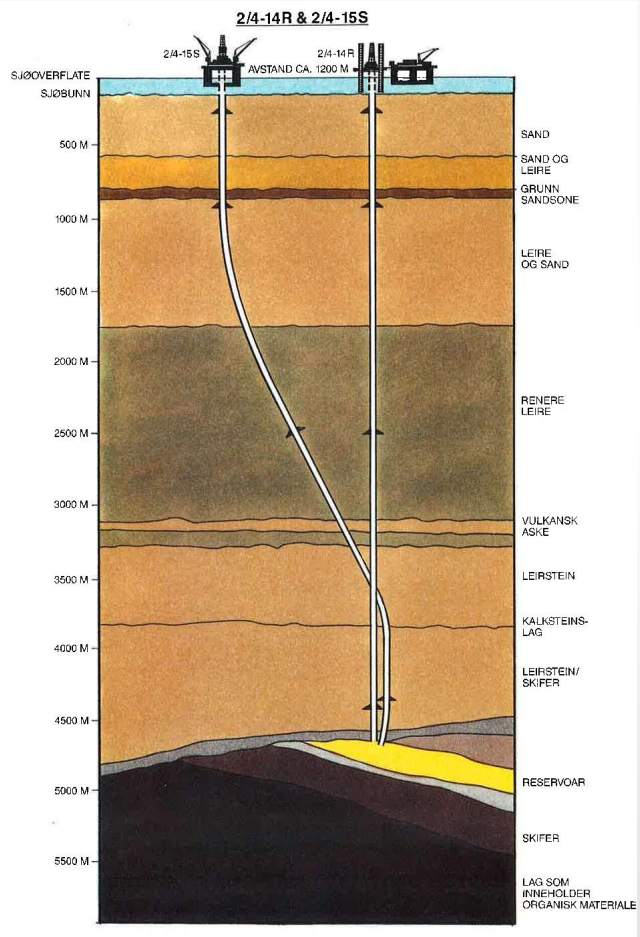
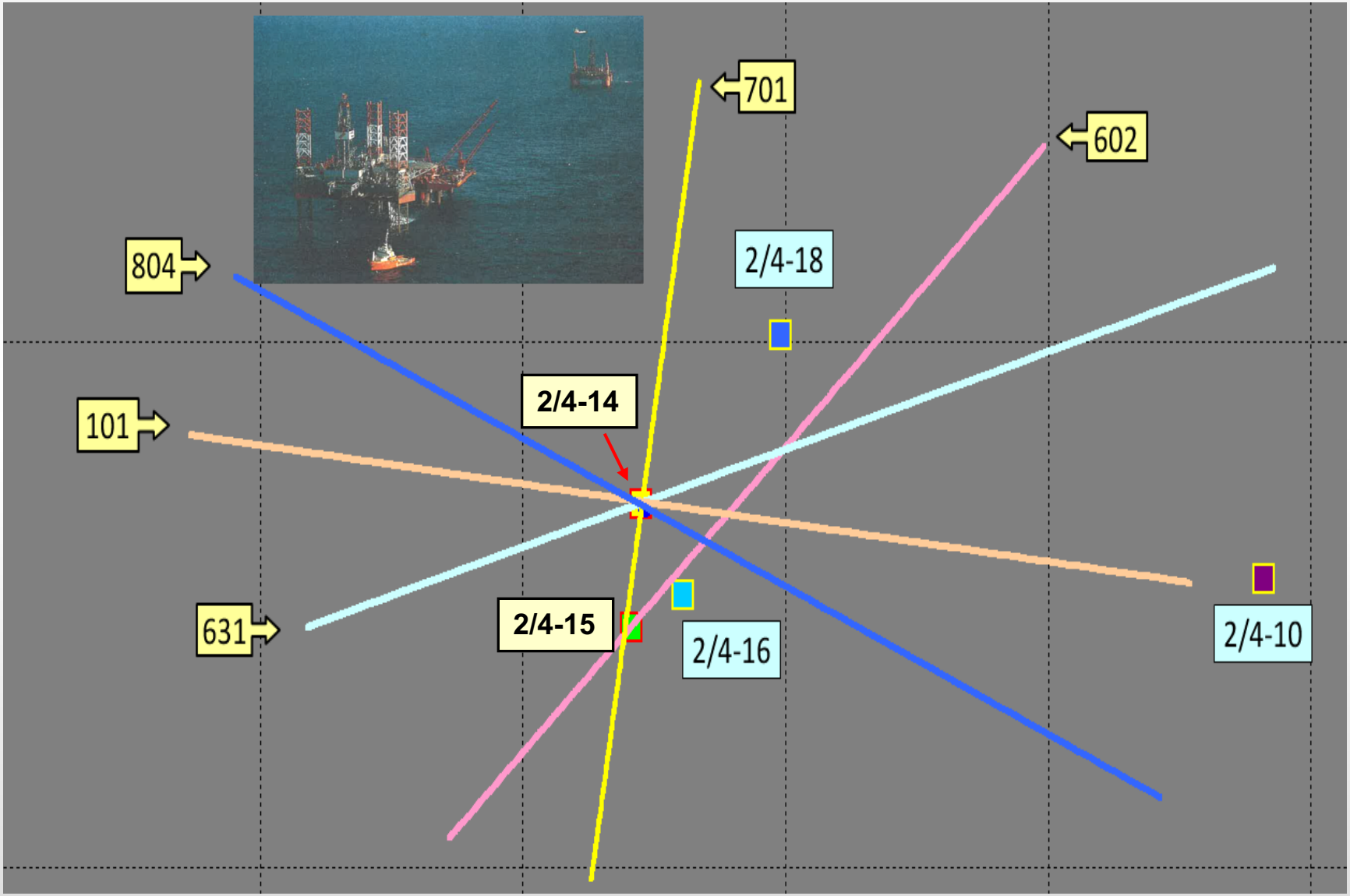
Gas leakage through shallow sediments – laboratory experiments compared to passive and active seismic data



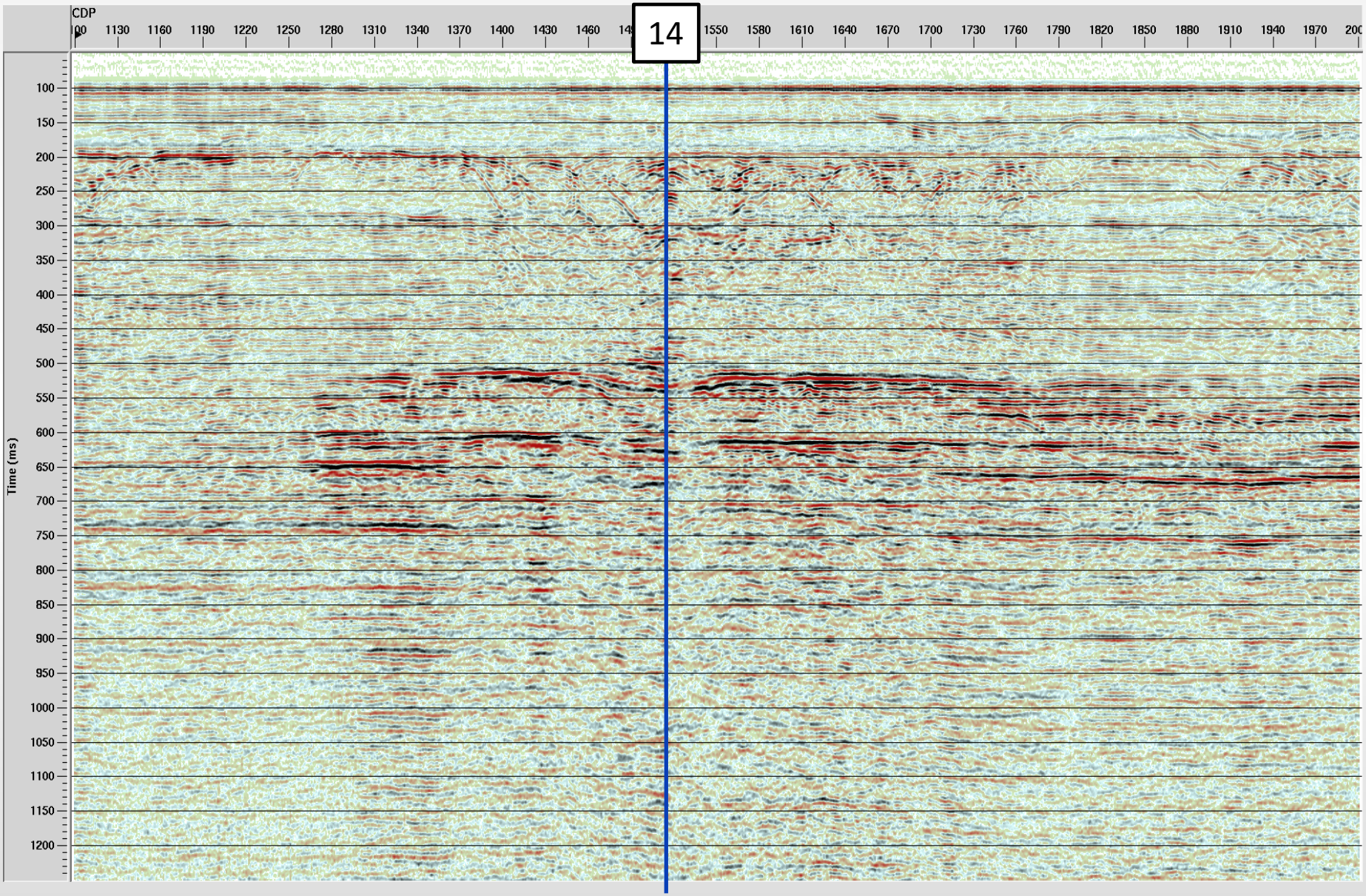
M. Landrø, P. Ringrose, D. Wehner and N. Vedvik and K. Berteussen

Repeated 2D lines acquired in 2009

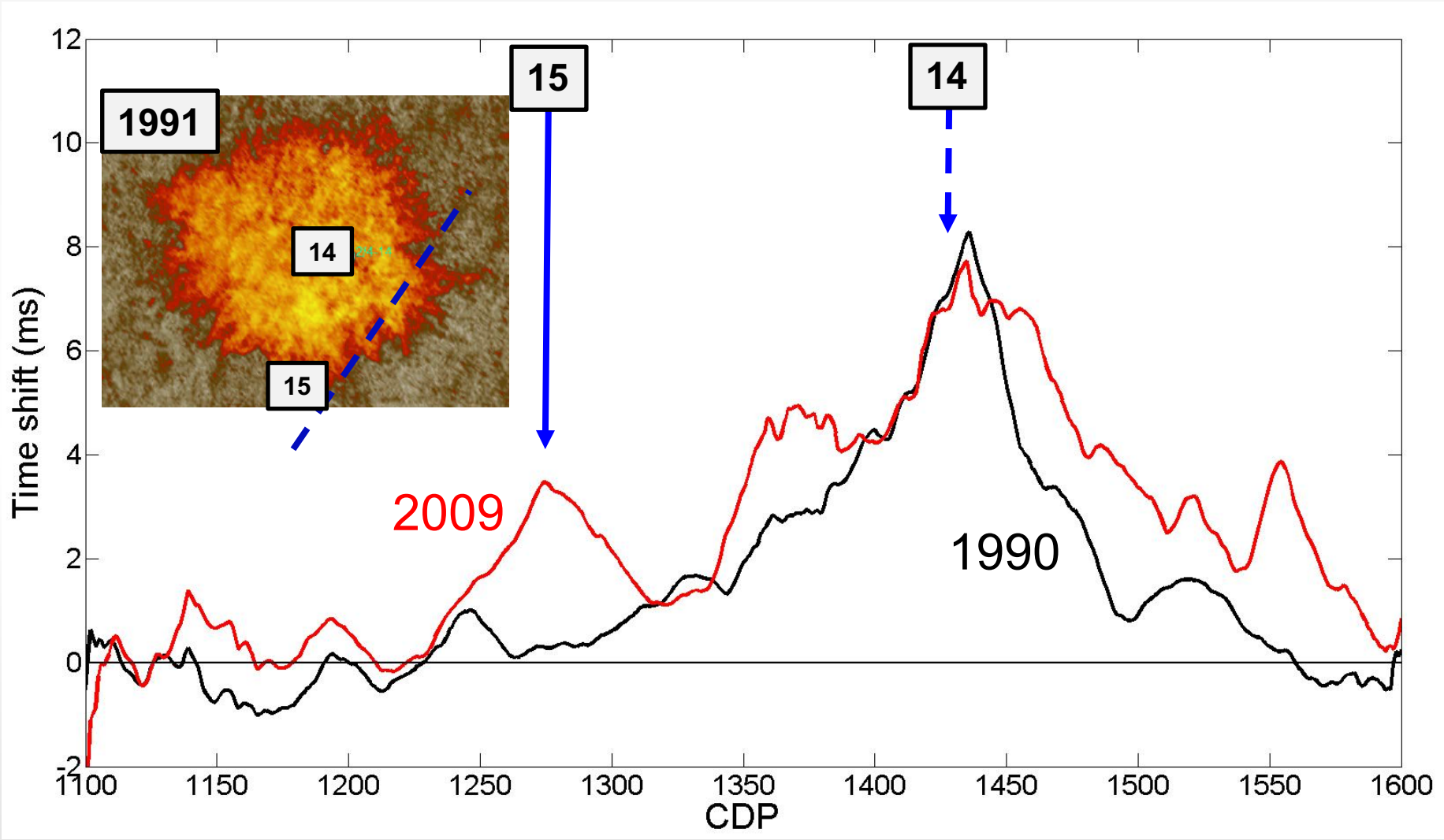


In this study we will use brute stacks from 602 and 804

Line 804 difference between 2009 and 1990, difference is scaled by t^1.3

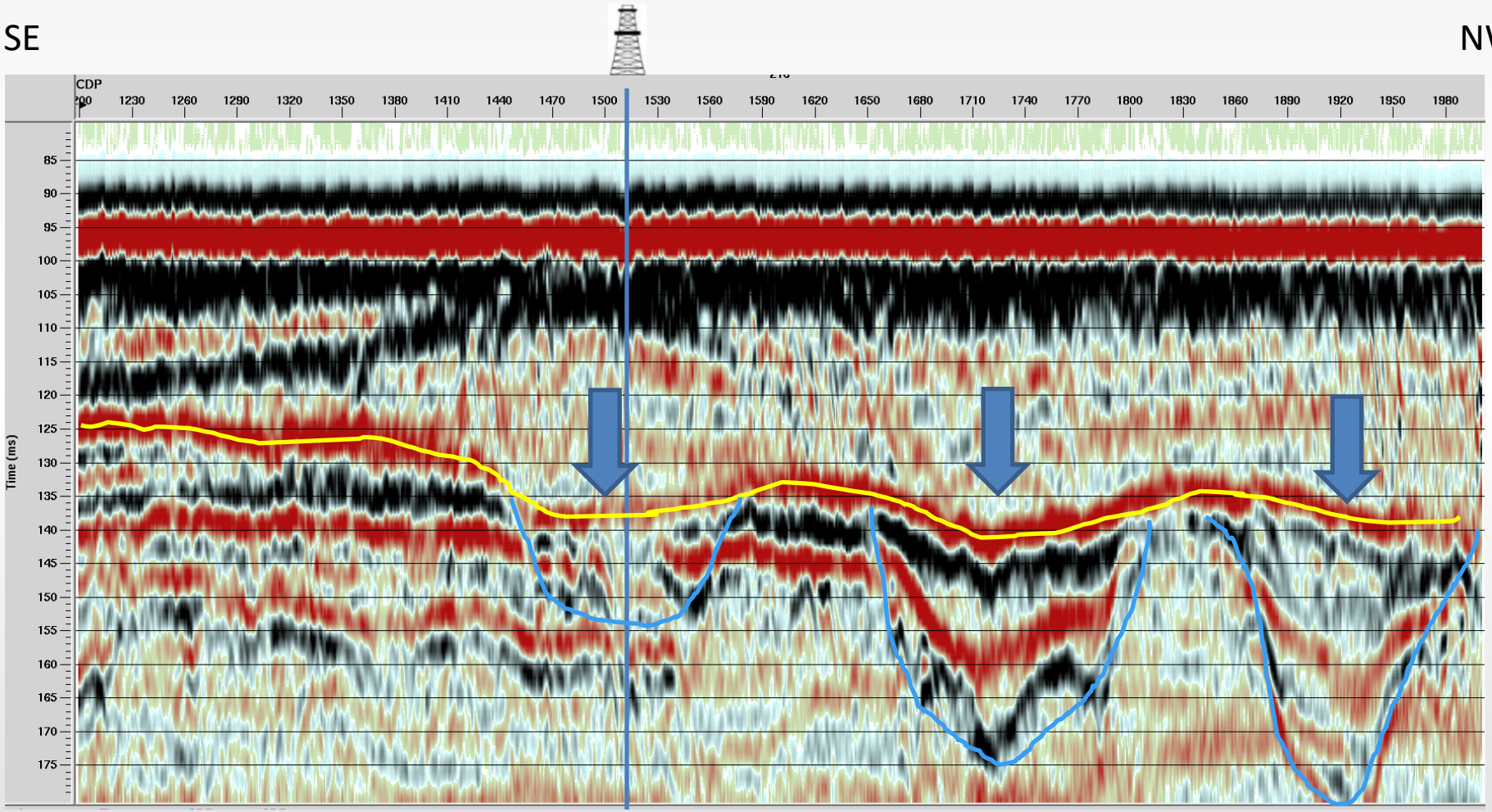


Smoothed timeshifts – line 602 (upper sand)



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

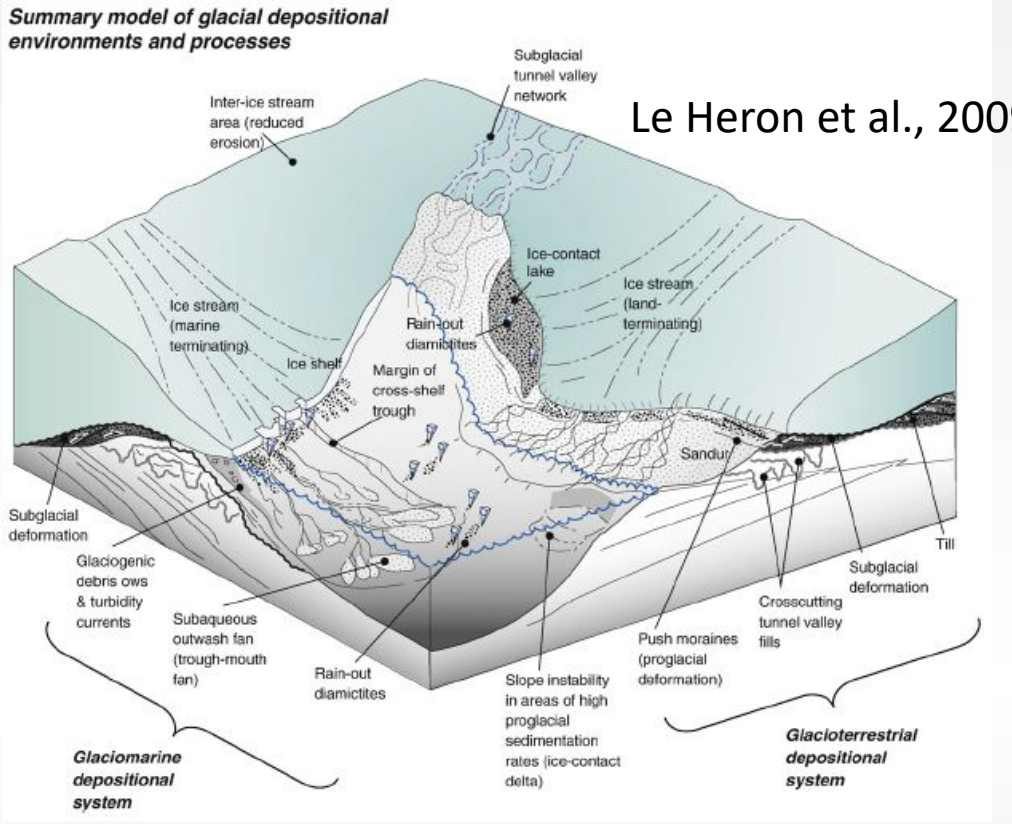


3 interpreted tunnel valleys shown by arrows marking the three depressions and subsequent erosion patterns below

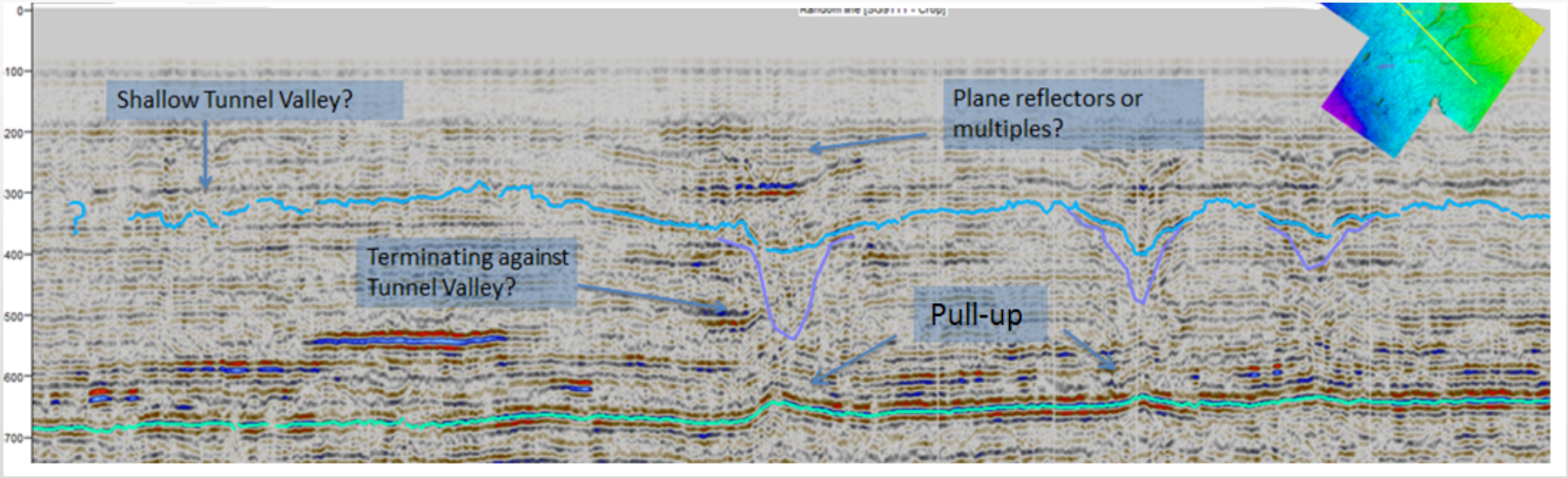
Tunnel valleys

Might store large volumes of gas (and CO_2) – and also serve as transport routes

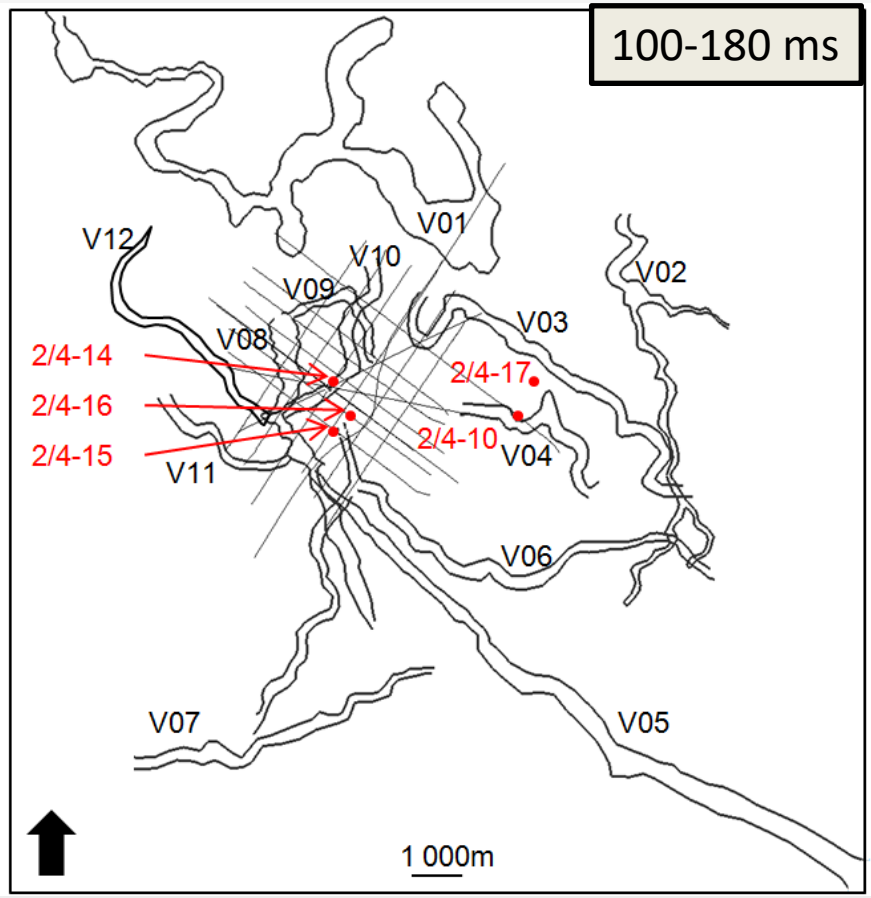
Seismic interpretation of tunnel valleys close to the blow out well:

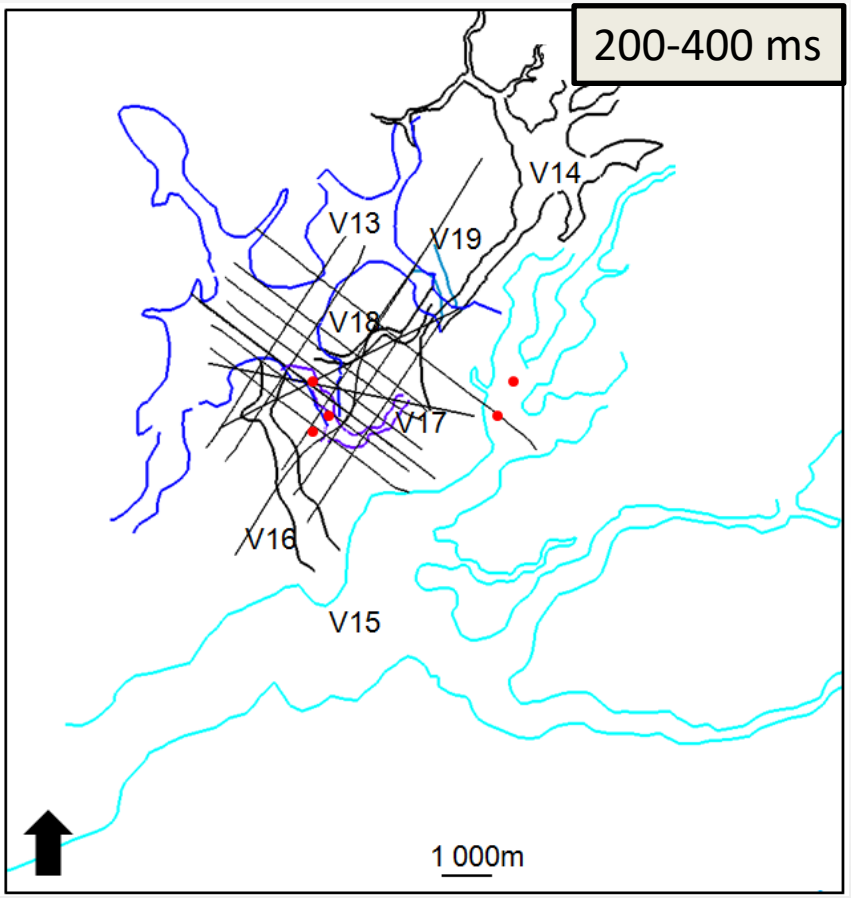


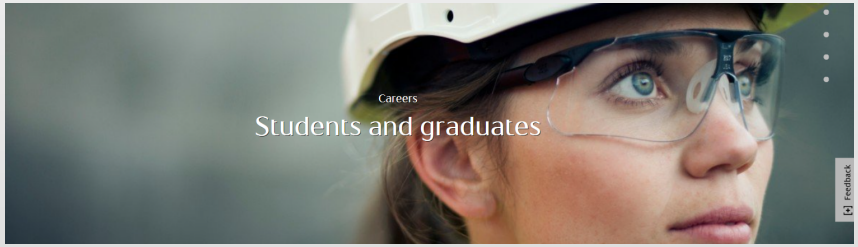
Le Heron et al., 2009



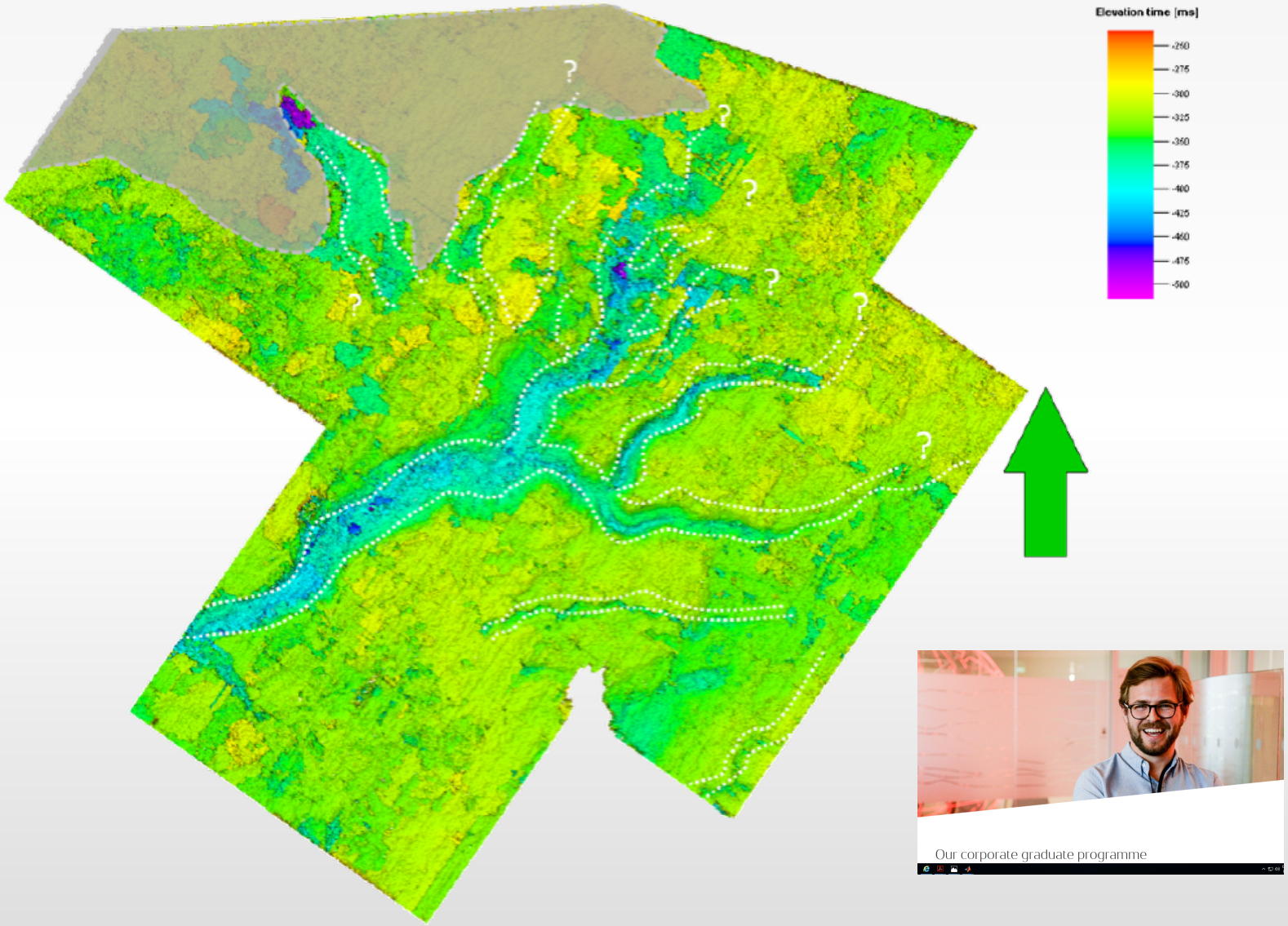
Interpreted tunnel valleys from 2D and 3D seismic data (Hanne Halvorsen's MSc-thesis)







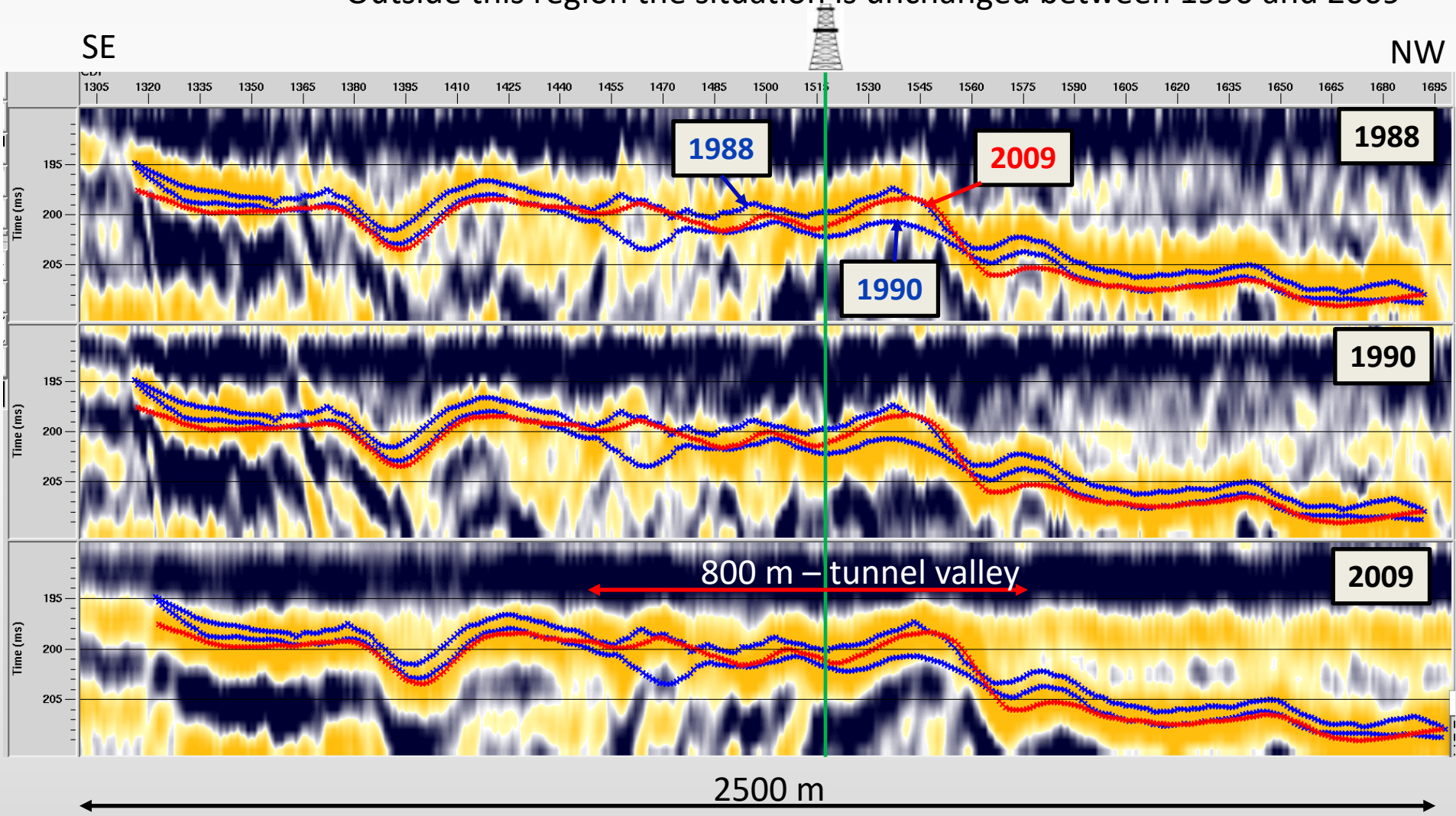
Interpreted tunnel valleys



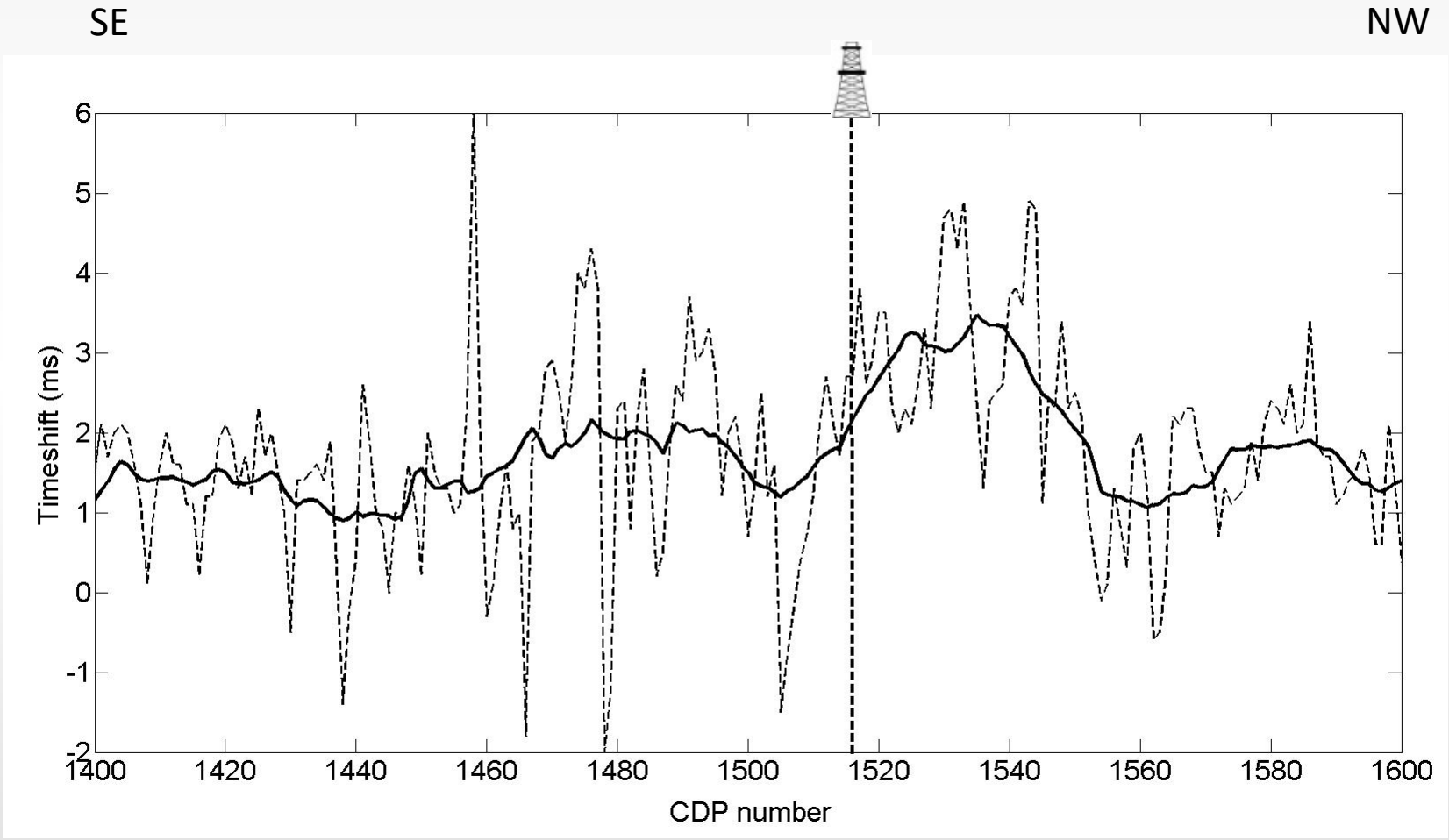
Work by K. Haavik

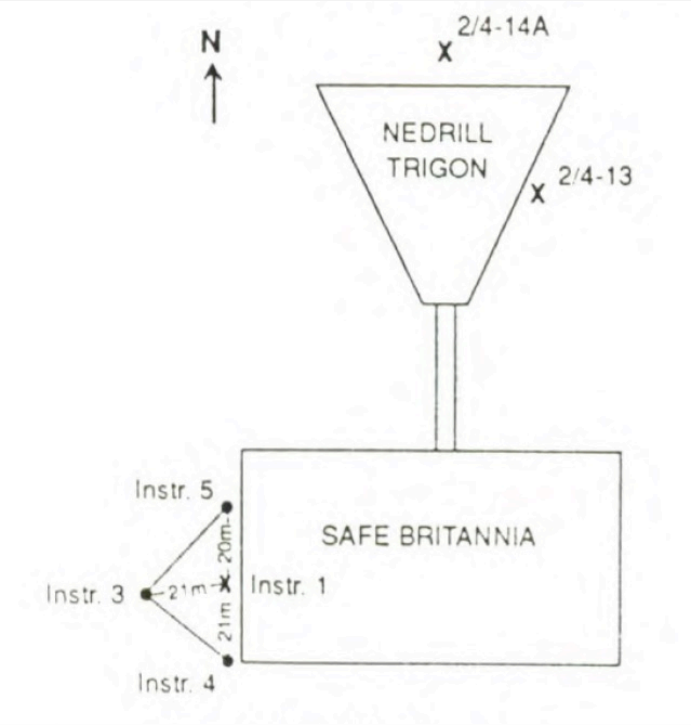
Line 804 – shallow timeshifts – indications of leakage patterns

- 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



Line 804: 1988-1990 Time shift of 3-4 ms gradually decreasing away from well position

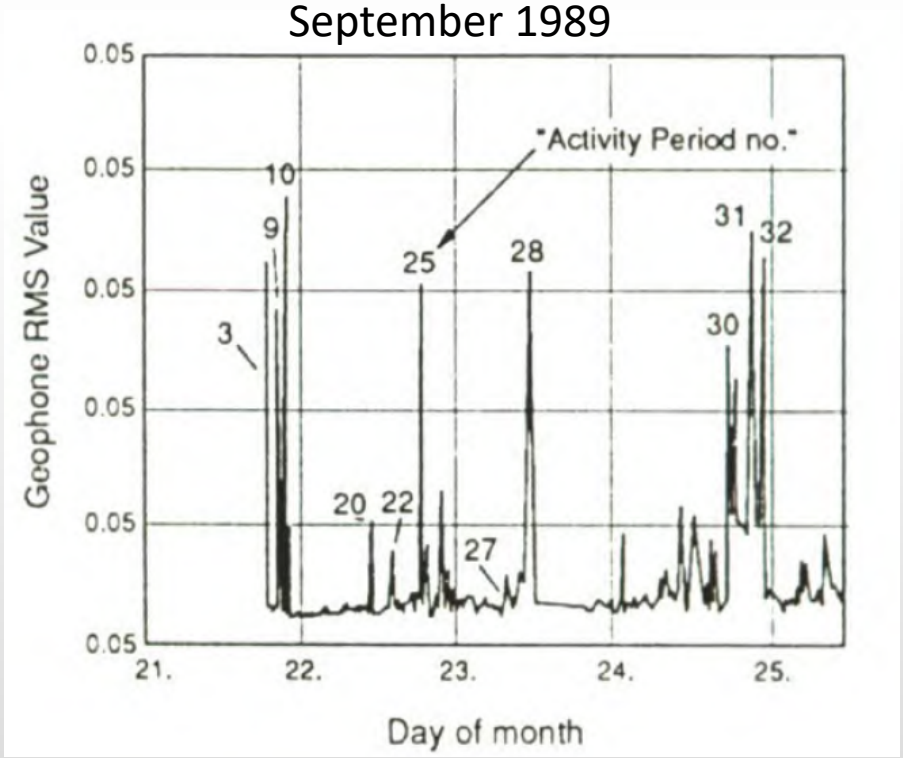




Nedrill Trigon

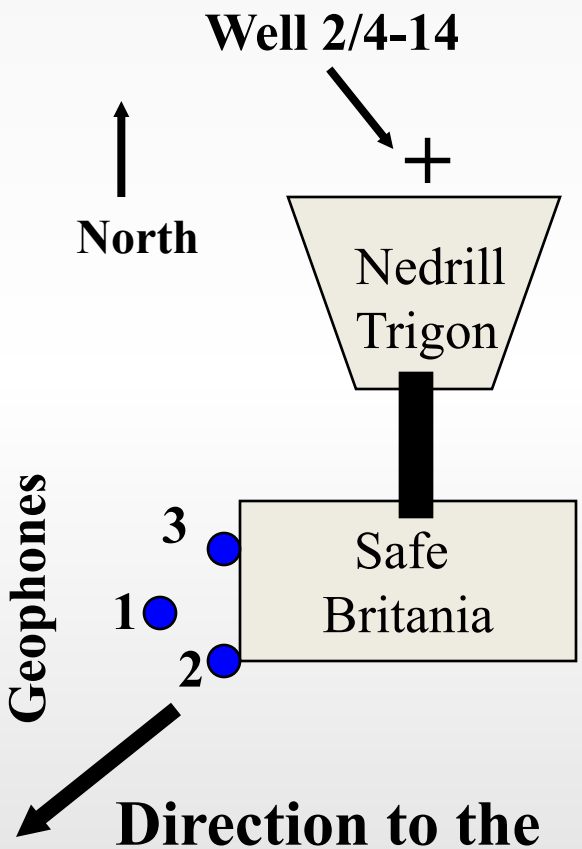
Safe Britannia

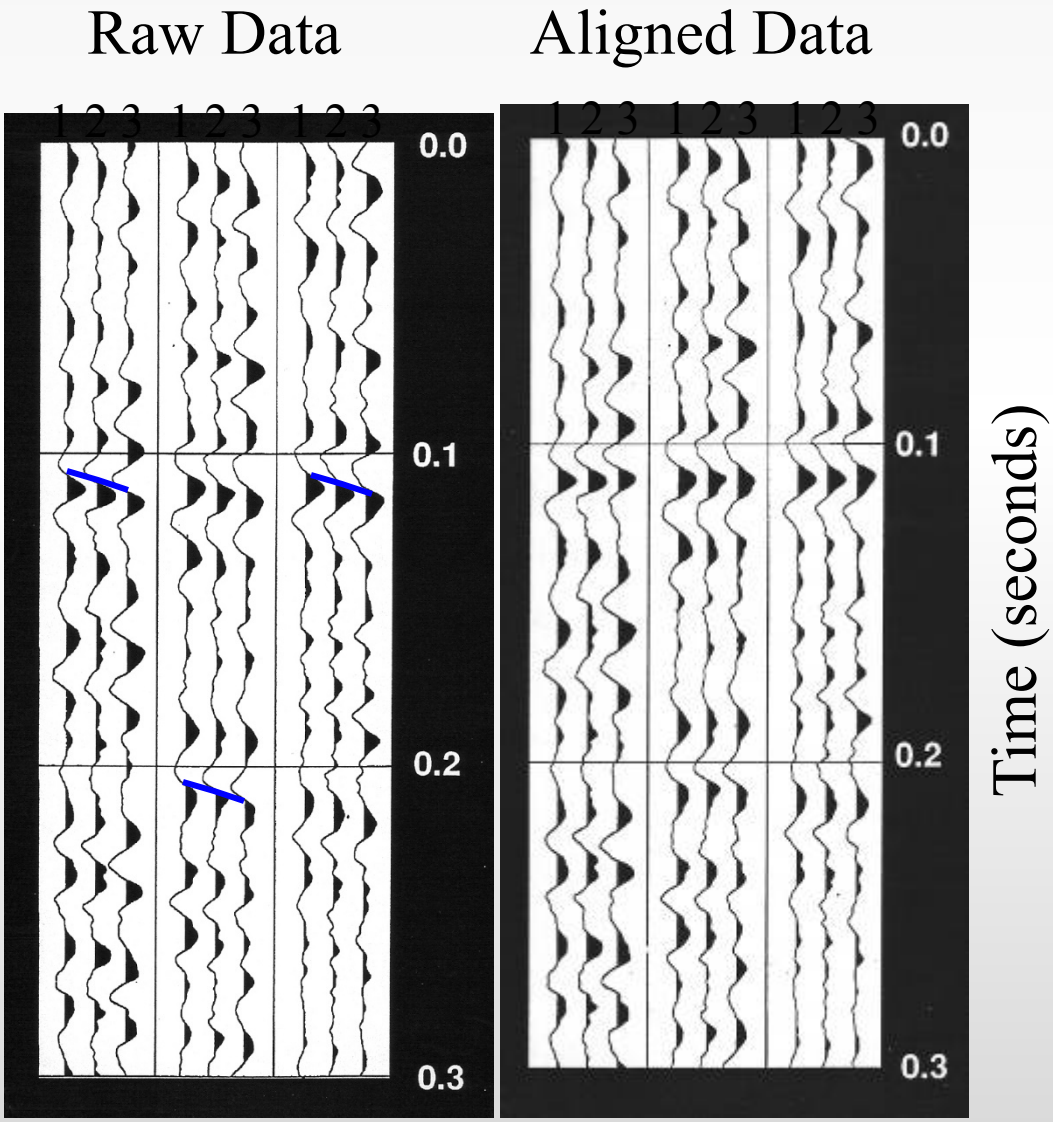
September 1989



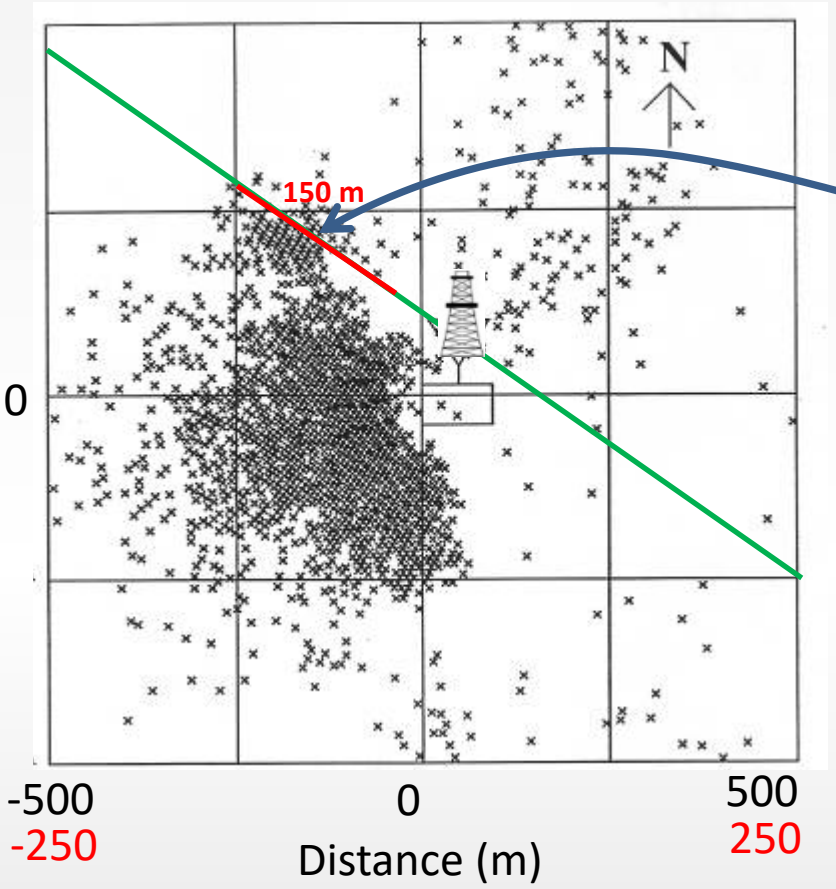
Passive Seismic Listening:

Acquisition geometry and example of seismic data from period 33

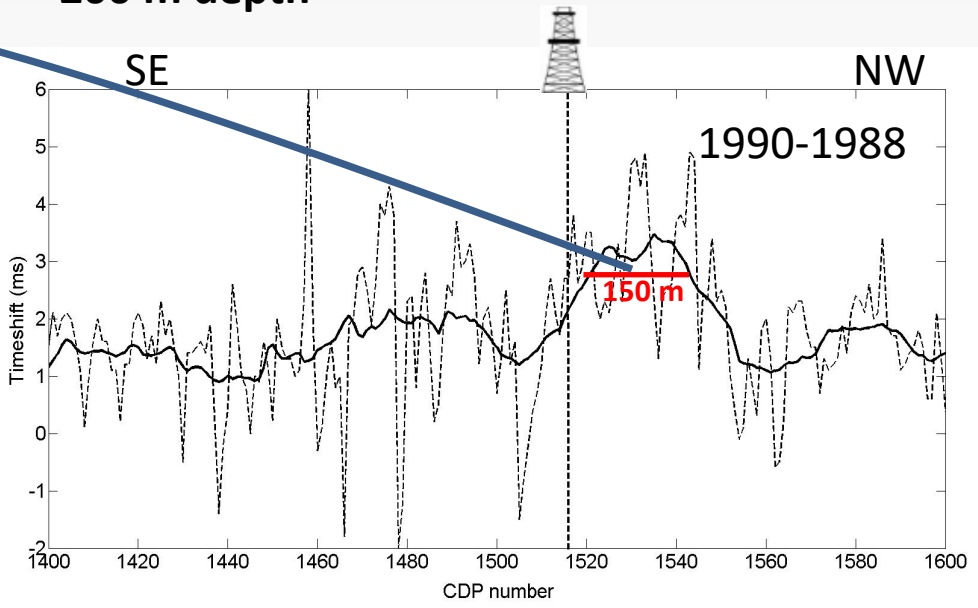




Event location (September 1989) assuming source at 492 m and 250 m



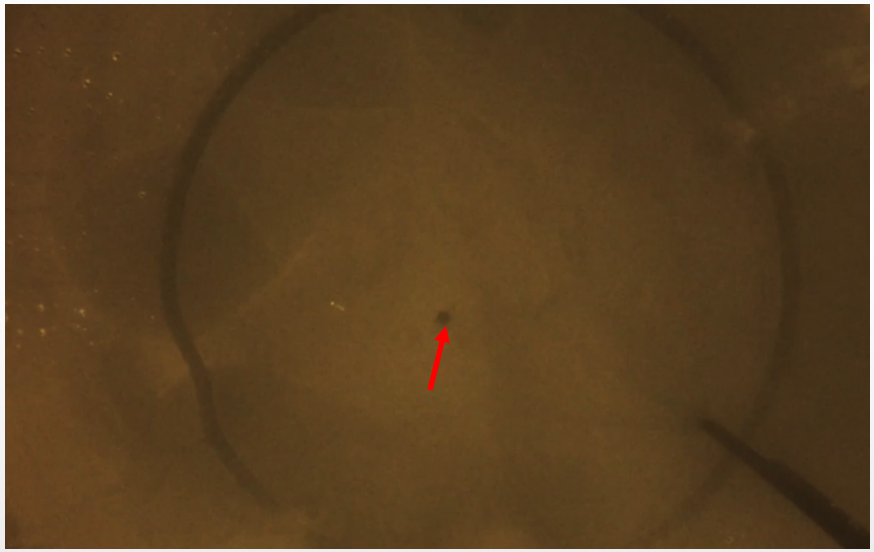
Estimated timeshifts at approximately 200 m depth

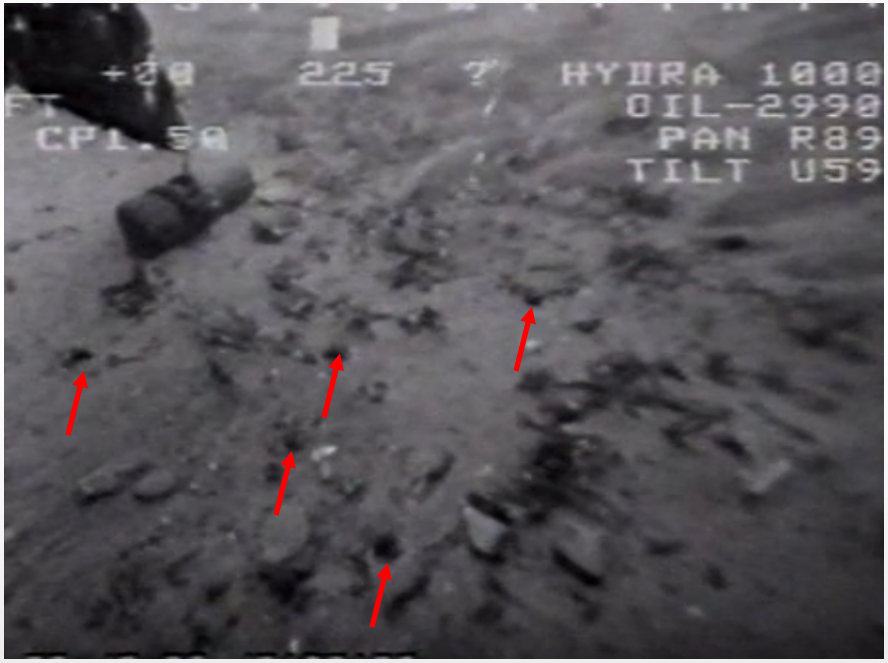


If we assume shallower source depth (half for instance) the horizontal scale will change from +/- 500 m to +-250 m

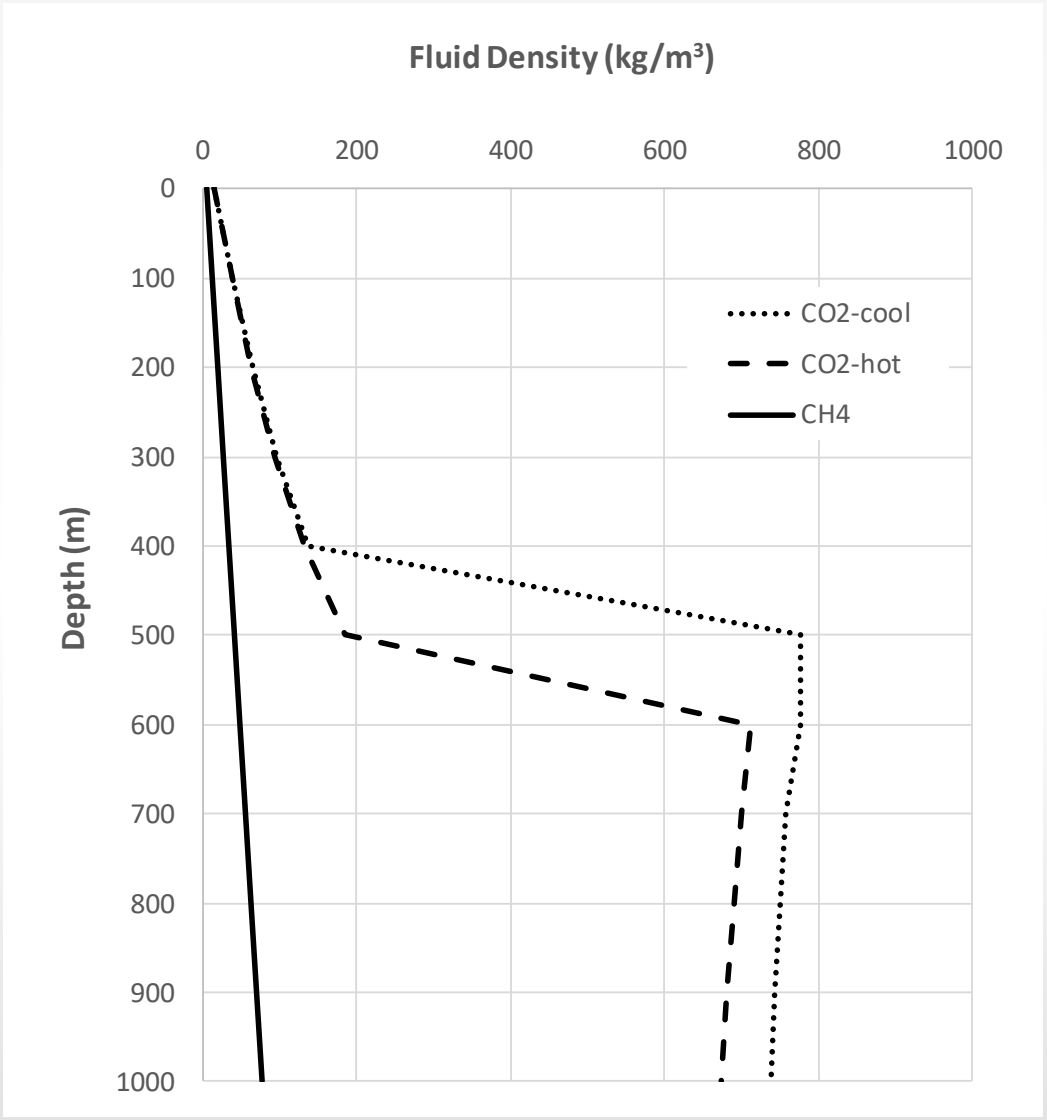
Sand tank experiment and leakage at 2/4-14 well

Similar structures in laboratory and field

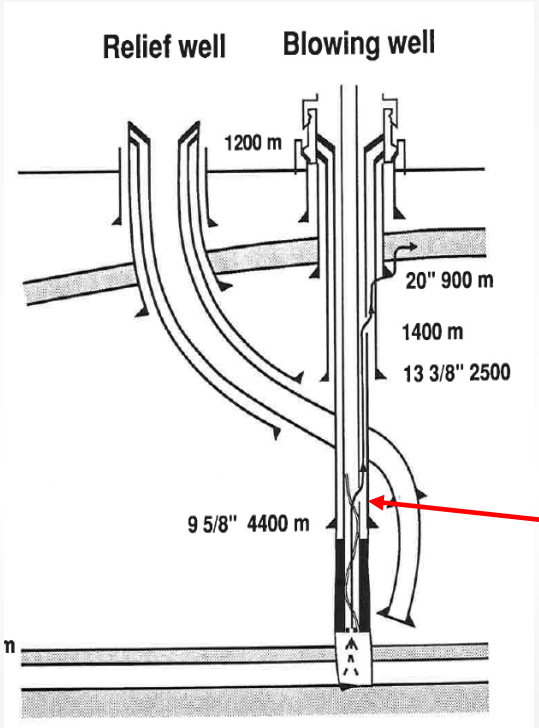




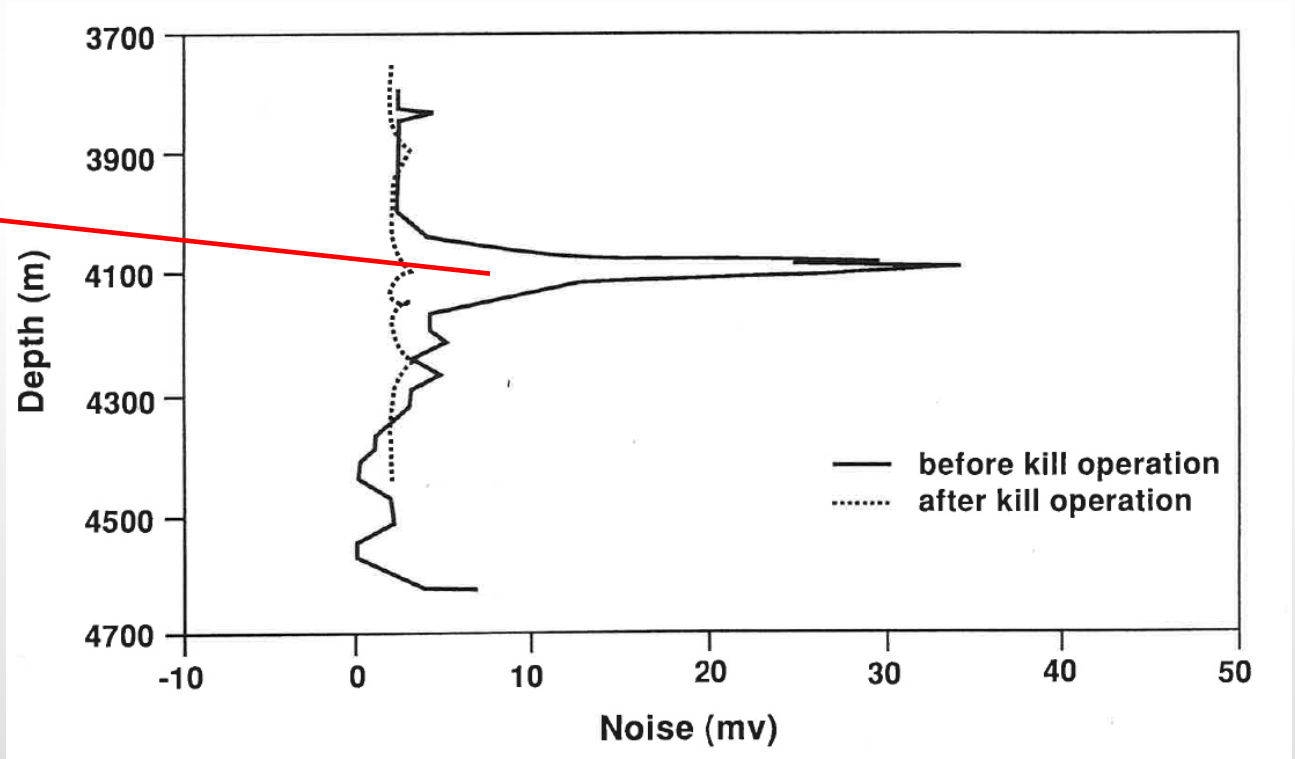
➡ How could we measure leakages?


Fluid Density (kg/m³)
0
200
400
600
800
1000
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
CO2-cool
CO2-hot
CH4

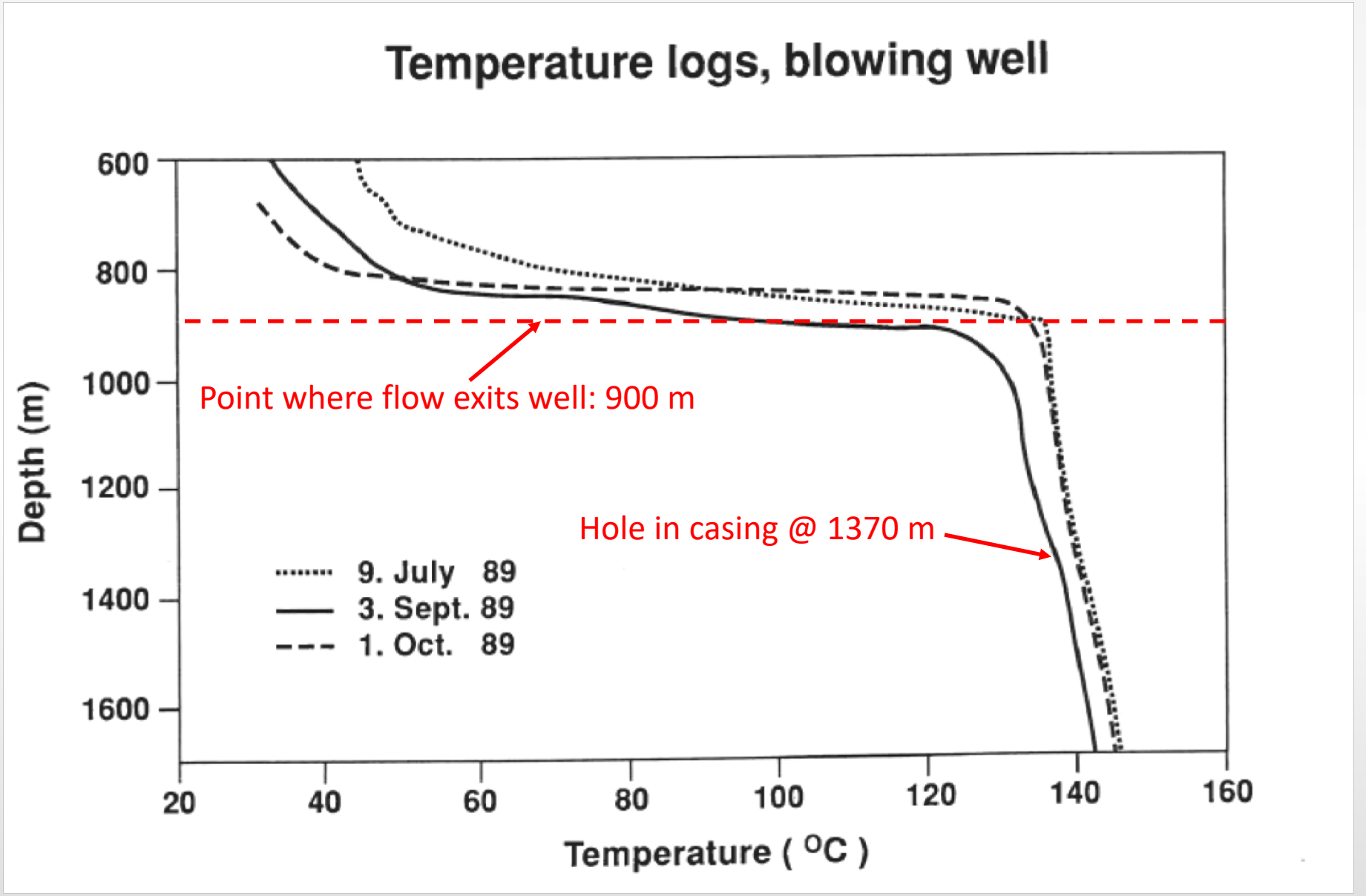
Noise log measured in May 1989 in the relief well



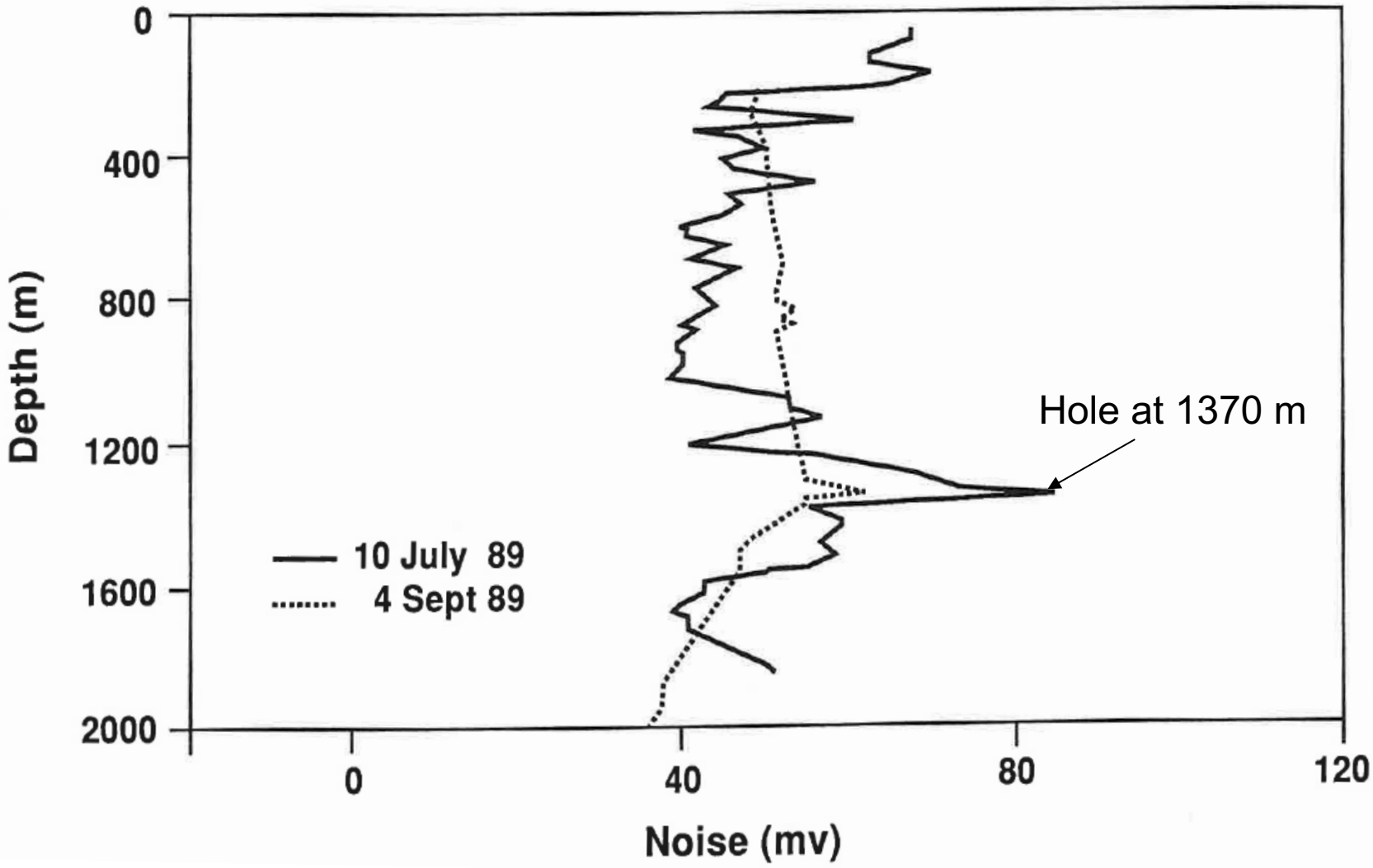
- 20 m between the wells
- Interpreted as hole in the drill pipe at 4100 m
- No noise after kill operation => successful



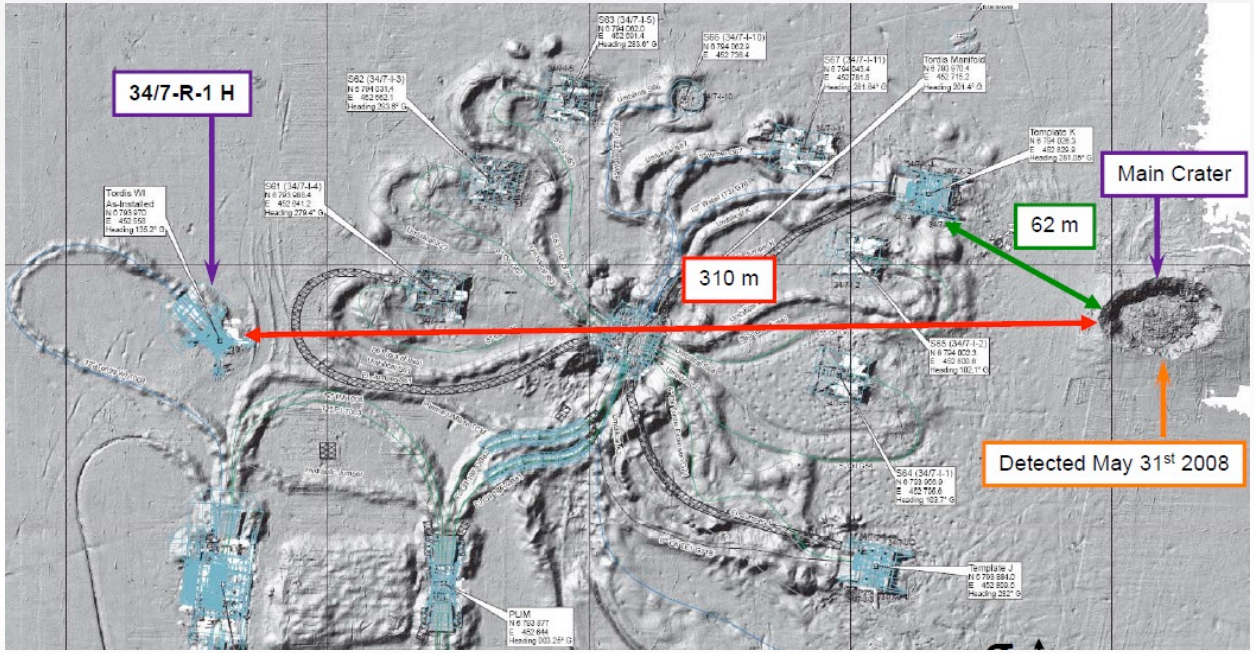
Source: C. Slungaard, 1991


Temperature logs, blowing well
600
800
1000
1200
1400
1600
Depth (m)
Point where flow exits well: 900 m
Hole in casing @ 1370 m
9. July 89
3. Sept. 89
1. Oct. 89
20
40
60
80
100
120
140
160
Temperature (°C)

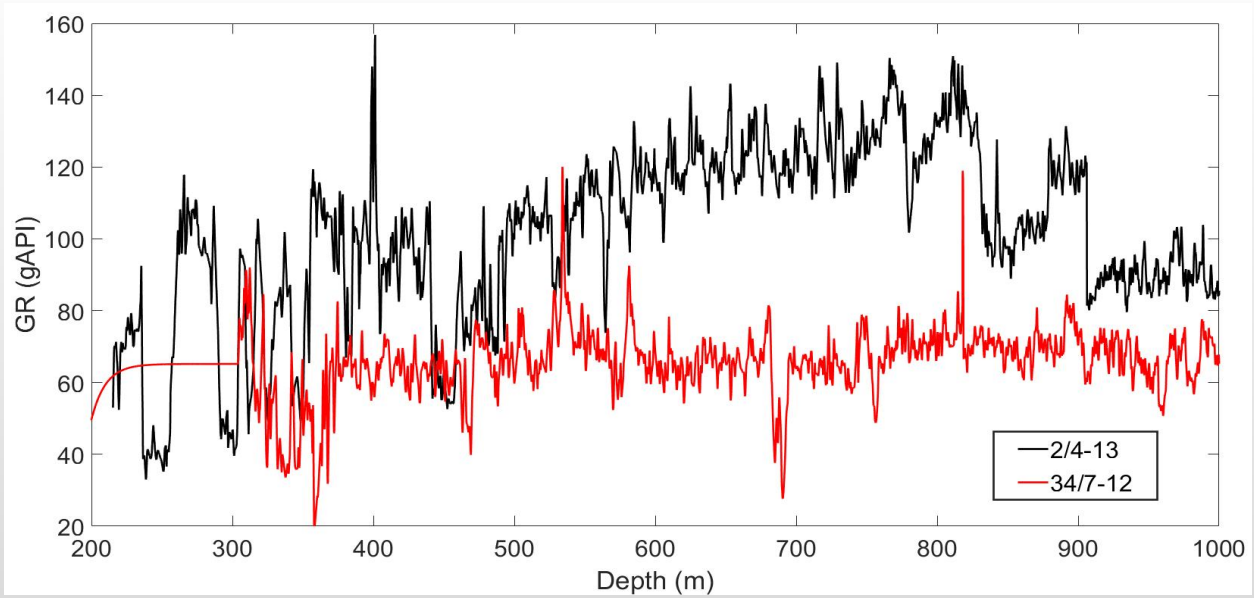
Noise logs recorded in the blowing well (14)

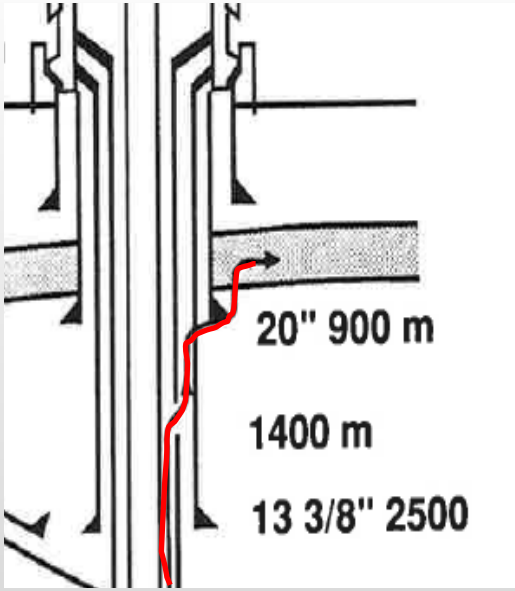


The 2008 Tordis event – very different from 1989 2/4-14

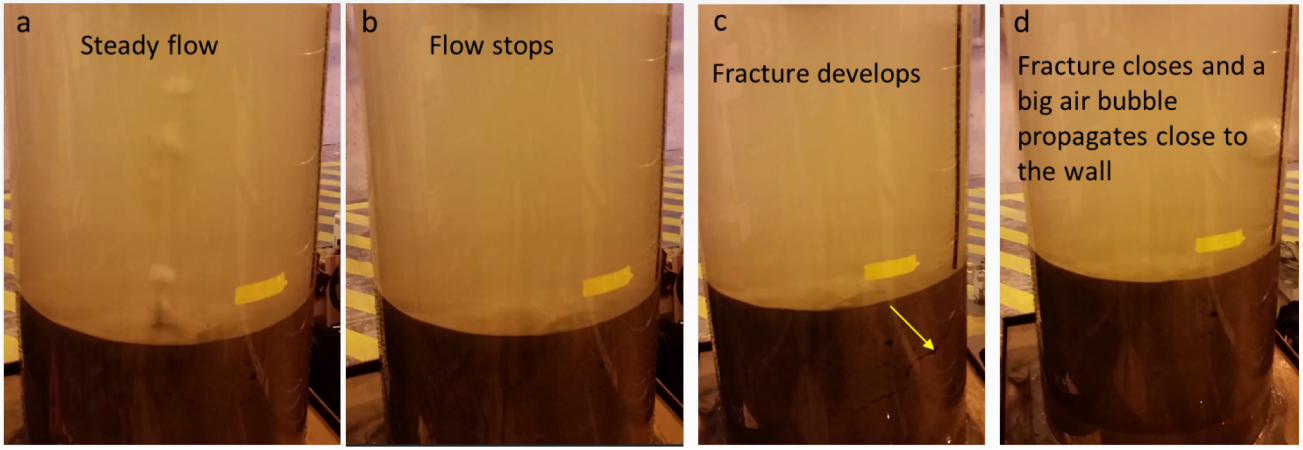


1. Overburden is very different: Clay-dominated sequence at Tordis
2. Source mechanism is different although same depth (900 m): Pump versus underground flow

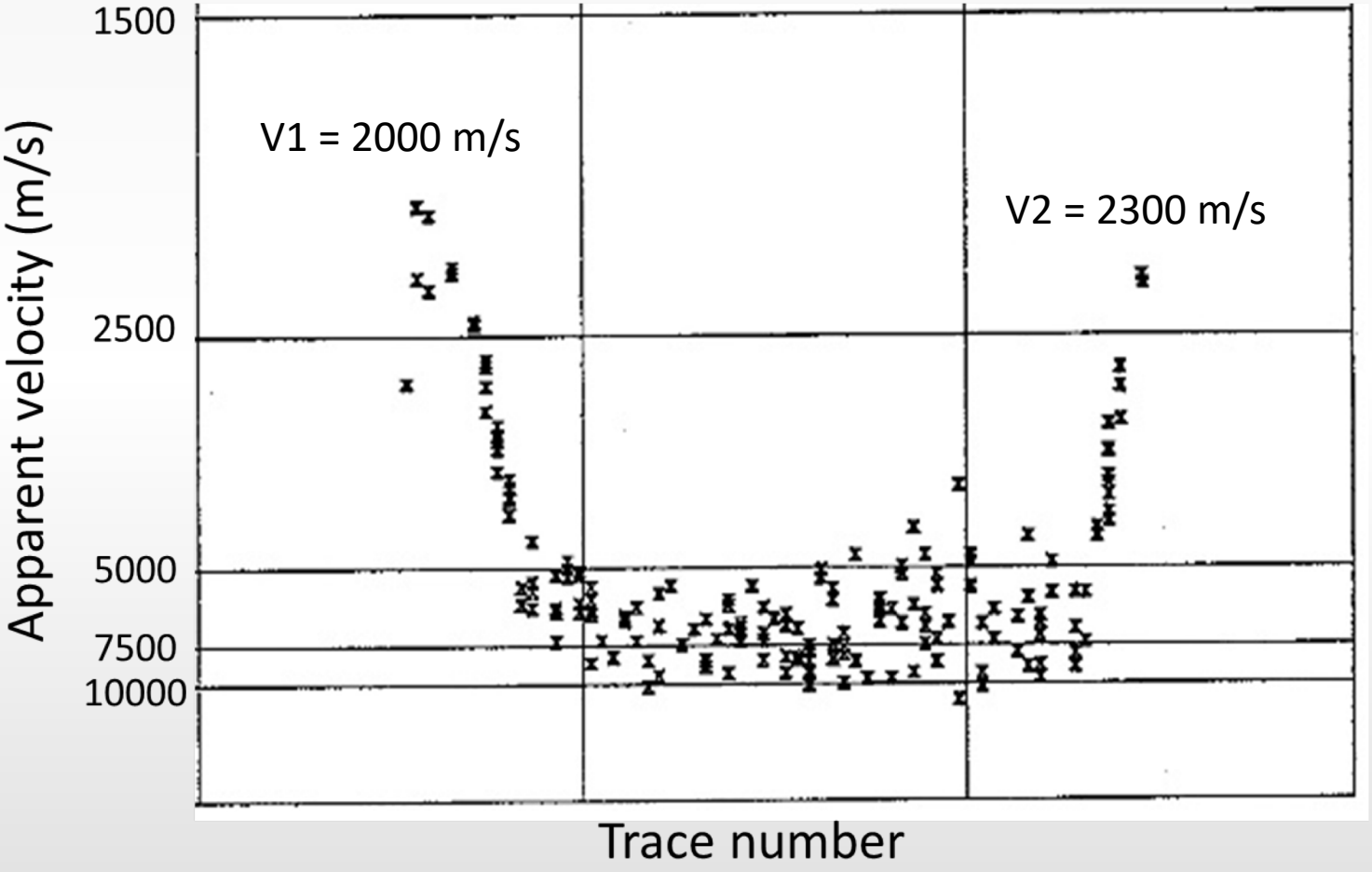




Sand tank experiment



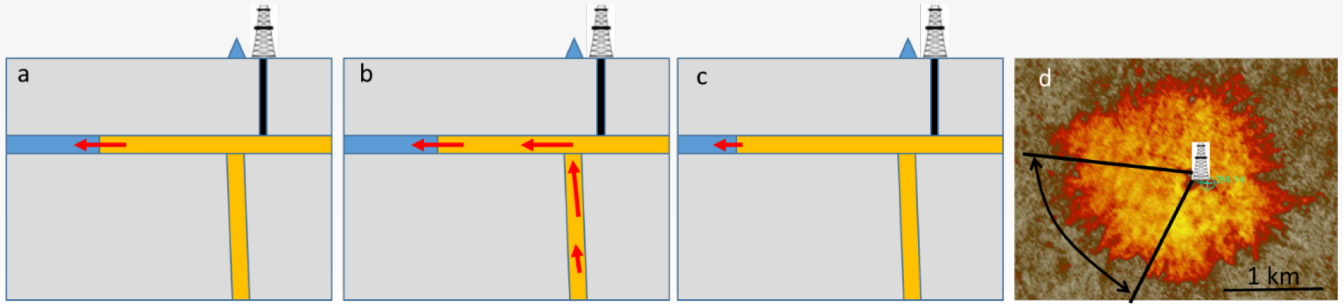
Grain size: 130 micrometer
Thickness of sand: 0.25 m
Air injected through 0.4 mm hole

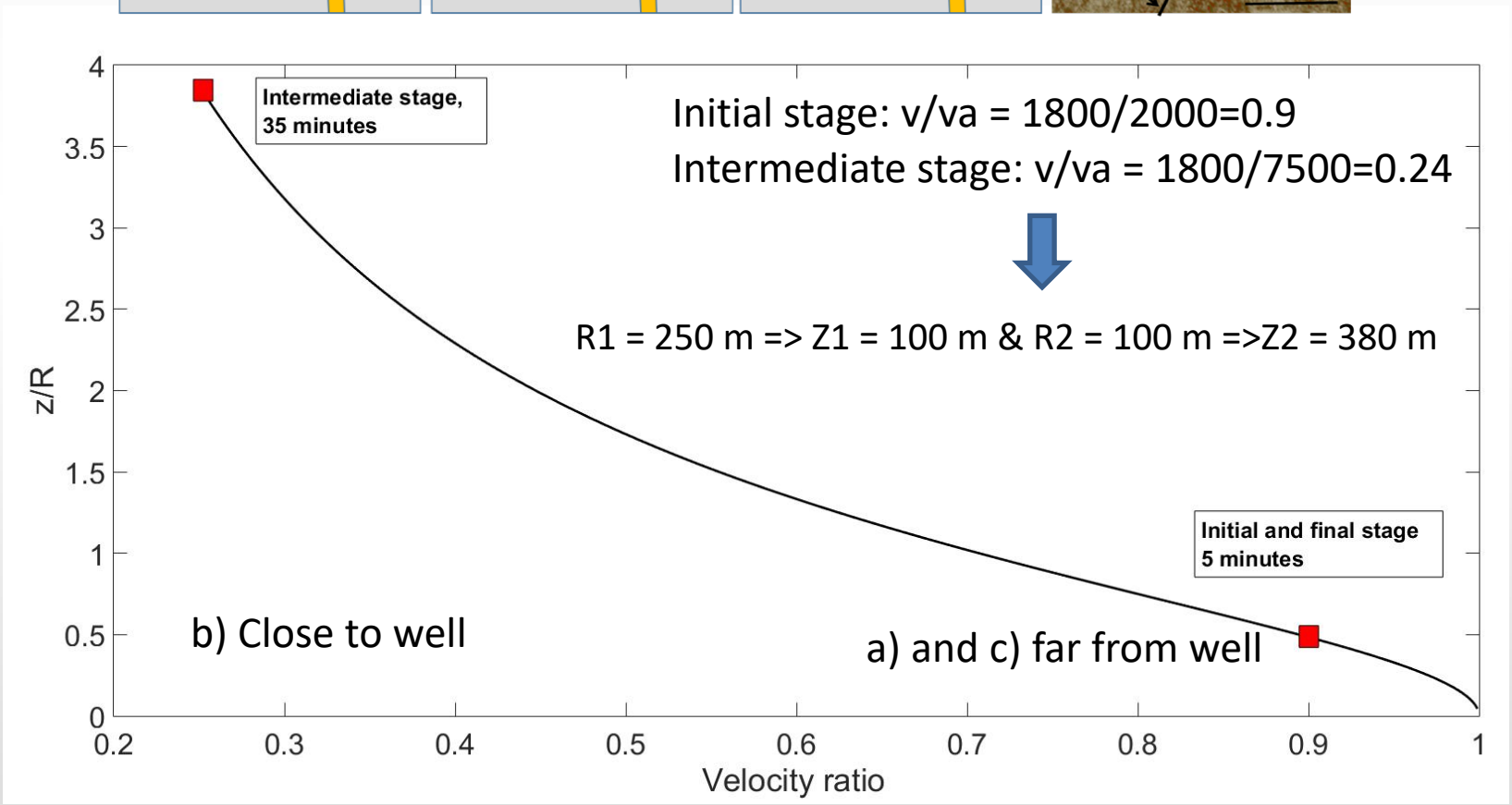

1500
2500
5000
7500
10000
V1 = 2000 m/s
V2 = 2300 m/s
Apparent velocity (m/s)
Trace number

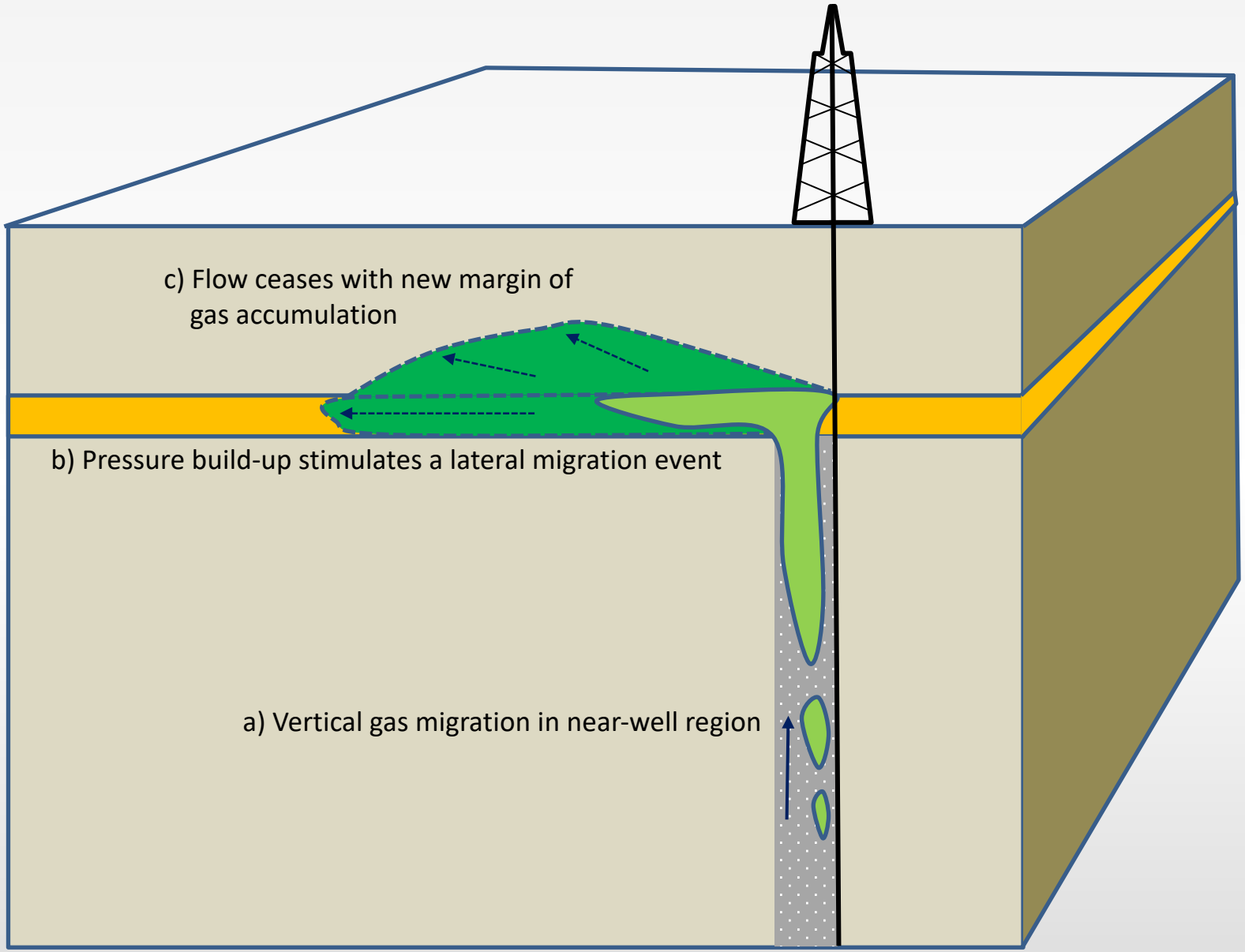
$$\frac{z}{R} = \frac{\sqrt{1-\alpha^2}}{\alpha}$$

$$\alpha = v / v_a$$

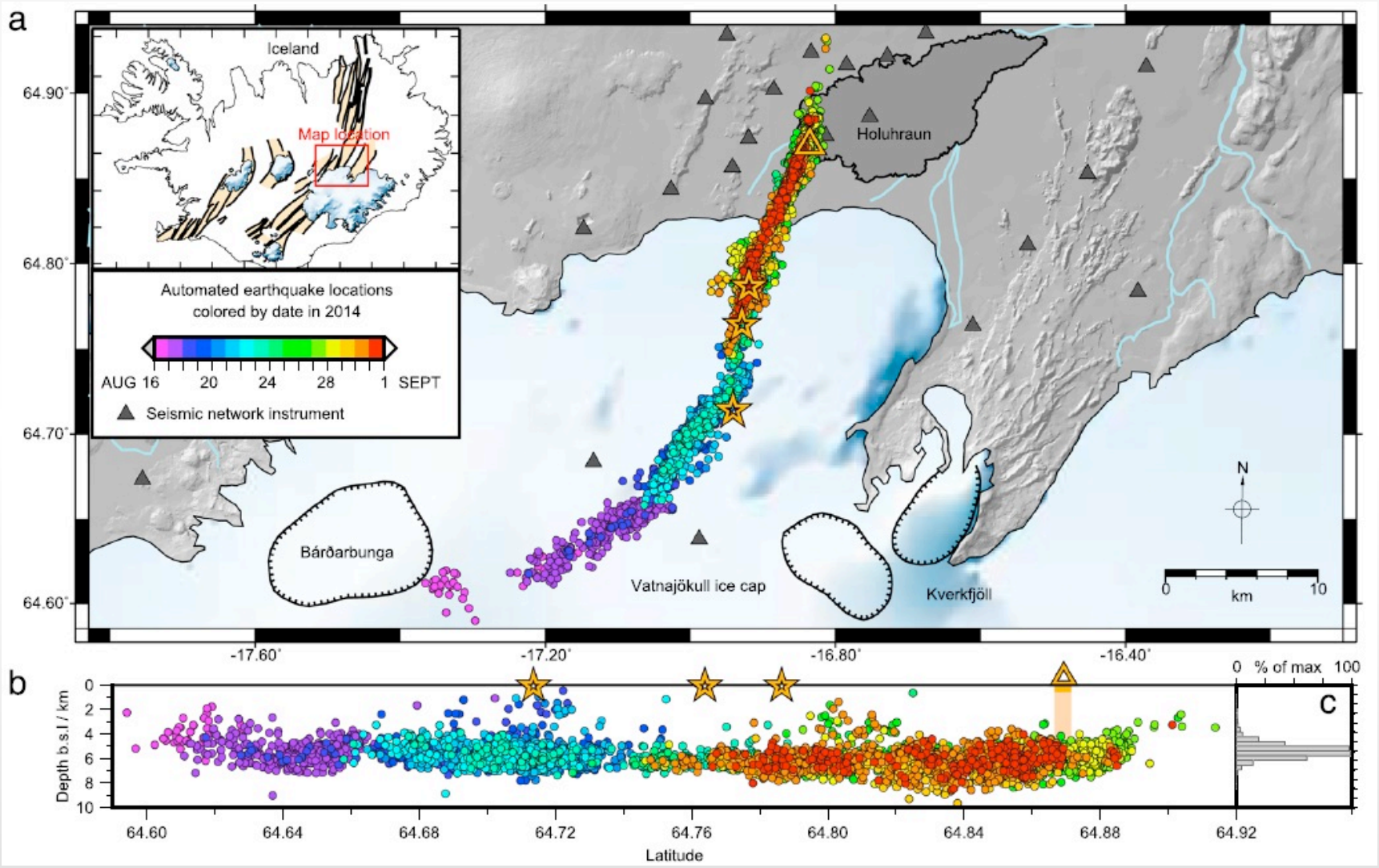
is the ratio between the formation *P*-wave velocity and the apparent velocity measured by the geophone array



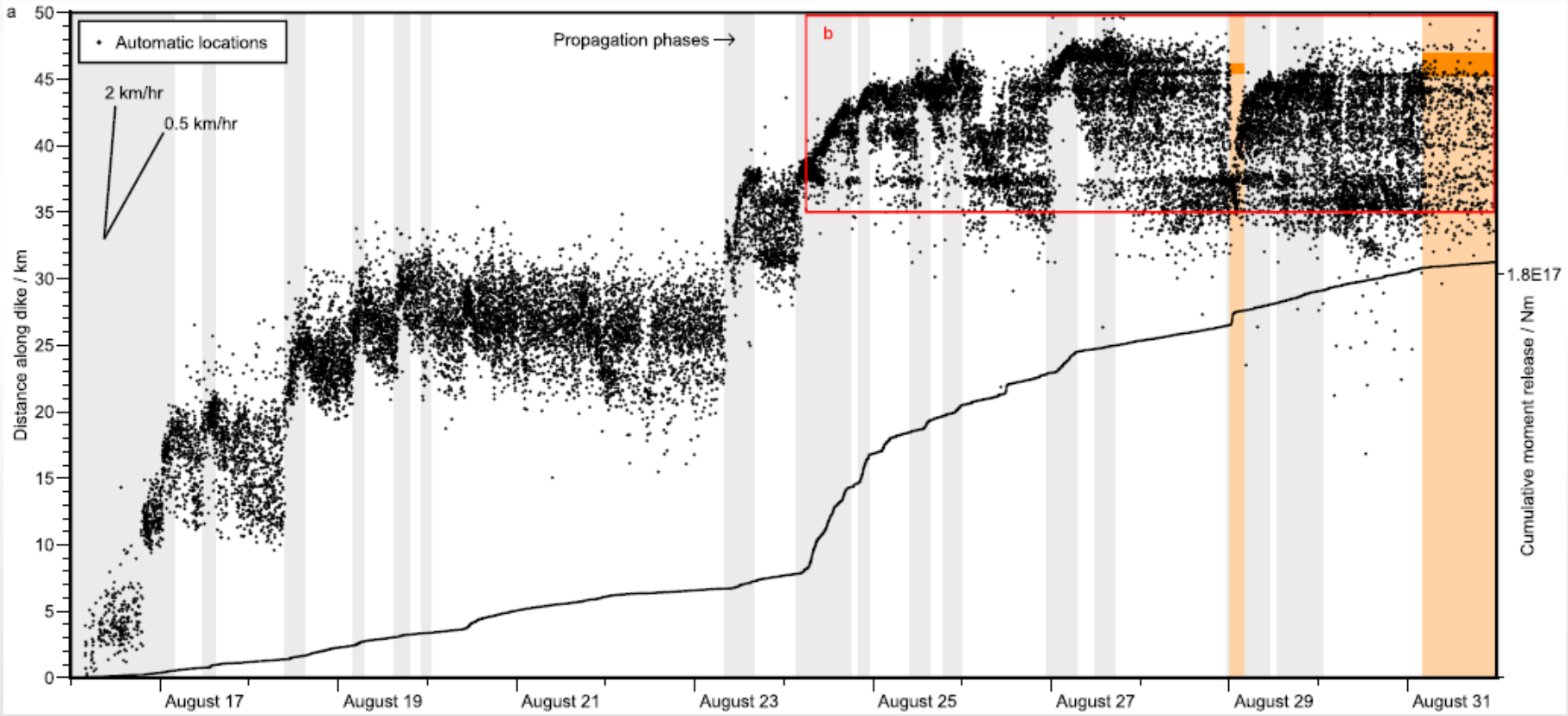



c) Flow ceases with new margin of gas accumulation
b) Pressure build-up stimulates a lateral migration event
a) Vertical gas migration in near-well region

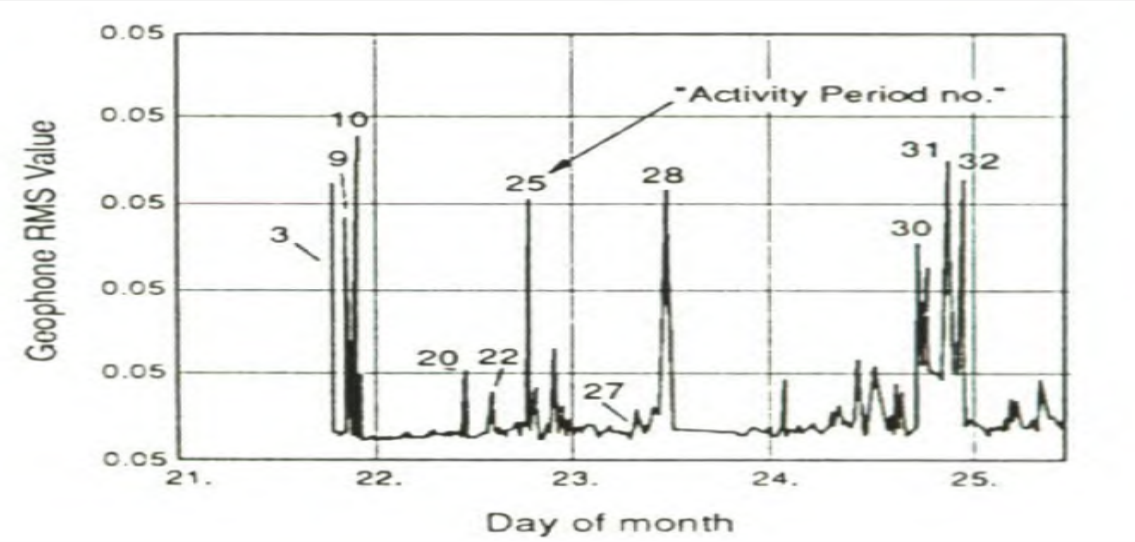
Magmaflow at Iceland: Bardarbunga-Holuhran dike intrusion - 2014

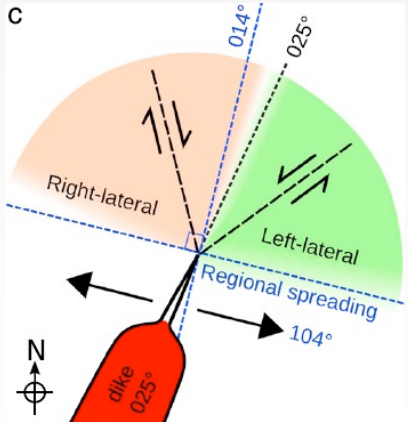


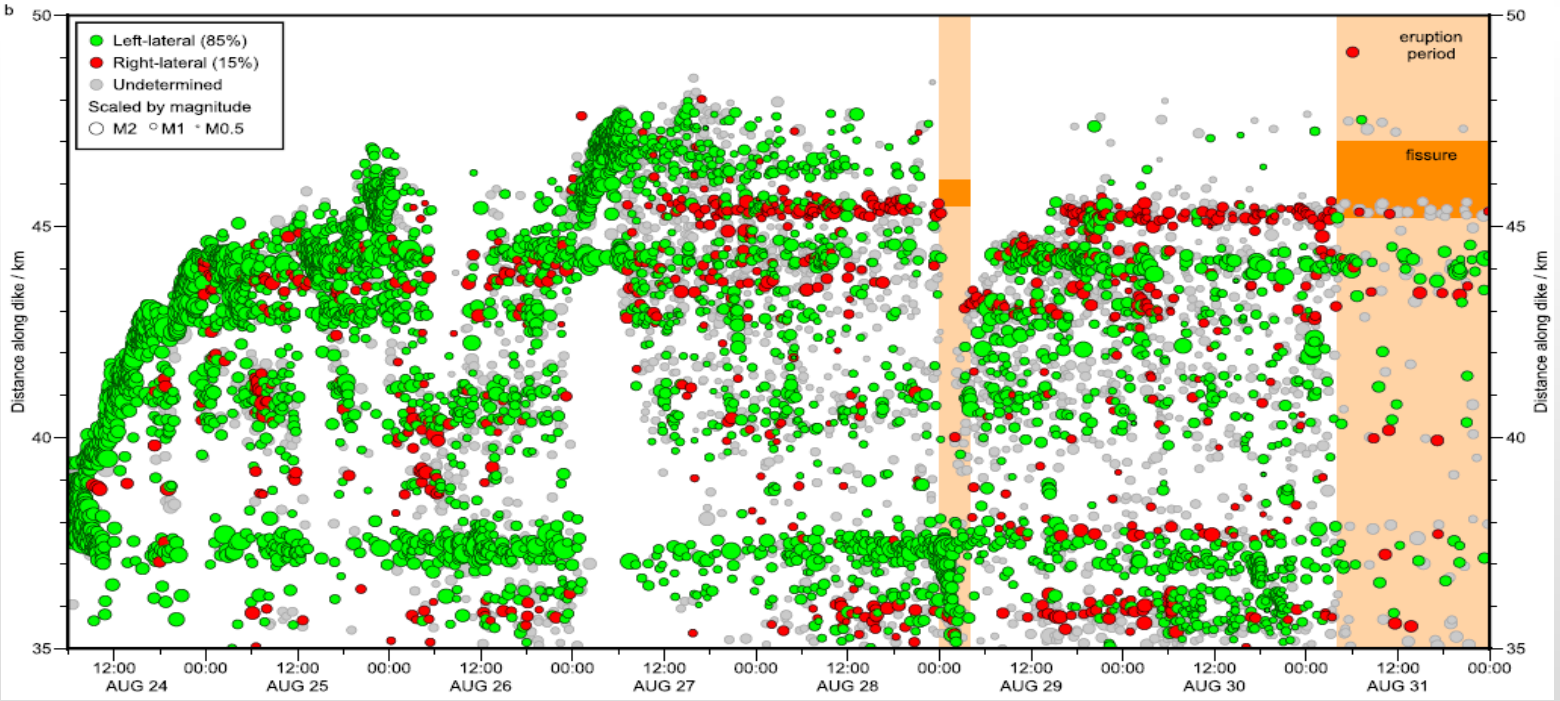
Seismic event location along the dike – 15 days



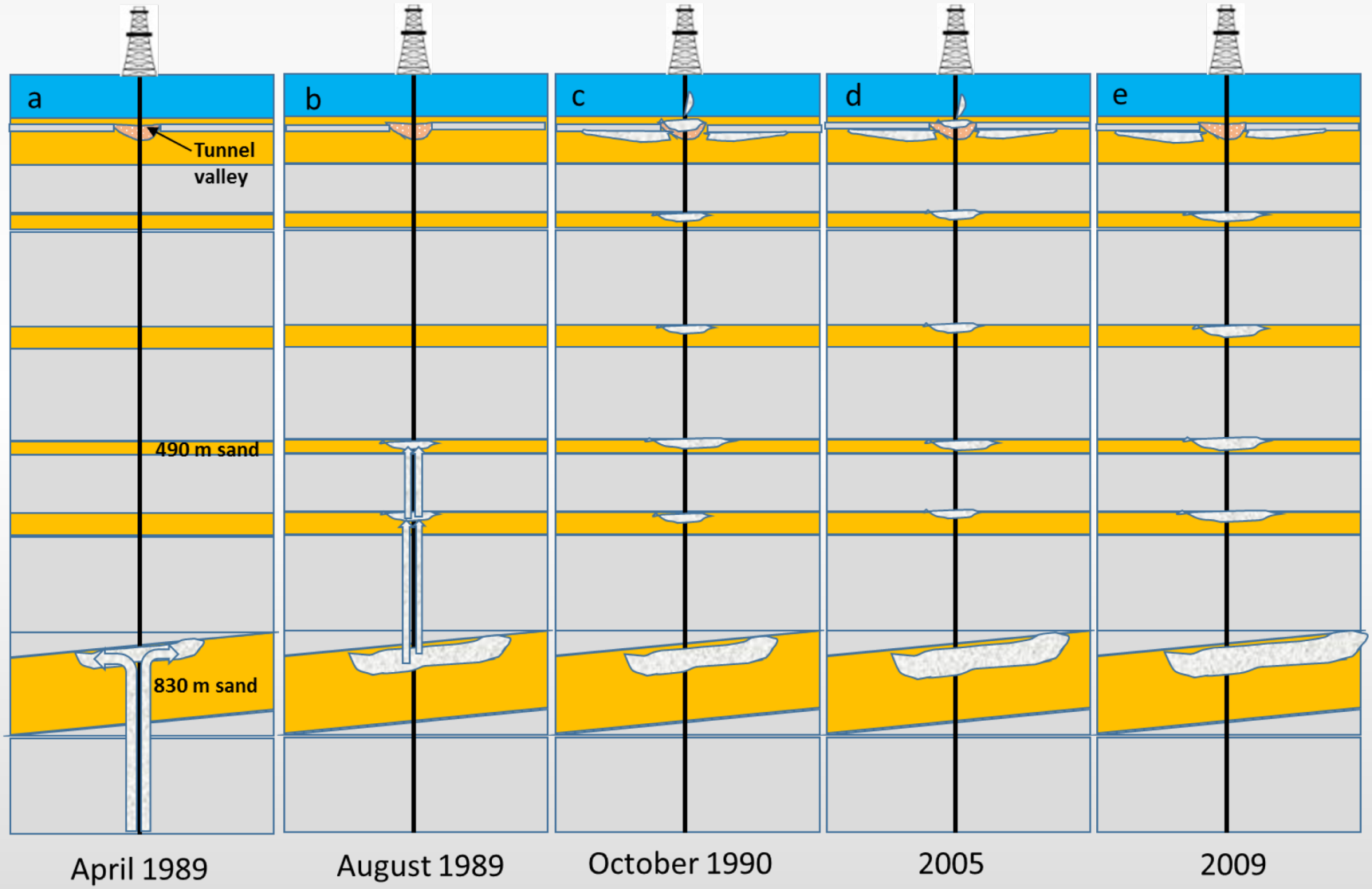
Similarities – but very different source mechanisms







Summary


a
b
c
d
e
Tunnel valley
490 m sand
830 m sand
April 1989
August 1989
October 1990
2005
2009

Experiment

before air injection

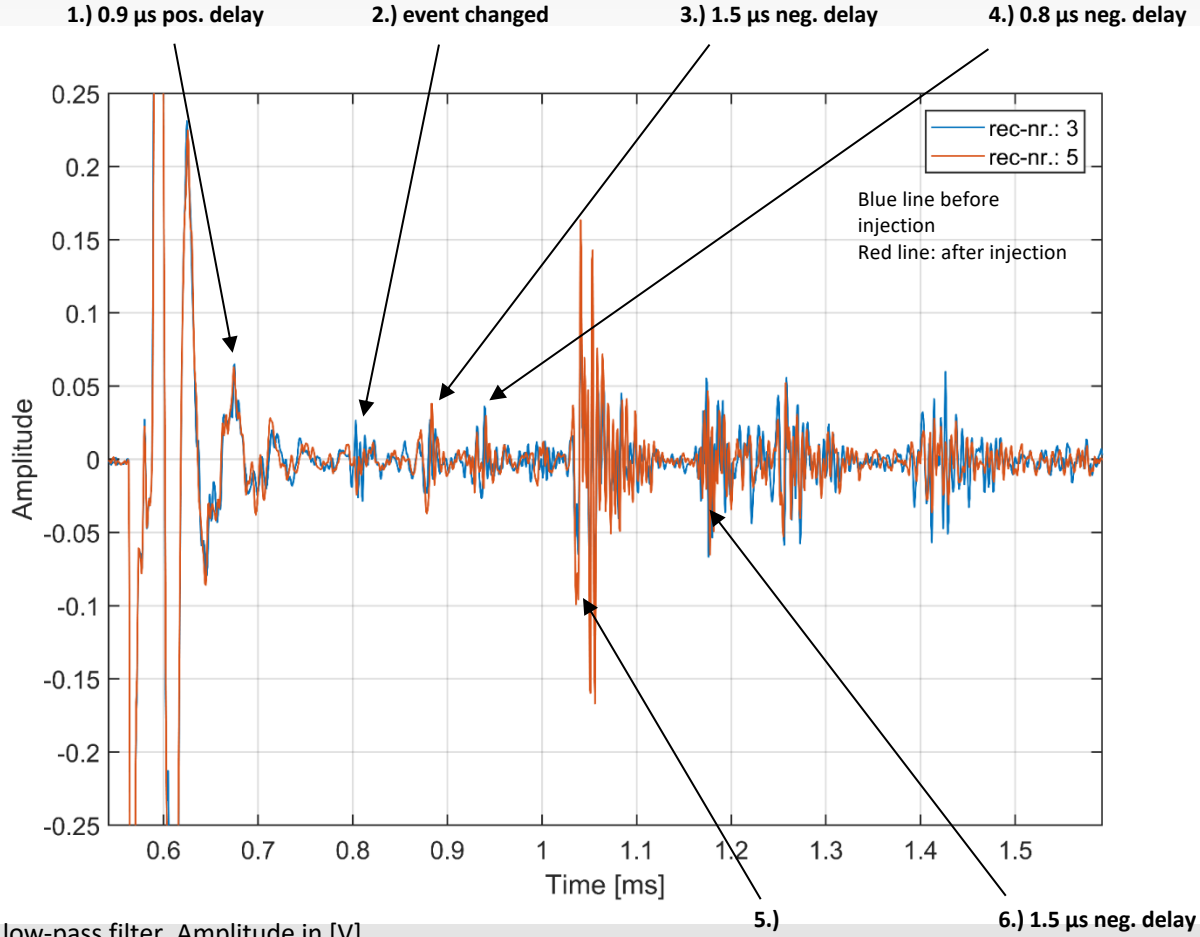
directly after air injection

ca. 30 min. after air injection

ca. 60 min. after air injection

air was released due to artificial earthquake
(hitting the cylinder with a hammer from the side)

First look



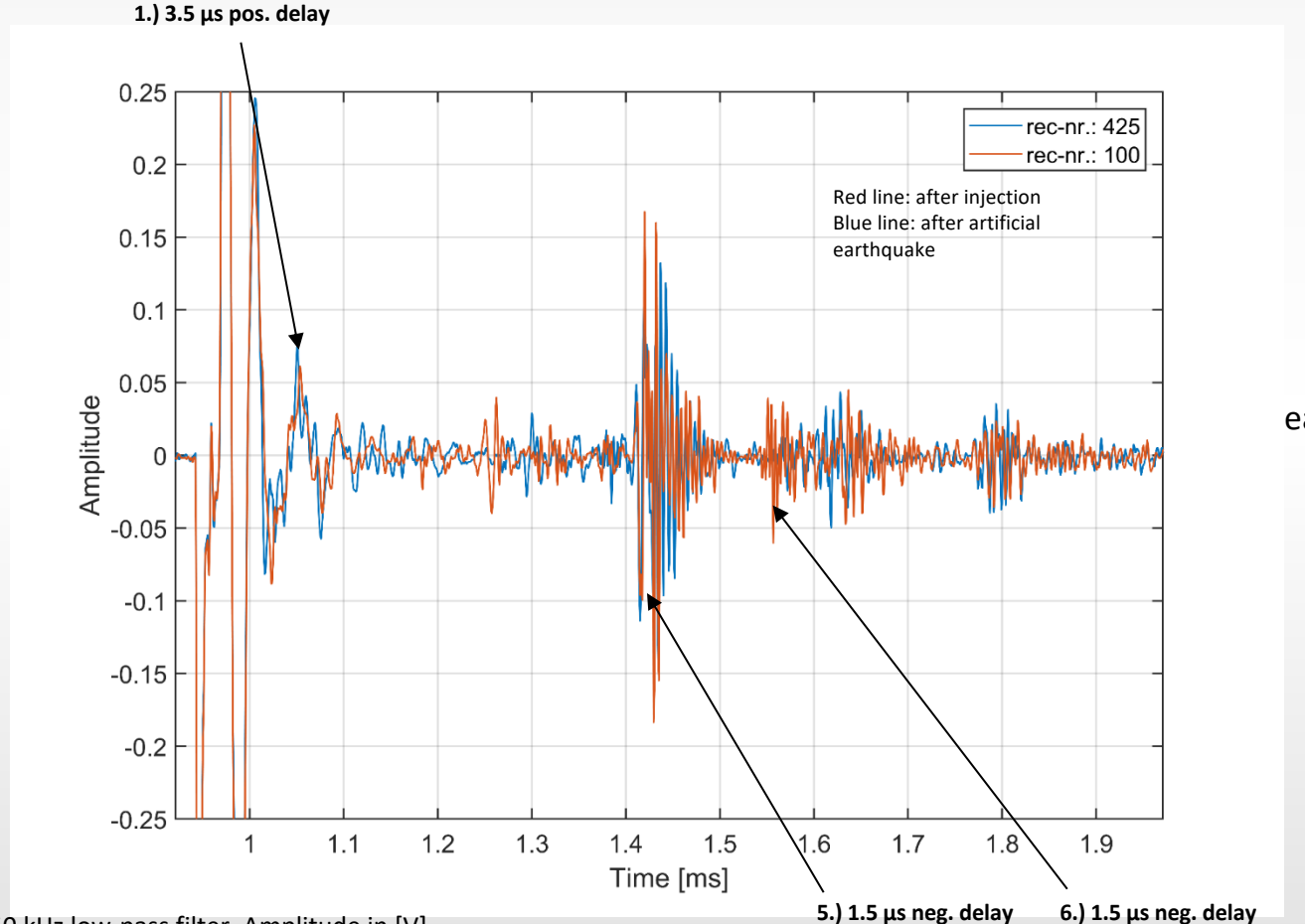
350 kHz low-pass filter, Amplitude in [V]

simple depth estimation of events:

$$\frac{v}{2} * t = z, \qquad v \approx 1700 \frac{m}{s}$$

1.) z = 8 cm
2.) z = 21 cm
3.) z = 26 cm
4.) z = 30 cm
5.) z = 40 cm
6.) z = 51 cm

First look



350 kHz low-pass filter, Amplitude in [V]

rec-nr.: 100

artificial earthquake

rec-nr.: 425