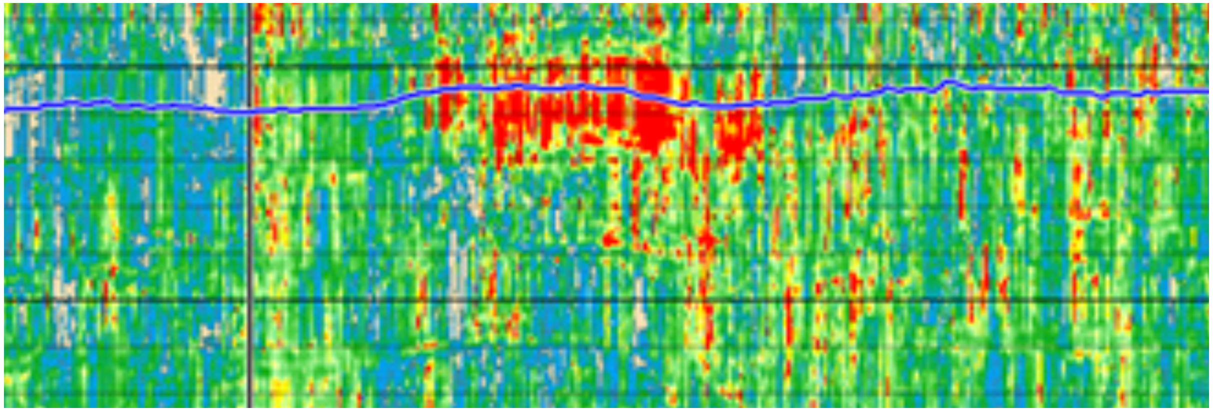
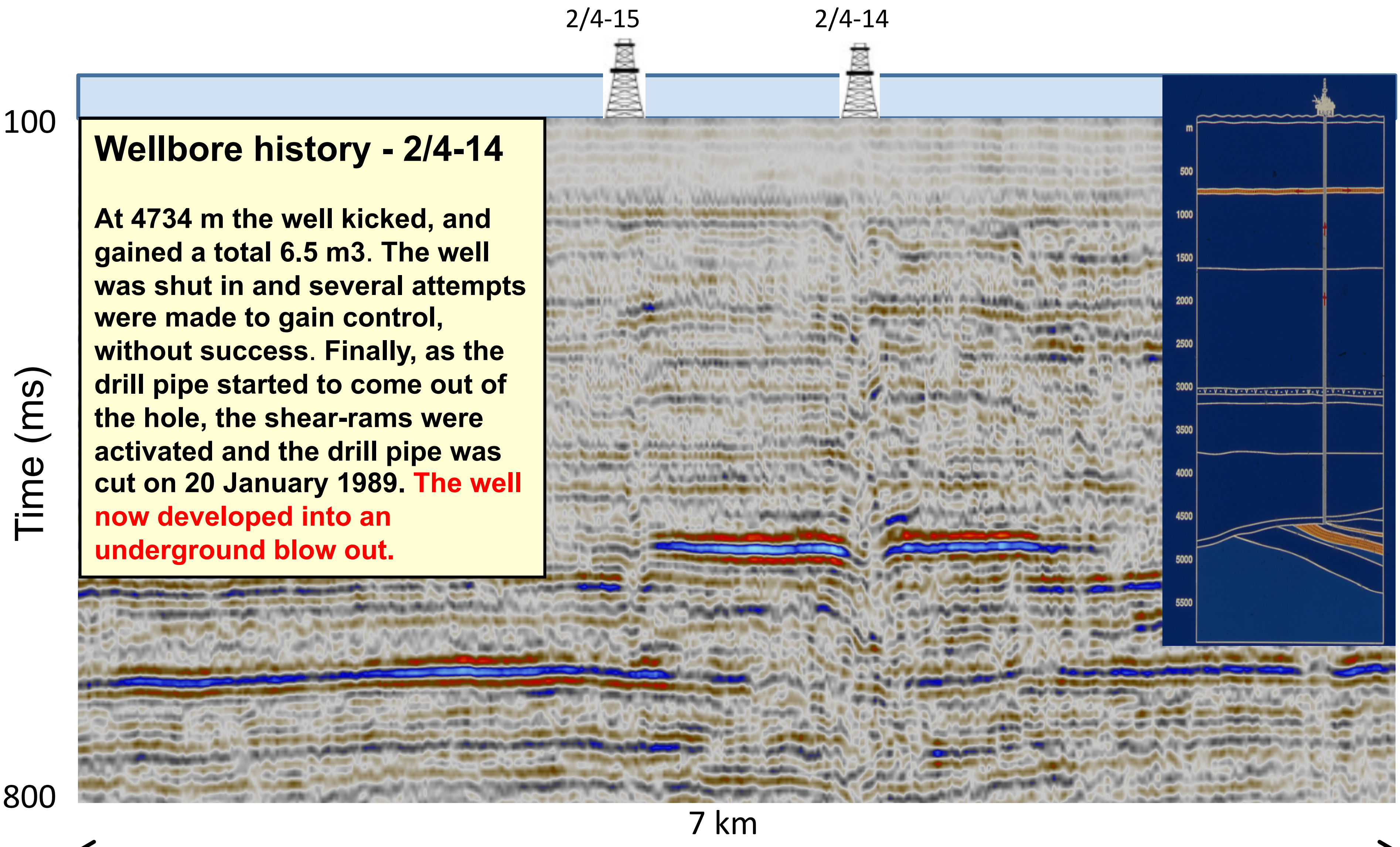
Time lapse Q difference estimation and Q-estimation by variation of source strength



ROSE meeting 2014 by M. Landrø, NTNU with input from Hung Dinh, Mirko van der Baan and Fredrik Jakobsen

NTNU LOSEM PROJECT: Long term monitoring of the 2/4-14 blow out (1989)

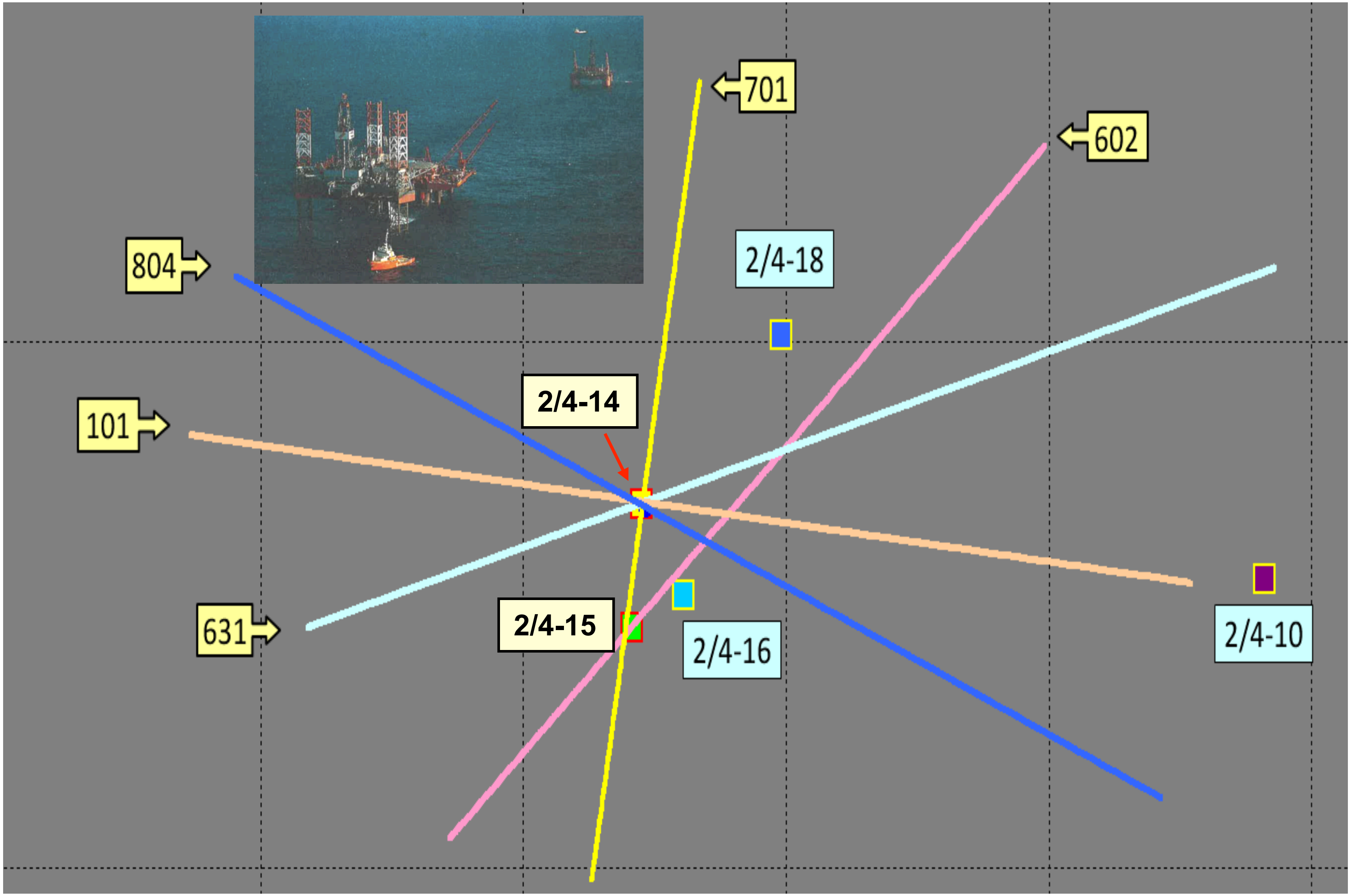


Wellbore history - 2/4-14

At 4734 m the well kicked, and gained a total 6.5 m3. The well was shut in and several attempts were made to gain control, without success. Finally, as the drill pipe started to come out of the hole, the shear-rams were activated and the drill pipe was cut on 20 January 1989. The well now developed into an underground blow out.

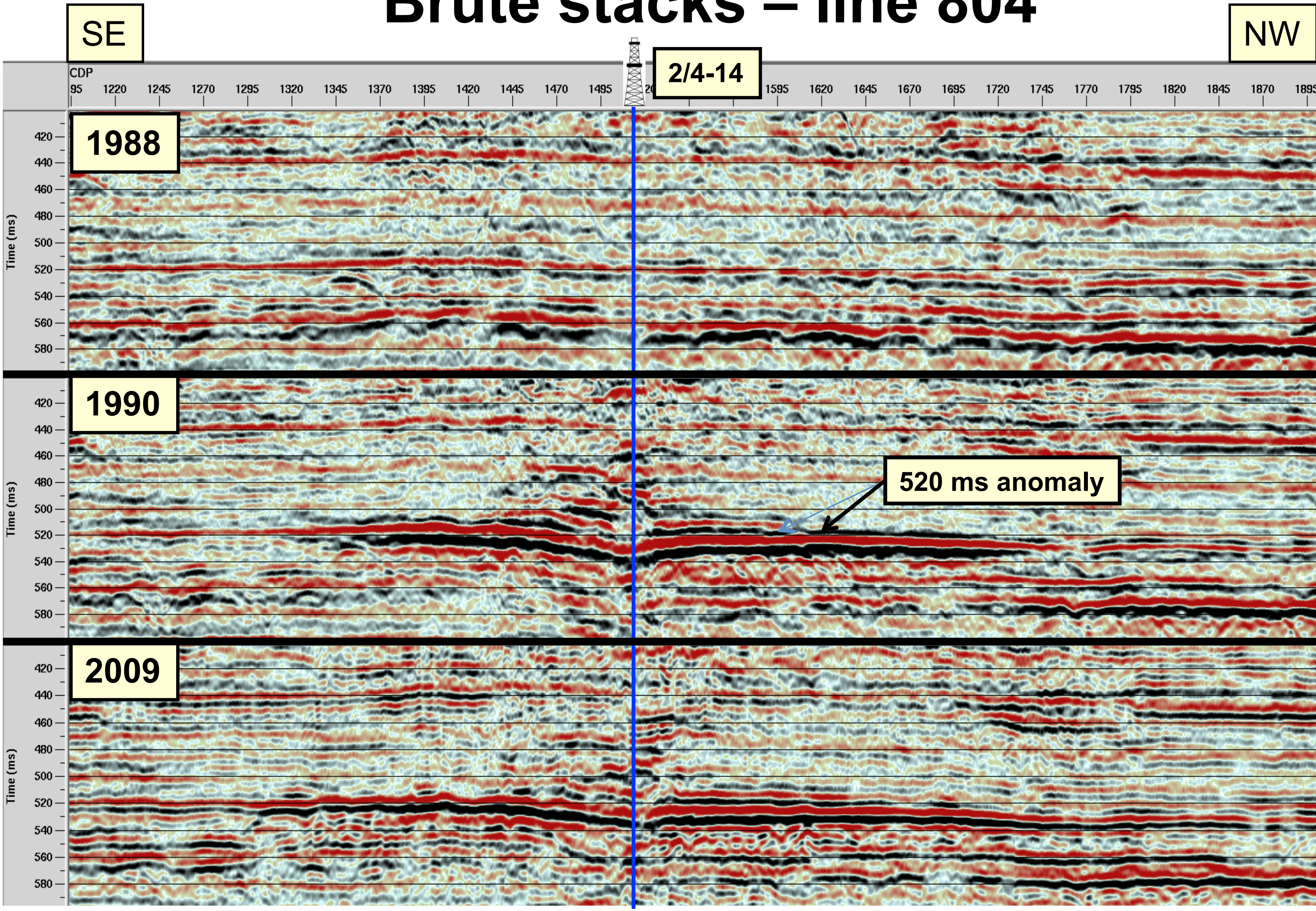
14-chimney propagates shallower (into seabed?) than 15-chimney

Repeated 2D lines acquired in 2009



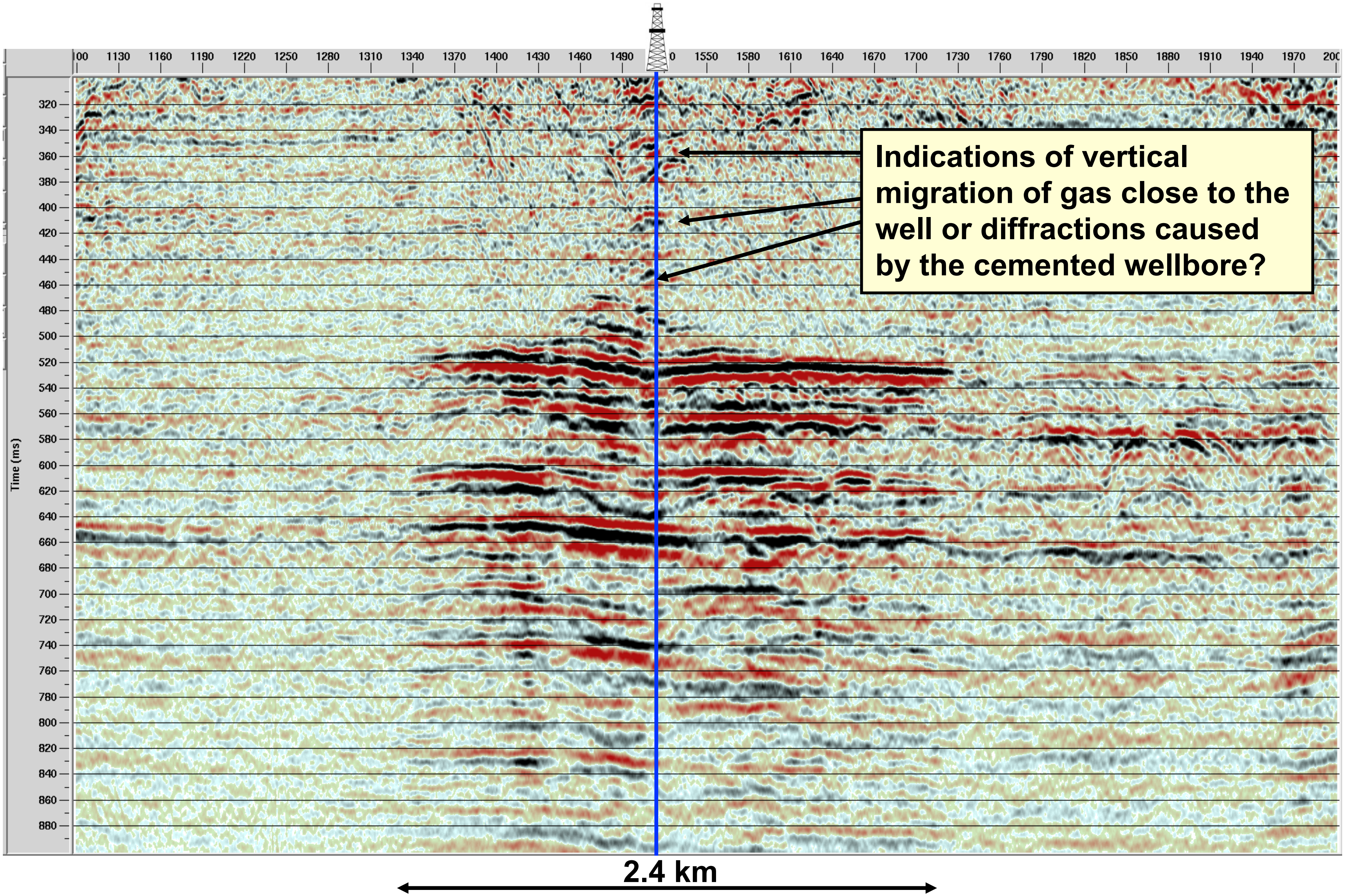
In this study we will use brute stacks from 602 and 804

Brute stacks – line 804

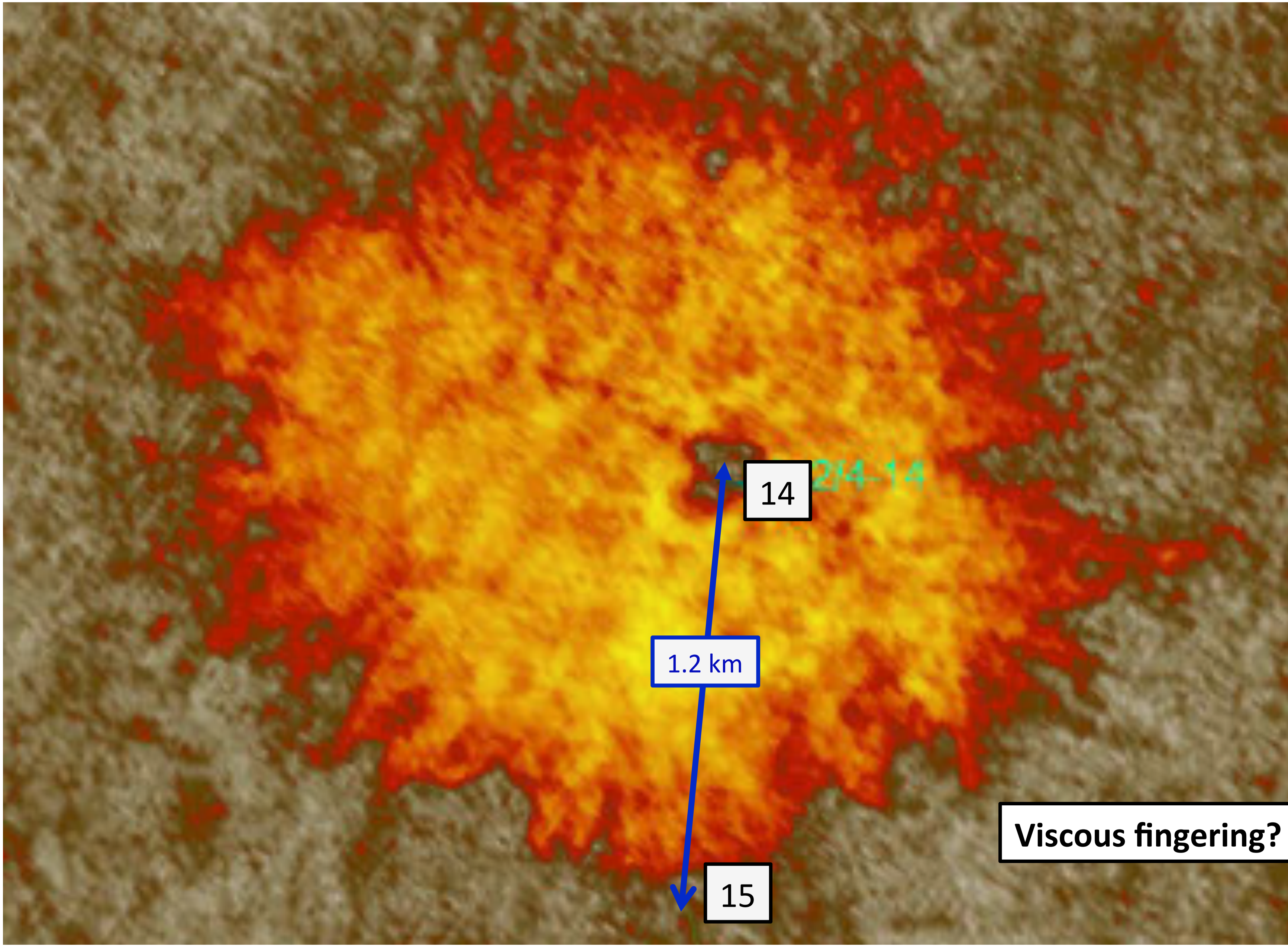


Less pulldown in 2009 – slight increase in horizontal extention

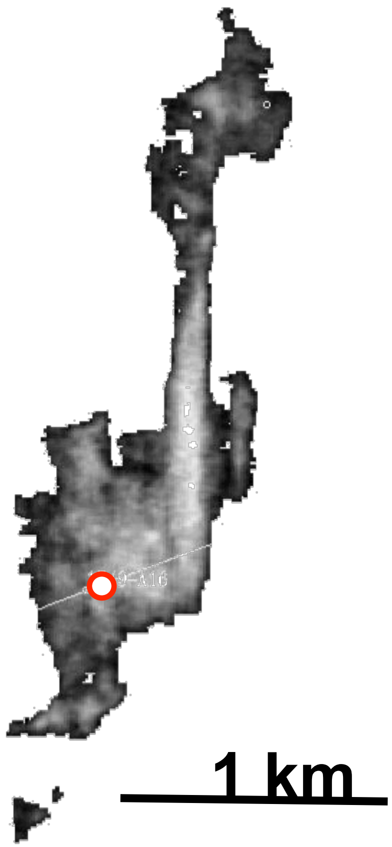
4D difference – line 804 1988-1990 after global scaling



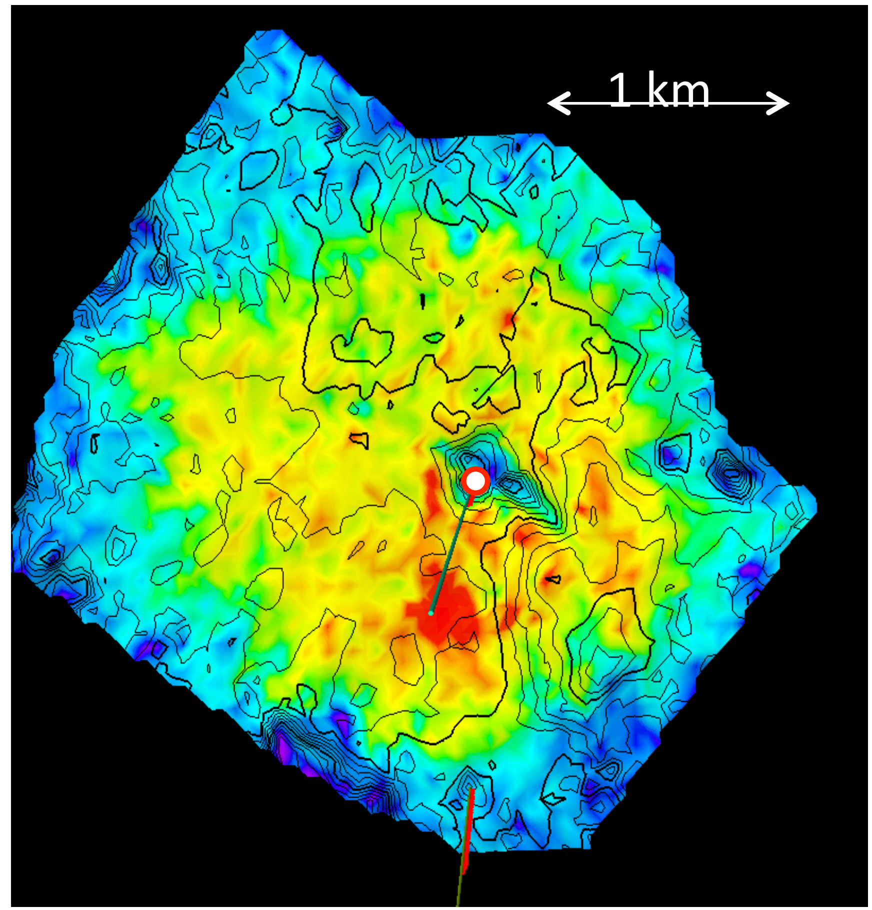
RMS amplitude map (504-560 ms window)



Comparing Sleipner CO2-plume (upper layer) and shallow gas leakage from the 2/4-14 blow out in 1989

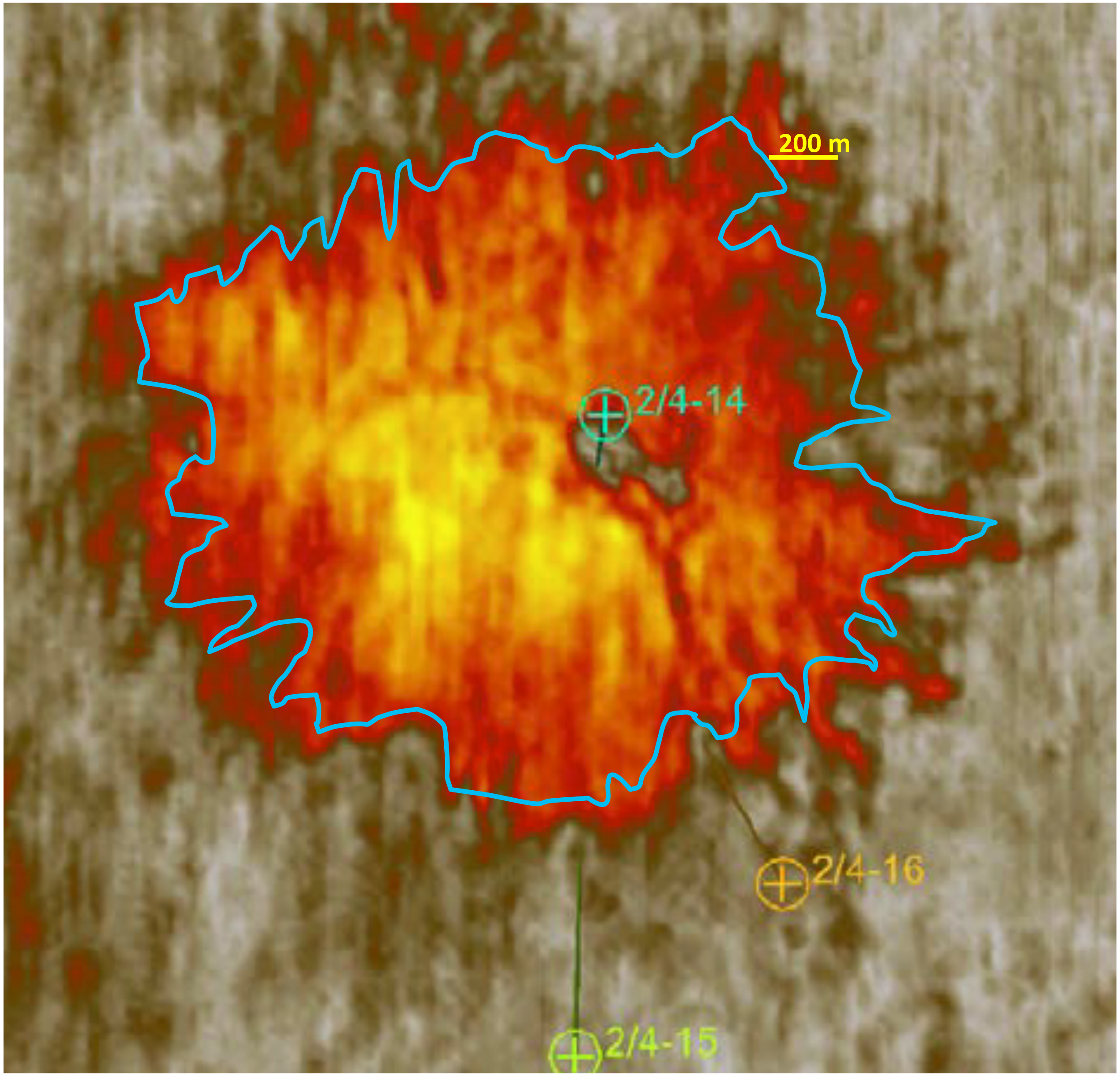


Low pressure => shape dominated by structure – 800 m depth

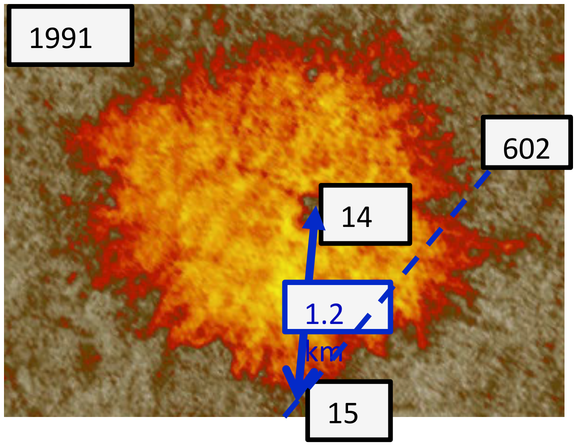


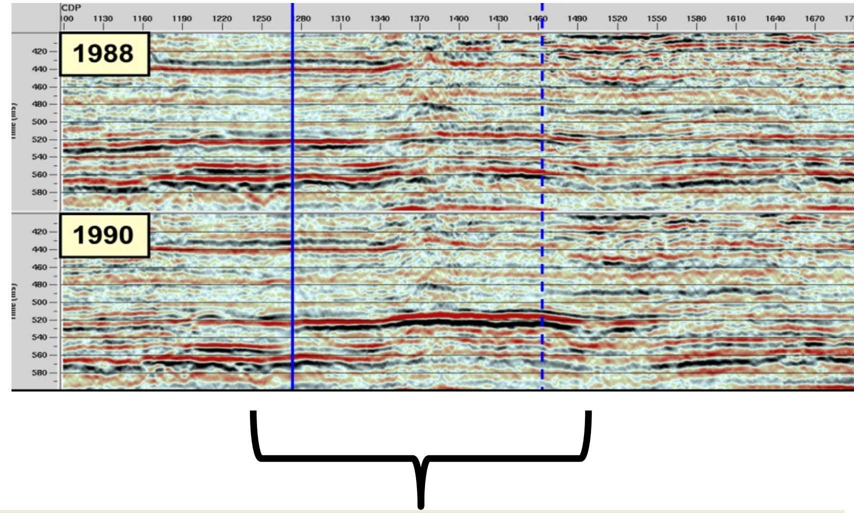
High pressure => circular shape – not dominated by structure – 490 m depth

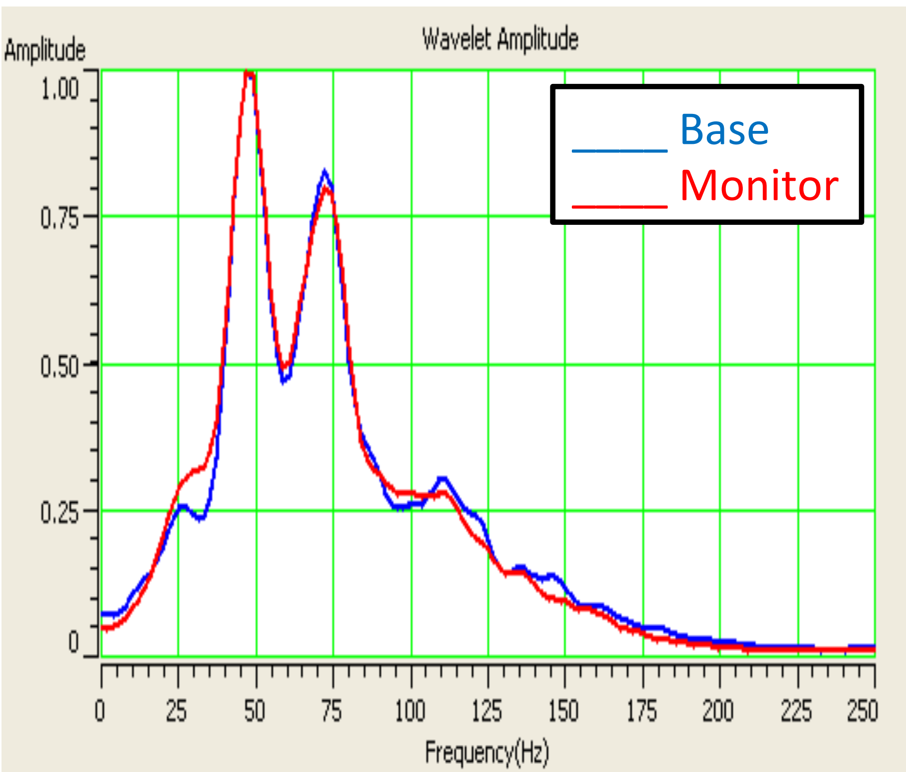
Migration of gas in 490 sand from 1991 (blue line) to 2005



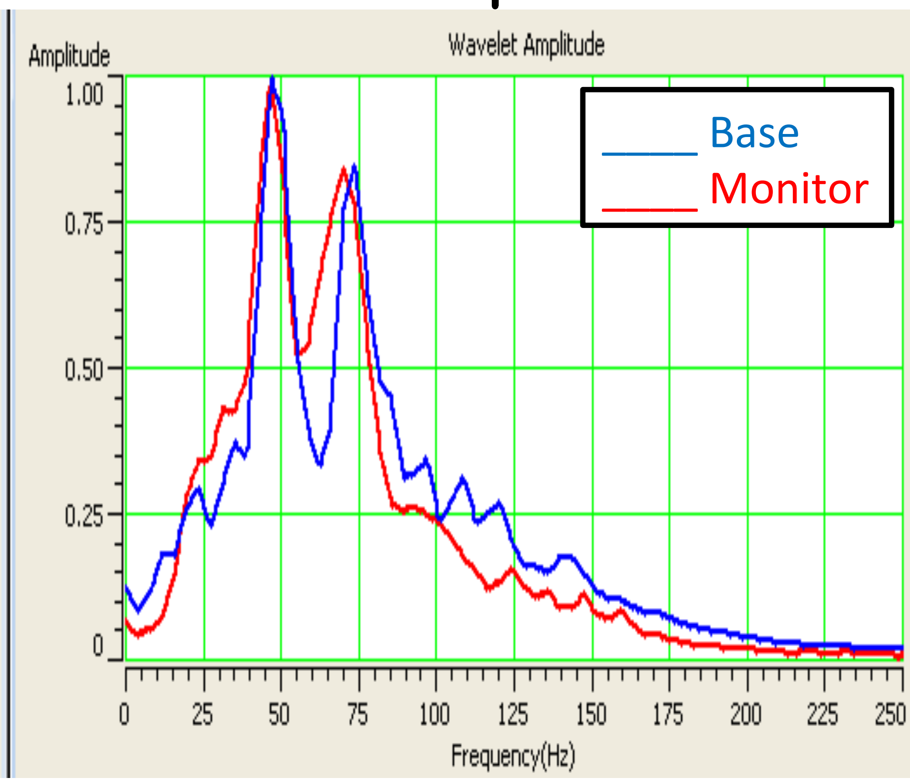
Repeated 2D site survey data







Outside gas

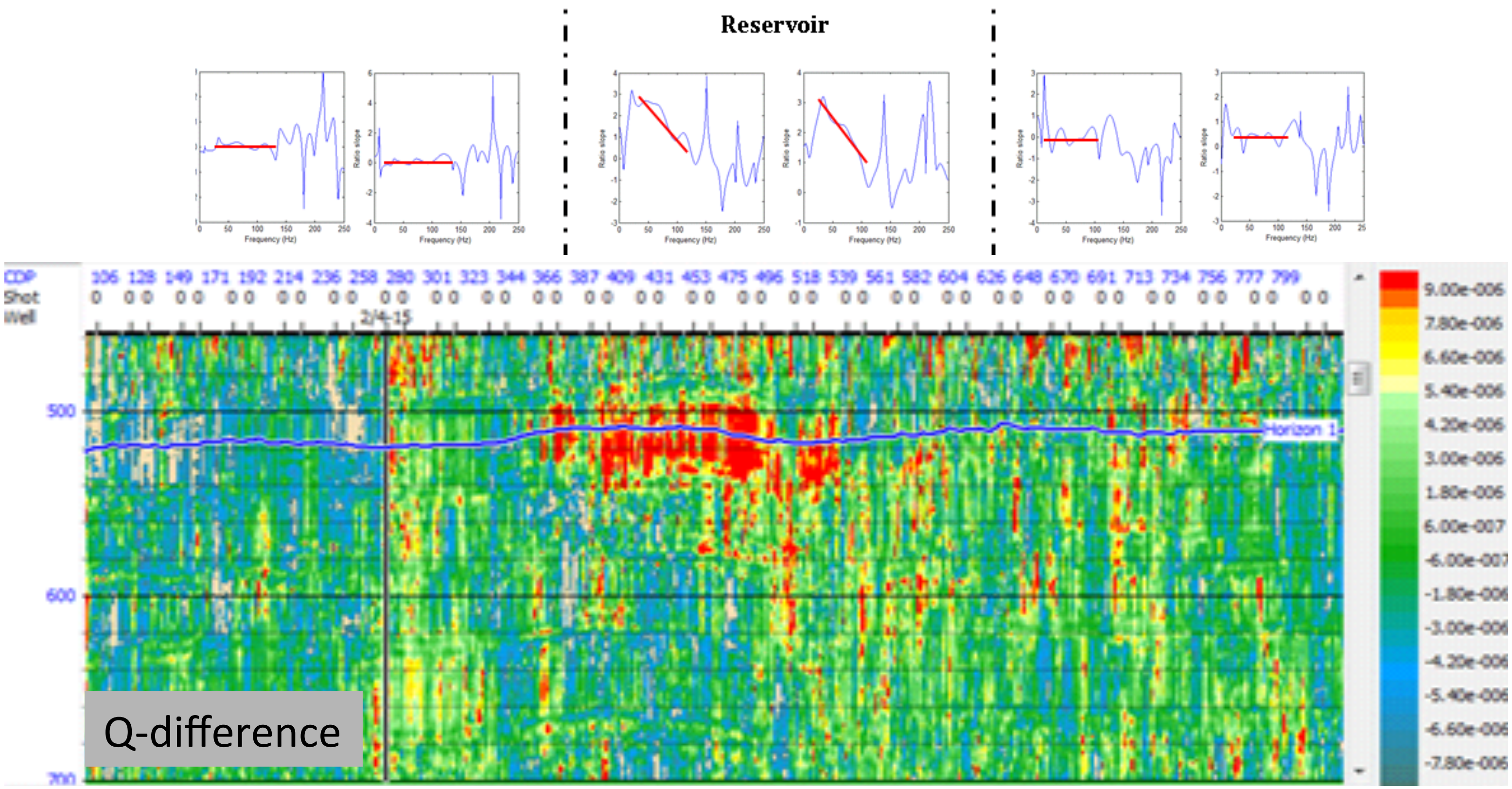


Inside gas

Estimating 4D absorption changes (88-91)

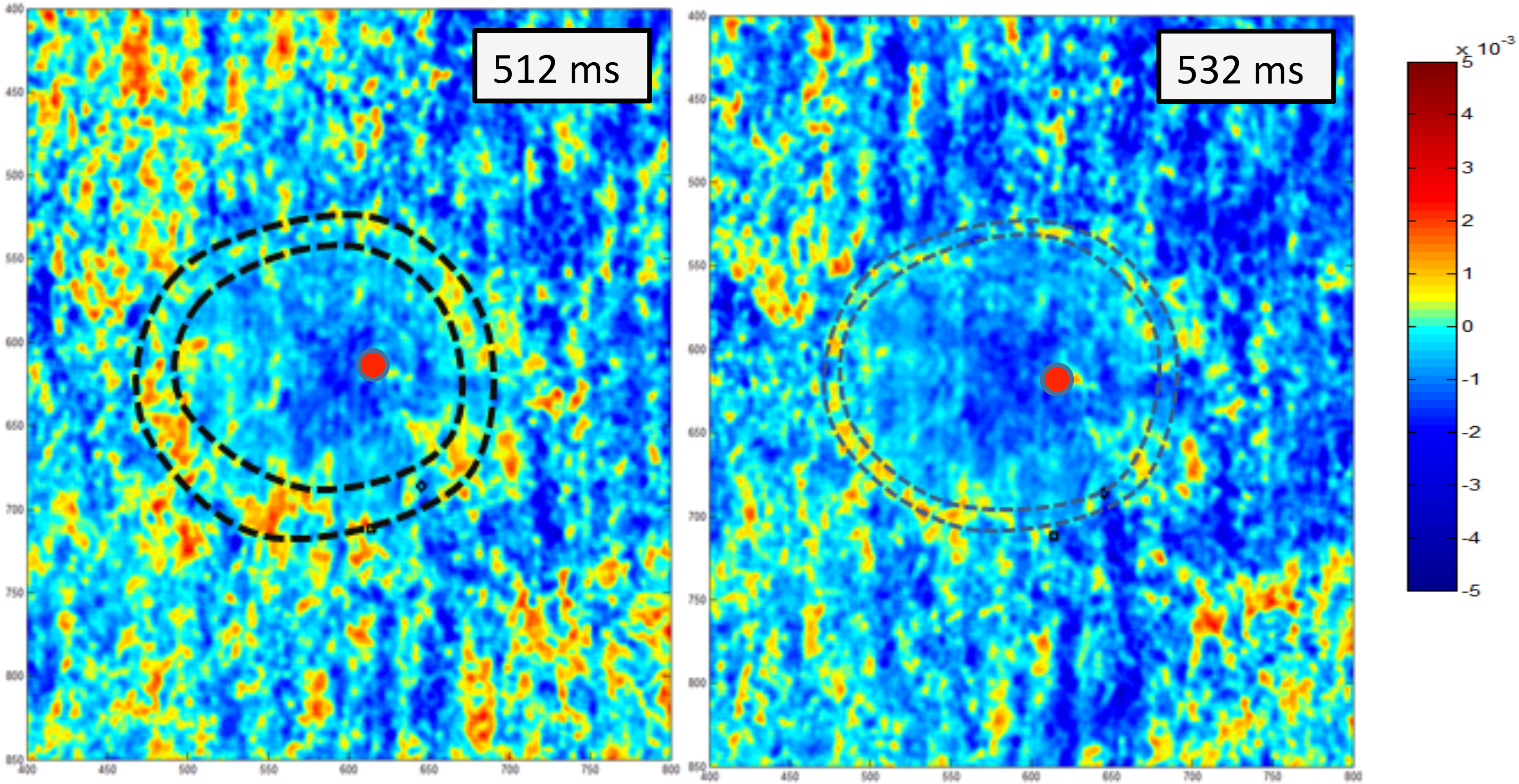
A cooperation between University of Alberta and NTNU

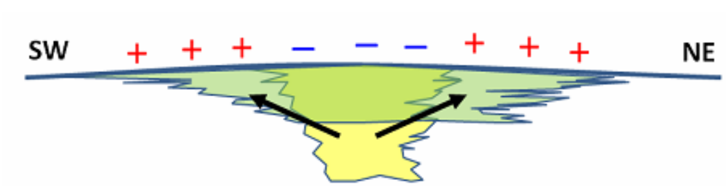
$$\ln[S'(f)/S(f)] = -(1/Q' - 1/Q)\Delta t^{*} \pi f + \ln[R'/R]$$



Source: H. Dinh, M. Landrø and M. van der Baan, 2014

4D dQ-estimate (2005-1991) for shallow sand layer



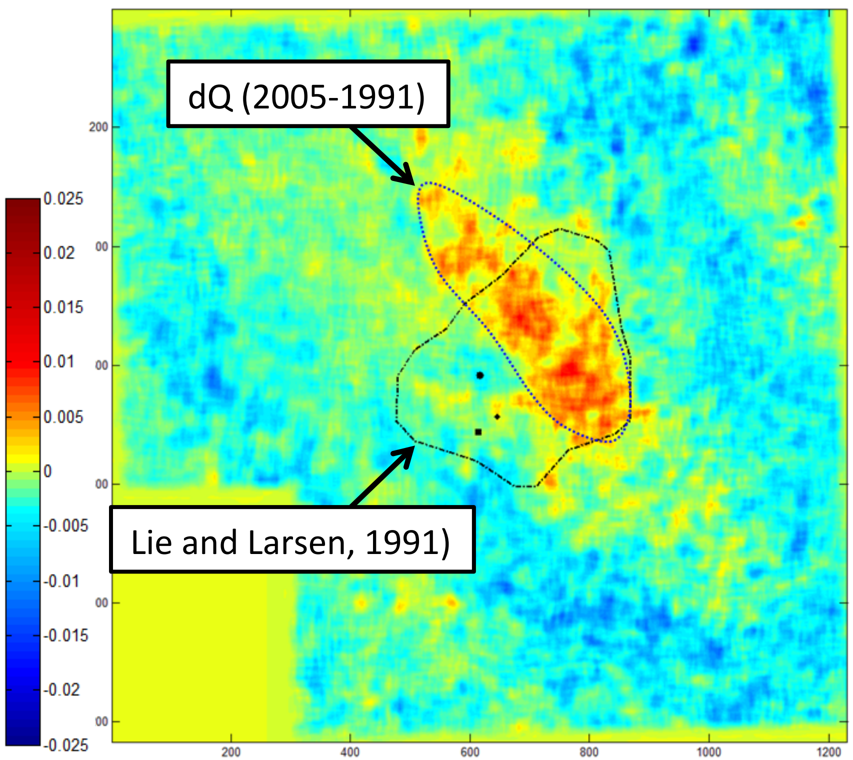


Less gas close to well surrounded by a ring of positive dQ (dashed lines)

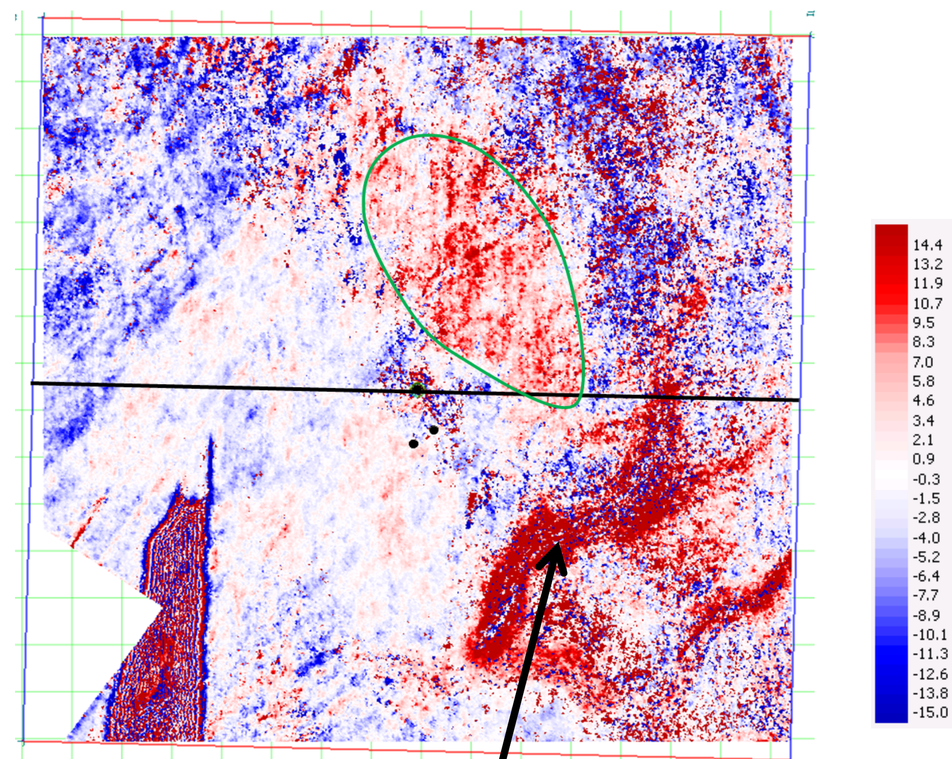
Source: H. Dinh, M. Landrø and M. van der Baan, 2014

4D dQ and dT estimates 830 m sand; 2005-1991

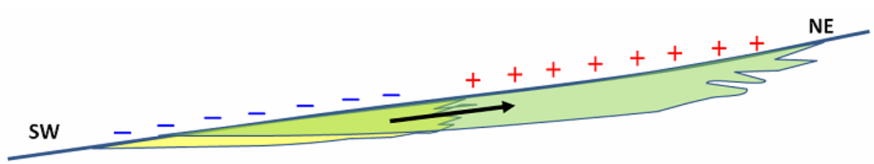
dQ-estimate deep sand layer



Time shift deep sand layer



Tunnel valley – processing artifact



Source: H. Dinh, M. Landrø and M. van der Baan, 2014

A simple Q-model for primary reflections –assuming repeated seismic data chaning ONLY the source strength

$$s_1(t) = a_1 e^{-\pi f t / Q(t)} t^{-2} + n_1(t)$$

$$s_2(t) = a_2 e^{-\pi f t / Q(t)} t^{-2} + n_2(t)$$

Geometrical spreading $G=t^{-2}$

Note: a1 and a2 includes reflection amplitude (which might be frequency dependent for multiple reflections) – we will assume that the major difference between a1 and a2 is caused by the different source strength. NOTE: It is straightforward to let a1 and a2 be frequency dependent as well.

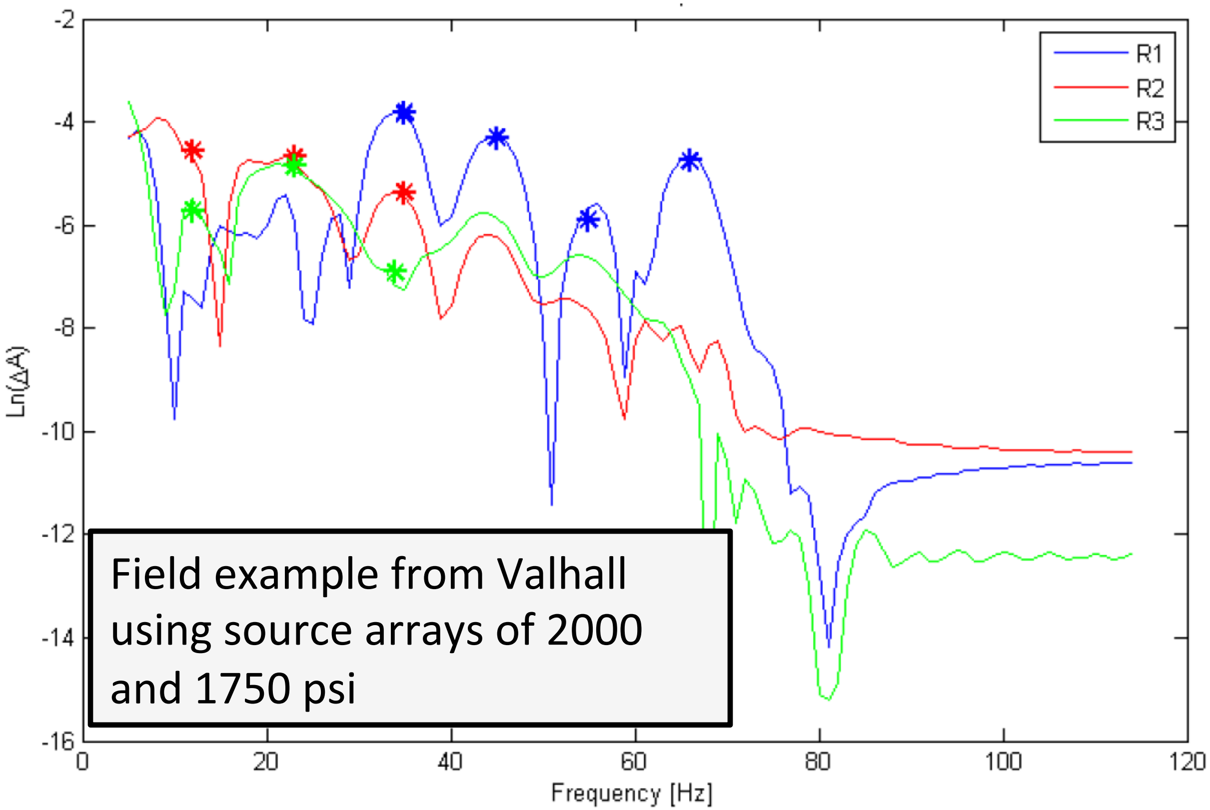
$$s_1 - s_2 = (a_1 - a_2) e^{-\pi f t / Q} t^{-2} + n_1 - n_2$$

$$\frac{1}{Q} = \frac{1}{\pi f t} \ln\left(\frac{a_1 - a_2}{t^2 (s_1 - s_2 - n_1 + n_2)} \right)$$

If n2-n1 is small (?) and a2-a1 is known and the measured data difference (s2-s1) versus frequency => Q-estimate

Q-estimation by varying the source strength

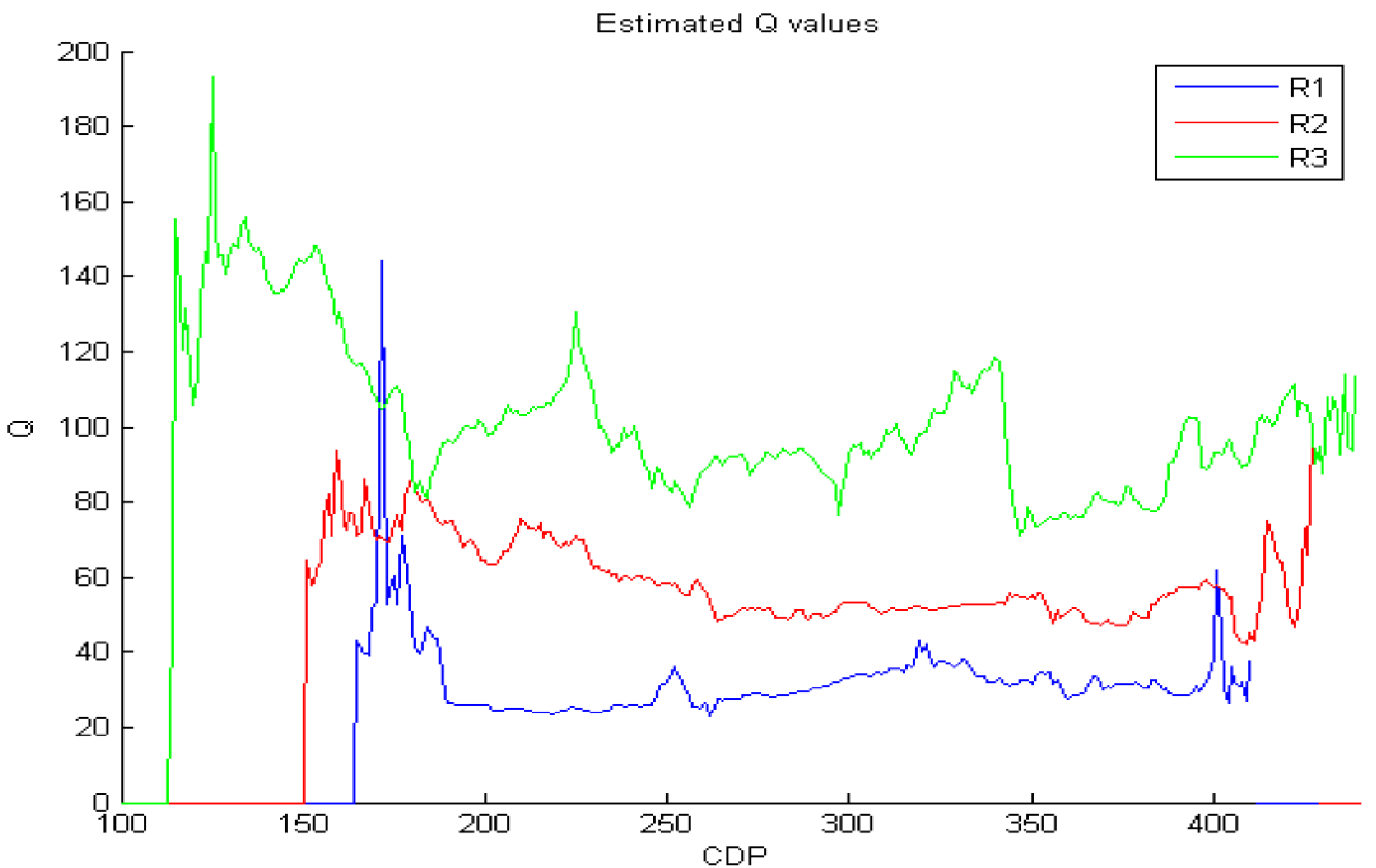
$$\ln\left(\frac{s_1 - s_2}{a_1 - a_2}\right) = -\frac{\pi f t}{Q} + 2\ln t$$



Field example from Valhall using source arrays of 2000 and 1750 psi

Three reflectors analyzed, R1, R2 and R3 (650 ms, 1750 ms and 2700 ms)

Estimated average Q-values for the test line



Assuming that the reflectivity series is frequency dependent:

$$a_1 = p_1(f)R(f)$$

$$a_2 = p_2(f)R(f)$$

$$\ln\left(\frac{s_1 - s_2}{a_1 - a_2}\right) = -\frac{\pi f t}{Q} + 2\ln t$$

$$\ln(s_1 - s_2) = -\frac{\pi f t}{Q} + 2\ln t + \ln(p_1(f) - p_2(f)) + \ln(R(f))$$

Walden and Hosken (Geophysical Prospecting, 33, 400-435): $R = const \cdot f^{\beta}$

$$\ln(s_1 - s_2) = -\frac{\pi f t}{Q} + 2\ln t + \ln(p_1(f) - p_2(f)) + \beta \ln f$$

Walden and Hosken found β-values between 0.5 and 1.5

Solution: Estimate beta for several wells, or estimate beta-ranges prior to analysis

Geophysical Prospecting 33, 400–435, 1985.

AN INVESTIGATION OF THE SPECTRAL PROPERTIES OF PRIMARY REFLECTION COEFFICIENTS*

A.T. WALDEN and J.W.J. HOSKEN**

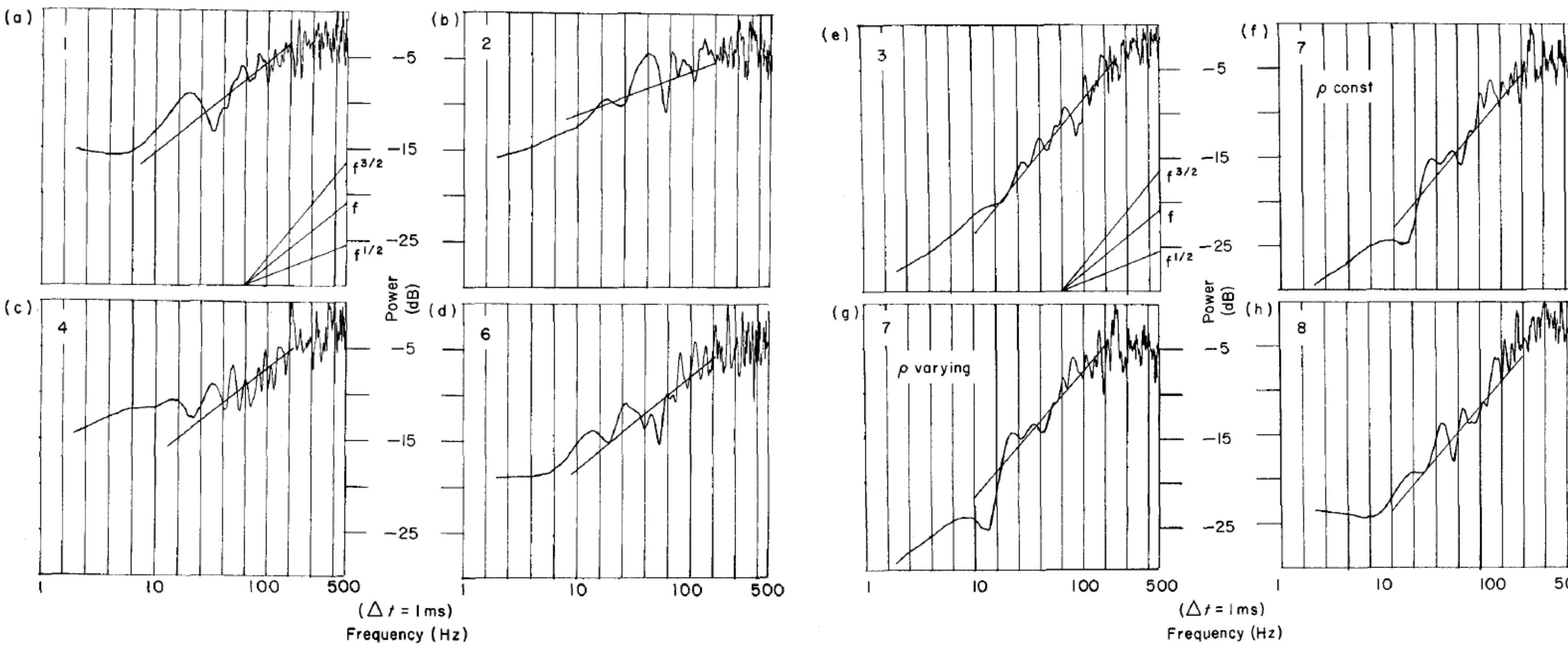


Fig. 3. Empirical power spectra of reflection coefficients from logs sampled at 1 ms marked with an appropriate slope, for (a) well 1: slope $\propto f$: (b) well 2: slope $\propto f^{1/2}$ (c) well 4: slope $\propto f$: (d) well 6: slope $\propto f$; (e) well 3: slope $\propto f^{3/2}$ (f) well 7 with density held constant: slope $\propto f^{3/2}$; (g) well 7 with density varying: slope $\propto f^{3/2}$; and (h) well 8: slope $\propto f^{3/2}$.

Walden and Hosken (1985):

Spectral slopes proportional to $f^{1/2}$, f and $f^{3/2}$ are marked on these figures, and it may be seen that for the first group of wells the sample spectra have slopes of f or $f^{1/2}$, while for the second group the sample spectra have slopes almost exactly proportional to $f^{3/2}$. The first group of wells have rock sequences which are fairly random, while the second group have repetitive-type sequences; these properties are immediately discernable from the sonic logs. The spectrum for well 5 has not been

It is very likely that with some knowledge of geology or wells that the slope in a given area may be determined reasonably well => we might hope to find a slope variability much less than 1

Discussion and conclusions

- Time-lapse Q is a complementary 4D analysis tool
- Observe Q-changes between 1991 and 2005 3D seismic data above noise level – comparable to time shift analysis
- Estimating Q by changing the source strength seems feasible