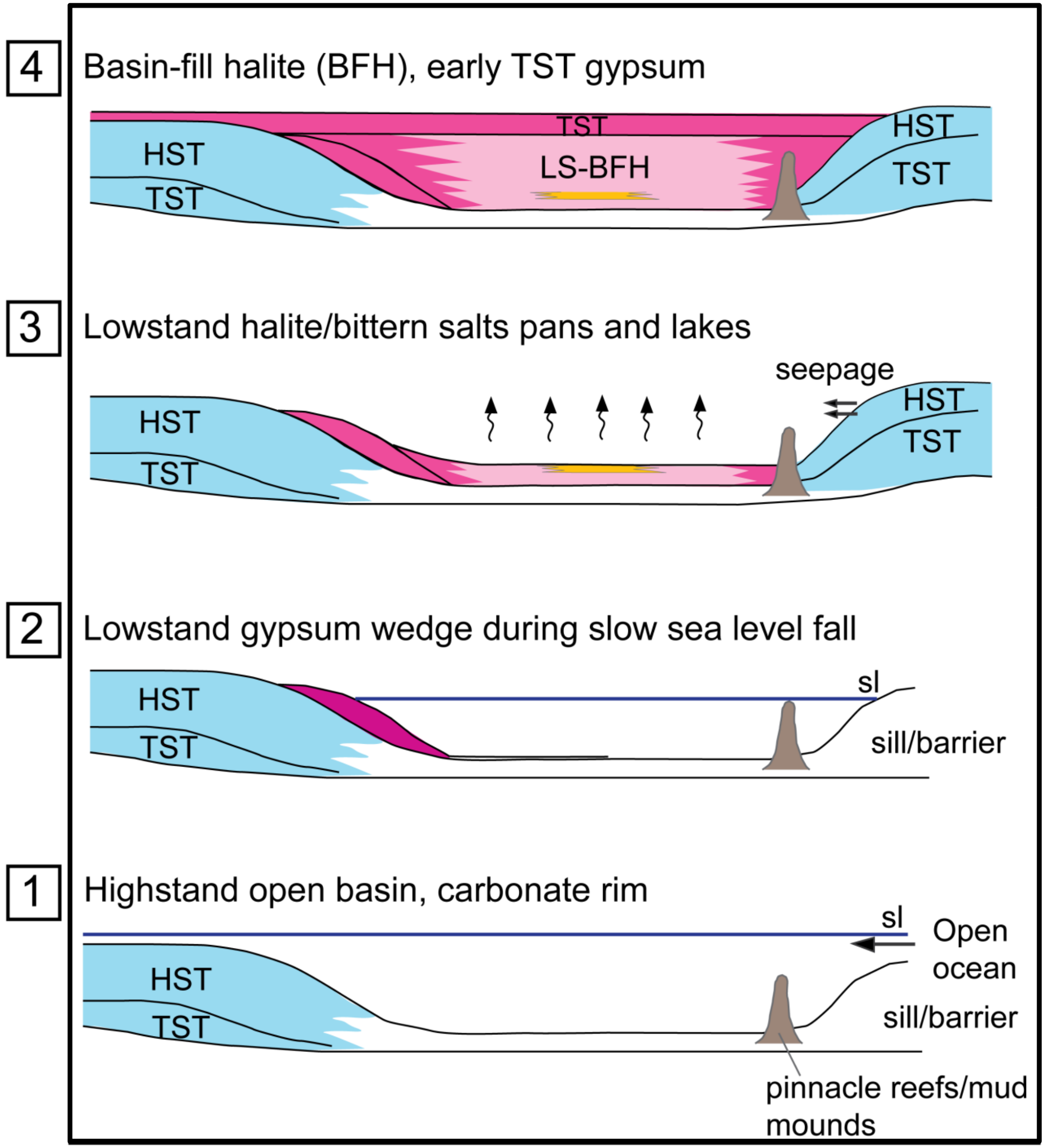
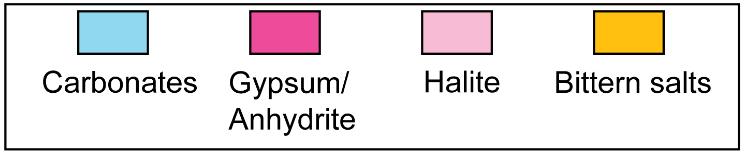
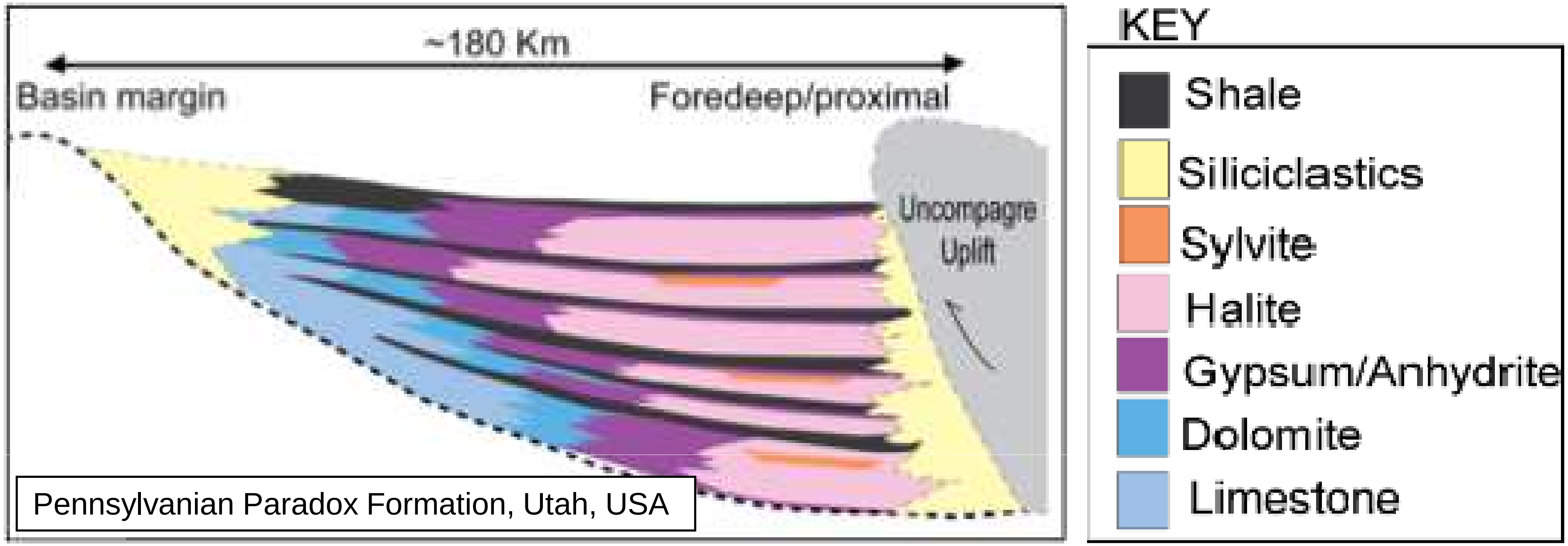


- Carbonate-evaporite basin subjected to complete drawdown

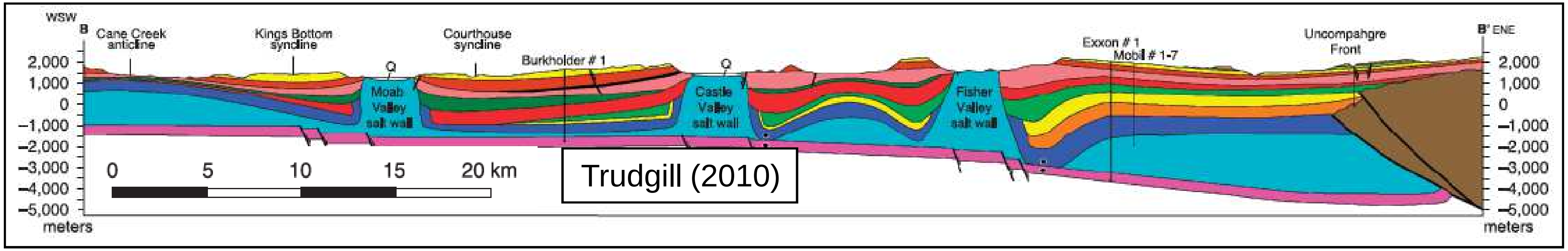
After Tucker (1991)



Analogues



modified from Peterson and Hite (1969), Hite and Buckner (1981) and Stroud (1994)



- Basin physiography can control lithology distribution in salt basins
- Post-depositional salt flow may modify primary lithology distribution
- Does present (post-flow) lithology distribution reflect primary distribution?

Rationale and Previous Work

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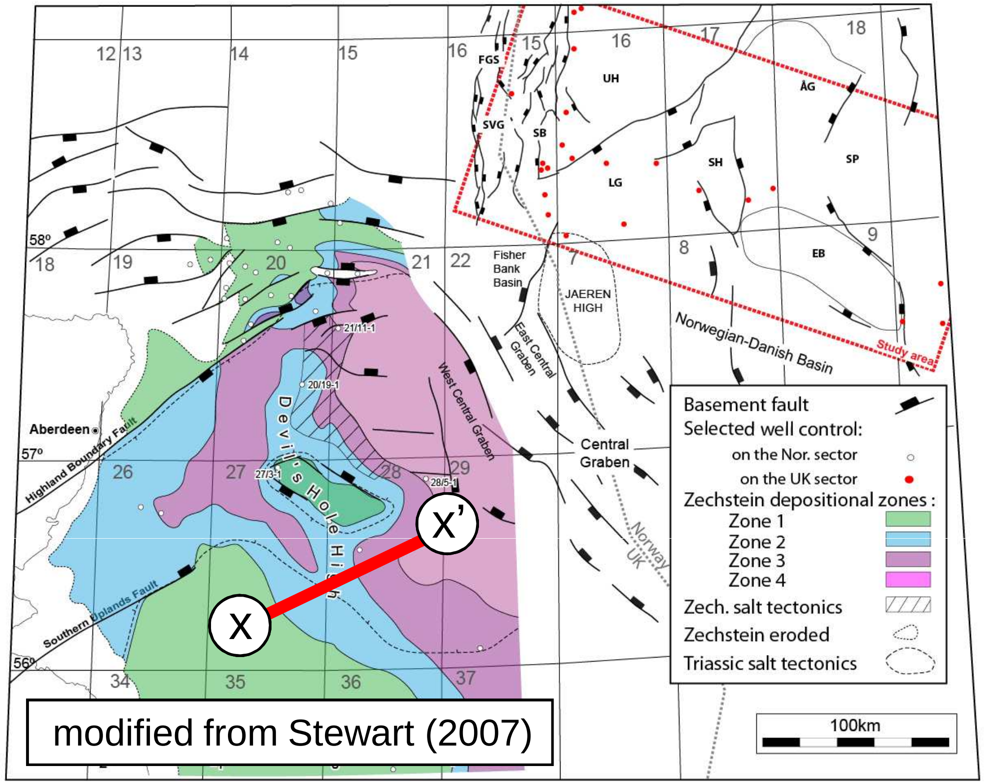
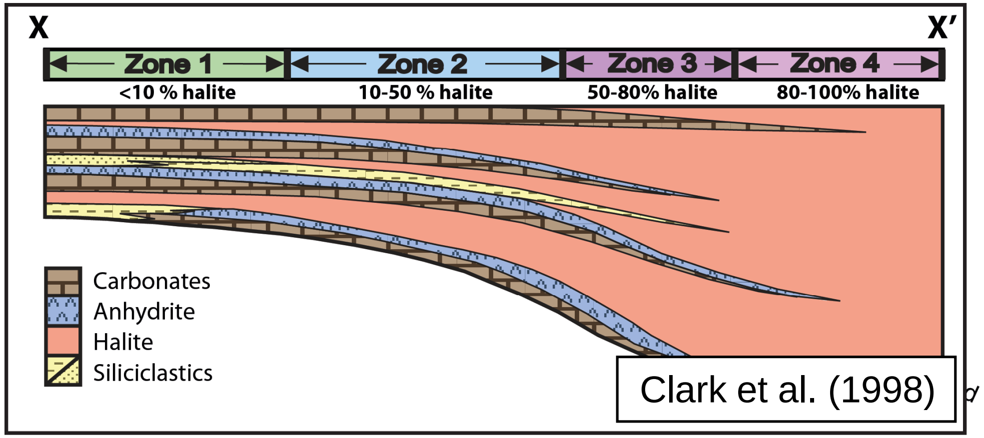


modified from Stewart (2007)



Clark et al. (1998)

- Lithology distribution in Zechstein Supergroup (ZSG) 'well known' in UK North Sea; mapping based on on variations in structural style with sparse (published) well calibration…
- Four depositional zones; carbonate-rich at basin margin (Z1-2) and halite-rich in centre (Z3-4)
- Lithology distribution in Norwegian North Sea poorly understood
- Well and seismic data from the Norwegian North Sea are used to investigate lithology variations in the ZSG and how these variations affect the evolution of rift systems
- Lithology variations may impact reservoir/seal potential, heat flow, etc

Study Area

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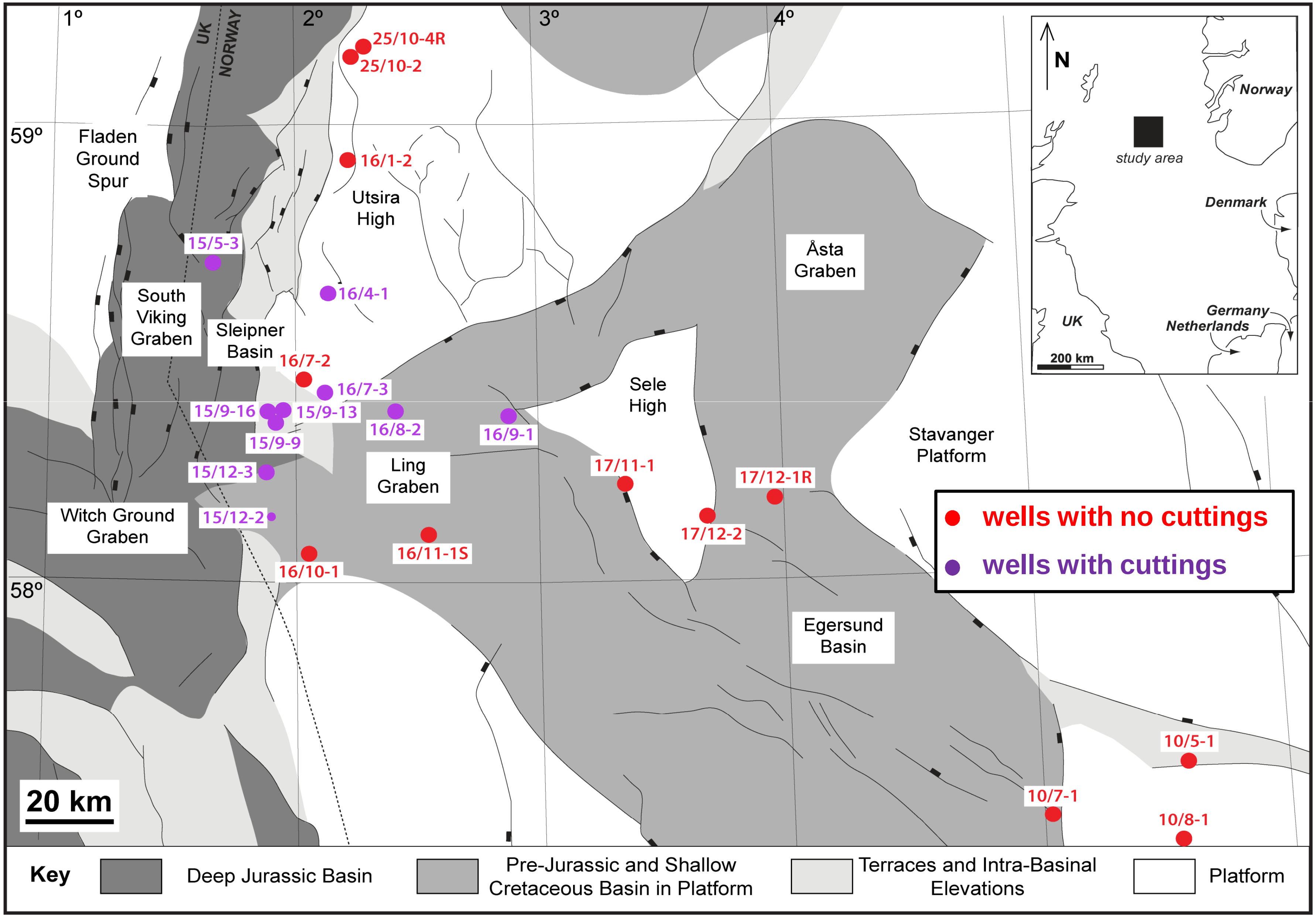

Salt Thickness and Structure

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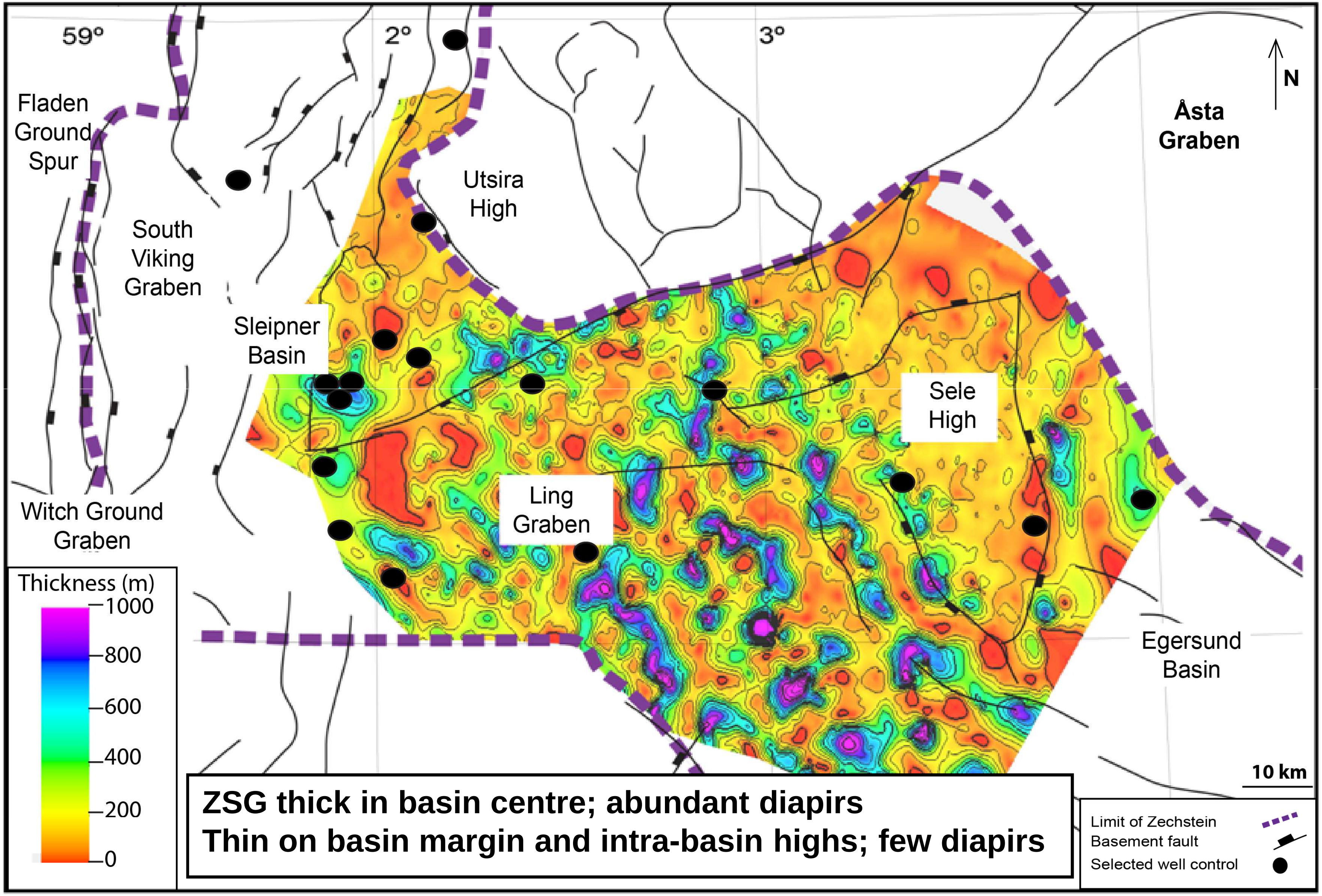

ZSG thick in basin centre; abundant diapirs
Thin on basin margin and intra-basin highs; few diapirs

Lithology Identification

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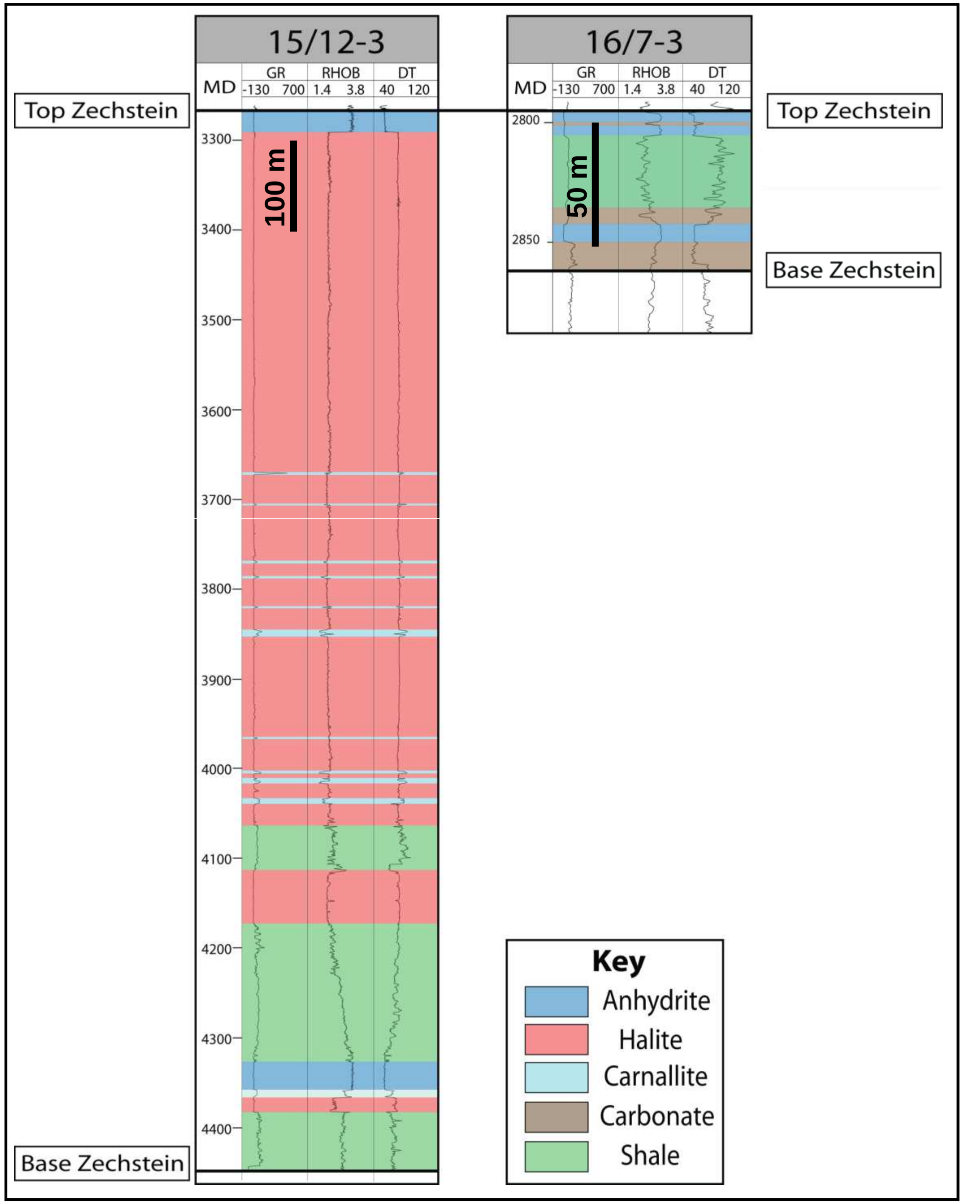
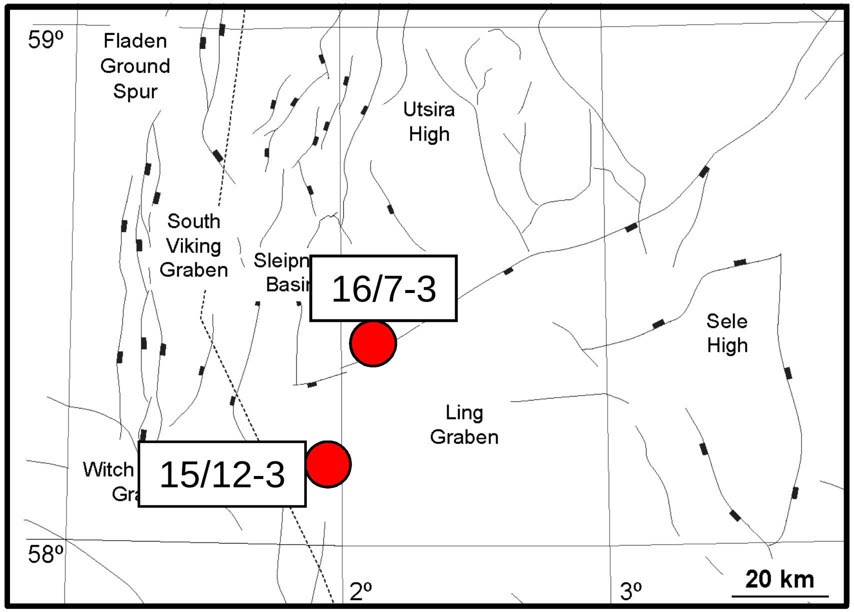
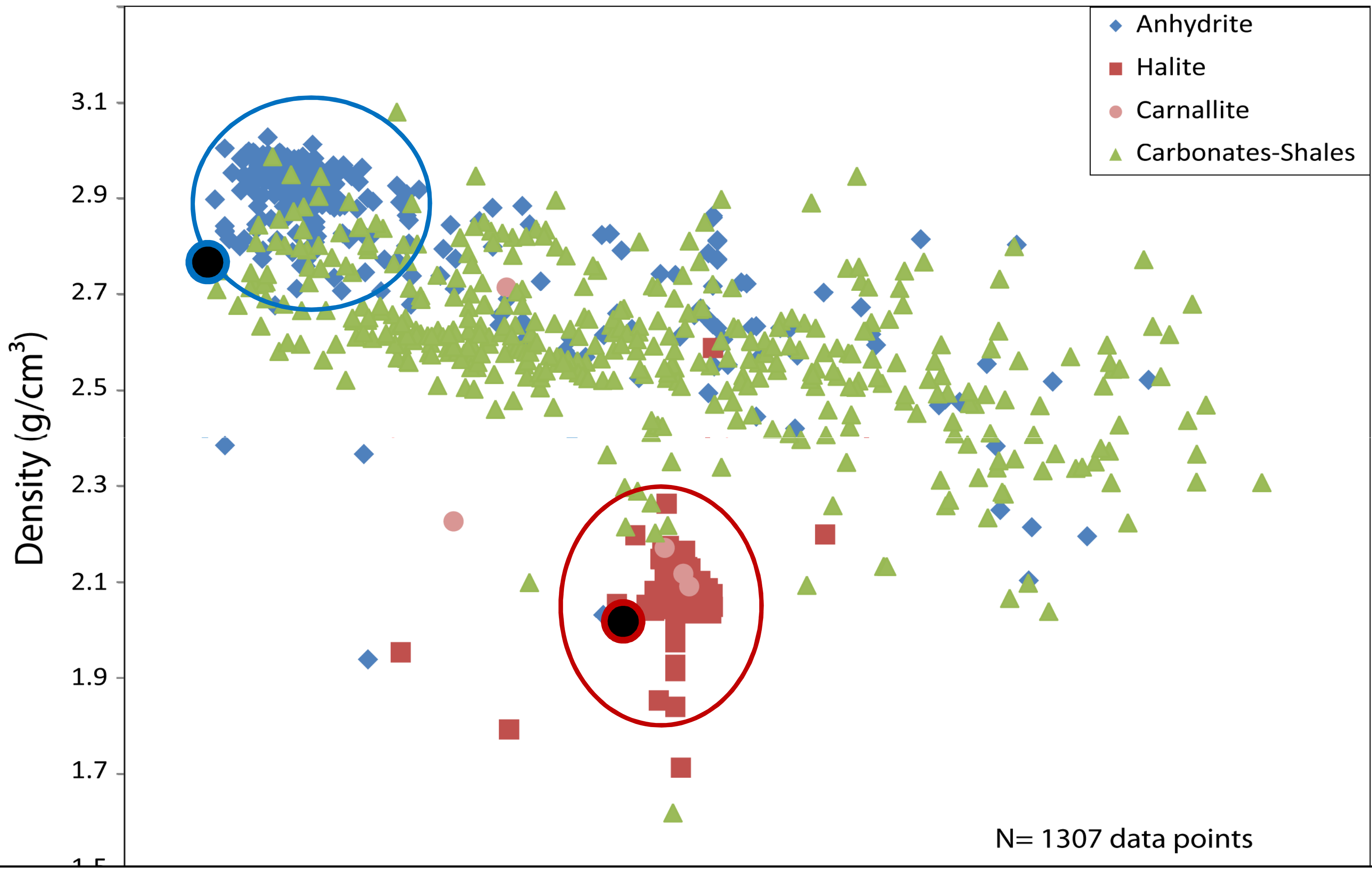


- Five lithologies identified based on cuttings from 10 wells: (i) halite; (ii) anhydrite; (iii) carbonate; (iv) carnallite; and (v) shale

- Cuttings-calibrated petrophysical data cross-plotted to determine lithology identification in wells lacking cuttings



Lithology Identification



- **Anhydrite-Halite**: relatively dense clustering; easy to discriminate between on logs
- **Carbonate-Shale**: relatively weak clustering; difficult to discriminate between on logs
- Anhydrite denser and slightly 'slower' than carbonate and shale

Lithology Identification

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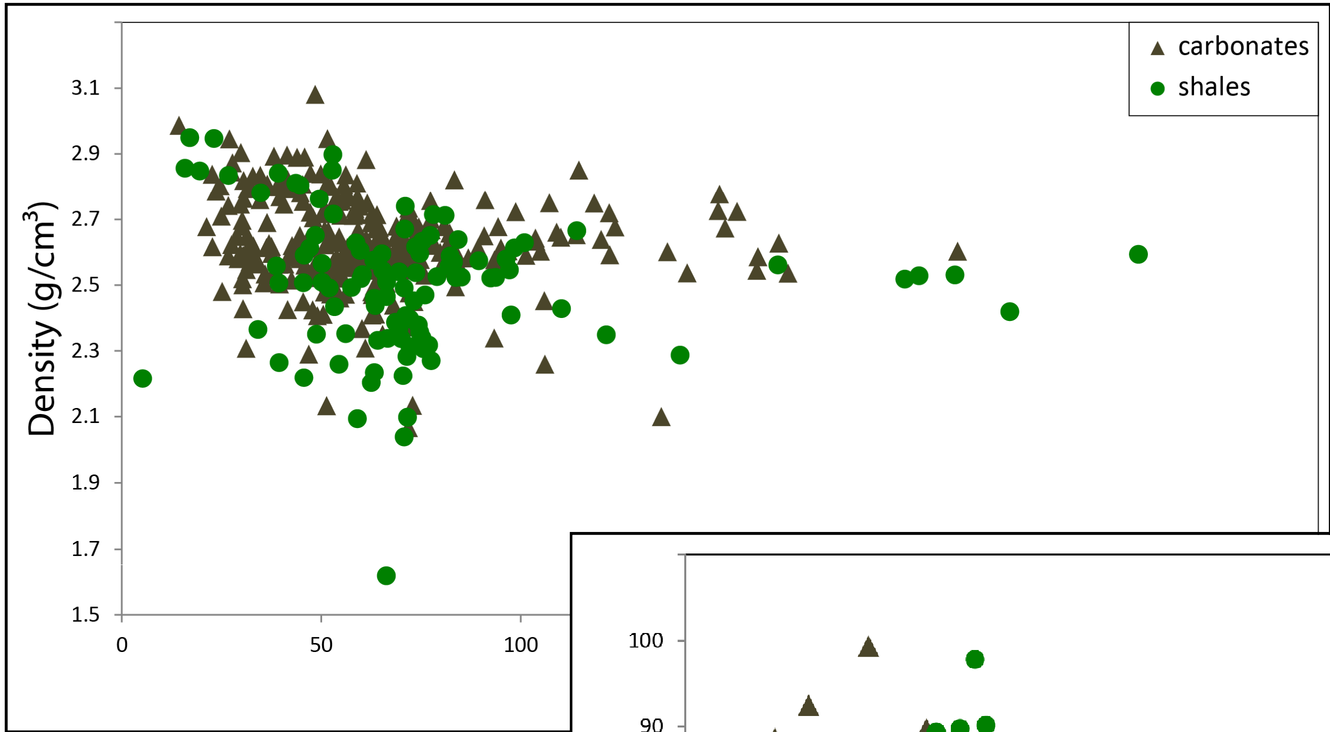

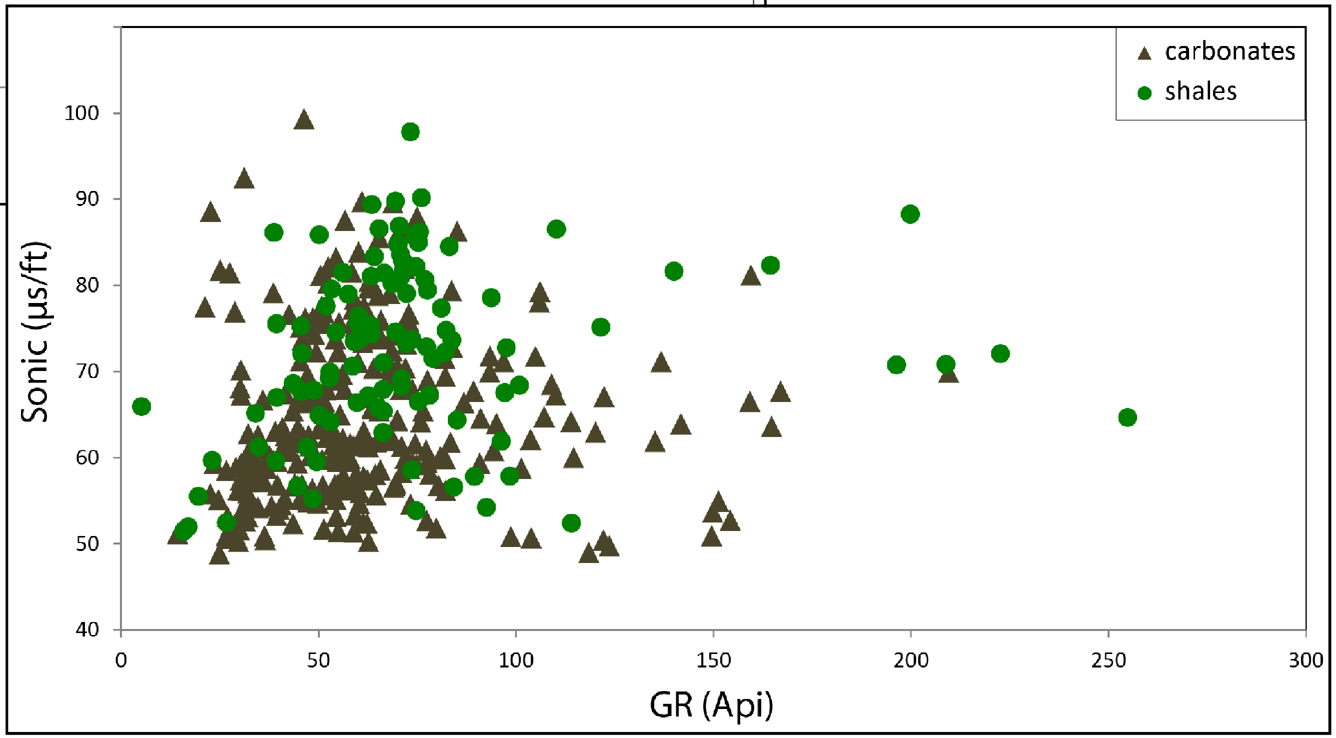

Carbonate cannot be differentiate from shale based on petrophysical characteristics alone

Lithology Distribution - UH

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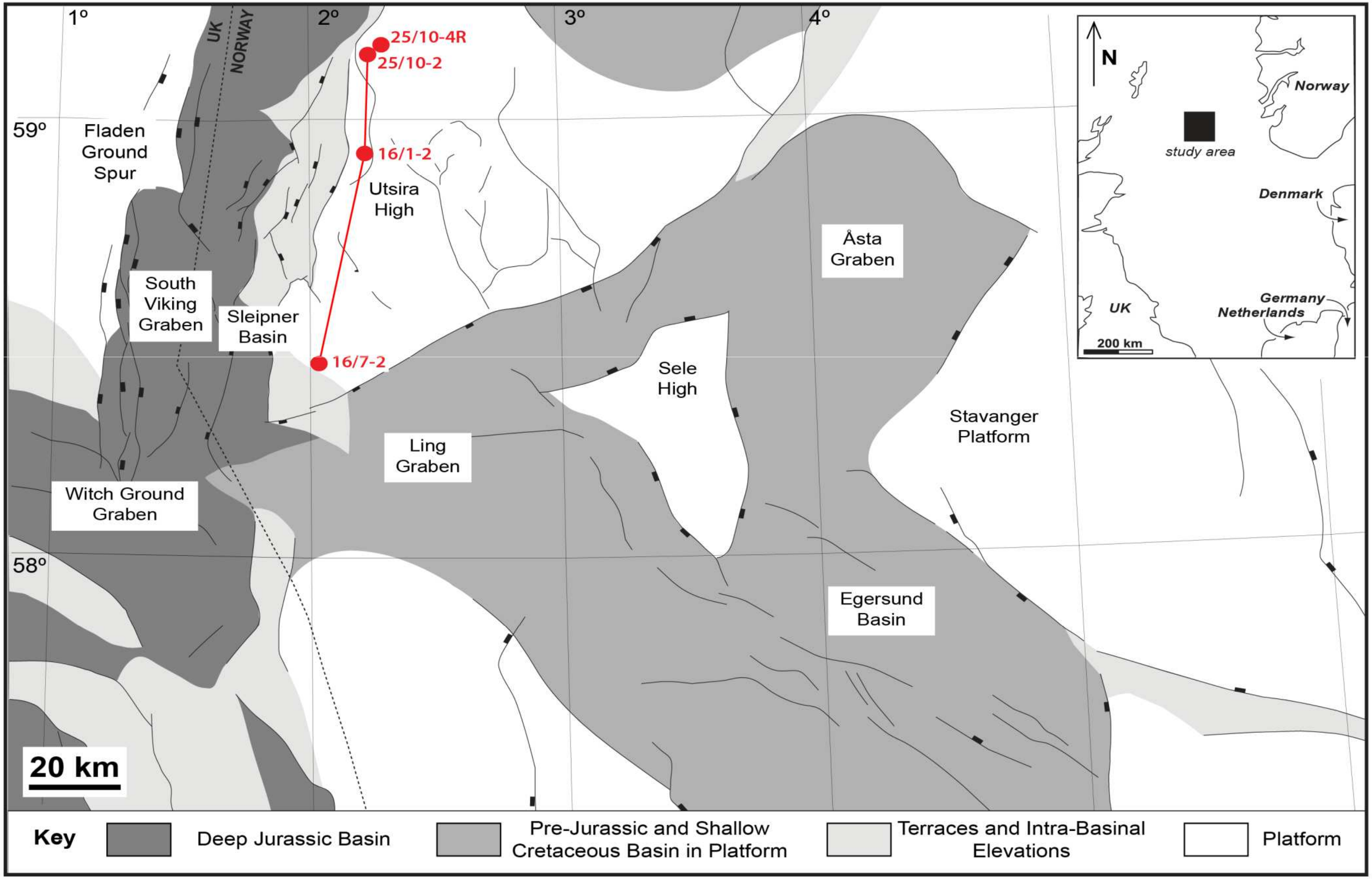
Basin margin



Lithology Distribution - UH

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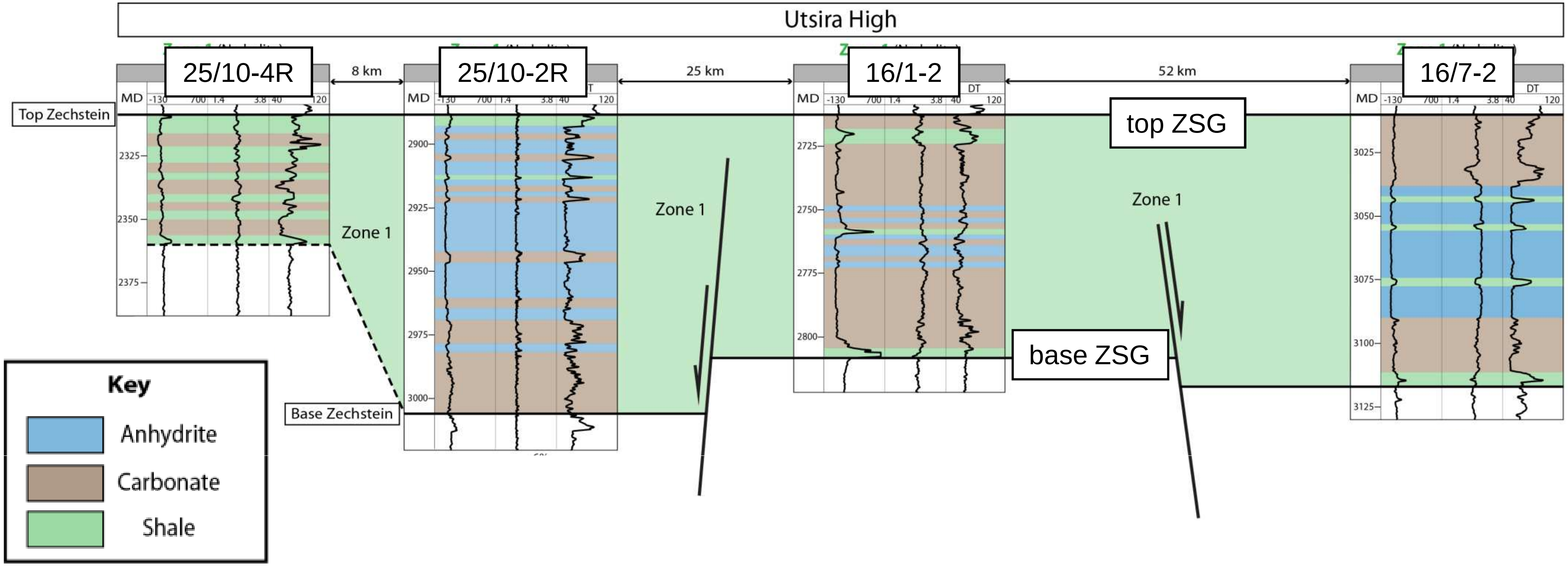

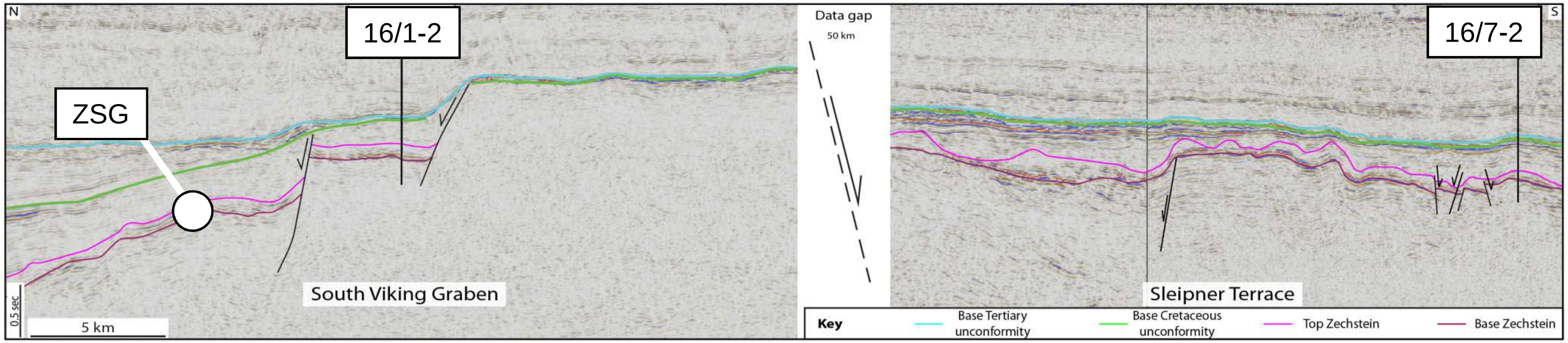

- Relatively thin ZSG (up to 120 m)
- Anhydrite, carbonates and shales; no halite

Lithology Distribution – ST-LG

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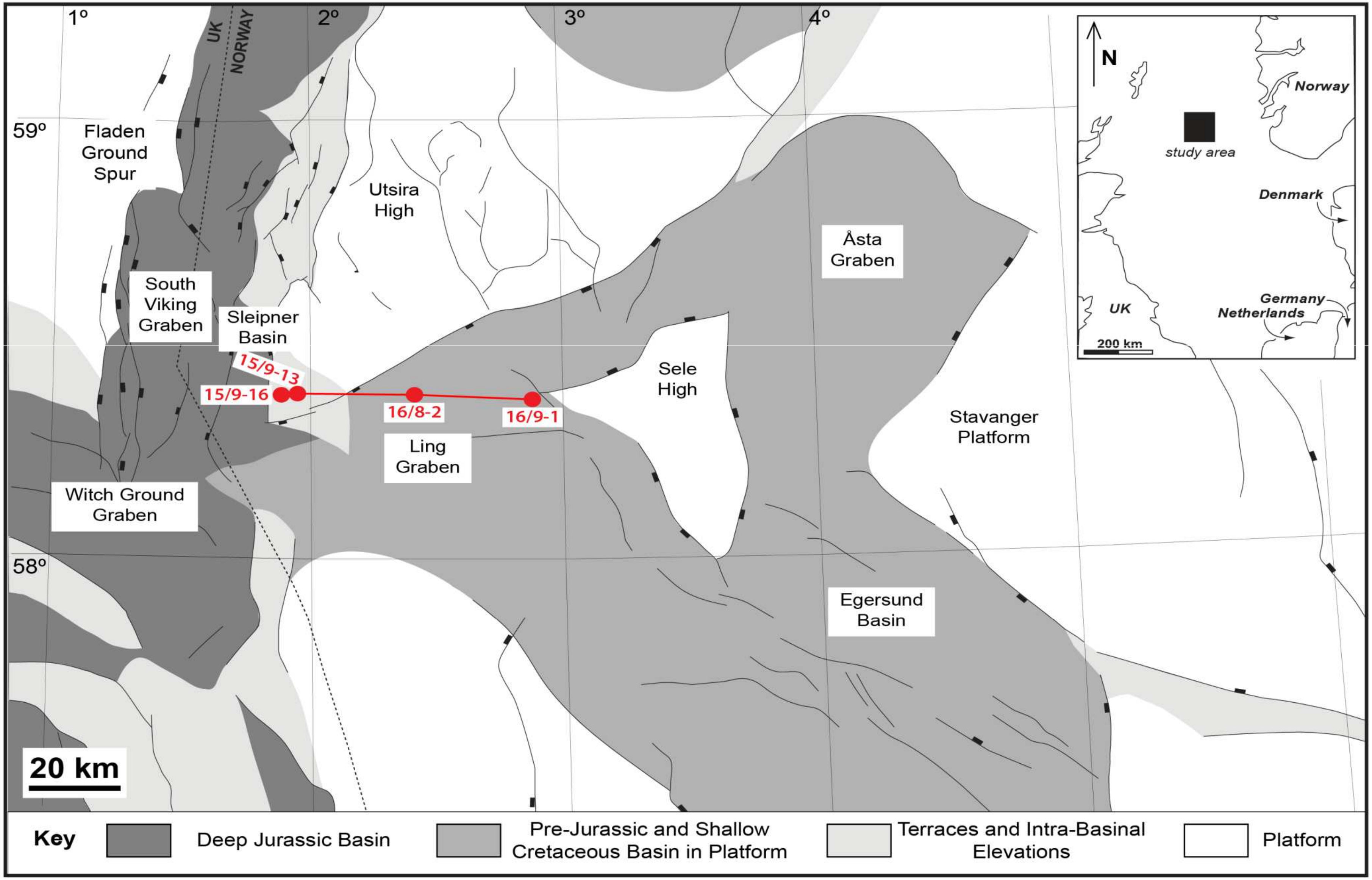
Basin margin-to-basin centre



Lithology Distribution – ST-LG

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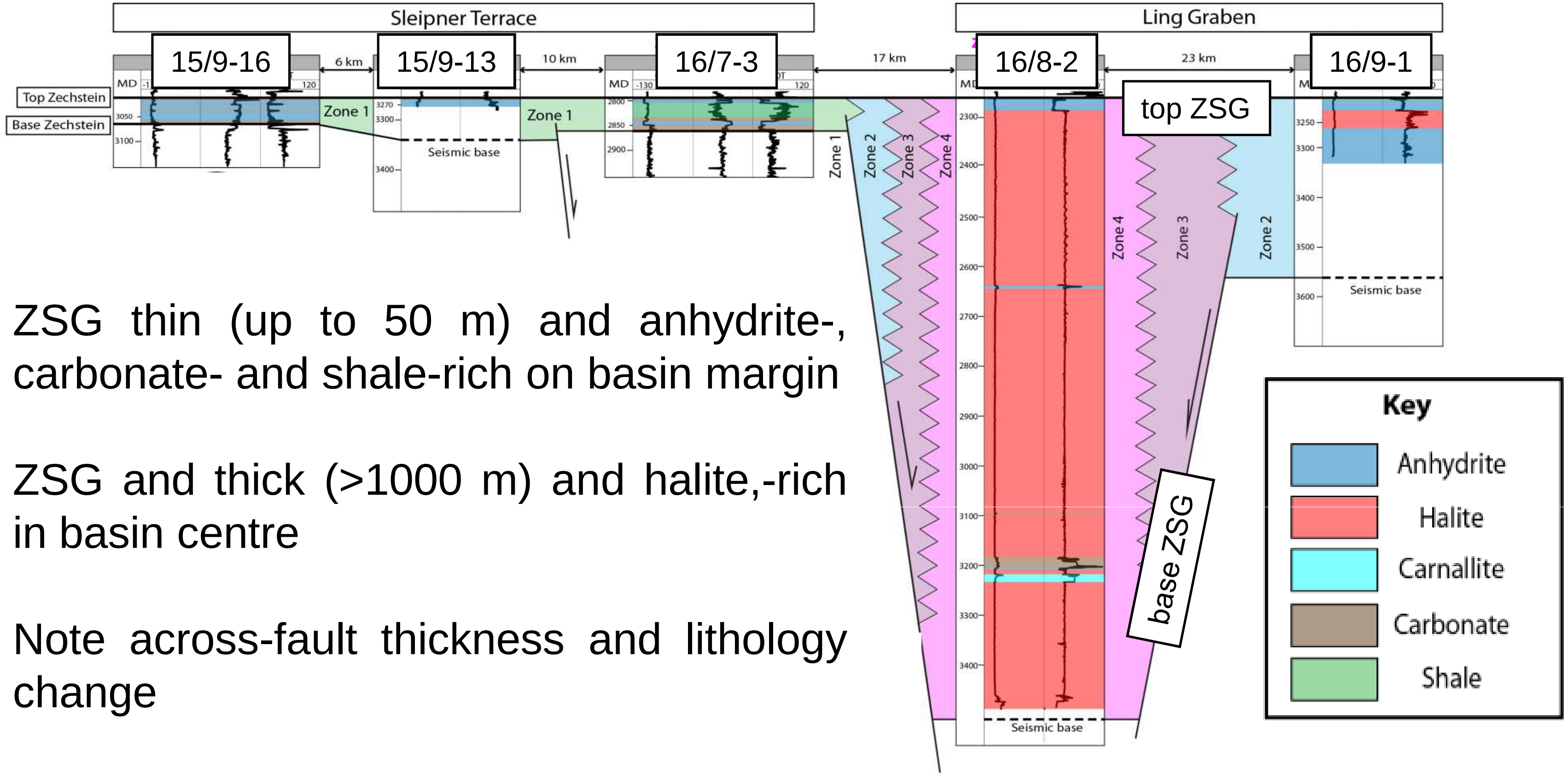
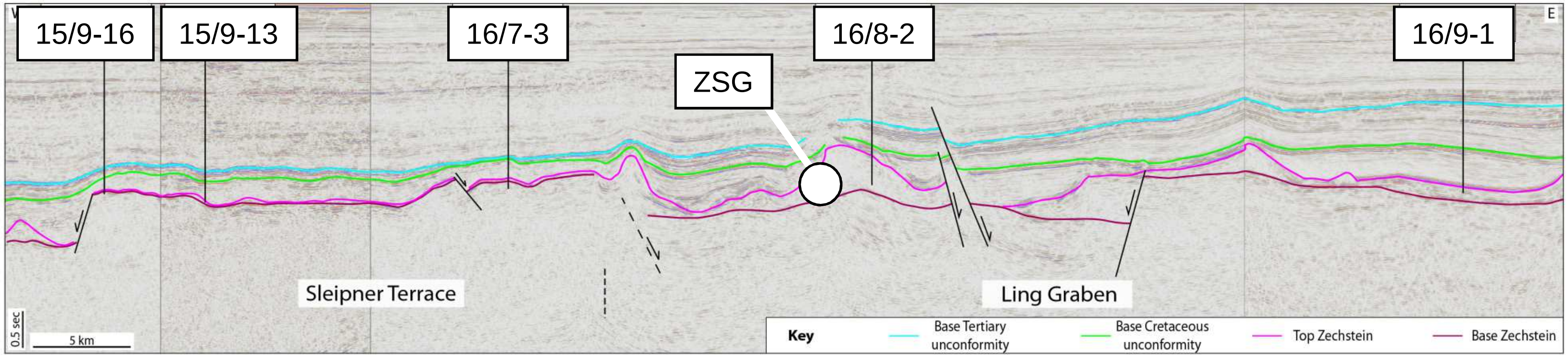


- ZSG thin (up to 50 m) and anhydrite-, carbonate- and shale-rich on basin margin
- ZSG and thick (>1000 m) and halite,-rich in basin centre
- Note across-fault thickness and lithology change



Lithology Distribution – LG-SH

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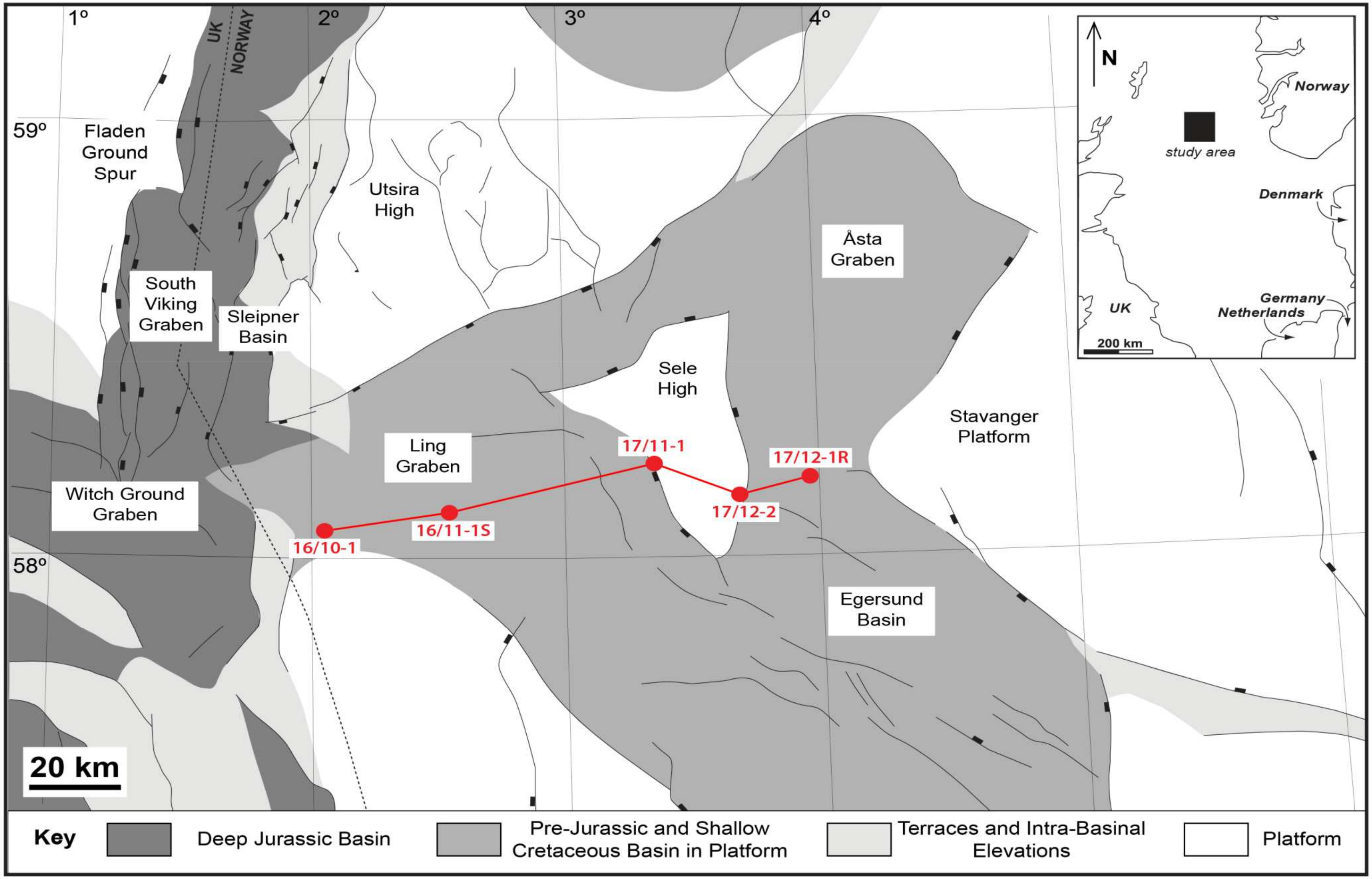
Basin centre-to-basin margin-to-basin centre



Lithology Distribution – LG-SH

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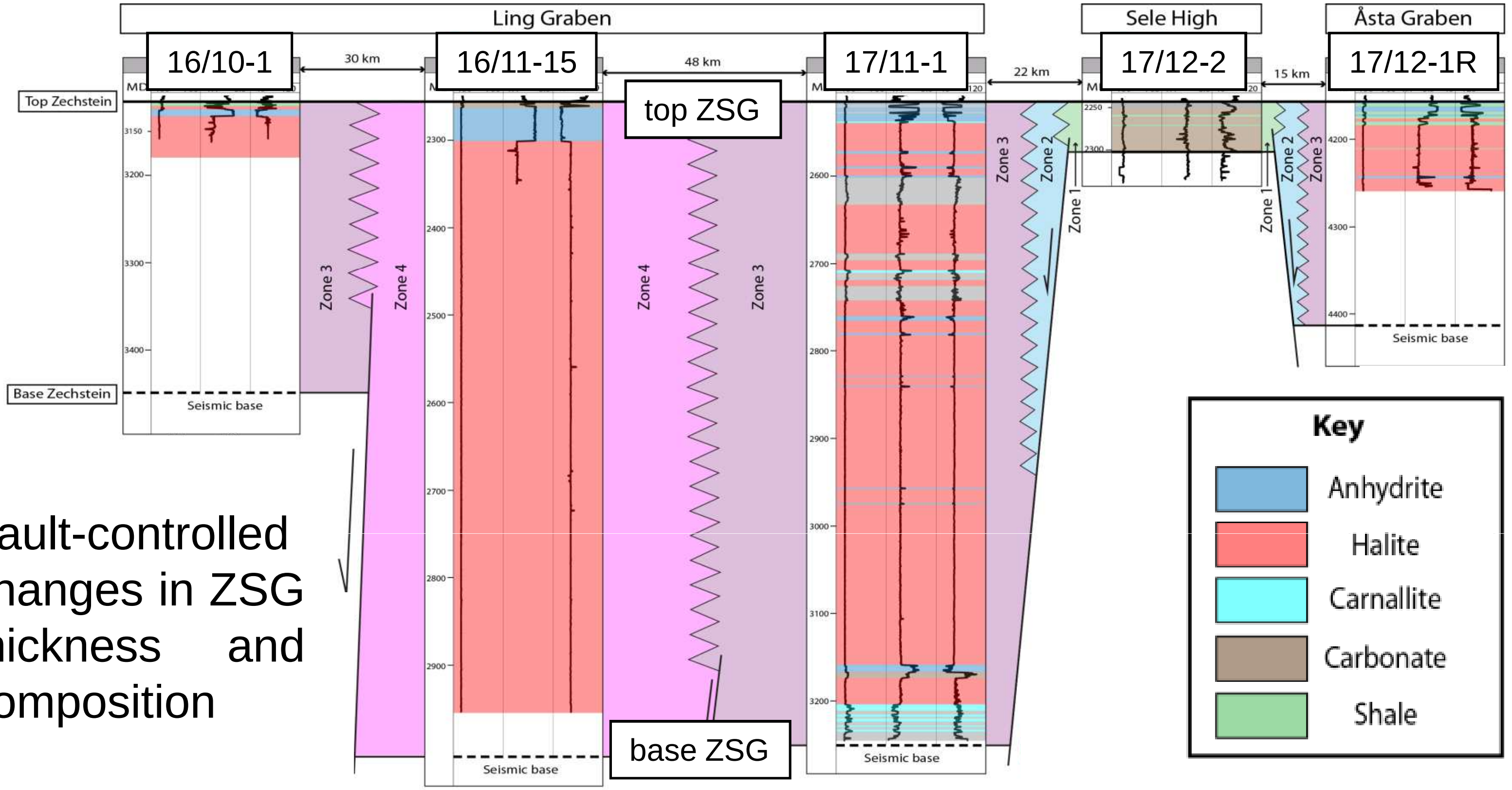
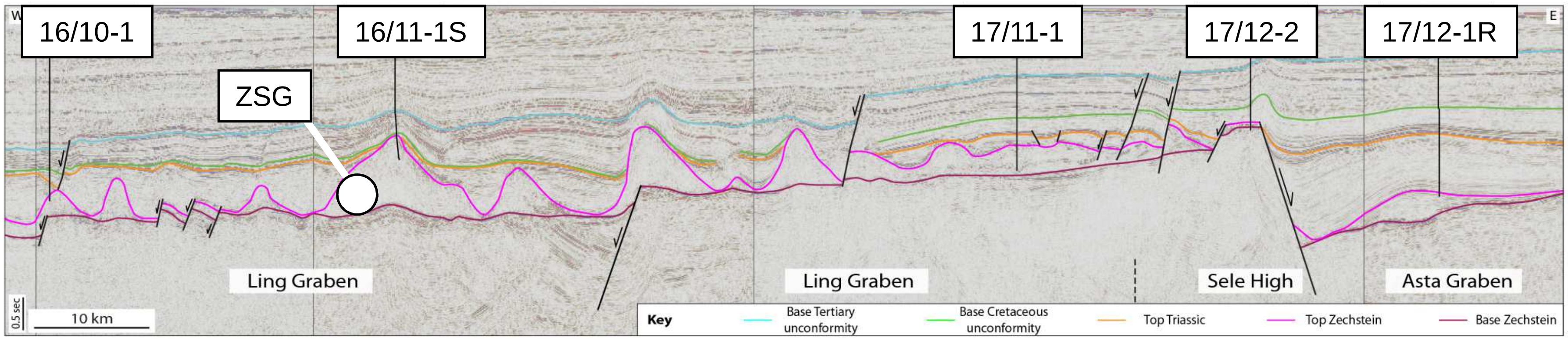


- Fault-controlled changes in ZSG thickness and composition



ZSG Lithology Distribution

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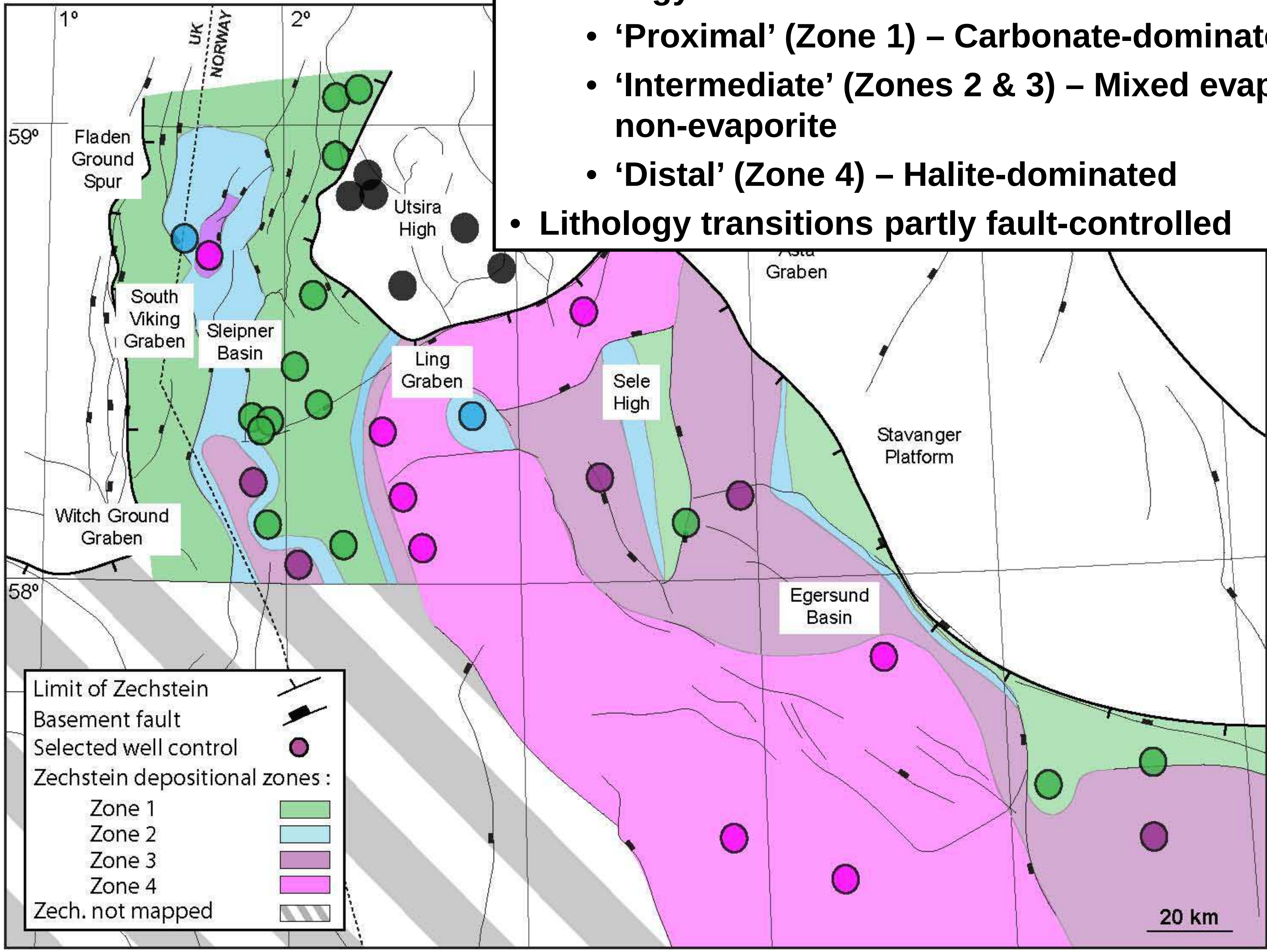
- **Lithology zones observed:**
  - **'Proximal' (Zone 1) – Carbonate-dominated**
  - **'Intermediate' (Zones 2 & 3) – Mixed evaporite-non-evaporite**
  - **'Distal' (Zone 4) – Halite-dominated**
- **Lithology transitions partly fault-controlled**



Basin-Scale Context

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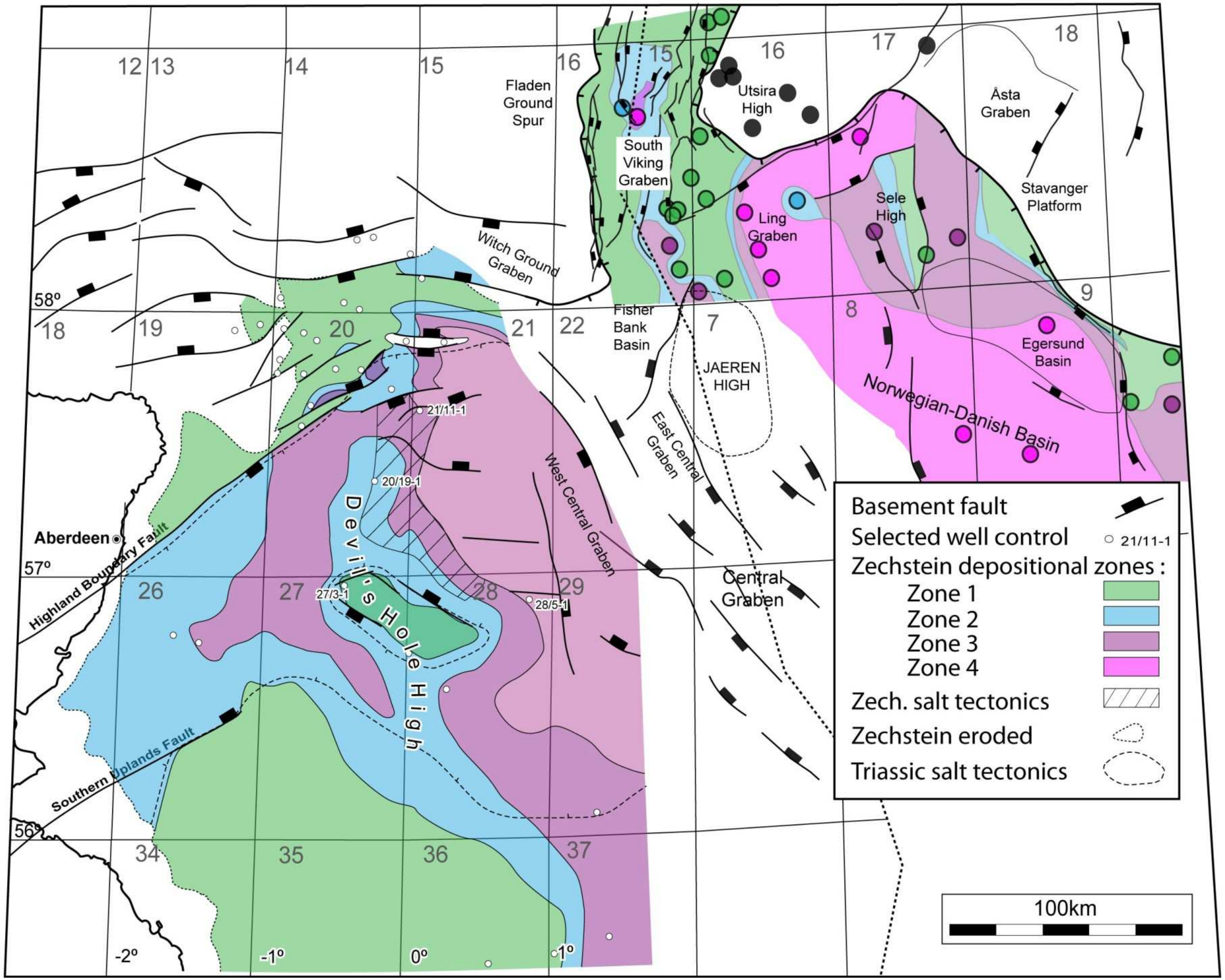

Controls on Lithology Distribution

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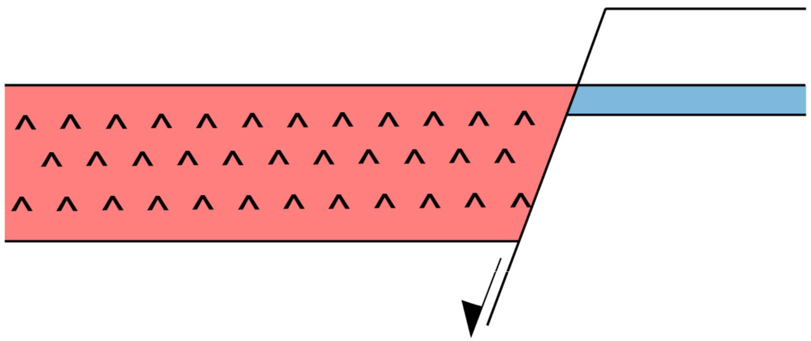
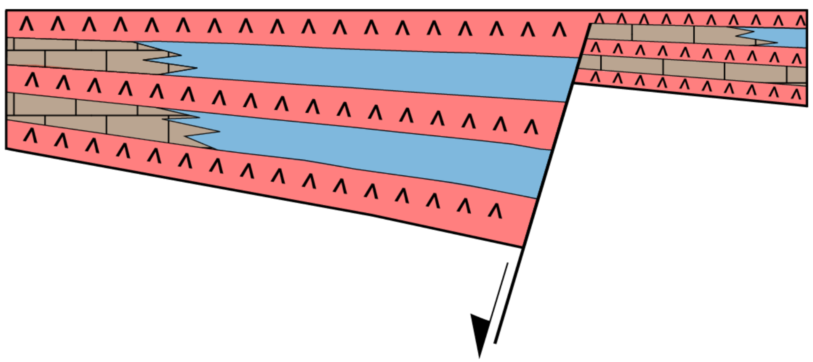
What controls lithology distribution in the ZSG in the Norwegian sector of the North Sea?

Model 2:Pre-ZSG fault movement



Model 3:Syn-ZSG fault movement



Model 1: no Early Permian rifting; ZSG deposited **before** Late Jurassic rifting; erosion and carbonate-dominated caprock develops on structural highs due to post-depositional footwall uplift

Model 2: ZSG deposited across underfilled Early Permian rift-related relief; LST halite deposition in basins and HST carbonate/anhydrite deposition on margins

Model 3: deposition of ZSG **during** Late Permian rifting; lithology variability was controlled in the same way as for Model 2.

Late Permian Relief?

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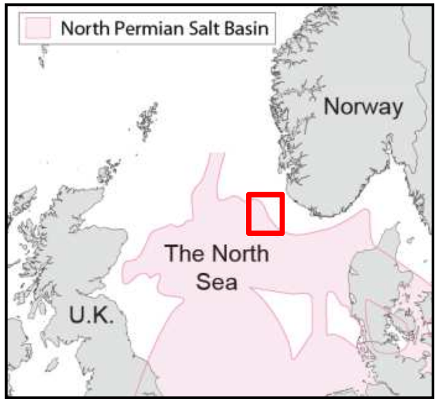
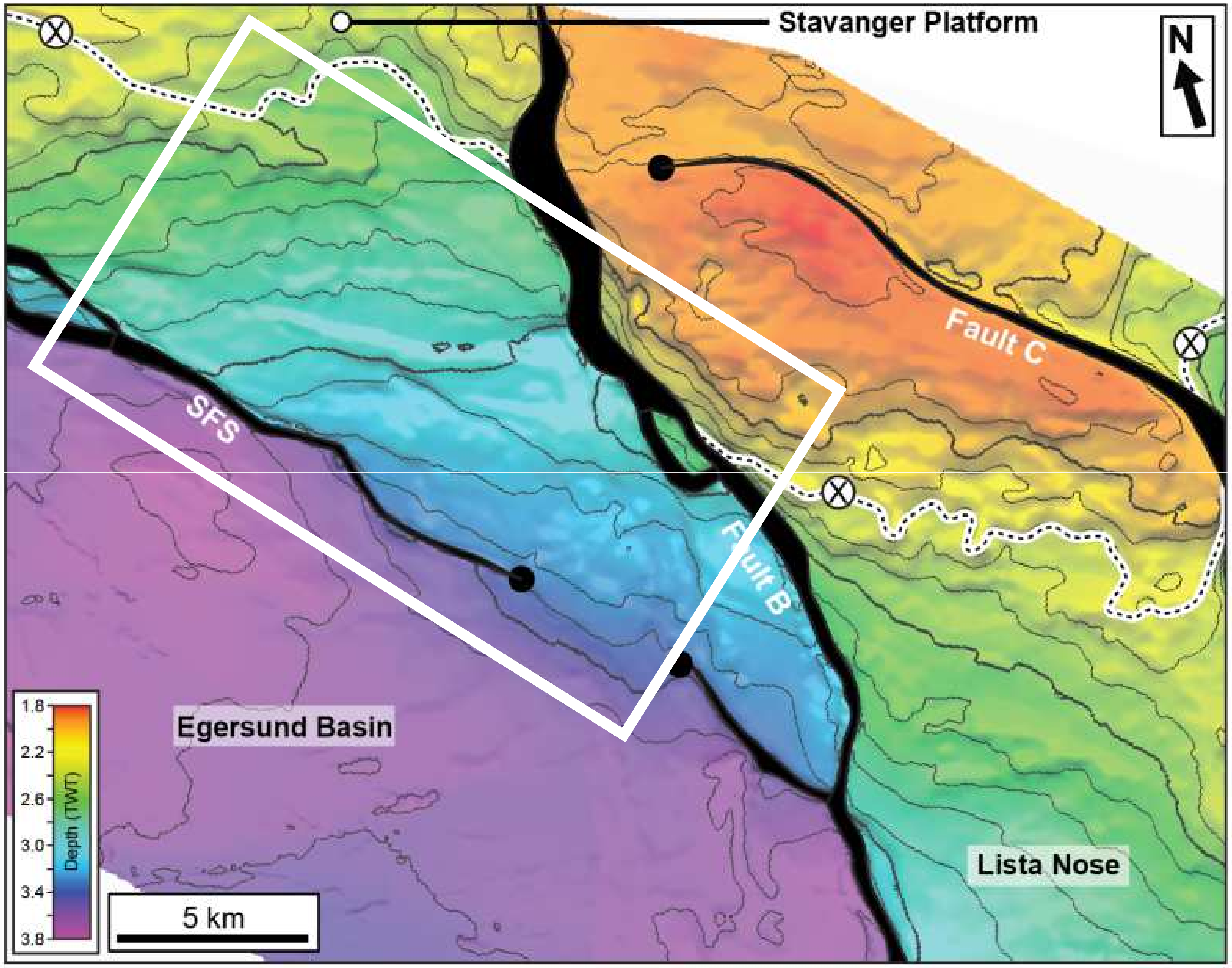


- northern Egersund Basin
- NE margin of the pan-European ZSG salt basin
- Salt pinch-out onto present-day structural high
- Is relief rift-related? If so, to which event?



Jackson & Lewis (2013)

Late Permian Relief?

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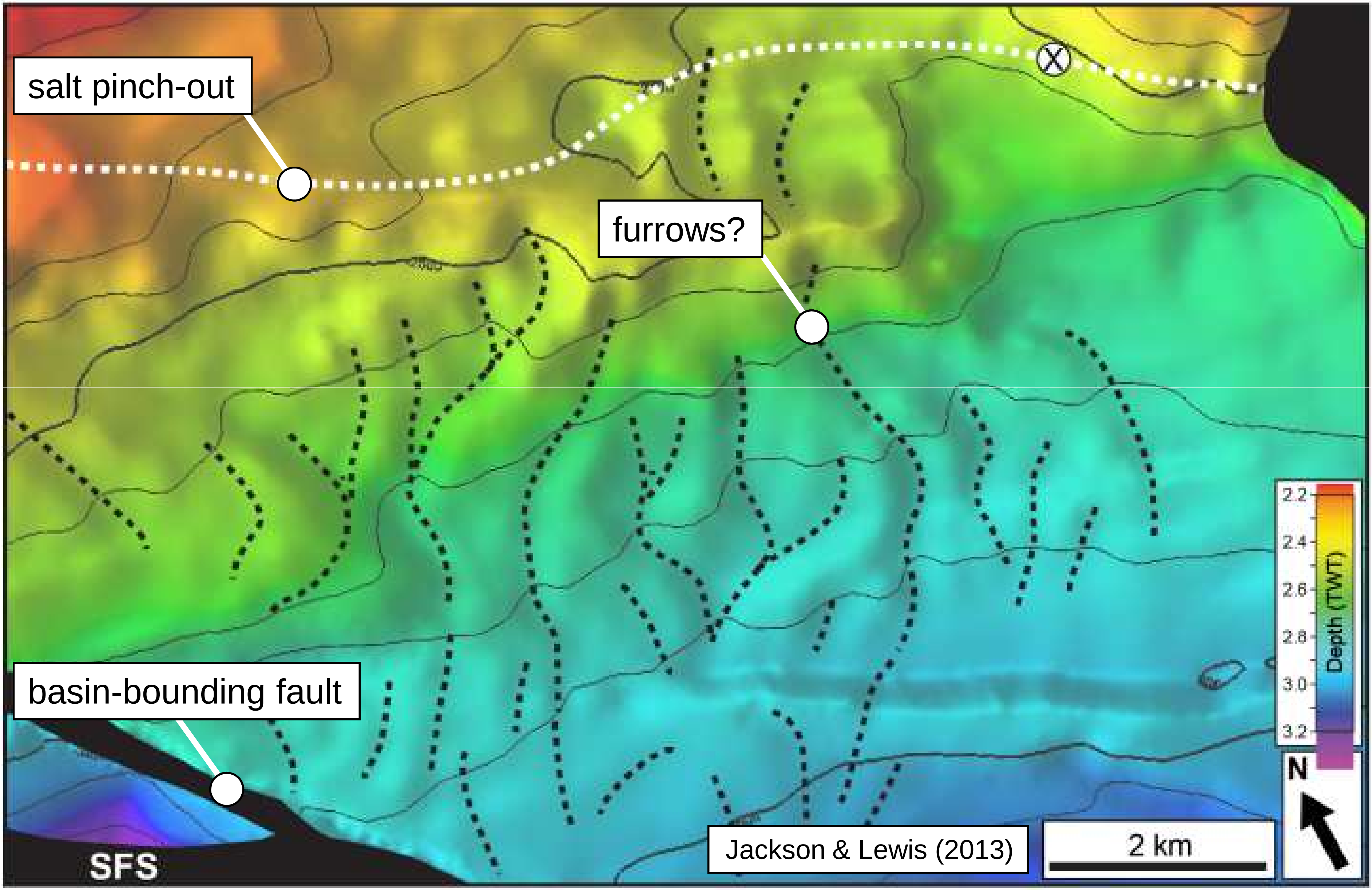
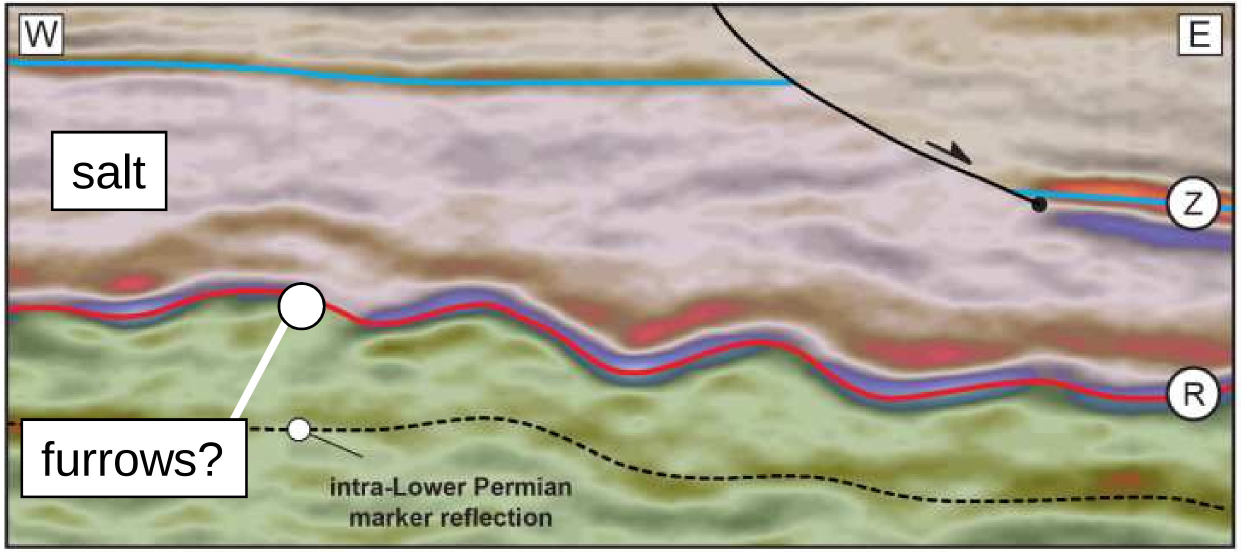
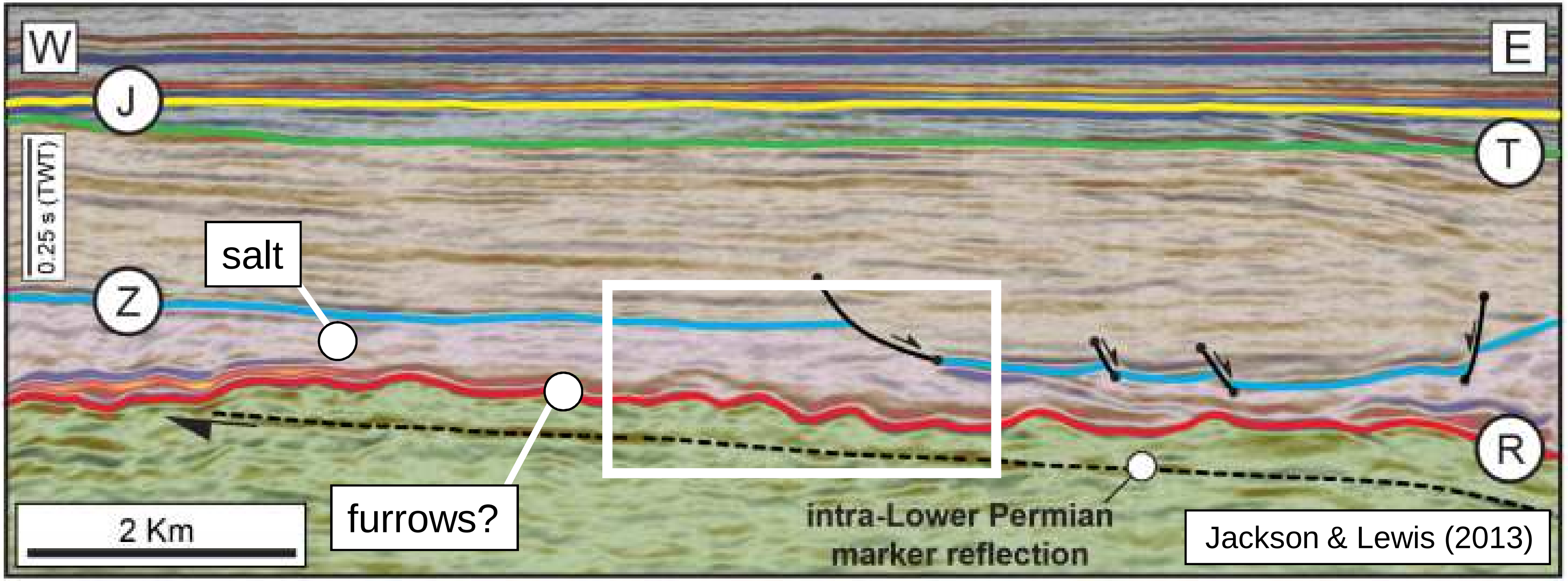


Late Permian Relief?



- Low-relief (few tens of metres) erosion surface developed along base salt)(top Rotliegend/Lower Permian)
- Erosional ‘furrows’ up to a few kilometres long and wide
- Only developed in footwall



Pre-ZSG Rifting?

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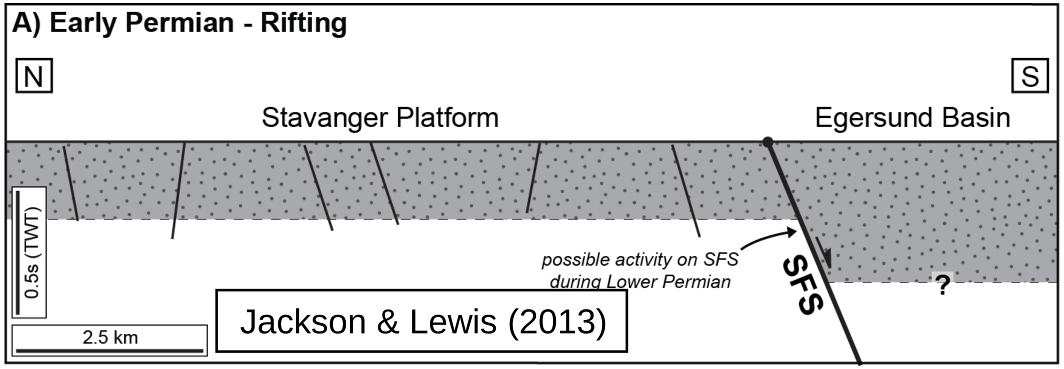
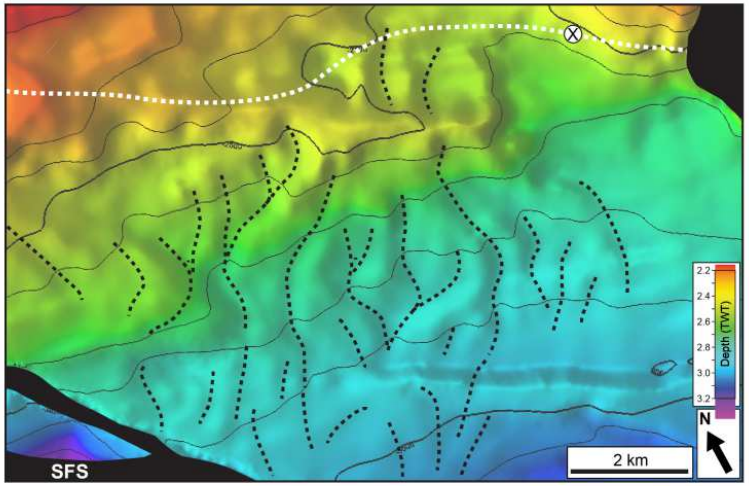


- **Stage 1 (Early Permian)** – SFS active?
- **Stage 2 (Mid-Permian to earliest Late Permian)** – SFS active; fault scarp relief developed and eroded; by fluvial systems; onset of ZSG onlap on fault scarp
- **Stage 3 (Late Permian)** – Onlap of ZSG onto and preservation of fault scarp relief
- **Evidence for pre-ZSG (Early Permian) rifting?**



Influence of ZSG on Rift Structure

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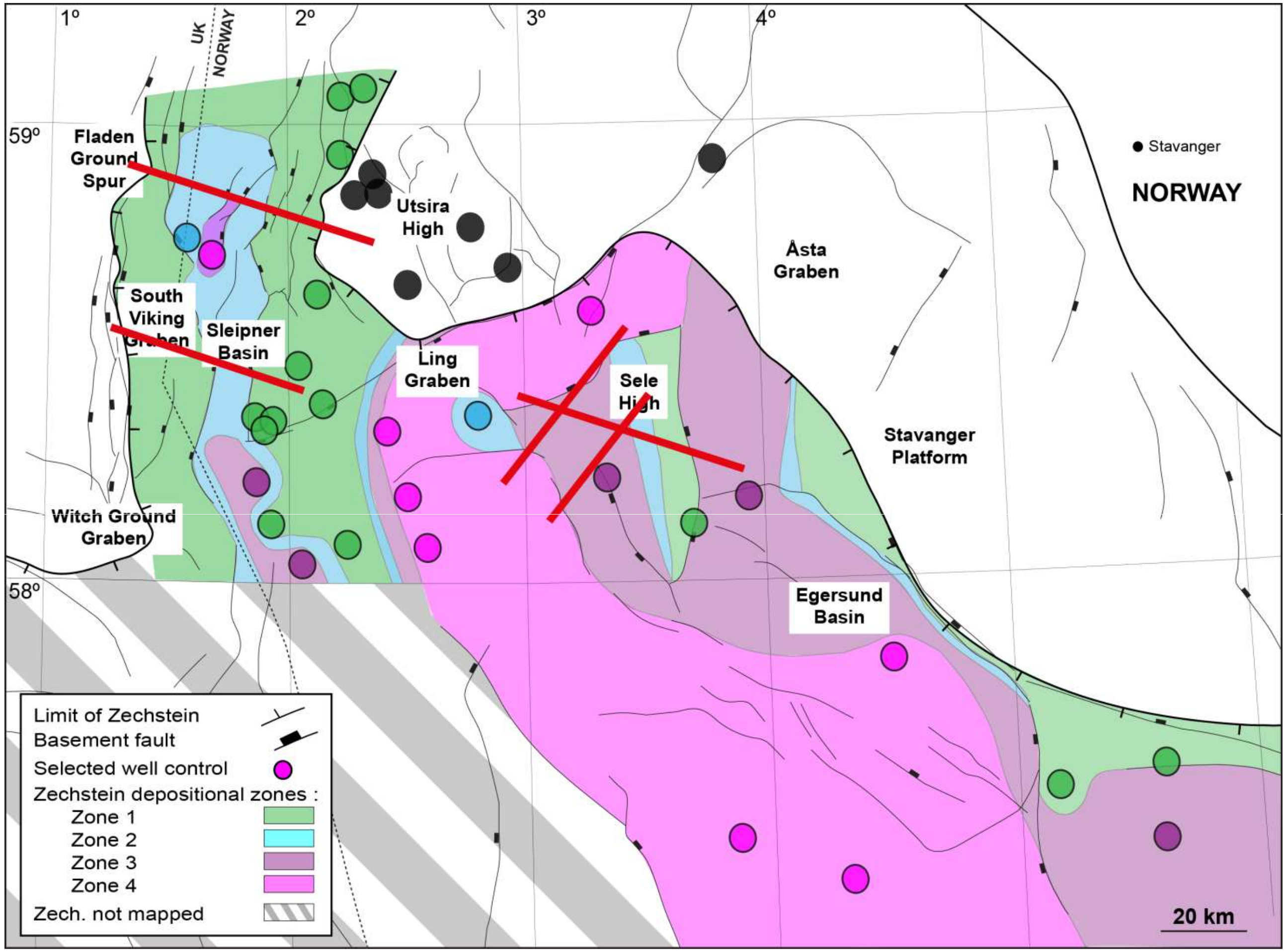
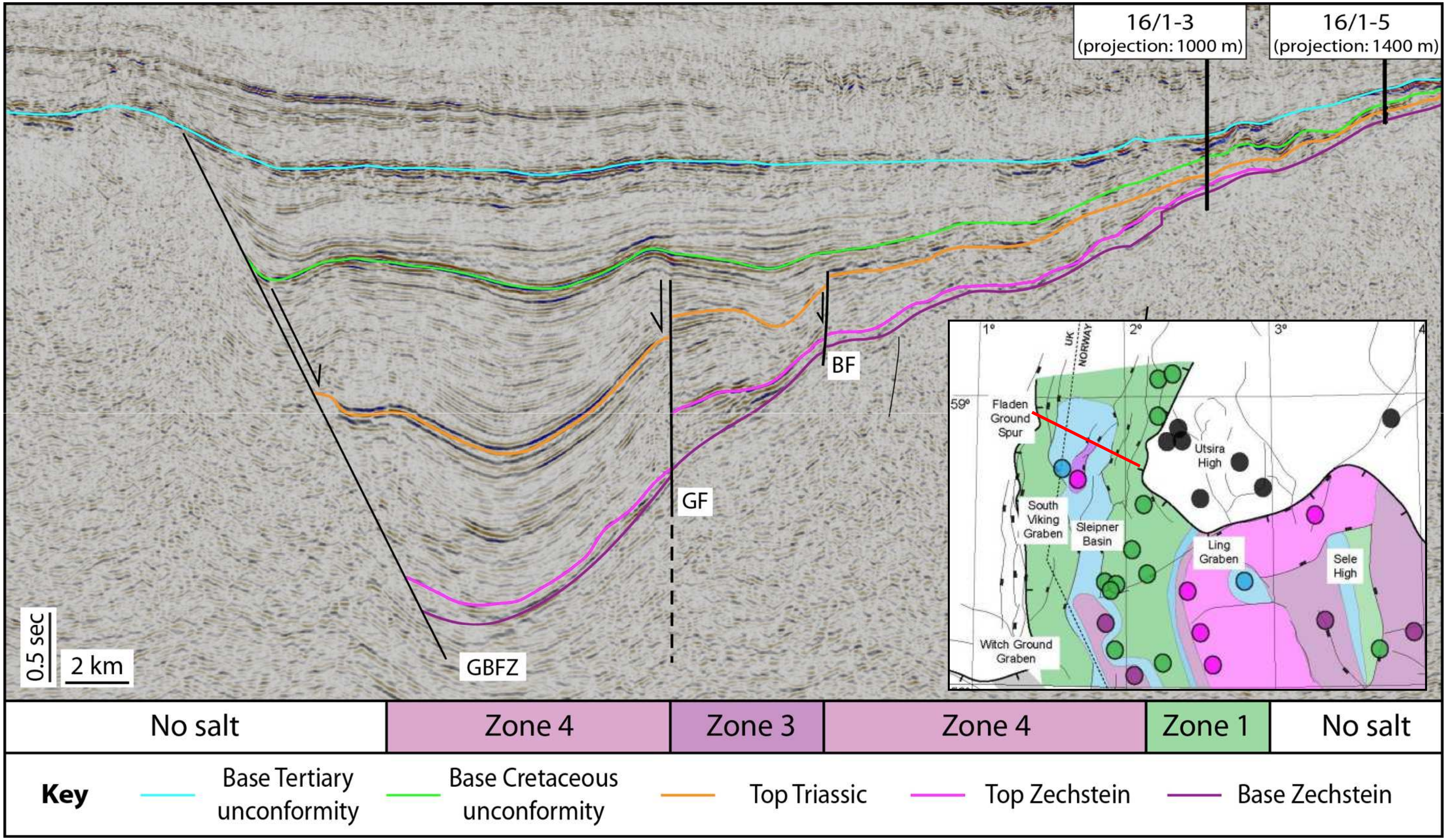


Seismic data reveals influence of ZSG lithology variations on rift structural style across the South Viking Graben and NE margin of the Central Graben

Northern South Viking Graben



- No salt-related deformation on basin margin; ZSG too thin and immobile
- Updip thin-skinned extension due to hangingwall tilting; formation of salt rollers

Ling Graben

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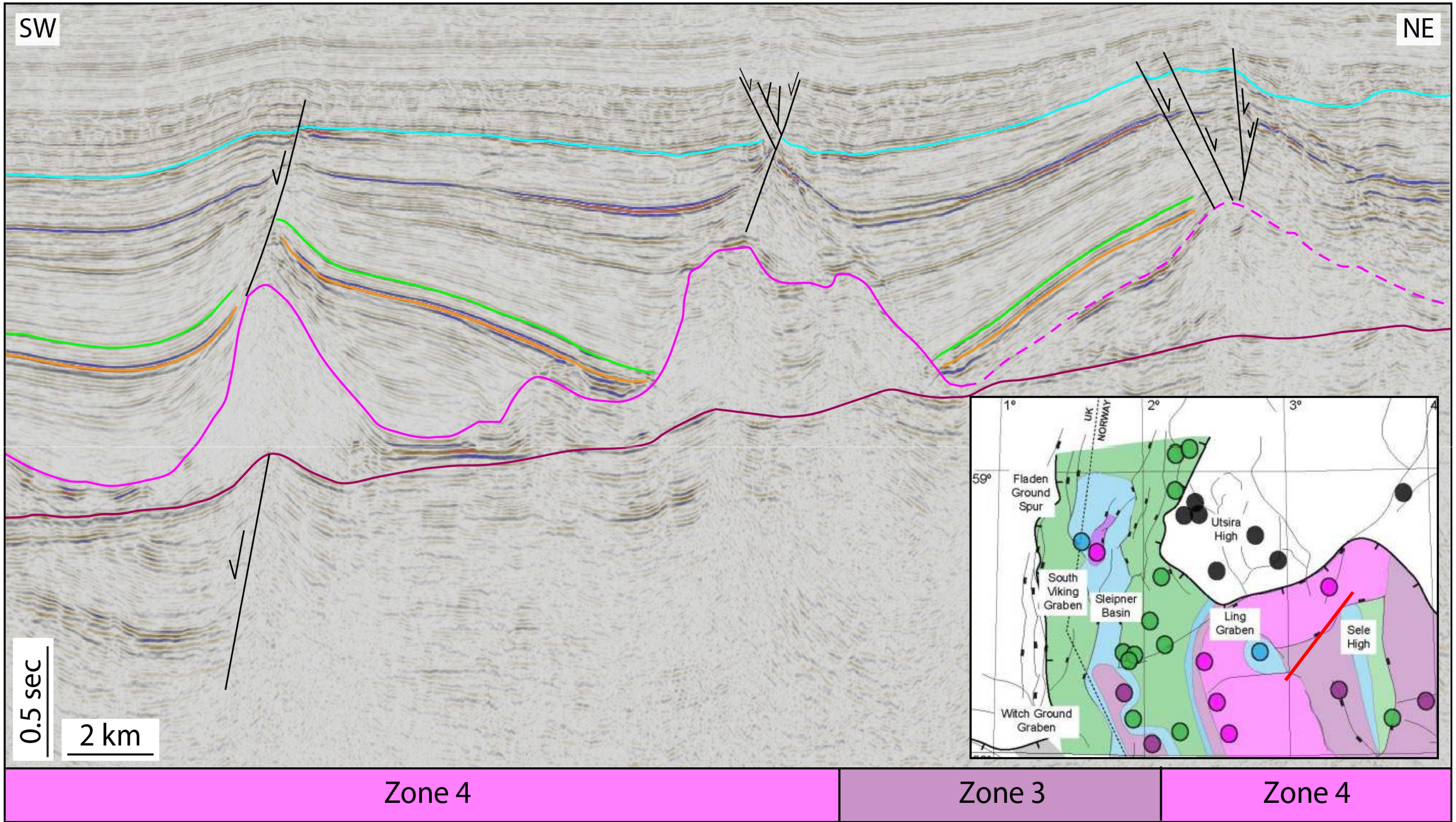
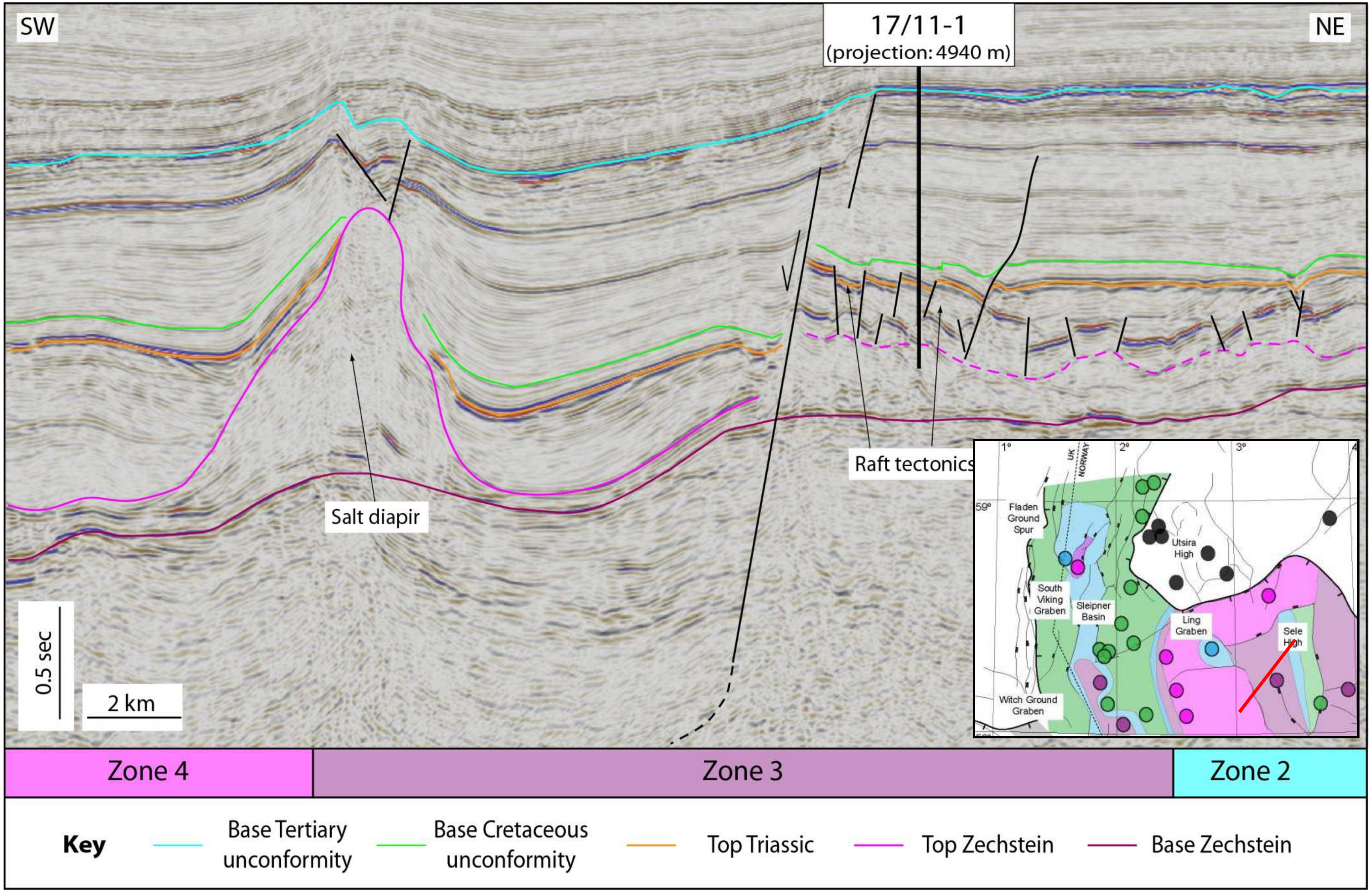


Key — Base Tertiary unconformity — Base Cretaceous unconformity — Top Triassic — Top Zechstein — Base Zechstein

- Diapirism in basinal areas comprised of thicker more mobile ZSG
- Reactive diapirism driven by thin-skinned extension?

Ling Graben



- Diapirism in basinal areas comprised of thicker more mobile ZSG
- Subtle thin-skinned extension and minor diapirism on structural highs

Conclusions

- Petrophysical and cuttings data allow construction of a lithology framework for the ZSG in Norwegian sector of the eastern North Sea

- Seismic mapping and stratigraphic correlations reveal prominent regional thickness and lithology variations in ZSG

- Four depositional ‘zones’ (*sensu* Clark et al. 1998) identified:
  - Basin margin – carbonate- anhydrite- and clastic-dominated (Zones 1 and 2)
  - Basin centre – halite-dominated (Zones 3 and 4)
  - Lithology transitions locally fault-controlled
  - Other lithology transitions controlled by subtle base salt relief

- Triassic and Jurassic rift structural styles linked to ZSG lithology:
  - Depositional Zone 1 – no diapirism or low-relief diapirs
  - Depositional Zones 2 and 3 – thin-skinned extension
  - Depositional Zones 3 and 4 – high-relief diapirs and minibasins

A Trick of the Light?

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- Does present lithology distribution reflect primary lithology distribution?

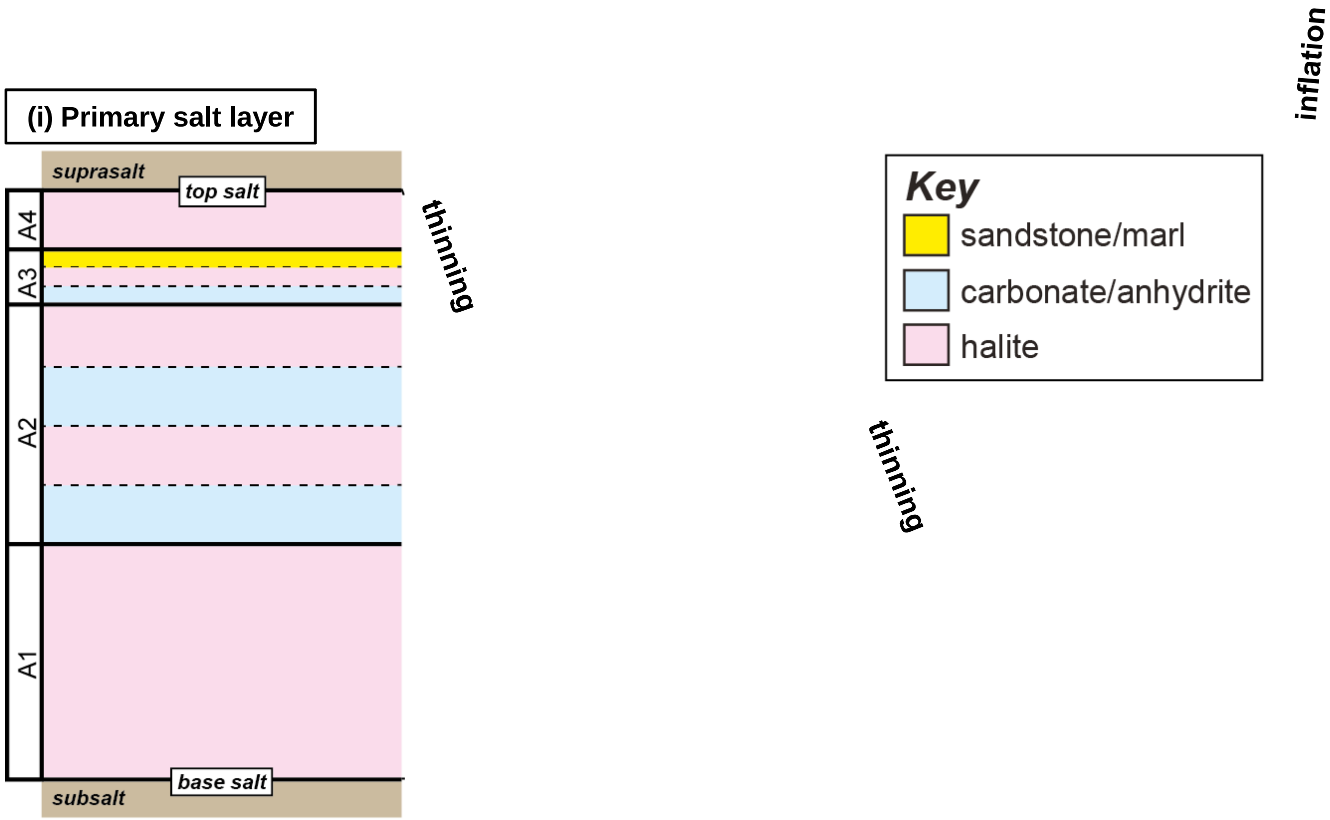
- Post-depositional erosion and dissolution (Model 1) cannot be ruled-out; however, unlikely to be dominant control because basin-centre successions contain almost no carbonate and relatively little anhydrite, suggesting basin margin/intra-basin structural high successions not simply anhydrite- or carbonate-enriched versions of those encountered in basin-centre

- Differential expulsion of halite unlikely to be dominant control; thin basin margin/intra-basin structural high successions are not flanked by large salt structures

- Evidence for Early Permian faulting and dramatic changes in thickness and lithology of the ZSG across basement-involved normal faults, but no independent evidence for a phase of Late Permian extension, making it problematic to discriminate between Model 2 and 3.

Differential Salt Flow

- **Stage (i)** – pre-thinning salt
- **Stage (ii)** – salt thinning; preferential expulsion of low-viscosity halite
- **Stage (iii)** – (apparent) welding; complete evacuation of halite; remnant non-halite (high-viscosity) lithologies
- Diapir grows in response to preferential addition of low-viscosity halite (cf. '**differential purification by movement**' (*sensu* Kupfer, 1968)



Differential Salt Flow

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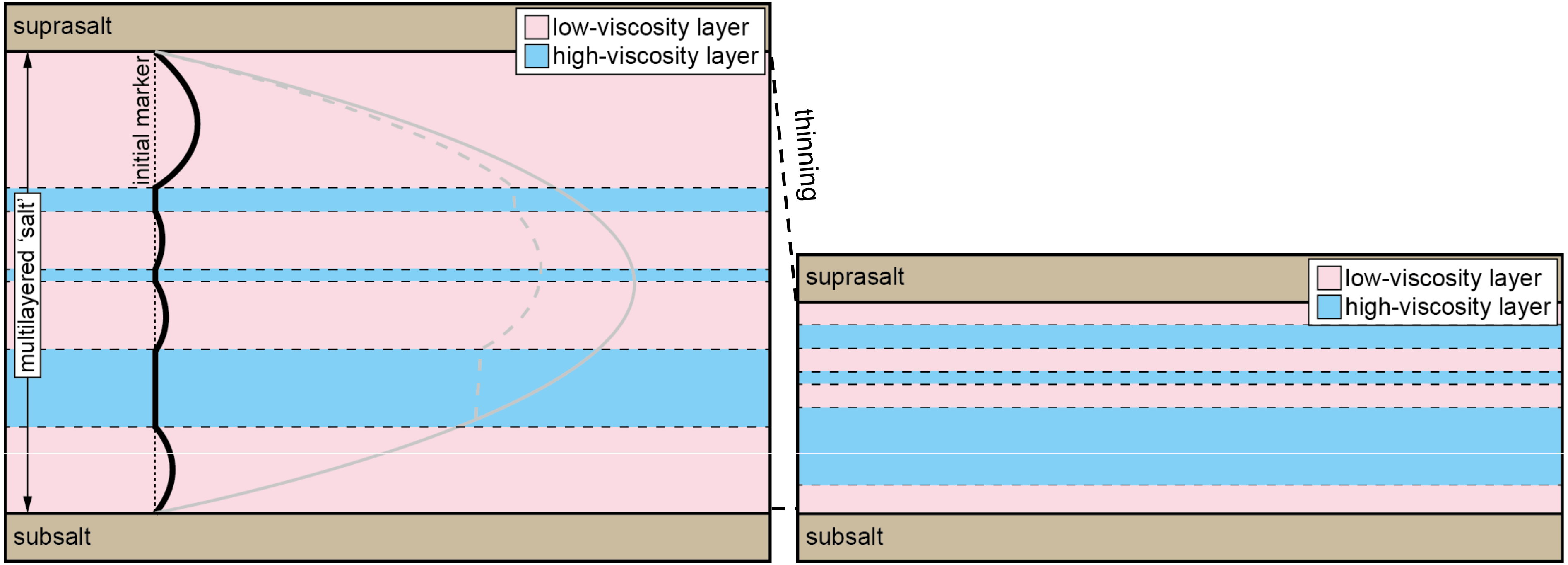

modified from Wagner & Jackson (2011)

Ling Graben

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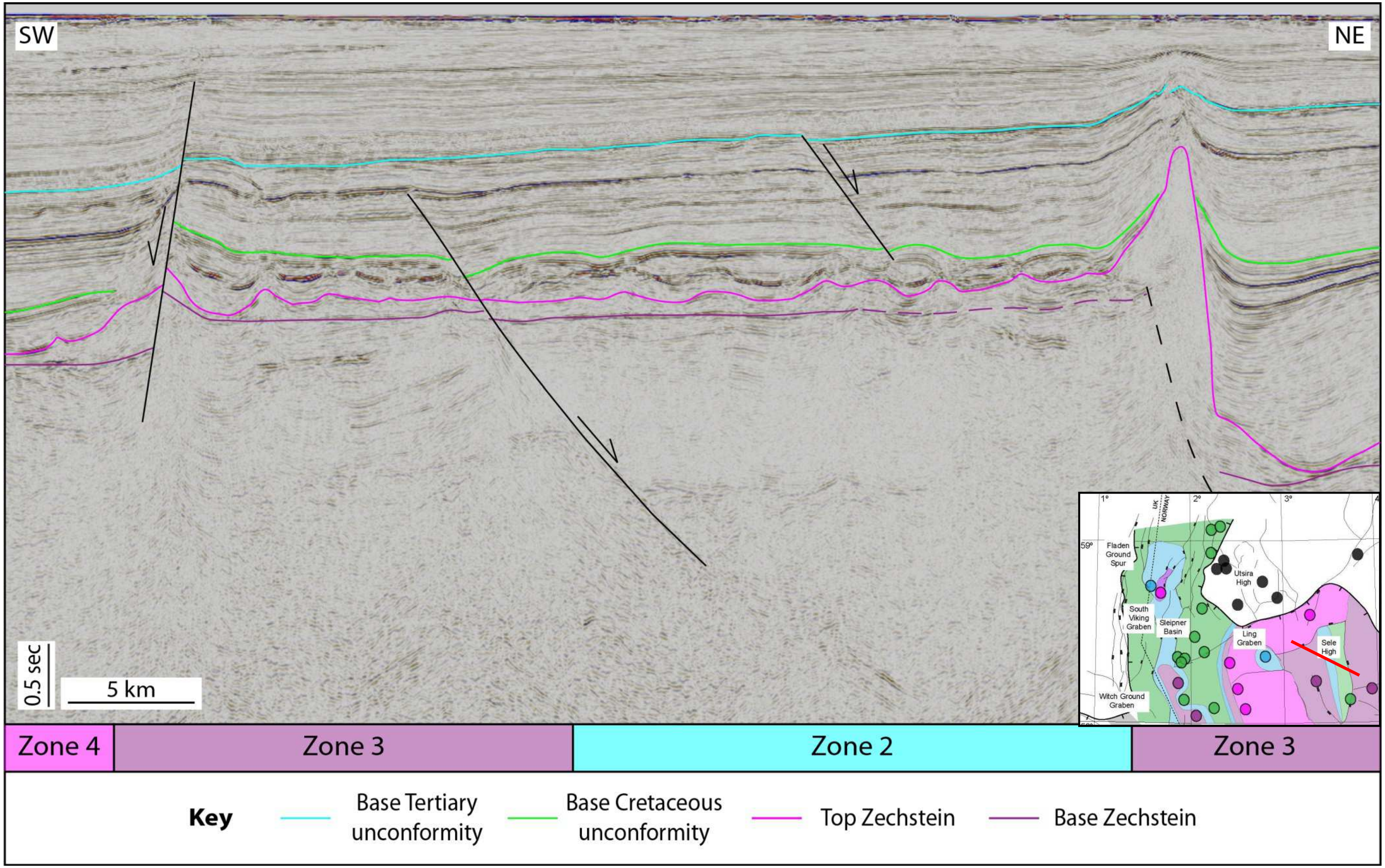
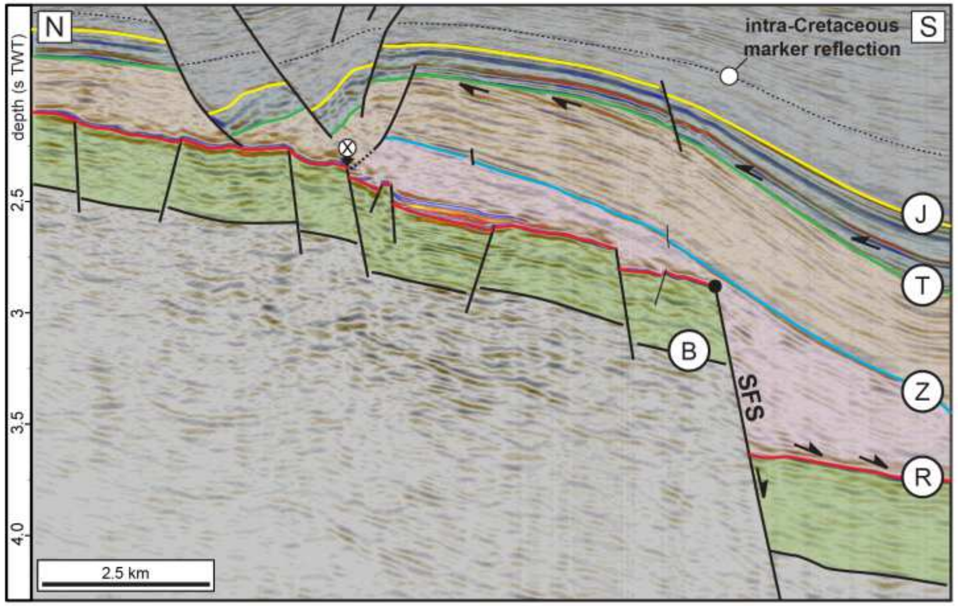
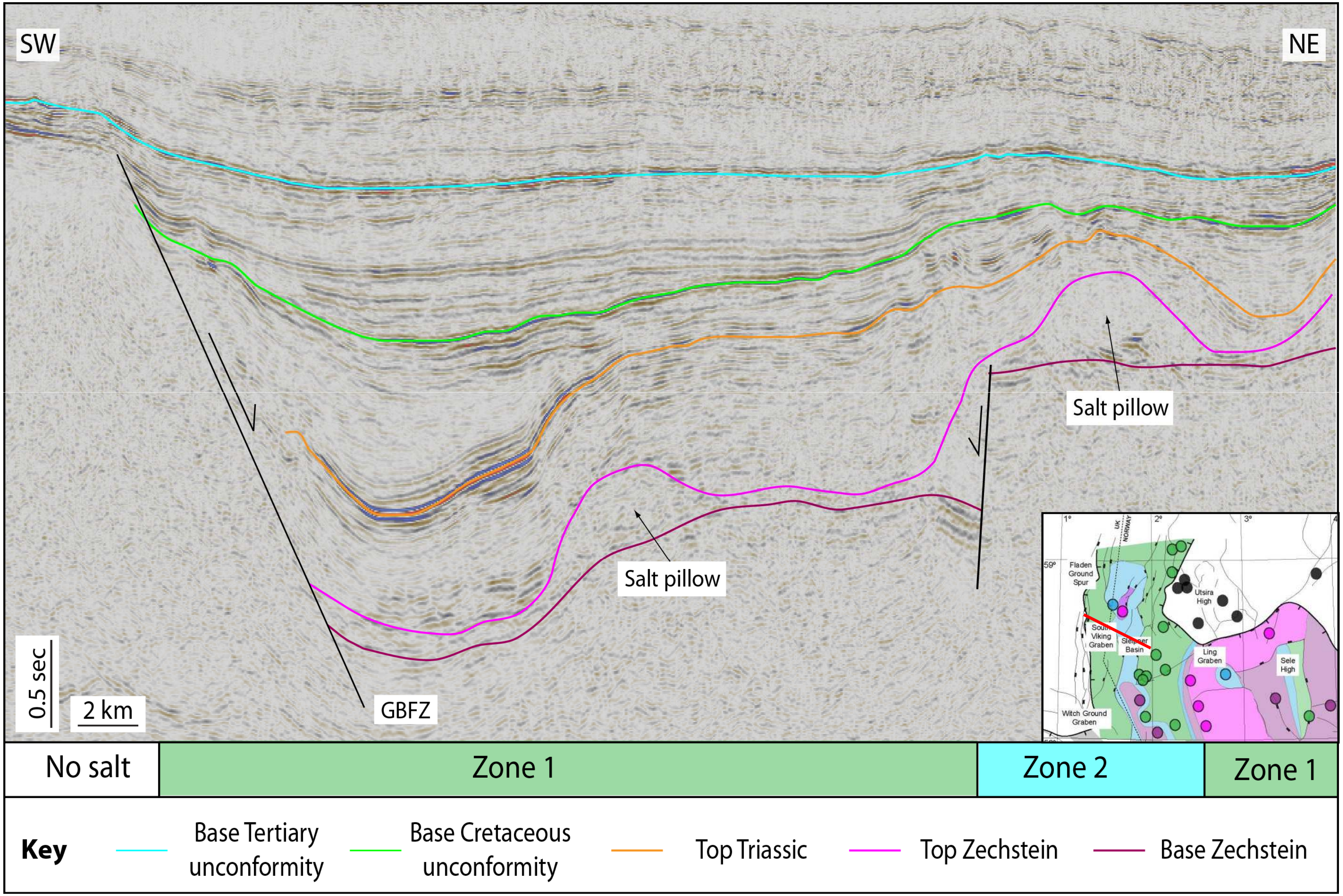



N
S
intra-Cretaceous
marker reflection
depth (s TWT)
2.5
3
3.5
4.0
J
T
Z
R
B
SFS
2.5 km

Southern South Viking Graben



- http://written-in-stone-seen-through-my-lens.blogspot.co.uk/2013_05_01_archive.html