Reconstructing the Triassic northern Barents Shelf;
basin infill patterns controlled by gentle sags and faults

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- **Combining onshore and offshore observations**
- **From Svalbard towards the south and east**

1) Setting: Caledonian to Devonian infra-structure
2) Setting: Carboniferous rifting before the Permian platform
3) Triassic foreland sag basins and their infill characteristics
4) Triassic extensional faulting modifying sediment routing
5) Summary

Force workshop, Stavanger, 4th April 2013

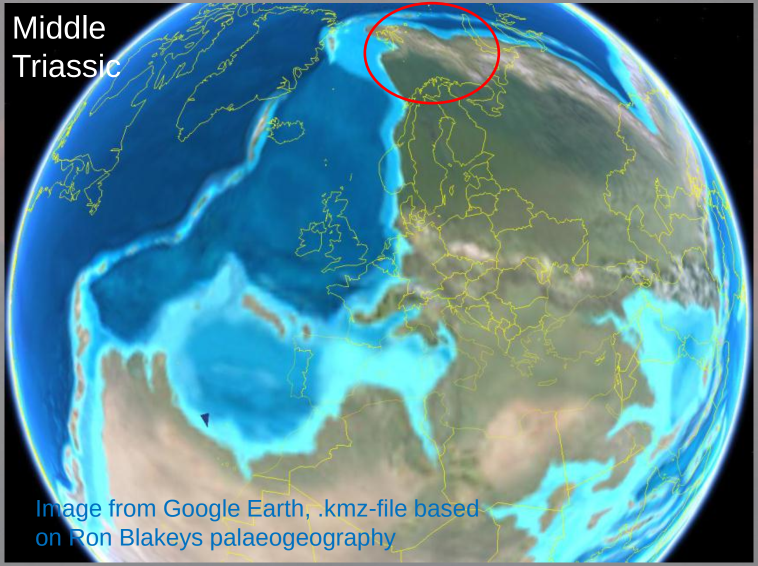
Project proposal submitted to Petromaks2 the 150213:

Reconstructing the Triassic northern Barents Shelf

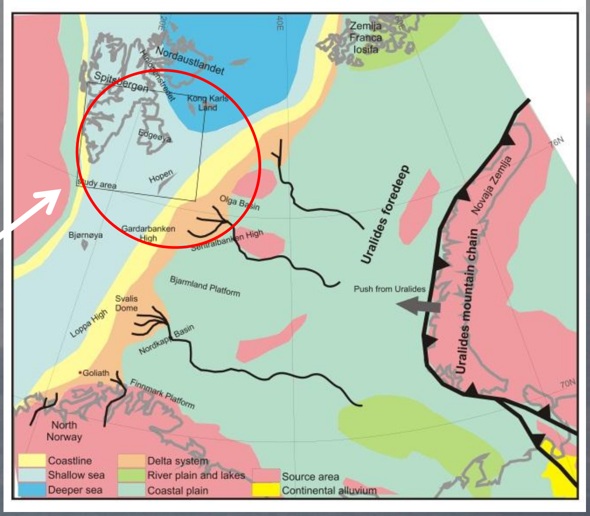
Proposal builds on a series of observations, presented here

Integrate onshore and offshore datasets to improve the understanding of basin development and tectonic activity of the northern Triassic Barents Shelf

- **Clinoform migration** across regional sag-type basins,
- Fluvial and shallow marine **depositional systems** of the migrating shelf,
- **Growth faulting** in the distribution of reservoir sandstones,
- **Interaction** between shelf progradation, sag-basin development and faulting,
- Deep-seated zones of weakness and far-field **stress configurations**



How did this foreland basin fill in?
What controlled infill patterns?
Can we establish sediment routing?



Braathen et al. 2012

1) SETTING

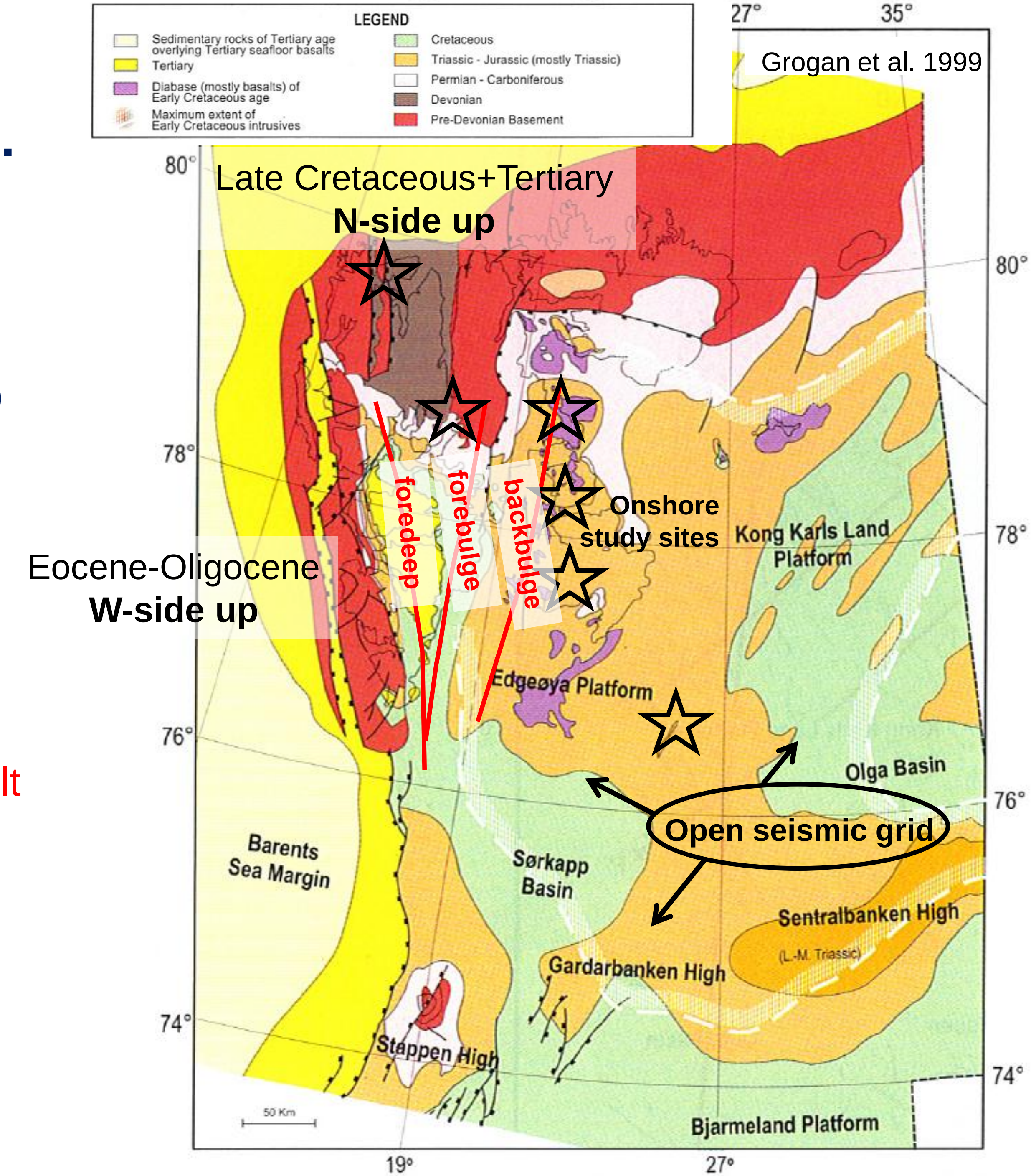
Todays exposures …

from Late Cretaceous to Oligocene events … controlling the map pattern domains

- N side up => rifting
- W side up => rifting

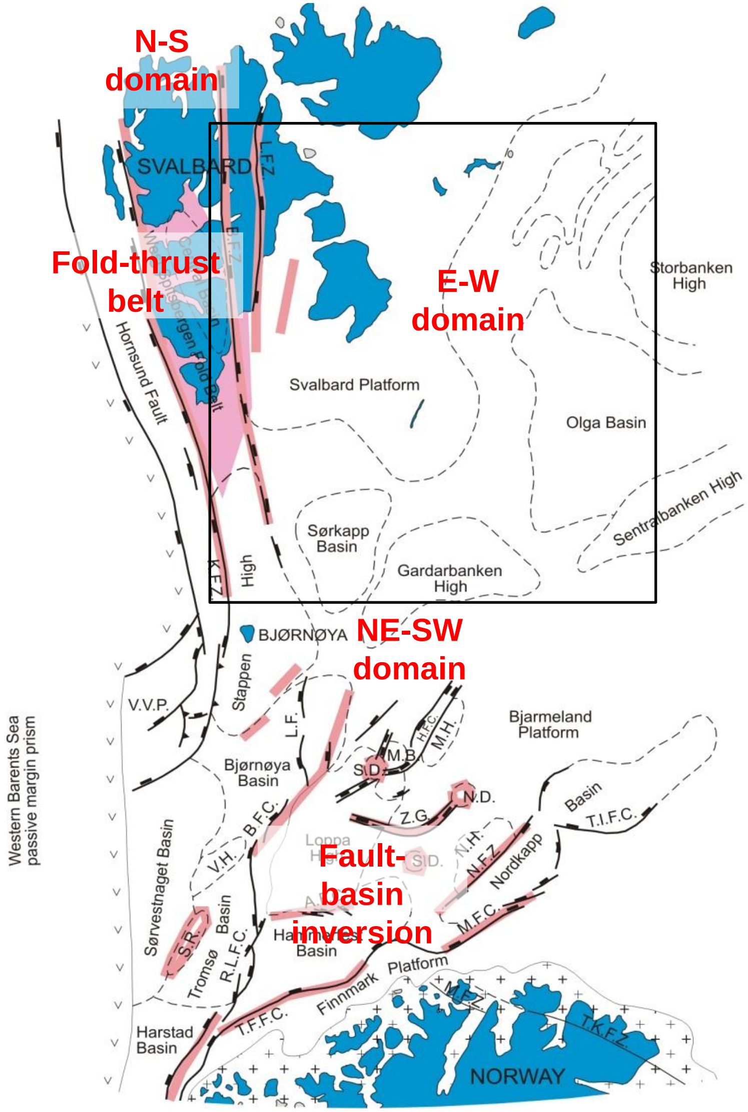
- Tertiary fold-thrust belt
  - Stacked crust in f-t belt
  - Foredeep
  - Forebulge
  - Backbulge

  Where are they?

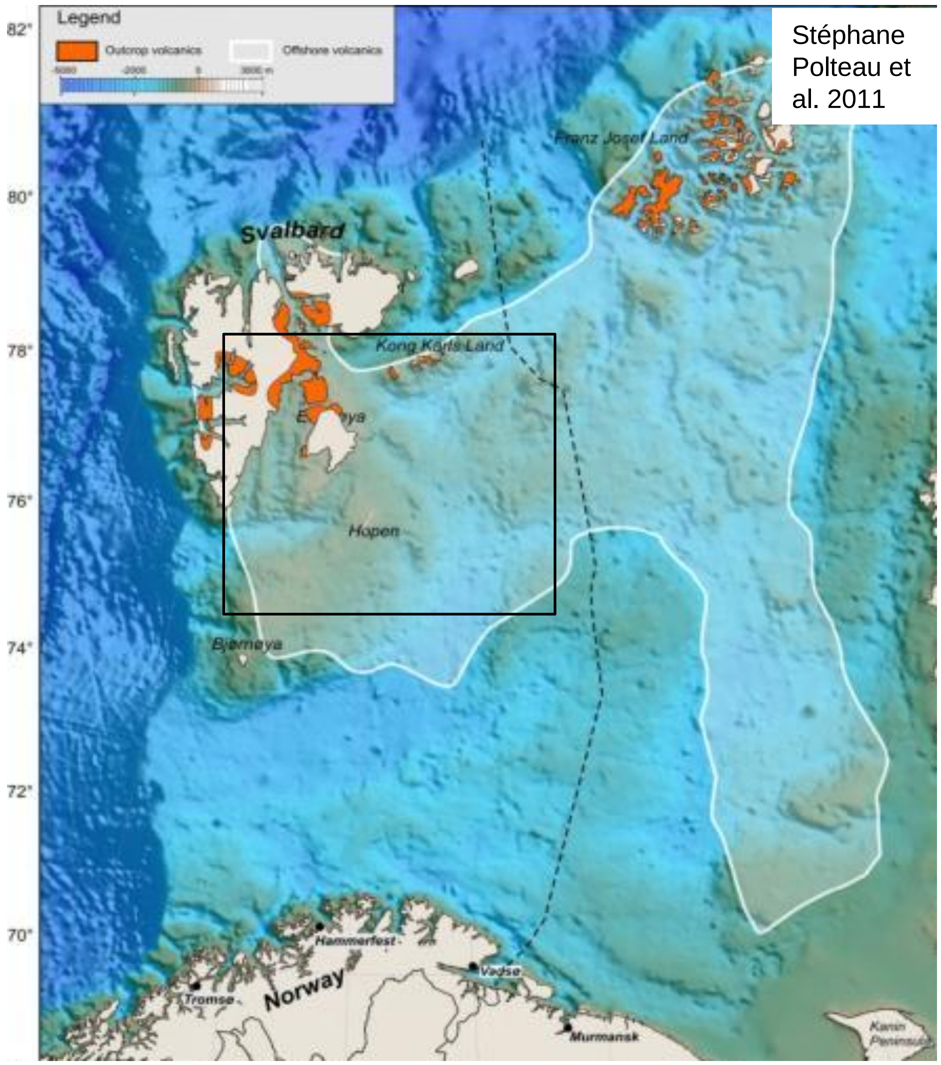


1) SETTING: Paleogene and Cretaceous

Paleogene transpression => transtension tectonics during North Atlantic break-up



Extensive Cretaceous (125 Ma) intrusive and extrusive basaltic rocks (HALIP)

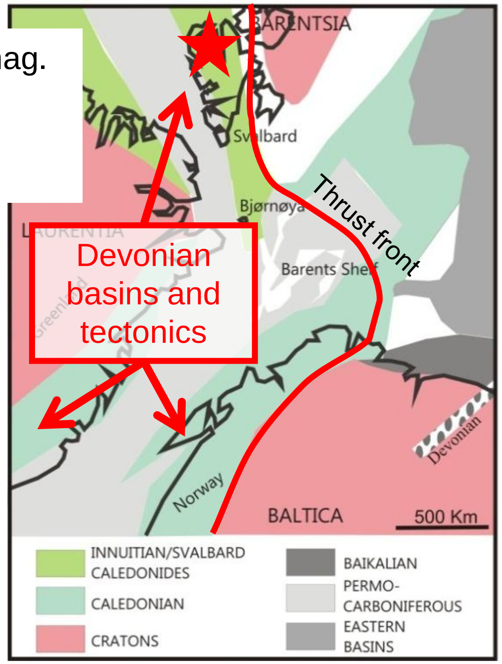


Stéphane Polteau et al. 2011

1) SETTING: basement

Linking mainland with Svalbard tectonics across the shelf

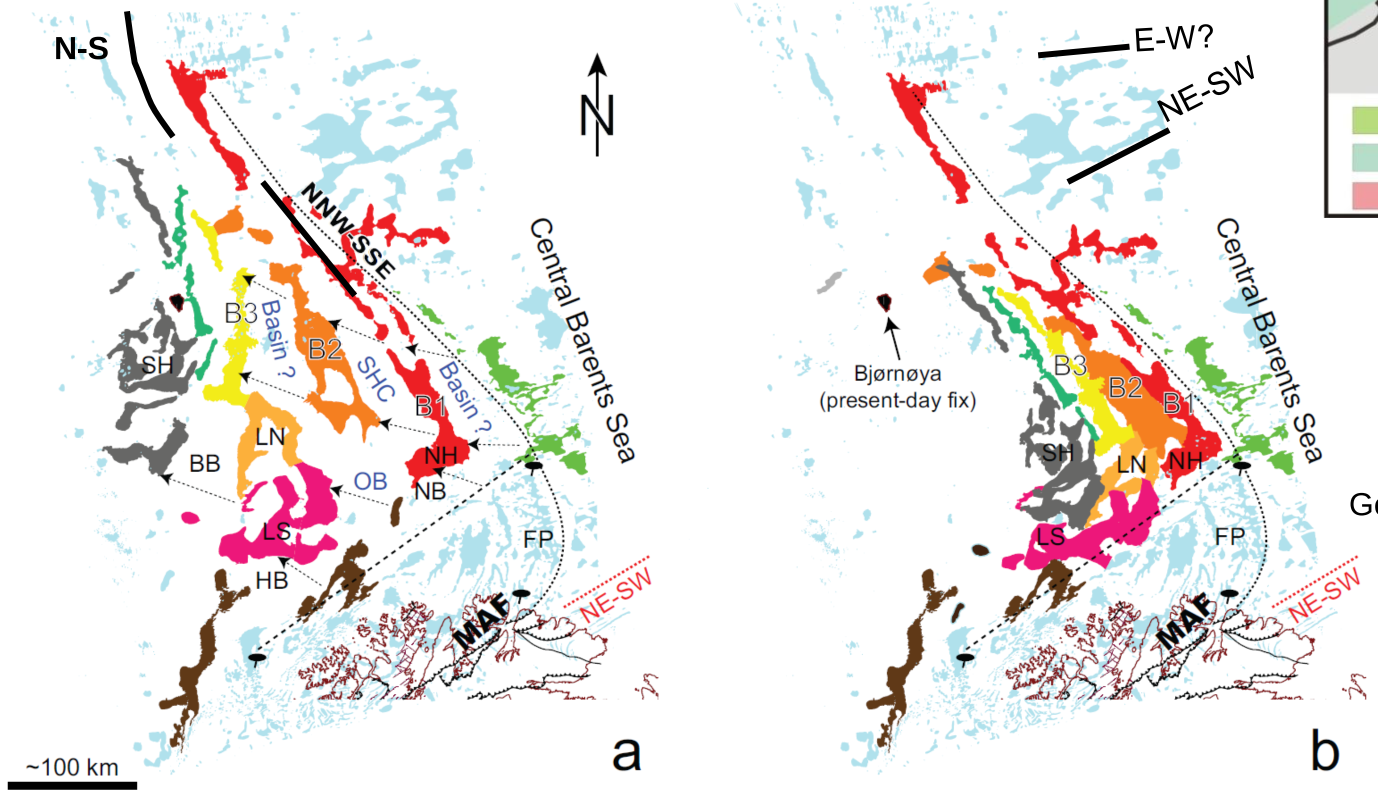
NGU grav.-mag. data linking Norway with Svalbard



Braathen et al. 1999

Current deep infrastructure: Caledonian nappes modified by Devonian extension

Restoration: Caledonian nappes in initial position



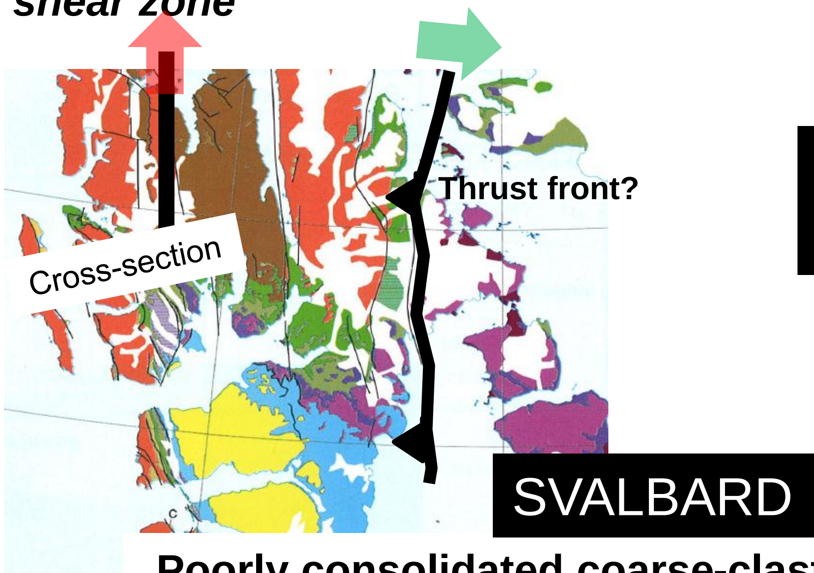
Gernigon & Brønner 2012

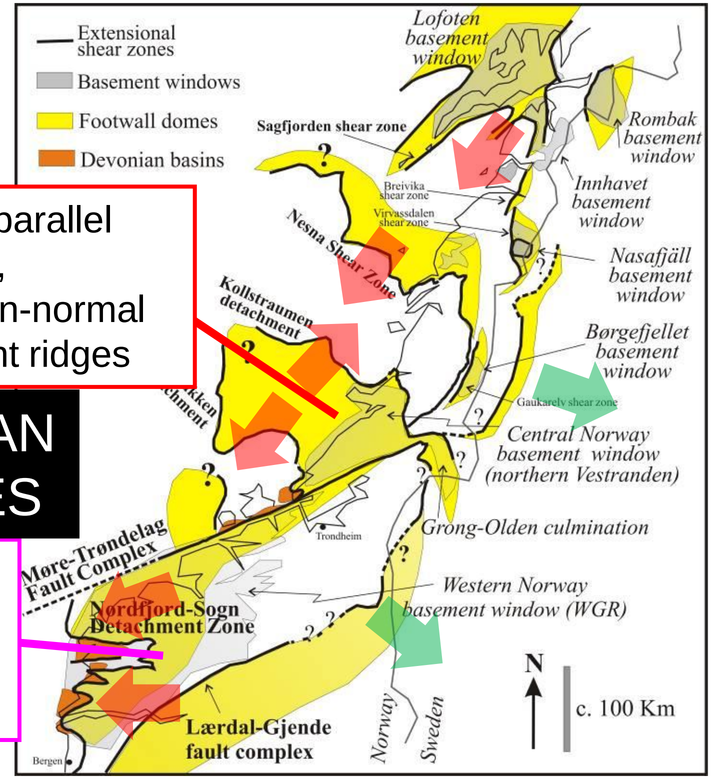
Fig. 7. (**a**) Main highs observed from the tilt derivative at the present day in the southwestern Barents Sea. (**b**) Tentative restoration of nappes in arc-shaped Caledonian thrust belt before back-sliding and Late Palaeozoic basin formation. BB, Bjørnøya Basin; B1, B2 and B3, prominent NNW–SSE magnetic anomalies interpreted as basement highs beneath the Bjarmeland Platform; FP, Finnmark Platform; HB, Hammerfest Basin; LN, Loppa High north; LS, Loppa High south; MAF, Middle Allochthons front; NB, Nodkapp Basin; NH, Norsel High; OB, Late Palaeozoic Ottar Basin; SH, Stappen High; SHC, Late Palaeozoic Scott Hansen complex.

Devonian basement grain

… infra-structural controlling later faulting

Top-N, corrugation- and orogen-parallel shear zone



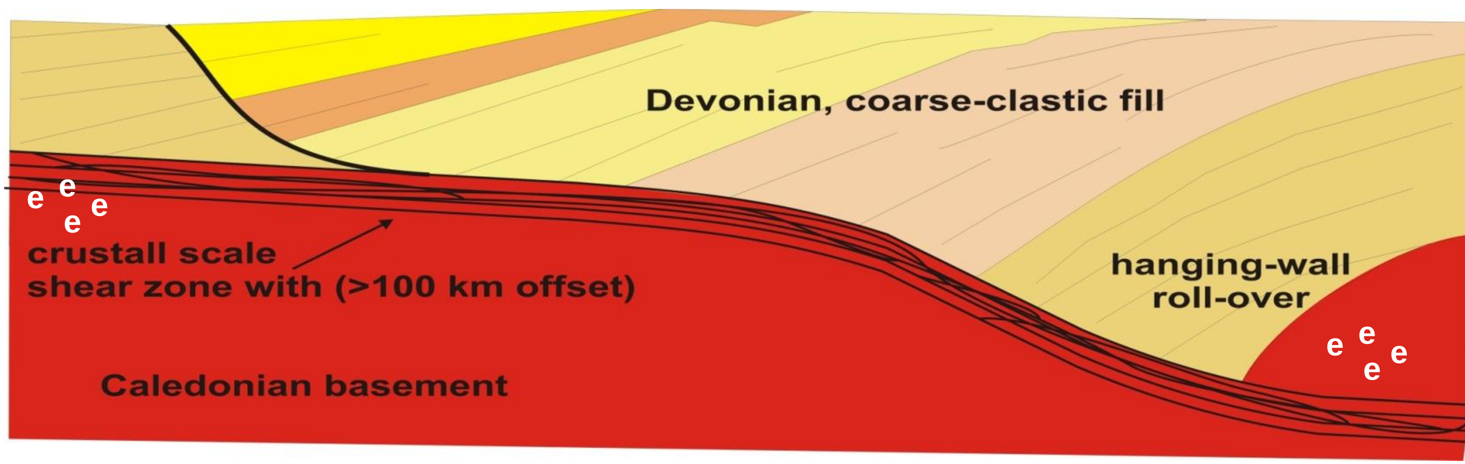


Orogen-parallel extenion, Extension-normal basement ridges

SCANDINAVIAN CALEDONIDES

Orogen-normal/ oblique extension, Extension-parallel basement ridges

Poorly consolidated coarse-clastic alluvial fan and fluvial deposits, with seismic-scale sedimentary architecture



Osmundsen, Braathen & Maher, in progress

Braathen et al. 2010: Extensional shear zone with top-N kinematics, truncating syn-tectonic hanging-wall basin fill, also with younger fault activity

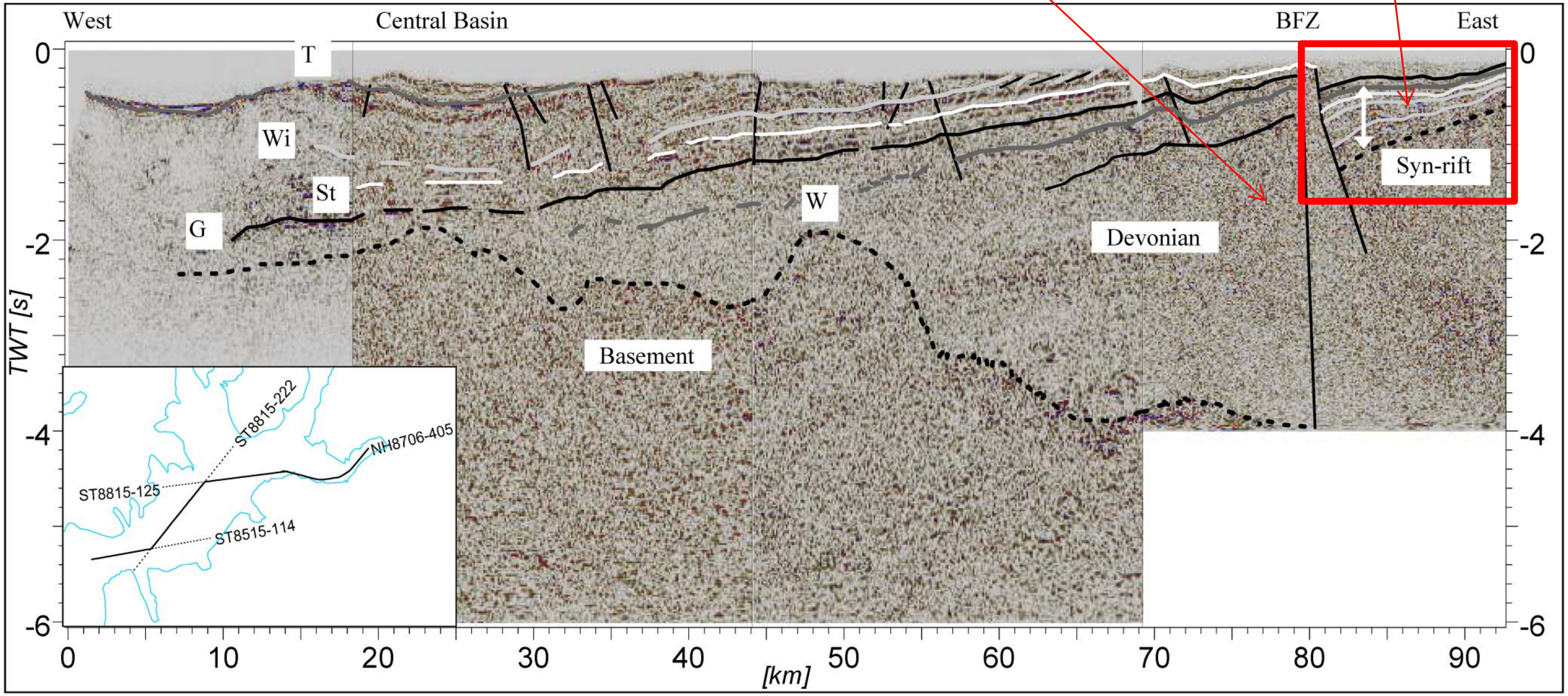
2) SETTING: Carboniferous rift basin, reactivating N-S Devonian fault zone

- Billefjorden Fault Zone reactivated as Carboniferous extensional fault
- Billefjorden Trough in the hanging-wall

Bælum & Braathen 2012
Carboniferous extensional basin

Bergh et al. 2011
Devonian reverse faulting

Regional W-E seismic line, Isfjorden

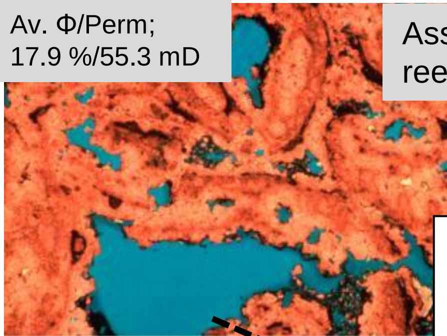


Carboniferous Billefjorden Trough

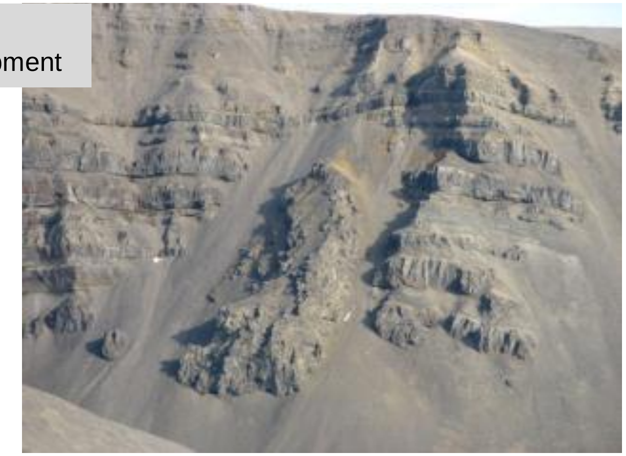
Palaeoaplysina bioherms

Av. Φ/Perm;
17.9 %/55.3 mD

Asselian
reefs



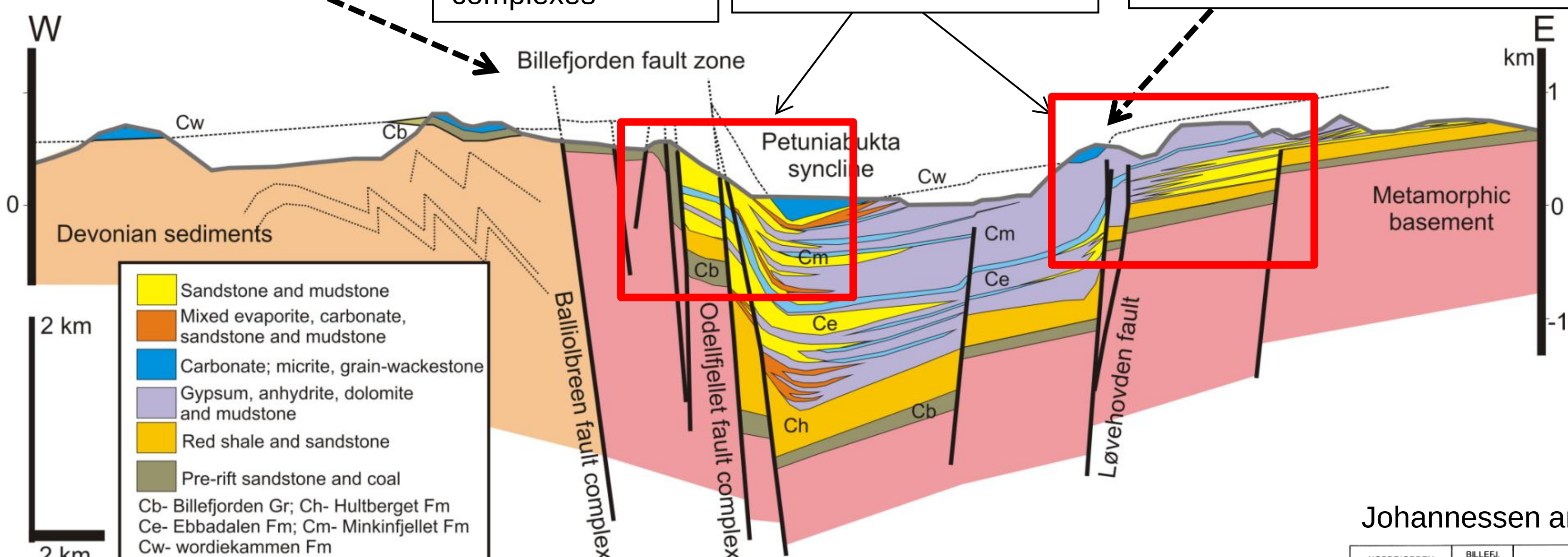
Karst
development



Basin shoulder
reefs/buildups
Localized fan
complexes

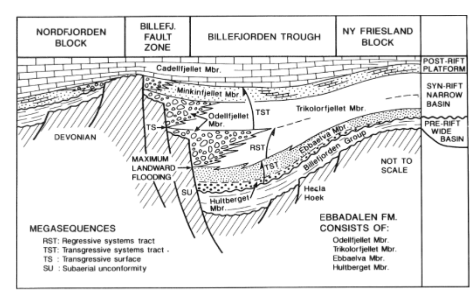
Fault-tip monoclines
in evaporite
dominated areas

Karst systems around/above intra-basin fault



Braathen et al. 2011

Johannessen and Steel 1992

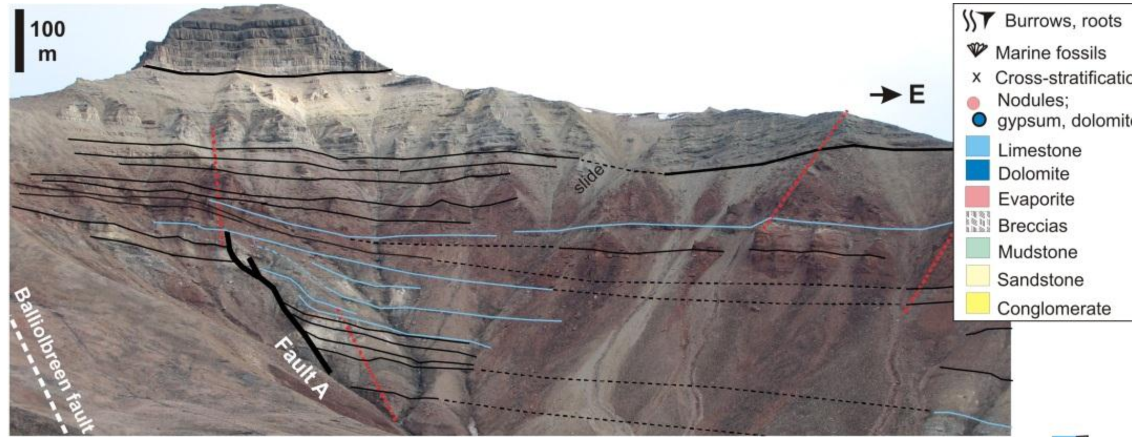


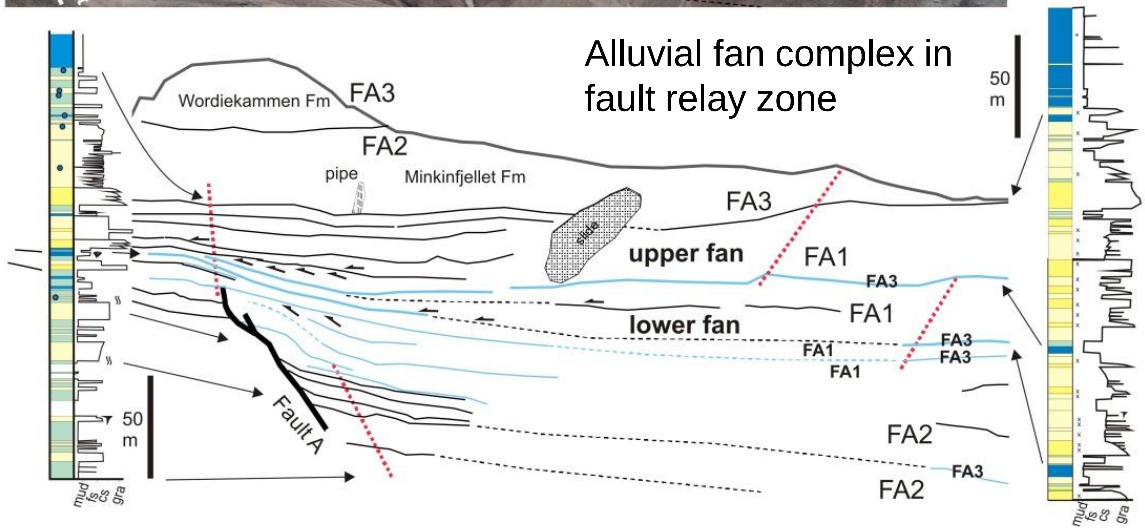
Detailed 3D geometries unravel basin configuration

Billefjorden Trough

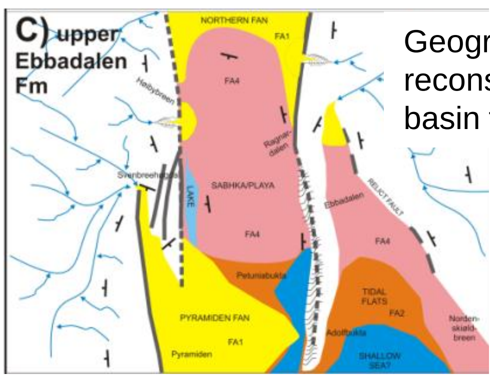
Boundary fault domain (west)

- N-S fault zone with relay structure between master faults
- Major alluvial fan complex building out from relay zone
- Large basin-parallel monocline along fault zone; Petuniabukta syncline





Alluvial fan complex in fault relay zone



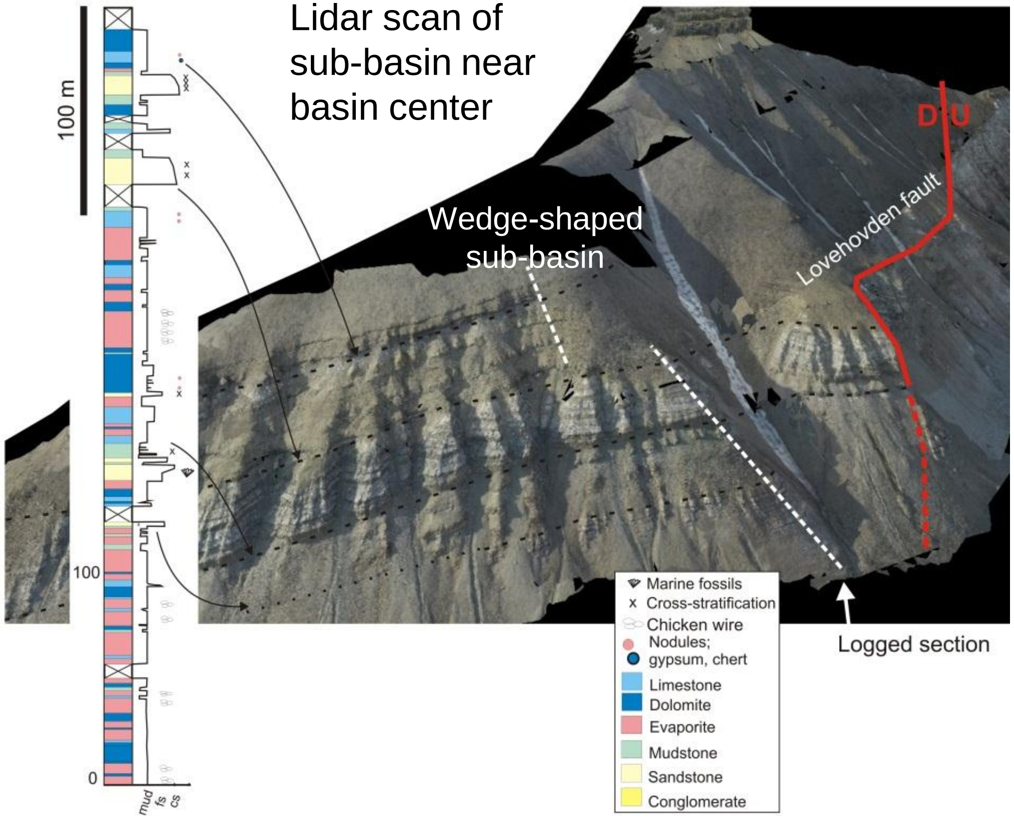
Geographic reconstruction of basin fill

Braathen et al. 2012

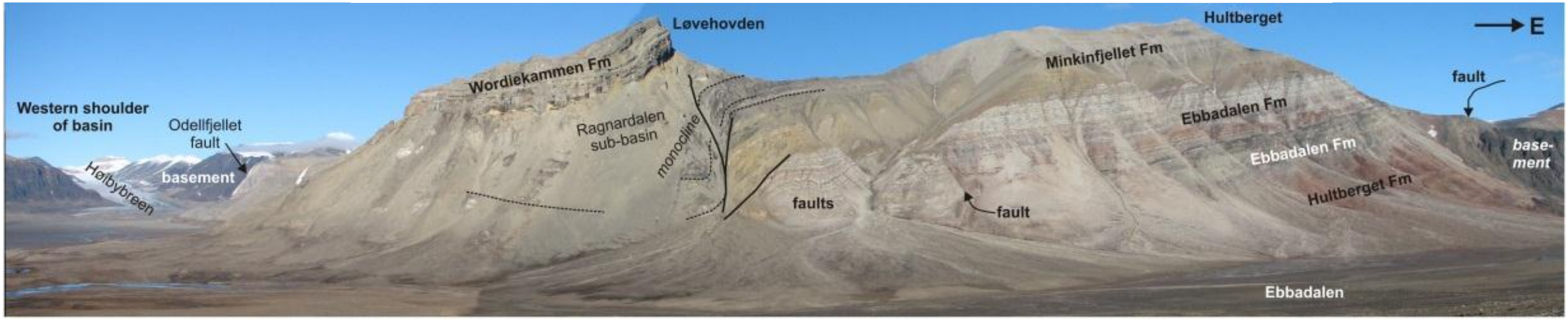
Billefjorden Trough

Central-East dip-slope side of half-graben

- N-S intra-basin faults and sub-basins
- Filled with interfingering siliciclastic, carbonate and evaporite rocks
- Fault-tip monocline and sharp-breaking extensional faults, controlled by evaporite fill



Extensional fault-tip monocline, with lenticular-shaped, HW sub-basin

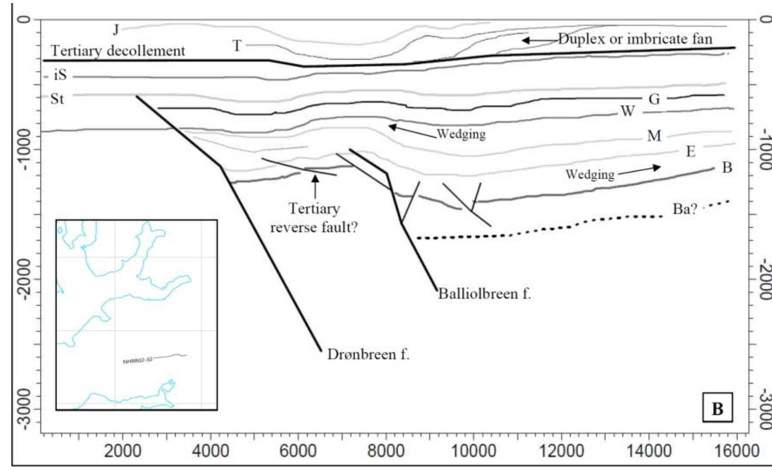


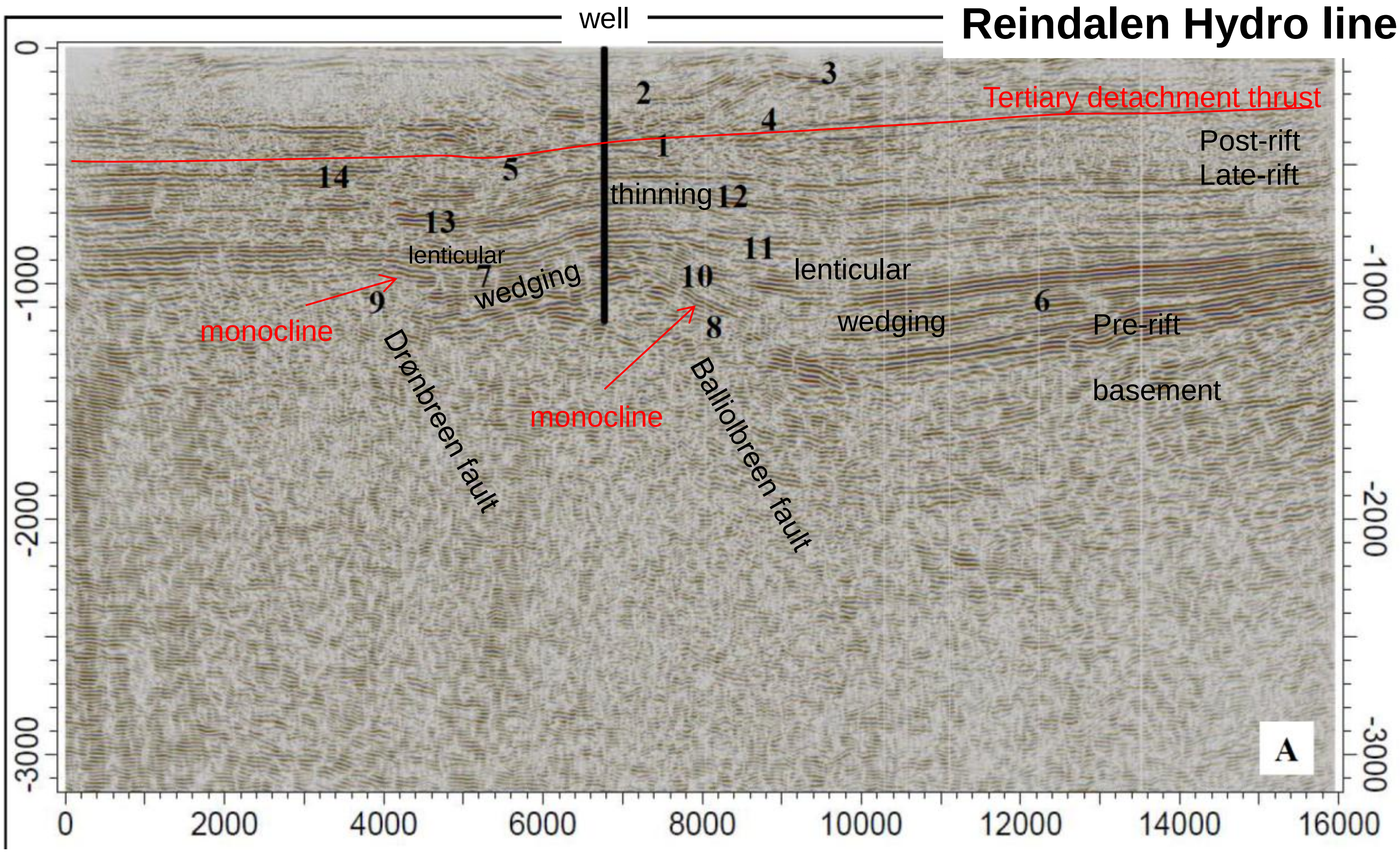
Braathen et al. In press

Seismic interpretation

of Carboniferous extensional basin

Applying onshore basin geometries and facies distribution models to cultivate a viable basin description





3) TRIASSIC SYSTEM…

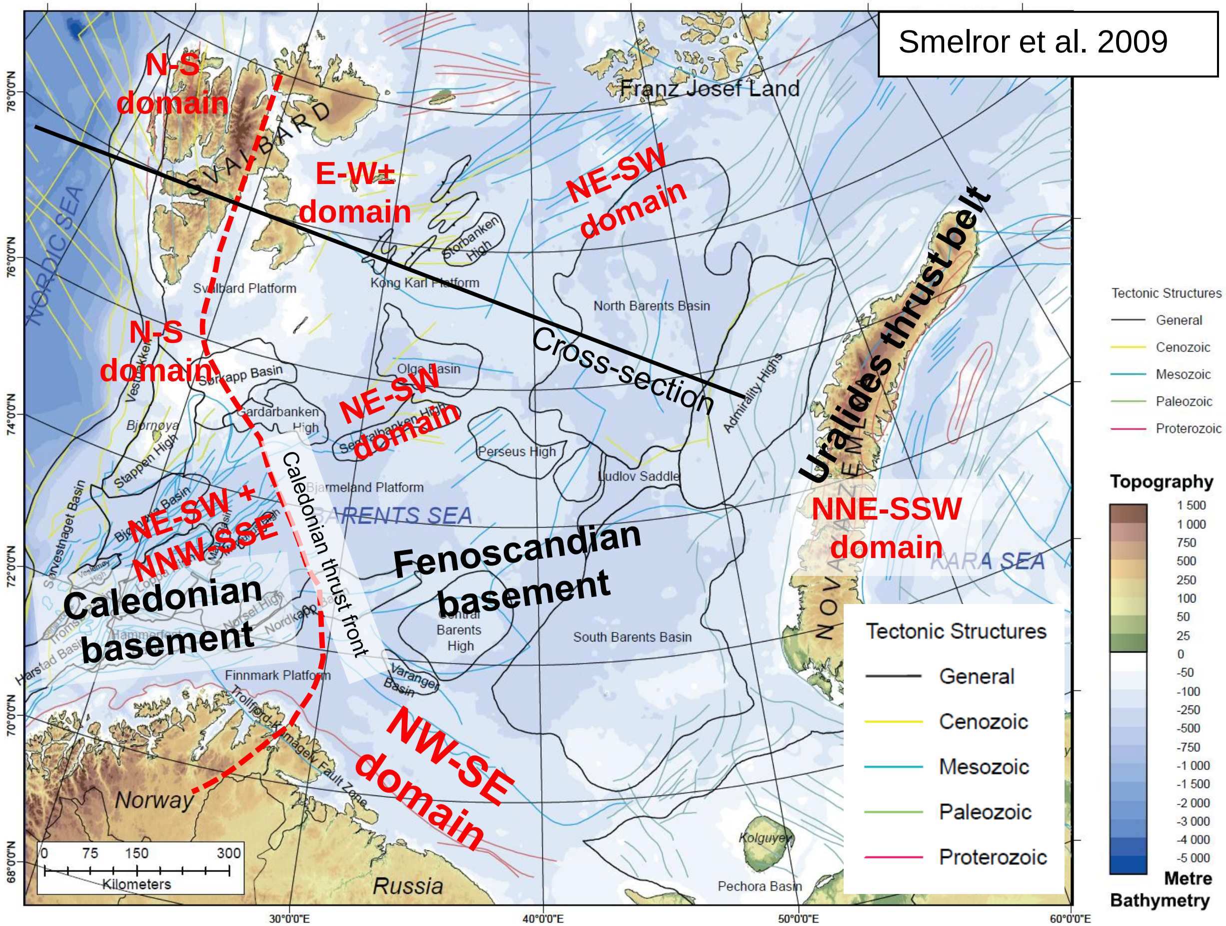
Peak of Uralides collision orogen …

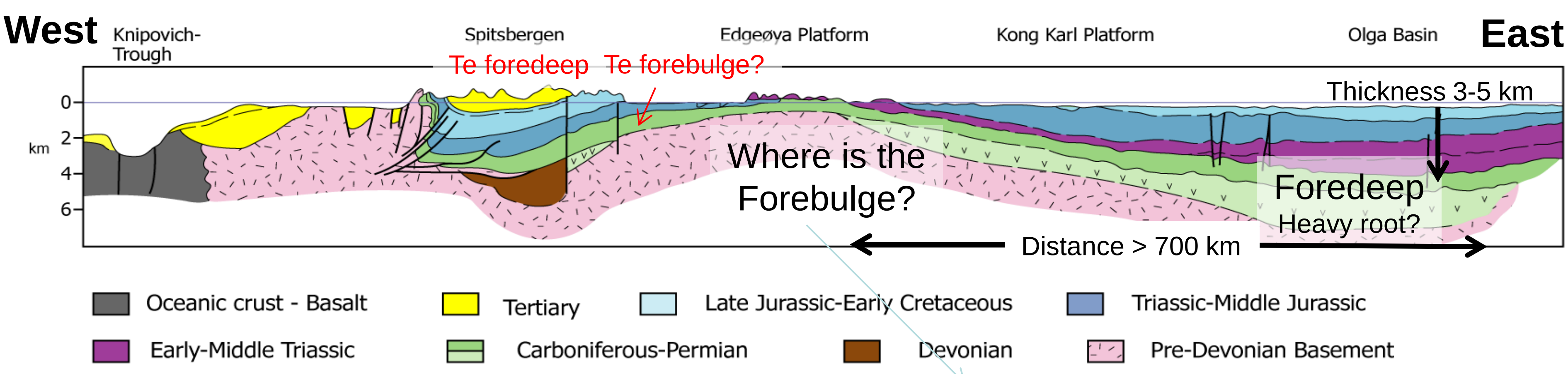
Foredeep?
Forebulge?

- Low relief sed. systems
- Sag basins

Faults?

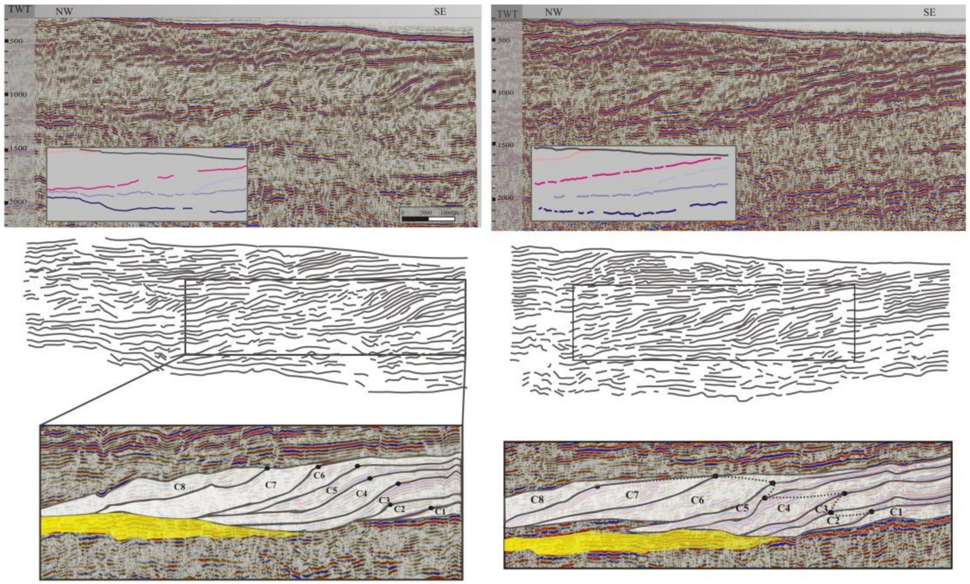
- Local high relief sed. systems
- Grabens

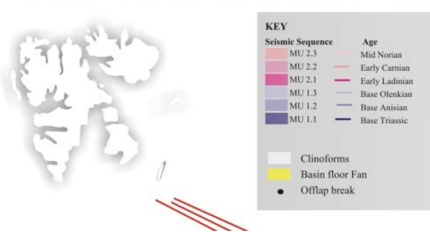




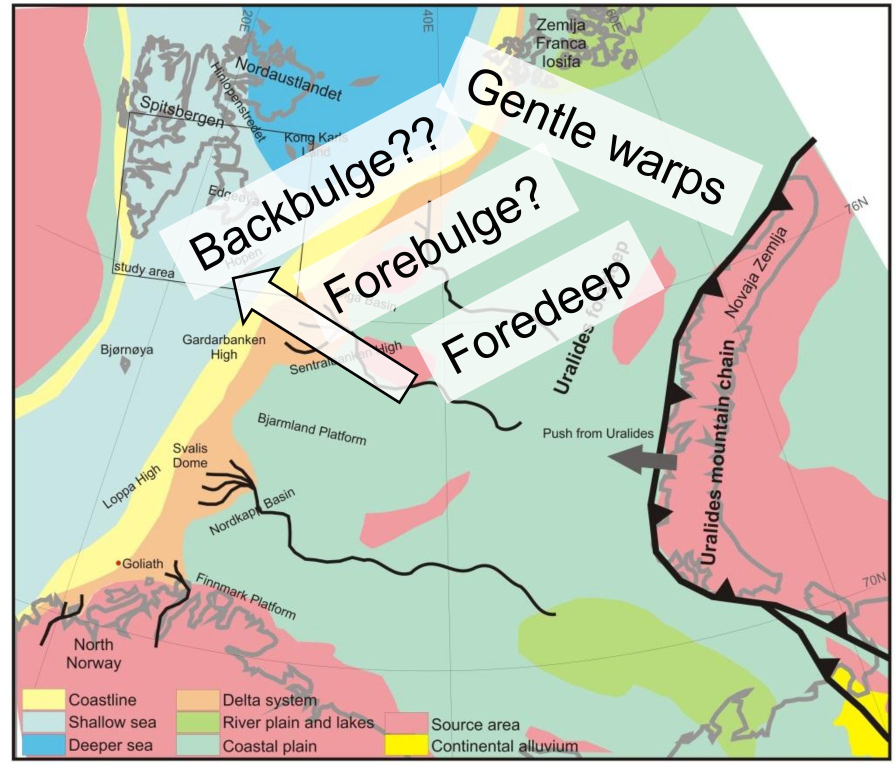
Triassic Palaeogeography

.. clinoforms filling a foreland shallow sea



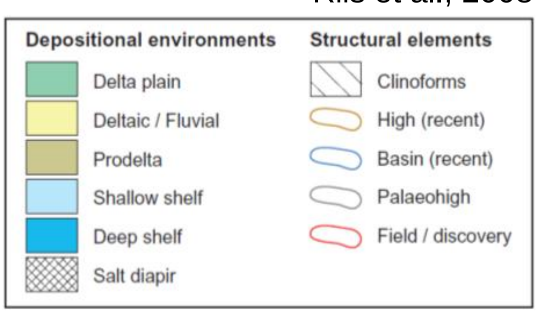


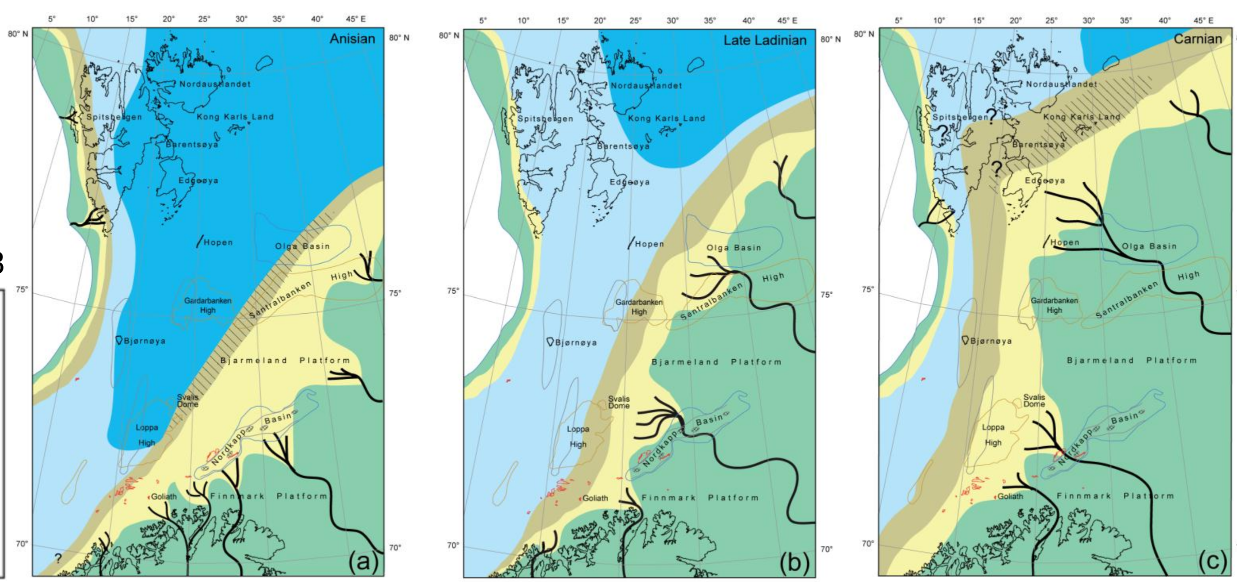
Anell et al. in prep.



Braathen et al. 2012

Riis et al., 2008



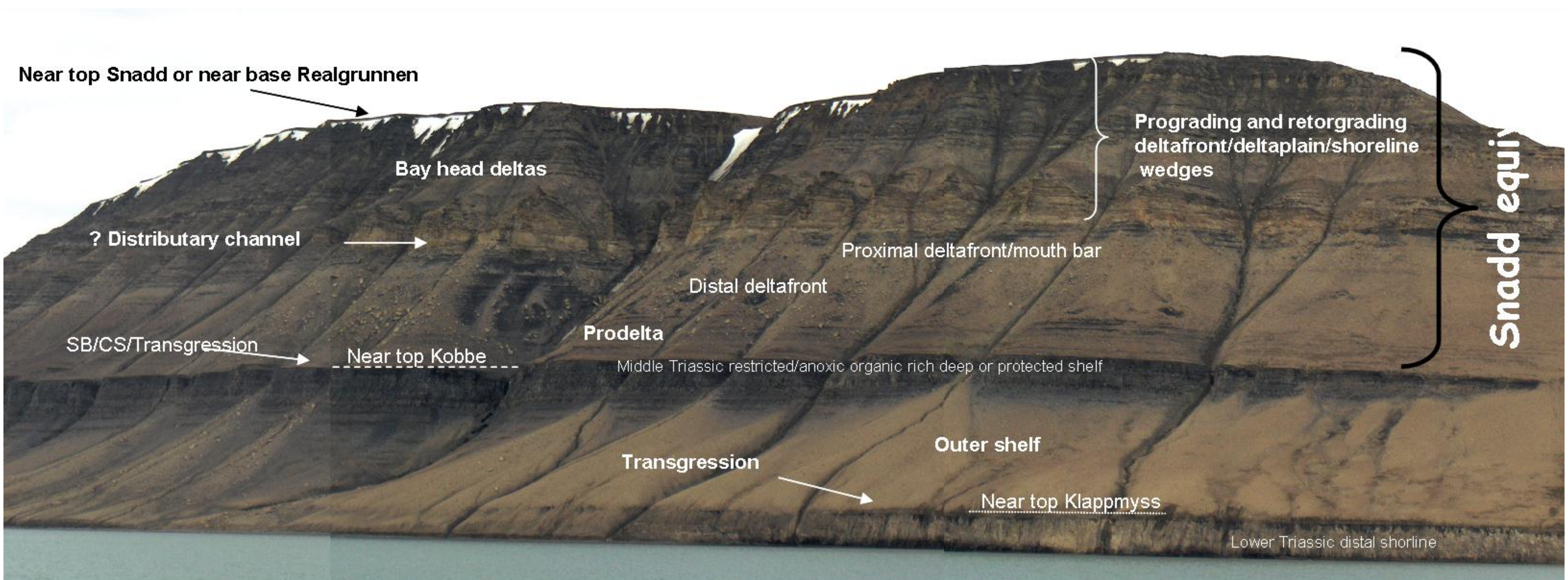


Onshore:
Triassic succession showing regional basin configuration

- **Regional shallow sag (foreland) basin with clinoforms infilling mainly from the ESE to SE**
- **Widespread upper Triassic fault-bound basins of mainly the Snadd Fm age**

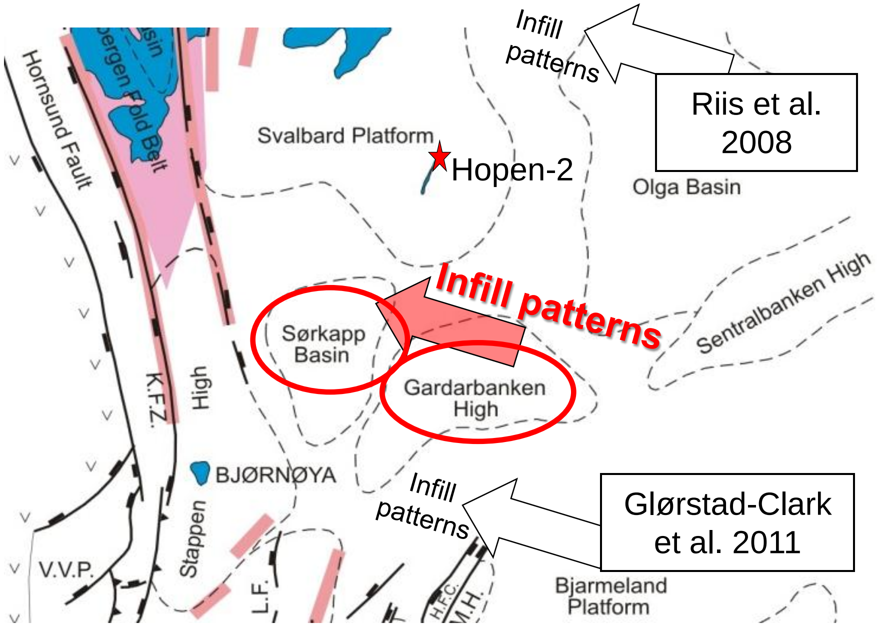
Outcrop analog of the Snadd Formation at Barents Sea

Blanknuten (Edgeøya)



Offshore:

Regional sedimentary system bypassing eastern foredeep basin



Tying seismics to well Hopen-2, and previous studies

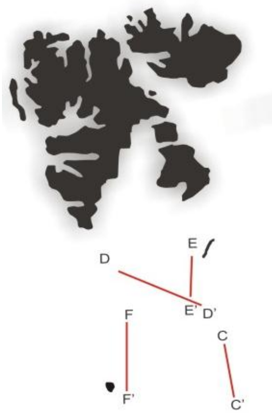
Limited distribution seismics

Triassic sags and up-warps

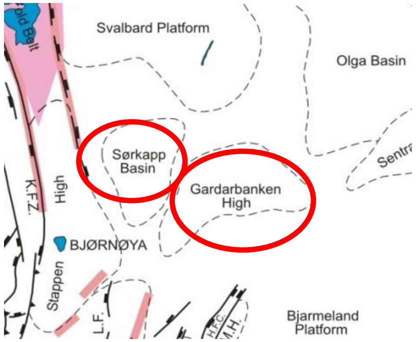
Gardarbanken High (GH)
- Regional up-warping in Early Triassic *(Forebulge - Deep salt - Other?)*
- Blocking Early-Mid Triassic clinoform migration
- Bypassed in Mid. Triassic

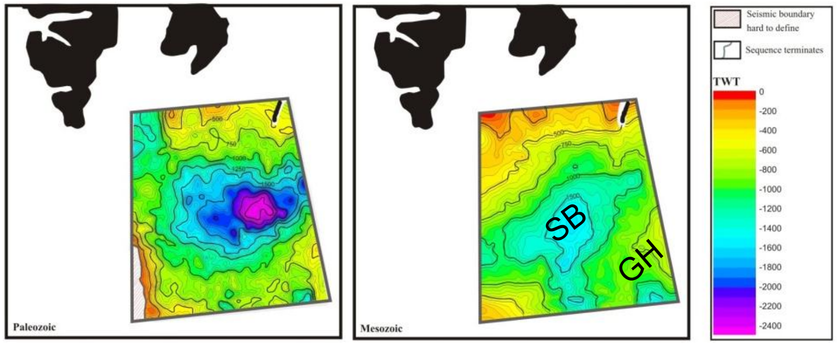
Limited distribution seismics

Sørkapp basin (SB)
- Regional sag basin (back-bulge?)
- Thick, continuous(?) Triassic succession



Limited distribution seismics





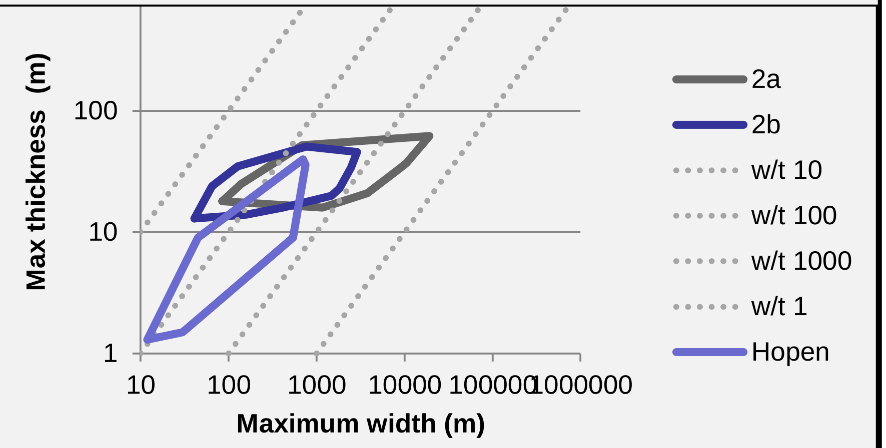
Details: Sediment routing systems

Correlation between Barents Sea 3D seismics and databases …

… ongoing work (Helland-Hansen et al., UiB)

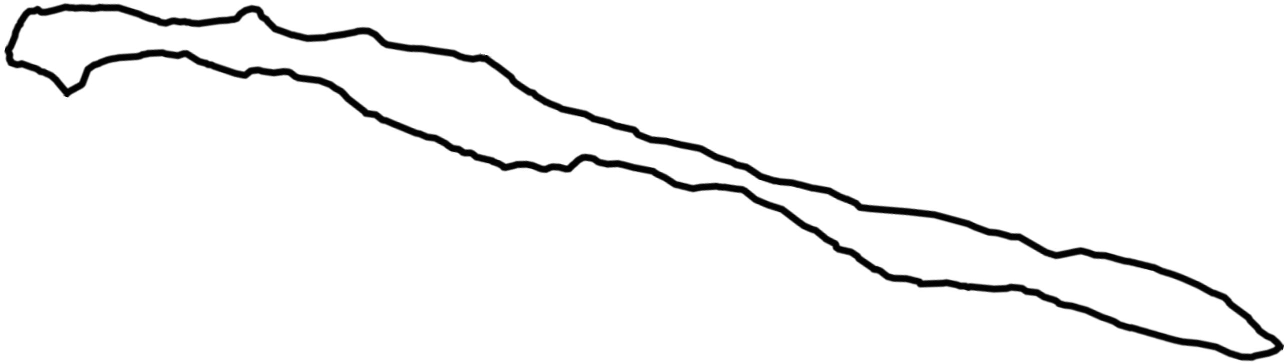
Where are the sand sinks? Upper Triassic drainage patterns identified with seismic attributes in the Hoop Graben area

Comparison of Snadd Fm channels (seismics) to De Geerdalen Fm channels (onshore Hopen)



Limited distribution seismics

Fluvial/Distributary channels



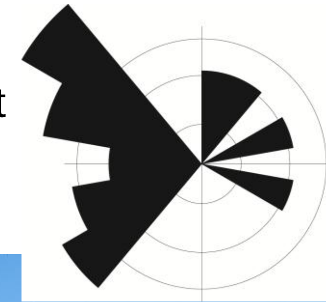
Outline of Hopen

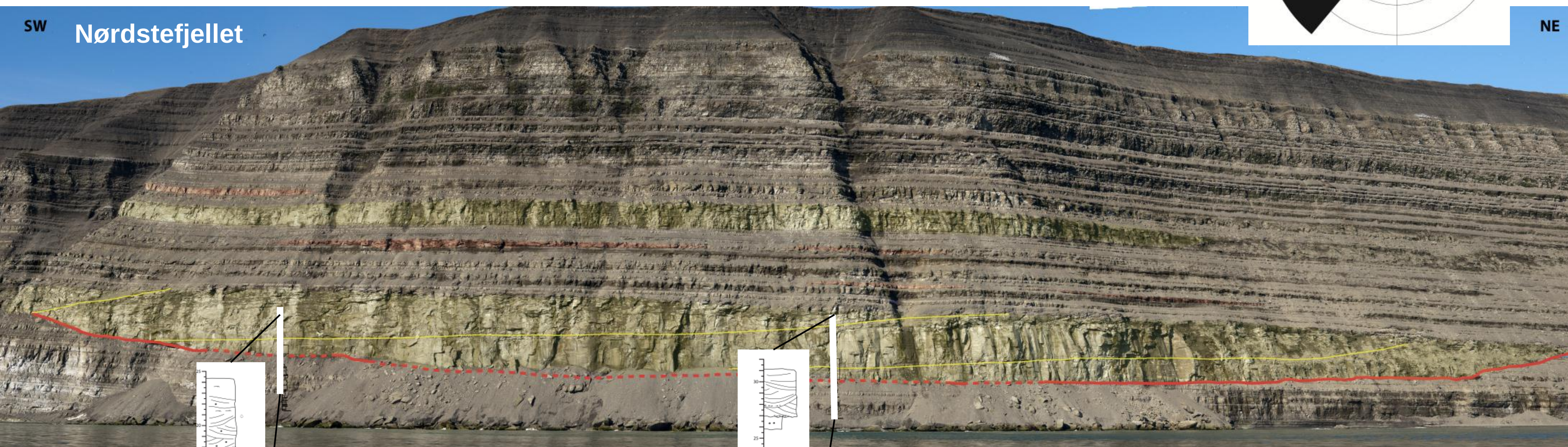
Hopen: Fluvial channel sandstone

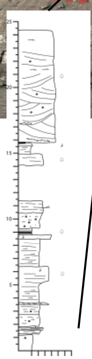
… point bar progradation

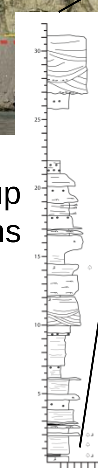
… partly on subseismic scale

Paleocurrent



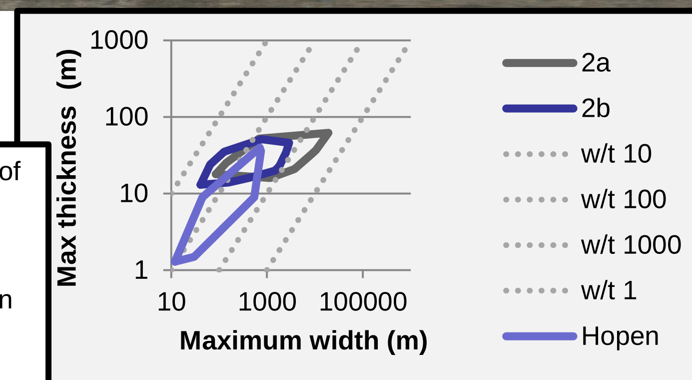




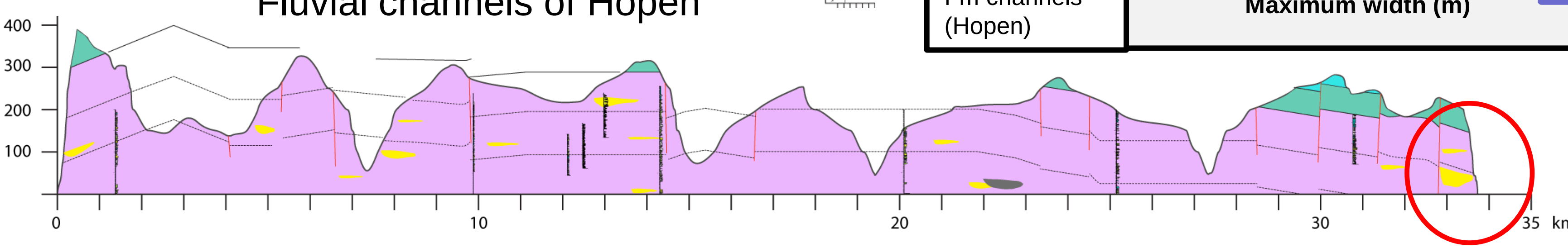


Fining-up successions

Comparison of Snadd Fm channels (seismics) to De Geerdalen Fm channels (Hopen)



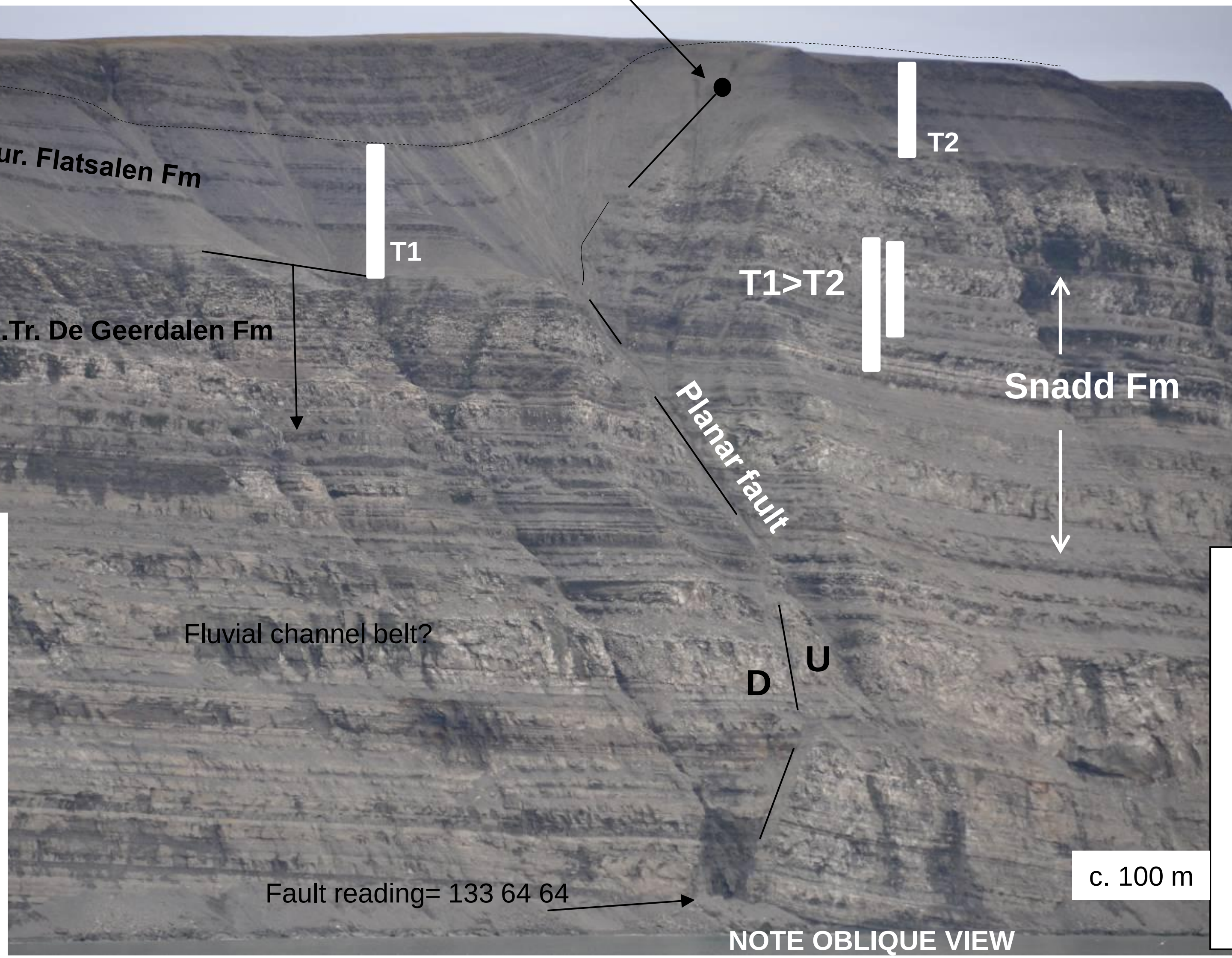
Fluvial channels of Hopen



4) TRIASSIC FAULTING – steep, planar faults of Hopen

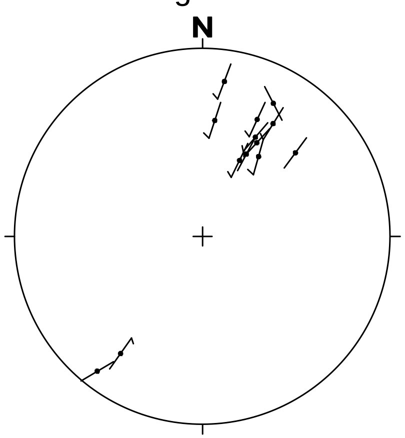
View from the SE of the northernmost fault on Hopen

Fault-tip defined as a major monocline in shale



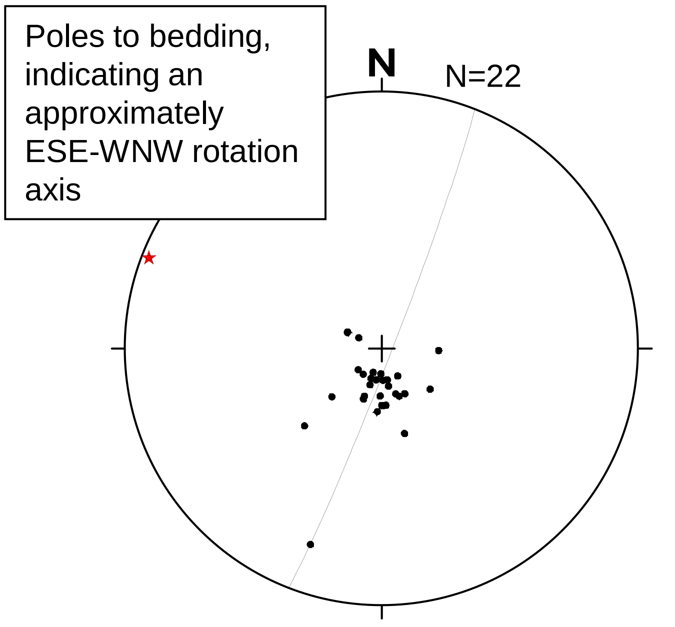
Fault throw c. 60 m

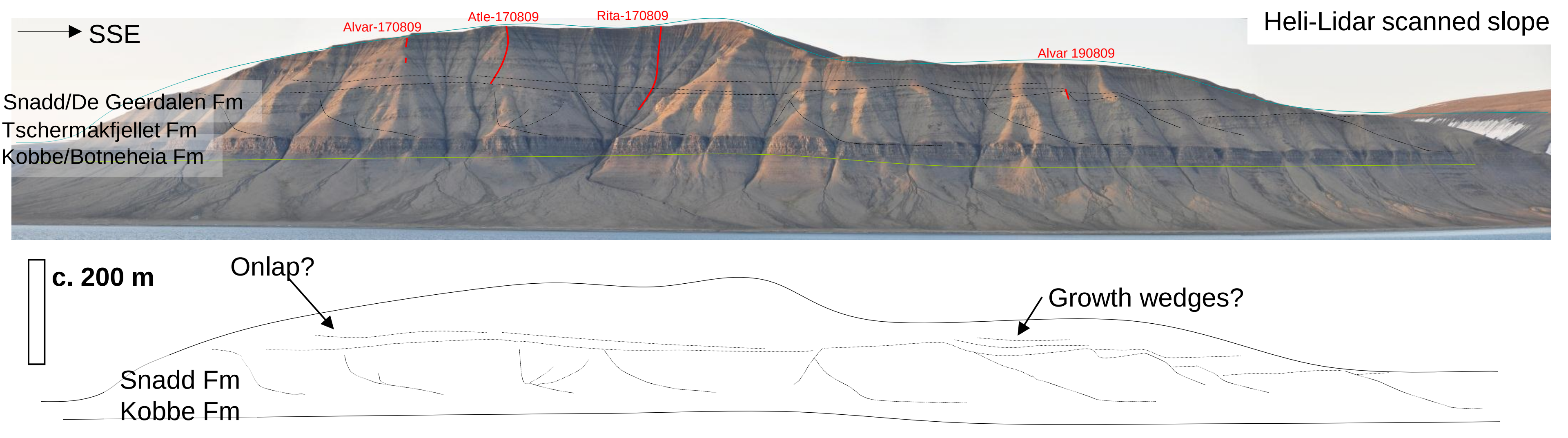
Dip slip normal fault striking c. 115°



Faulting of Klinkhammaren, Edgeøya

- Faults inferred from truncated sandstone sections
- Domino-style block faulting above bedding-parallel detachment near top Kobbe Fm
- Growth deposits seen in the upper shale section to the south.
- Erosional base below the upper succession that buries the faults.
- Snadd/DeGeerdalen Fm develops from a marine, thick-bedded and sandstone dominated lower succession, into variable paralic deposits in the upper half.





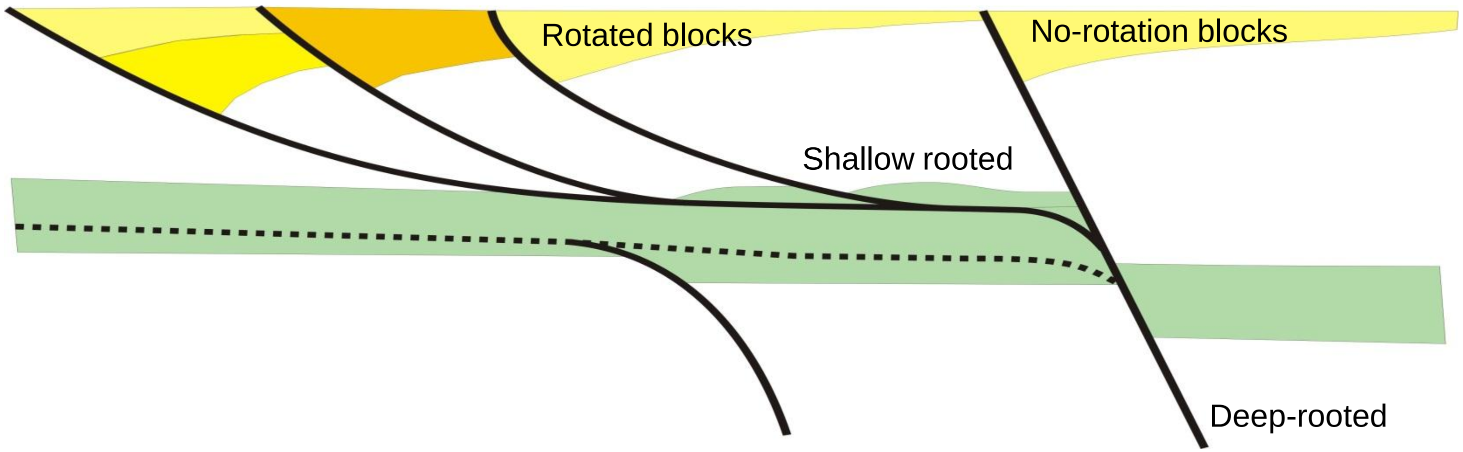
Fault style summary: Edgeøya (Hopen)

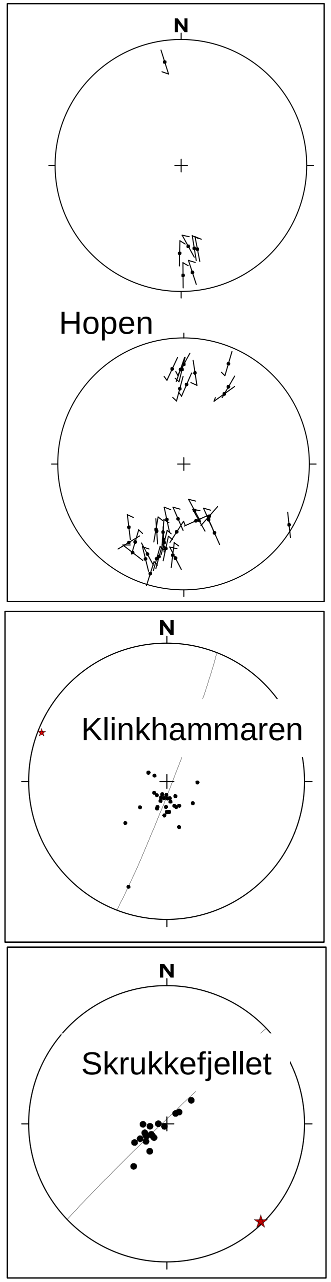
- Steep, planer 50-100m faults cutting Kobbe/Botnheia Fm shale
- Listric faults rooting in Kobbe/Botnheia Fm shale

- Both fault systems with similar strike (~ E-W)
- Both fault systems with sedimentary growth wedges, hence active in Late Triassic time

⇒ **Detachment in Kobbe/ Botnheia Fm pro-delta shale**

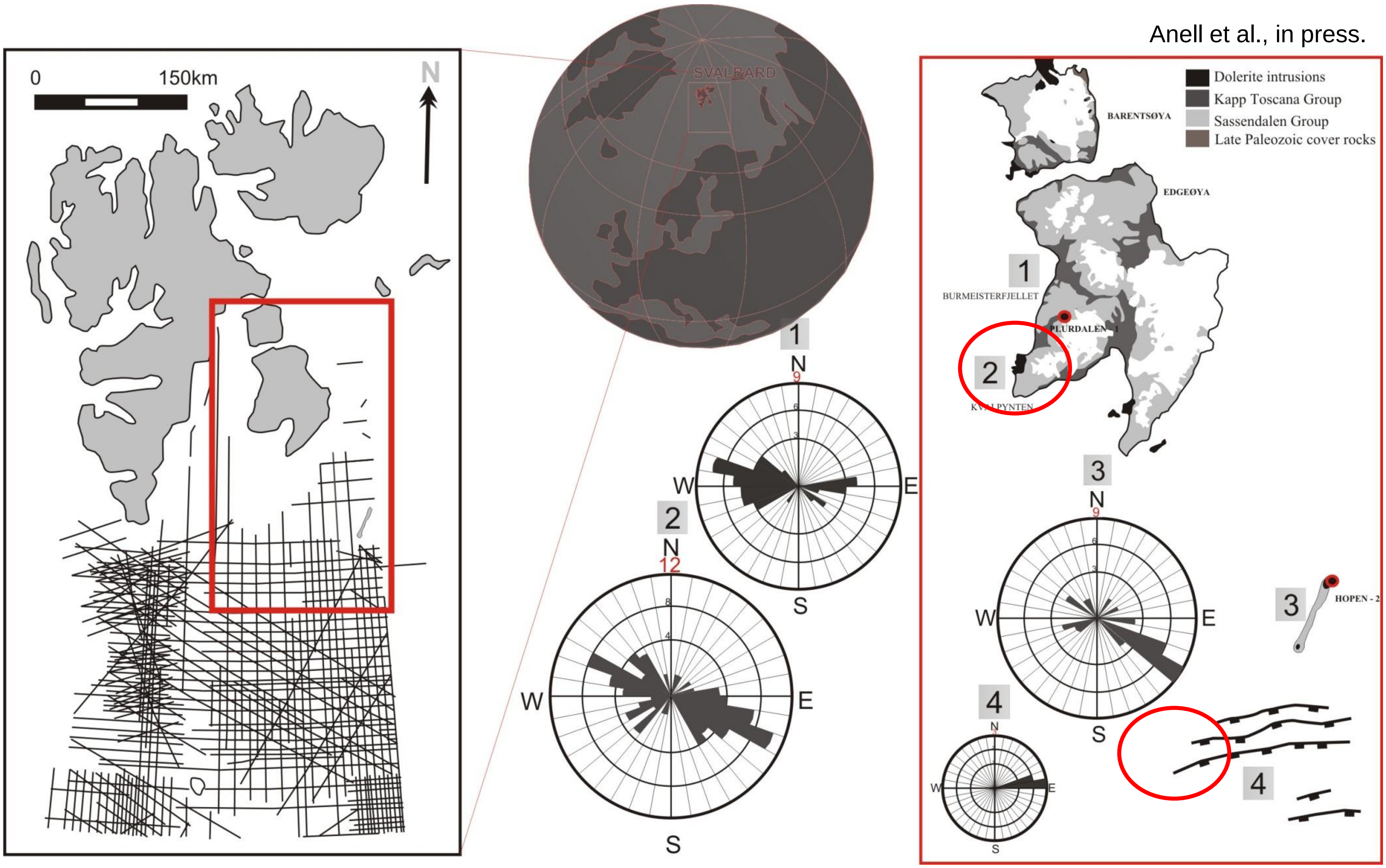
⇒ **Decoupled but linked deep-rooted (planar) and shallow-rooted (listric) faulting**





Orientation of Triassic fault system, as seen in onshore and offshore data

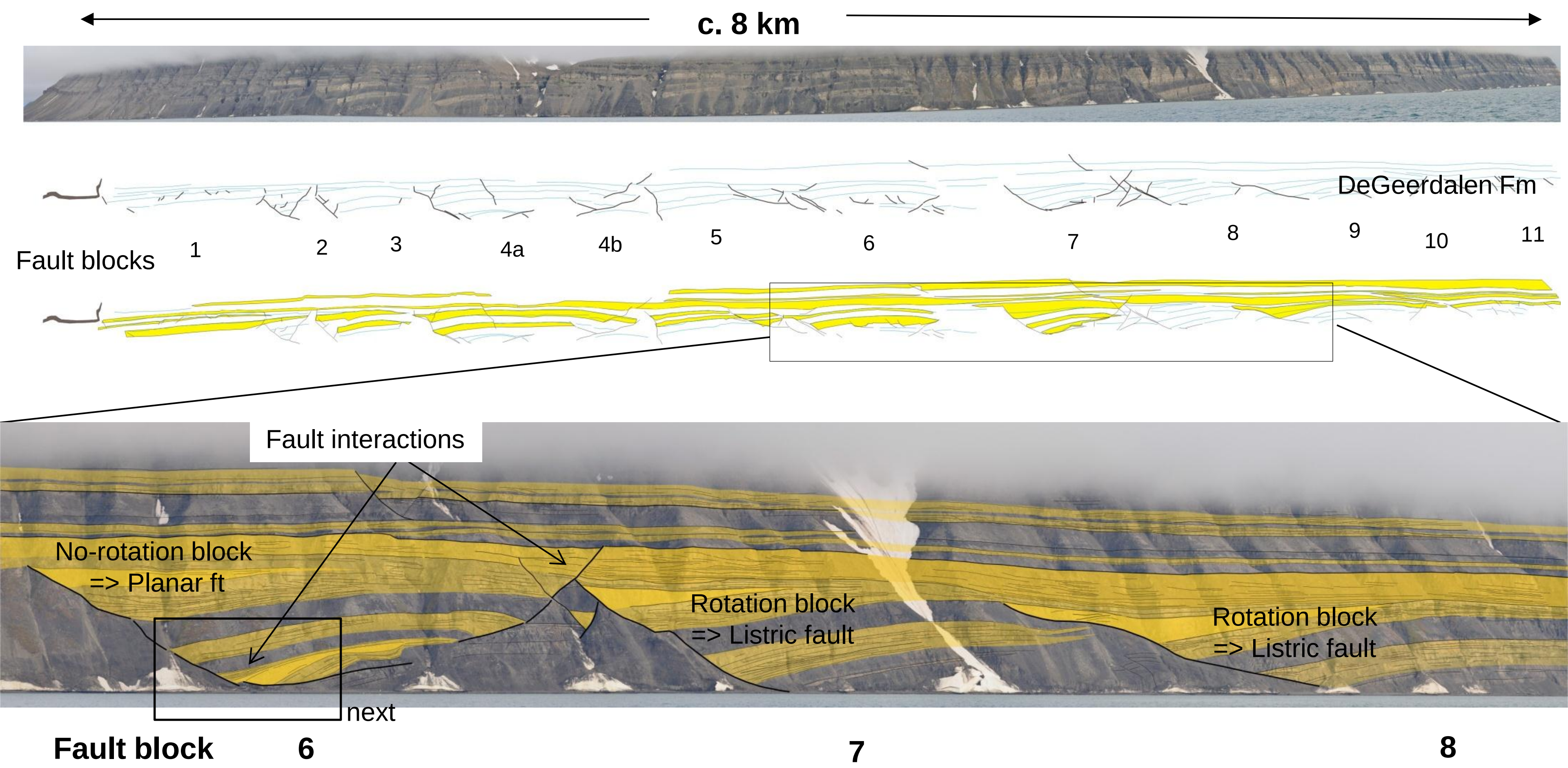
Anell et al., in press.



World class example of interacting shallow and deep rooted fault system

- Kvalpynten growth fault system, South Edgeøya

Growth fault = contemporaneous faulting and sedimentation, evidenced by abrupt increase of thickness across fault ……
e.g., Edwards (1976)



Kvalpynten fault characteristics

Note rotated low-angle to bedding ”normal” fault

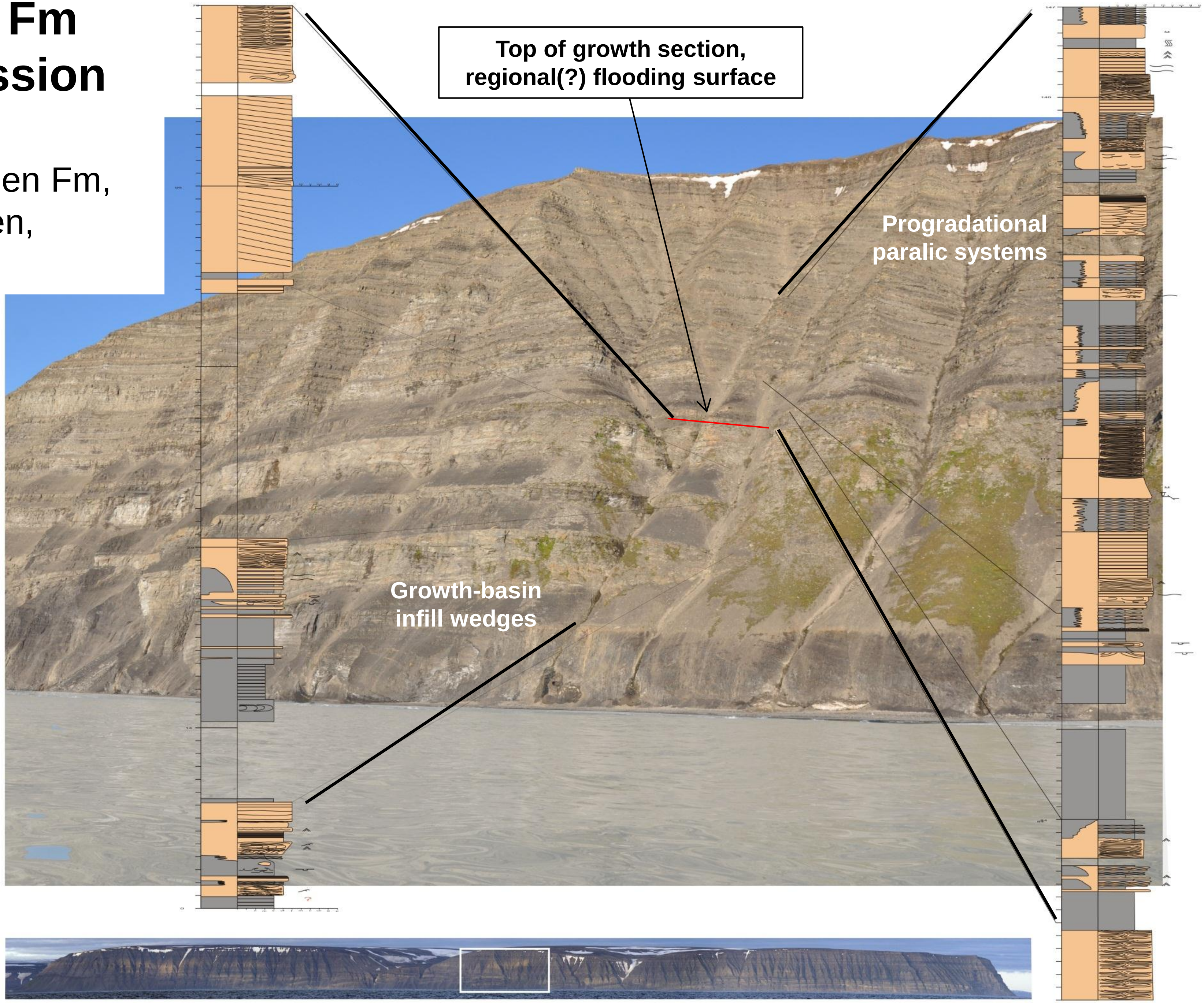
Slip surface with 2-5 cm sheared sand membrane on HW side, and 5-10 cm sheared shale mebrane on FW side

Disaggregation (grain rolling) deformation band with sand smear

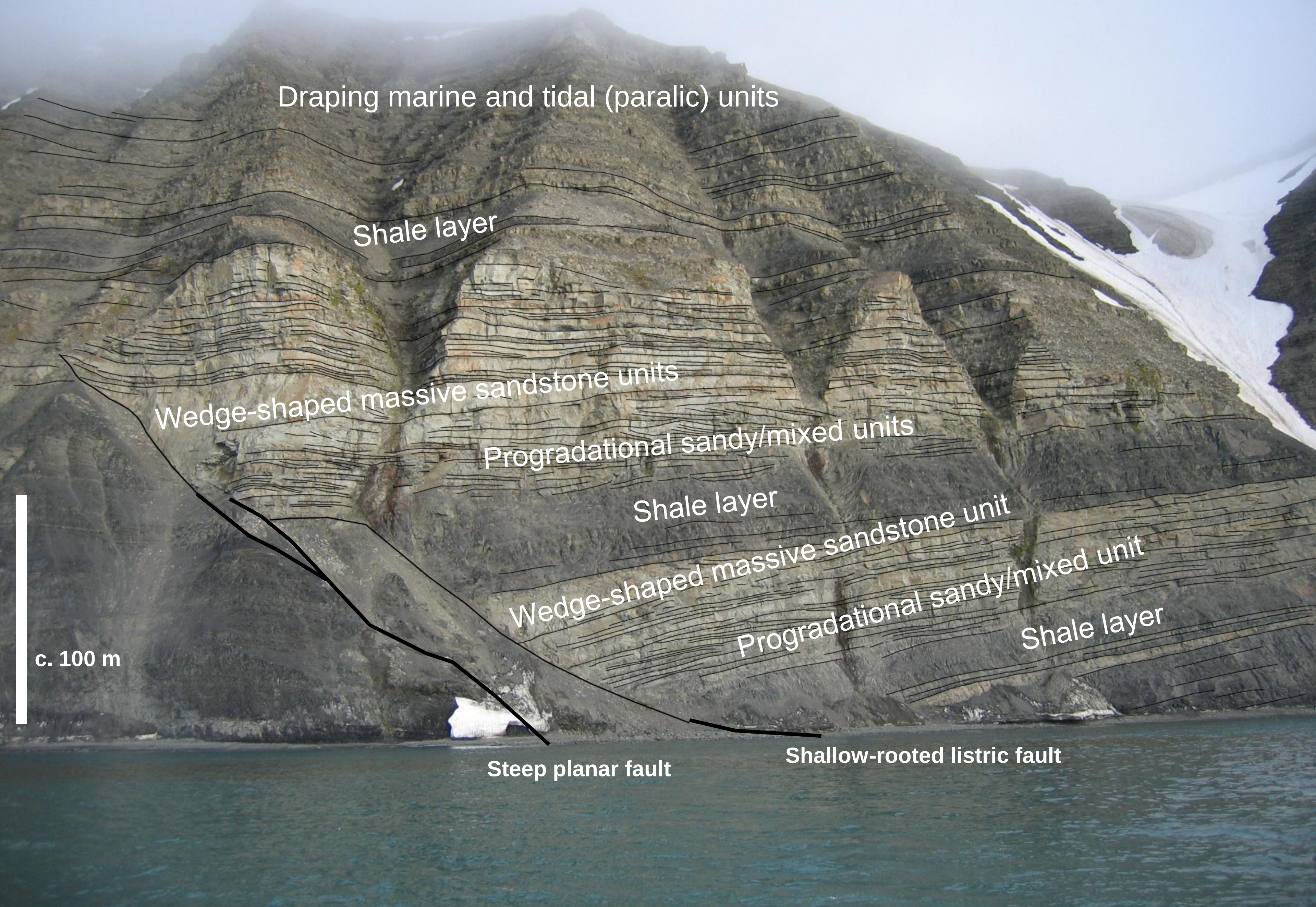
Sheared sand membrane (c. 10 cm) hosting mixed-in clay and diagenetic pyrite. No slip surface!

Snadd Fm succession

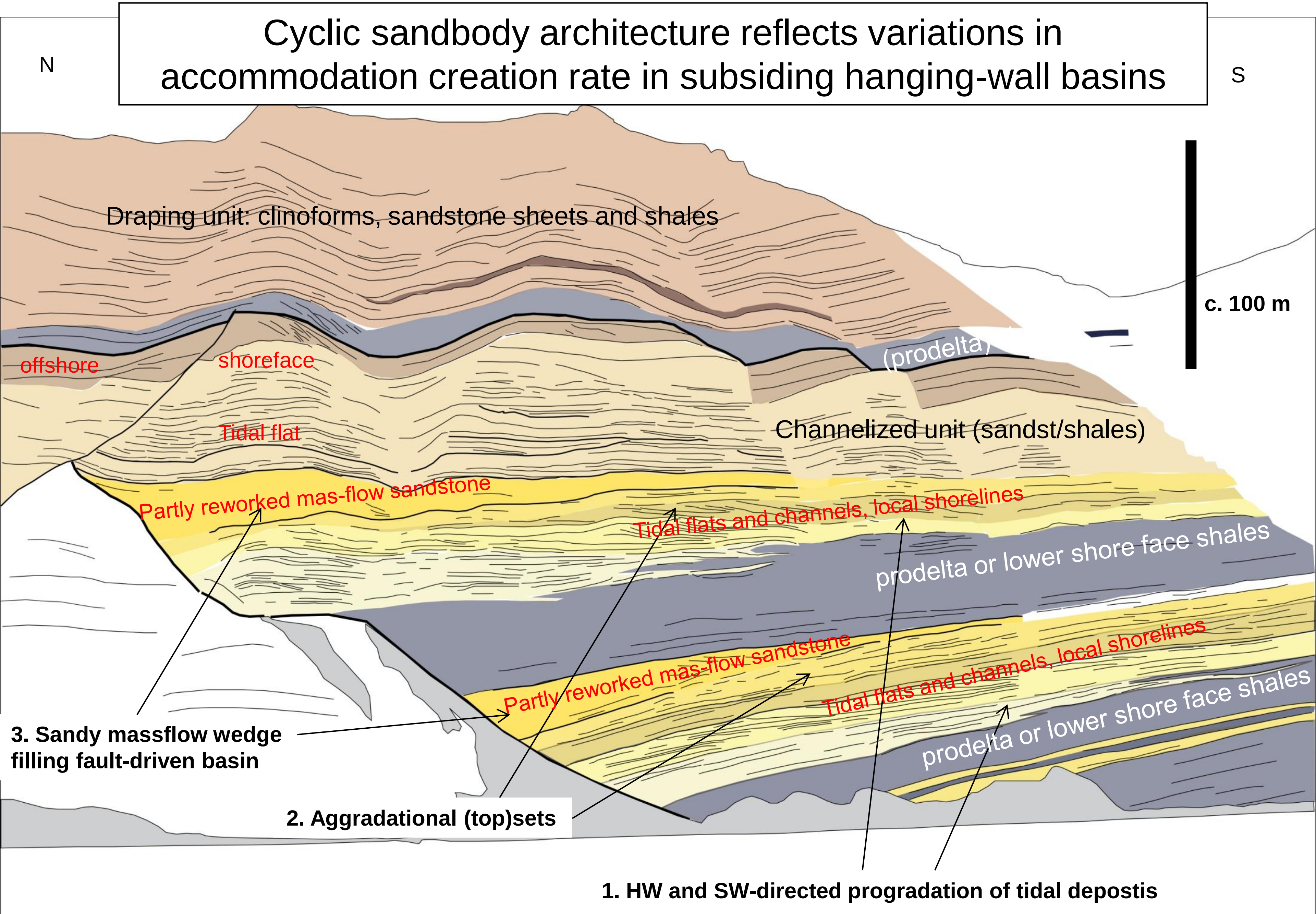
DeGerdalen Fm,
Kvalpynten,
Edgeøya



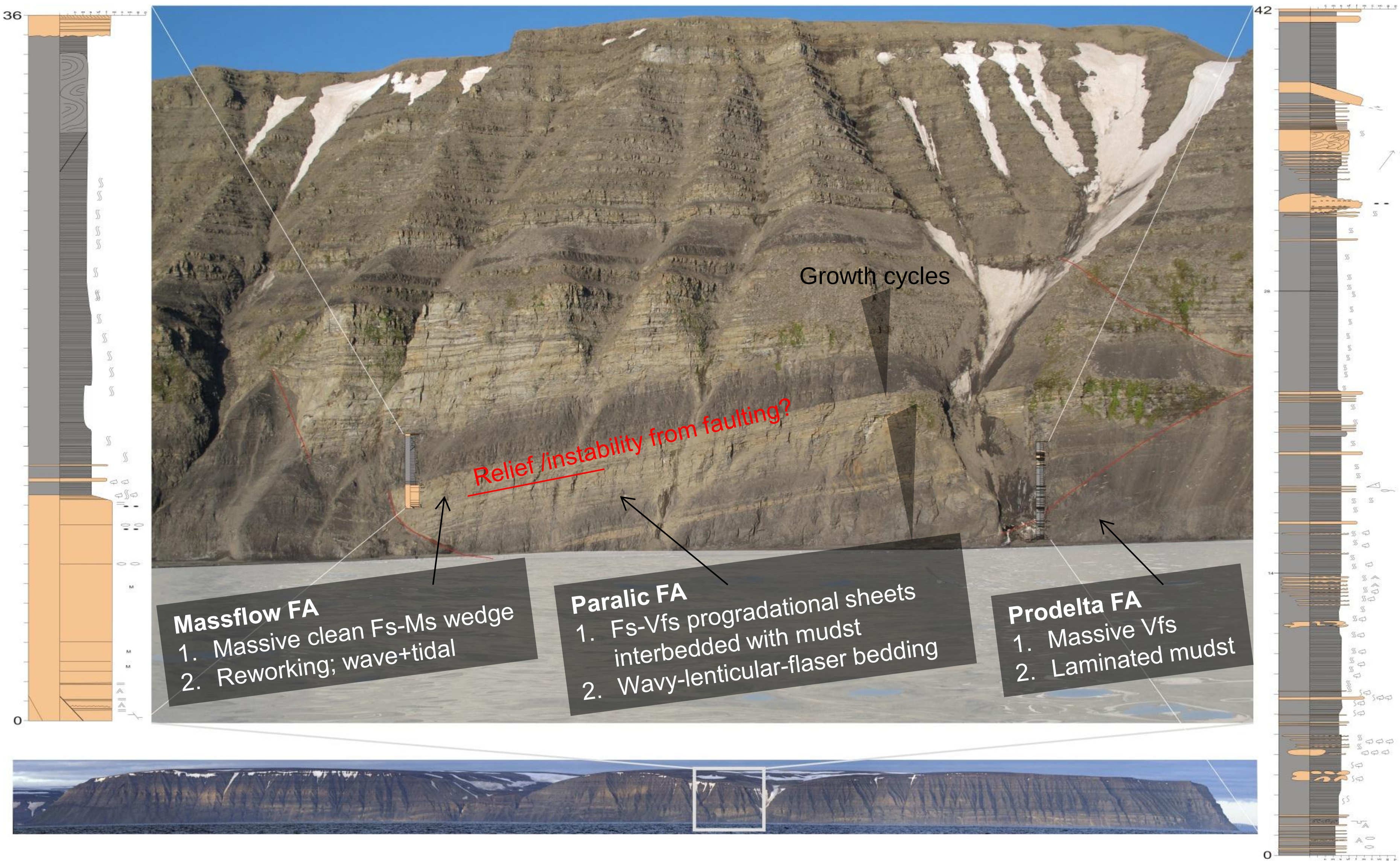
Growth basin successions



Cyclic sandbody architecture reflects variations in accommodation creation rate in subsiding hanging-wall basins



Growth successions – typical facies associations (FA)



Deep-rooted faults terminating in the Snadd Fm, as seen in seismic lines of SE Svalbard

Complex reflection patterns in the upper Triassic succession could be caused by listric, shallow rooted faults, setting up 100m deep (< 100 ms) growth basins. This will be pursued through comparison with synthetic seismics

Limited distribution seismics

Deep root

Deep root

Deep root

Distorted level

Distorted level

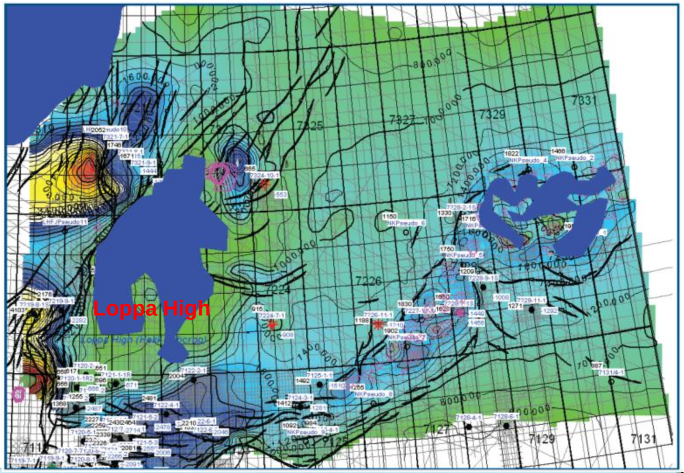
Growth

Growth

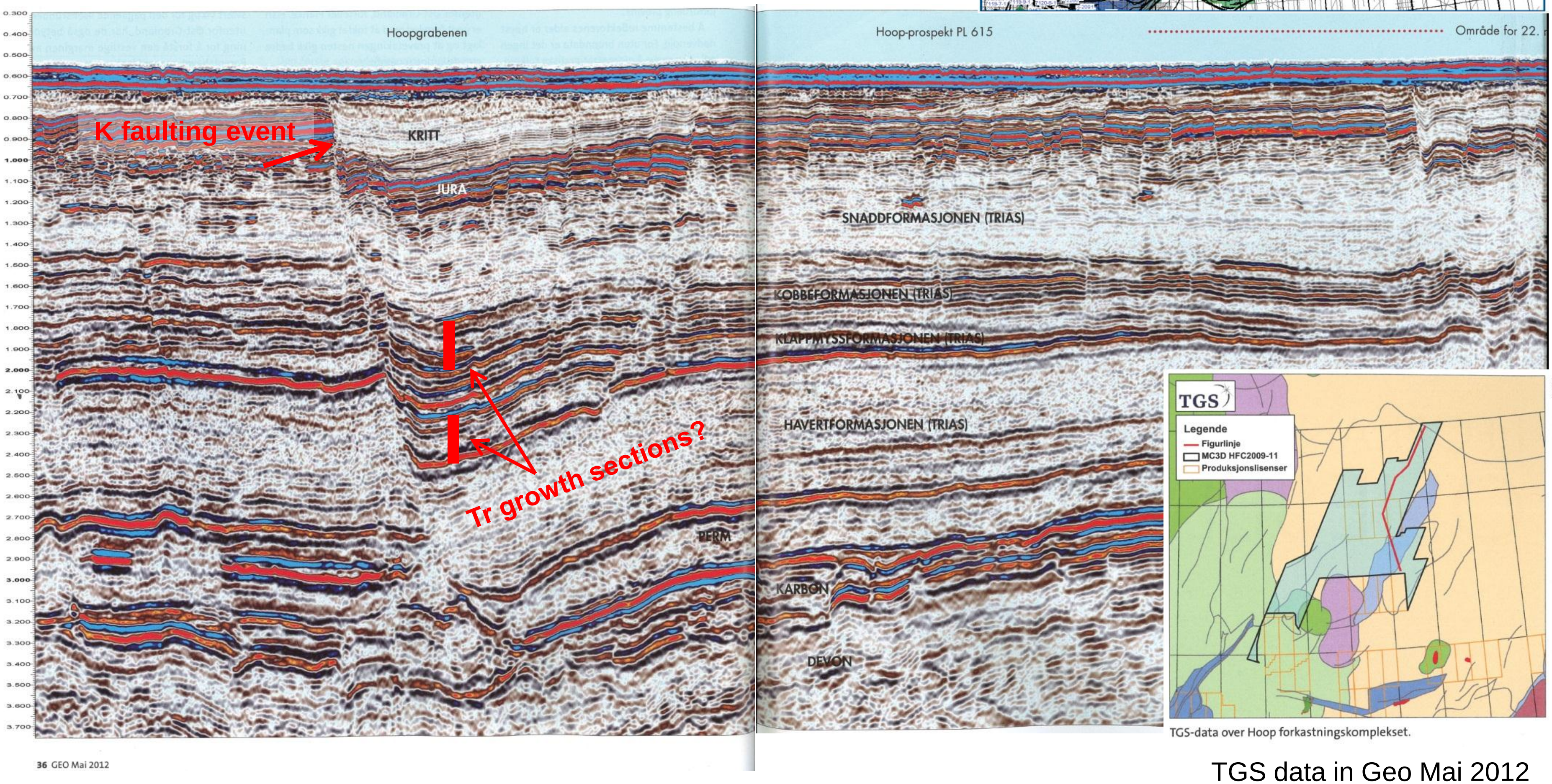
Deep root

Anell et al., in press

Triassic faulting is regional



Hoop Graben with Triassic fault activity; ongoing PhD work on growth successions as seen in 3D seismics



TGS data in Geo Mai 2012

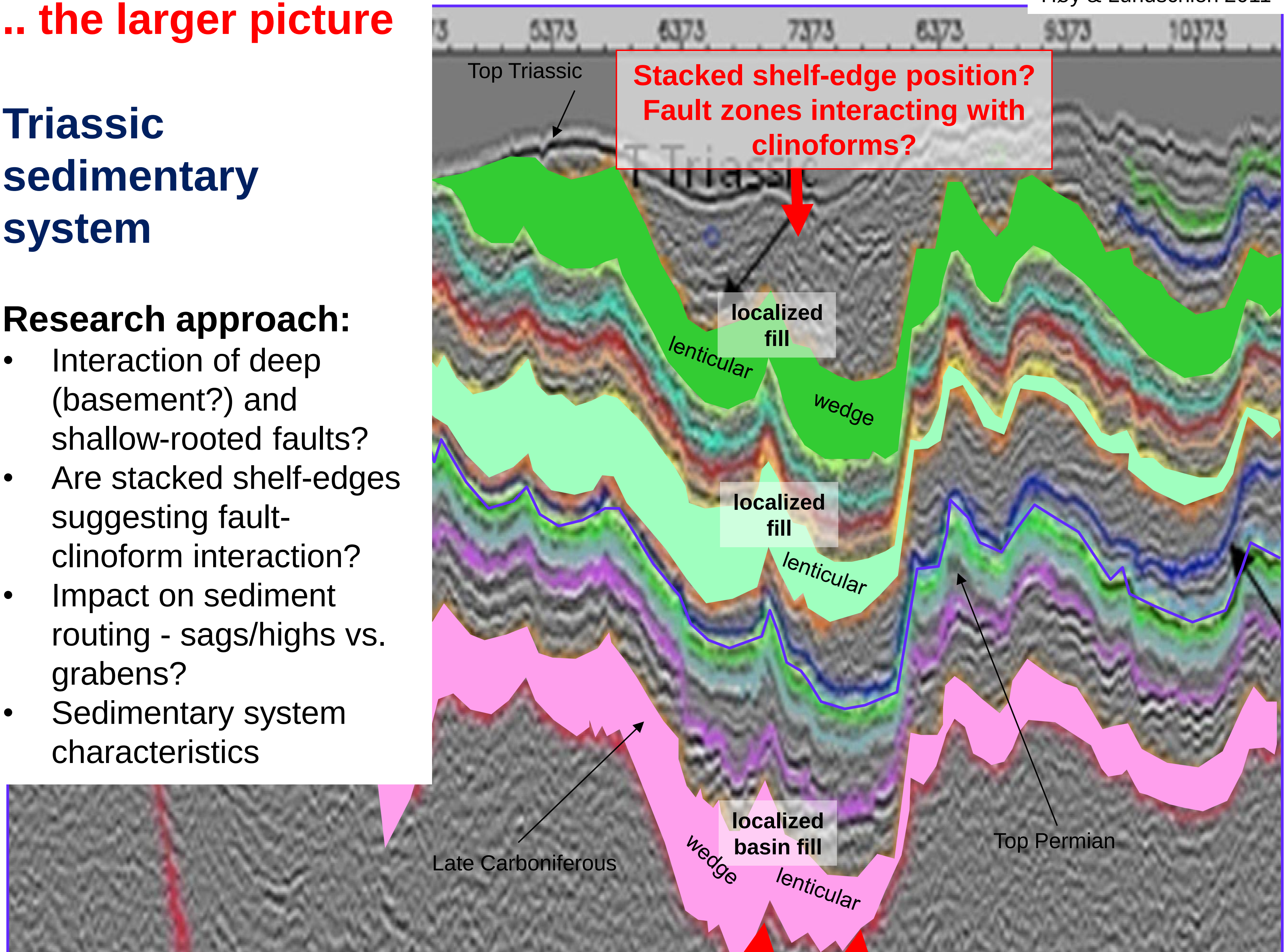
.. the larger picture

Høy & Lundschien 2011

Triassic sedimentary system

Research approach:

- Interaction of deep (basement?) and shallow-rooted faults?
- Are stacked shelf-edges suggesting fault-clinoform interaction?
- Impact on sediment routing - sags/highs vs. grabens?
- Sedimentary system characteristics



5) SUMMARY:

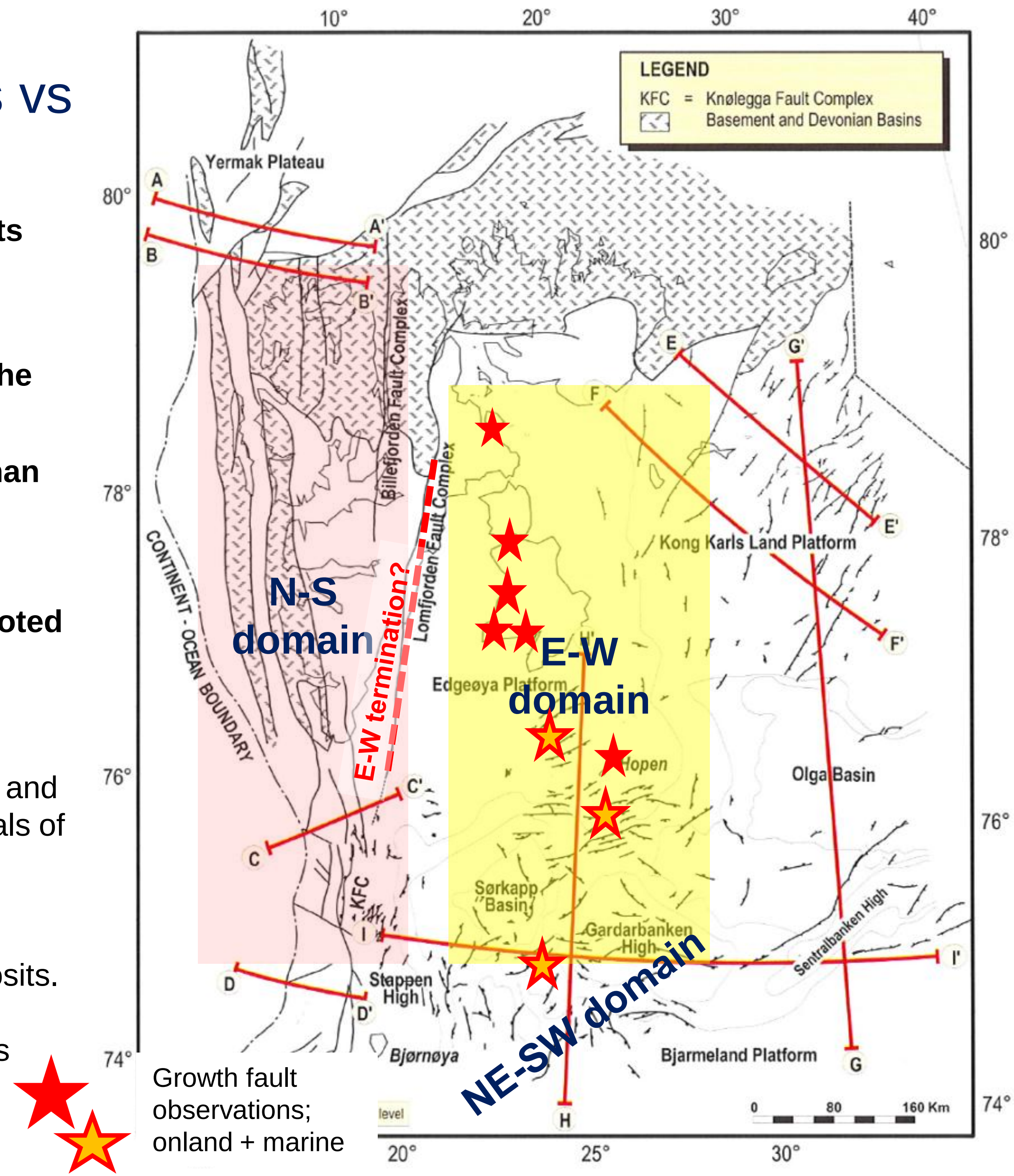
Triassic growth basins vs clinoform shelf infilling

- ✓ **Clinoform progradation interacts with sags and highs;** forebulge–backbulge, deep salt or other drivers?
- ✓ **Clinoforms locally arrested by Triassic fault-bound basins of the Snadd Fm age**

- ➢ **Regional faulting event rather than delta collapse** (proposed earlier)
- ➢ **Reactivated Carboniferous, basement-rooted faults?**
- ➢ **Partly detached fault system, rooted in Kobbe Fm shales** (Edgeøya and distorted seismic levels)

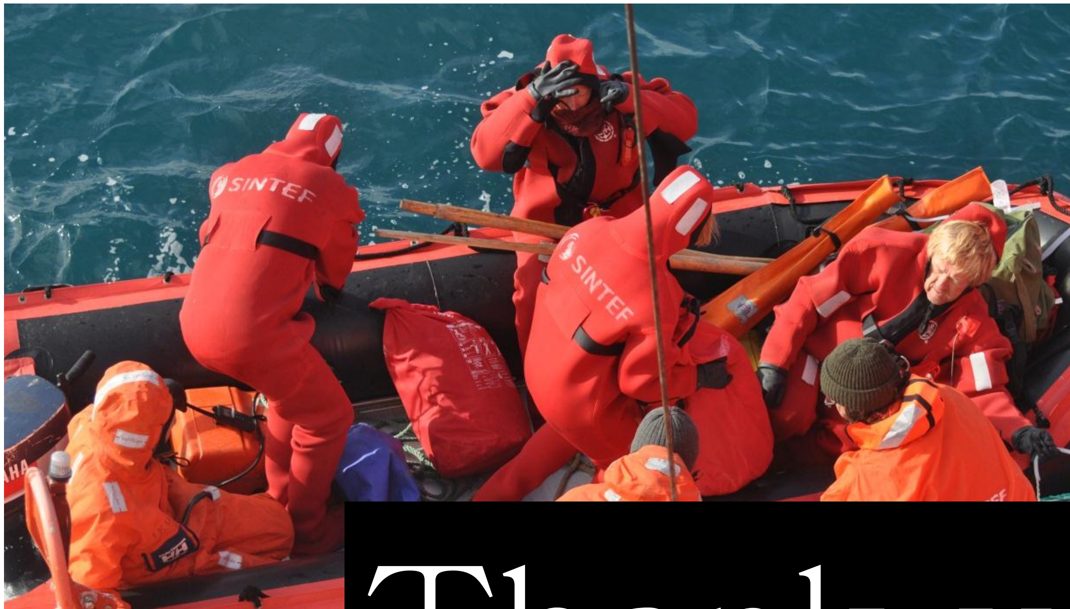
Snadd Fm growth wedges:

- ✓ Pro-delta shales to delta/shoreline and partly fluvial deposits. Strong signals of tidal influence.
- ✓ Basins locally filled with massive sandstone, considered as fault-triggered instability massflow deposits.
- ✓ Significant variation in reservoir sandstone location and geometries => exploration strategy?



DATASETS FROM:

- ✓ NPD EXPEDITION, 2009
- ✓ UNIS EXPEDITION 2012



Thank you ...