ROSE Meeting

Time Lapse Refraction and Plans for Full Waveform Inversion

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May 2, 2011

NTNU
Norwegian University of Science and Technology

Objectives

- Perform detailed Finite-Difference modeling to investigate the 4D refraction effects caused by shallow gas accumulations.

- Implement full waveform Inversion on field-data to map the expected gas anomalies due to the underground blow-out (well-14).

Outline

1. Background (4D Refraction):

   Hossein Mehdi Zadeh, PhD Thesis, NTNU

2. Future Plan
   - **Modeling:** Petrophysical modeling & Finite difference (FD) seismic modeling.
   - Processing of Seismic Data
   - Full waveform inversion

1. BACKGROUND:
4D REFRACTION ANALYSIS

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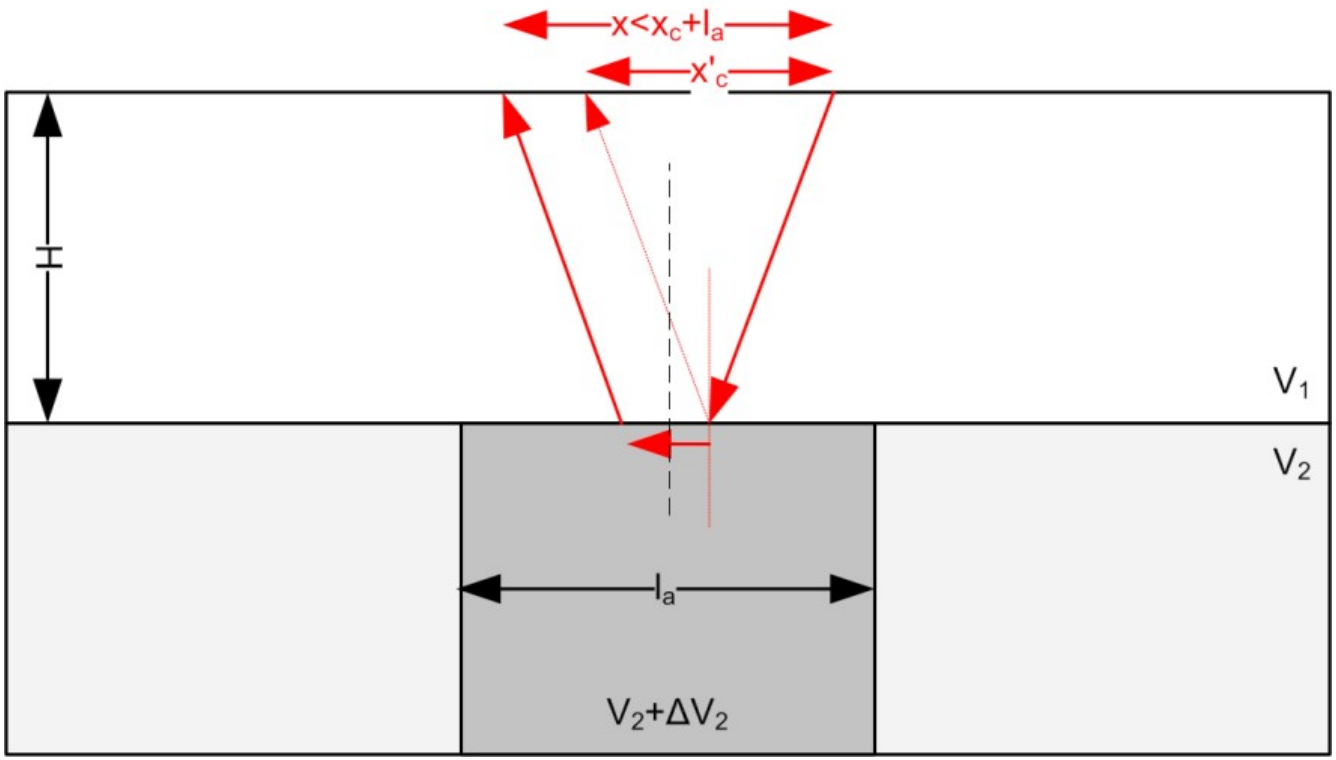
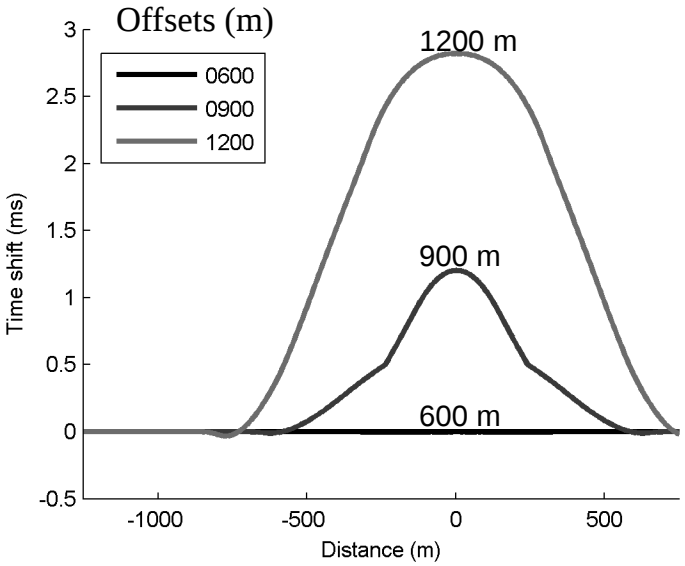
Basic Principal of Head-wave Timeshifts (HWΔT)

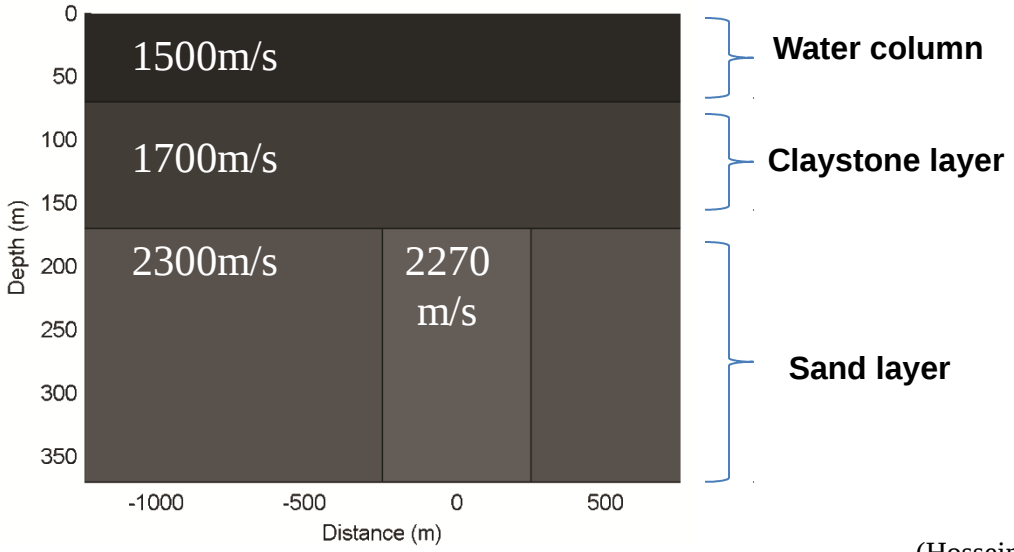
$$\Delta t \approx -\left(x - \frac{2HV_1}{\sqrt{V_2^{\,2} - V_1^{\,2}}} \right) \frac{\Delta V_2}{V_2^{\,2}} \qquad x_c < x < x_c + l_a$$



(Hossein Mehdi Zadeh, PhD Thesis)

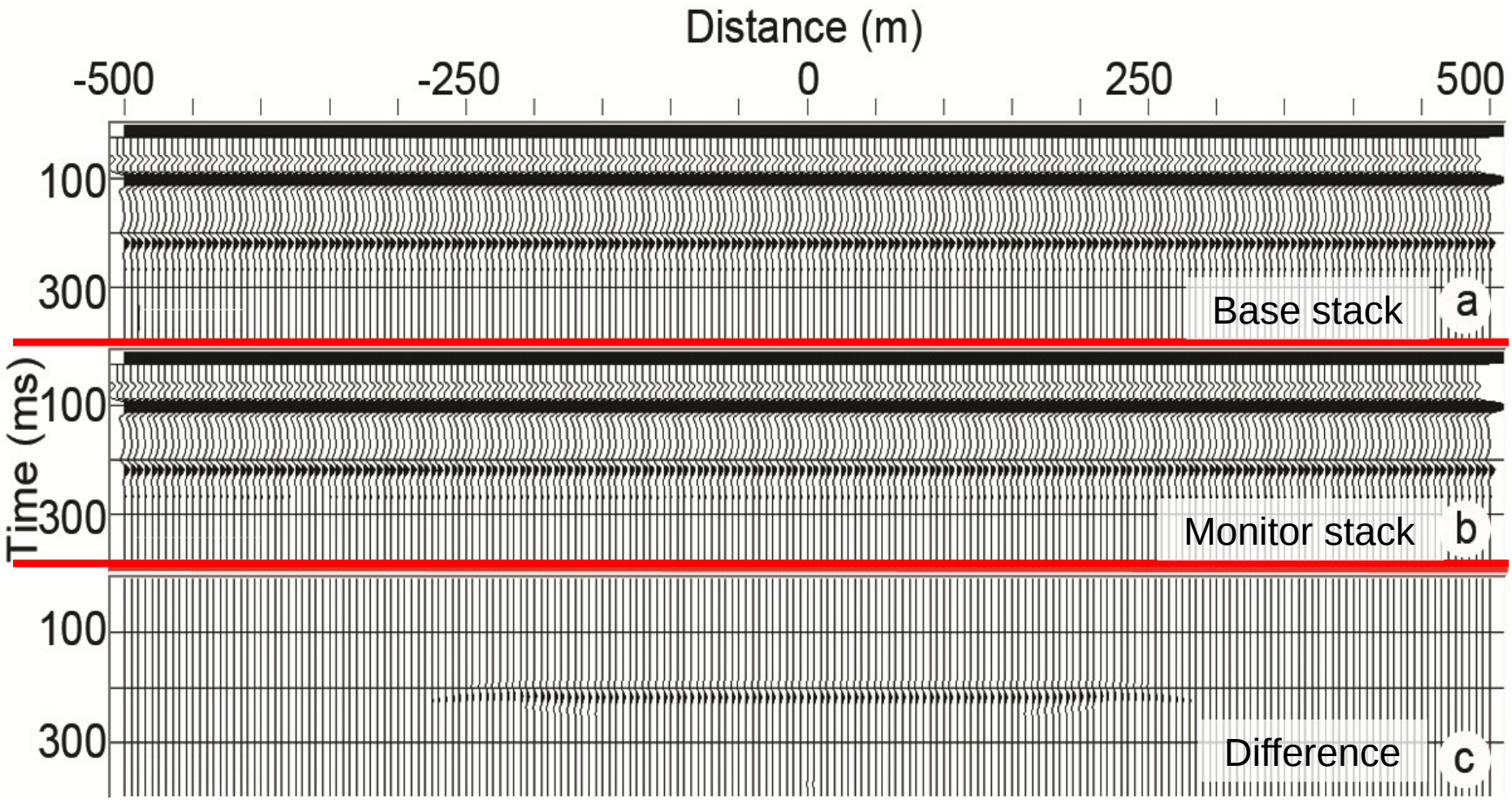
Analysis of synthetic Refraction ΔT





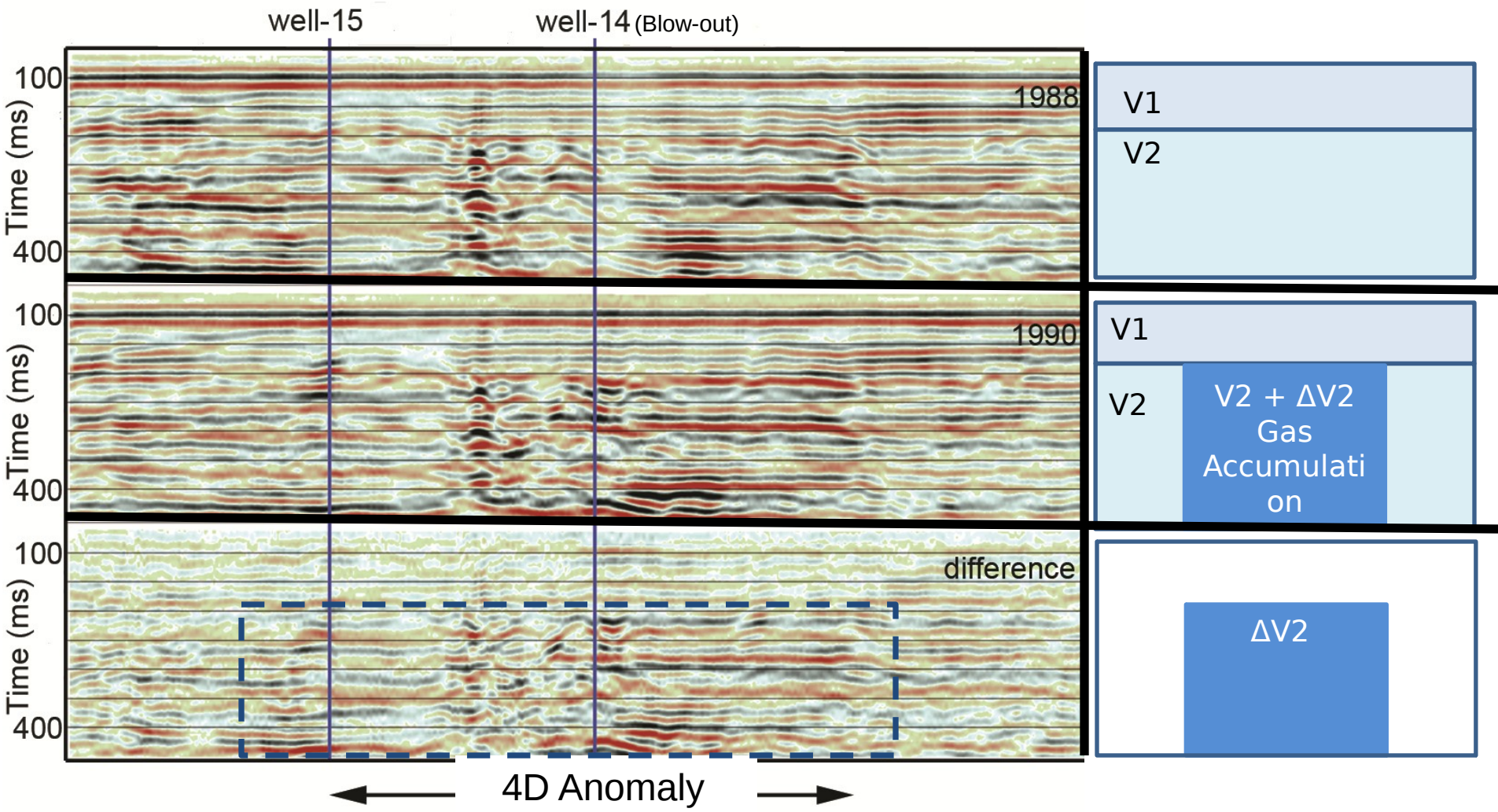
(Hossein Mehdi Zadeh, PhD Thesis)

4D Reflection



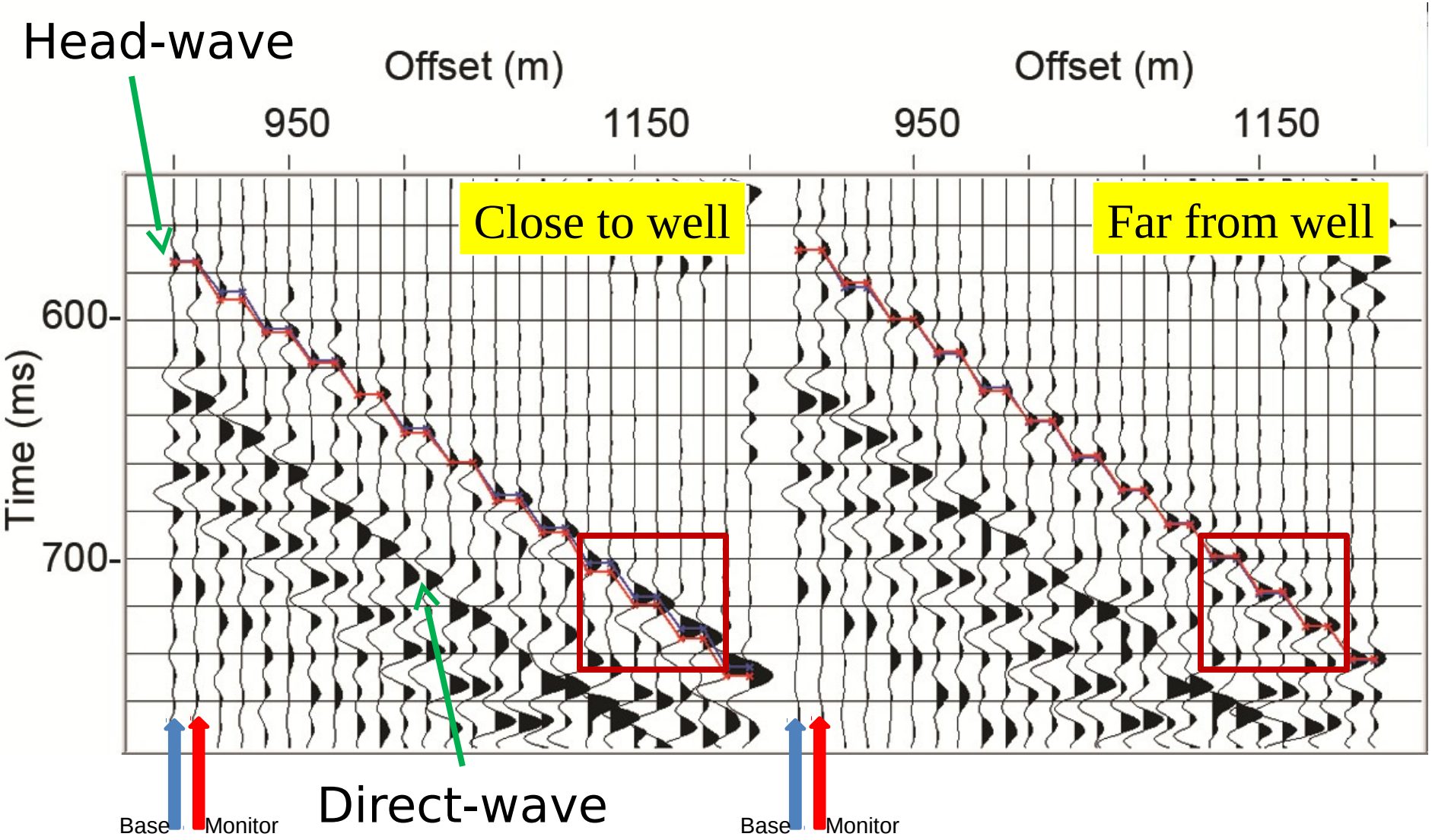
a) Base stack b) Monitor stack c) Difference stack (x10)

4D Reflection Seismic



(Hossein Mehdi Zadeh, PhD Thesis)

Field data observation



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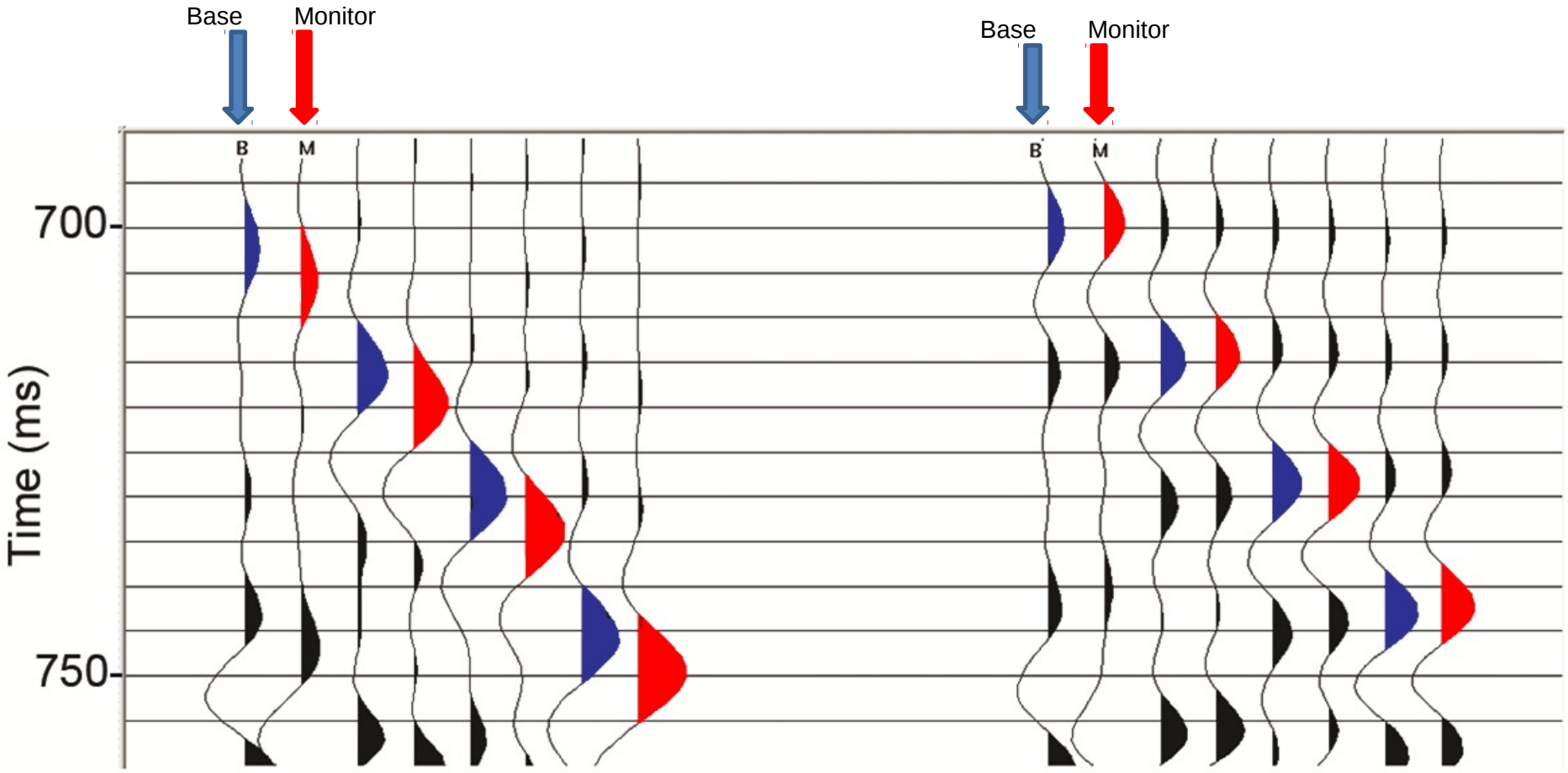
Field data observation

Close to well

Far from well



Time shift

No time shift

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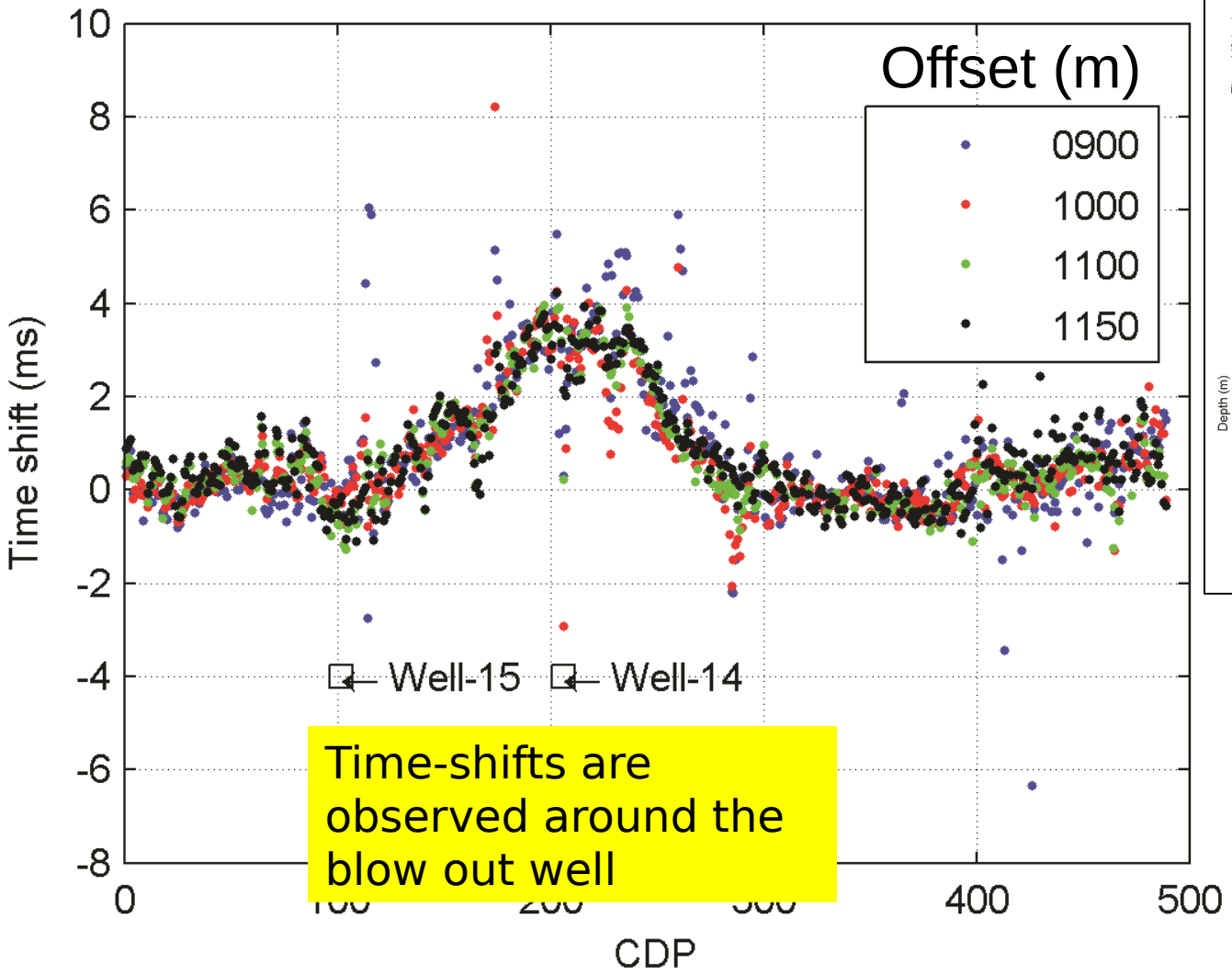
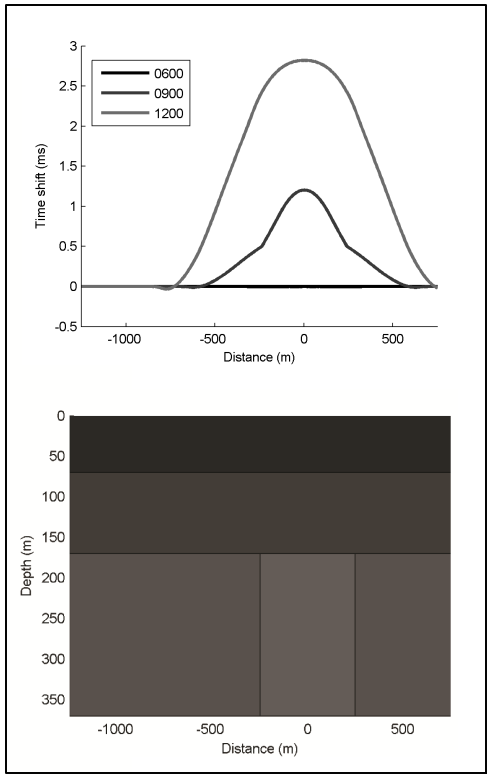
HWΔT relative to well location





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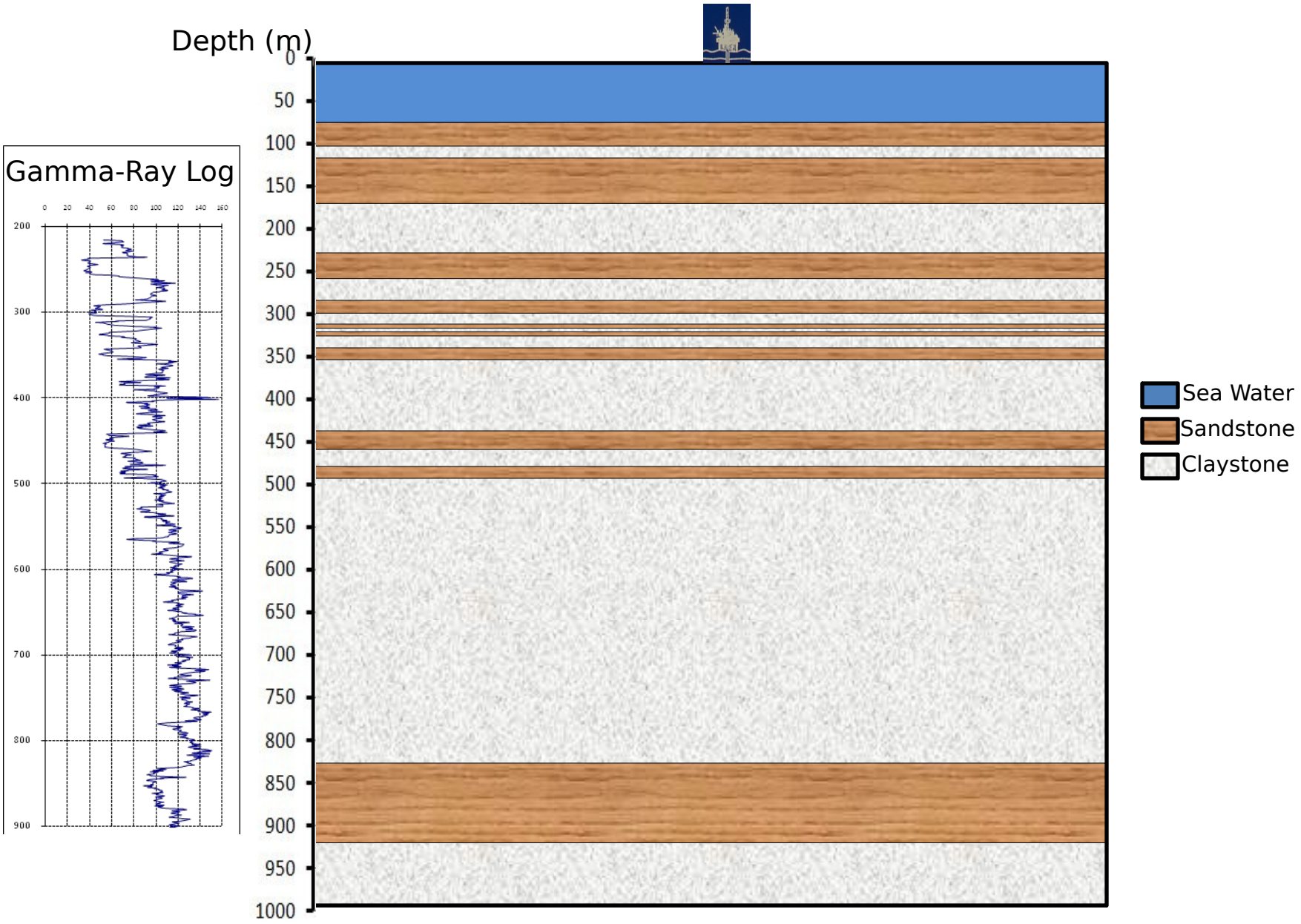
2. TOWARDS FULL WAVEFORM INVERSION

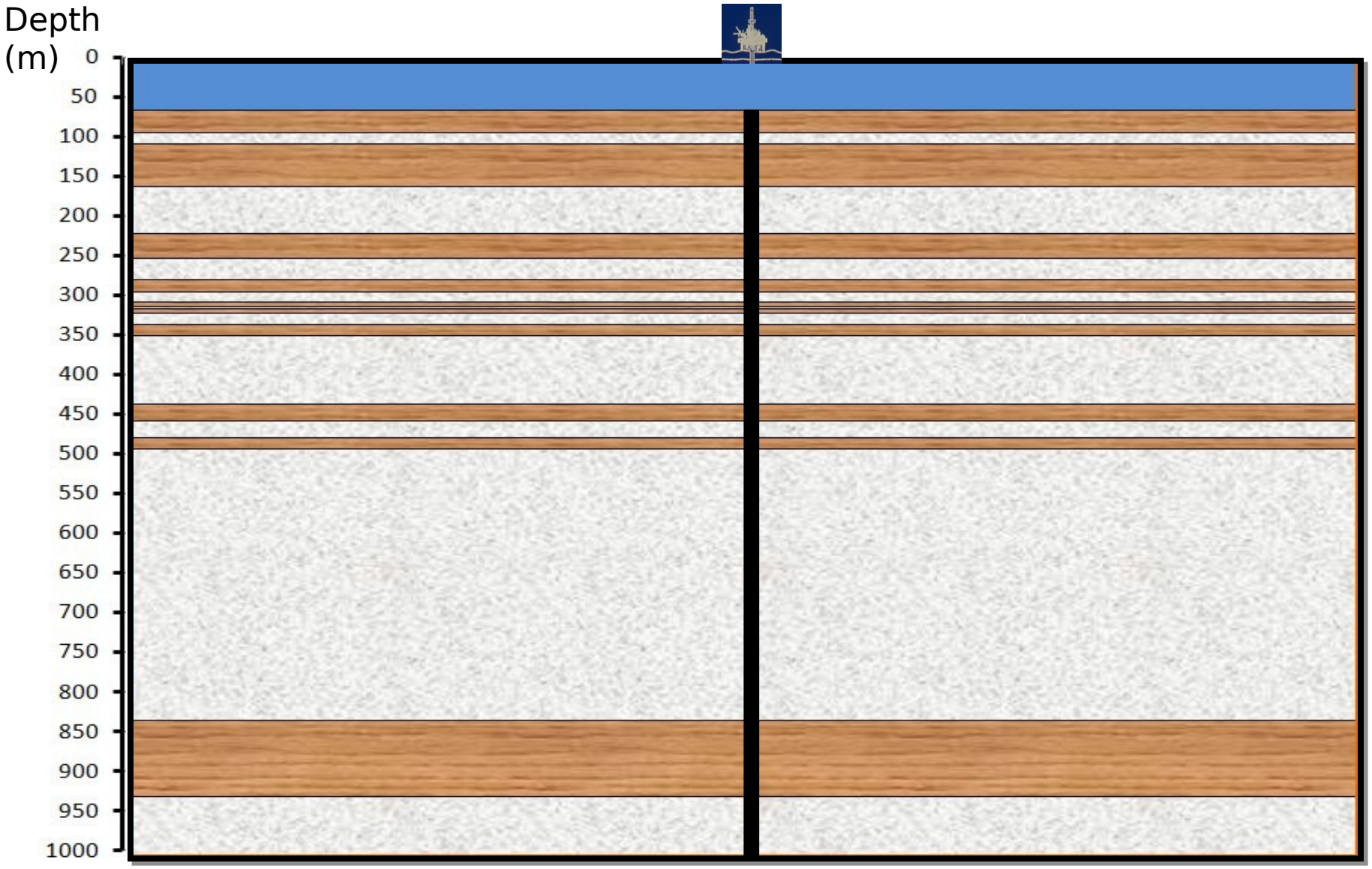
- Modeling (Petrophysical & FD seismic)
- Seismic processing
- Full waveform inversion

Petrophysical Model



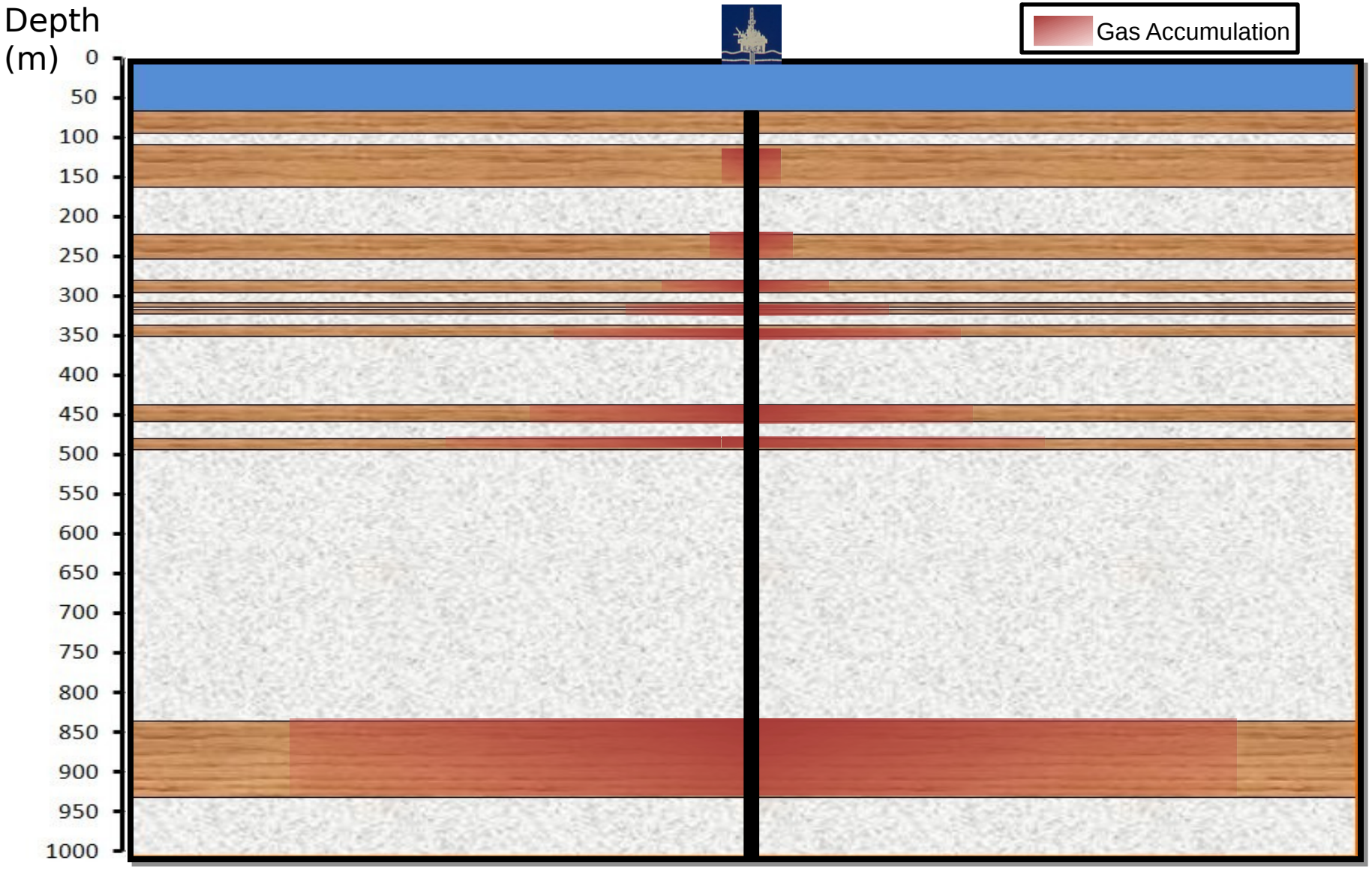
First Scenario:

Prior to Gas Leakage (100% Brine Saturation)

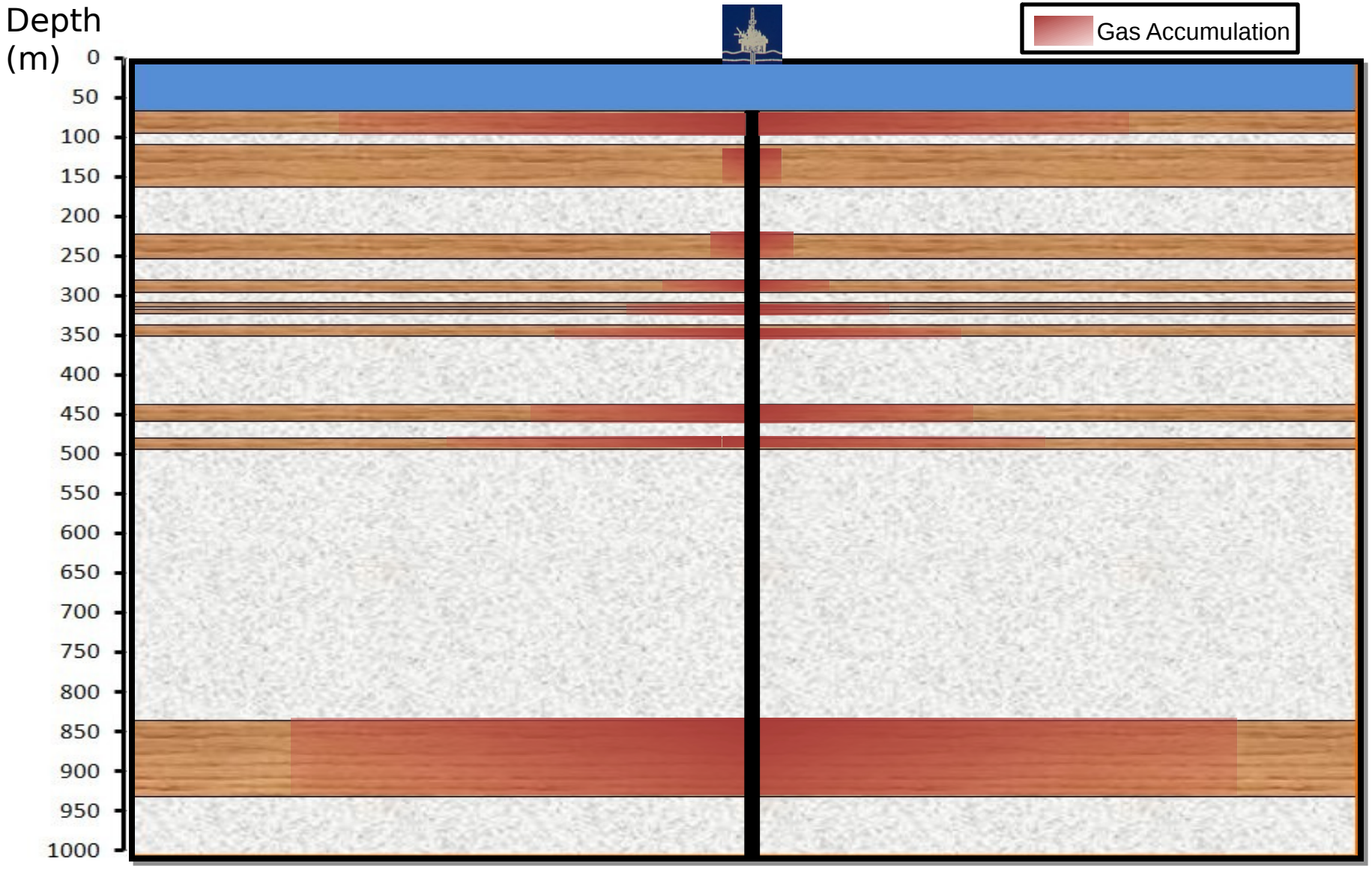


Second Scenario:

Gas Charging into All sand Layers (Decreased Lateral extend upward)



Third Scenario



Fourth Scenario (Glacial Channels)

2. 2D Finite Difference (FD) Seismic Modeling

- 4D Refraction feasibility study (Amplitude & Timeshifts)

3. Seismic Processing

1. Refraction-events' oriented processing.
2. Standard reflection processing.

4. Refraction Full-Waveform Inversion

Objective: Localized gas-accumulations model

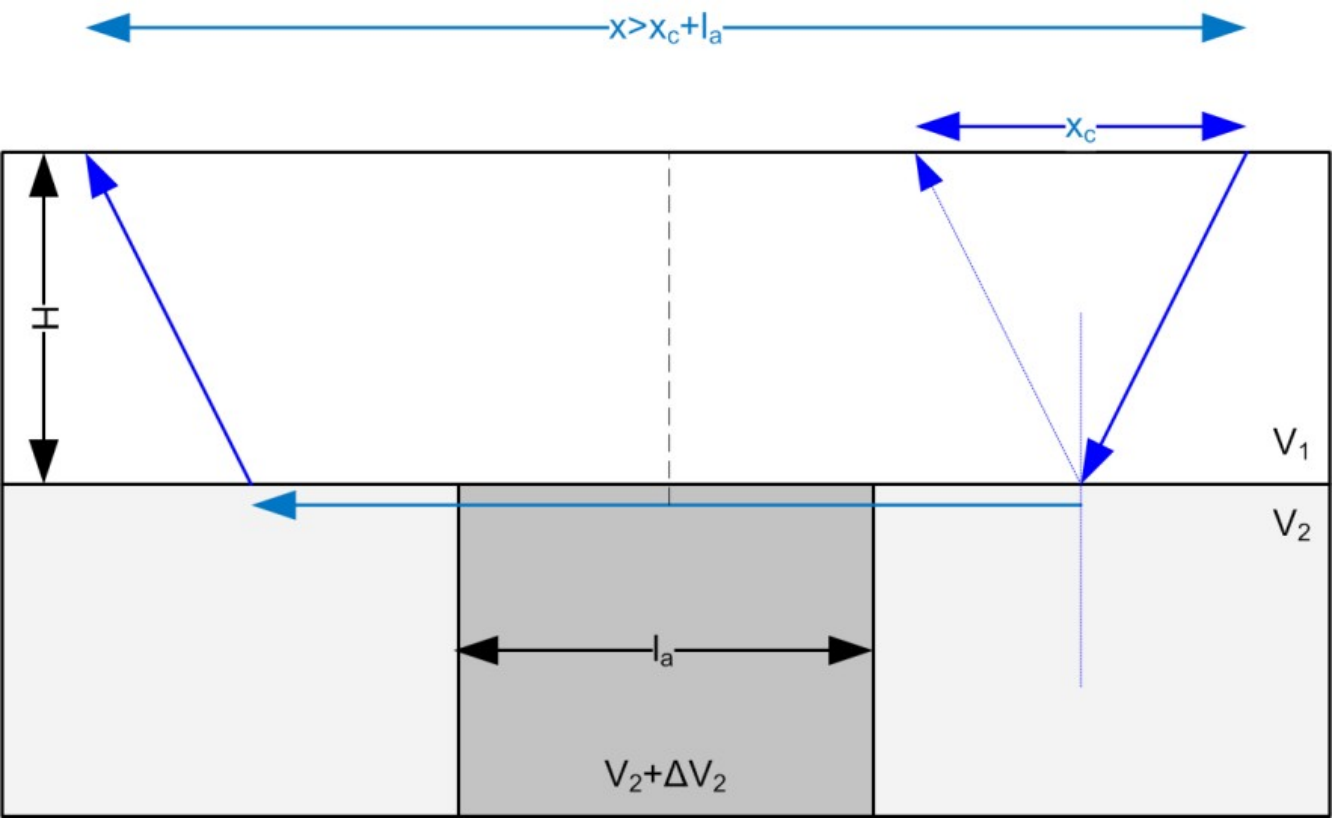
- Depths
- Shape (Lateral & Vertical extent of gas anomaly)

Acknowledgments

- Statoil and Total for permission to use seismic data
- BayernGas, BP, Det Norske, Lundin, Statoil and Total for financial support to the LOSEM-project at NTNU
- CGGVeritas for invitation to perform FWI
- Saudi Aramco for financial support to my PhD studies
- Hossein Mahdi Zadeh, Statoil

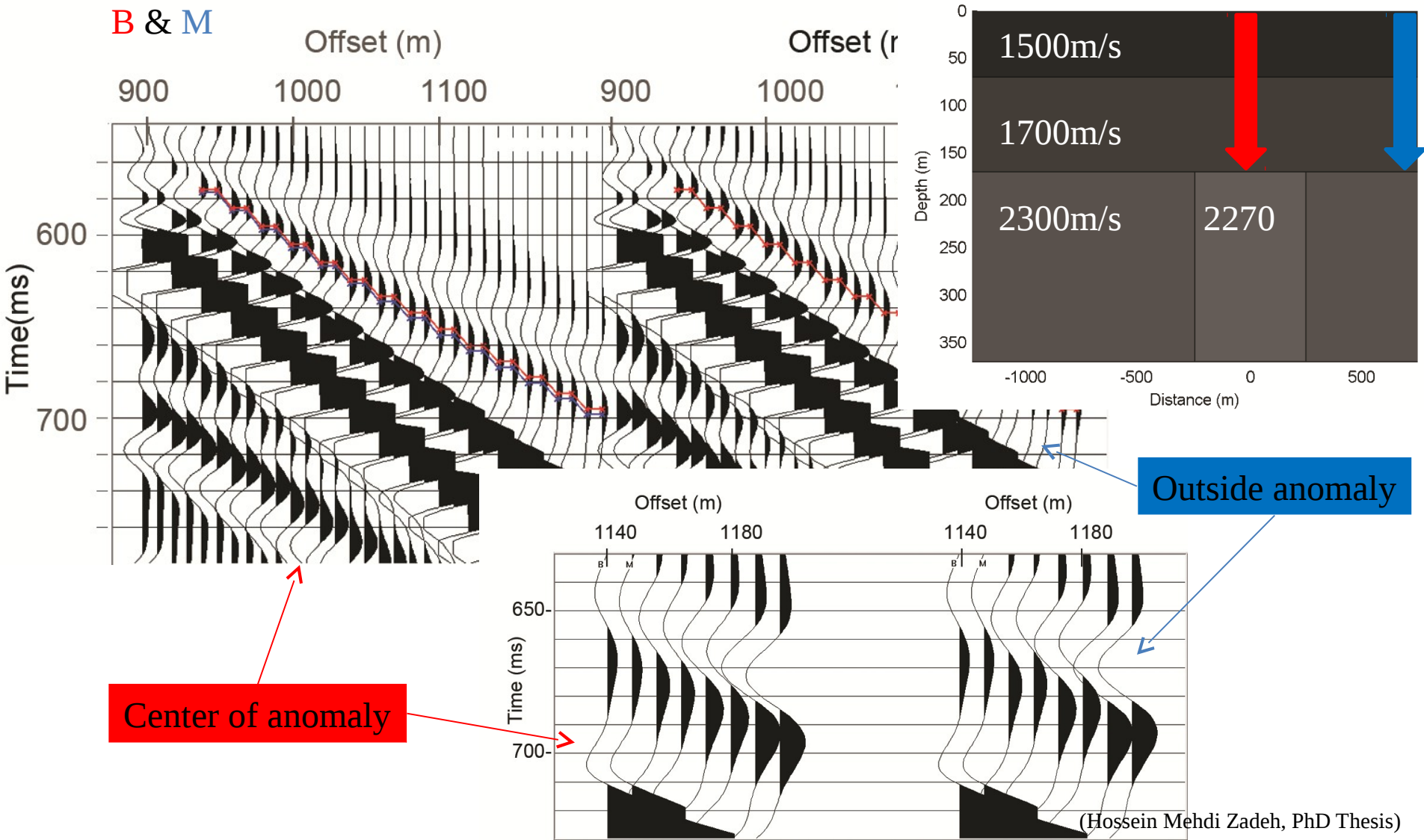
Basic principal of head-wave timeshift (HWΔT)

$$\Delta t \approx -l_a \frac{\Delta V_2}{V_2^2} \qquad x \geq x_c + l_a$$

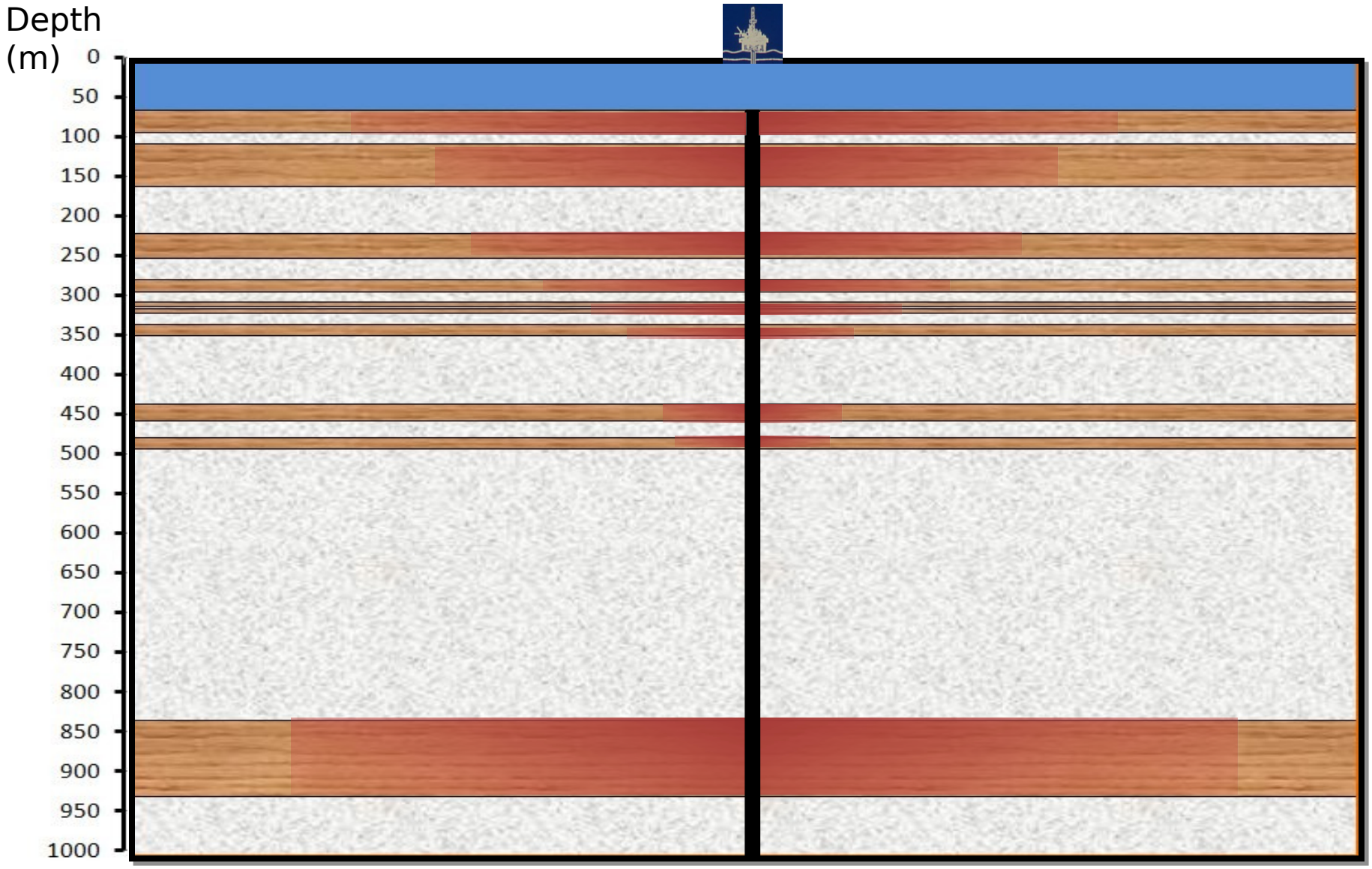


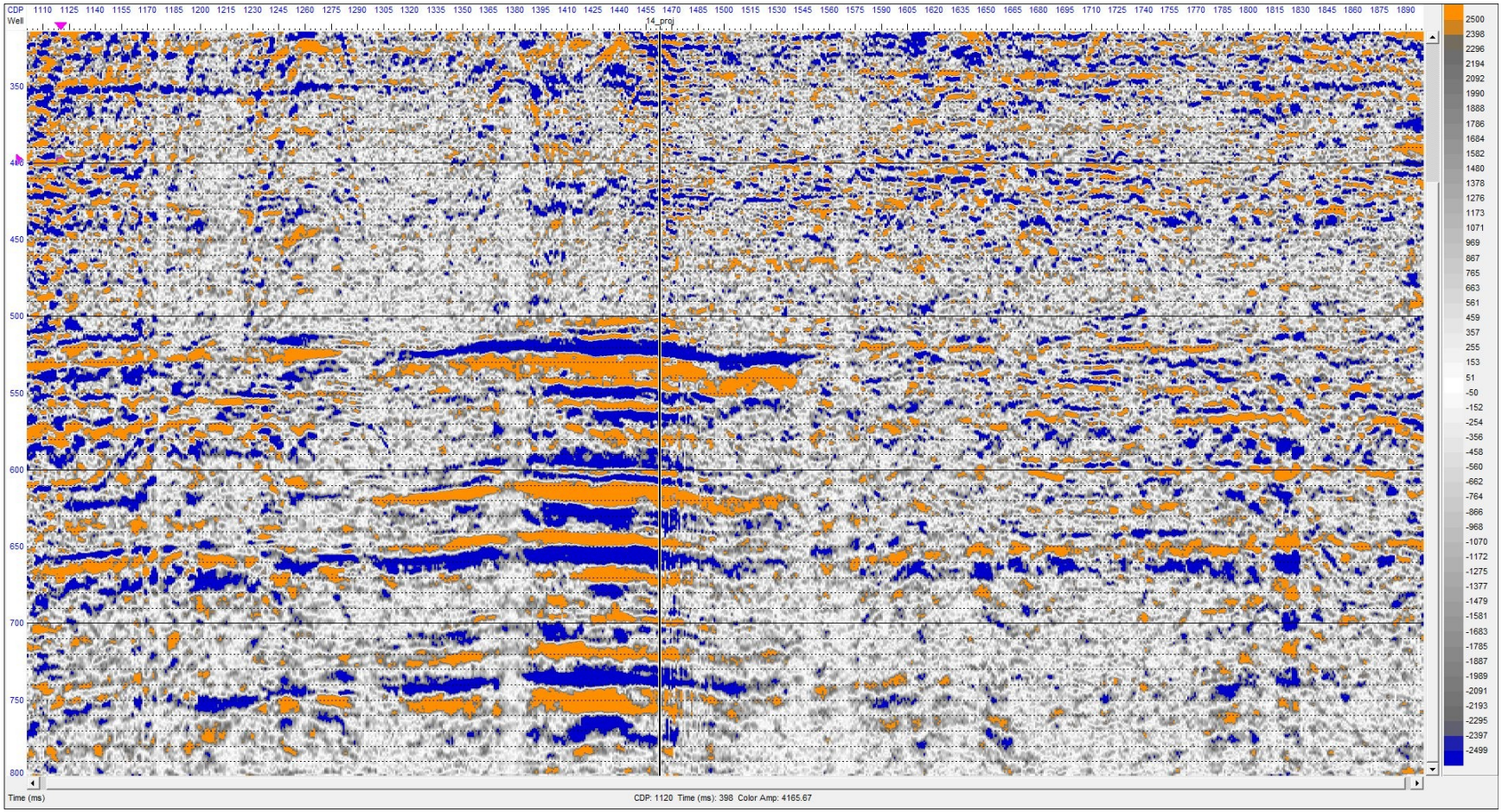
$$\Delta t_{Max} \approx -l_a \frac{\Delta V_2}{V_2^2}$$

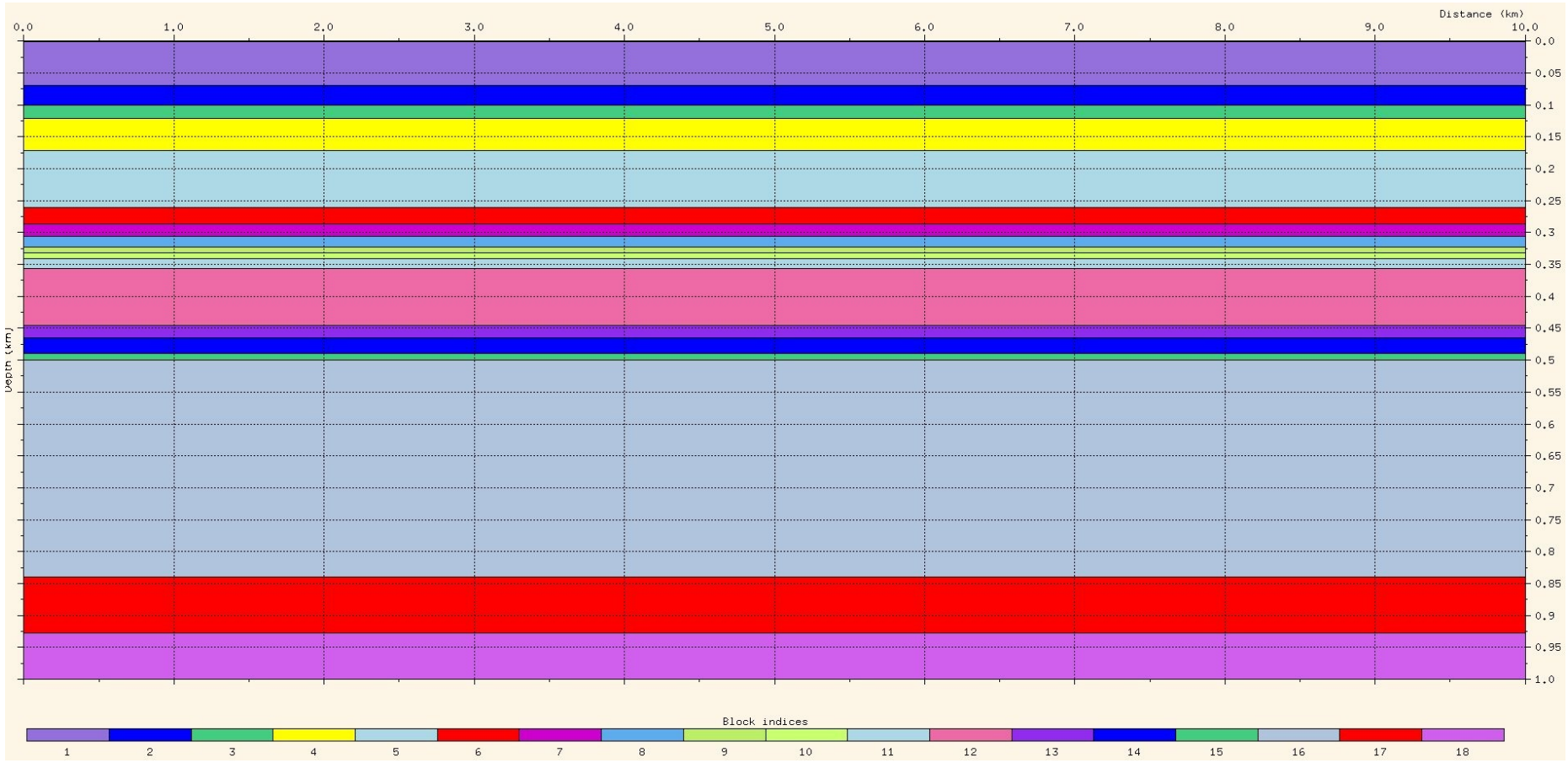
Synthetic modeling of HWΔT

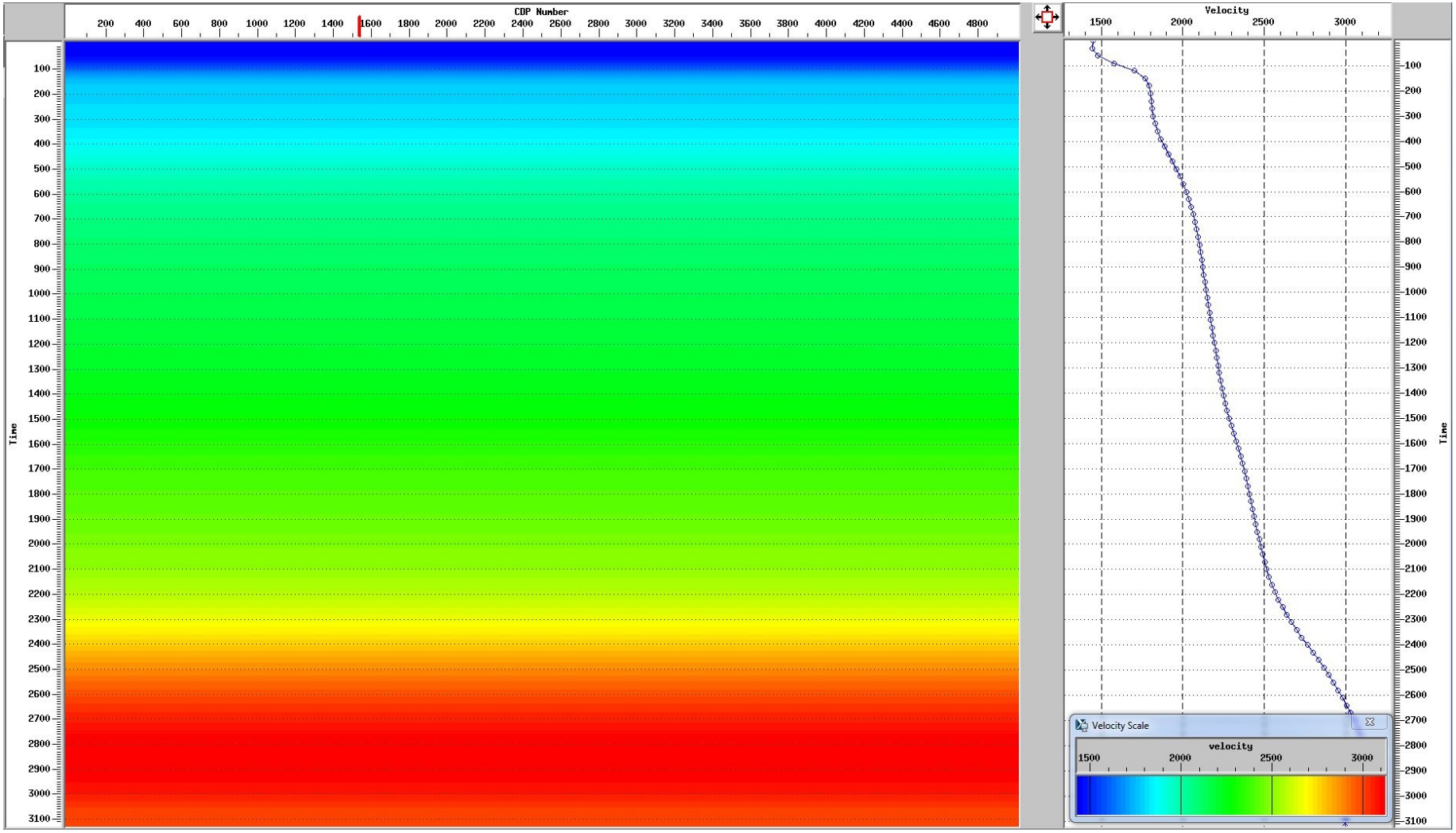


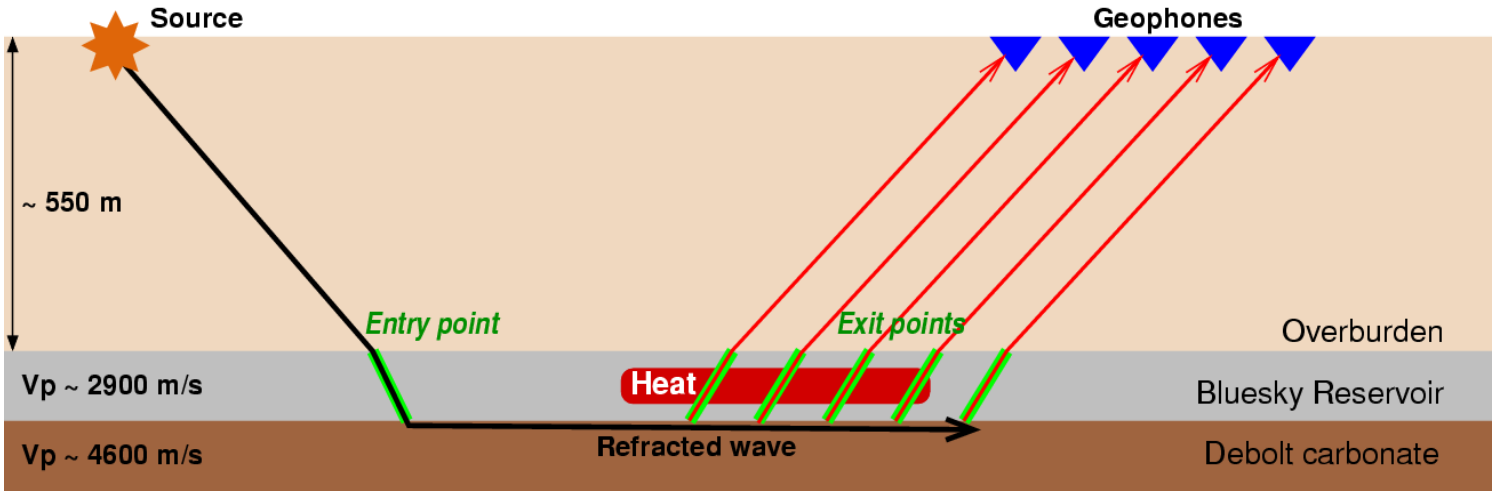
(Hossein Mehdi Zadeh, PhD Thesis)


Depth
(m)
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
850
900
950
1000


CDP
Well
f4_proj
Time (ms)
CDP: 1120 Time (ms): 398 Color Amp: 4165.67

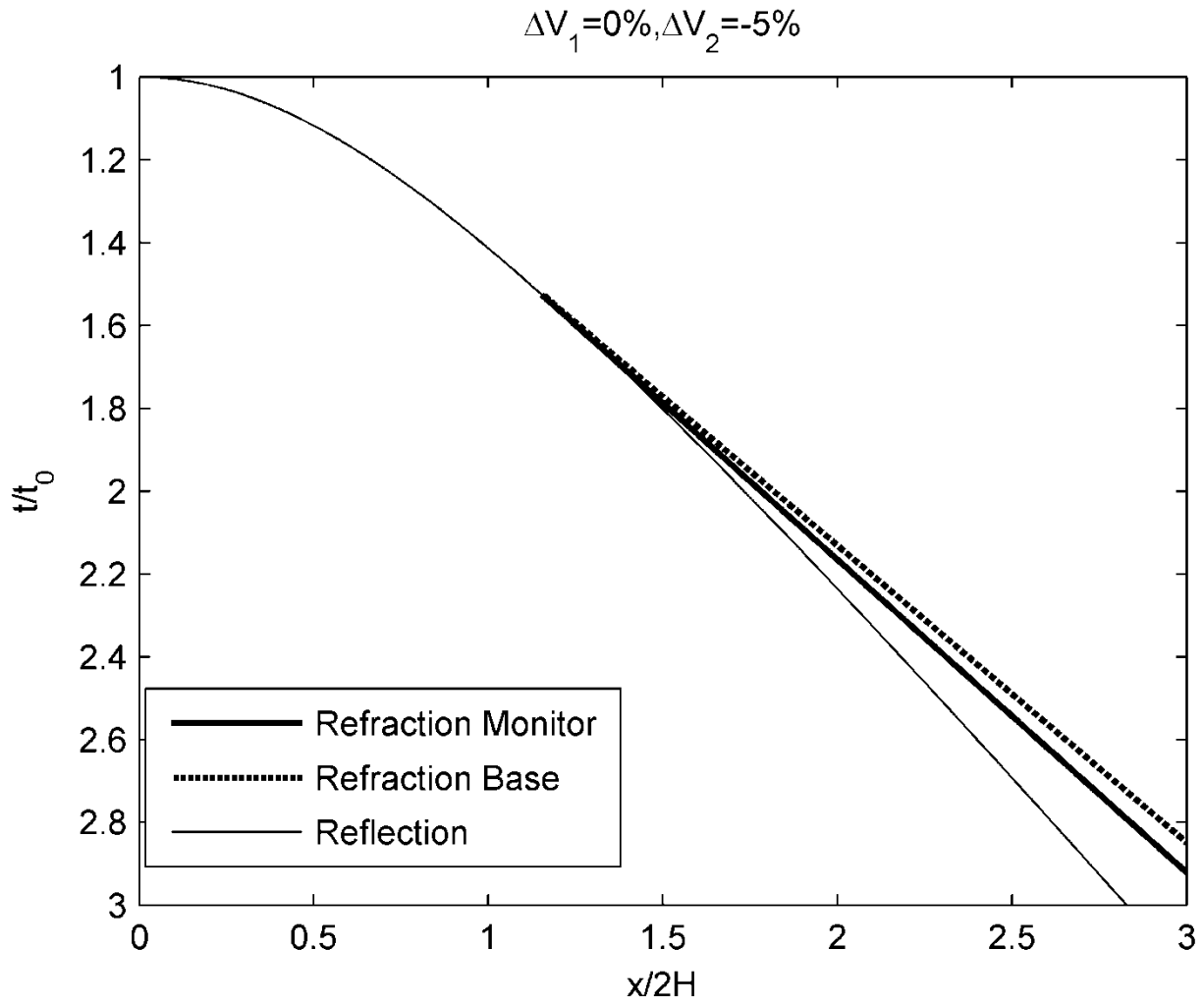

Distance (km)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Depth (km)
0.0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1.0
Block indices
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18


CDP Number
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800 4000 4200 4400 4600 4800
Time
100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100
Velocity
1500 2000 2500 3000
Velocity Scale
velocity
1500 2000 2500 3000

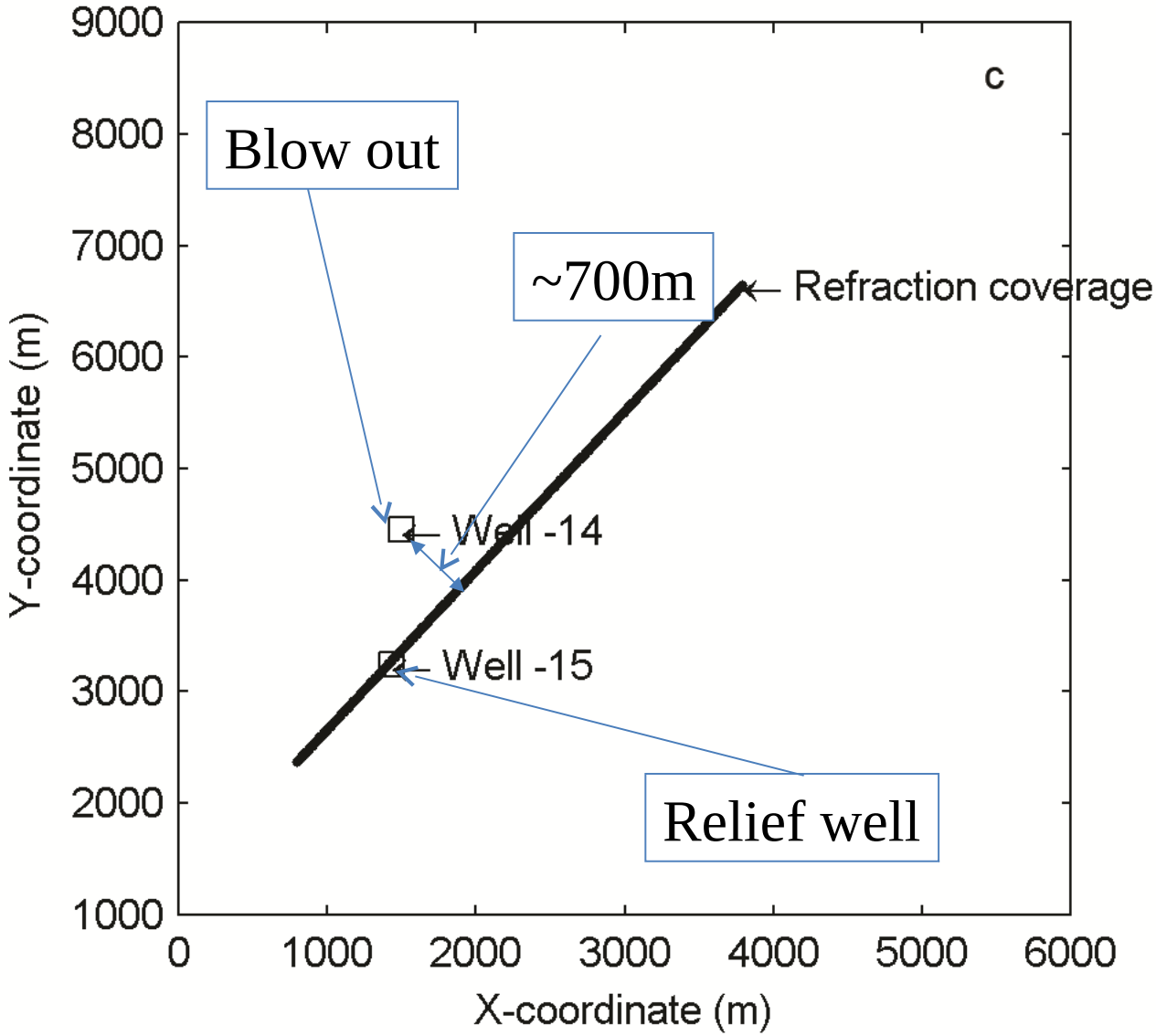


(*Fredrik Hansteen et al., 2010):* **Time-lapse Refraction Seismic Monitoring :** SEG Denver 2010 Annual Meeting

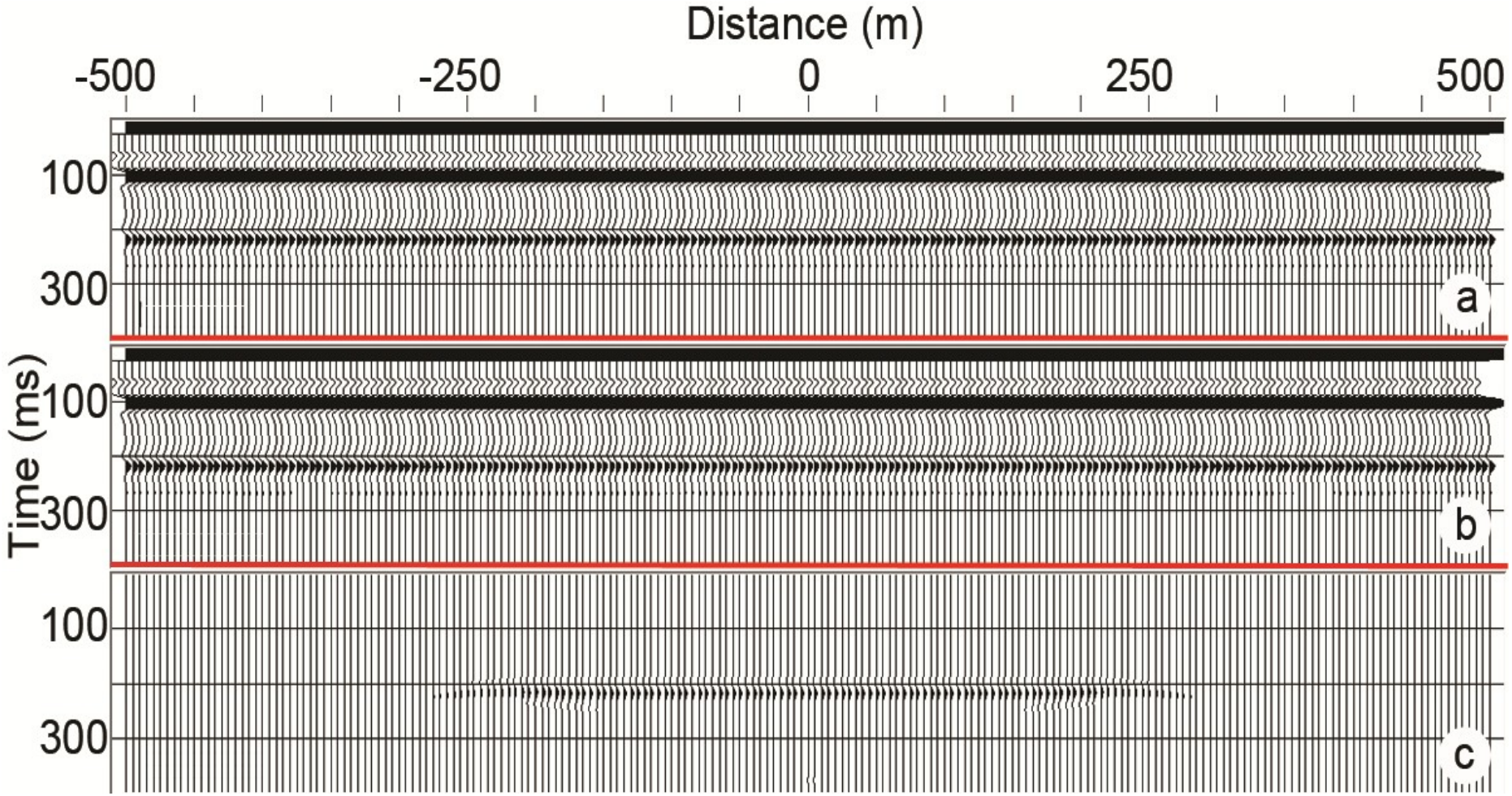
Timeshifts vs offset



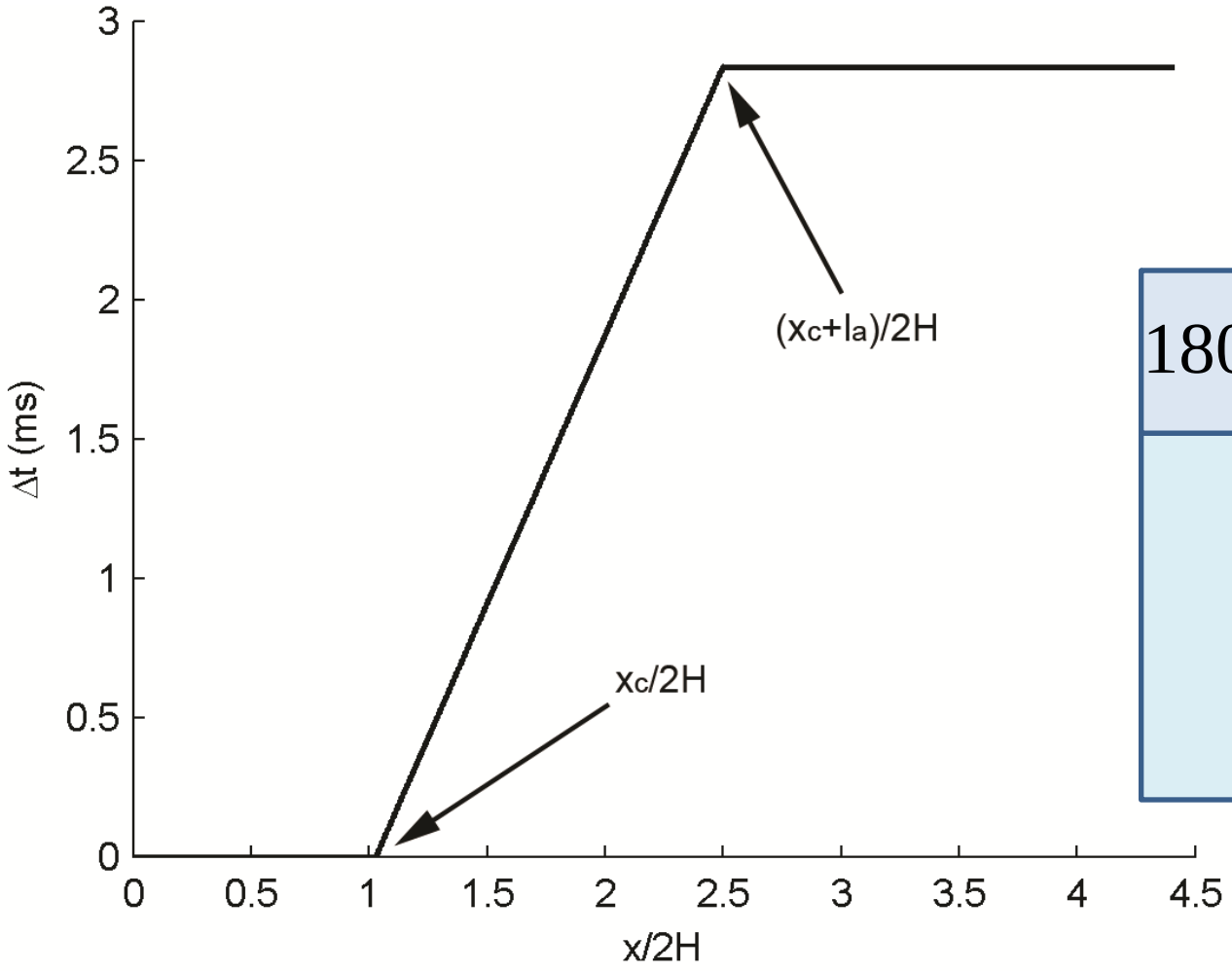
Underground blow out

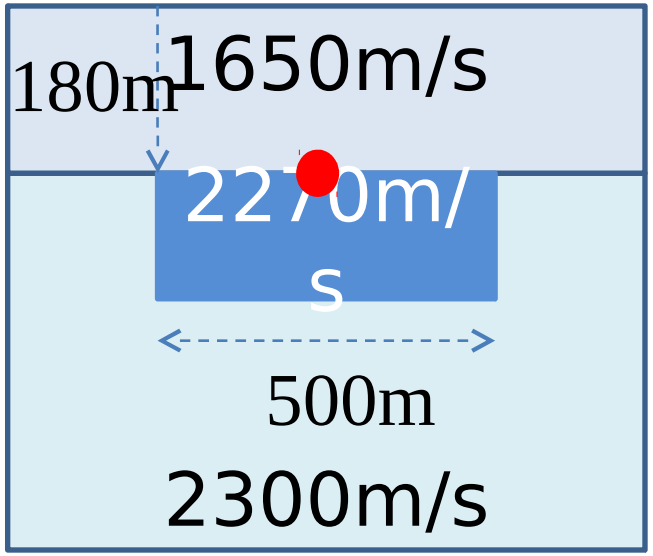


(Hossein Mehdi Zadeh, PhD Thesis)


Distance (m)
-500
-250
0
250
500
Time (ms)
100
300
a
100
300
b
100
300
c

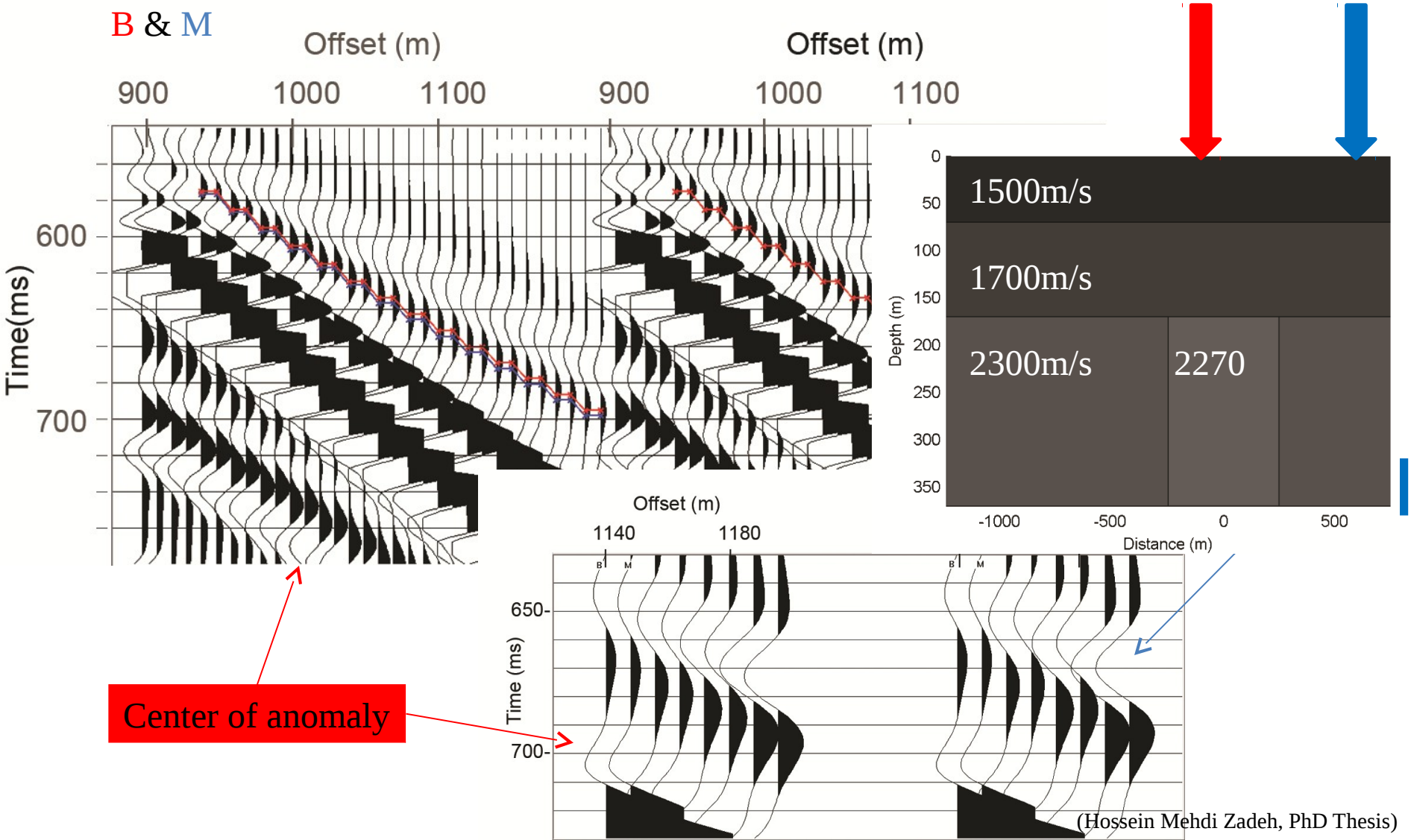
Timeshift vs offset @ anomaly center





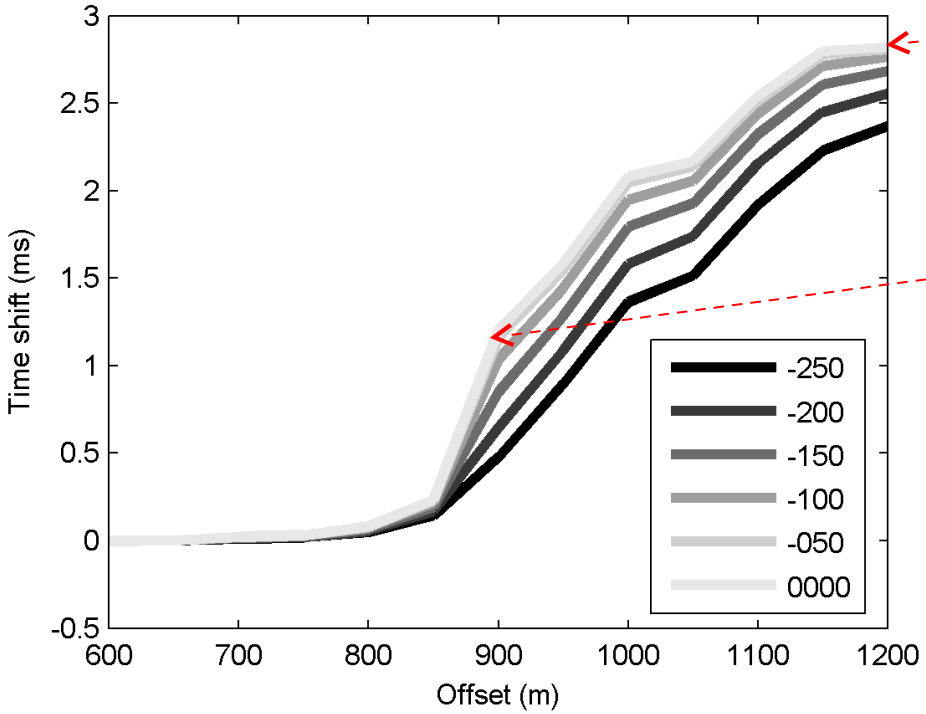
(Hossein Mehdi Zadeh, PhD Thesis)

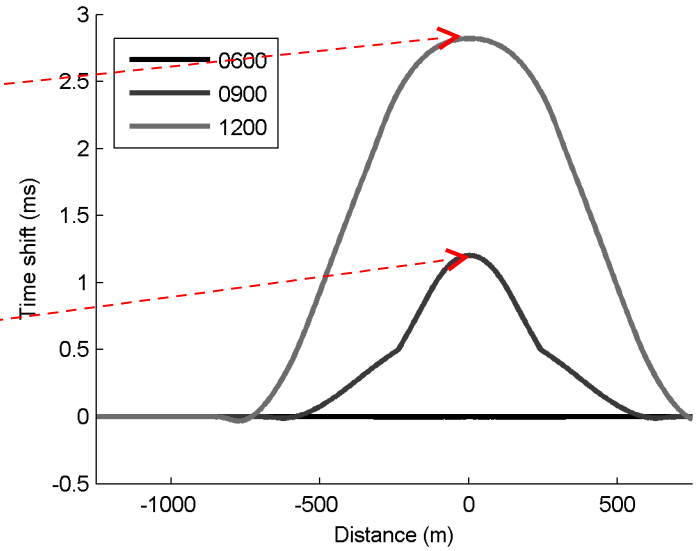
Synthetic modeling of HWΔT

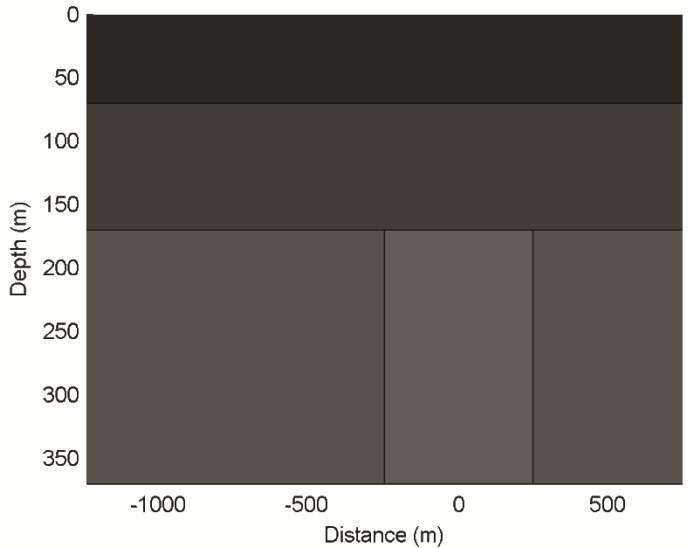


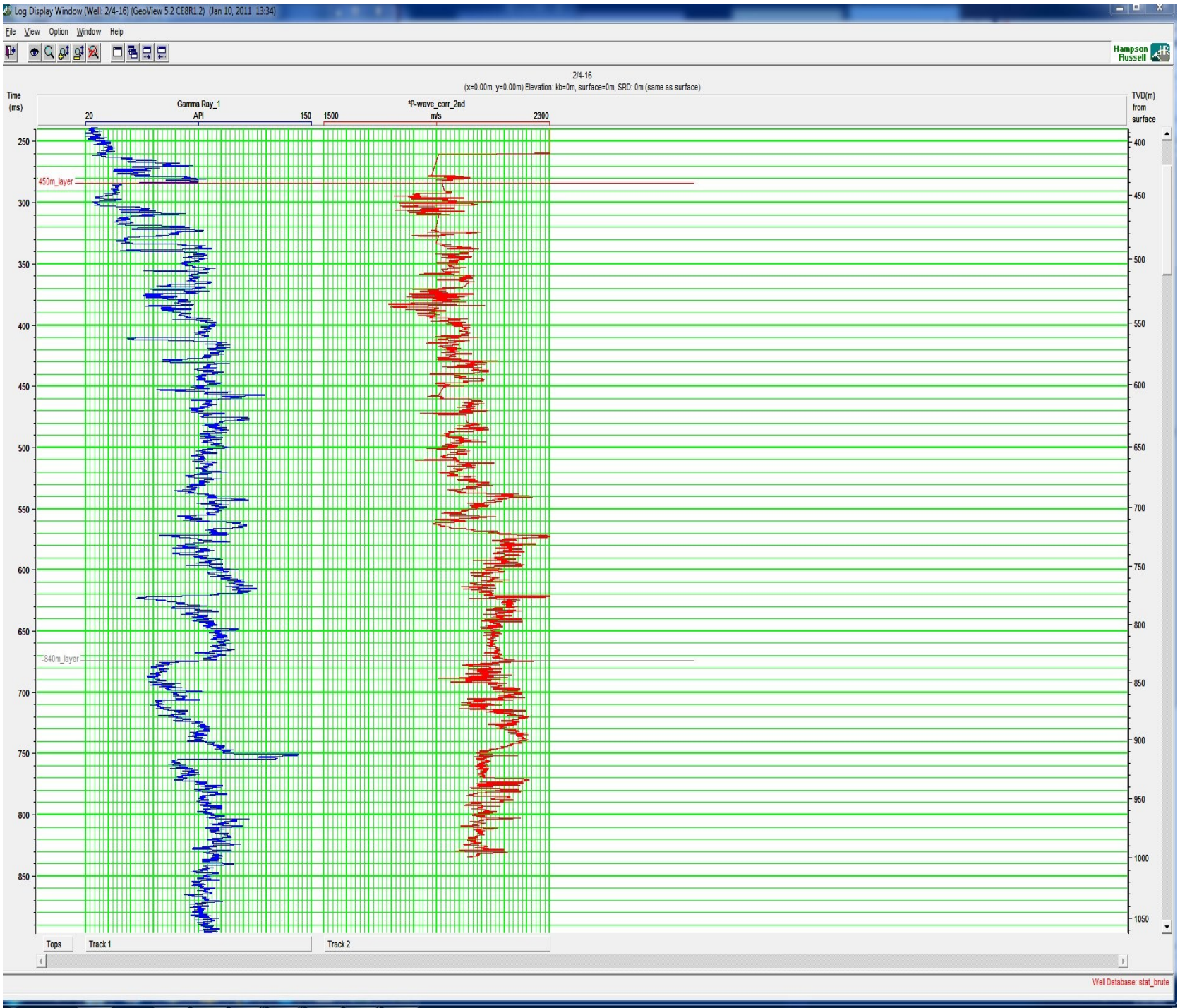
(Hossein Mehdi Zadeh, PhD Thesis)

Analysis of synthetic HWΔT

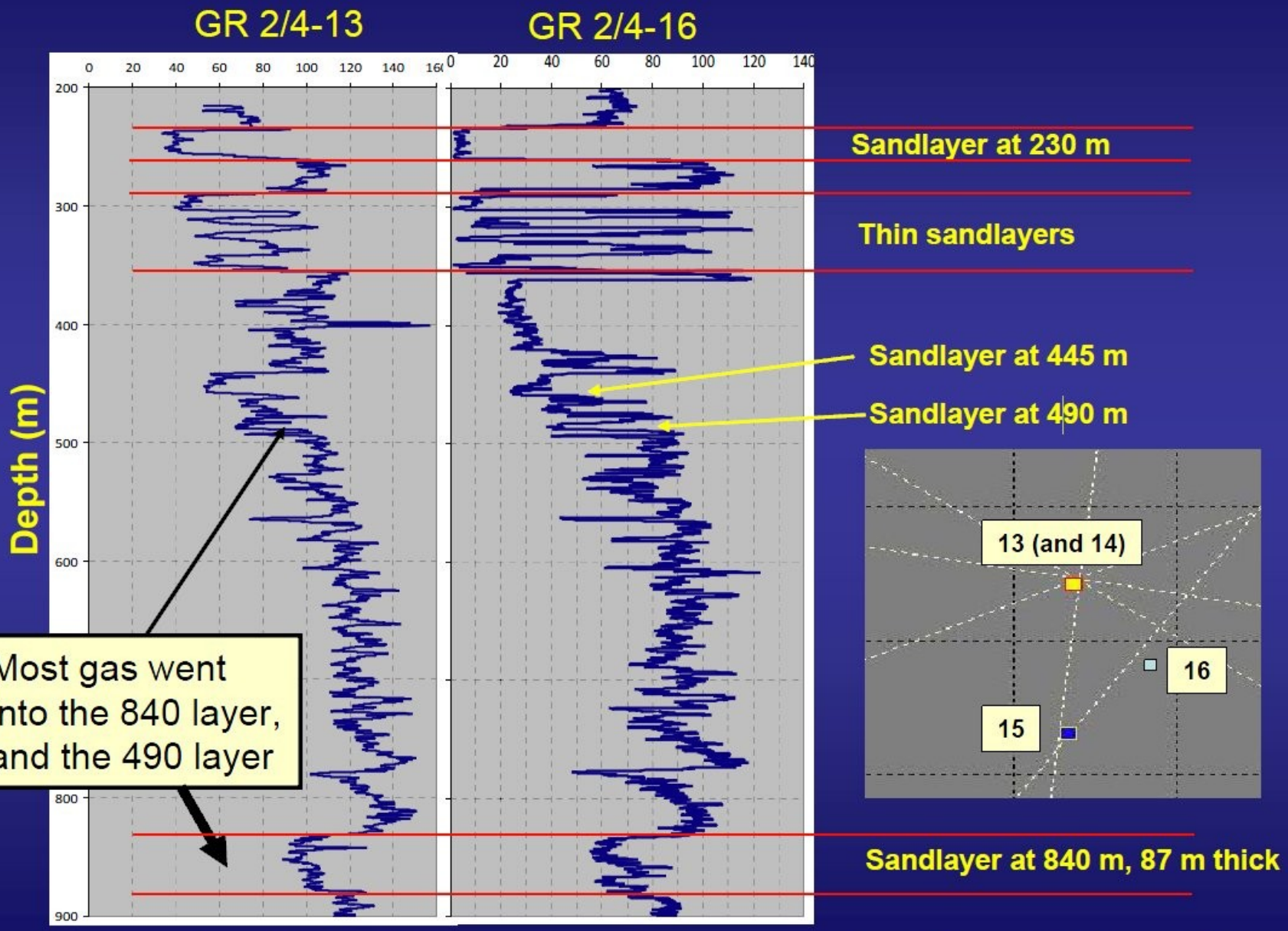







Log Display Window (Well: 2/4-16) (GeoView 5.2 CE8R1.2) (Jan 10, 2011 13:34)
File View Option Window Help
Hampson Russell
2/4-16
(x=0.00m, y=0.00m) Elevation: kb=0m, surface=0m, SRD: 0m (same as surface)
Time (ms)
Gamma Ray_1
API
20
150
*P-wave_corr_2nd
m/s
1500
2300
TVD(m) from surface
450m_layer
840m_layer
Tops
Track 1
Track 2
Well Database: stat_brute

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



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

Conclusions

- Promising alternative to conventional 4D analysis.
- Monitor velocity changes in shallow sedimentary layers.
- Major limitations:
  - Interfaces that create refracted events,
  - Noise.
- North Sea field example:
  - 4D travel time shifts of up to 4 ms for one interpreted refracted event.