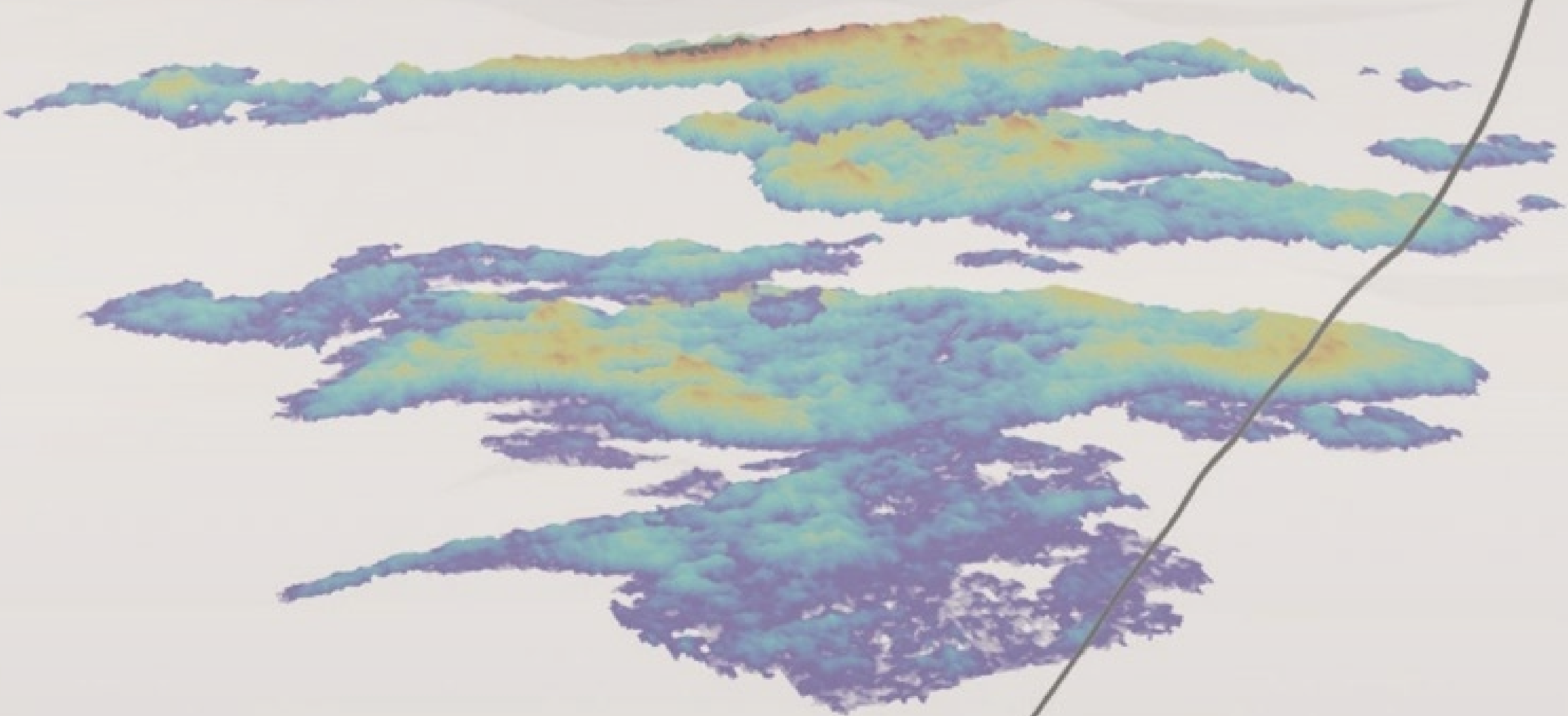
Geophysical monitoring in the overburden, what can we detect?

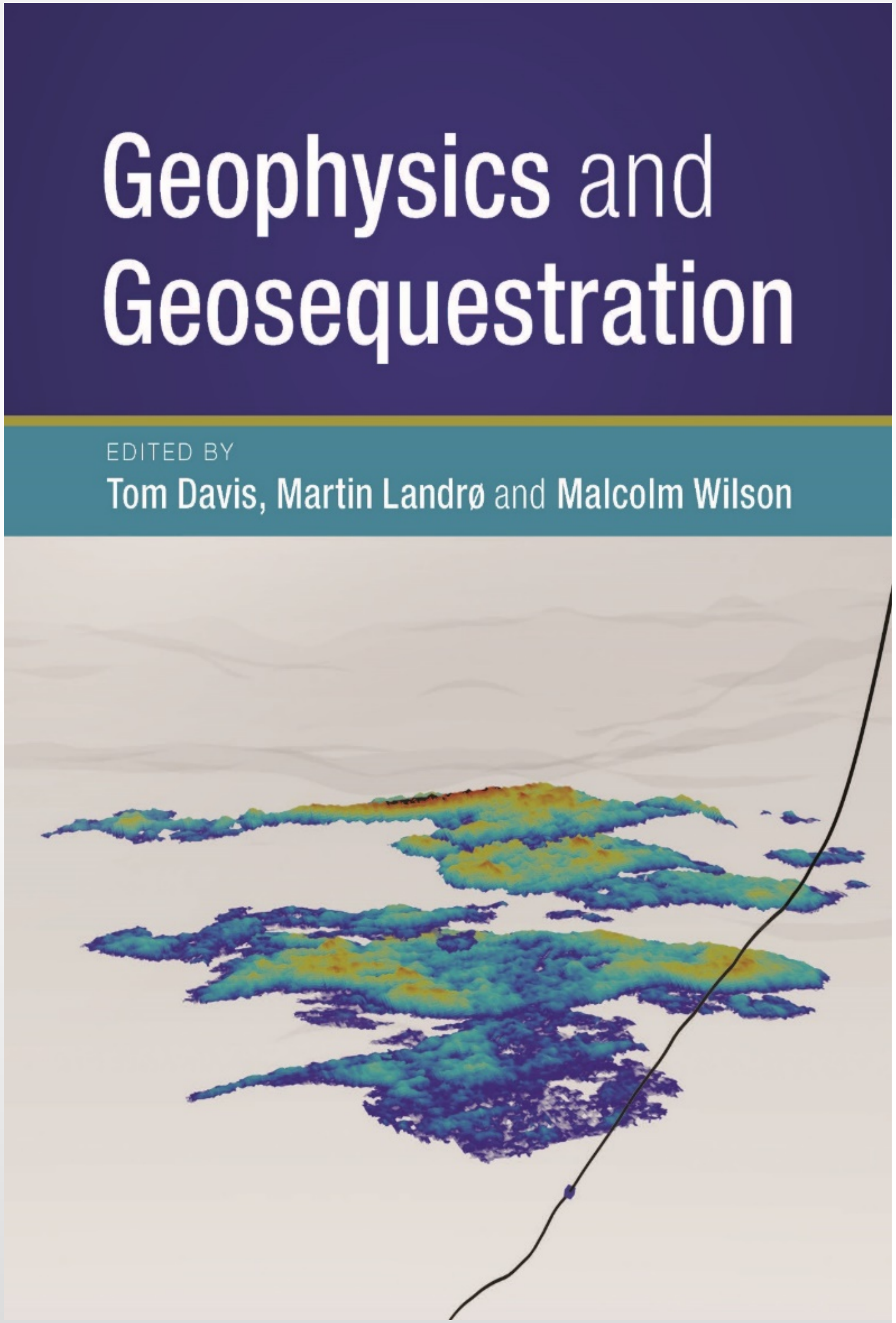


STEMM-CCS Open Science Meeting, 11th February 2020

M. Landrø, NTNU

Geophysical Methods

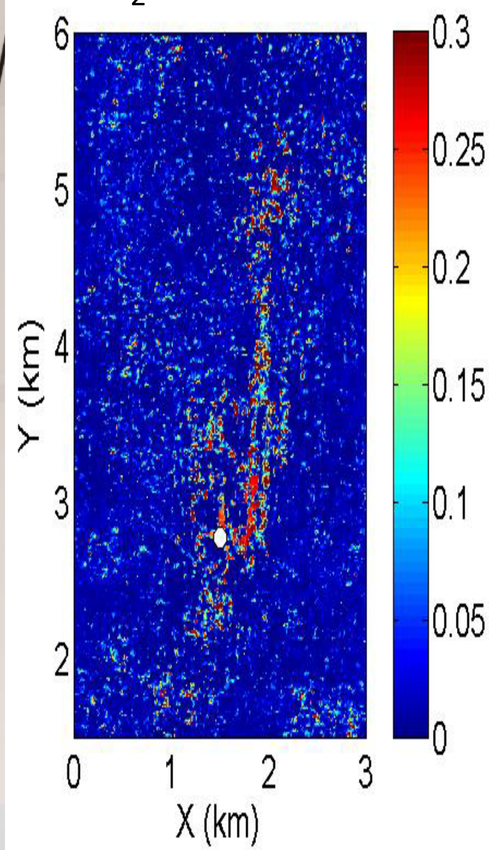
- Seismic (active and passive)
- Fibreoptic seismic (DAS)
- Gravity
- Electromagnetic methods (CSEM)
- Altimetry (satellite, onshore only)



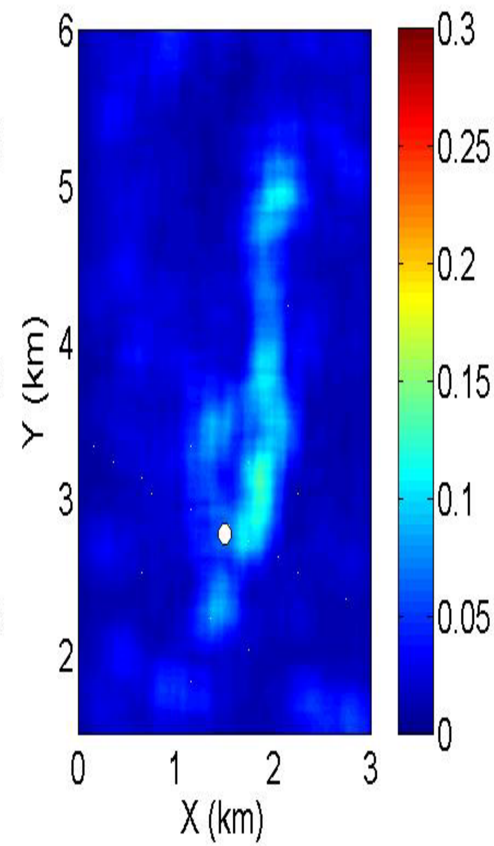
Using time lapse seismic data from 2001 and 2008 we can estimate saturation changes for the upper layer – for deeper layers it turns out to be more complex:

Add gravity data to the analysis!

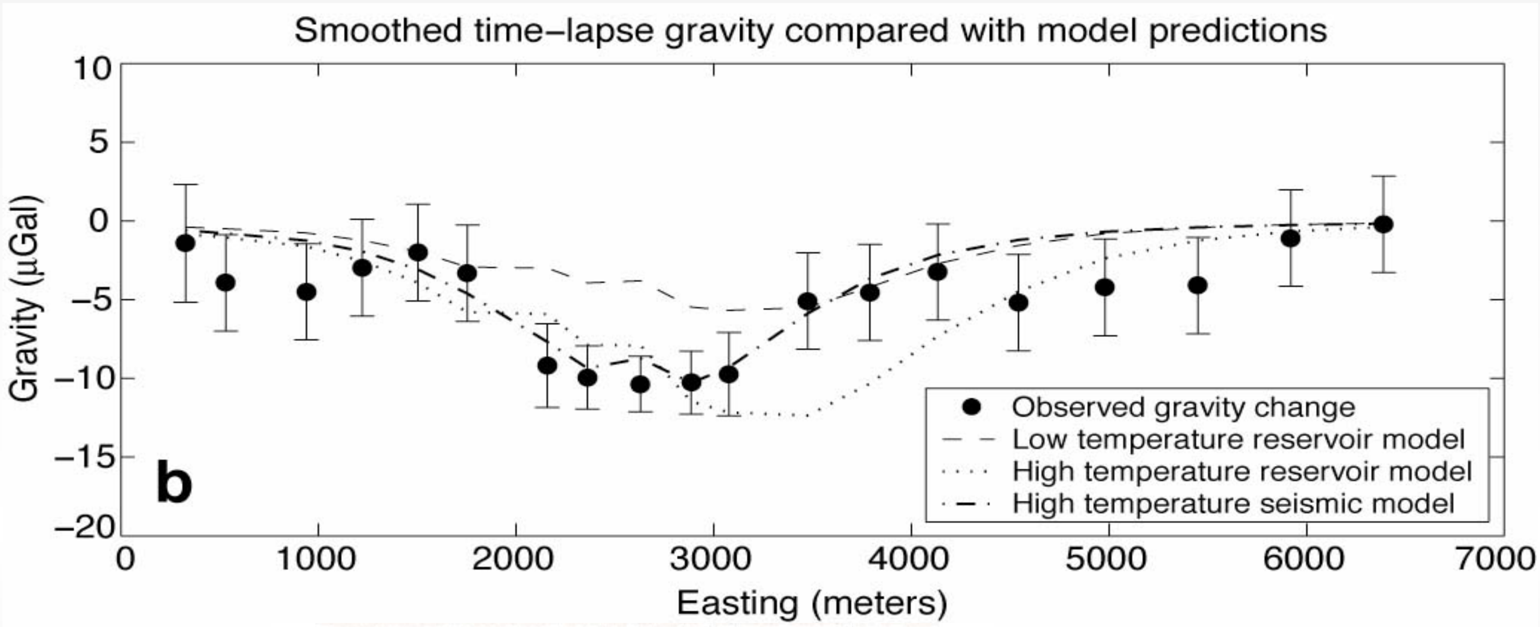
CO_2 saturation

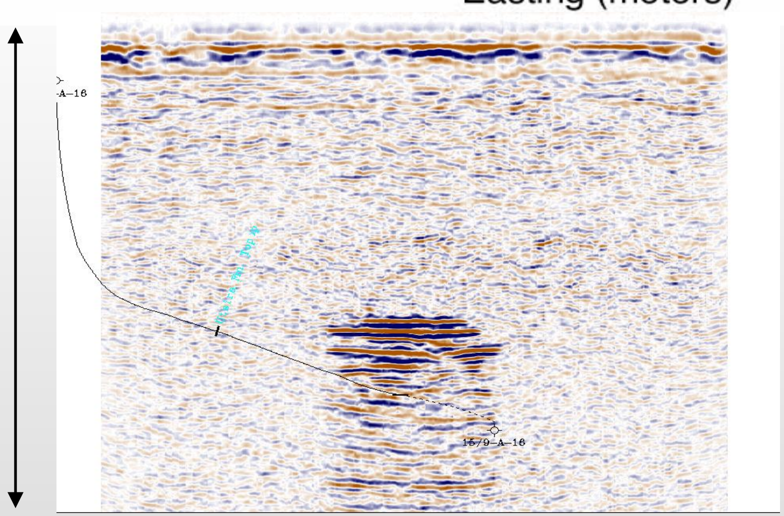


Smoothed



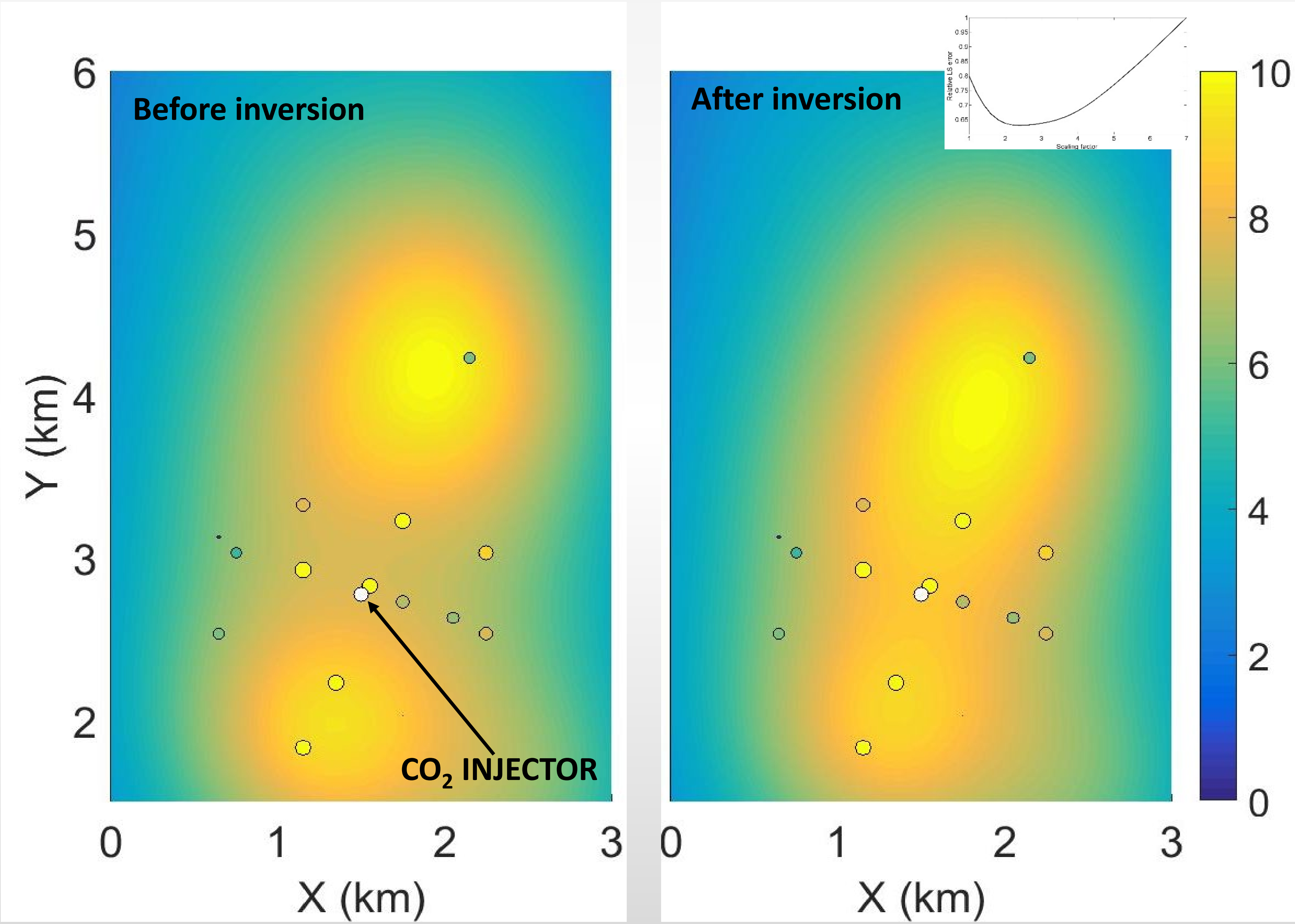
Time lapse gravity – Sleipner CO_2 plume



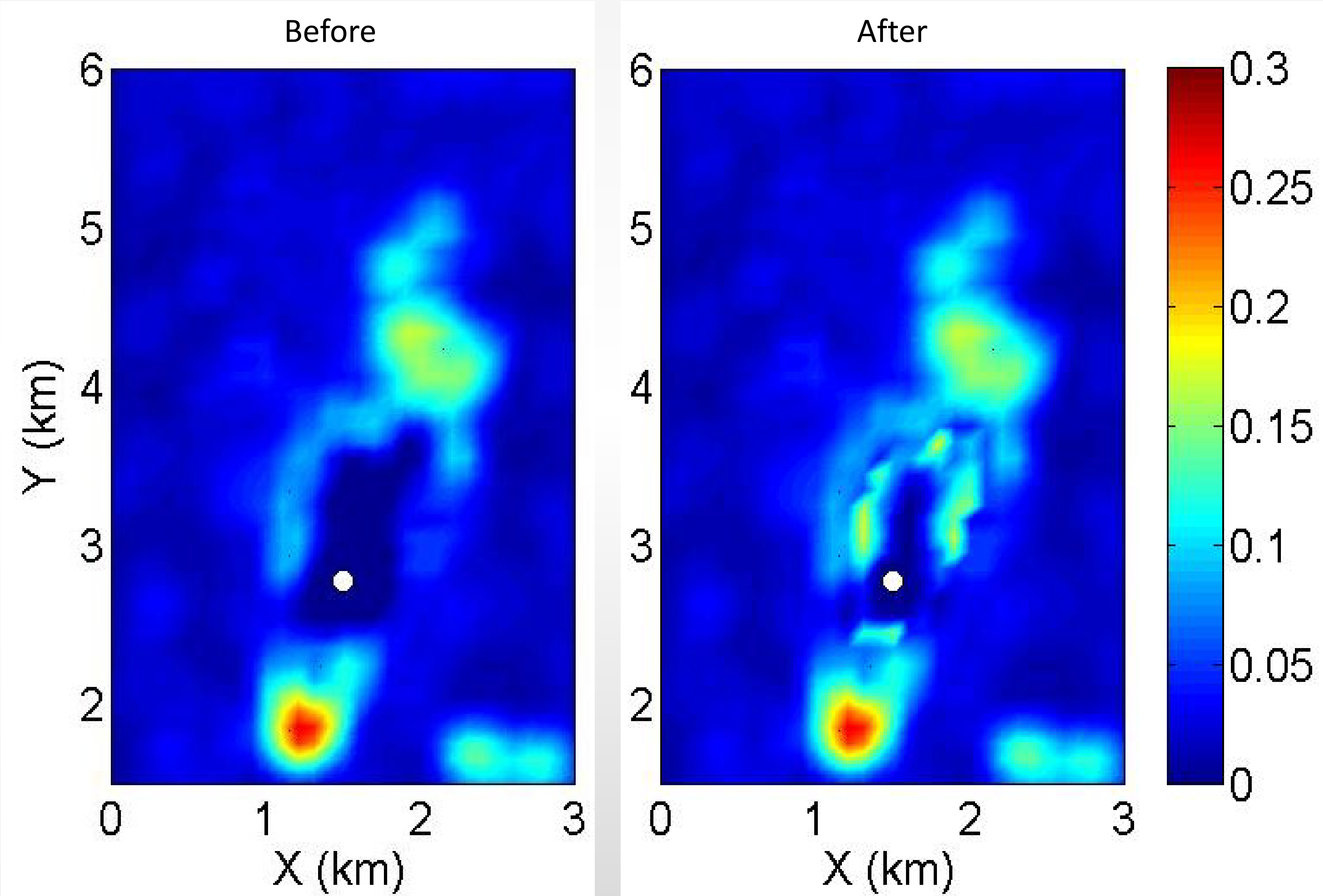


Work by H. Alnes, O. Eiken, S. Nooner, G. Sasagawa, T. Stenvold and M. Zumberge

Modeled and measrued (circles) gravity data



Including all layers .. => need help from gravity



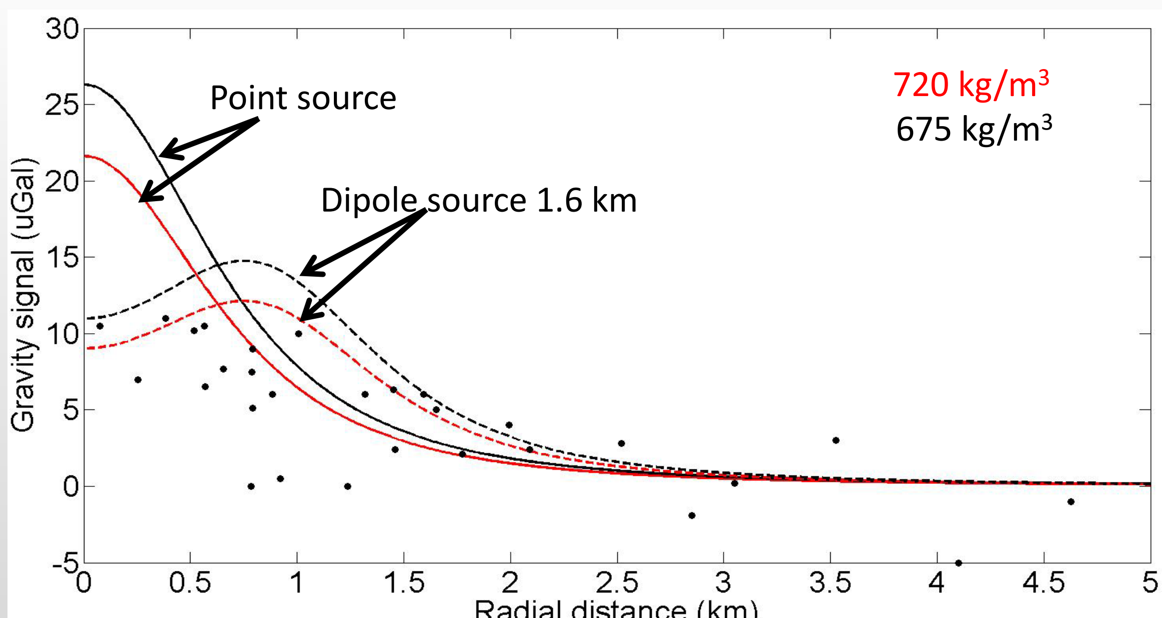
Back of the envelope ...

Sleipner: $5.88 \cdot 10^9$ kg CO_2 injected 2001–2008.

$$\rho_{CO_2} = 675\ kg/m^3 \Rightarrow V = 8.7 \cdot 10^6\ m^3$$

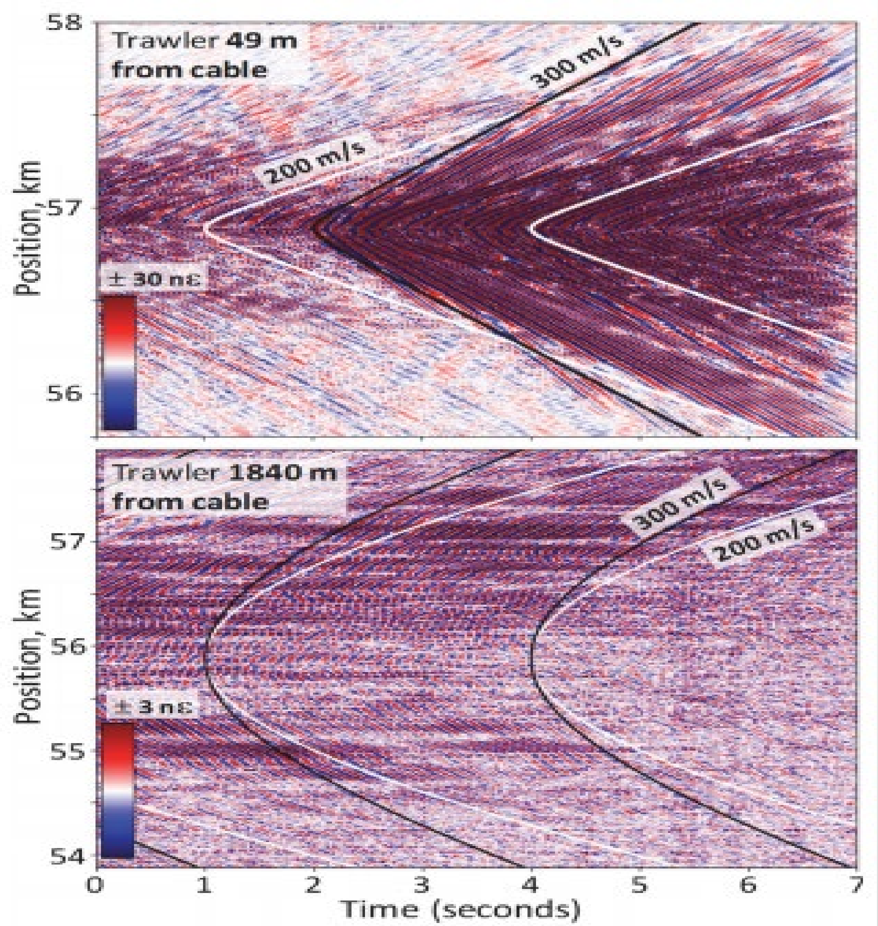
$$\Rightarrow \Delta m = \Delta\rho \cdot V = \underline{2.83 \cdot 10^9\ kg}$$

$$\Rightarrow \boxed{\Delta g_z = \frac{G\,\Delta m}{r^2}} = \frac{6.7 \cdot 10^{-11} \cdot 2.83 \cdot 10^9}{(900)^2} = \boxed{23\ \mu Gal}$$

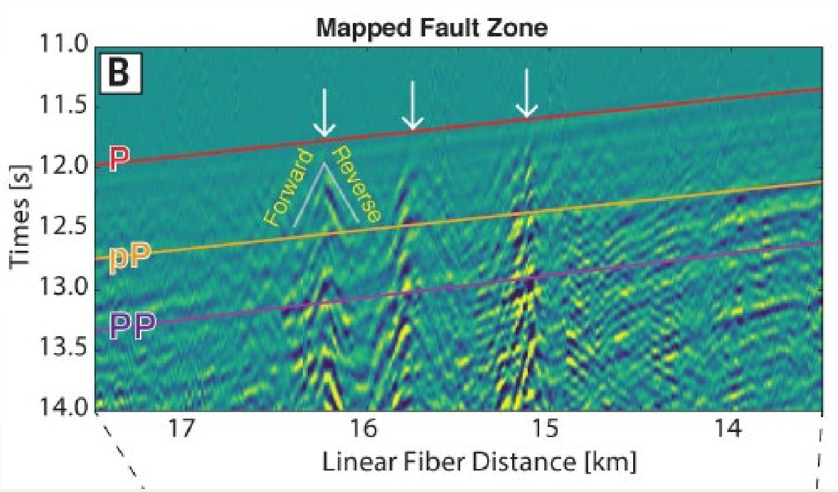


Optical seismology: Measuring seismic signals in a fibre at long distances (up to 100 km)

DAS data recorded in a telecom cable crossing the North Sea showing seabed wave modes originating from a trawler. Courtesy of ASN, Trondheim



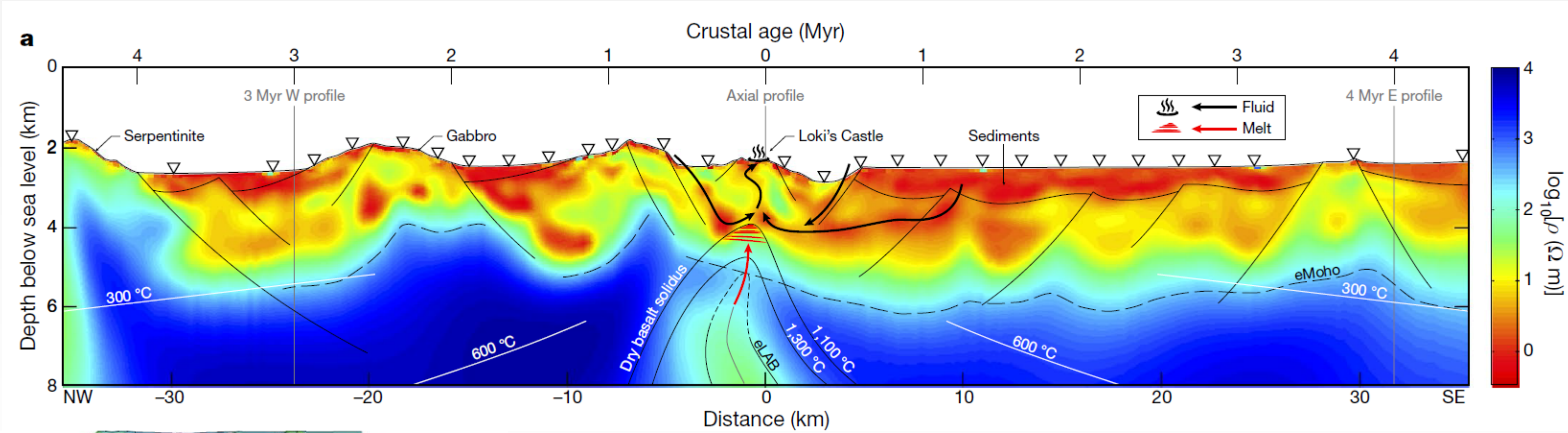
11 March 2018 Gilroy earthquake Mw=3.4

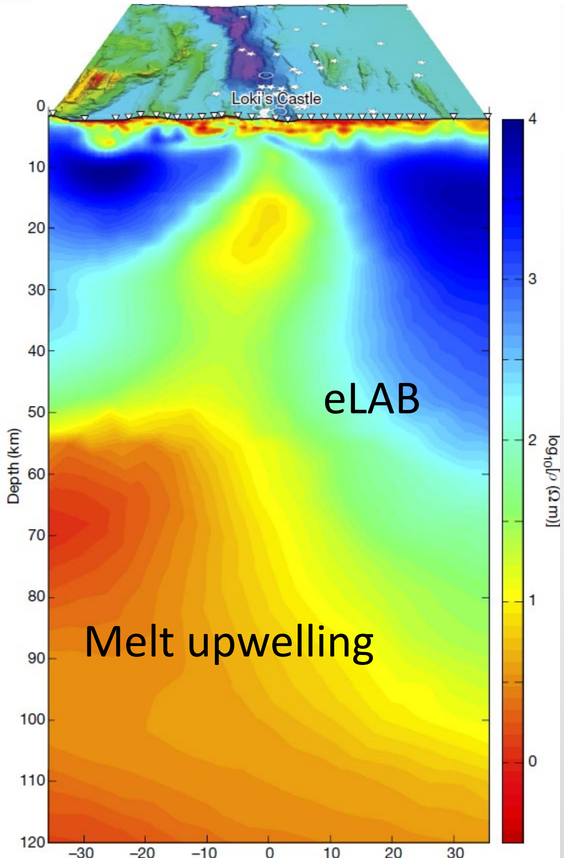


Lindsey et al., Science 366, 1103–1107 (2019

DAS-technology is rapidly evolving

Electromagnetic methods: CSEM and MT





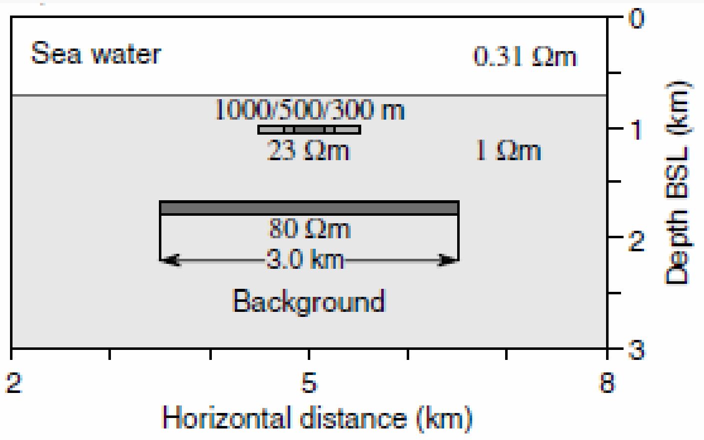
From Johansen et al., 2019, Nature

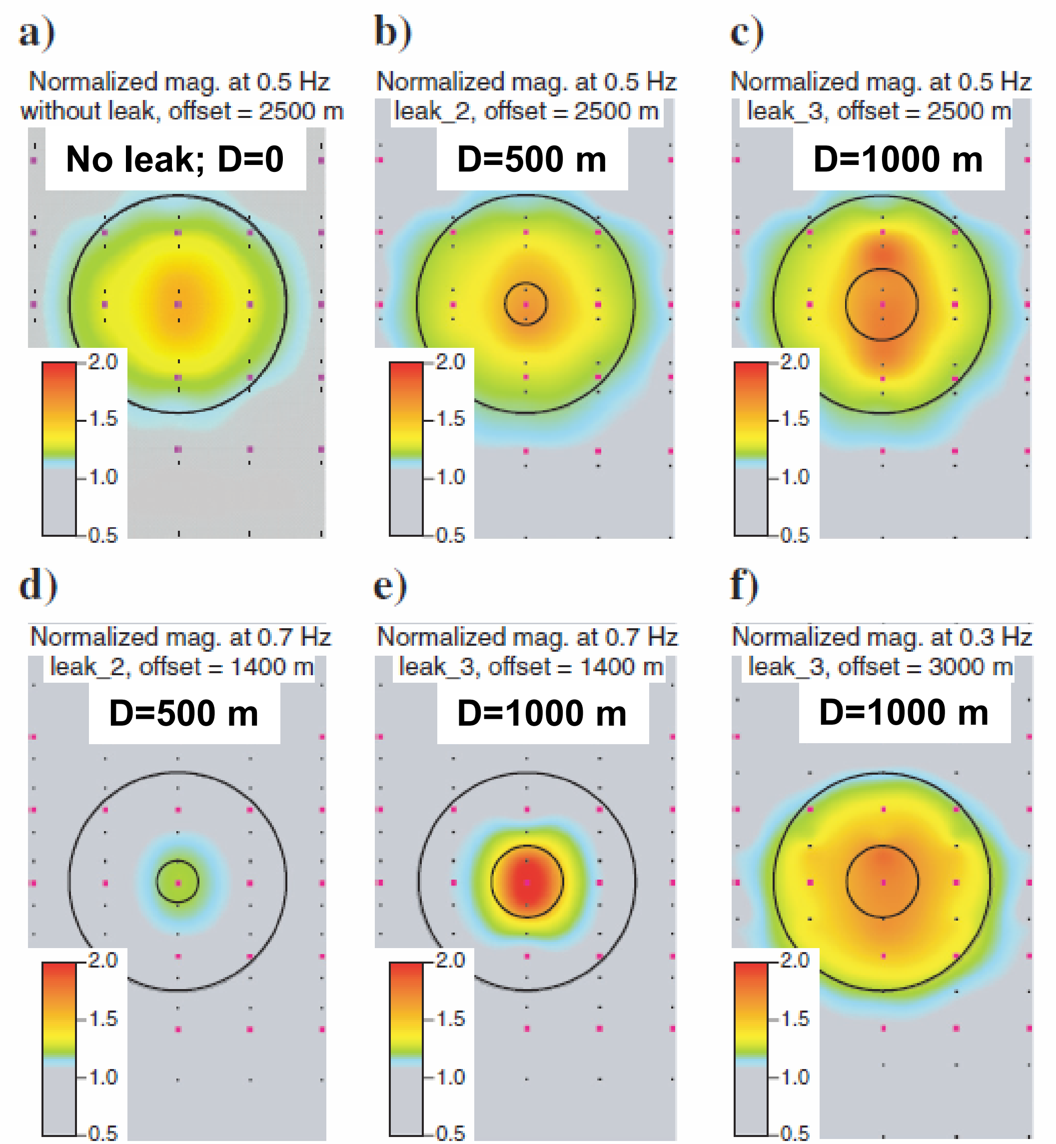
Magnetotellurics (MT) to the left and Controlled Source Electromagnetics (top)

eLAB: electric boundary between Lithosphere and Astenosphere

Since CO_2 is high resistive, there is a strong potential for using CSEM for CO_2-monitoring

Detection of a thin CO_2-layer above the storage site

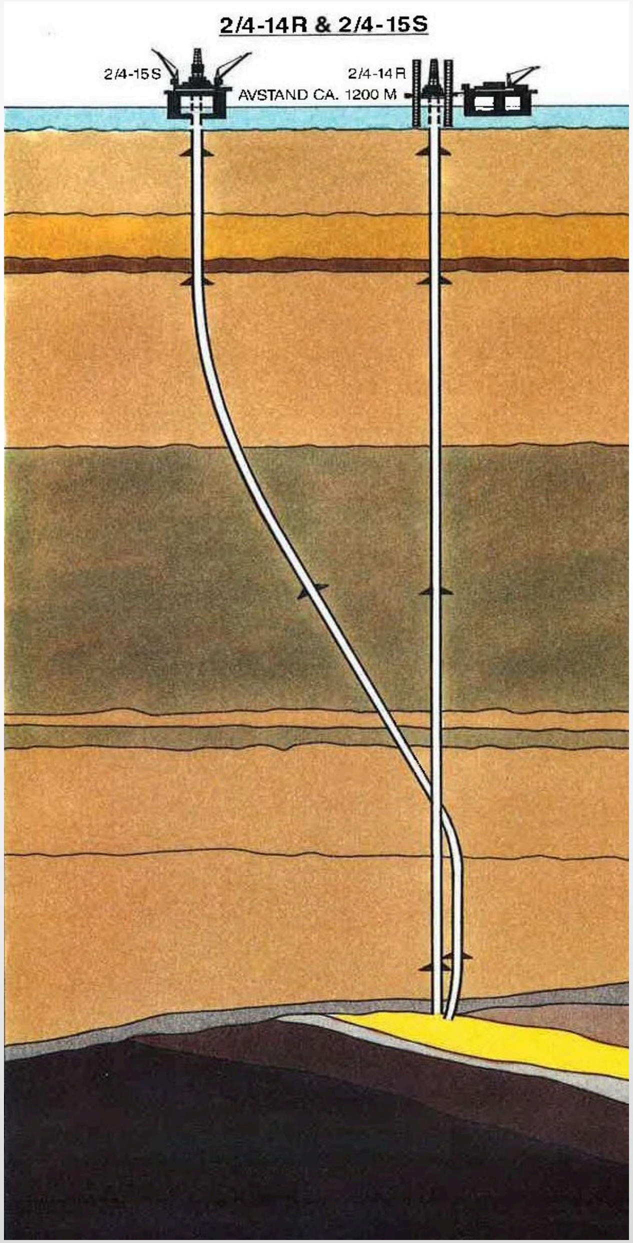


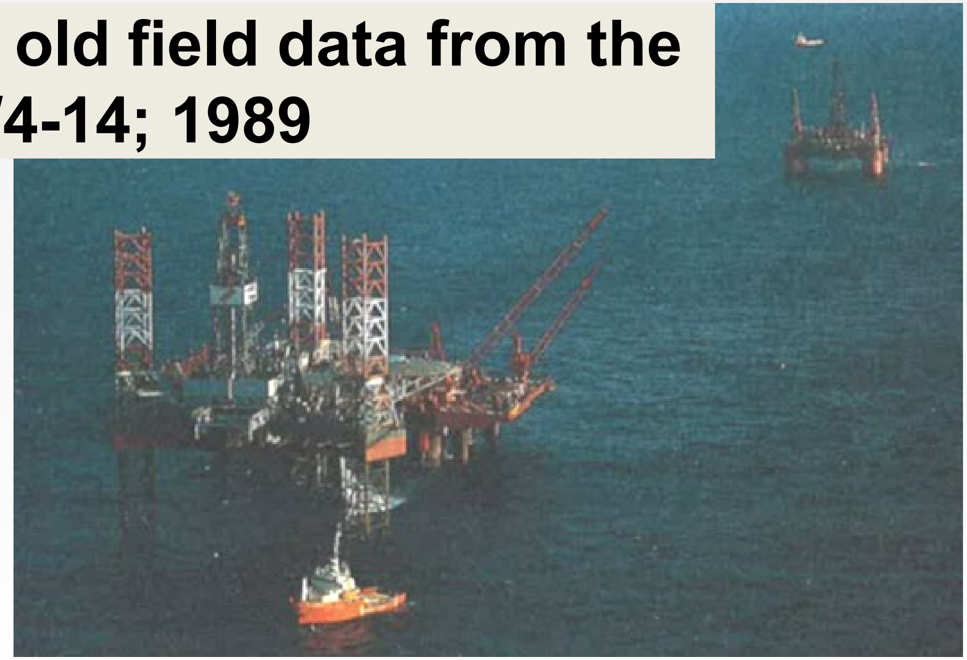


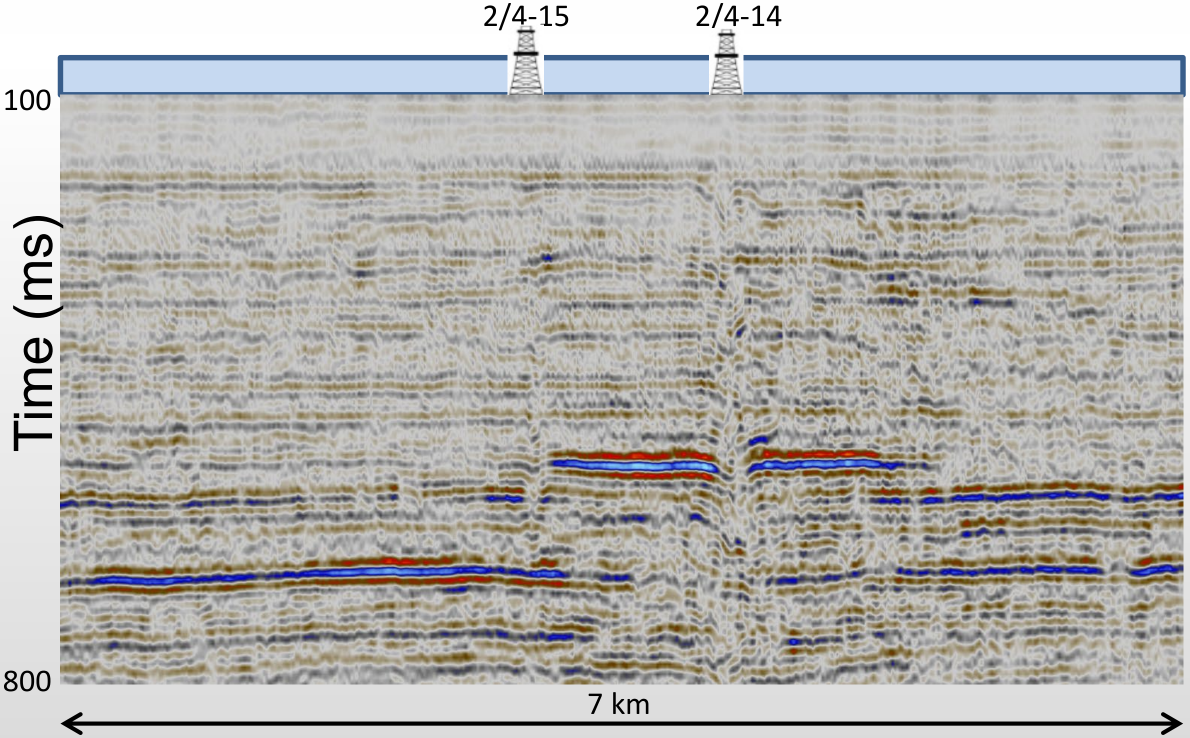
Thickness of main plume: 100 m
Thickness of leakage plume: 50 m

Bhuiyan et al., 2012, Geophysics

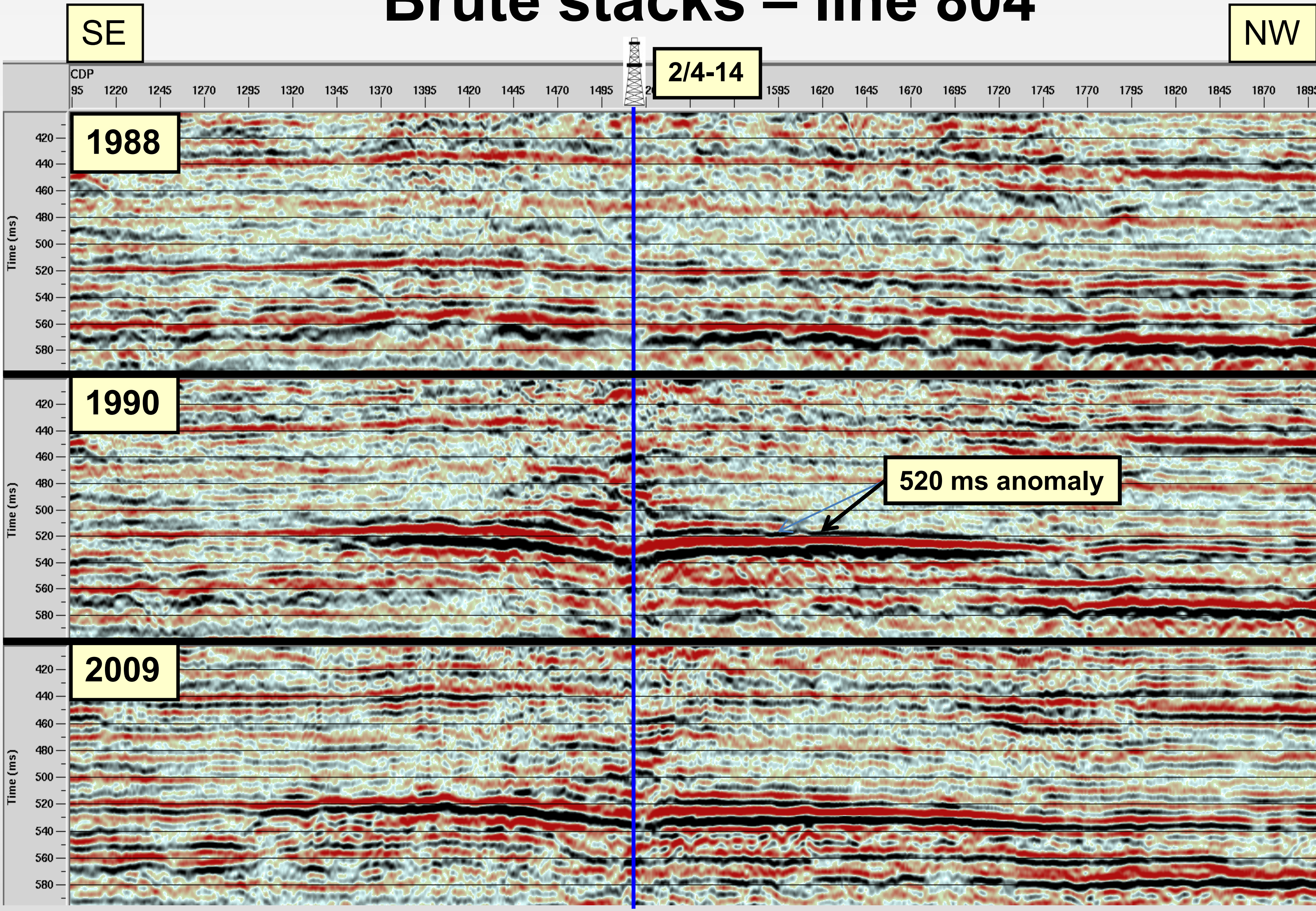
Shallow gas leakage – using old field data from the underground blowout well 2/4-14; 1989





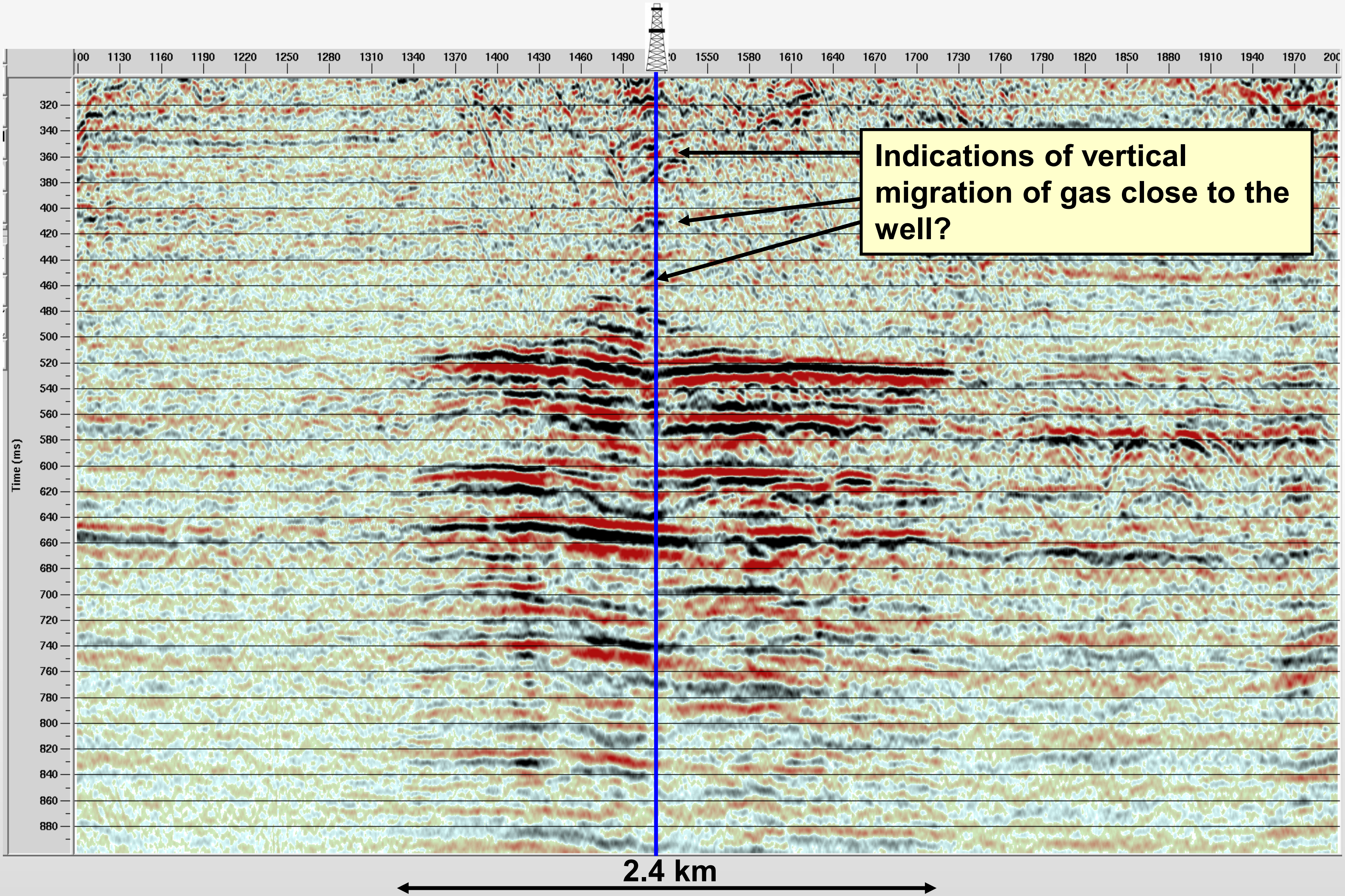


Brute stacks – line 804

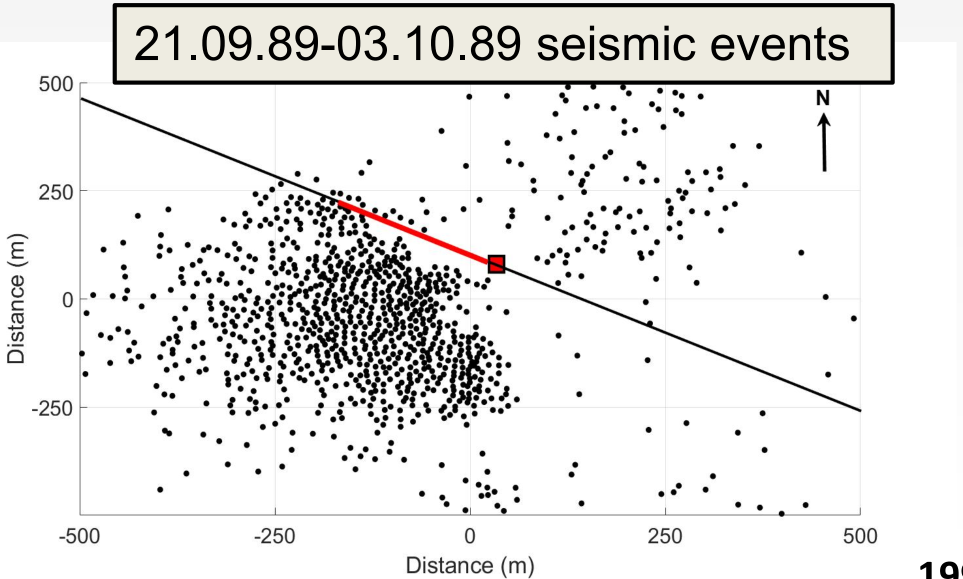


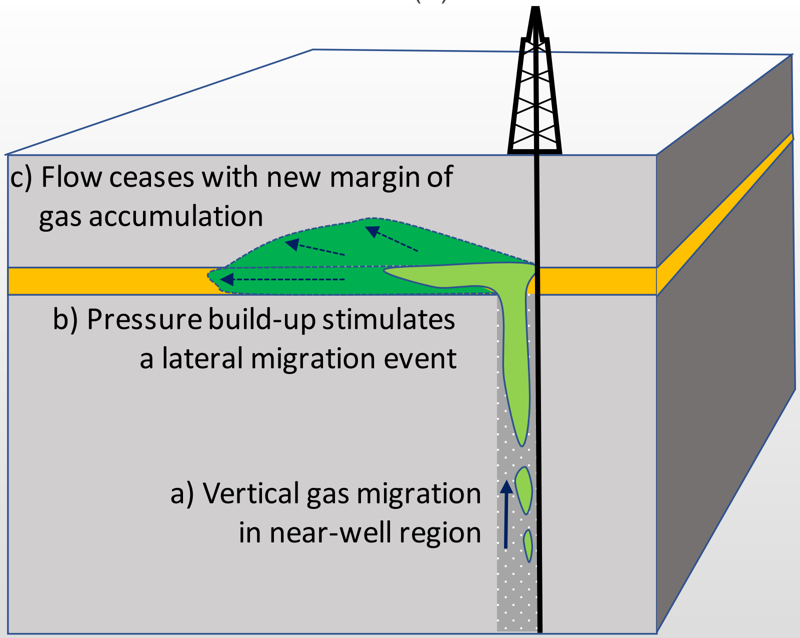
Less pulldown in 2009 – slight increase in horizontal extention

4D difference – line 804 1988-1990 after global scaling

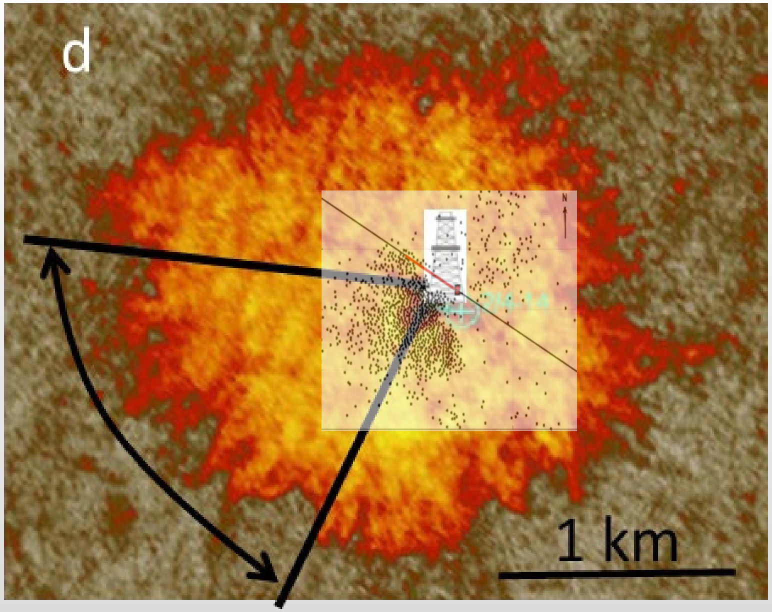


Combining active and passive seismic data

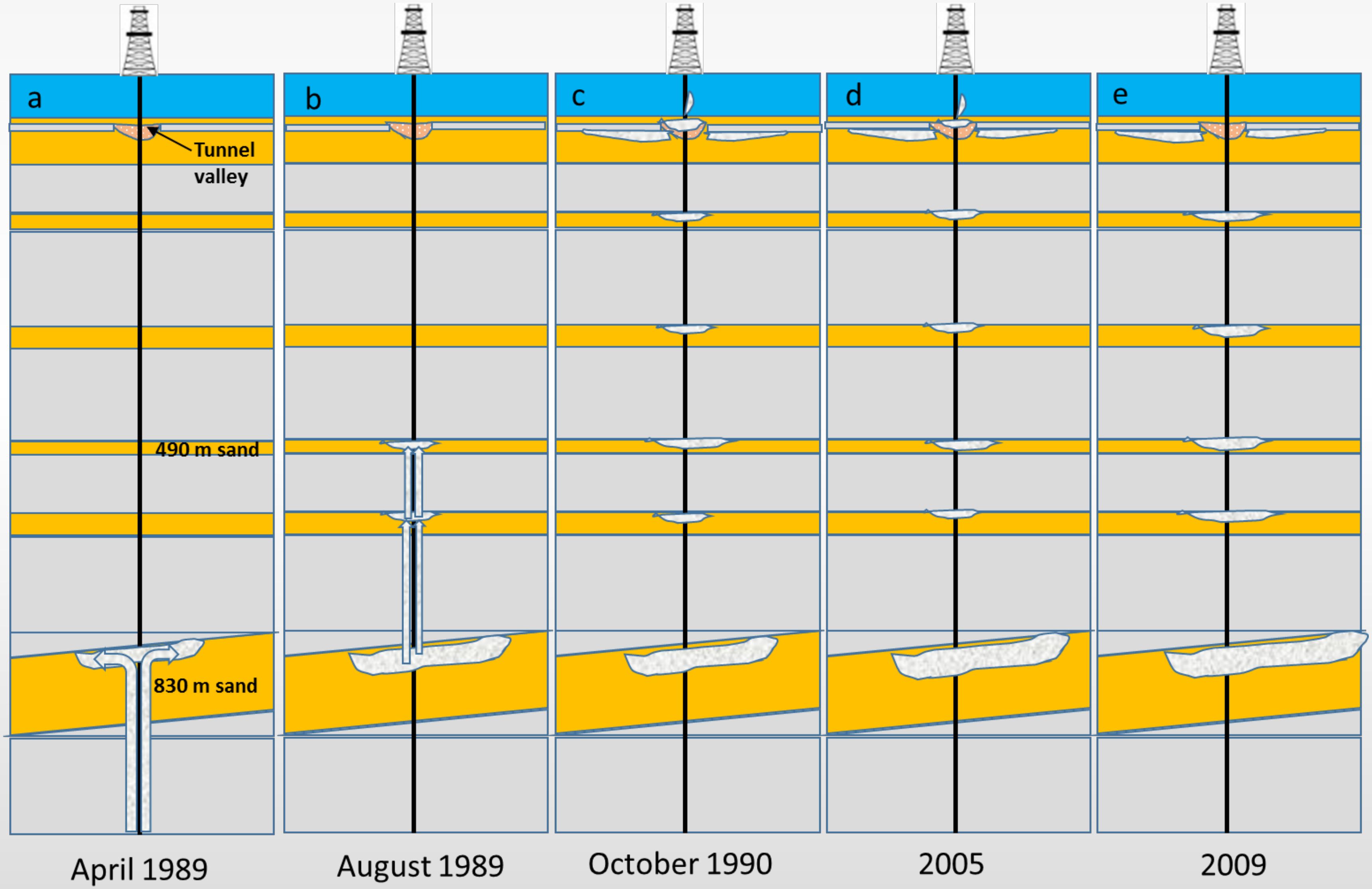




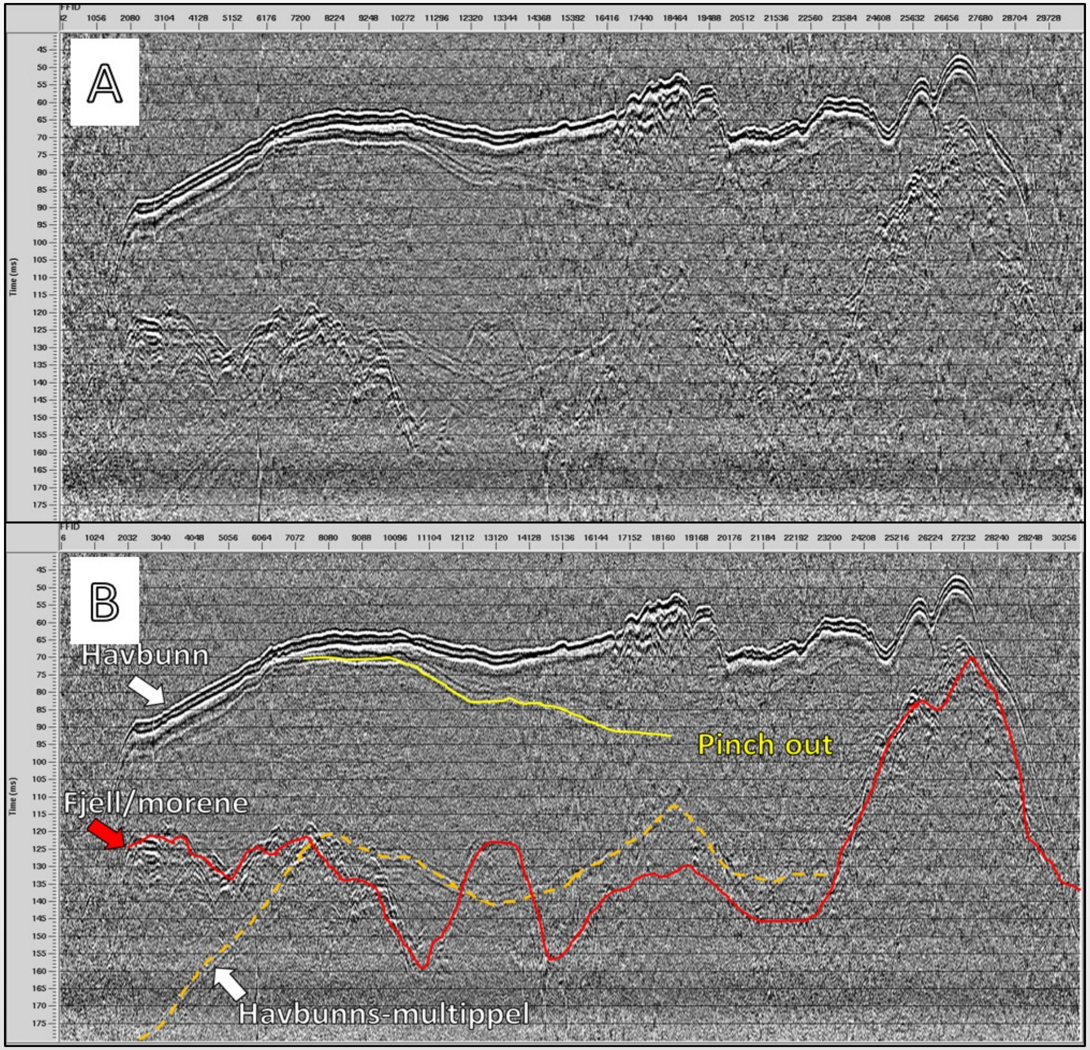
1991 3D amplitude map of top 490 sand layer



Time lapse interpretation



Shallow seismic using electric source (bubble gun)



High resolution mapping of 100 m below seabed – repeatable source

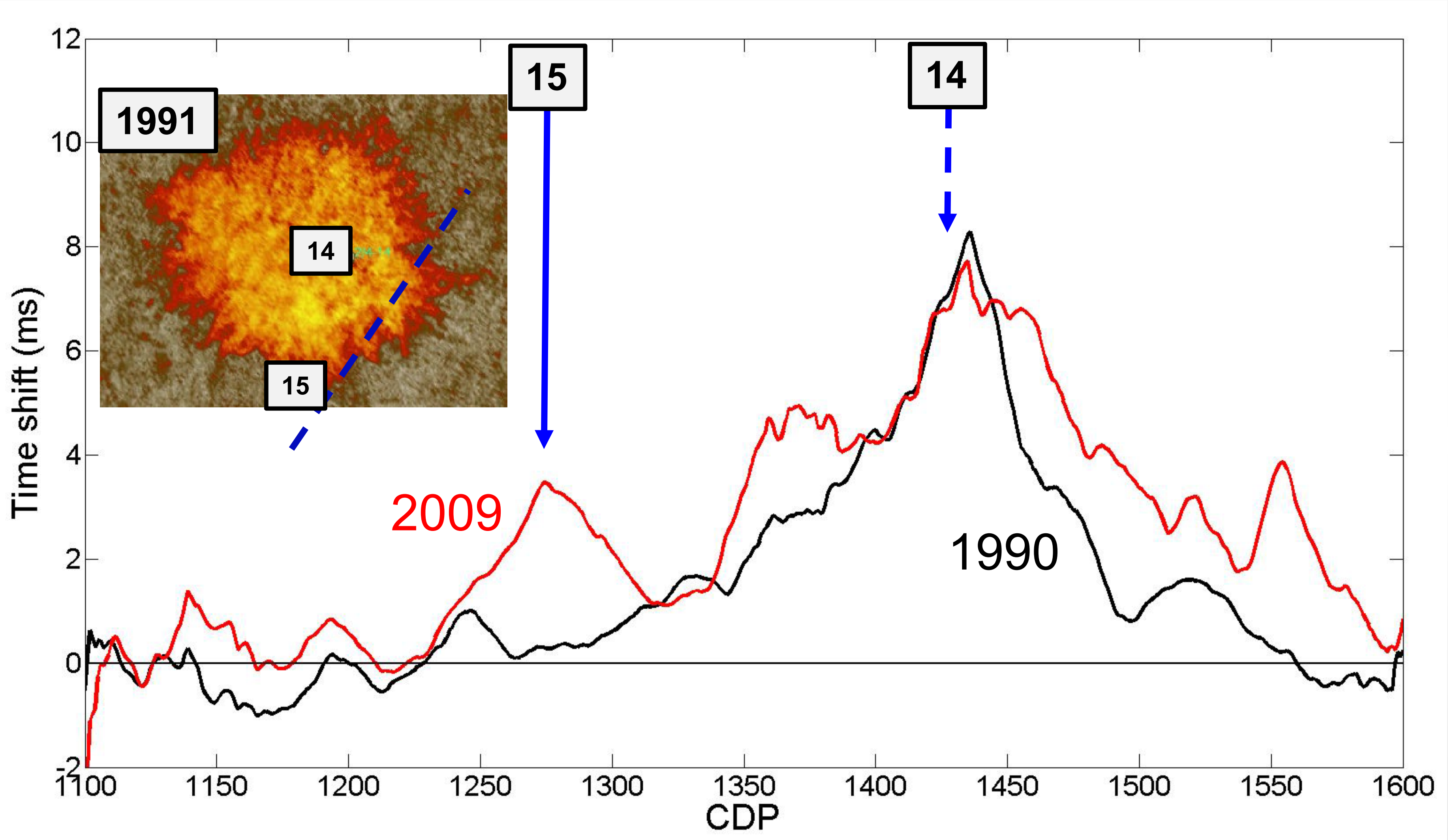
Conclusions

- **4D seismic is robust and provides high resolution**
- **Gravity and CSEM adds useful information**
- **Fibreoptic DAS technology is costeffective and promising**
- **High resolution seismic for the upper 100 m**

Acknowledgments

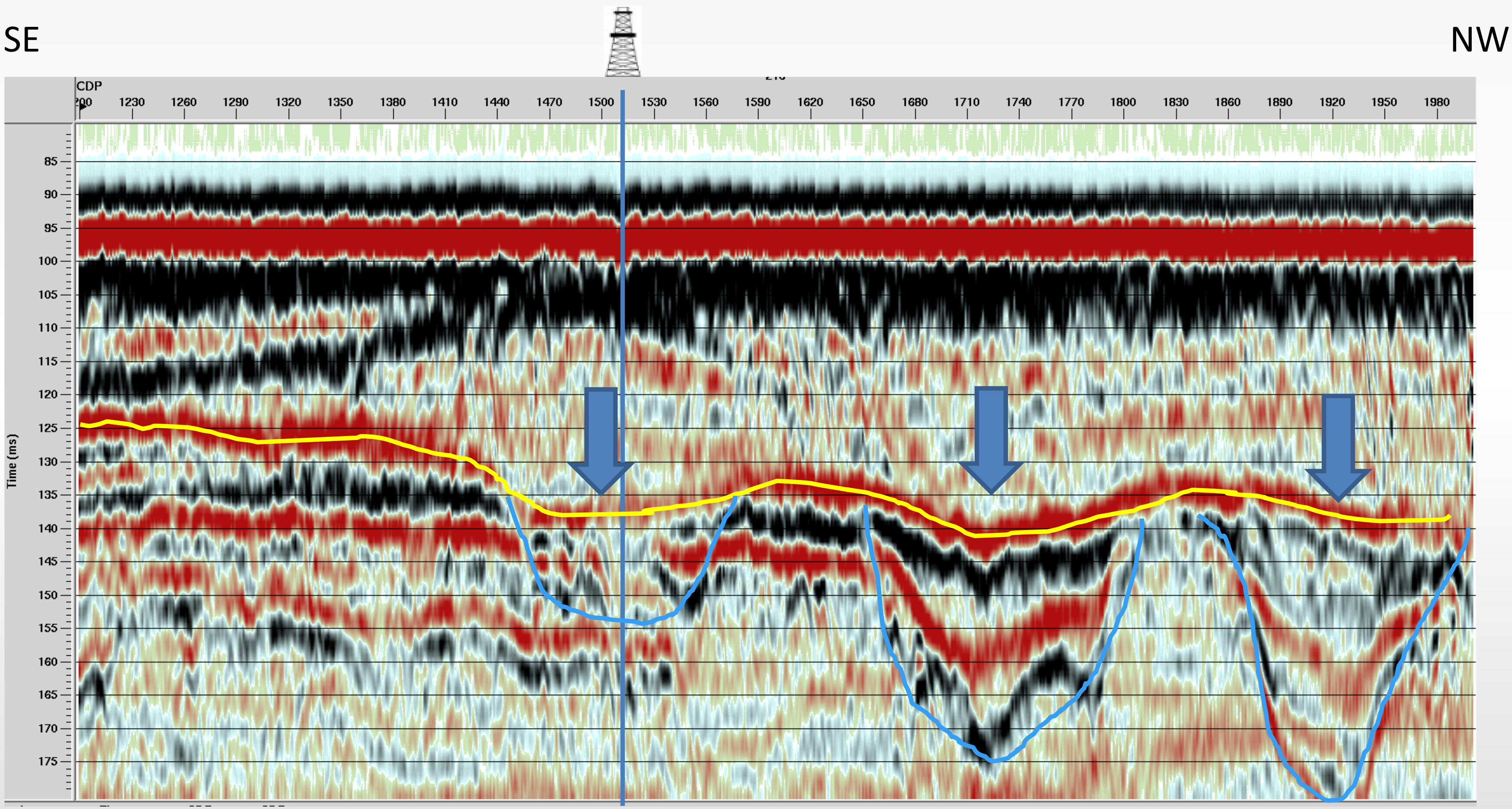
- Equinor for providing data

Smoothed timeshifts – line 602 (upper sand)



Note: Significant time shift increase close to relief well between 1990 and 2009

Line 804; 1990: 2/4-14 well is drilled in the middle of a shallow tunnel valley; 30 m below seabed



3 interpreted tunnel valleys shown by arrows marking the three depressions and subsequent erosion patterns below

Line 804 – shallow timeshifts – indications of leakage patterns

- Alignment of seabed reflection to 100 ms
- Near to the well: significant increase in timeshift between 88 and 90 – followed by a reduction back to pre-blowout values again – 800 m width
- Outside this region the situation is unchanged between 1990 and 2009