Using site survey data to monitor shallow subsurface leakage

by
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The NPD's Fact-pages

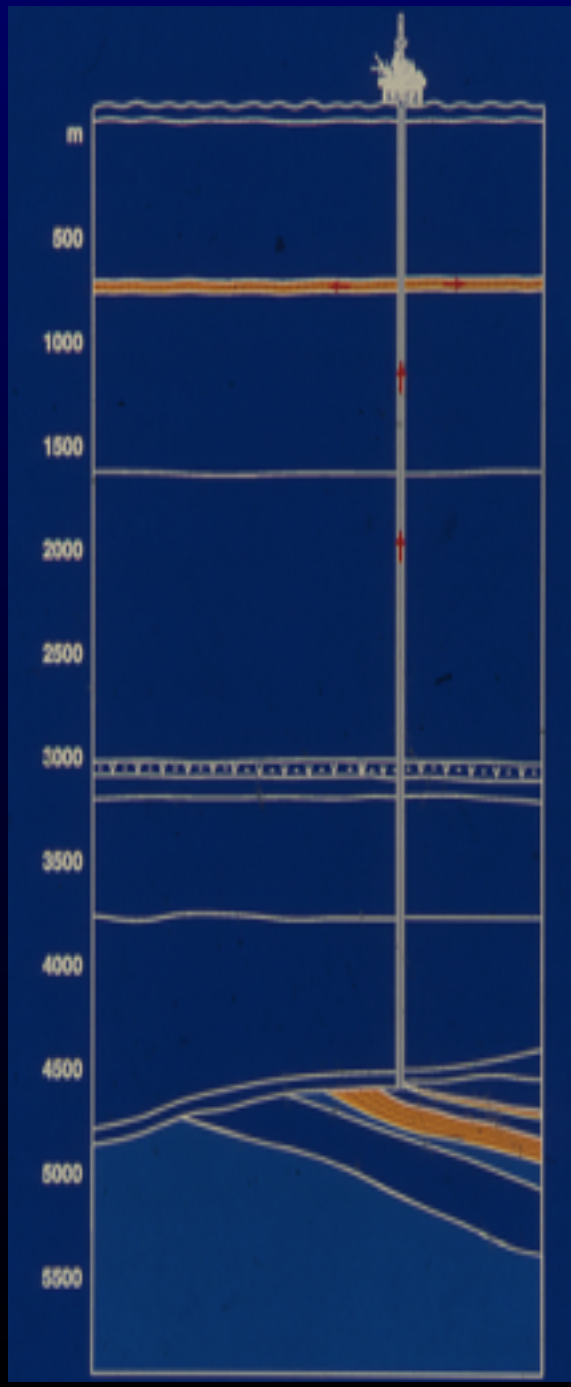
Wellbore history - 2/4-14

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.

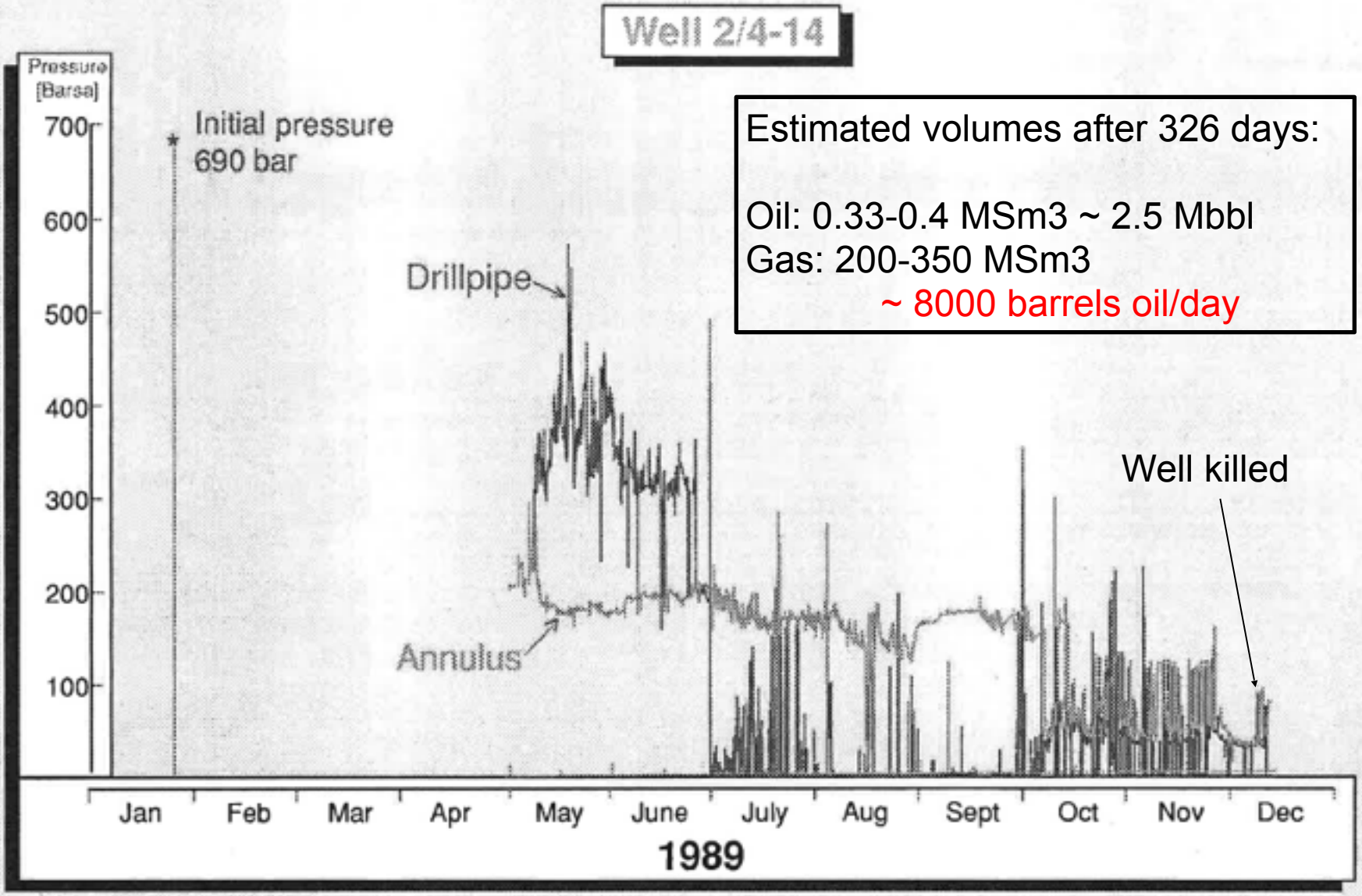
A relief well was drilled 1182 m south of the 14-well:

Well 15 was spudded 31 January 1989, 11 days after the kick – this well was sucessful and stopped the blow out

All information on the well operations is public domain



Recorded wellhead pressure as a function of time

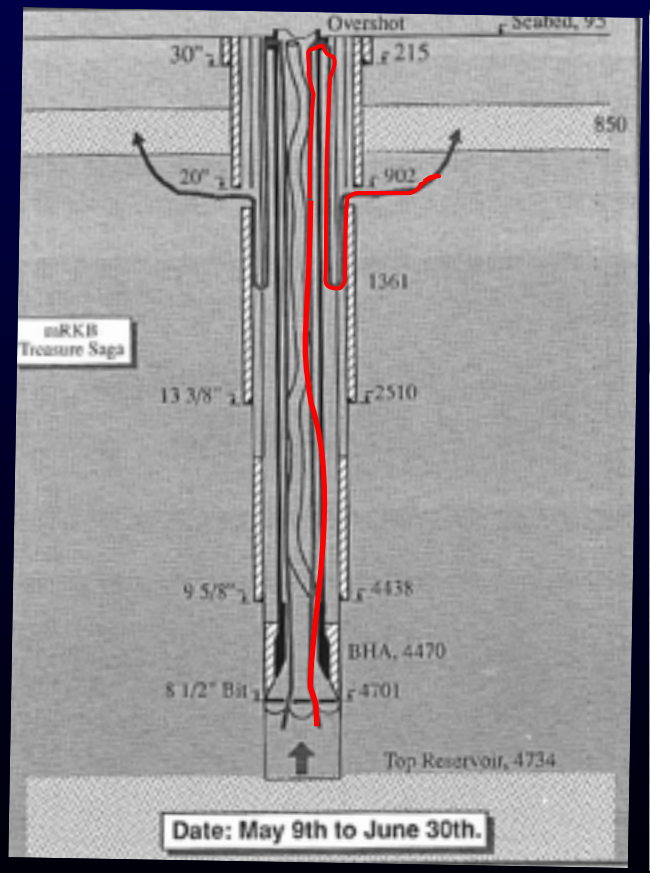


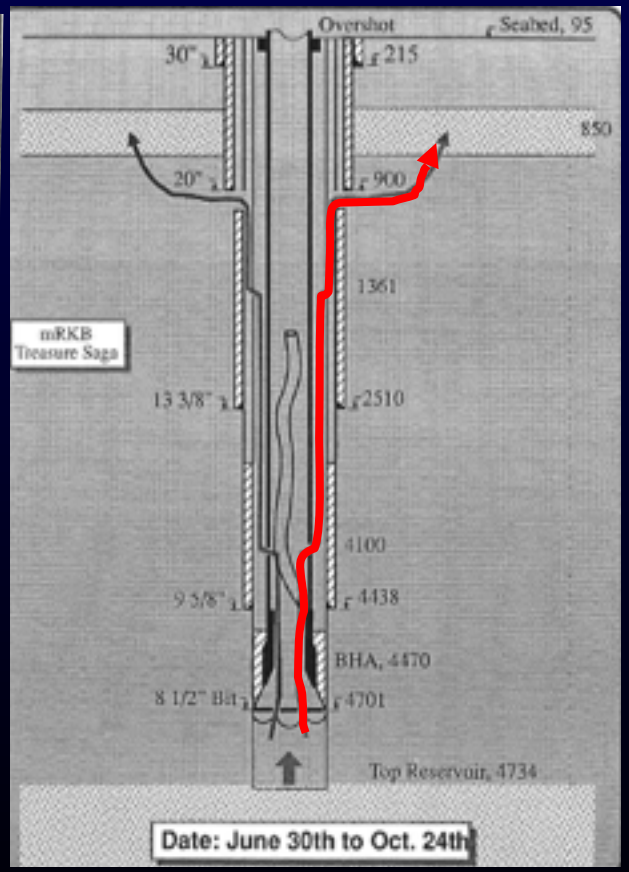
Estimated volumes after 326 days:

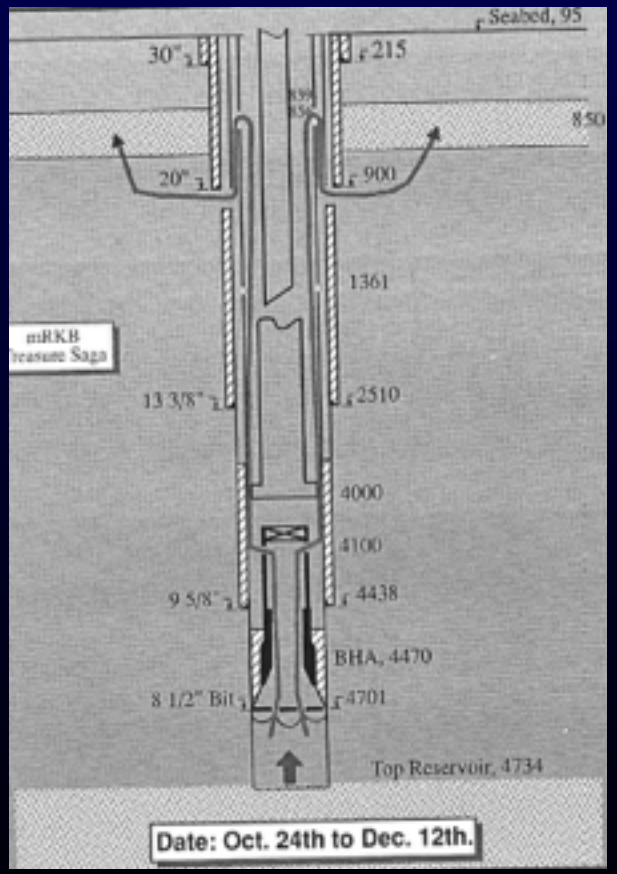
Oil: 0.33-0.4 MSm3 ~ 2.5 Mbbl
Gas: 200-350 MSm3
~ 8000 barrels oil/day

Ref.: A. Remen, 1991

3 different leakage paths for different periods after the blow out

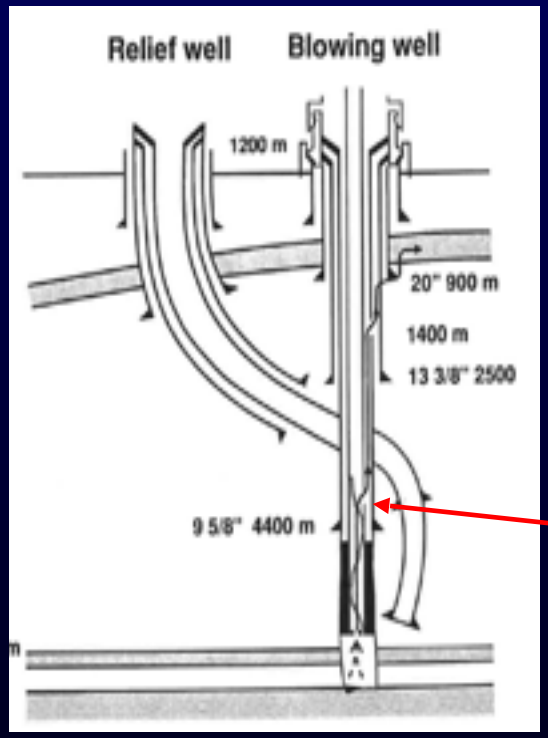




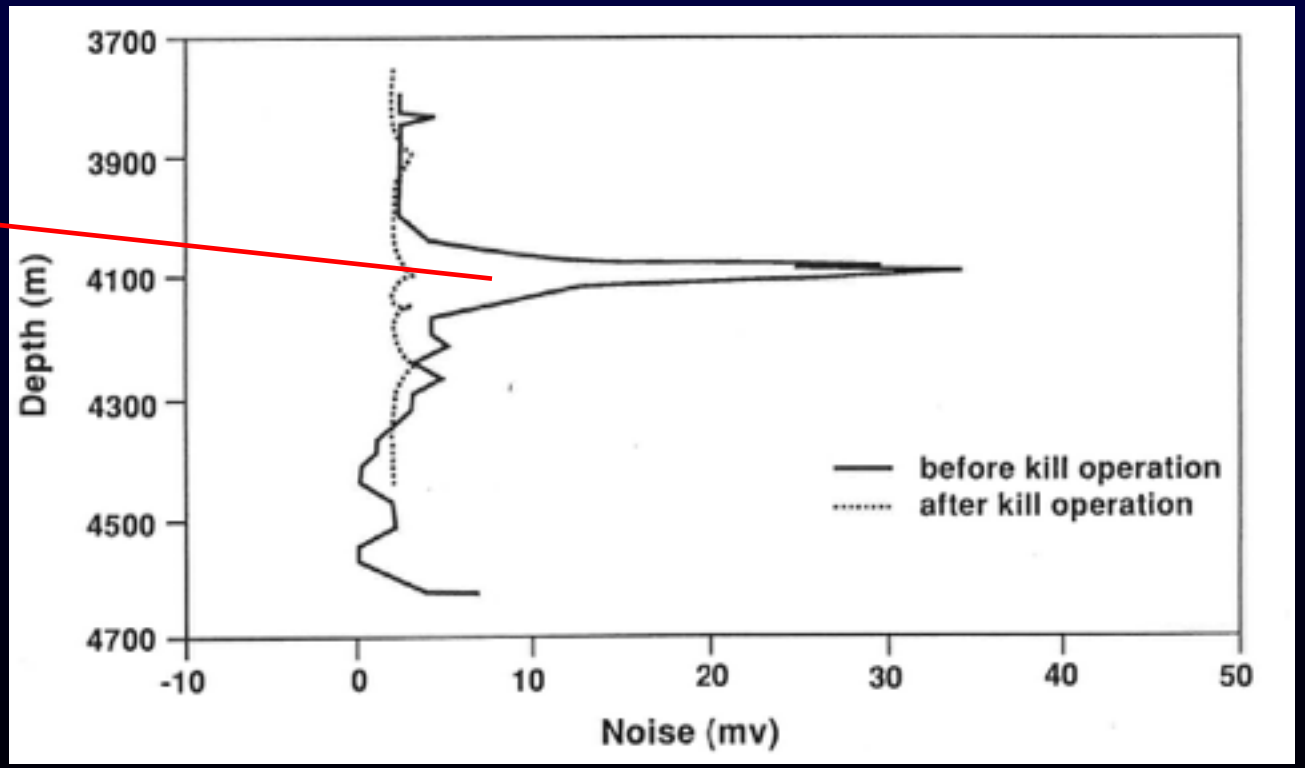


Ref.: Arild Remen, 1991

Noise log measured in May 1989 in the relief well

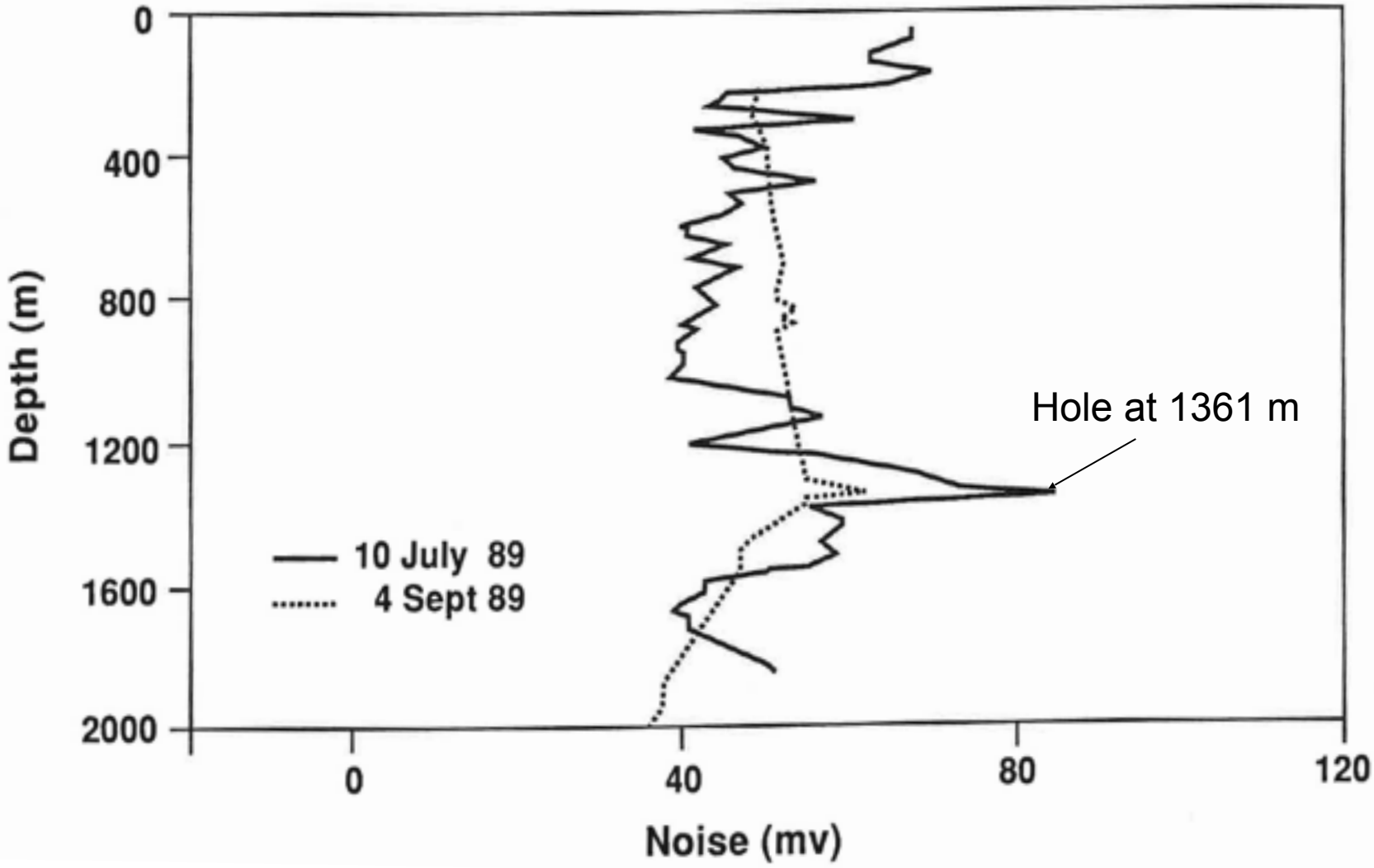


- 20 m between the wells
- Interpreted as hole in the drill pipe at 4100 m
- No noise after kill operation => successful



Source: C. Slungaard, 1991

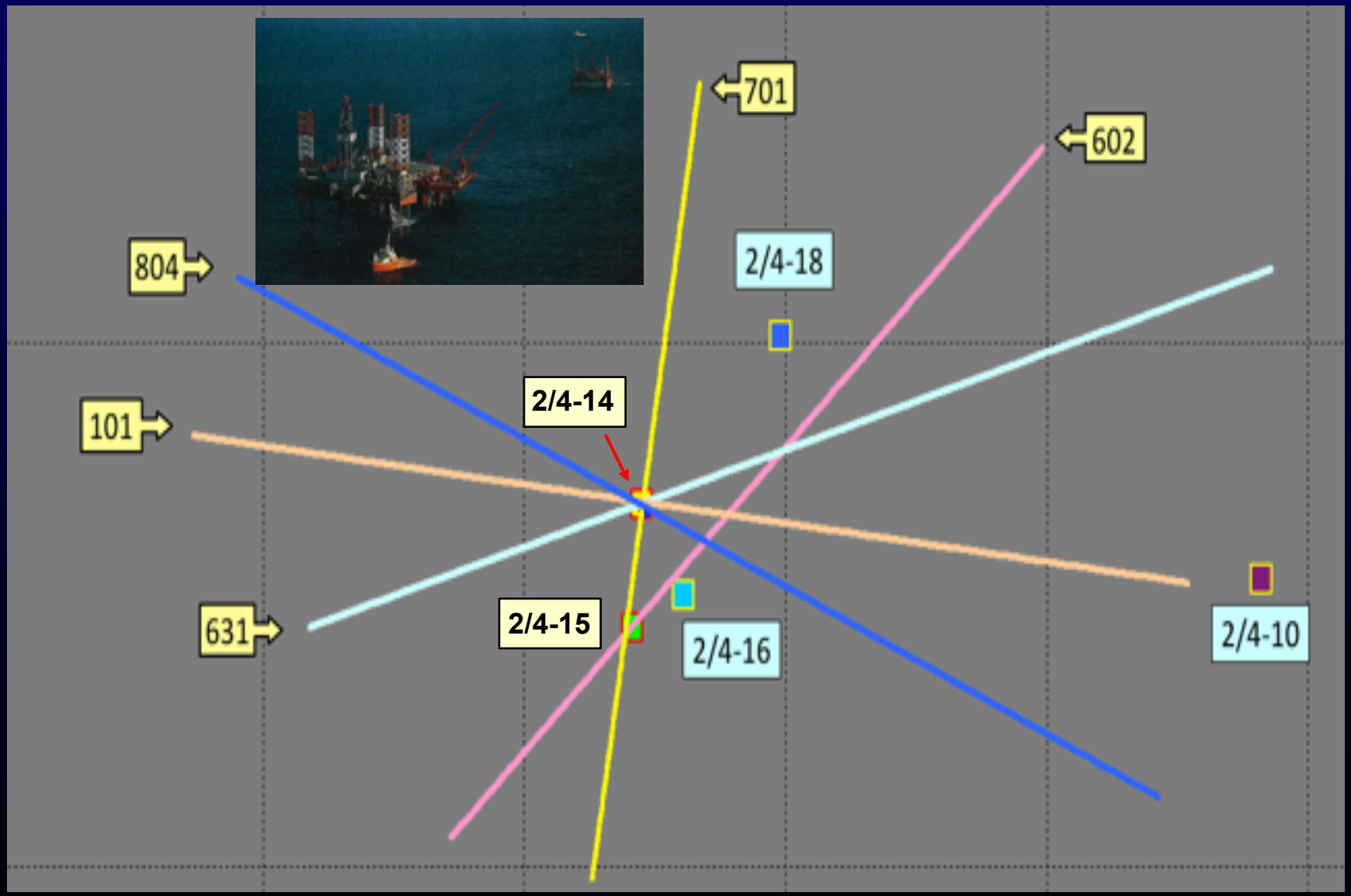
Noise logs recorded in the blowing well (14)



9th December 1989: Some gas bubbles observed at the 2/4-13 well (47 m away from the blowing well)

Bubble counting showed no changes in rate => indicate that this is probably natural gas

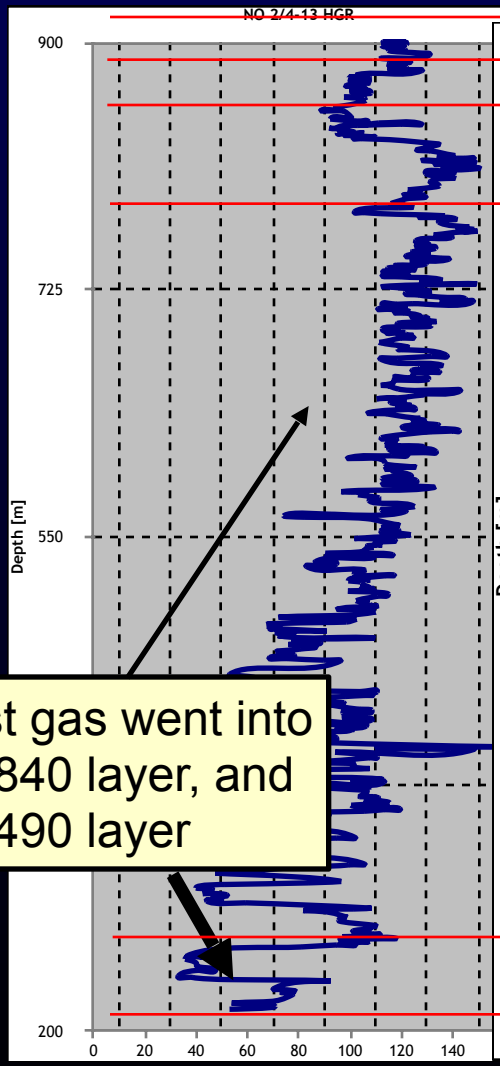
Repeated 2D lines acquired in 2009

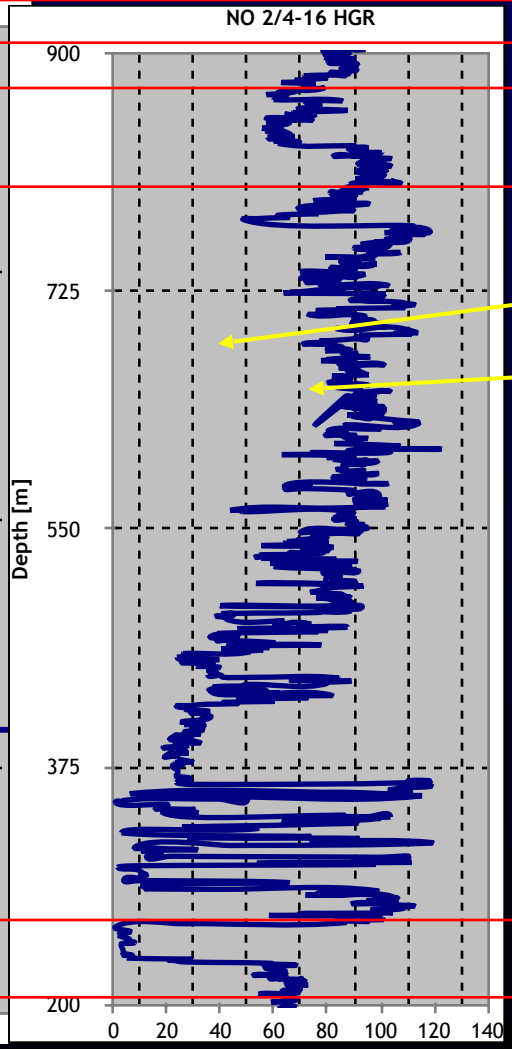


In this study we will use brute stacks from 602 and 804

Comparing gamma-logs for two wells (880 m apart)

GR 2/4-13 GR 2/4-16





Depth (m)

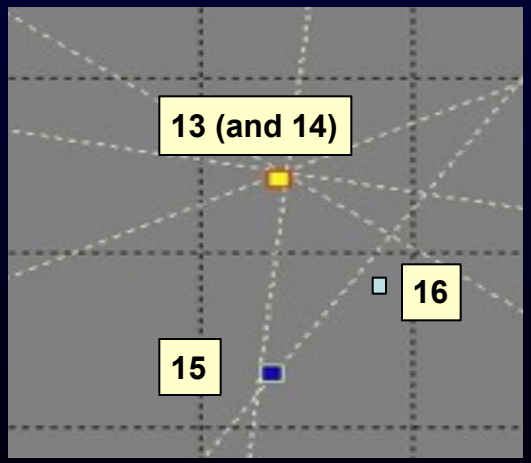
Most gas went into the 840 layer, and the 490 layer

Sandlayer at 230 m

Thin sandlayers

Sandlayer at 445 m

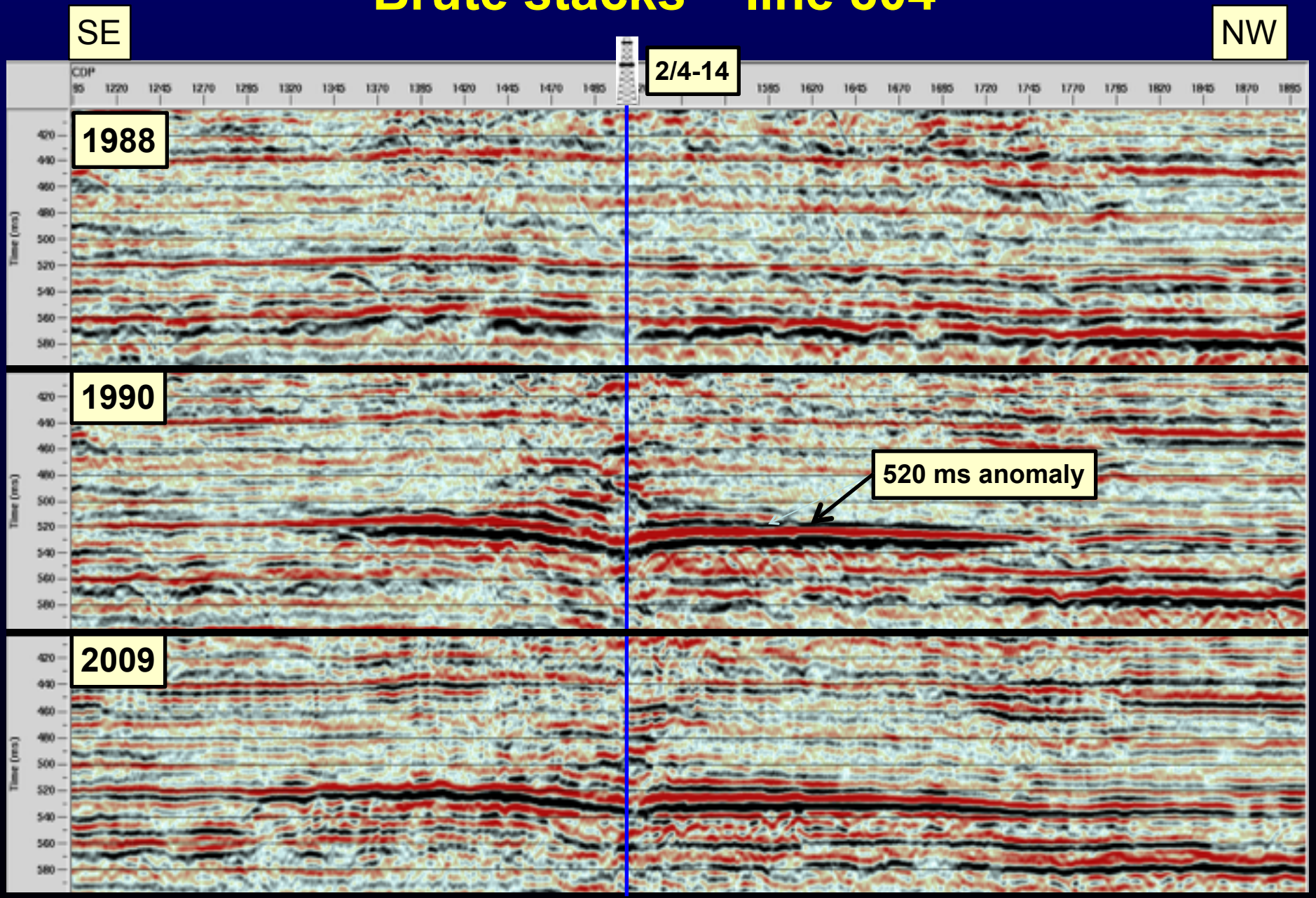
Sandlayer at 490 m



Sandlayer at 840 m, 87 m thick

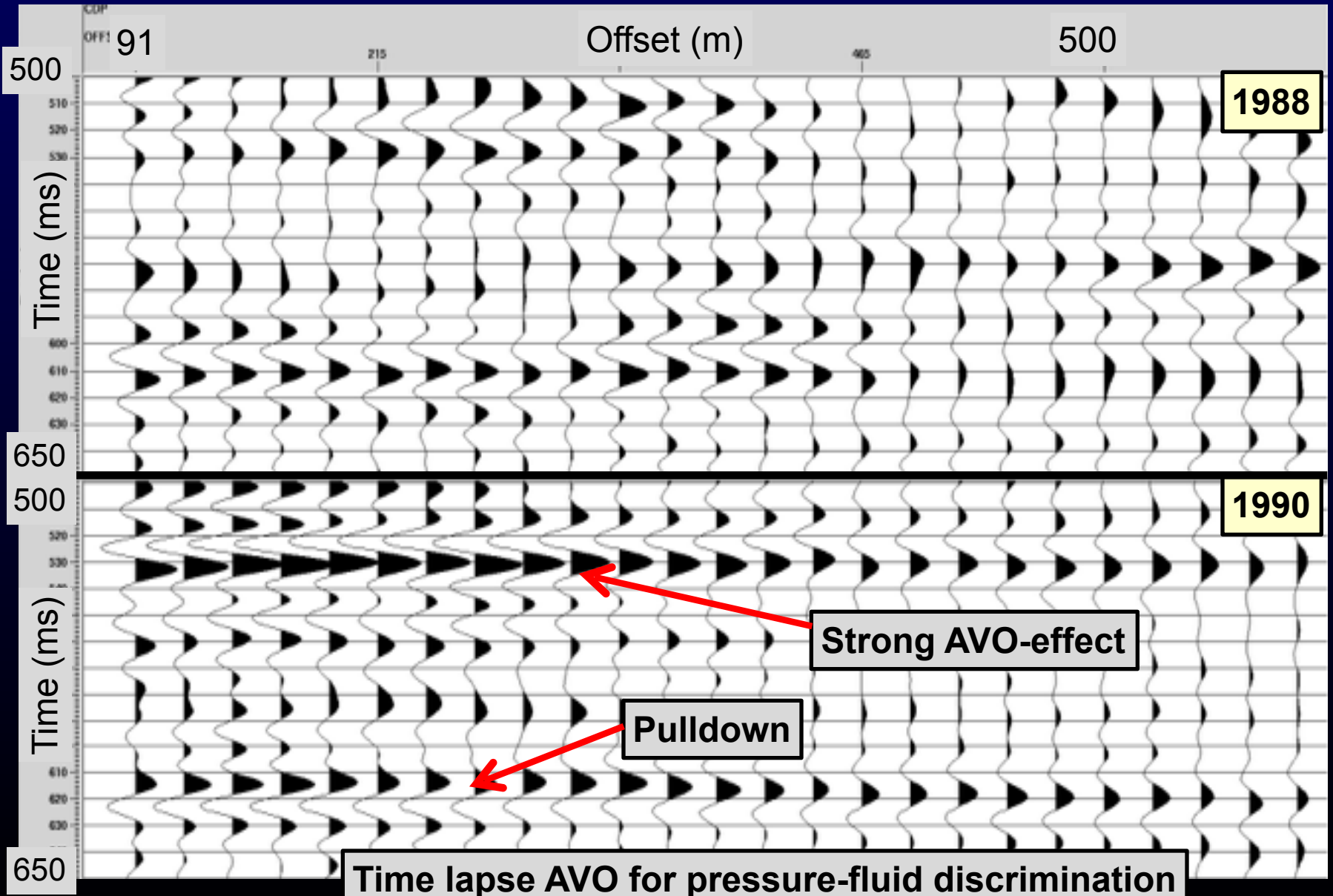
Surprise: 16-well (1991) showed no gas in the 450 and 840 sand layers!

Brute stacks – line 804

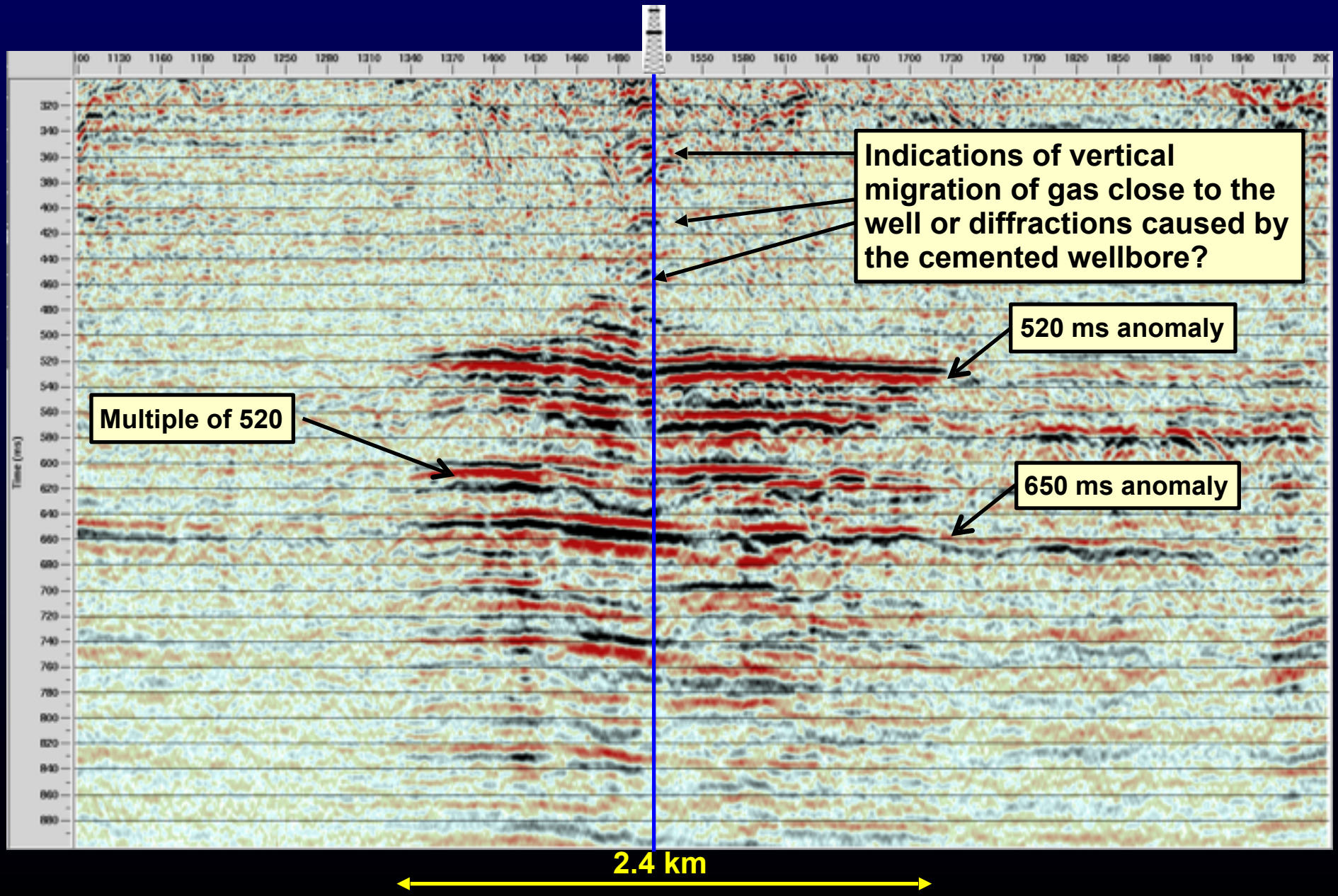


Less pulldown in 2009 – slight increase in horizontal extention

AVO example: Line 804 CDP 1550



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



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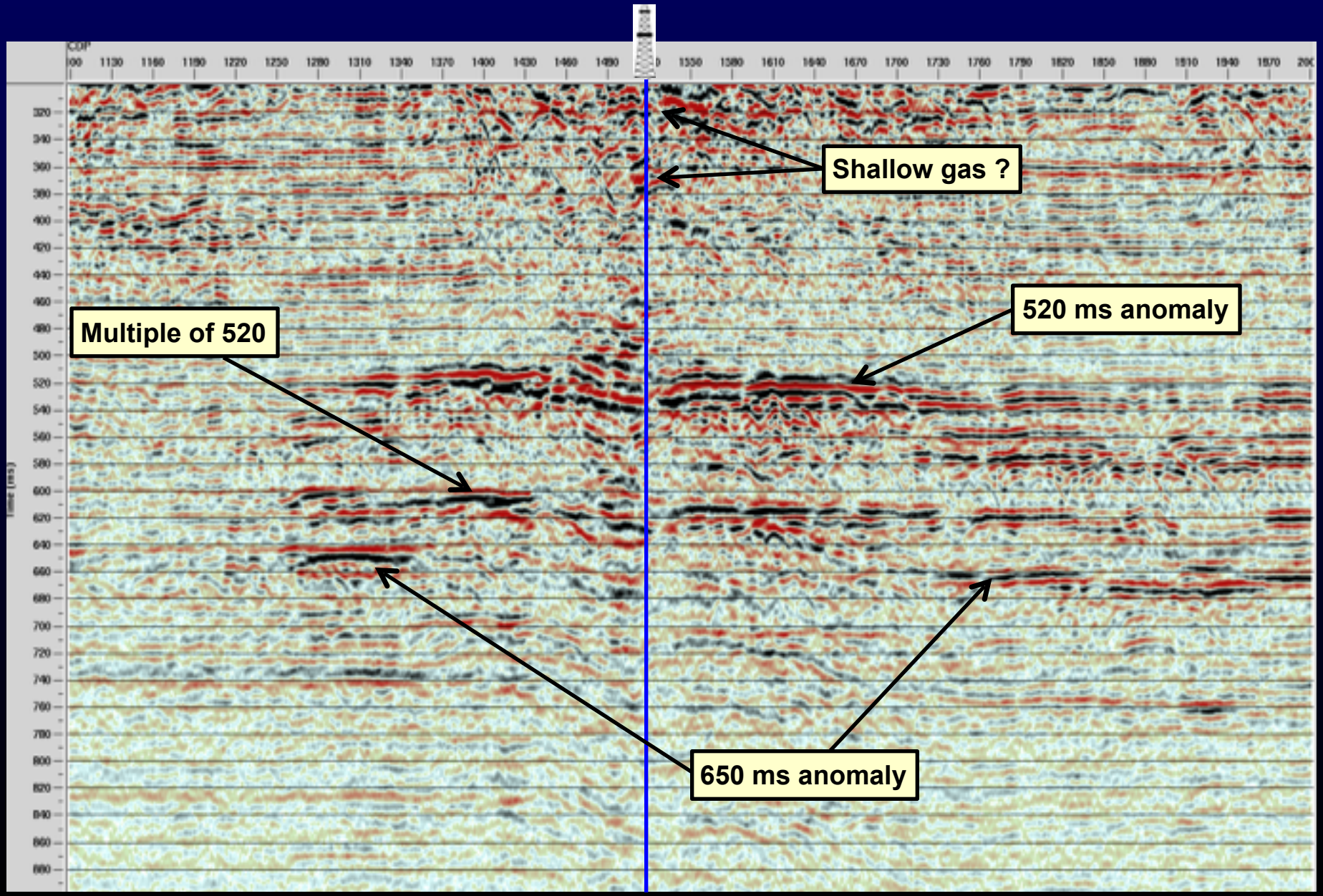
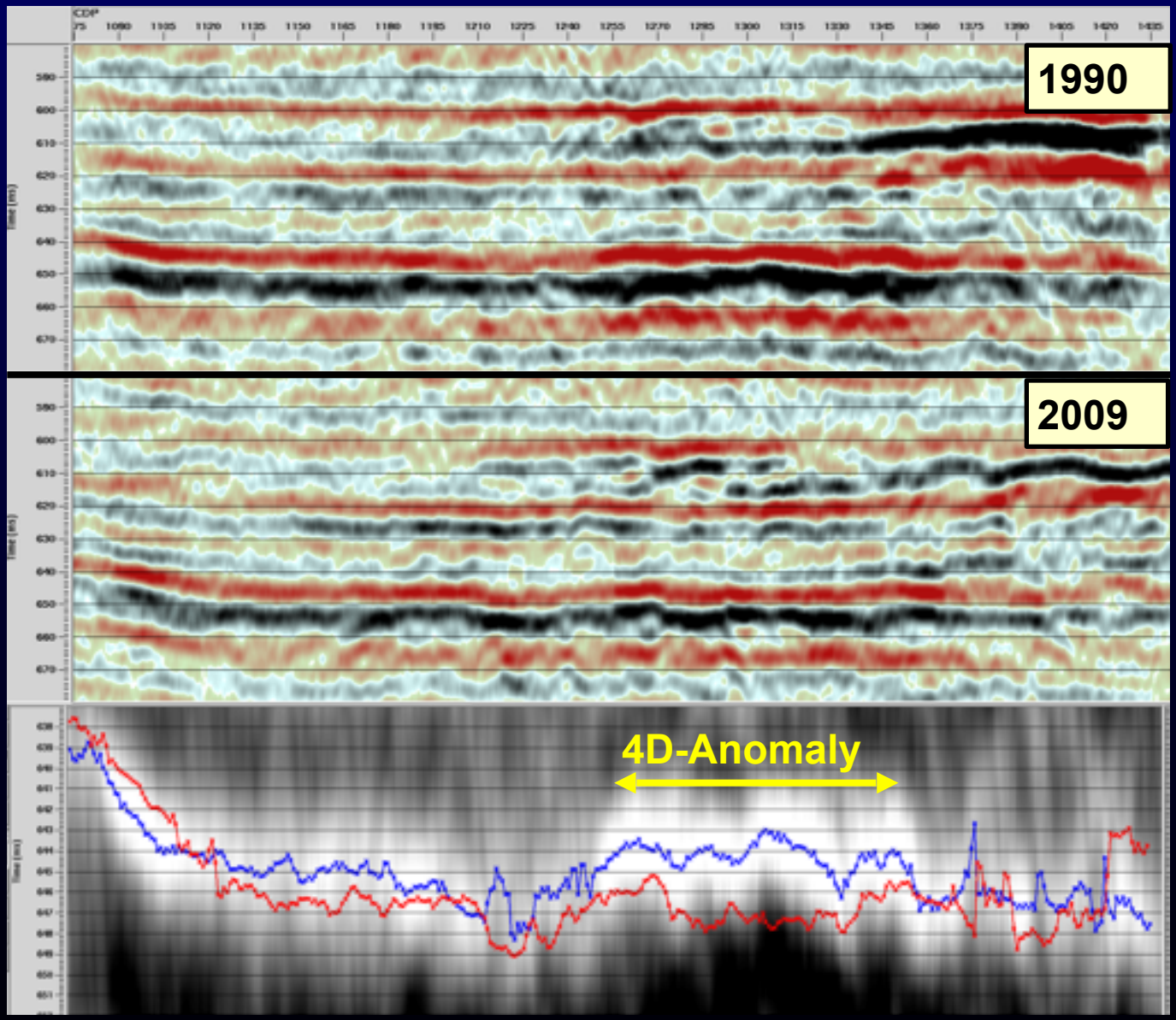
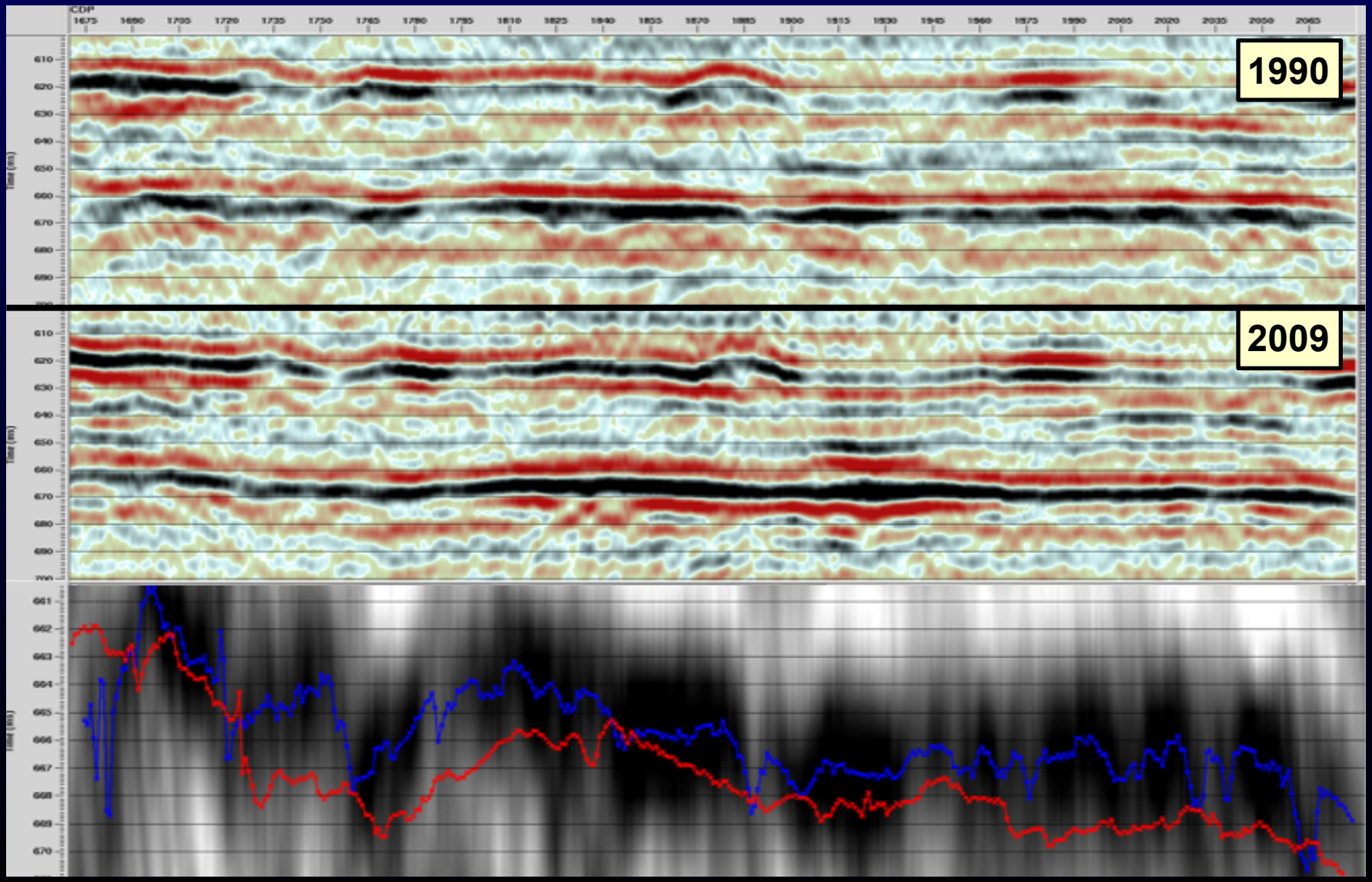


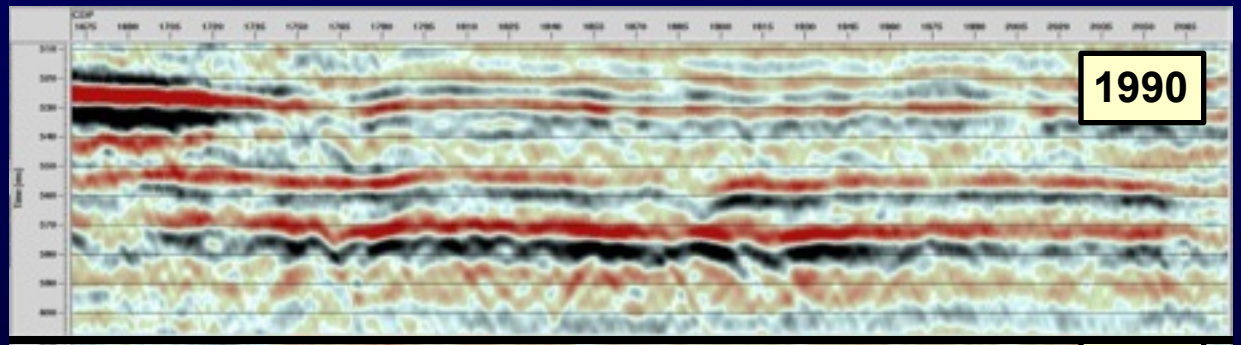
804: The 4D anomaly at 640 ms: A significant time shift

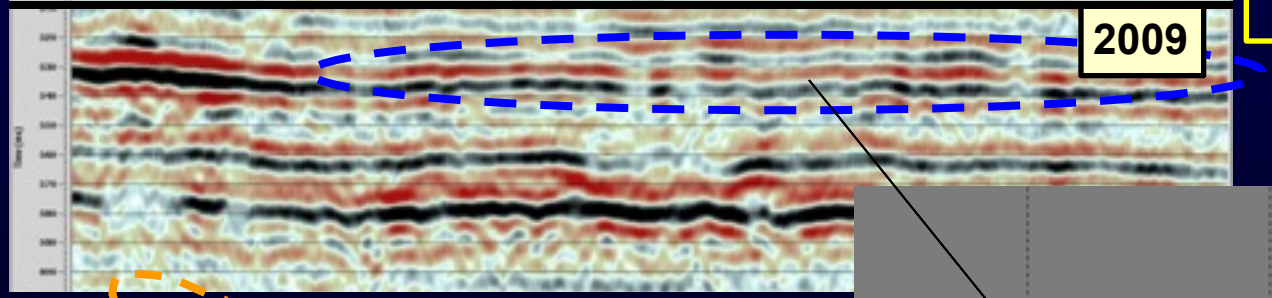


804: 4D anomalies caused by timeshifts => lateral gas migration above

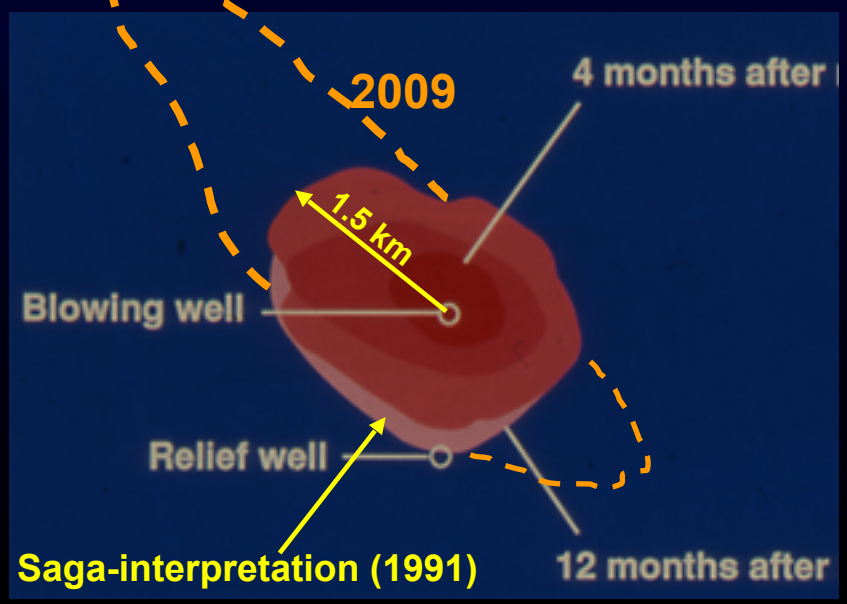


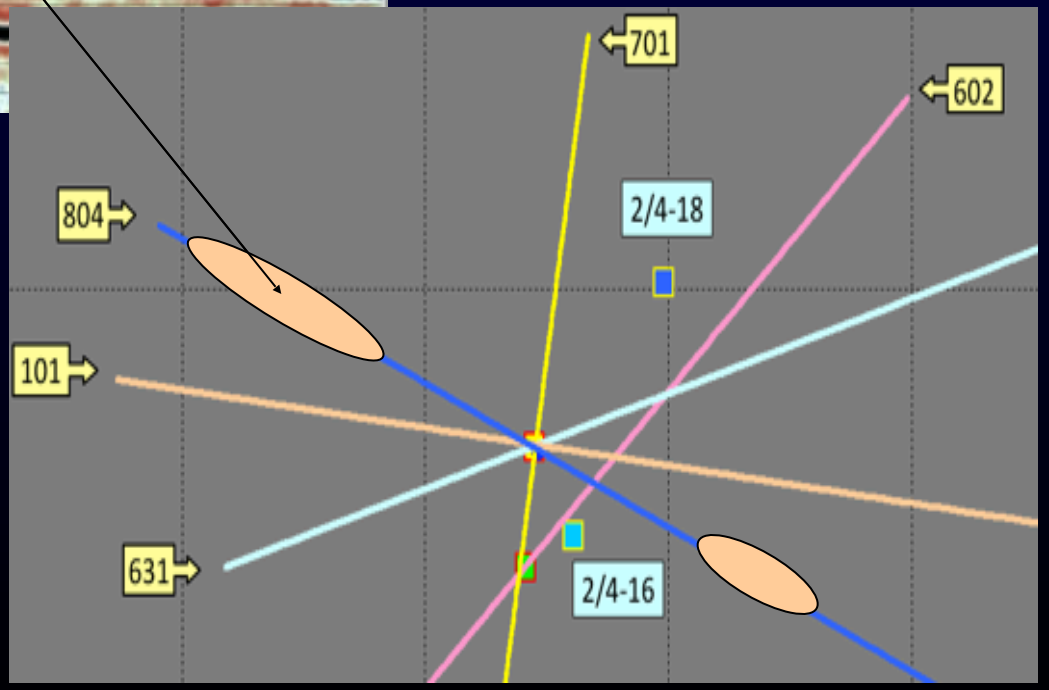
804: Slight amplitude increase for the 520-ms event in this area – indicating lateral gas migration 3.5 km NW of the 2/4-14-well



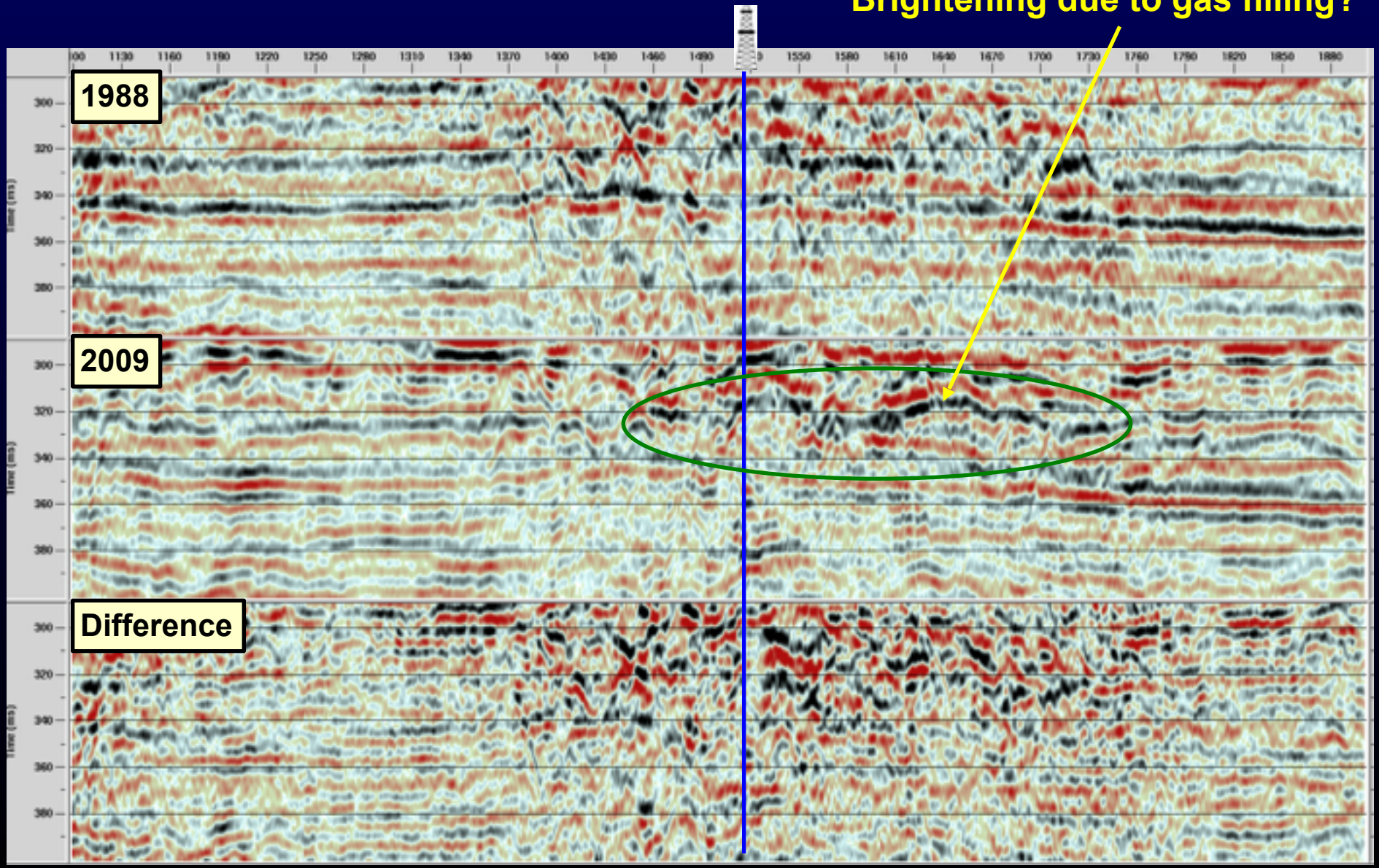


1. Dimming (closer to well) followed by slight amplitude increase
2. Timeshift of 2-3 ms between 1990 and 2009 for event below the sand layer

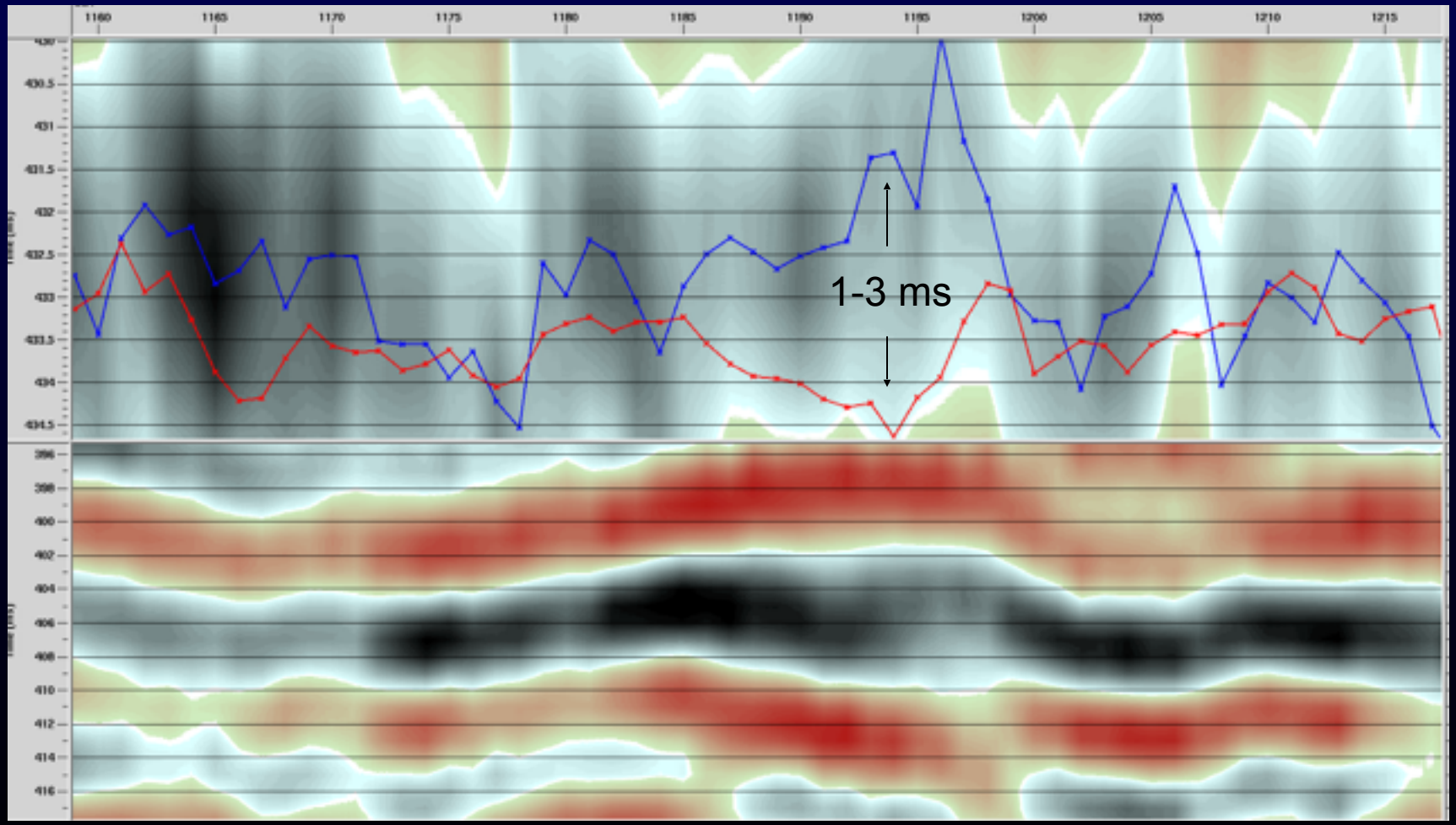




Detailed shallow comparison – line 804

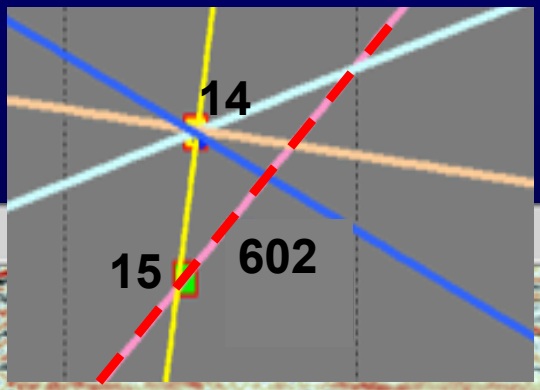


Potential local accumulation of gas (1990-2009) – and corresponding time shift (estimated from an interface below the anomaly) – line 804



345 m

Brute stacks – line 602



2/4-15

2/4-14 (proj.)

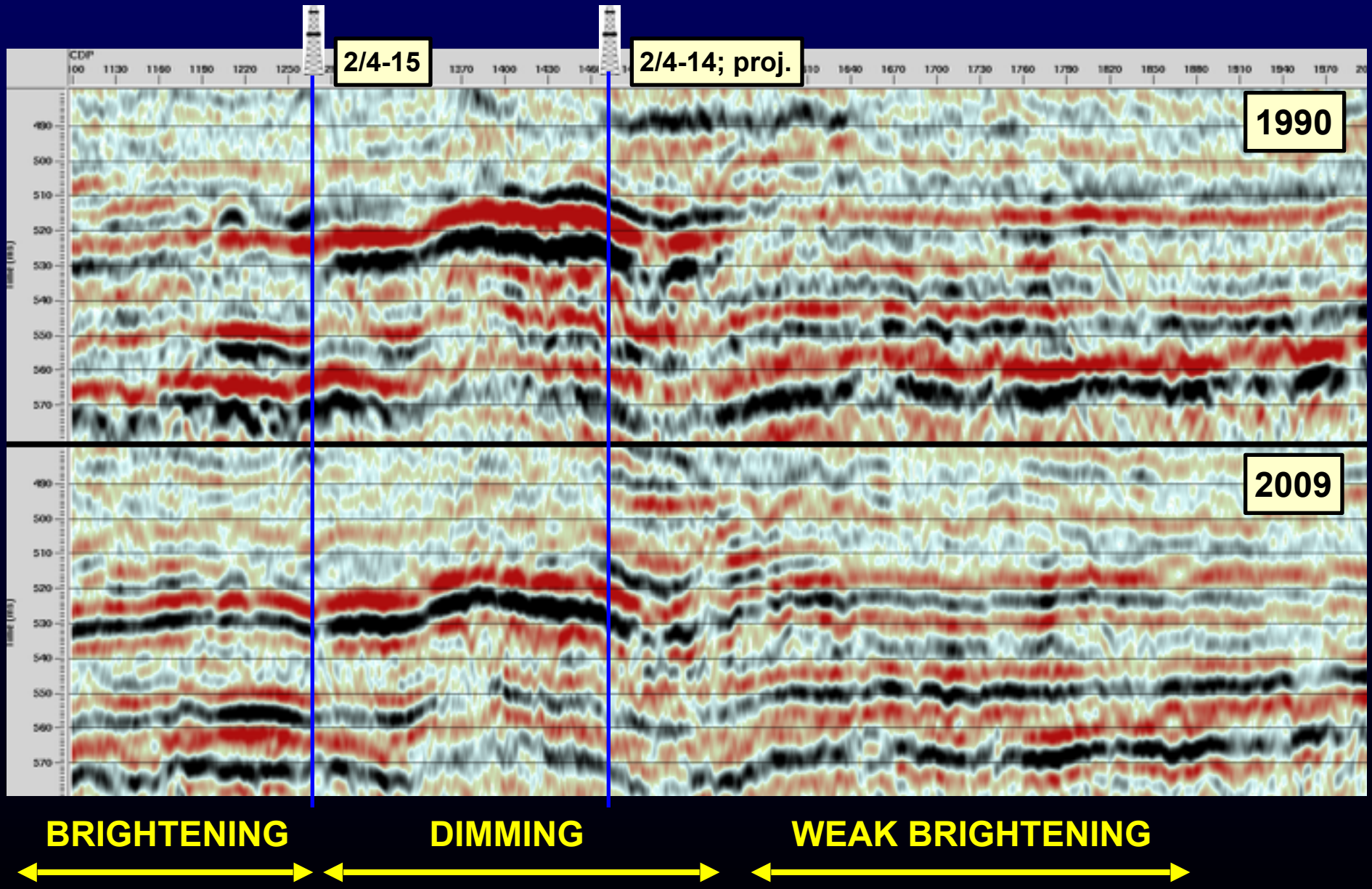
1988

1990

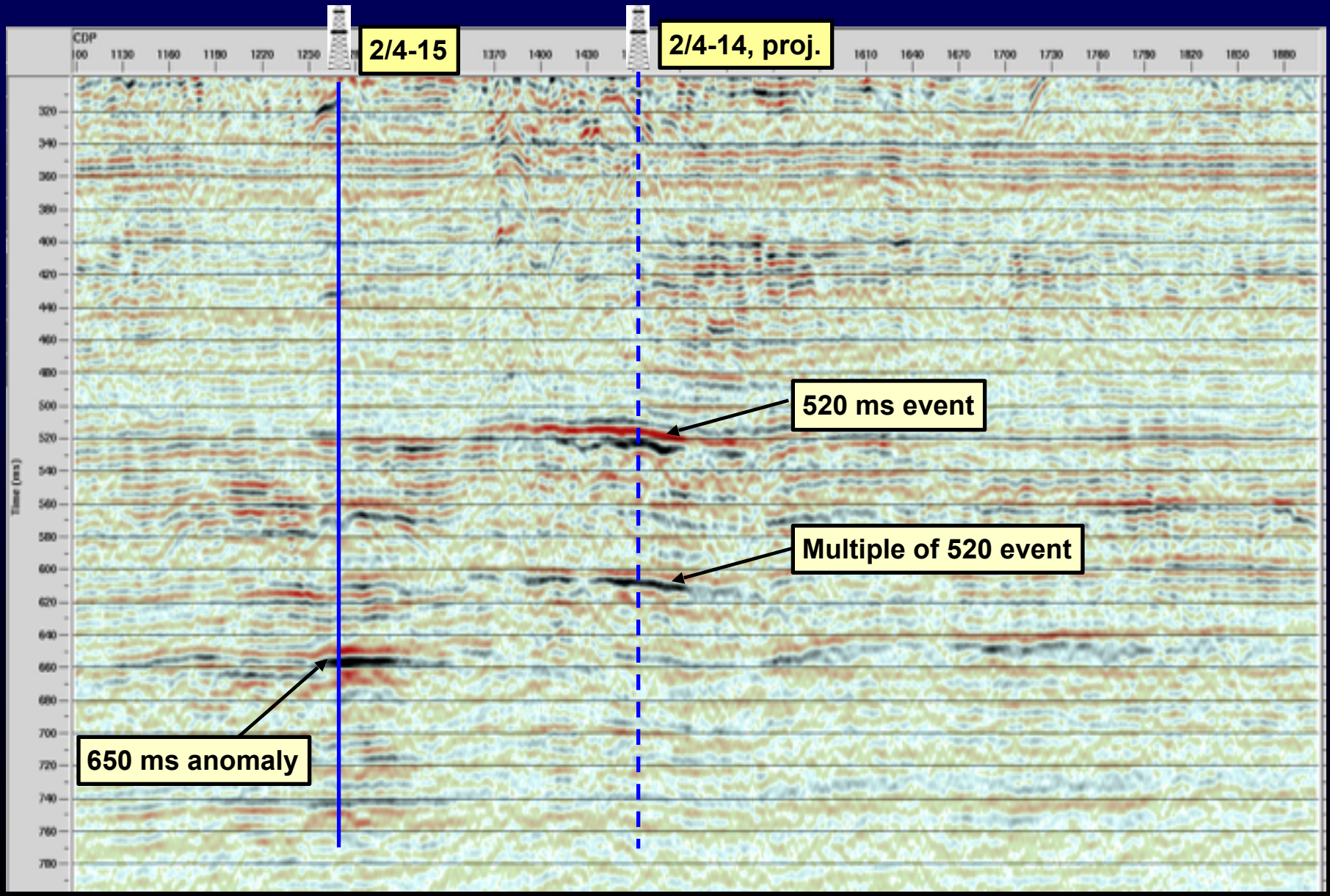
2009

Increased lateral extension in 2009

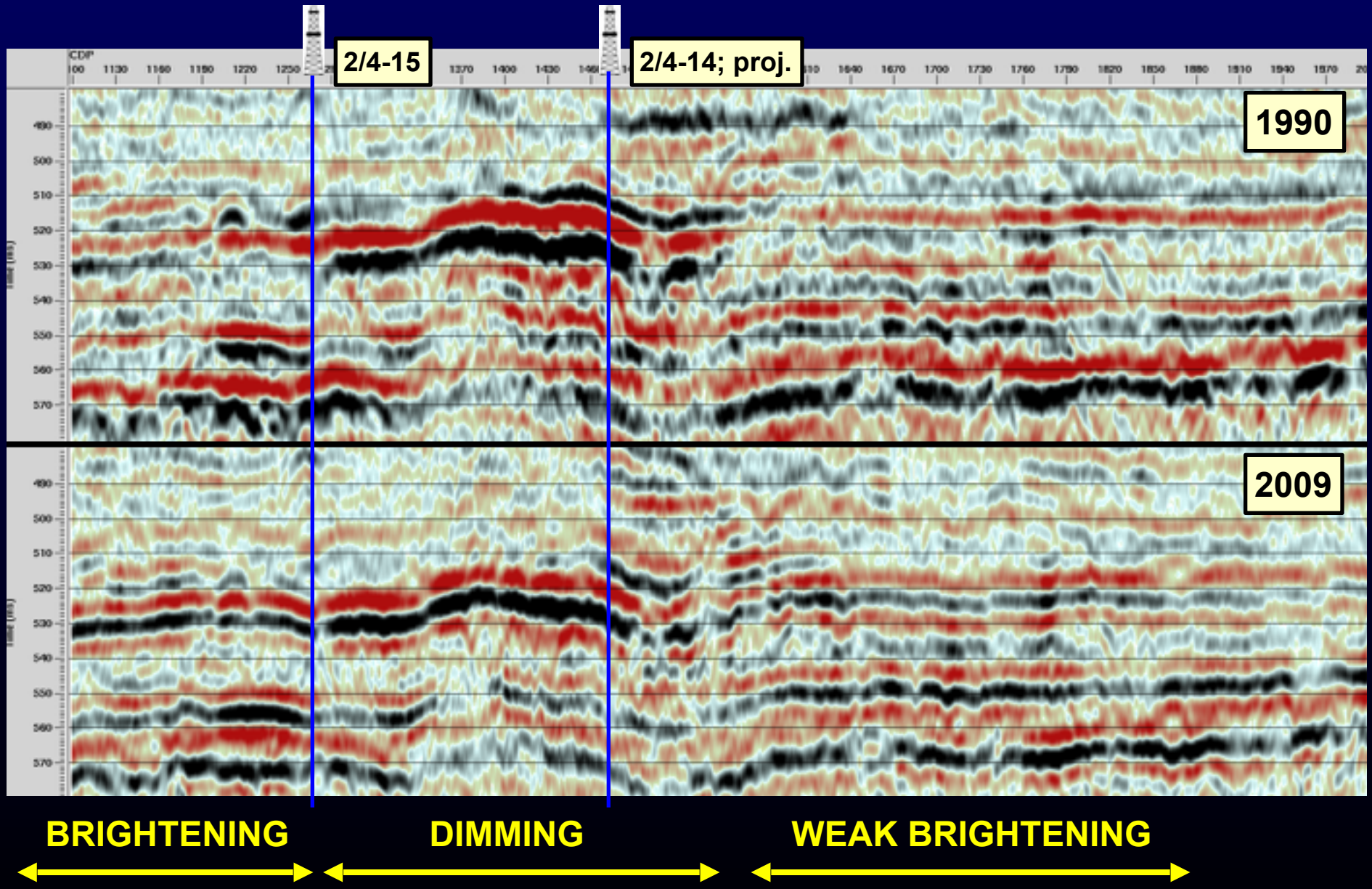
602: Amplitude dimming close to well, slight increase away from well



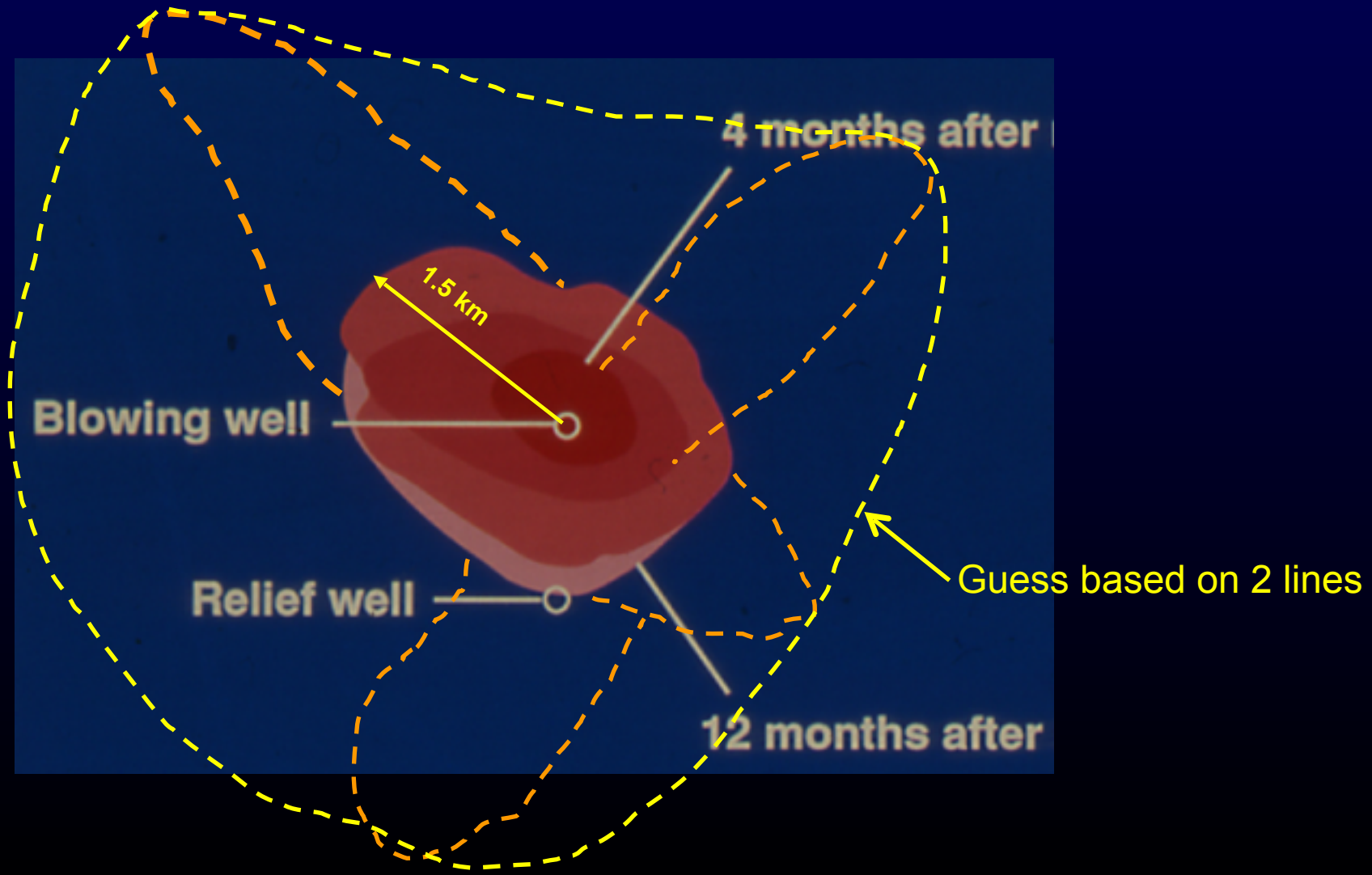
4D difference – line 602, 1990-2009 after global scaling



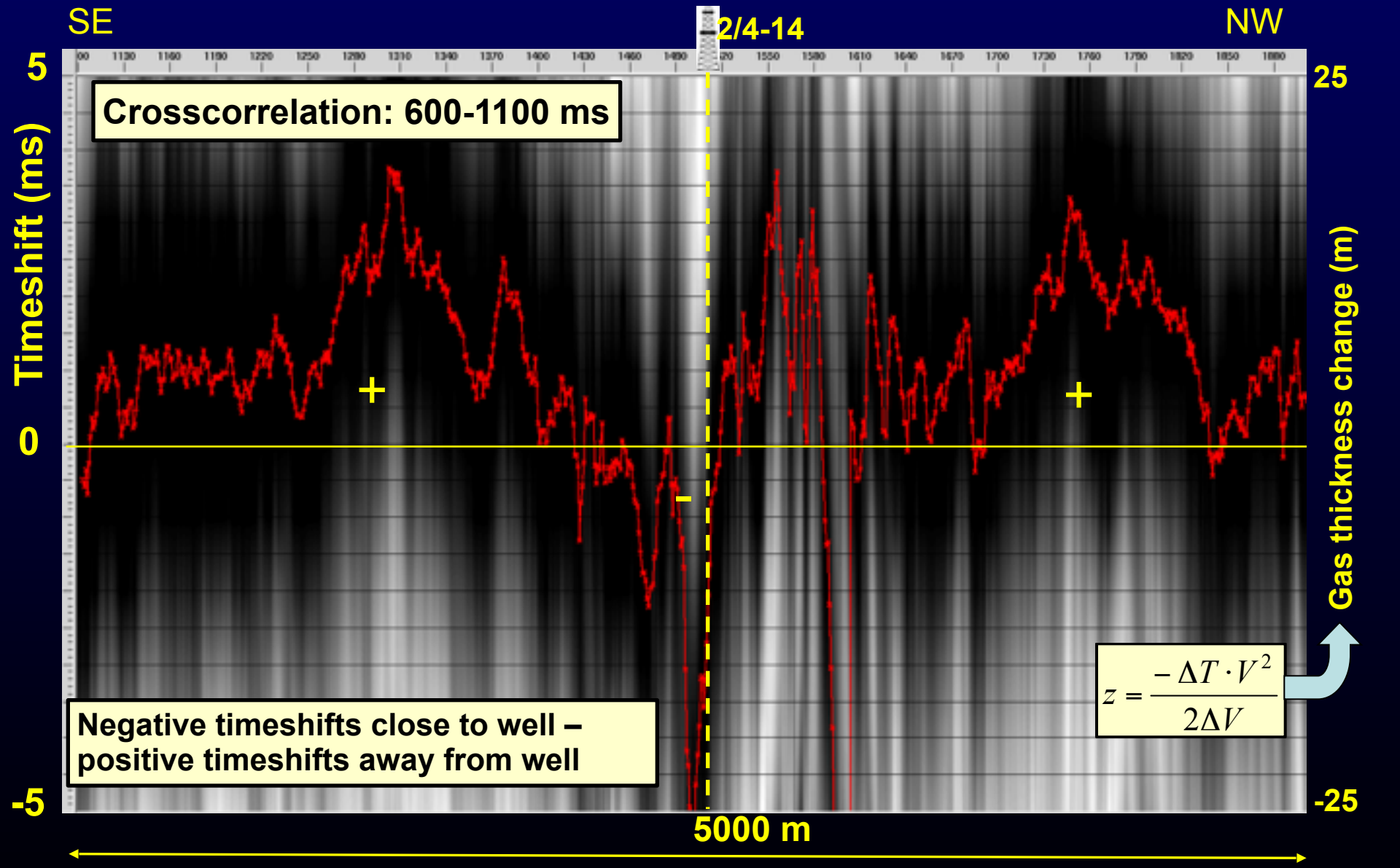
602: Amplitude dimming close to well, slight increase away from well



The 490 sand layer: Interpreted horizontal gas migration between 1990 and 2009 based on lines 804 and 602

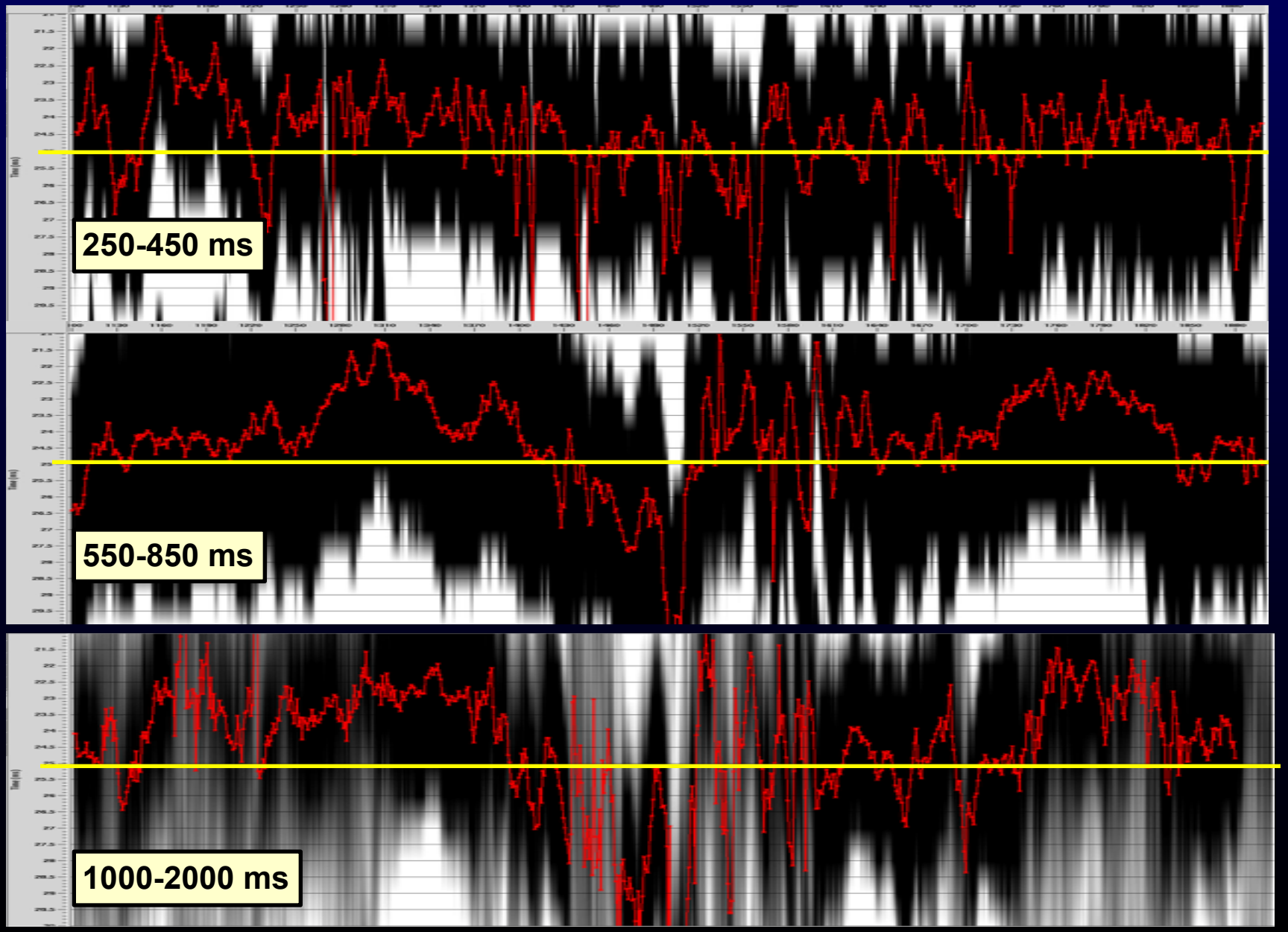


Timeshifts between 2009 and 1990 – line 804

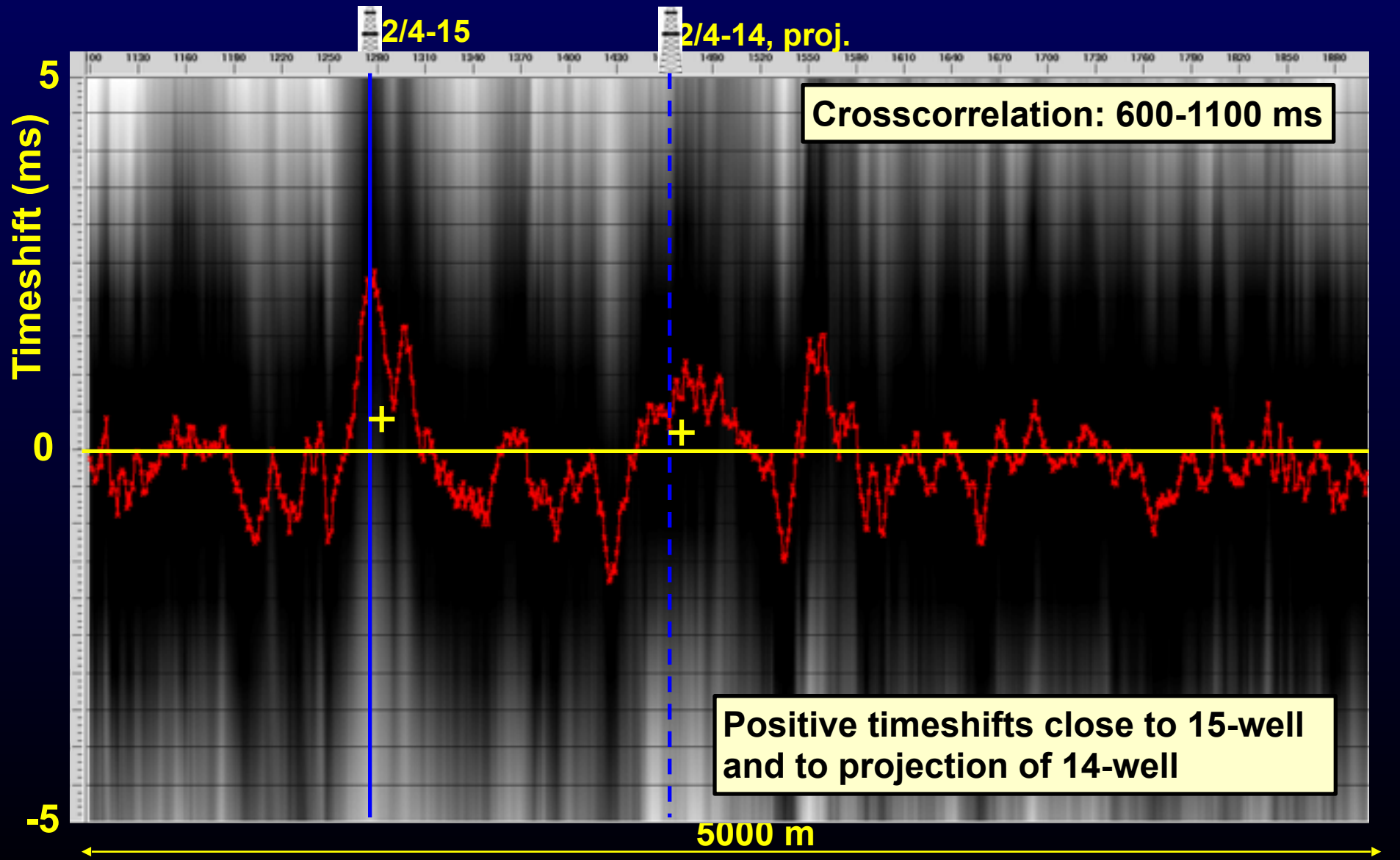


Indicating less gas around well – more gas to both sides

Comparing 3 different crosscorrelation windows – line 804, 1990-2009

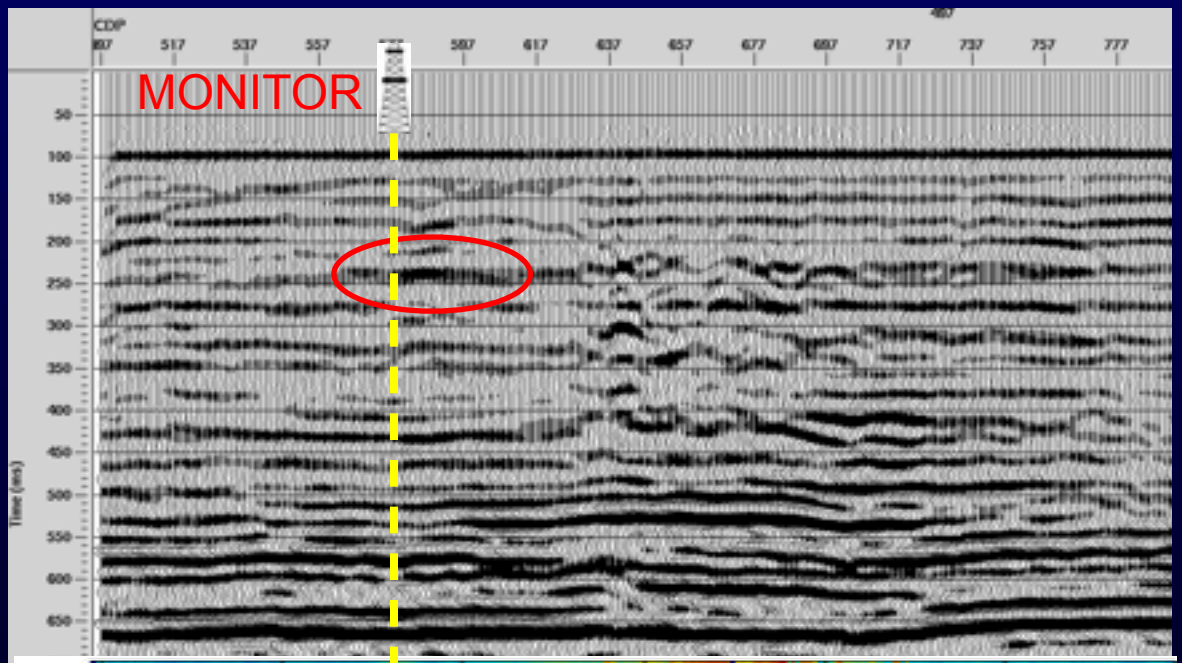


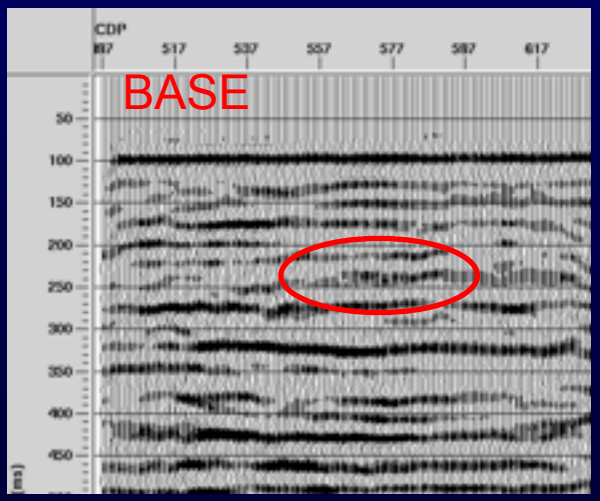
Timeshifts between 2009 and 1990 – line 602



Indicating more gas around well 15 and to the projection of 14

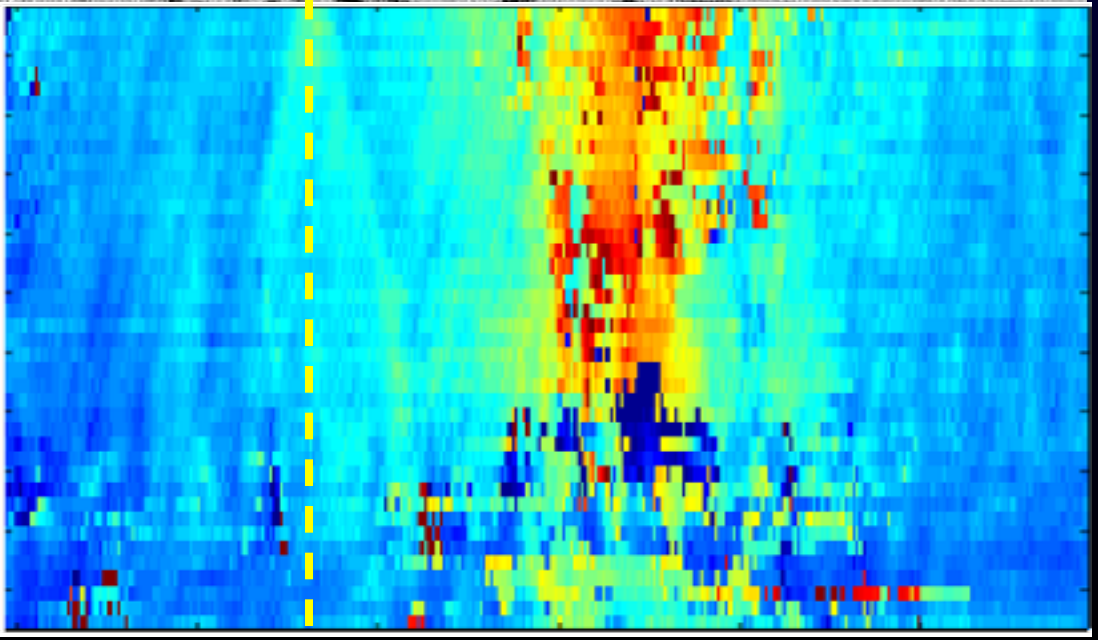
4D time shifts versus CMP and offset





Reflector used for time shift analysis

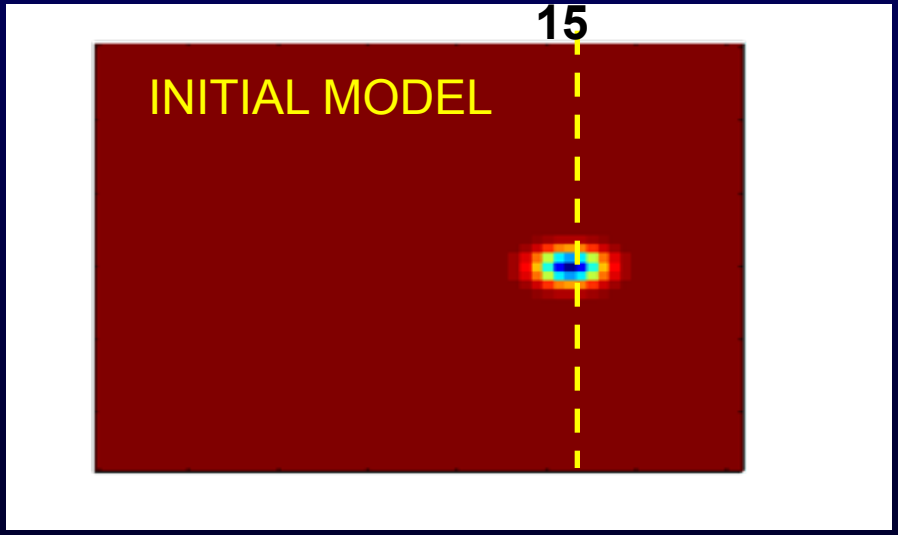
OFFSET

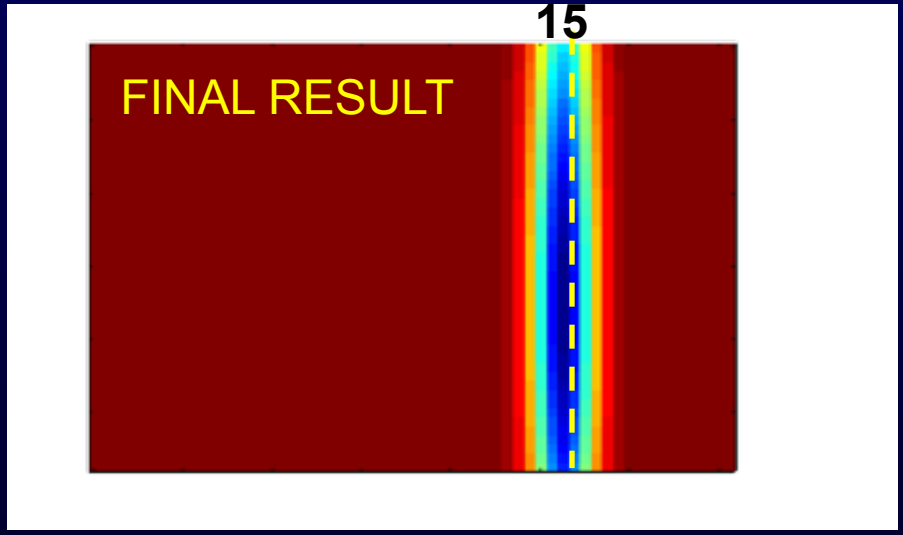


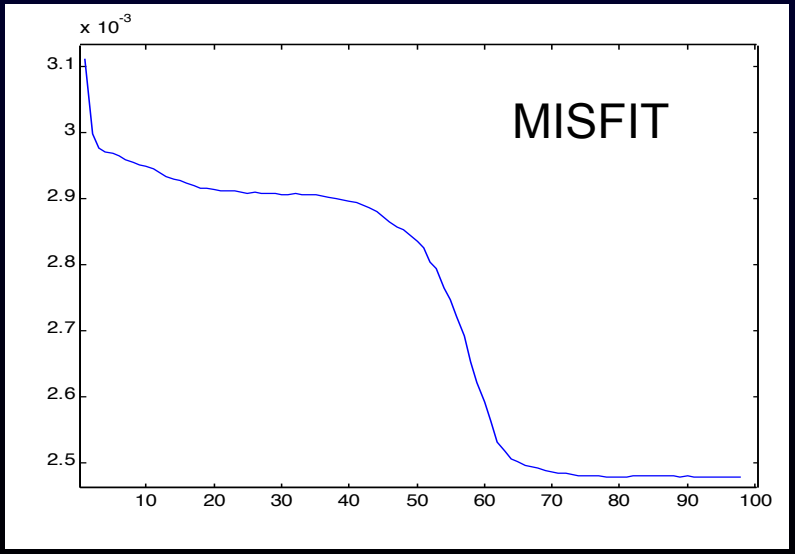
Colorcoded time shifts as function of offset and CMP

4D tomographic inversion

PhD work of Andreas Evensen







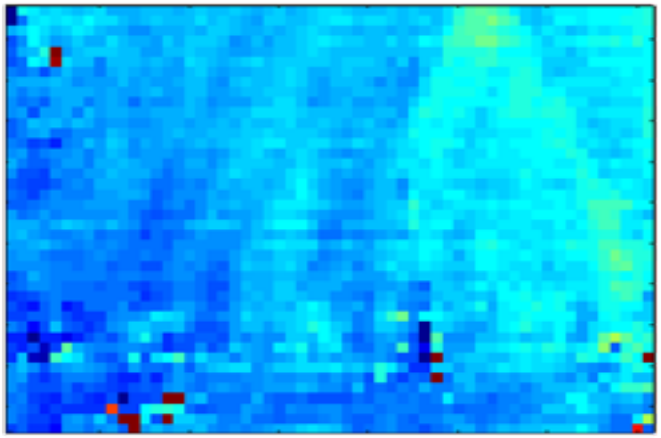
Velocity changes in km/s => ~ 25 m/s

Time-lapse tomographic inversion using a Gaussian parameterization of the velocity changes

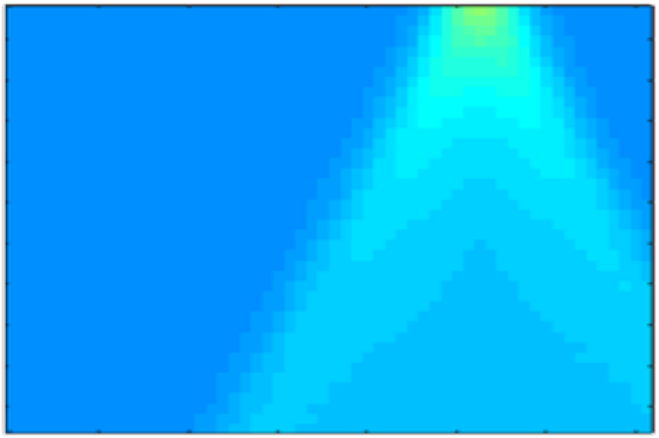
Geophysics, 2010, **75**, U29-U38

Andreas Kjelsrud Evensen[1] and Martin Landrø[1]

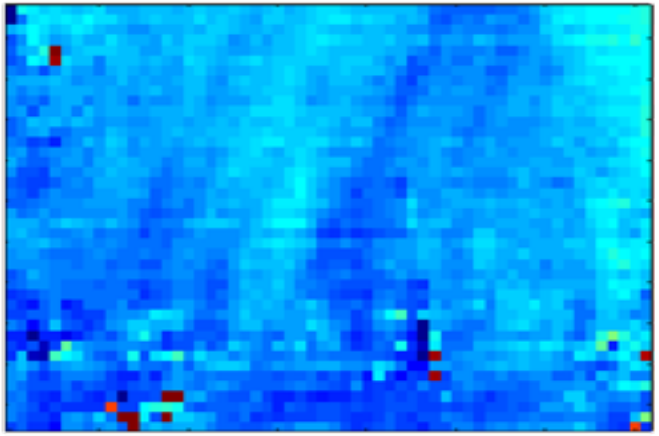
Real time-shifts



Time-shifts of inversion result



Residual time-shifts



Views for discussion

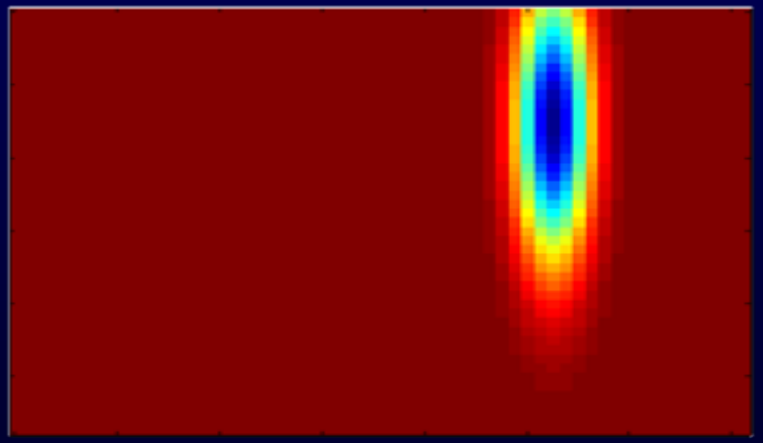
- Repeated site survey data has good resolution and can be used to detect gas leakage in thin layers (less than 10 m) – restricted to shallow (less than ~1-2 km)
- Site surveys are MUCH cheaper than 3D and should therefore be a part of the monitor plan for problem wells
- Vertical migration close to well paths: Less gas close the blowing well in 2009 and more gas close to the relief well – lateral movement of gas
- Preliminary comparison between 4D seismic and fluid flow simulations show good agreement
- Unique dataset that is useful as a proxy for evaluating potential leakage scenarios from CO2-storage

Acknowledgments

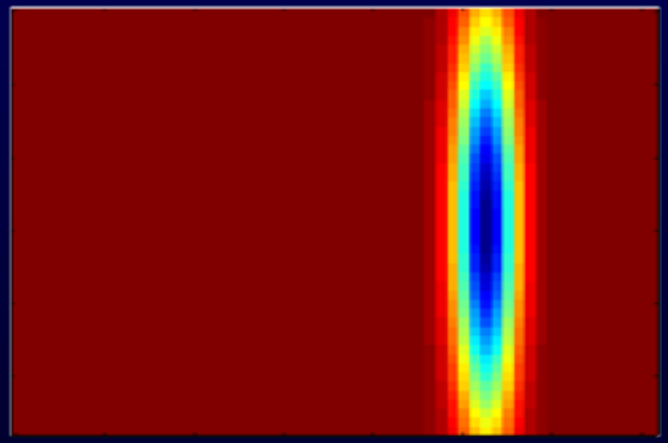
- Statoil and Total for permission to use the data
- Dag O. Larsen for providing material from his 1991 SEG presentation
- Hans Rønnevik and Kristian Kolbjørnsen for discussions
- Jon A. Haugen for data processing
- The LOSEM-consortium partners: BayernGas, BP, Det Norske, Lundin Norway, NPD, Statoil and Total
- The Norwegian Research Council for financial support to the ROSE project at NTNU

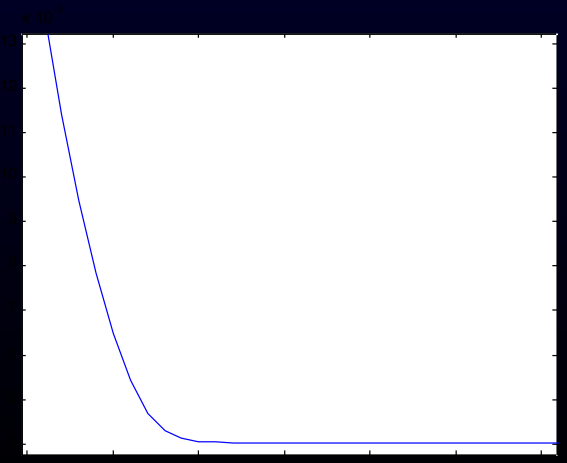
Real data inversion results for time-shifts picked on horizon at 900ms.

Initial estimate

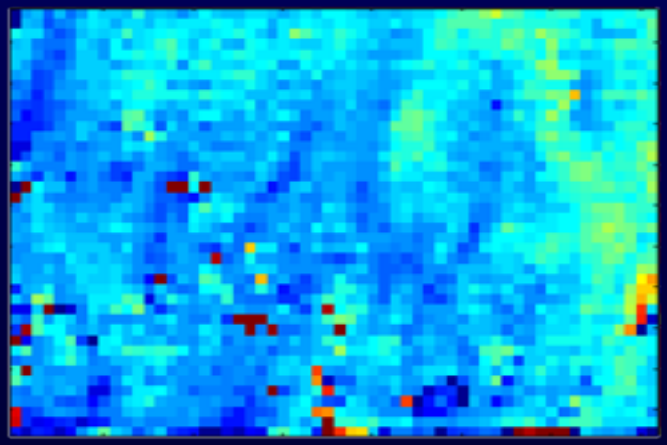


Inversion result

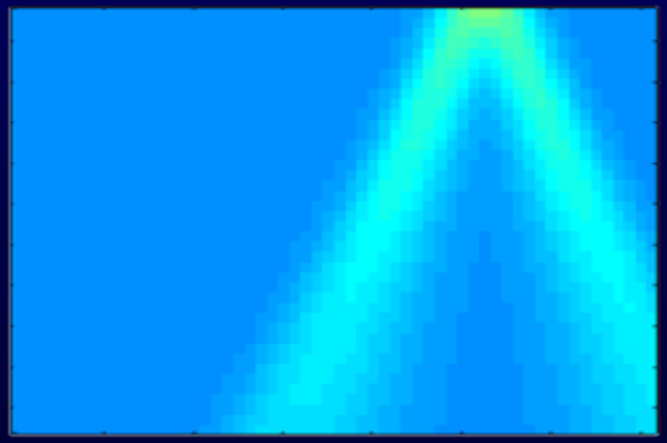




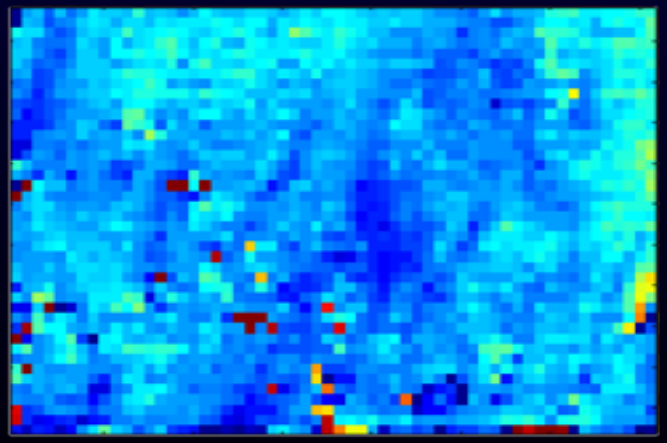
Real time-shifts



Time-shifts of inversion result



Residual time-shifts



Proxy for CO_2?

- Seismic velocities are similar
- Relative permeability curves are similar
- There are differences, however, this dataset can be used to study long term migration of gas through shallow sediments, and this is obviously of interest to study leakage scenarios from a CO2 storage site