

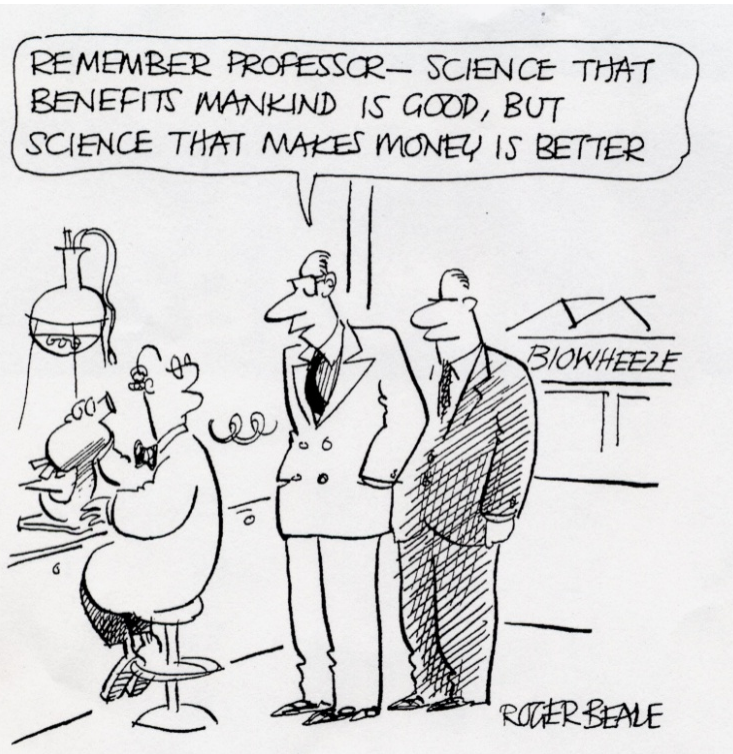
# **Crustal fluid systems (in sedimentary basins)**

**Joe Cartwright**

**Cardiff University**

**Santa Fe, Nov 4th, 2010**

## Interesting, Important and Useful (?).....

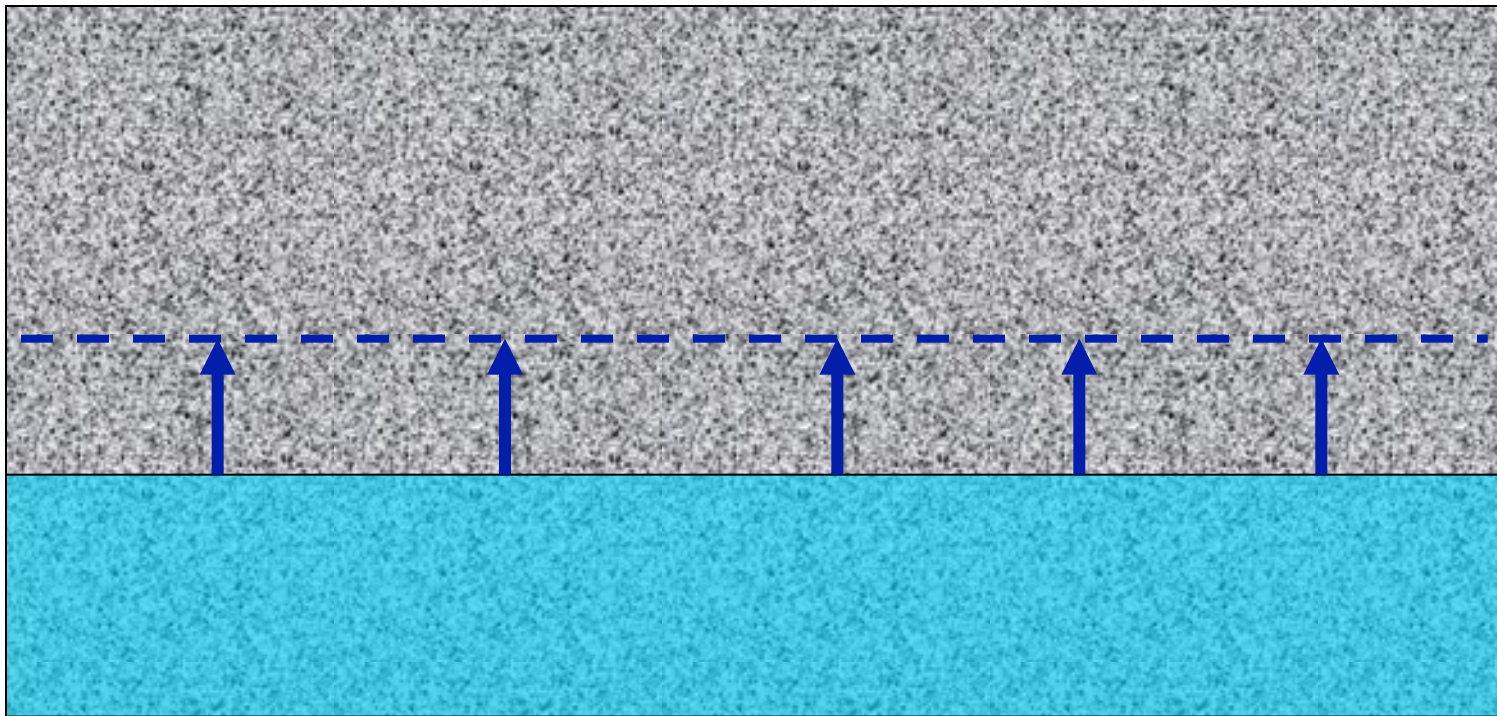


## ACKNOWLEDGEMENTS

Anadarko  
BP, BHP, ENI  
ChevronTexaco, Conoco Phillips  
StatoilHydro, Petrobras,  
Schlumberger, Shell, Total  
BG Group,  
NERC, Royal Society, BERR

**Standard model approach:  
uniform flux through a porous medium, driven by gravitational  
consolidation**

$$Q_w = K \cdot \phi \cdot (dp/dz) \text{ AND } 1d \text{ consoldn} = f(\sigma'_m)$$



————— > 1km

# Lusi mud volcano, Indonesia

$30 \times 10^6$  cubic metres/annum





# Focused Fluid Flow: Aqueous, HC and Magmatic

'Blowout' Pipes/ Conduits/Hydrates/Submarine Slides

Mafic Intrusions into Sediments and Crustal Magma transport

Sandstone Intrusions as evidence for supralithostatic pore fluid pressure

All examples based on advances made with 3D Seismic data...

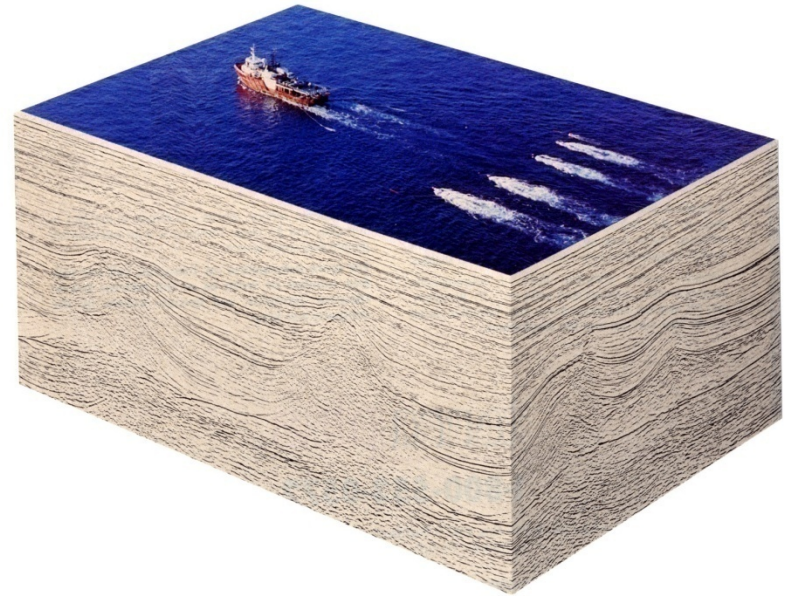
## 3D Seismic Data: **the Geological 'Hubble'**

A revolutionary method for  
imaging the interior of the Earth

Survey lines 12.5m apart over areas  
of c.1000km<sup>2</sup>

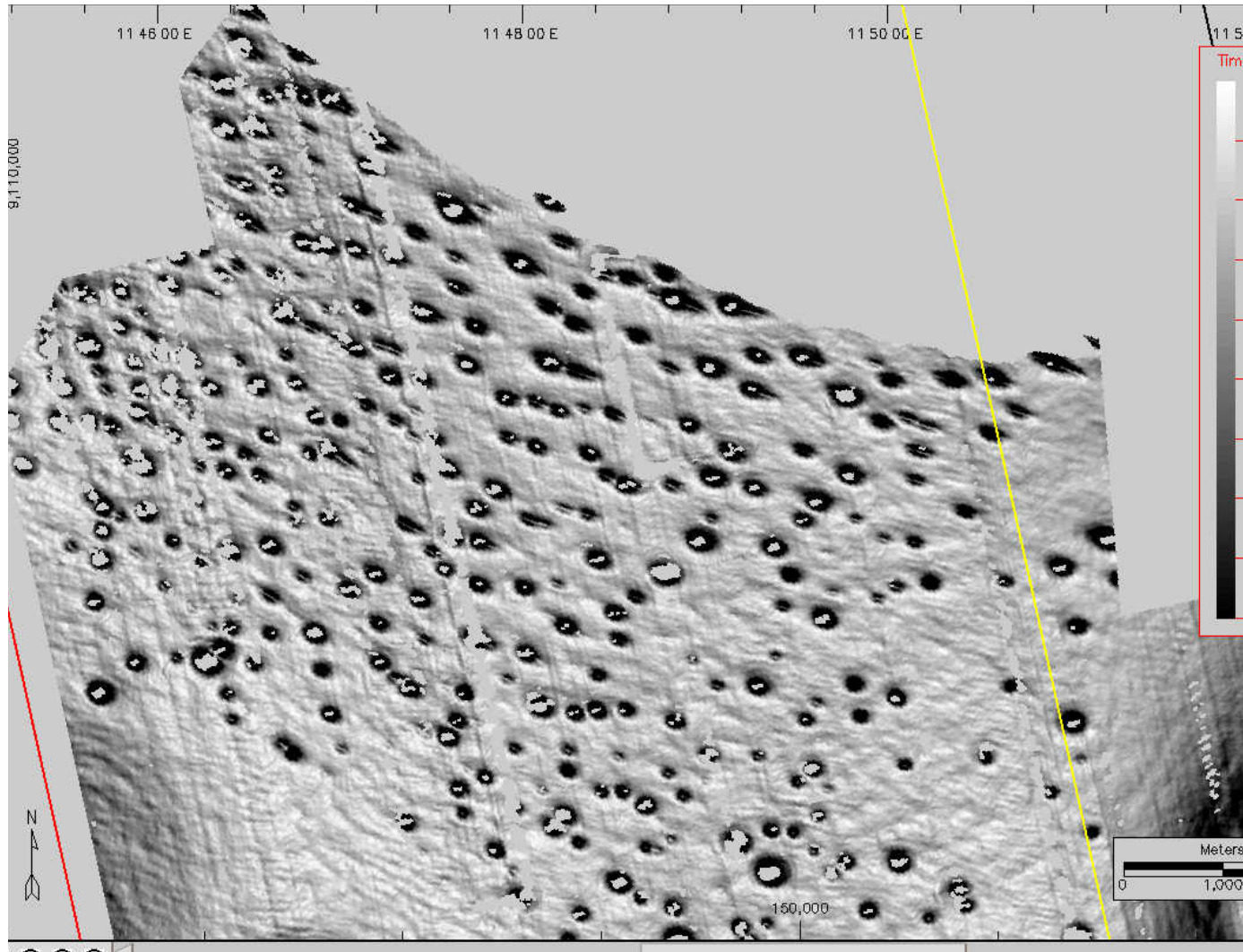
Can resolve objects c. 20-40m wide  
and tall to depths of 5-10km within  
the Earth's crust

**Petroleum Exploration  
3D seismic - state-of-the-art**

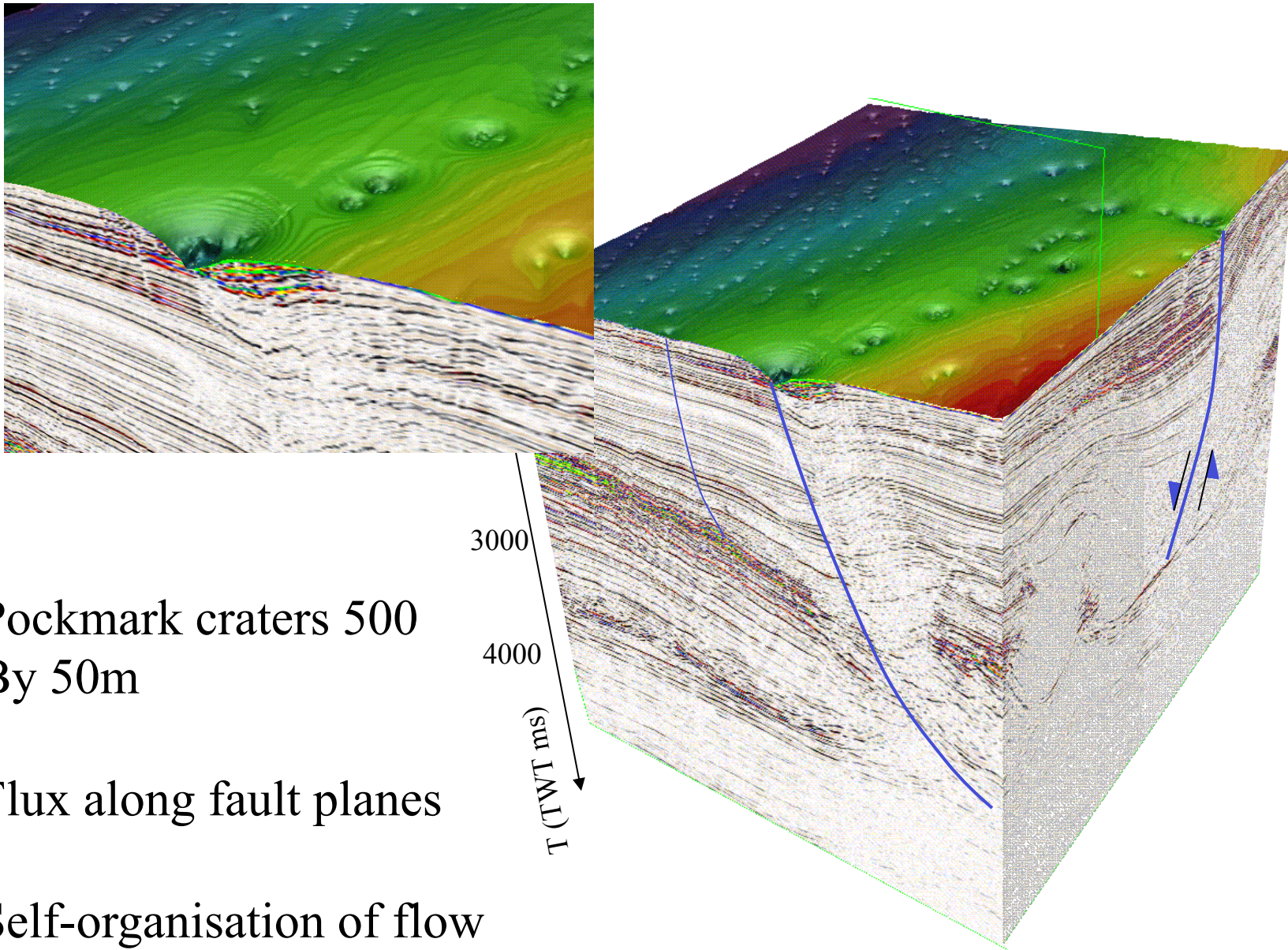


# Pockmark (fluid expulsion) craters at seabed: 200-400m diameter Commonly seen worldwide

Does flux scale with diameter? Single event? Conduit?







Pockmark craters 500  
By 50m

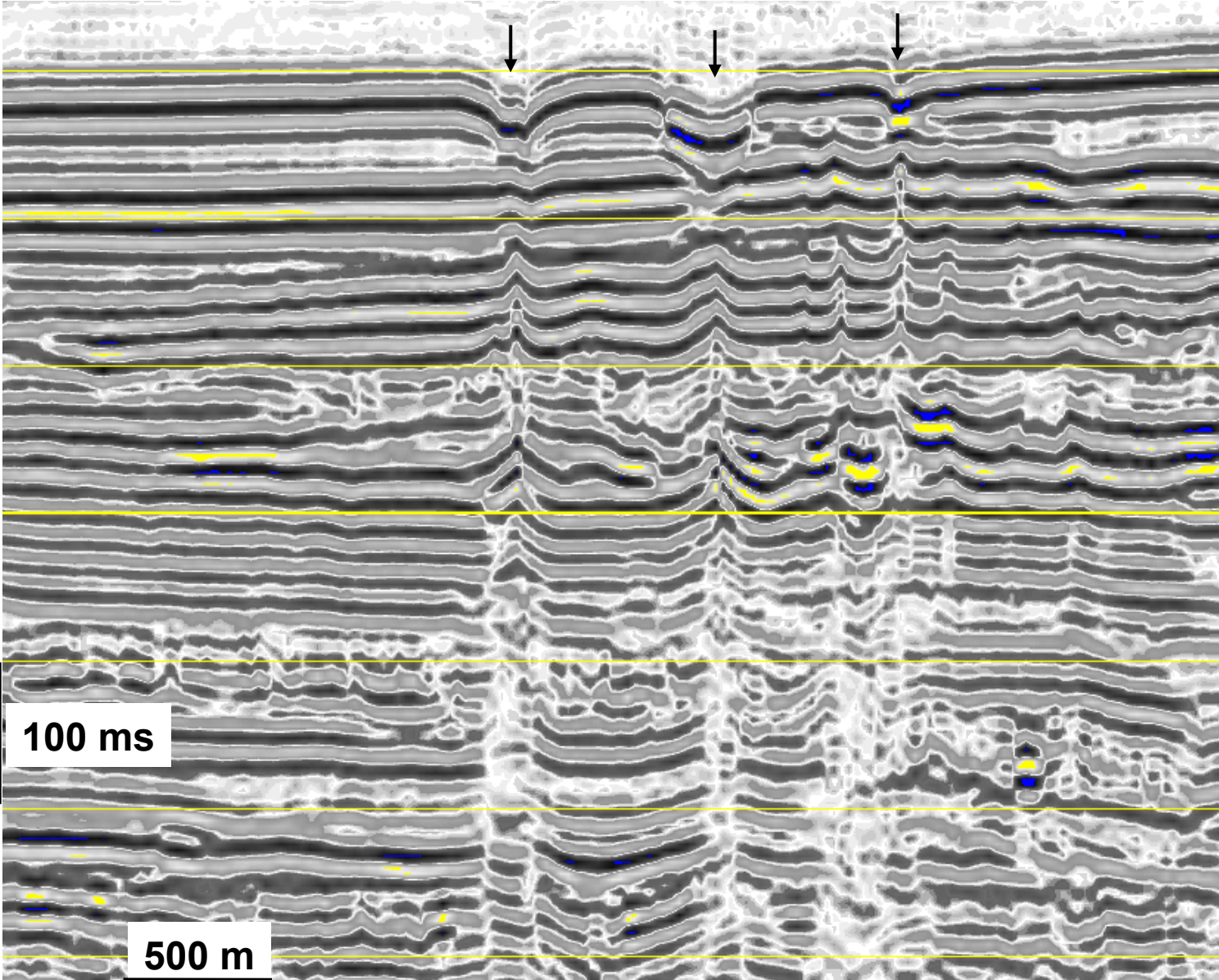
Flux along fault planes

Self-organisation of flow

From sheet to cylinder

**What are the Conduits???**

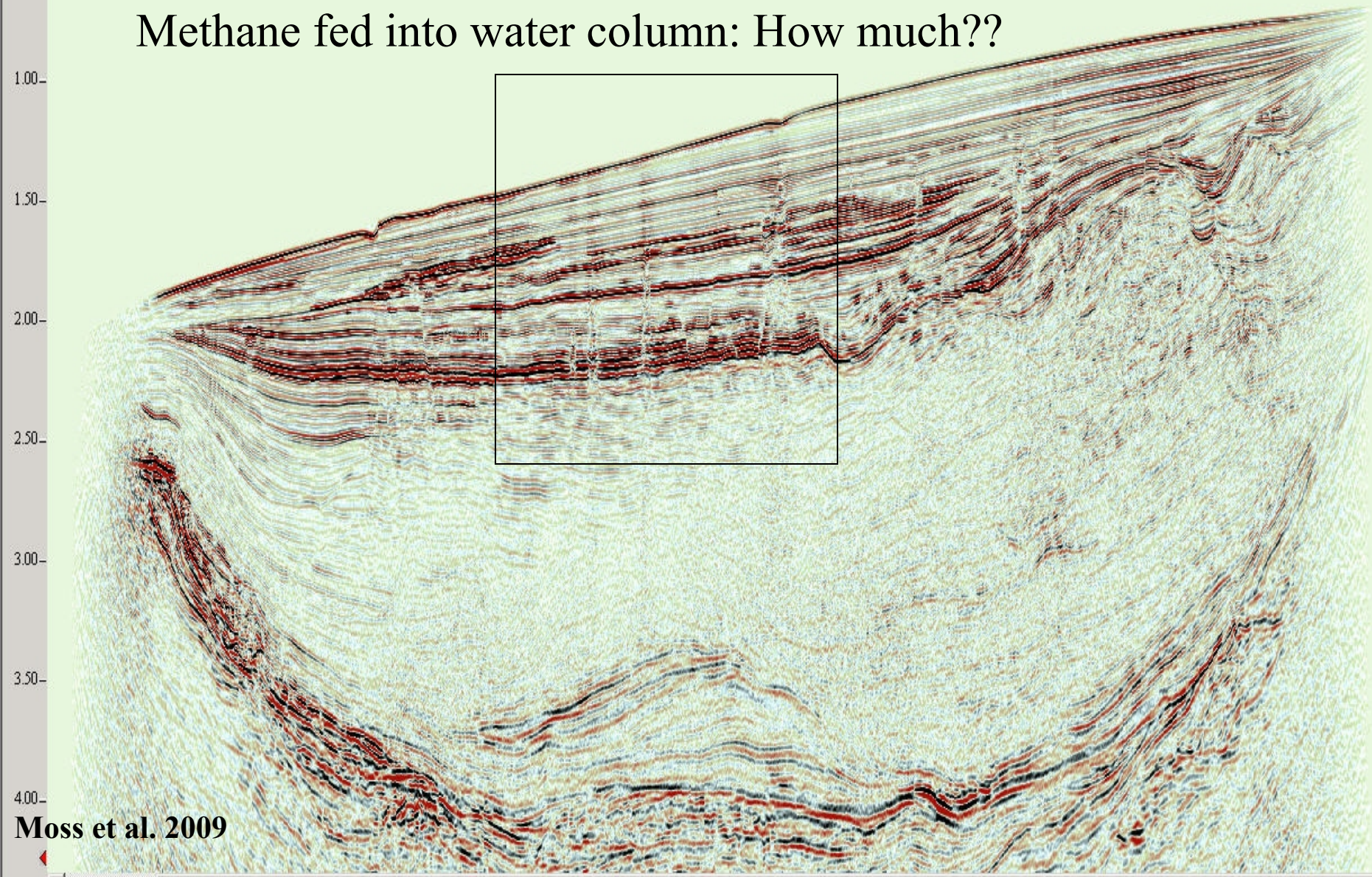






# Namibian continental slope: sub-vertical pipes crossing the BGHSZ

Methane fed into water column: How much??

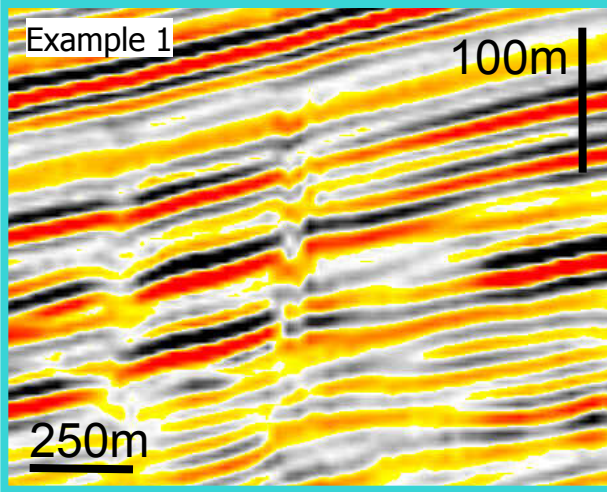




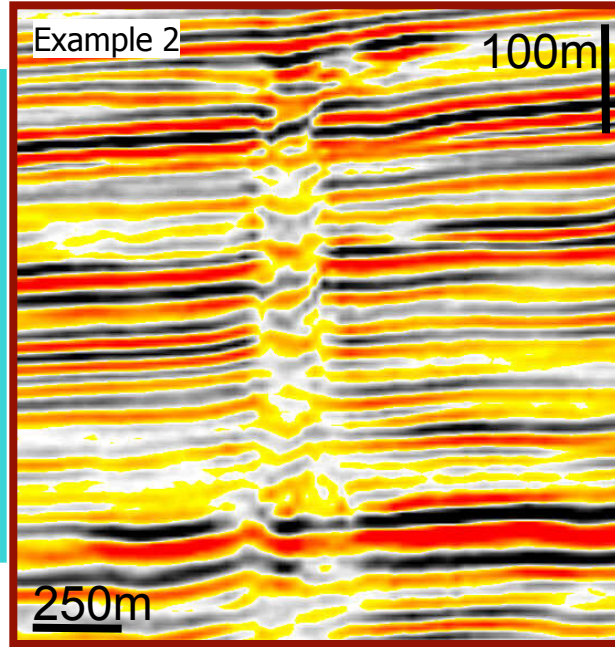
# Geometry of Conduits??

Not drilled, few outcrop analogues

Precursors for Mud Volcanoes??

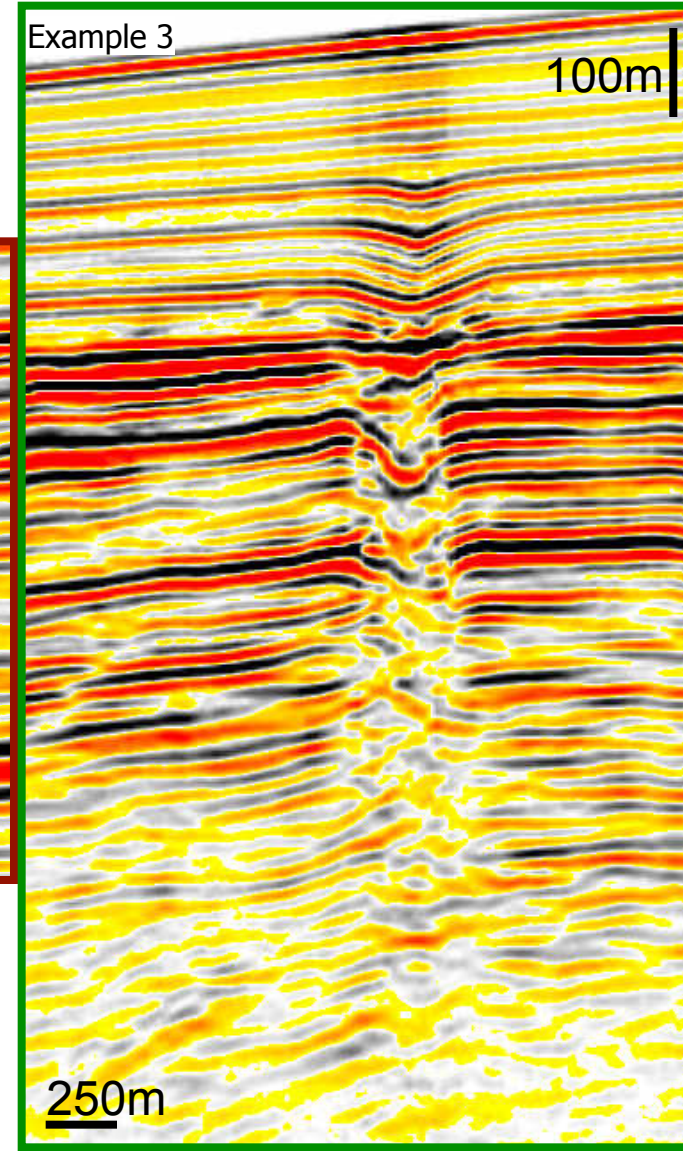


~25m diameter  
~100m height

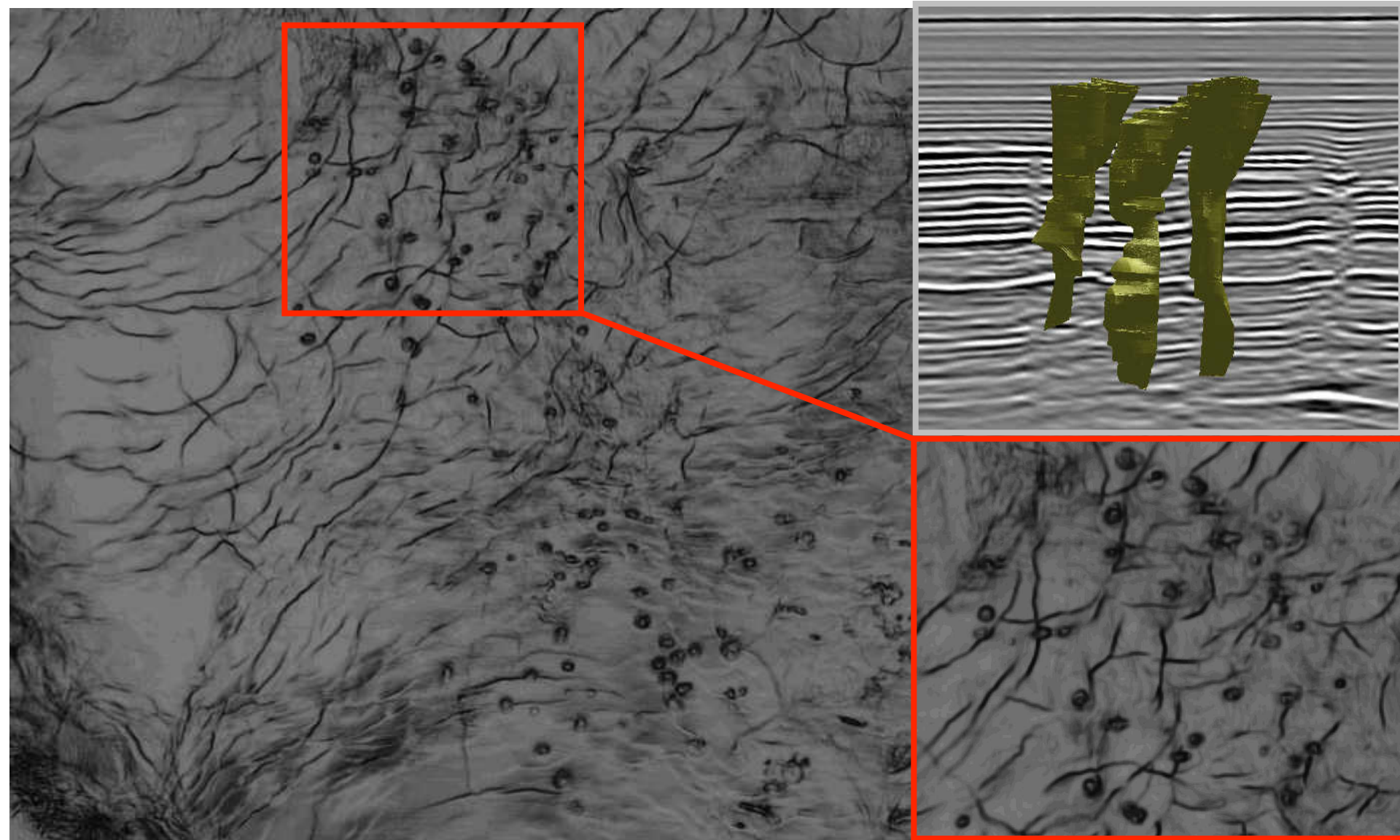


~100m diameter  
~300m height

Min ~300m diameter  
Min ~500m height



# Pipe geometry: use of attributes



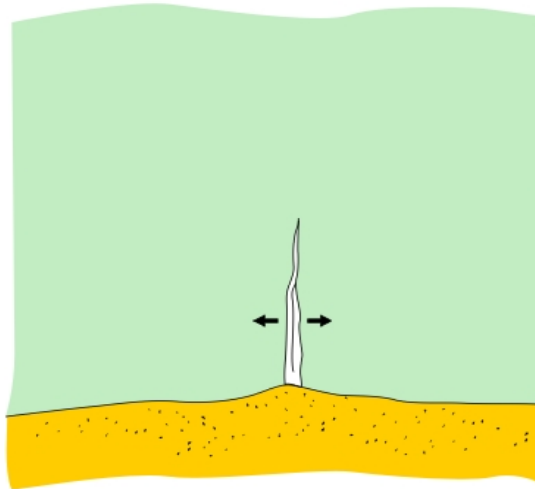




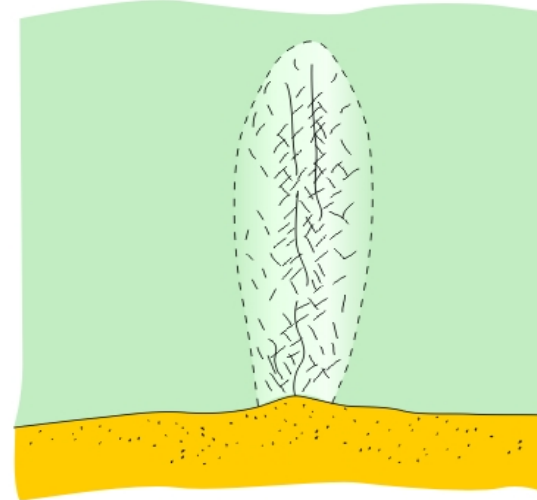
# Conduit formation....but how long-lived are they?? 'PIE'

A

CAPROCK FAILS  
by HYDRAULIC FRACTURING



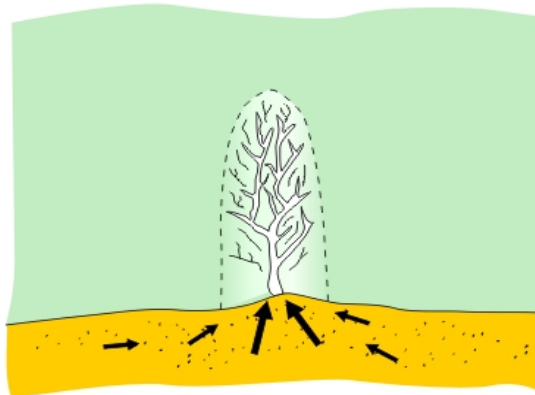
UPWARD PROPOGATION  
FRACTURES DILATE  
BRECCIA FORMS IN CORE



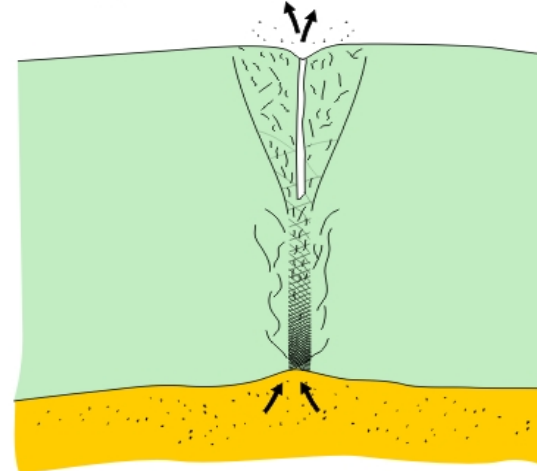
C

B

FLOW SELF ORGANISES  
HYDROFRACTURED REGION  
PROPOGATES



GAS EXPANSION  
EXPLOSIVE VENTING



D

# GAS HYDRATES ON MARGINS

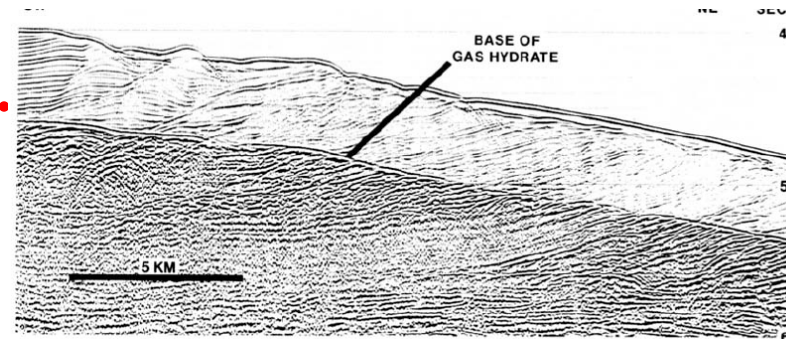
Hydrates are widely developed on most rifted continental margins

They are a huge potential resource (DOE and international)

Their dissociation has been implicated in past rapid climate change

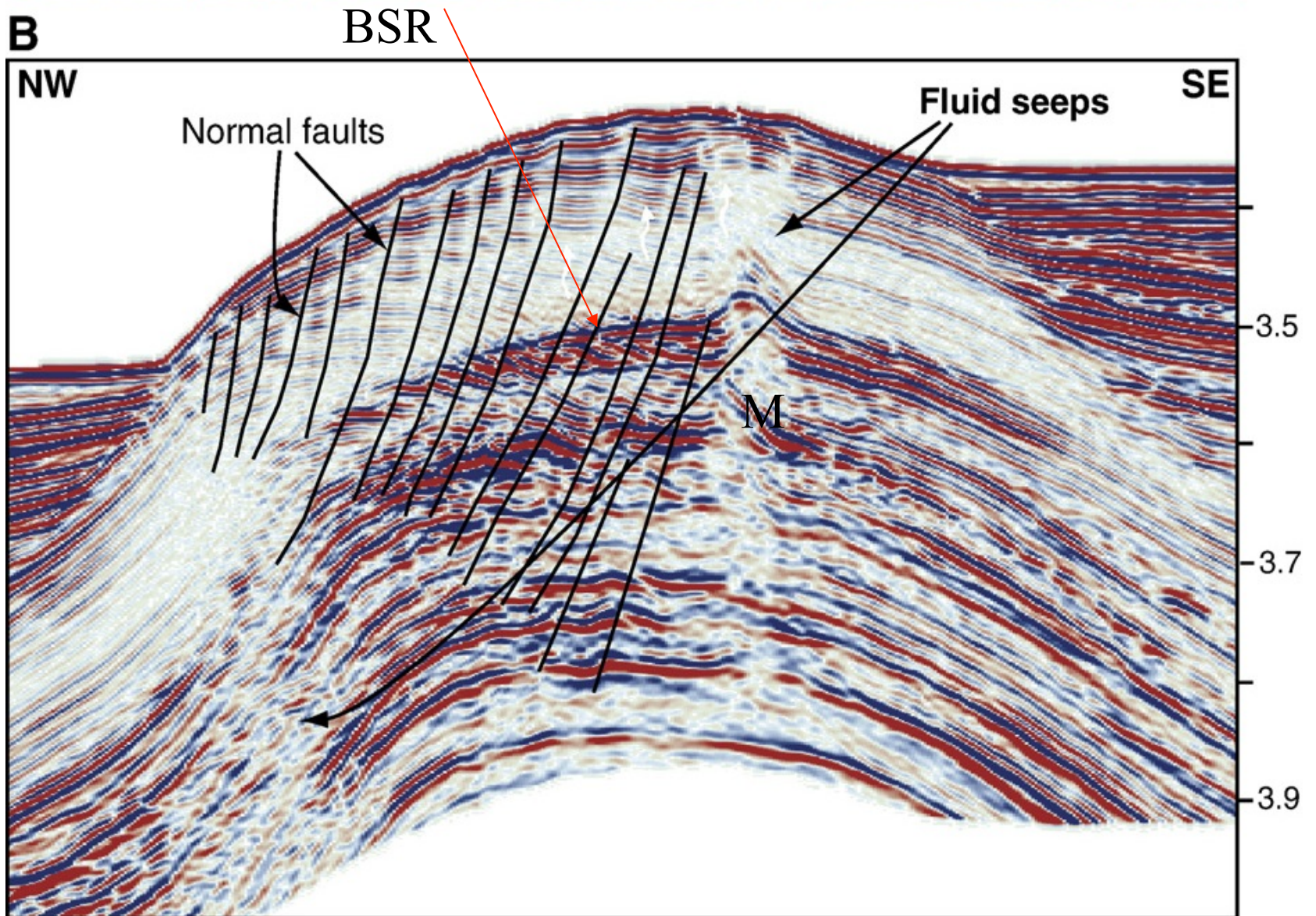
They may have triggered slope failure.....(James, 1981) et al.

**MANY QUESTIONS REMAIN.....**



Shipley 1981

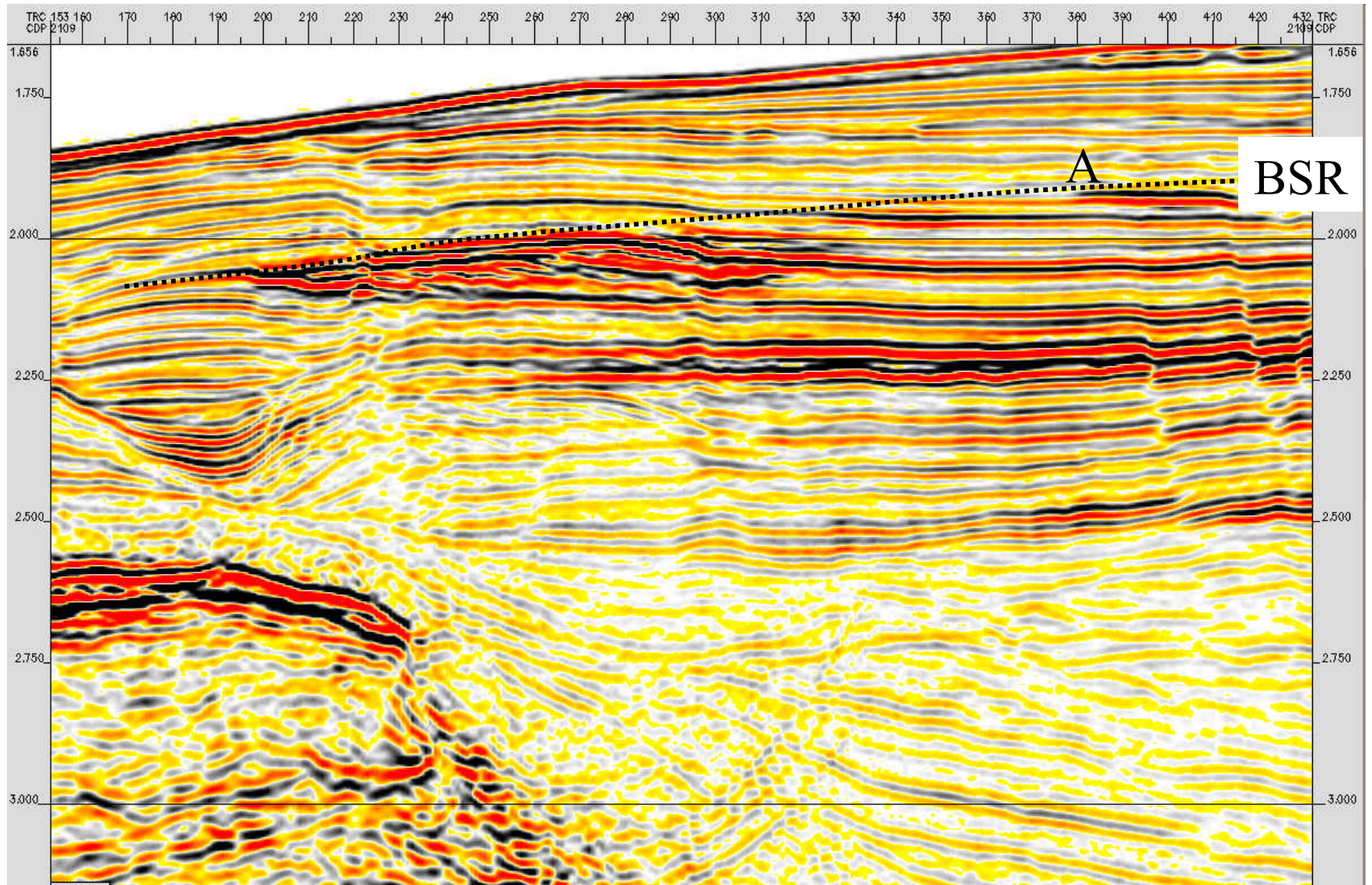




Gee et al. 2008 ( image is 10km across )

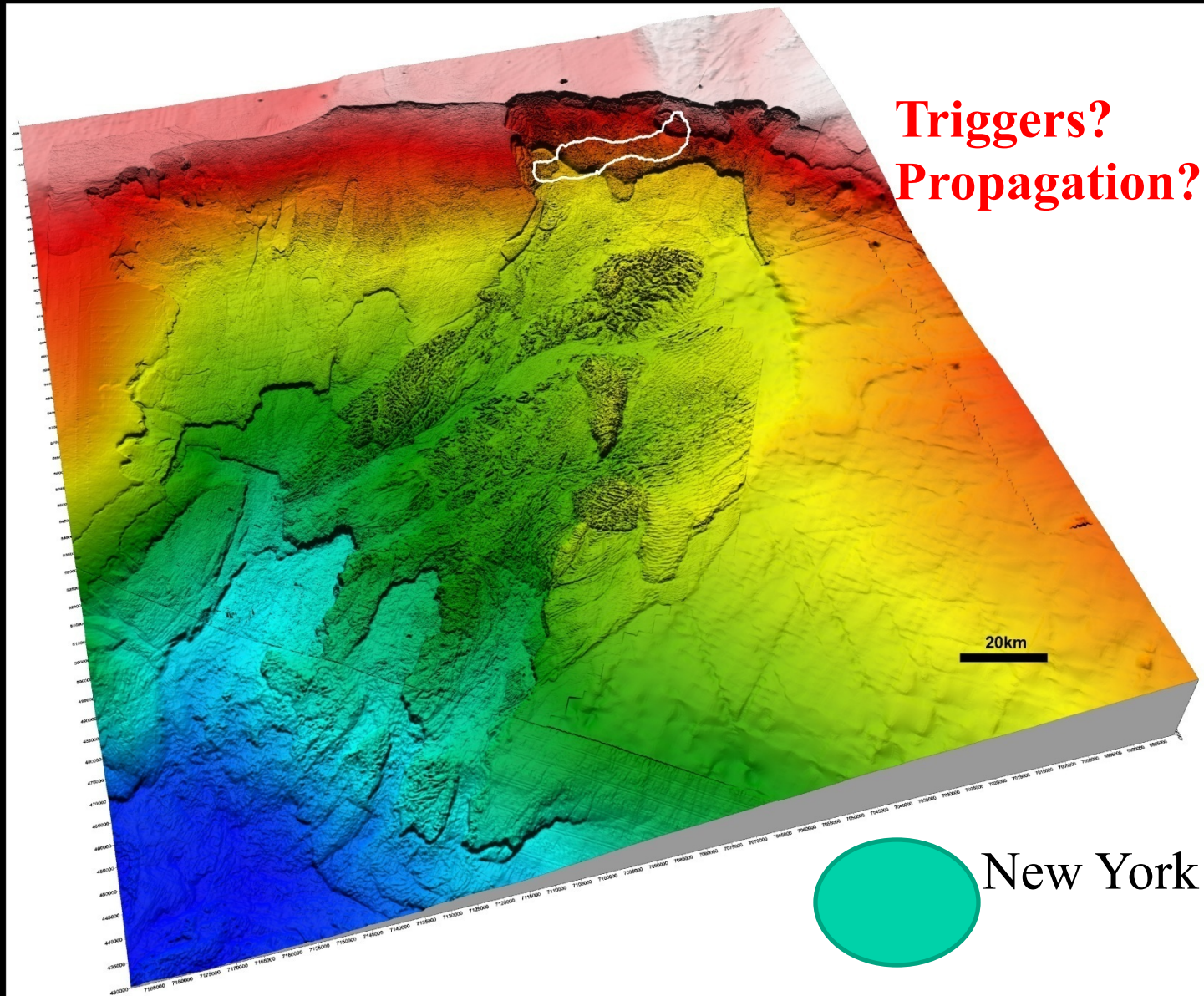


# Namibe Basin, Namibia



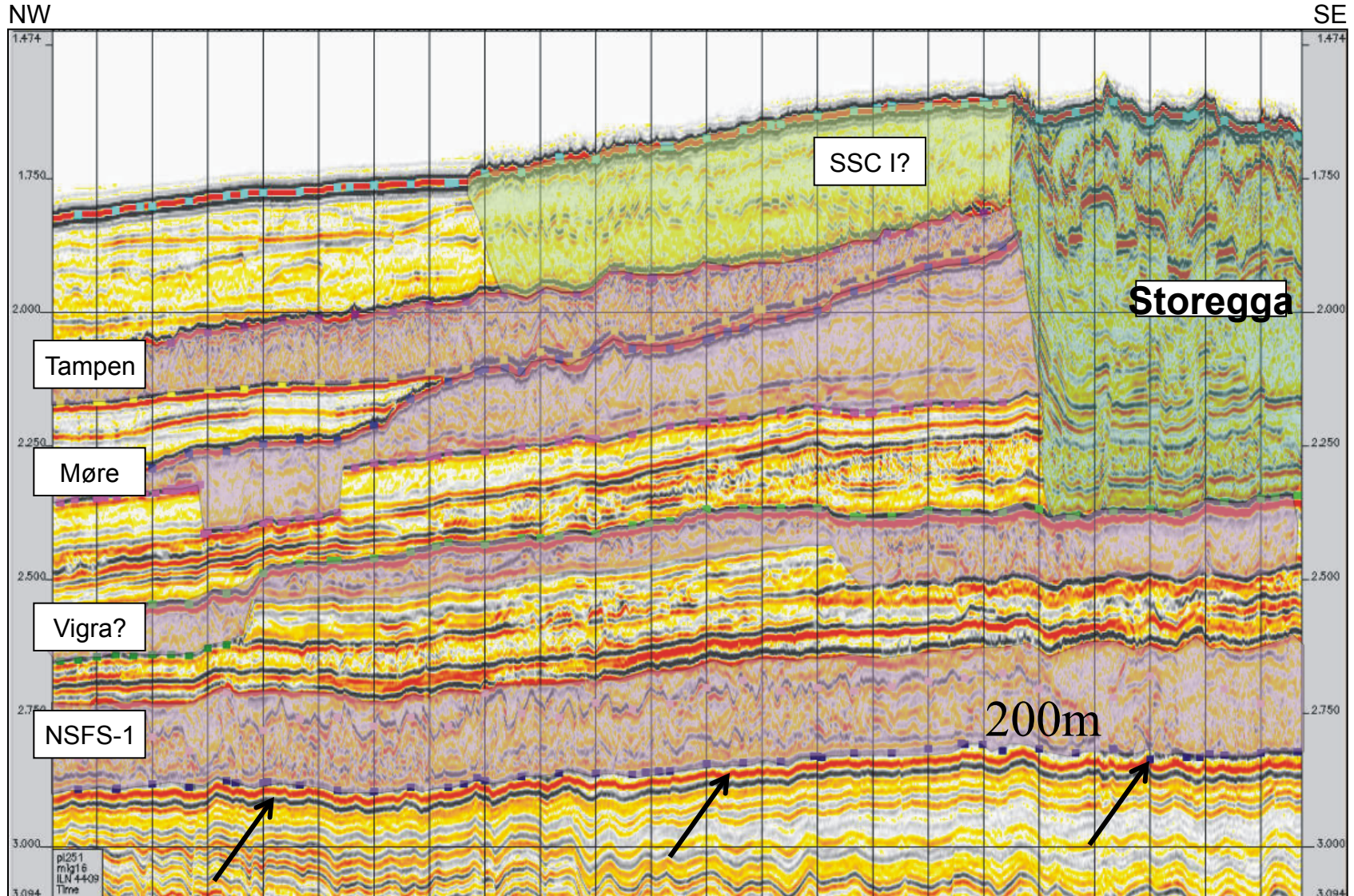


# The Storegga Slide, 7,200 yrs BP



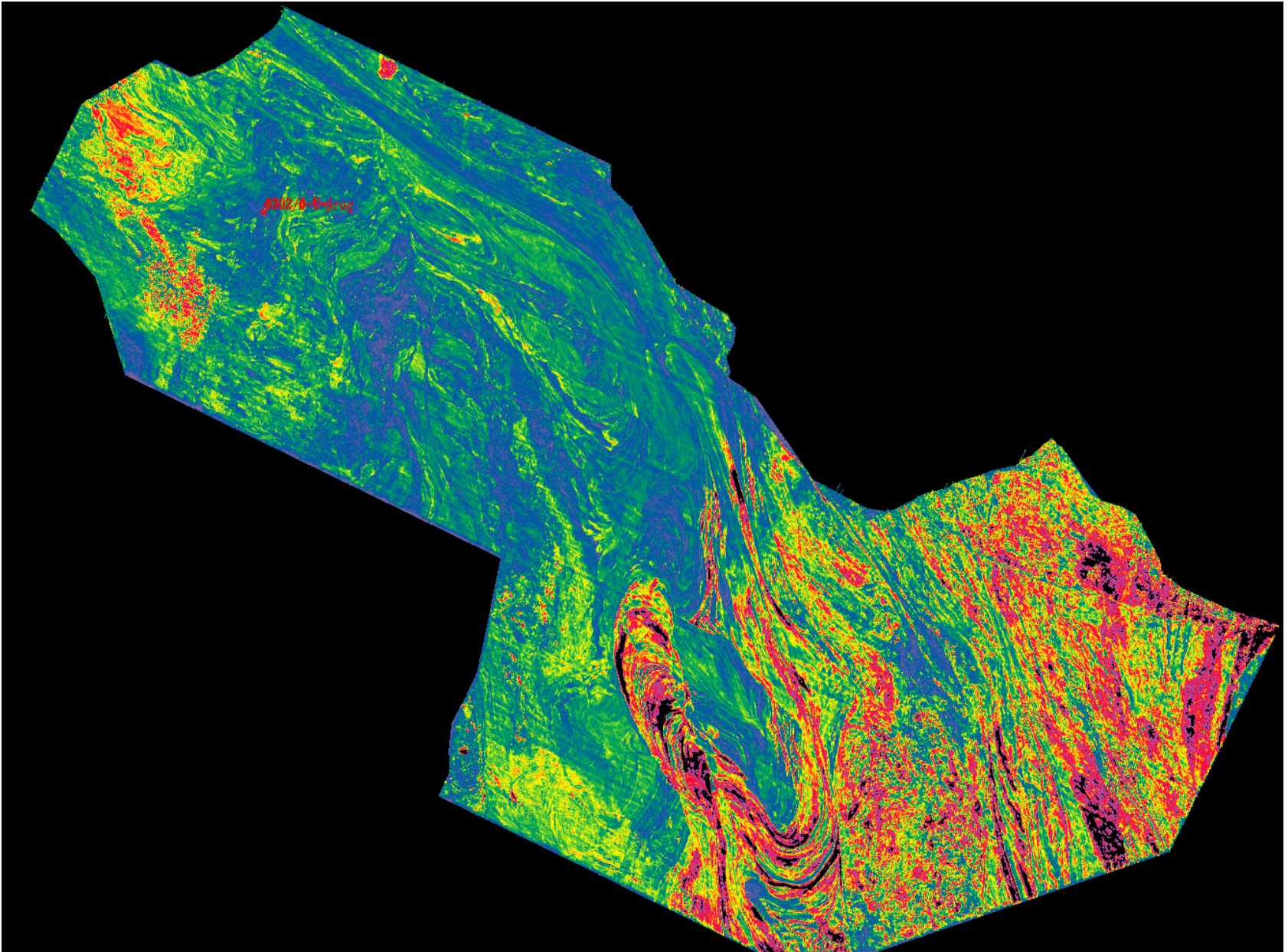


# Slide Stratigraphy: Norway past 1 Myrs



Major failures episodic, but why, and what controls?

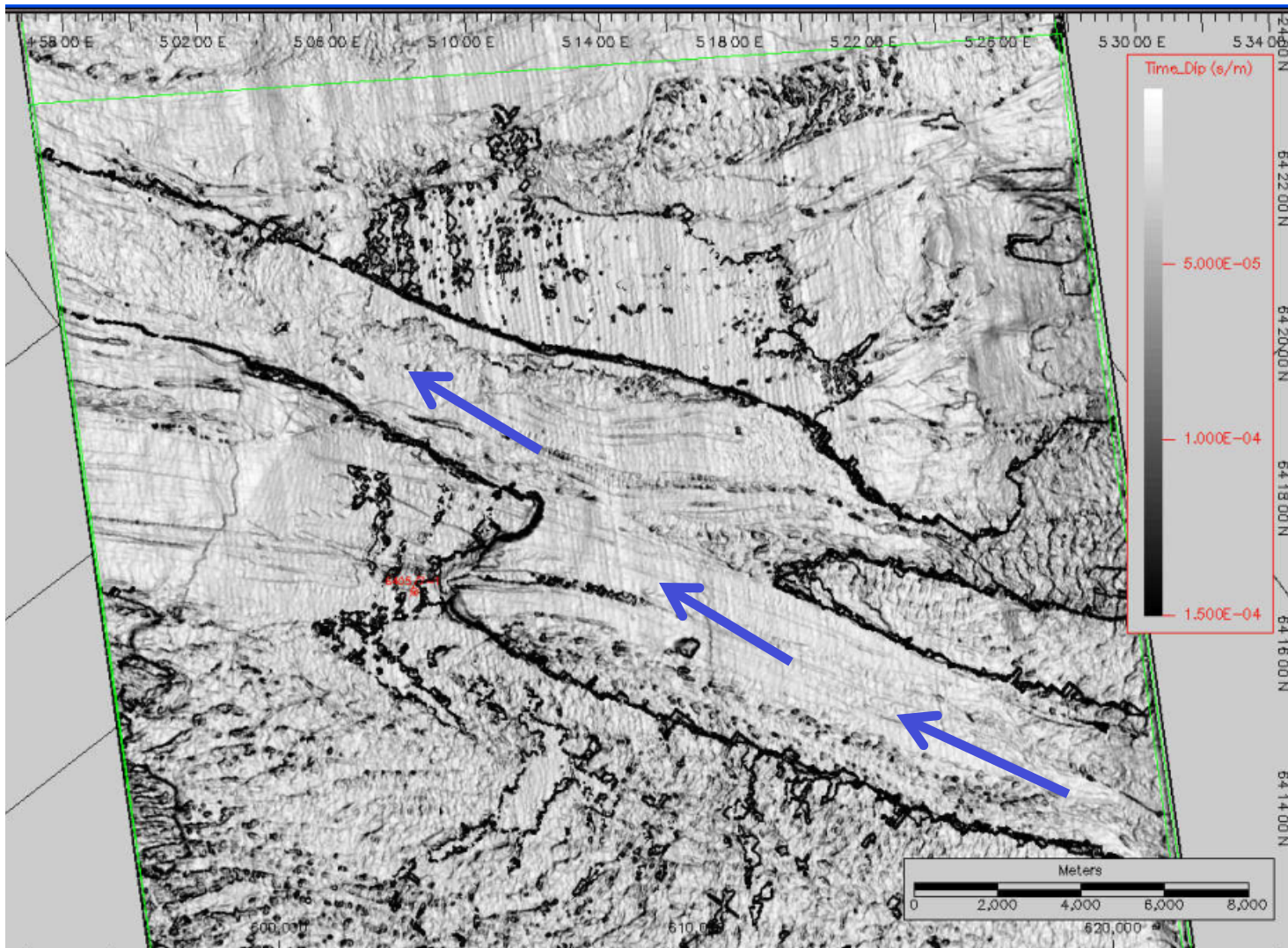




Amplitude map of basal shear surface, 30 by 20km



# Slide Kinematics from basal shear surface (dip attribute)



Bull et al. 2009

# **IGNEOUS INTRUSION INTO BASINS**

**Mechanics...OK.....(fluid driven fracture theory)**

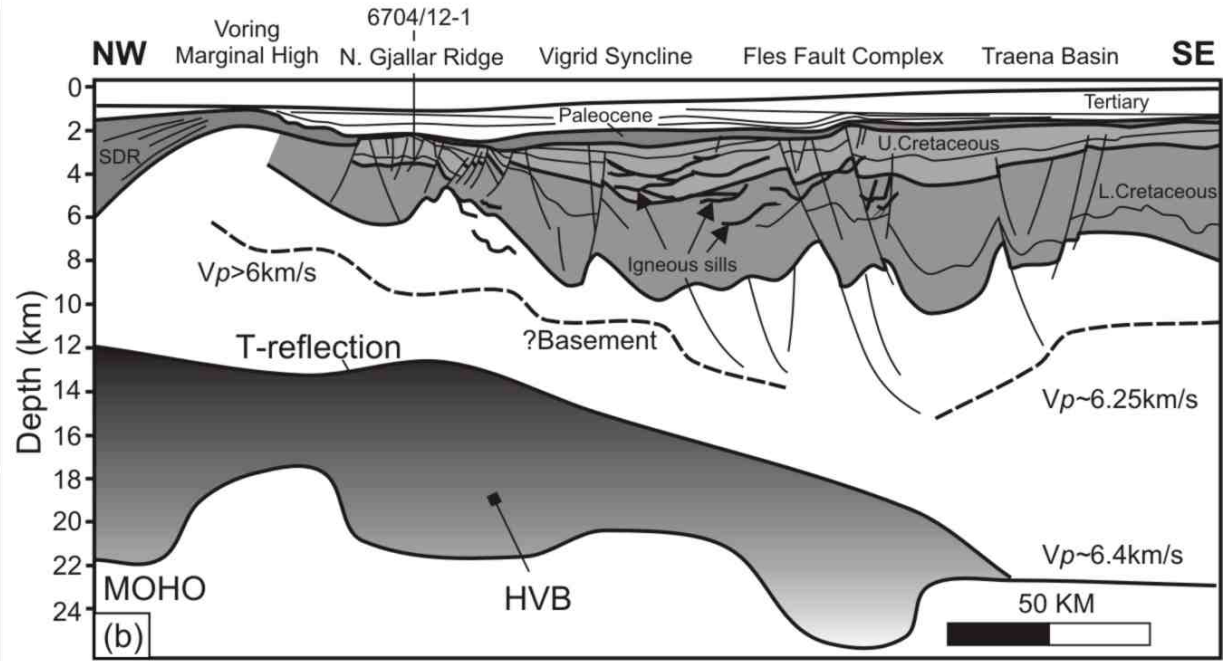
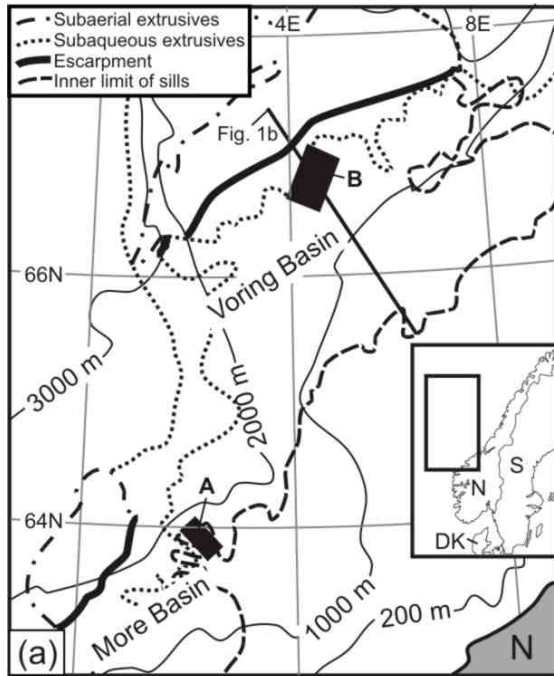
**Geometry...good start.....**

**Relationships to Host...infancy**

**Role of magma composition.....????**

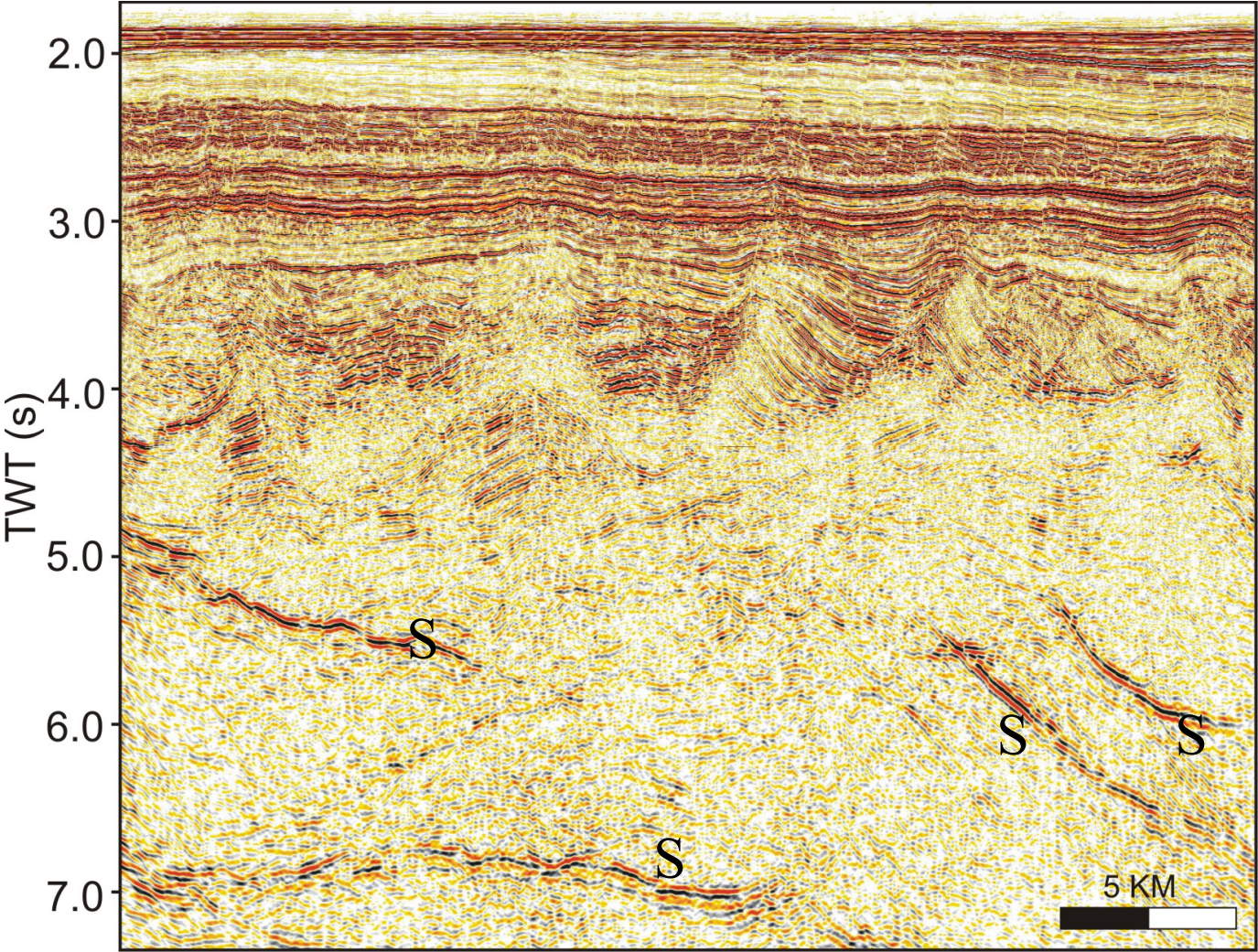
**Hydrothermal systems.....infancy**

# Sills as trans-crustal magma feeders?



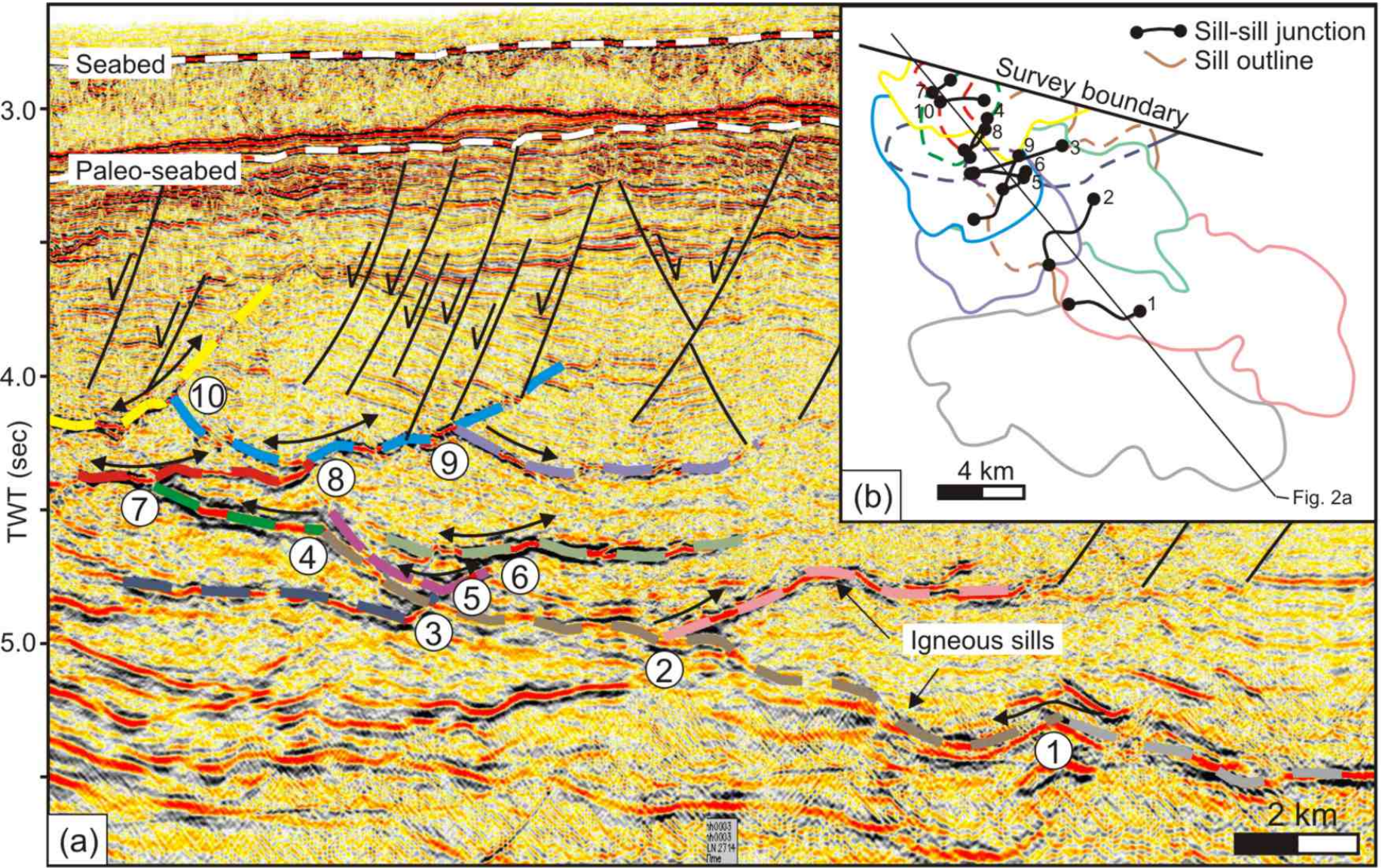


# Sills climb from mid crust (15km) offshore Norway



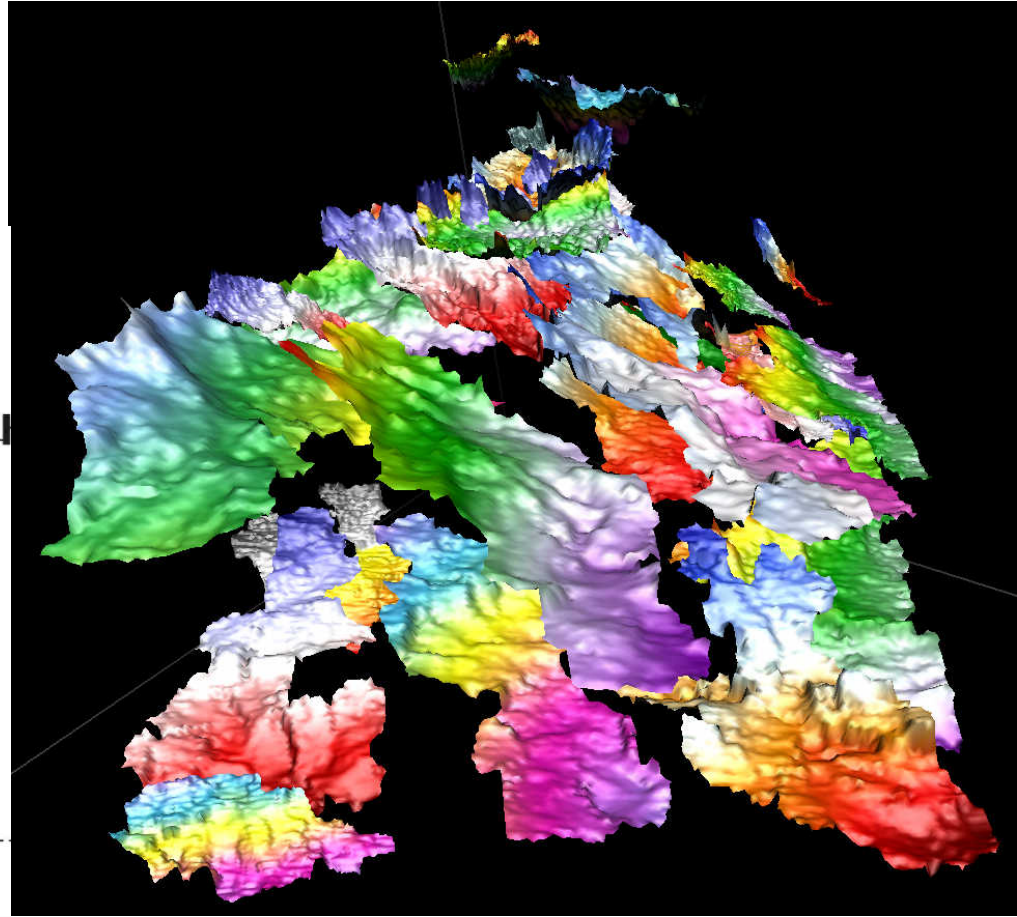
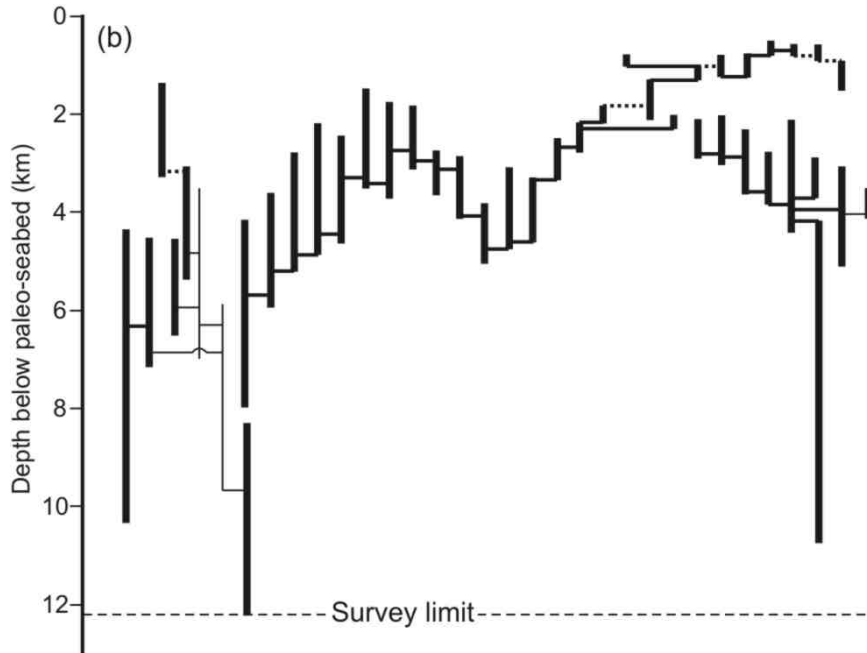


# Connectivity mapped using 3D seismic

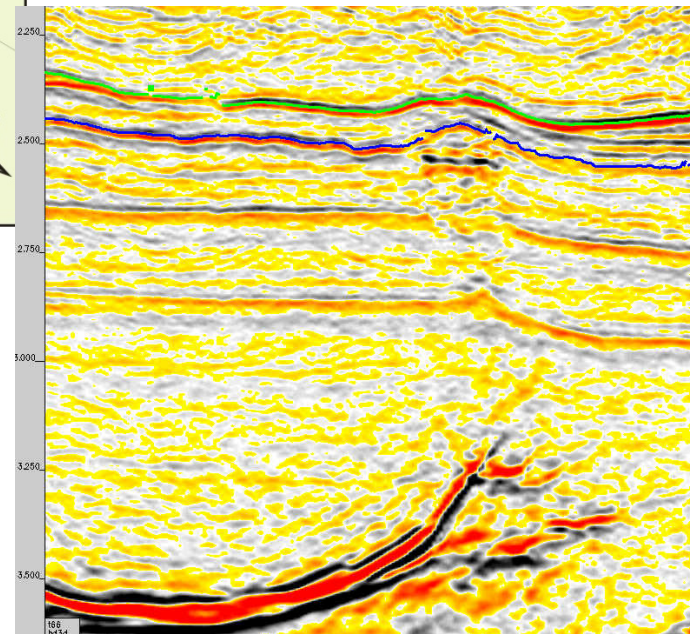
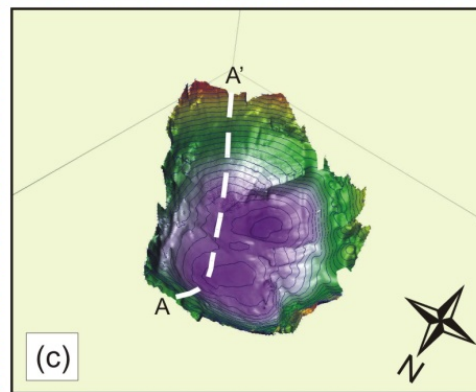
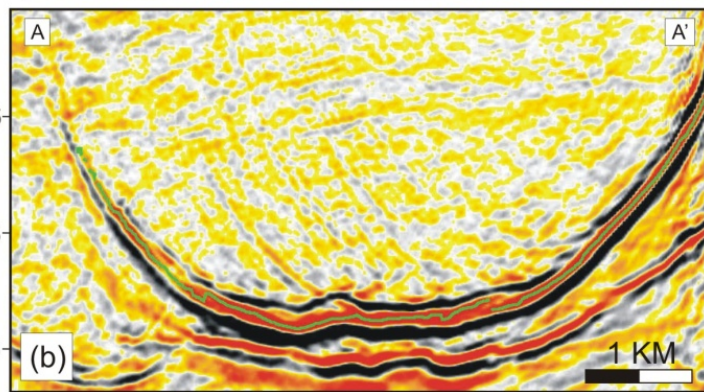
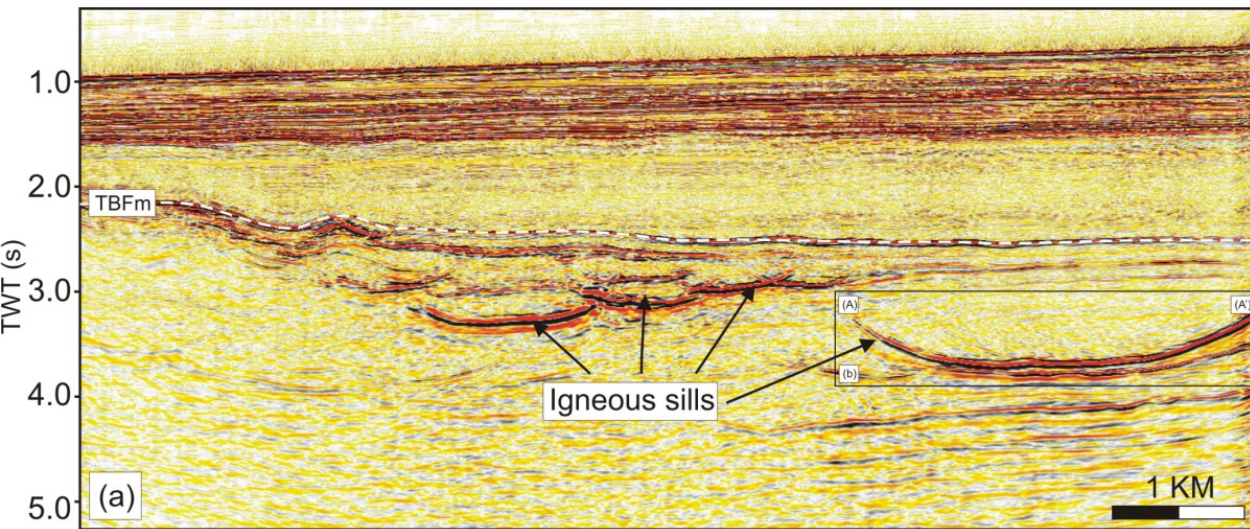




# Interconnected sill complex crosses 12km vertically of basement and sed

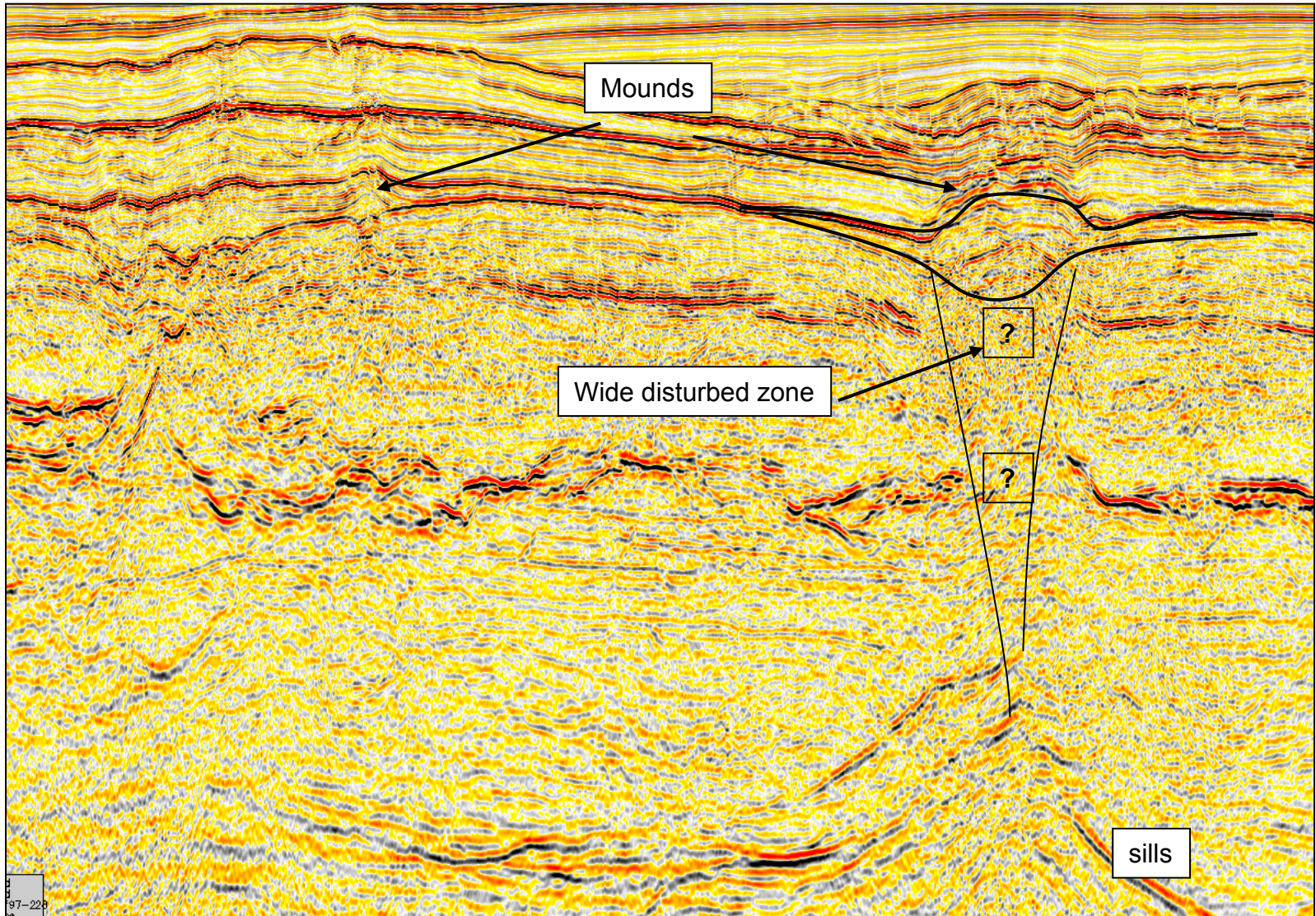






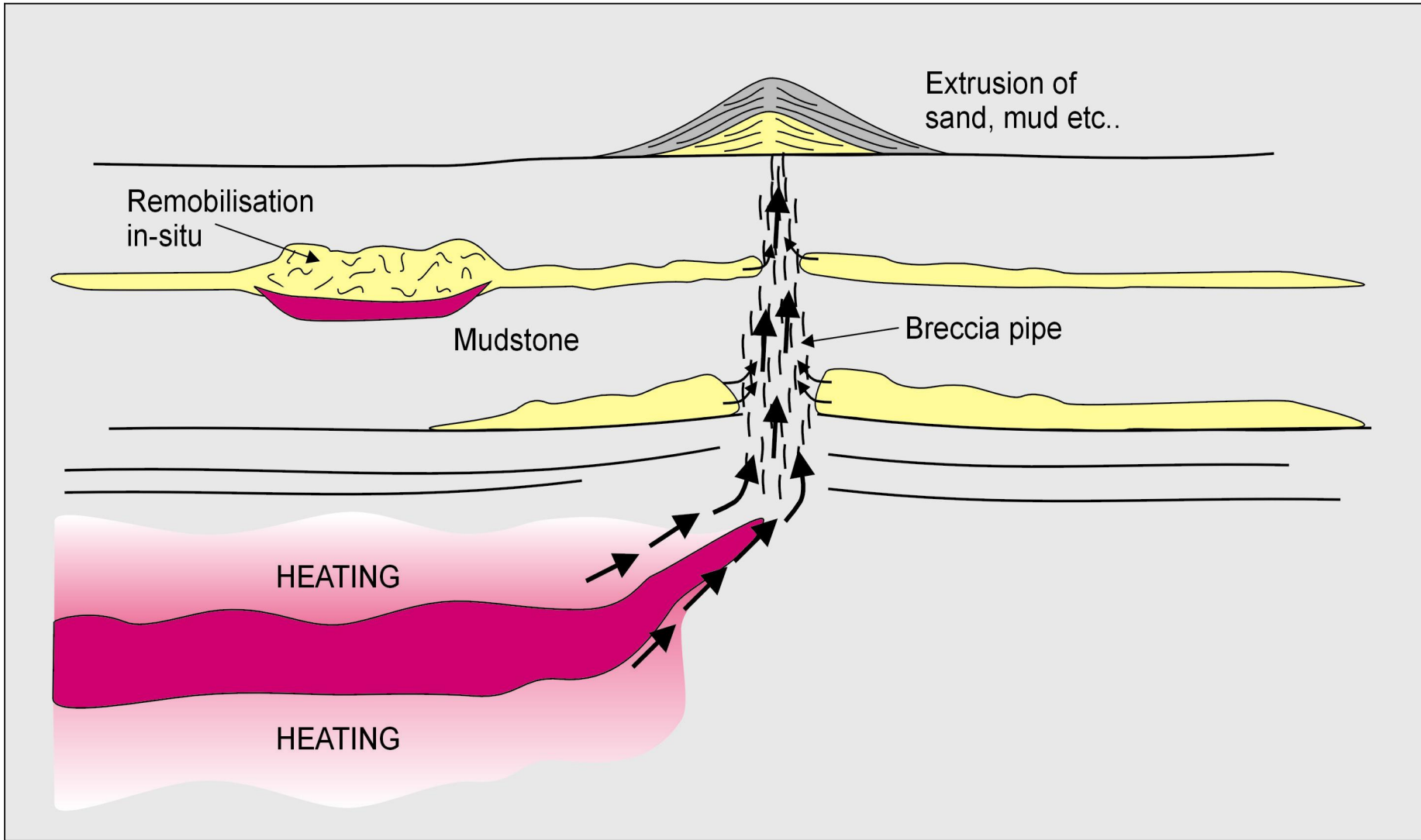
DM Hansen et al. 2004







# PLUMBING AND FILL



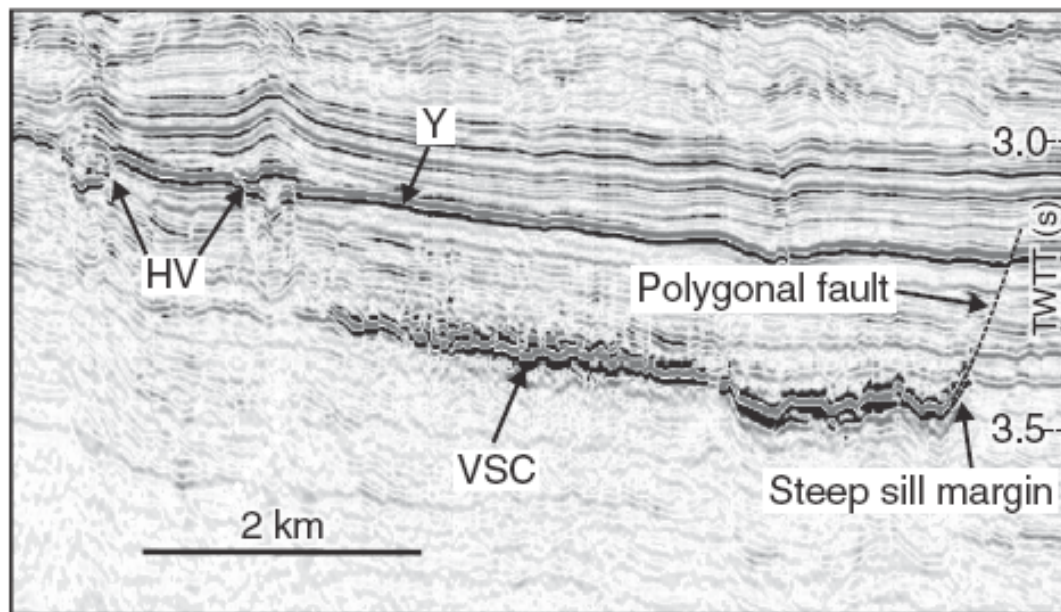
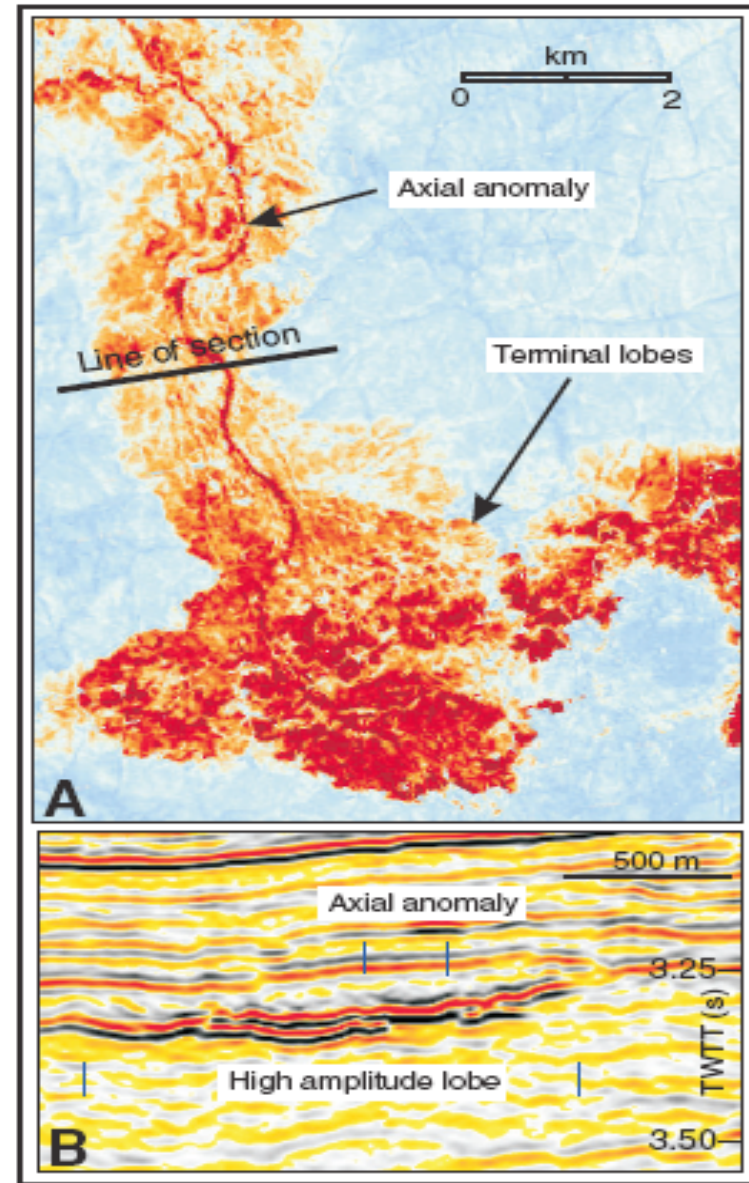


Figure 3. Two-dimensional seismic section through southeast lobes illustrating complex stepped upper surface geometry of Vigra sill complex (VSC). Right margin of VSC can be seen exploiting preexisting polygonal fault, denoting discordant relationship to surrounding sedimentary strata. See Figure 2 for location of section and abbreviations (also see the Data Repository [see footnote 1]).





# Fluid Expulsion Pipes: Summary

Cylindrical geometry....implies what?

10s to 100s m diameter.....scales with flux? With longevity?

Association with amplitude anomalies... CH<sub>4</sub>?  
Mineralising fluids?

Episodicity....suggests hysteresis or external triggers

Cross 100s to 1000s of metres of low permeability mudrocks.....implies genesis is highly energetic...

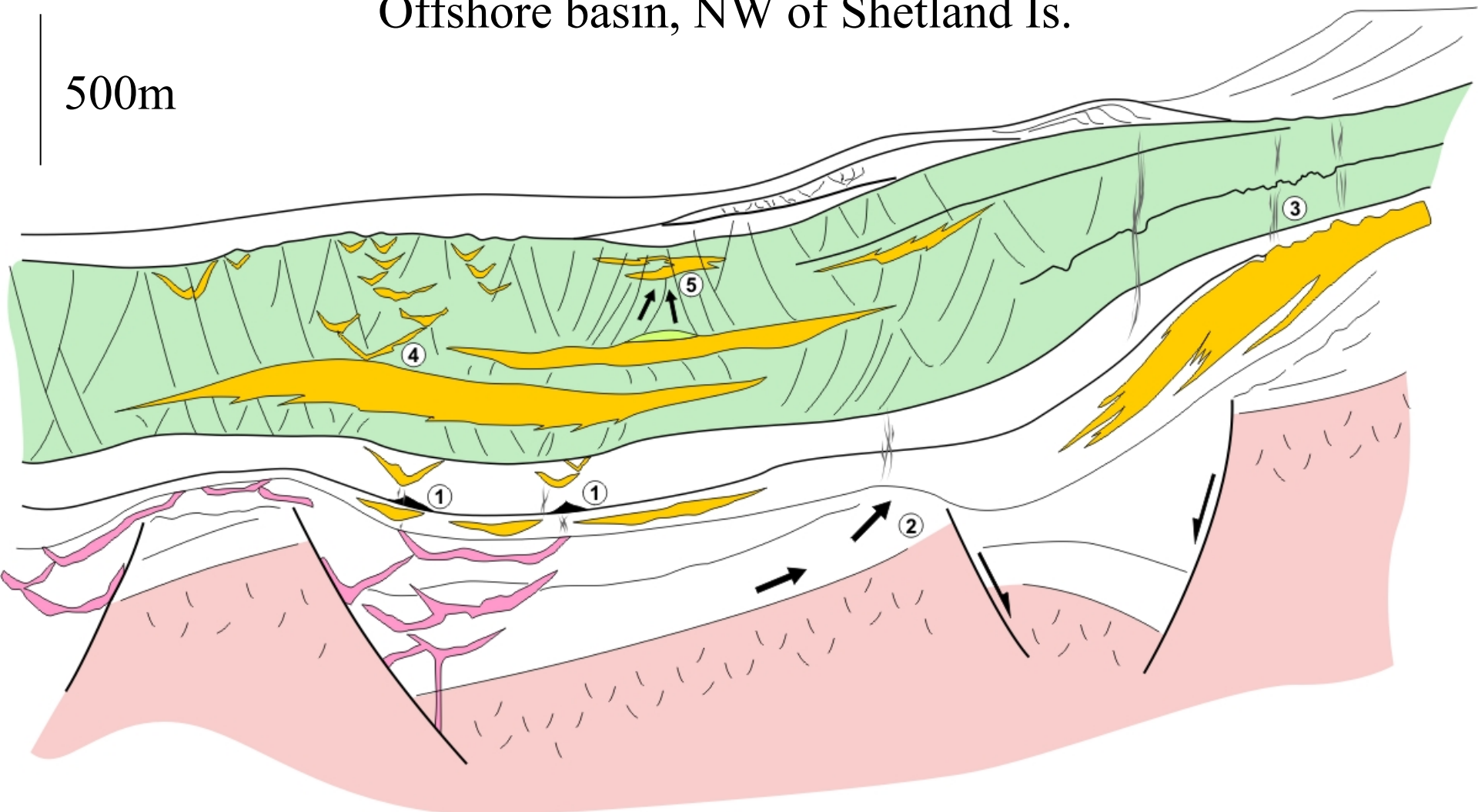
High pore fluid pressures implied  
Implications for Mud Volcanoes??





# Offshore basin, NW of Shetland Is.

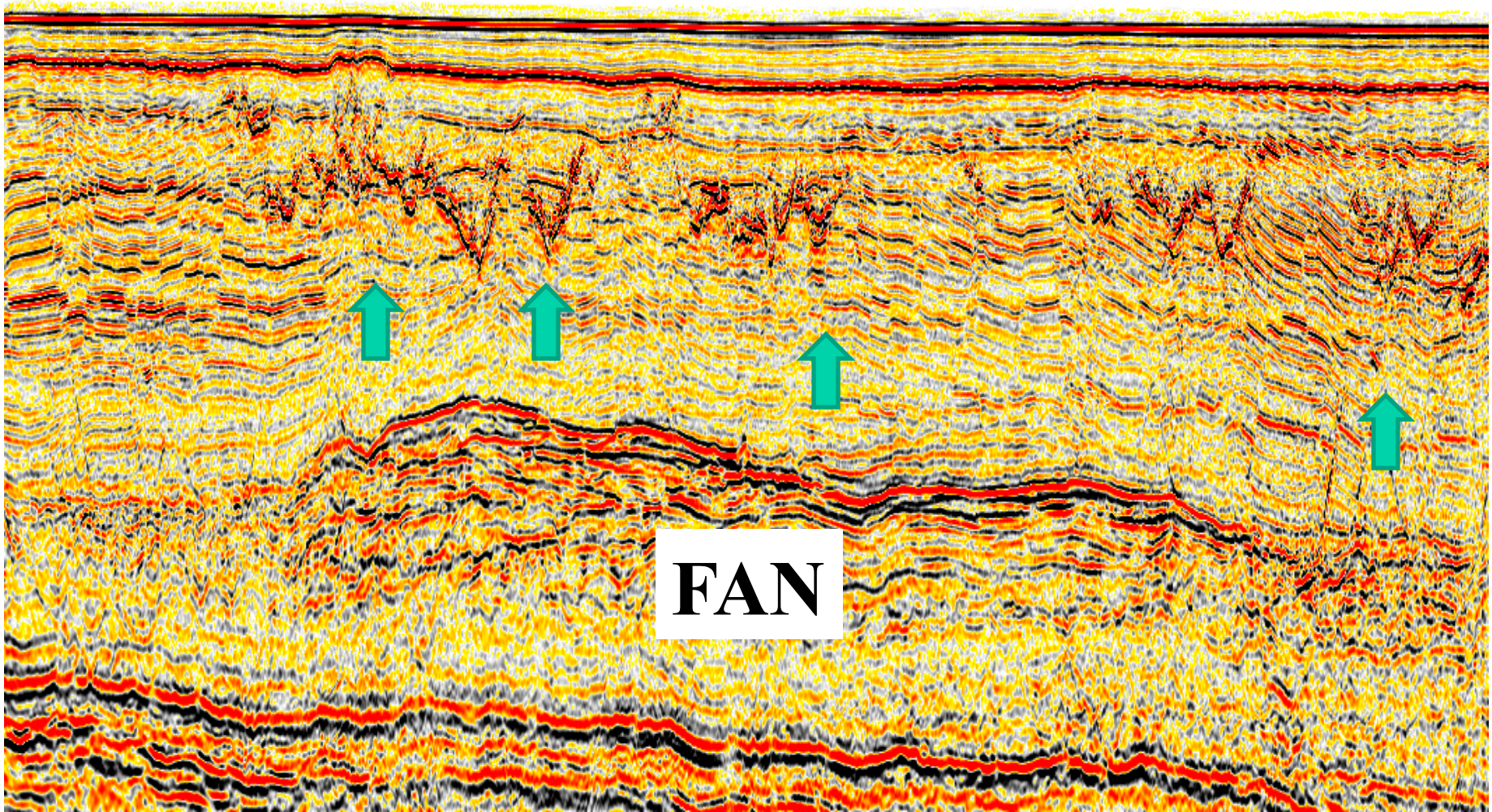
500m



10km



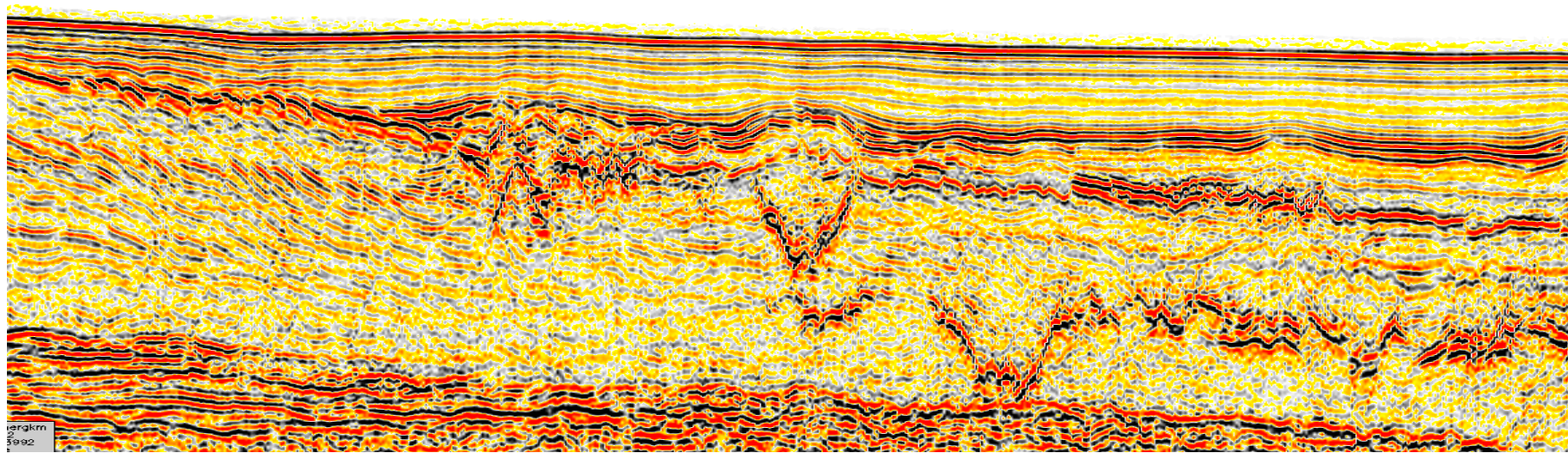
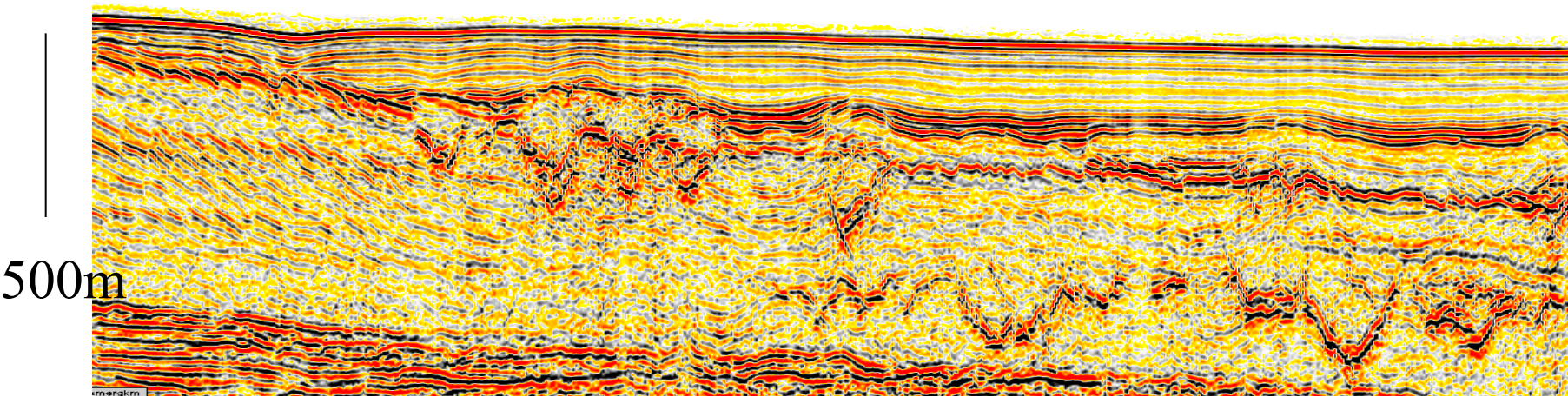
500ms



5km

Submarine fan sands remobilised and intruded up to 1000m higher



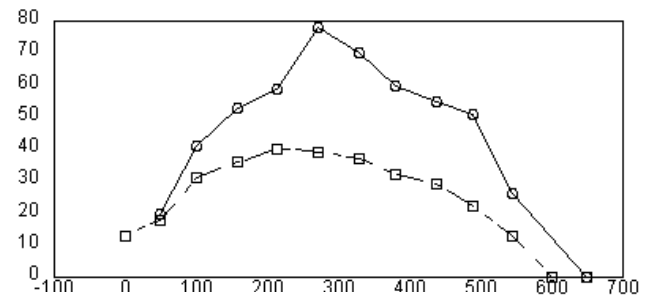


———— 1km

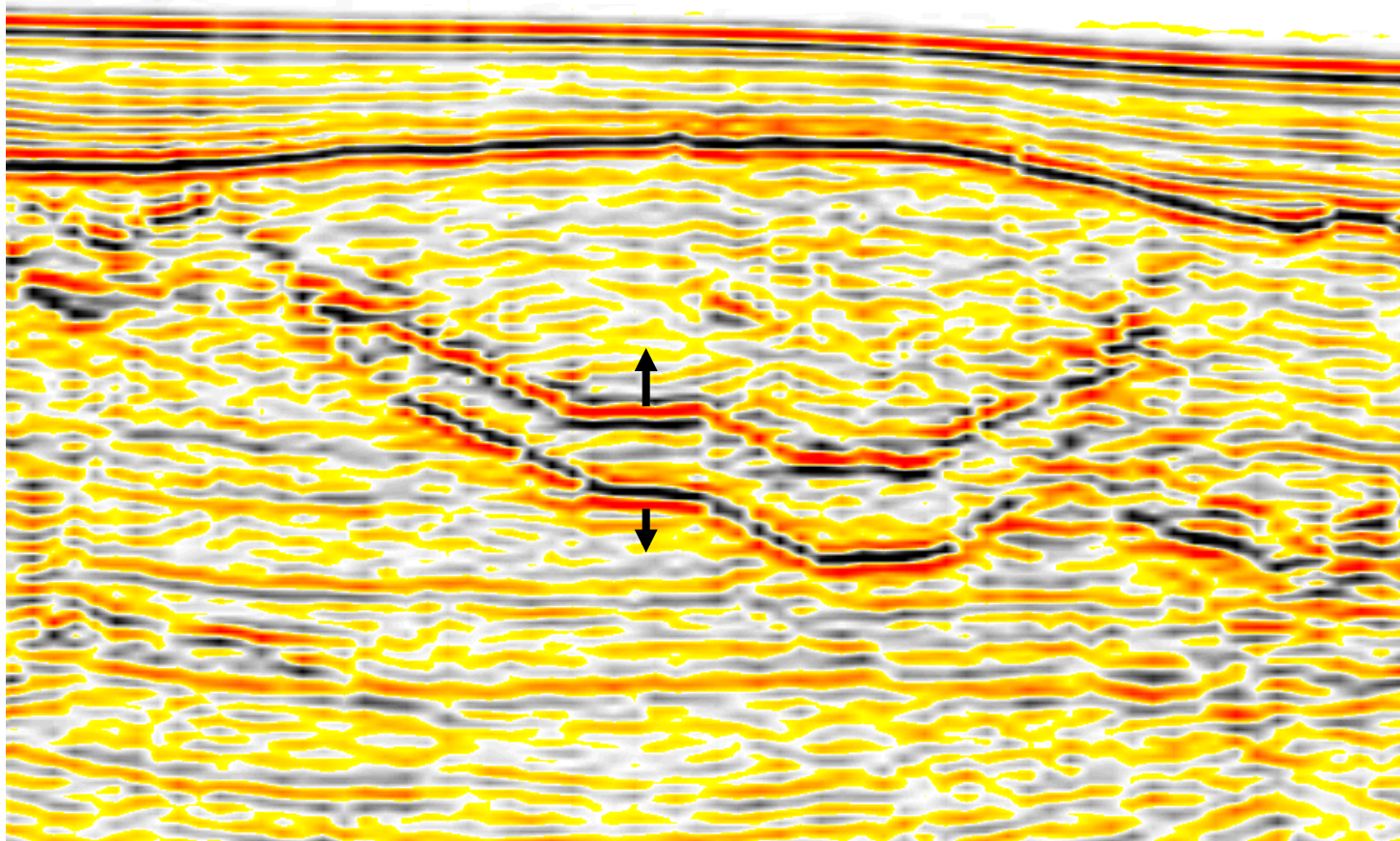


To form sills (Hubbert and Willis, 1957)

$$P \neq \sigma_v + T$$

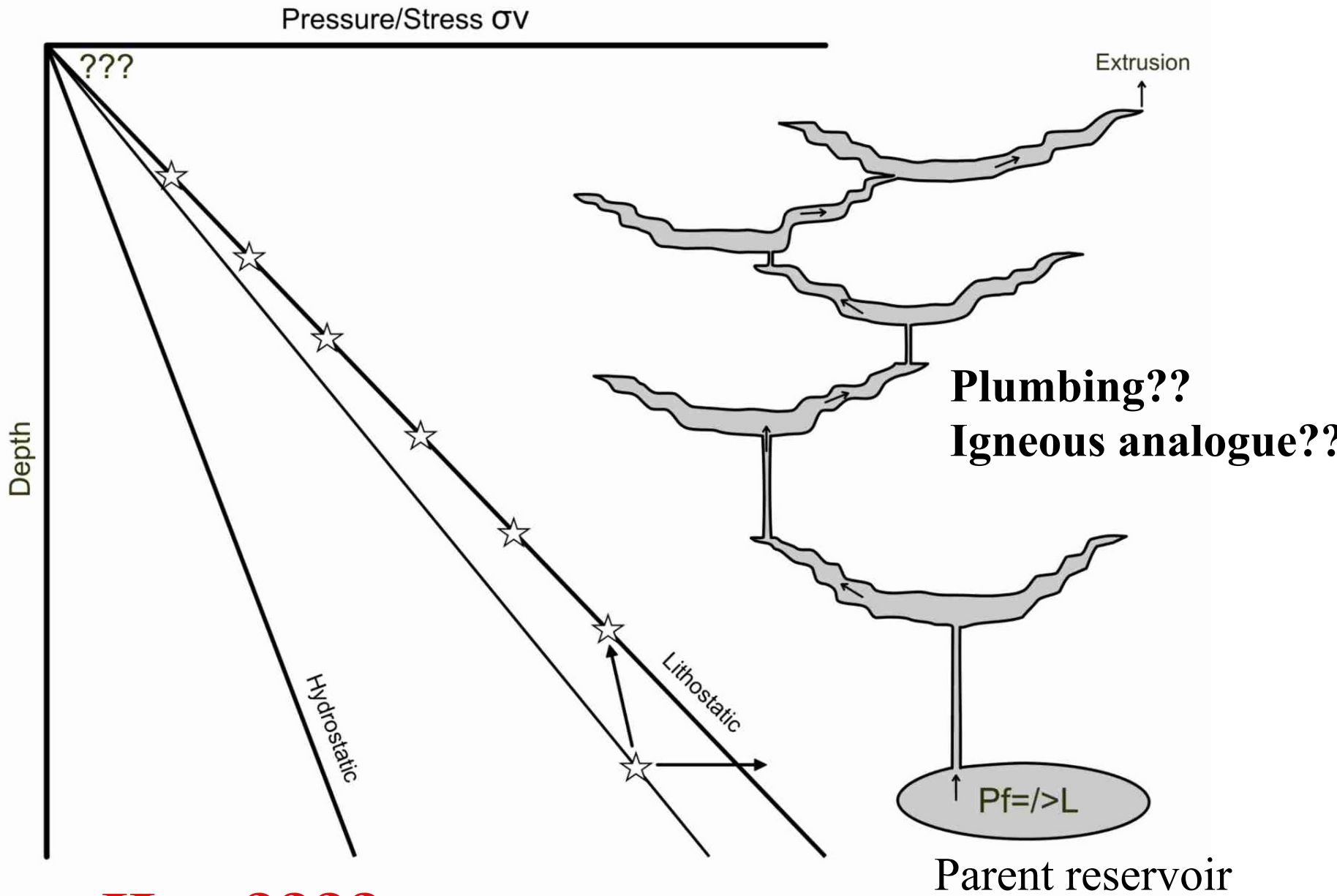


200m



1km

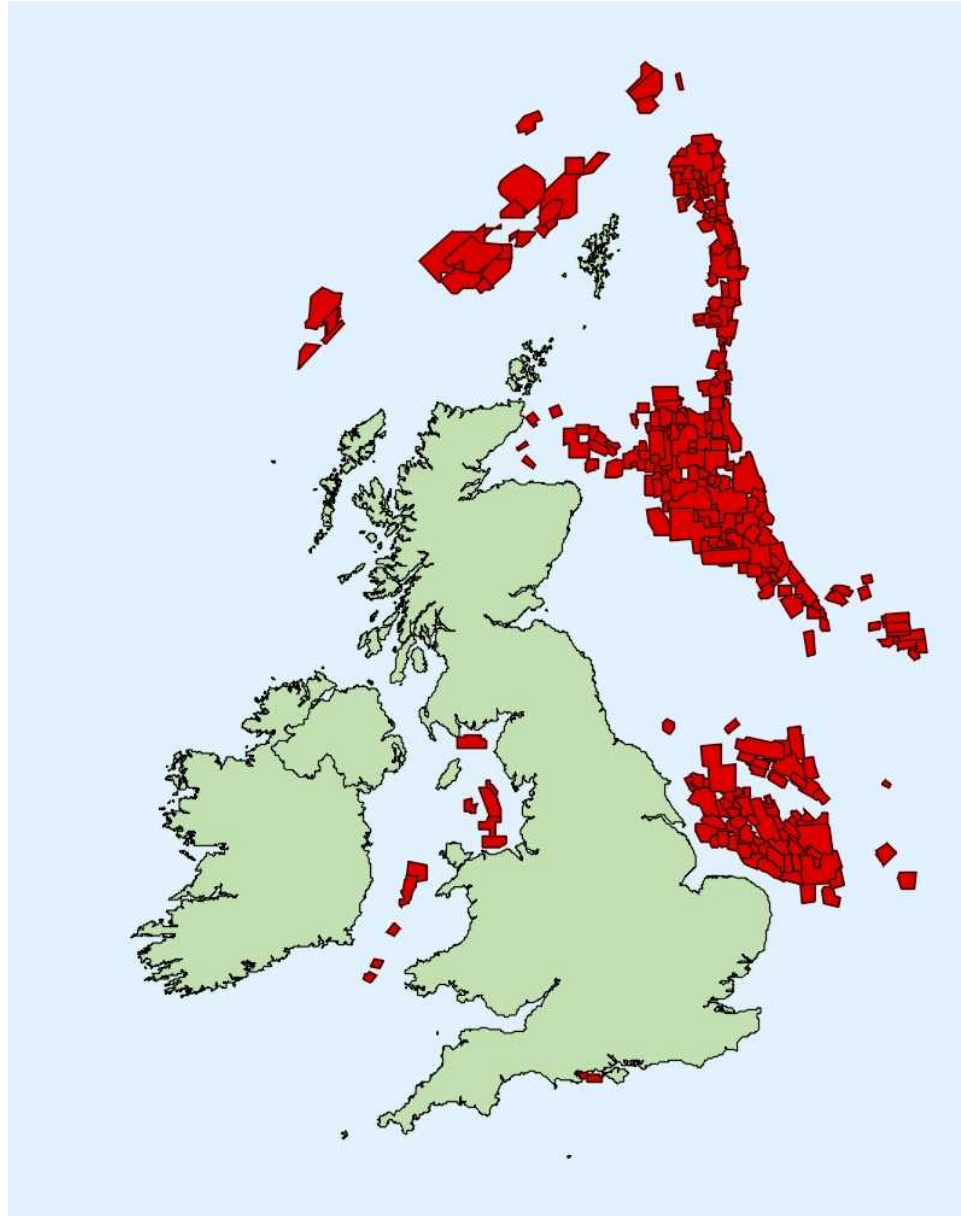




How????

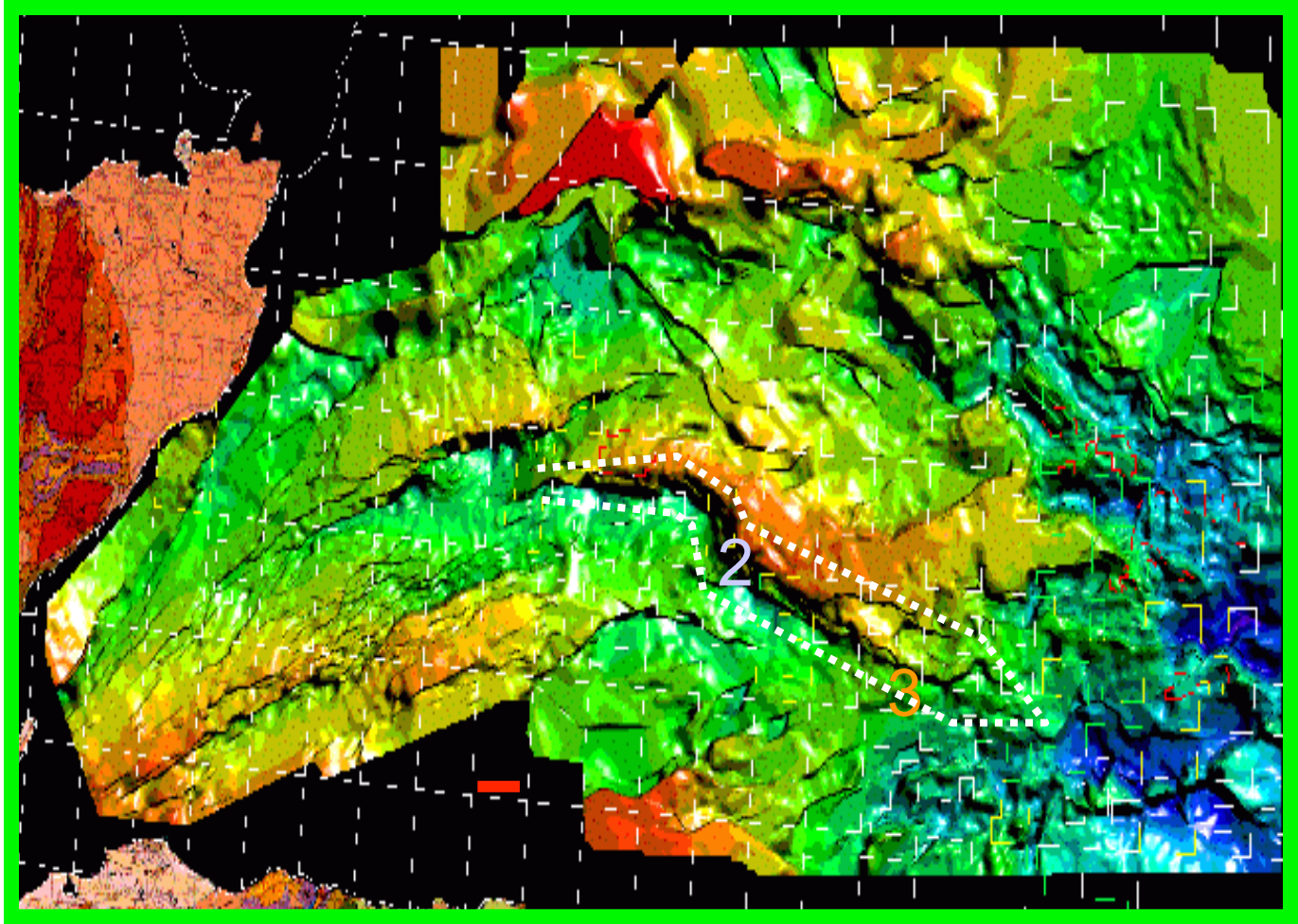
# UKCS 3D coverage: 137,688km<sup>2</sup>

By 2002





# North Sea Rift System, Western Flank



50km



# Conclusions

Abundant evidence of highly focused fluid venting from most (if not all) sedimentary basins....more questions than answers

High pore fluid pressures and methane generation are common to many documented examples of focused fluid flow

HAZARD plus RESOURCE IMPLICATIONS

Mafic melts can migrate large vertical distances via bowl-shaped SILL COMPLEXES

HUGE POTENTIAL TO EXPLOIT AN EXTRAORDINARY 'HUBBLE' ....WIDELY AVAILABLE DATA