Application of FWI for Monitoring Shallow-Gas Migration from a Subsurface Blowout

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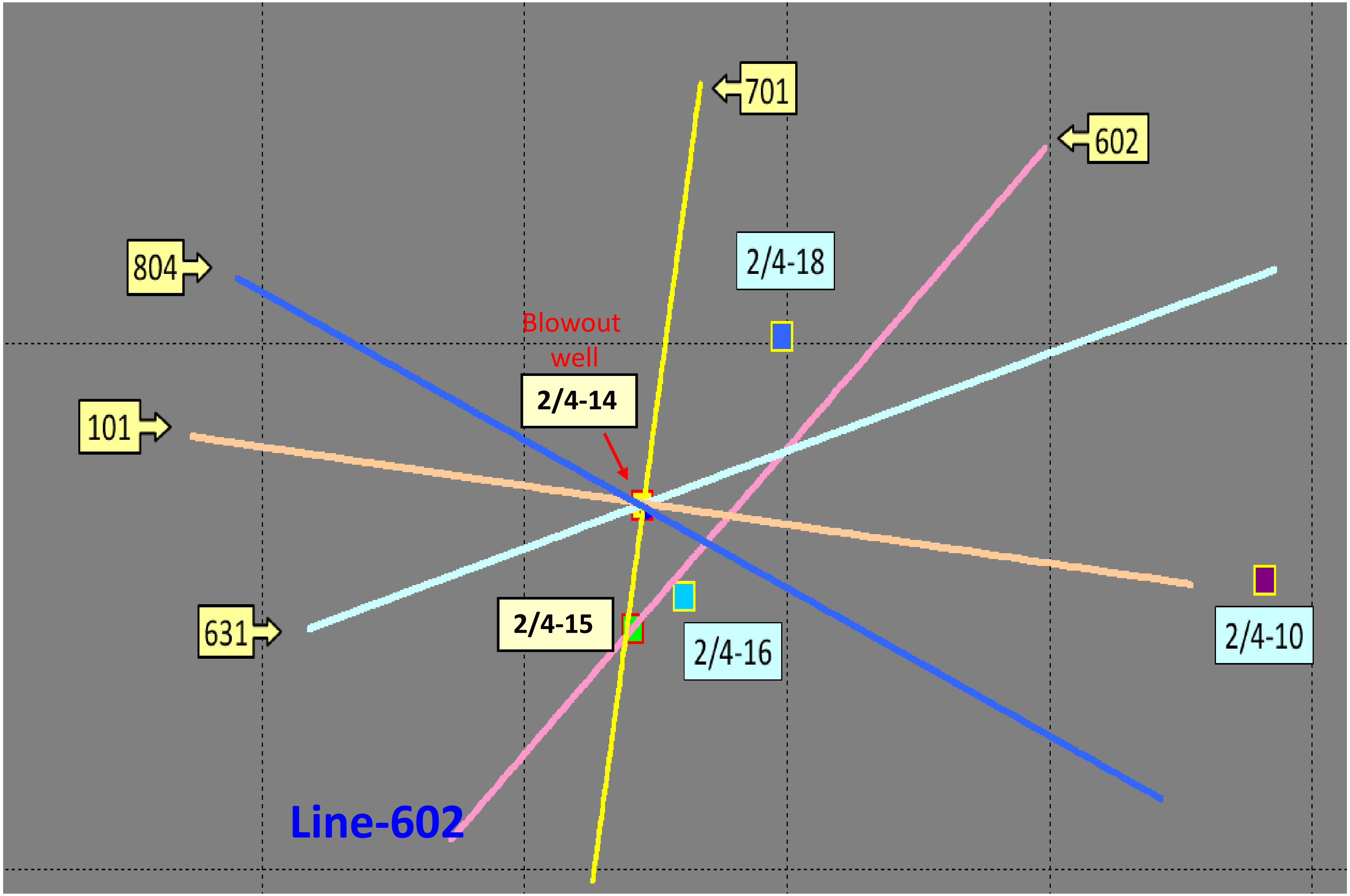
ROSE Meeting (24 April, 2012)

NTNU
Norwegian University of Science and Technology

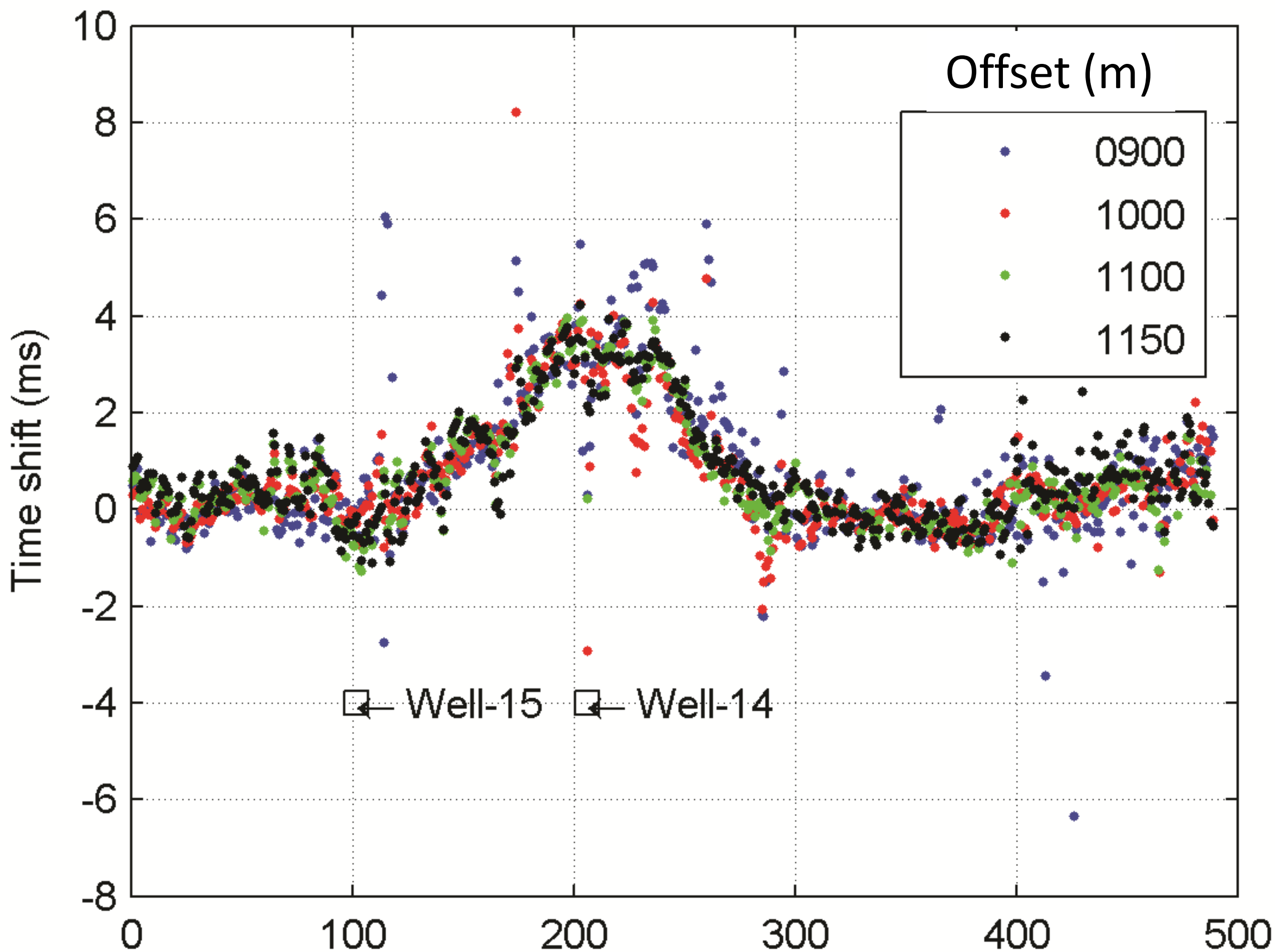
Study Area



Max offset =1200 m

(Martin Landrø, et. al, 2010)

Motivation:
HeadWave time-shift (ΔT) relative to well location



Timeshifts are observed around the blow out well

(Hossein Mehdi Zadeh, PhD Thesis, NTNU)

Objective

- Apply FWI to map the gas migration, into the shallow section, by making use of the seismic **transmitted energy (refracted & diving waves).**

FWI Methodology

The method used is an acoustic, finite difference, time domain method that updates the P-wave velocity using linearized least squares inversion process (adjoint-wavefield approach)*

***(Ratcliffe, et. al, 2011,** Full Waveform Inversion: a North Sea OBC case study, SEG, Expanded Abstract)

Outline

PART 1: FWI Input

I. Selection of Inversion Frequency-Range
II. Wavelet Modelling
III. Initial Velocity Models (#1, #2, and #3) + Forward Modeling

PART 2: FWI Results & Discussions

I. Inversion #3

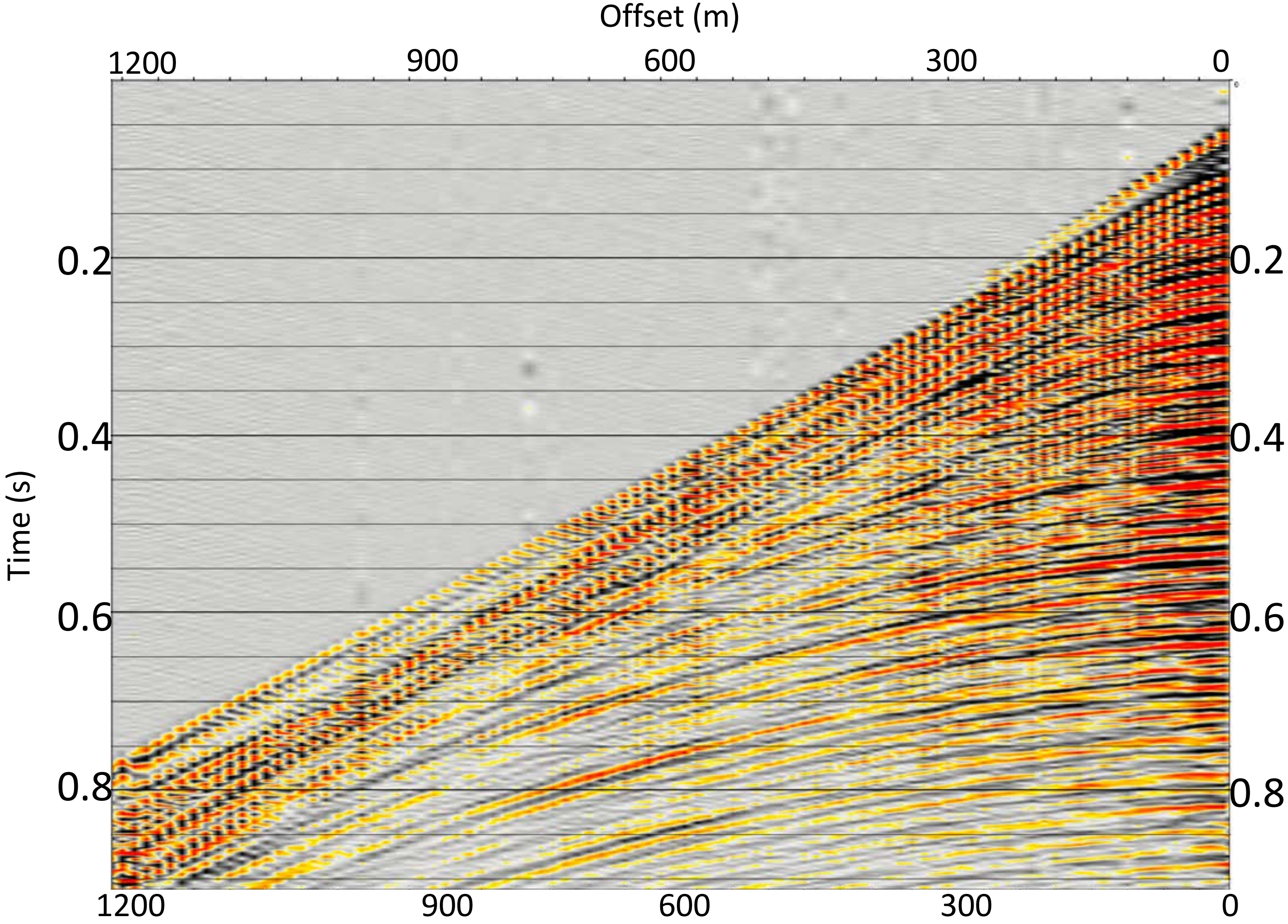
PART 3: Conclusions

PART1: FWI Input

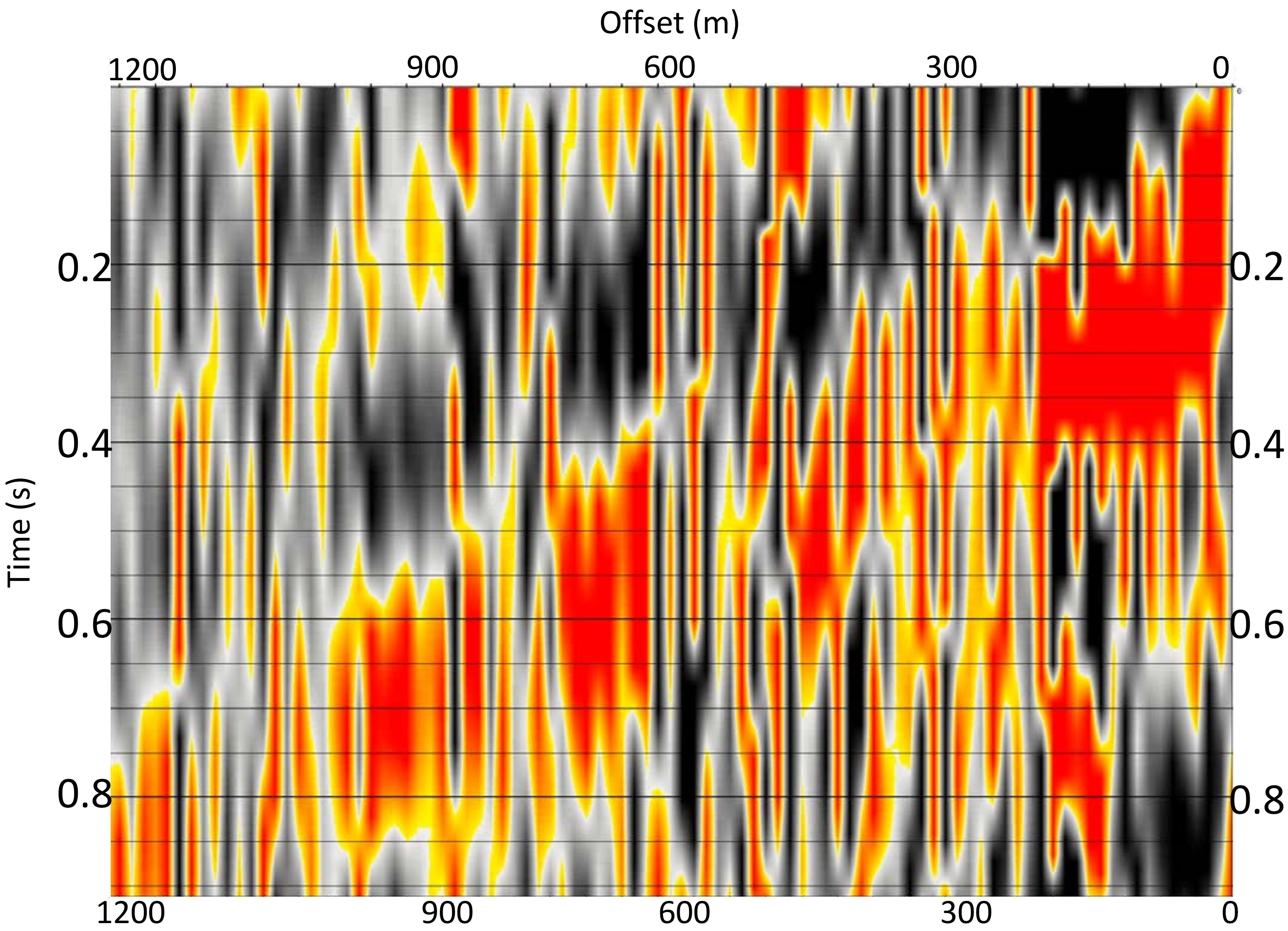
I. Selection of Inversion Frequency Range
II. Wavelet Modelling
III. Initial Velocity Models (#1, #2, and #3) + Forward Modeling

I. FWI Frequency Range

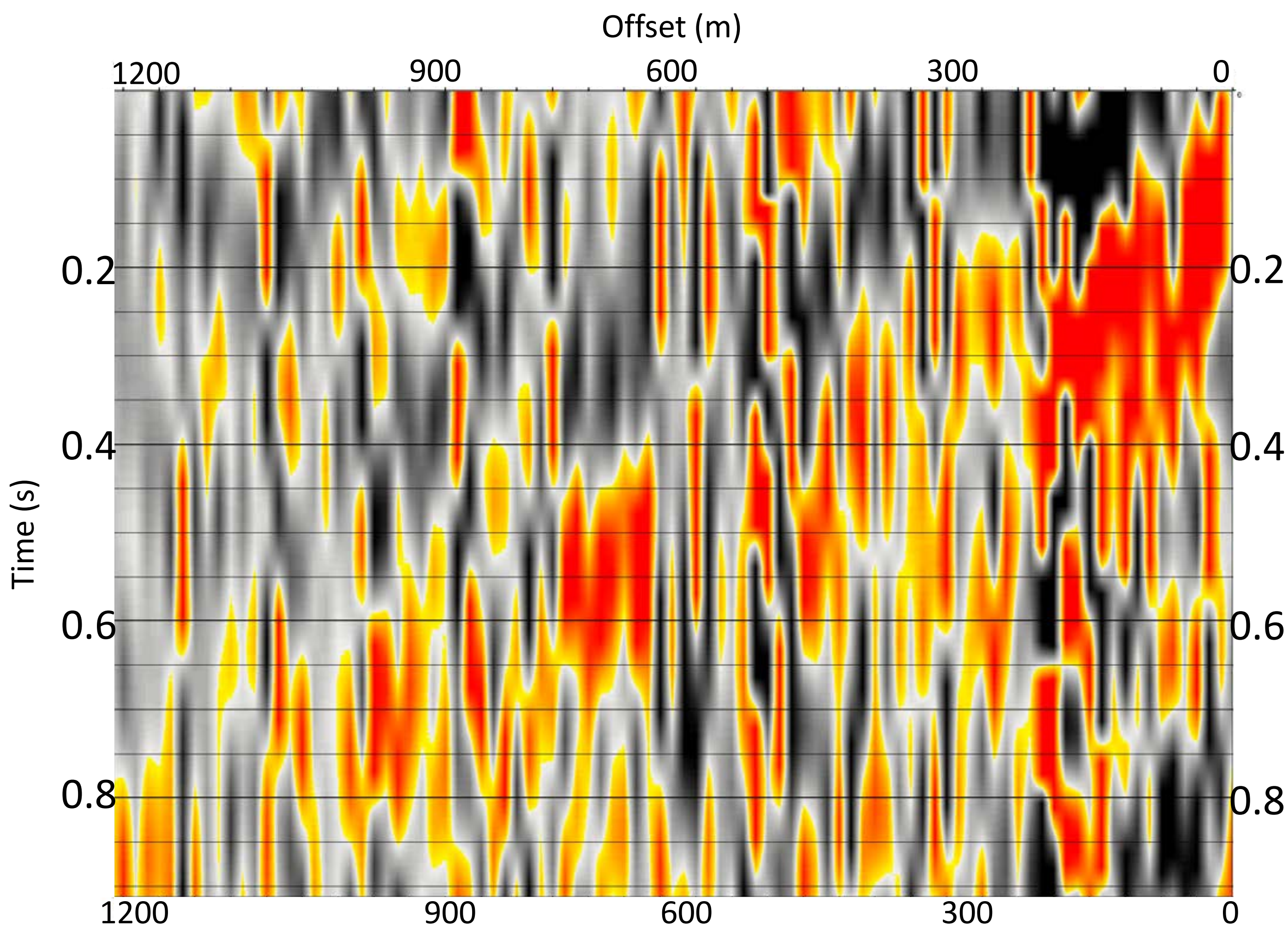
Raw Field Data (1988)



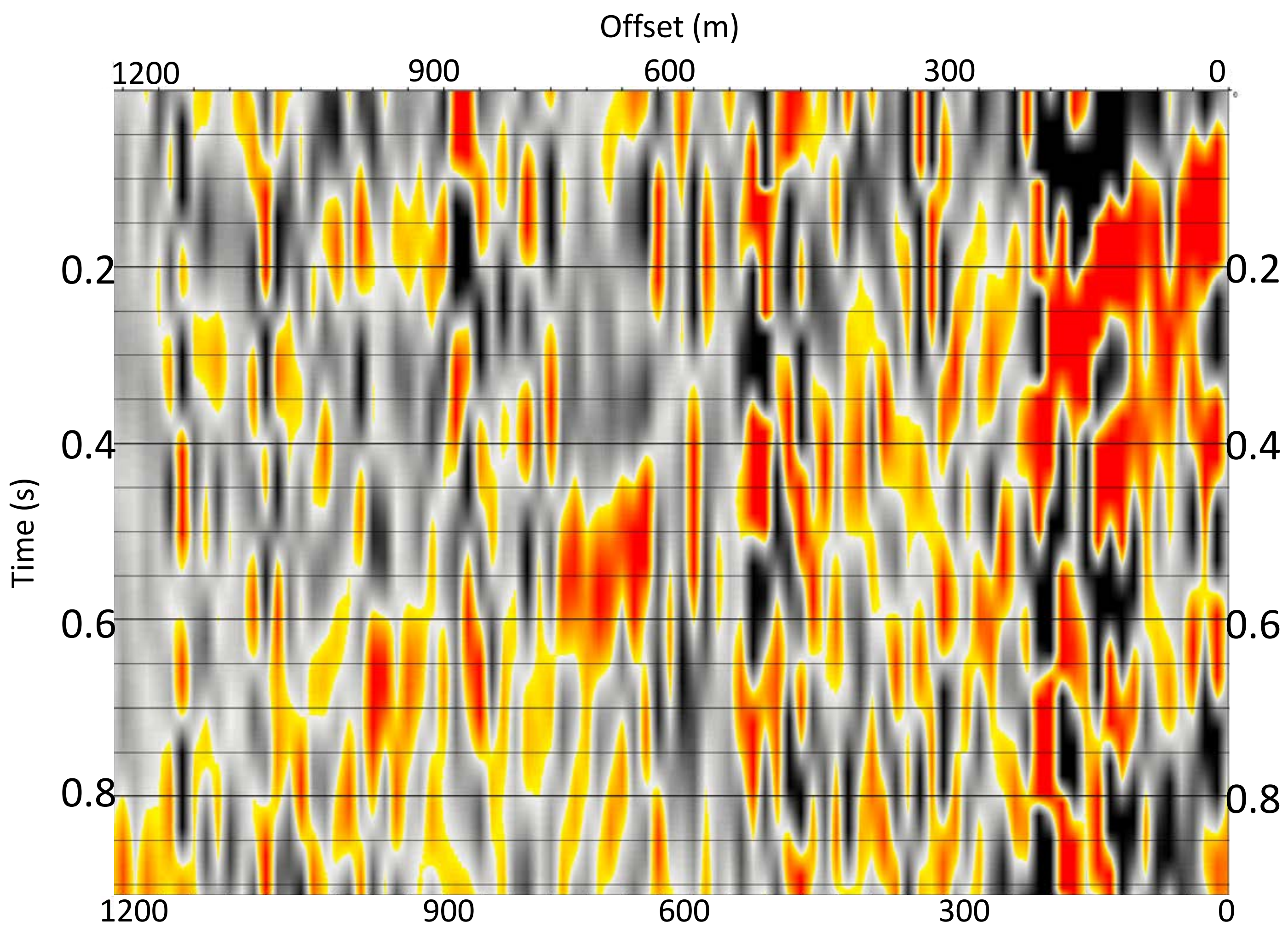
Bandpass Filter (0-1-2-3)Hz



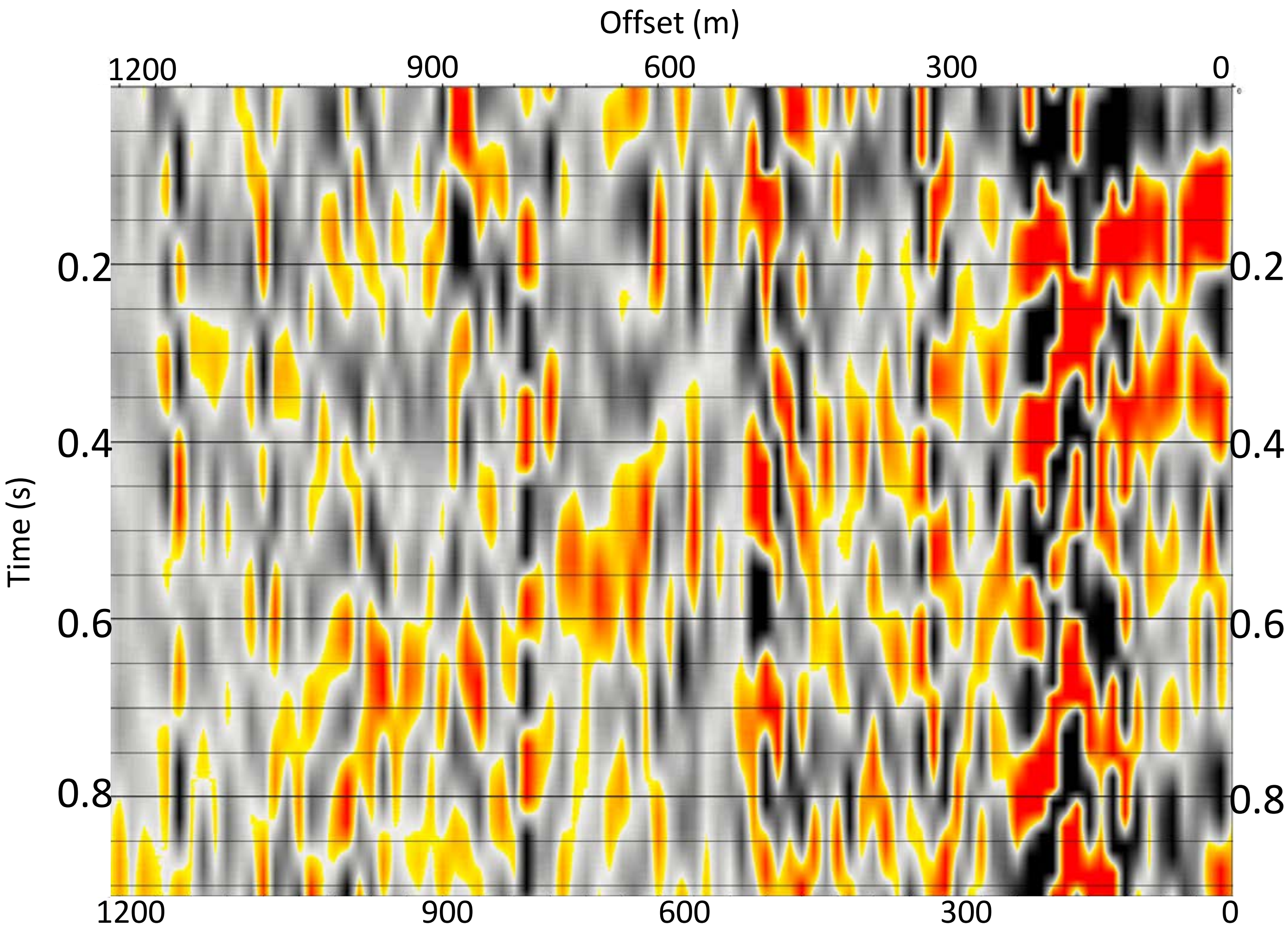
Bandpass Filter (0-1-3-4)Hz



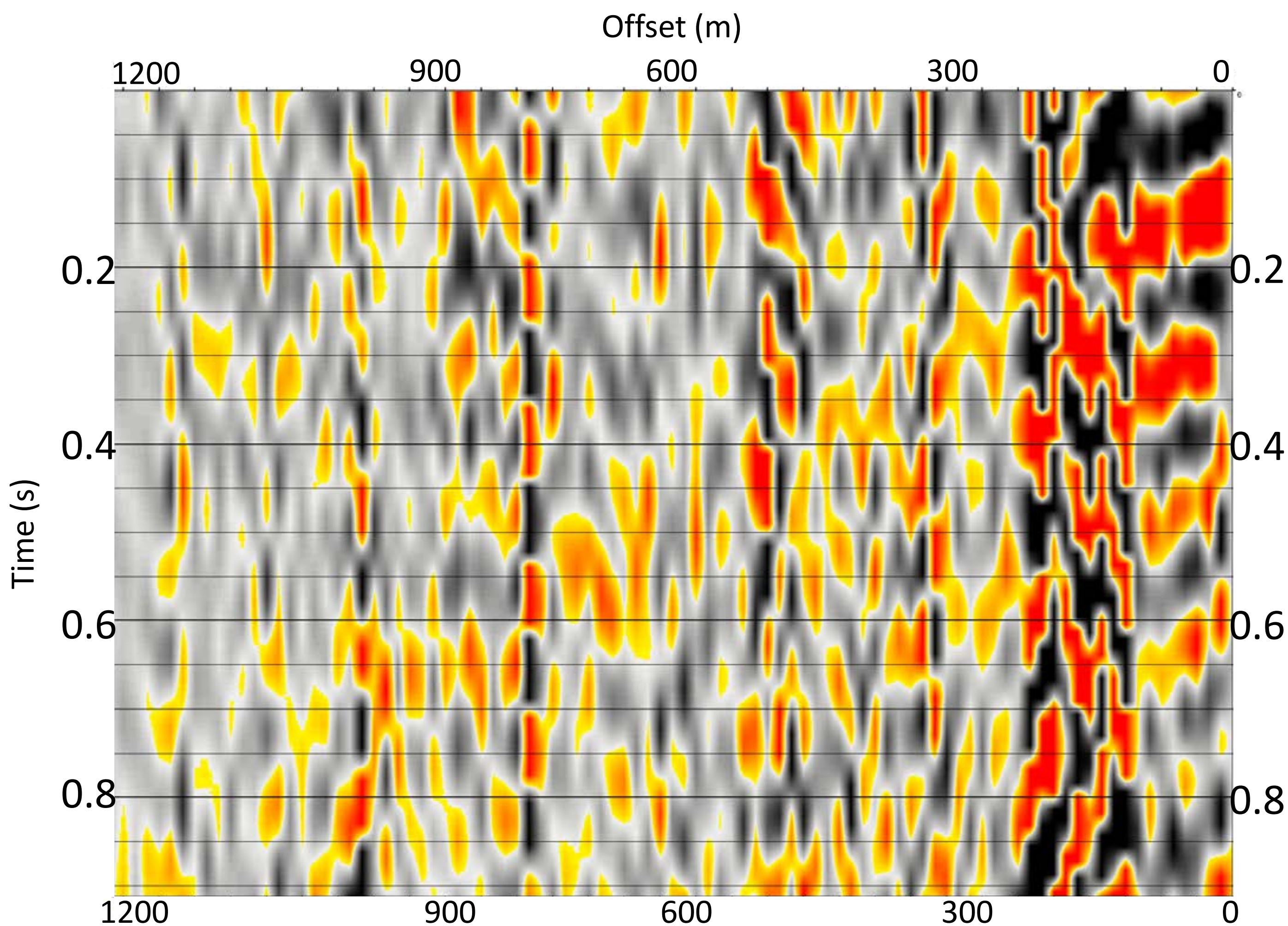
Bandpass Filter (0-1-4-5)Hz



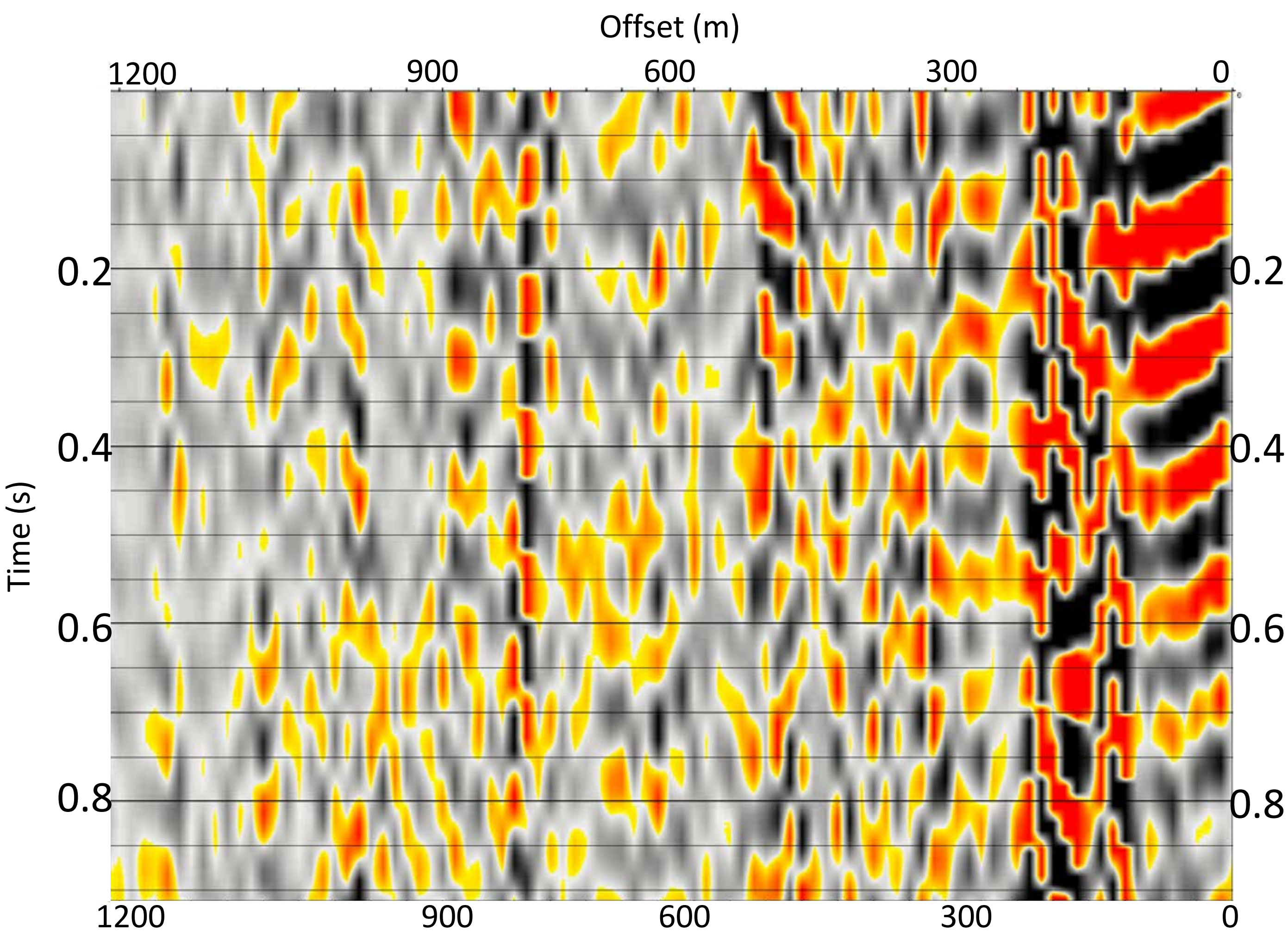
Bandpass Filter (0-1-5-6)Hz



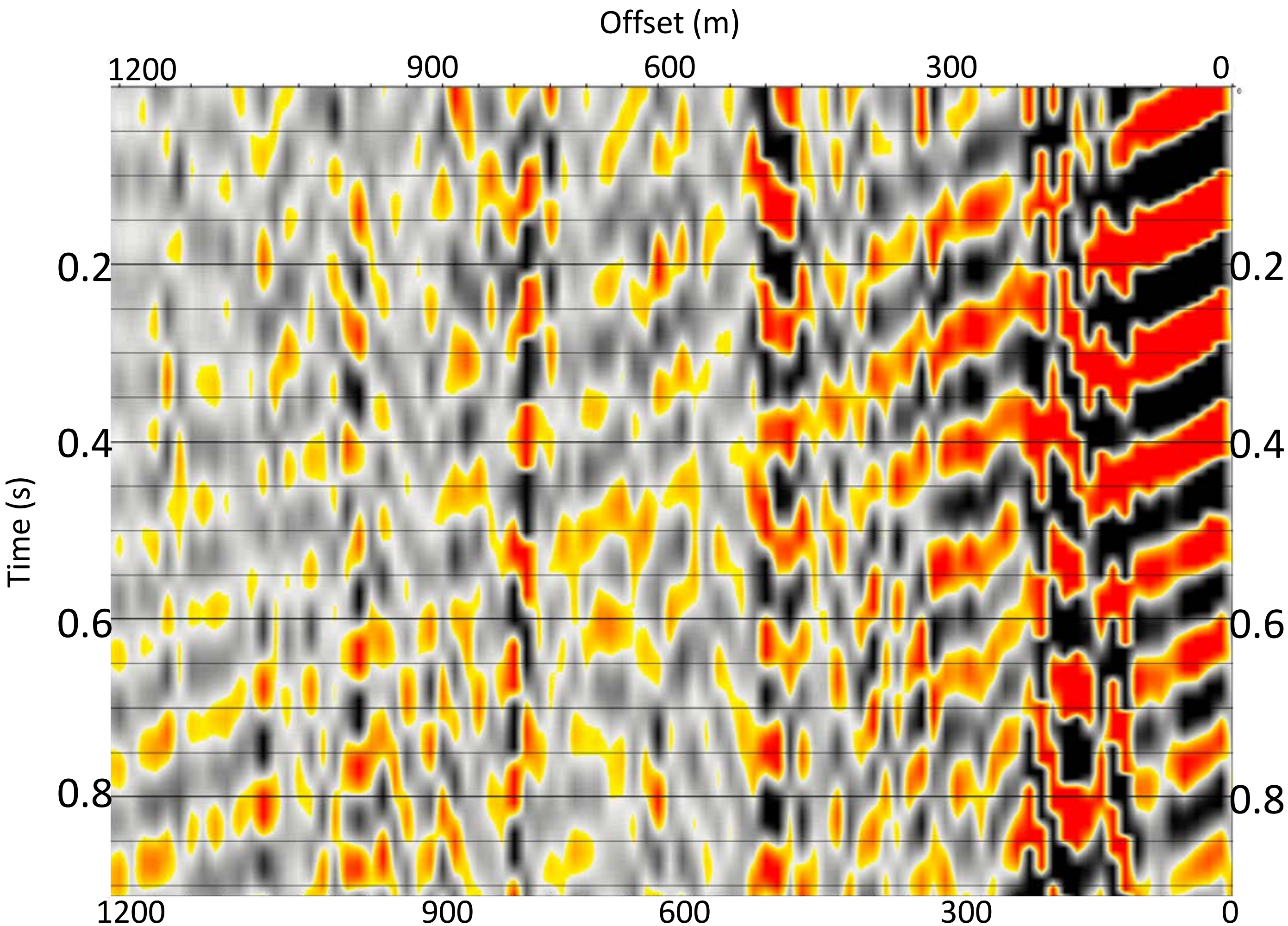
Bandpass Filter (0-1-6-7)Hz



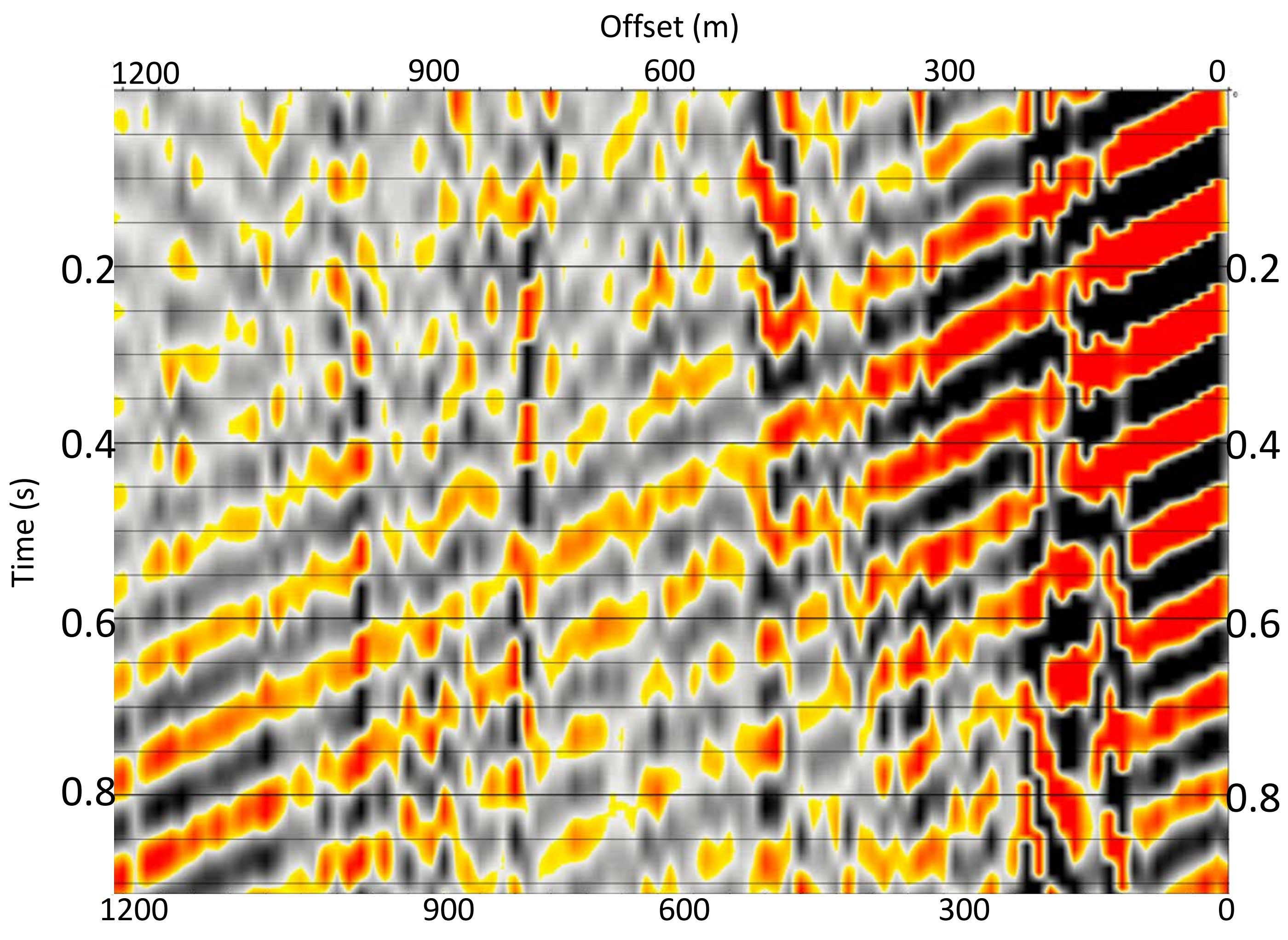
Bandpass Filter (0-1-7-8)Hz



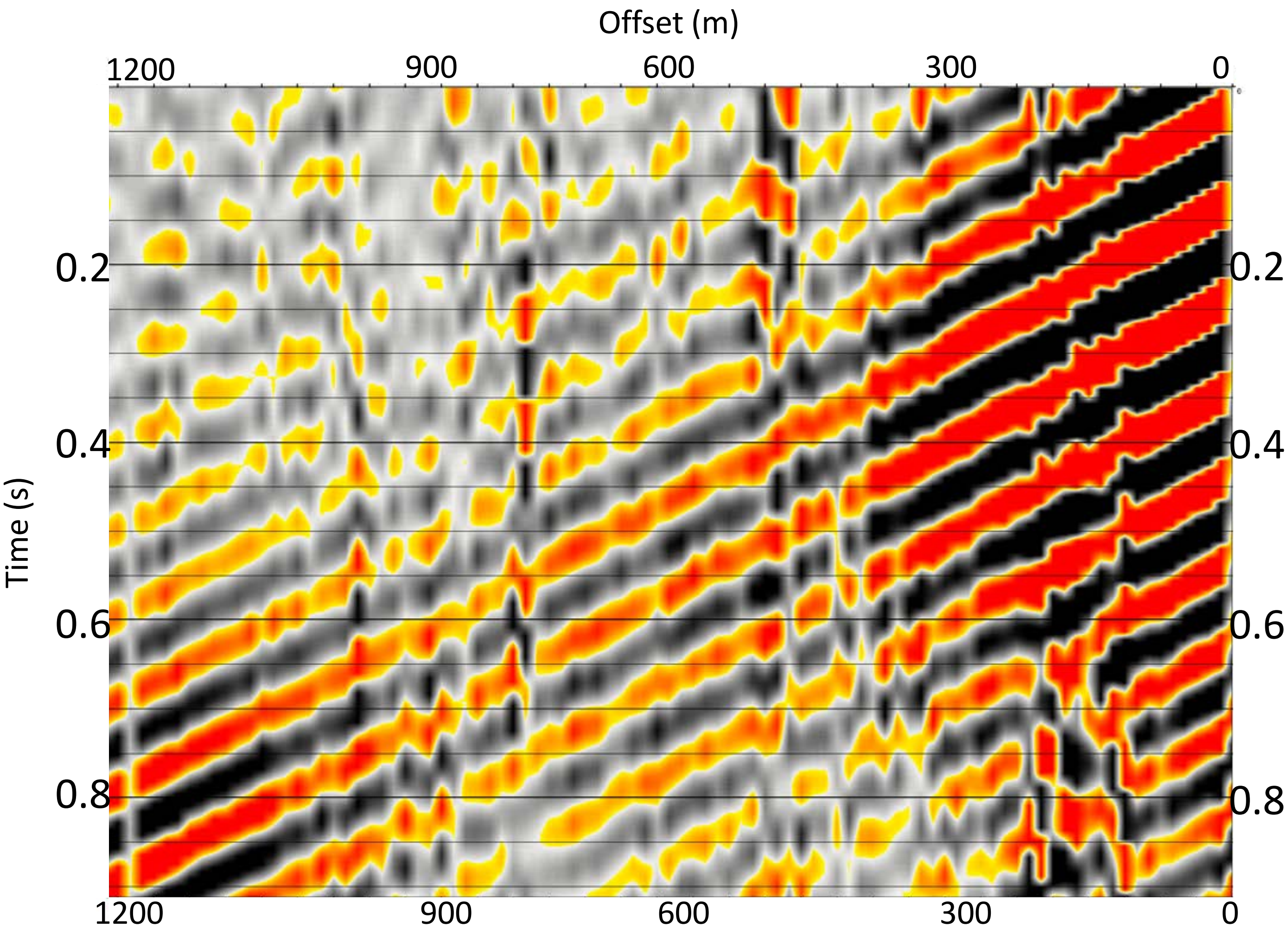
Bandpass Filter (0-1-8-9)Hz



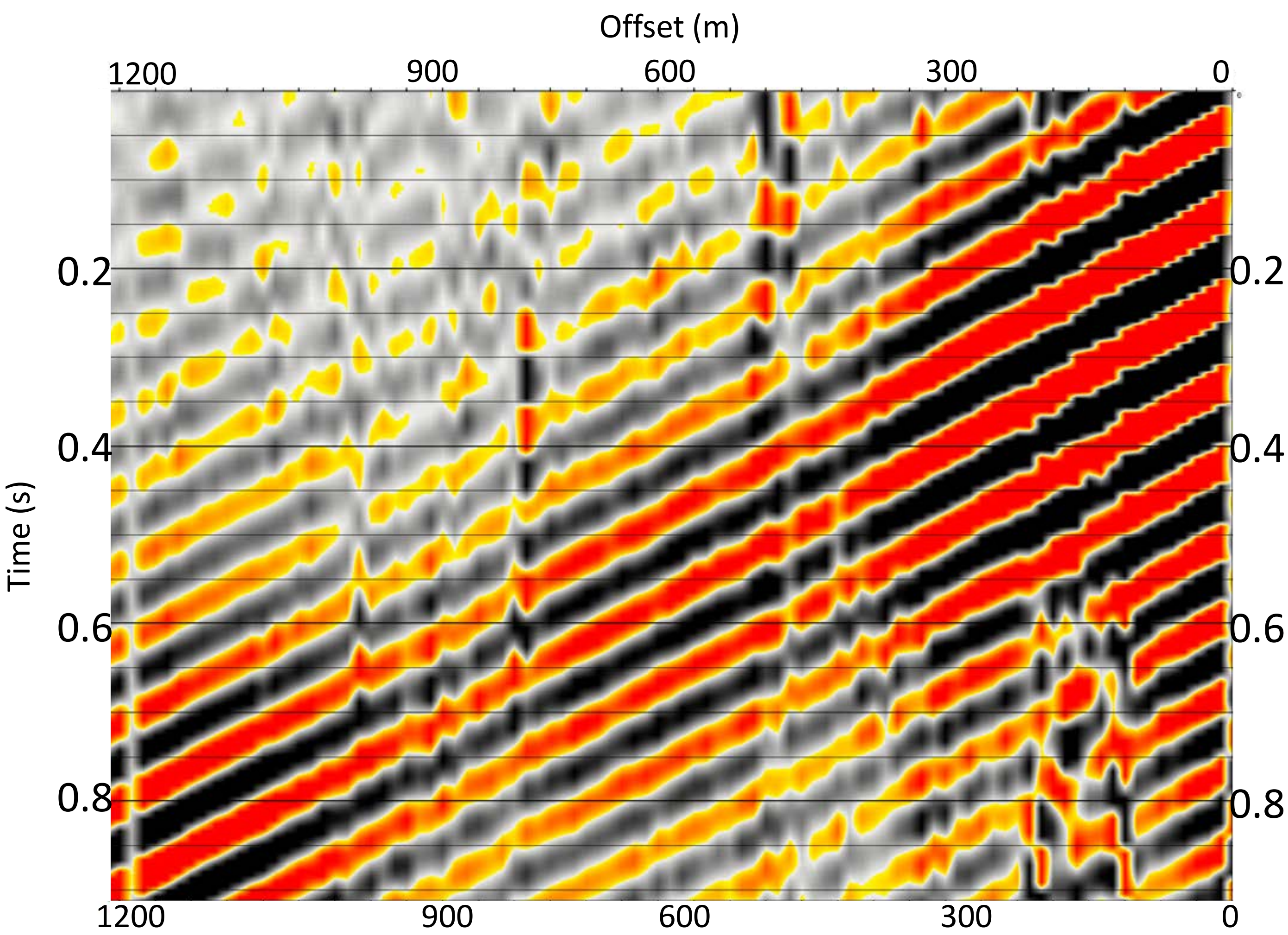
Bandpass Filter (0-1-9-10)Hz



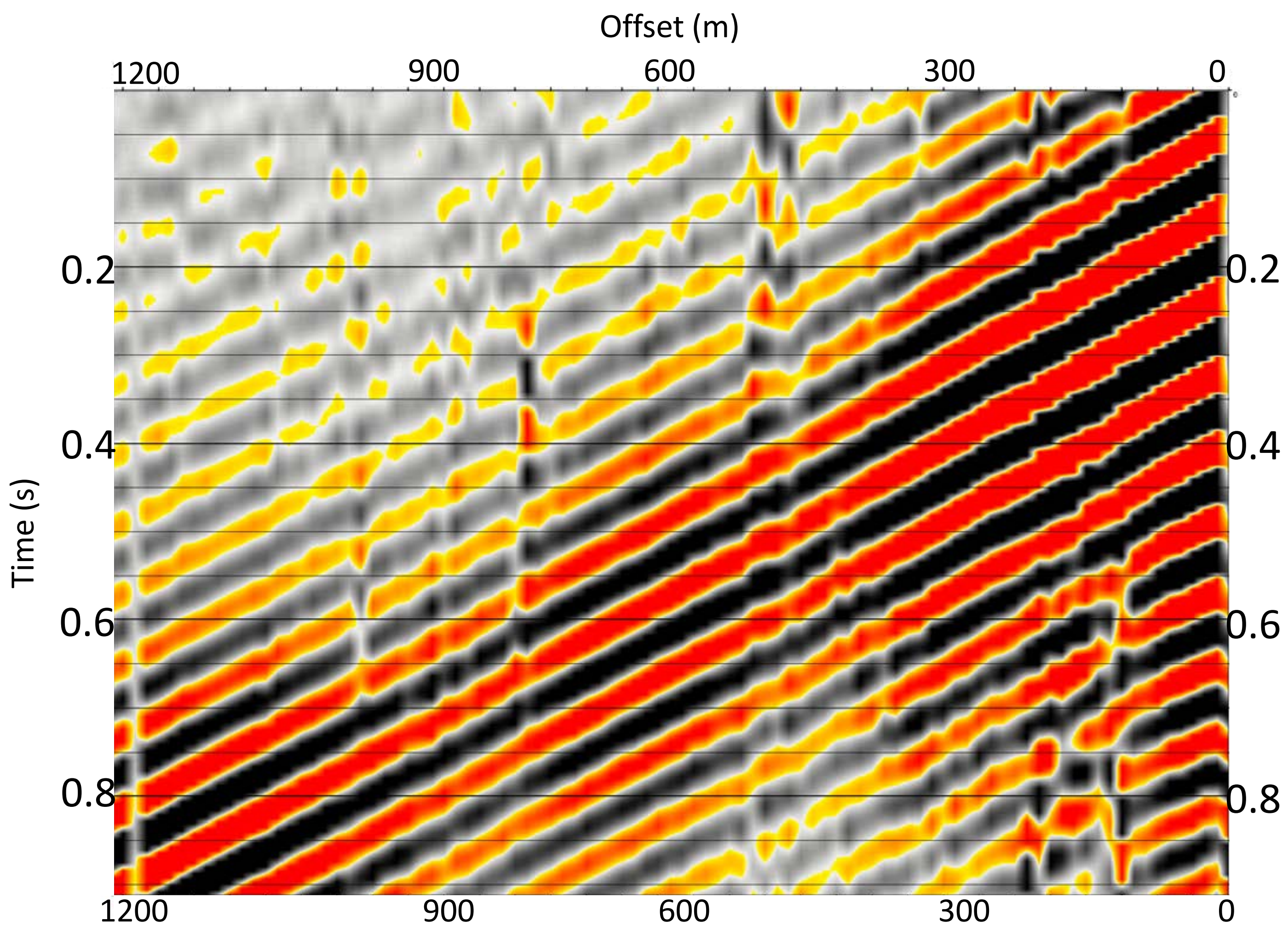
Bandpass Filter (0-1-10-11)Hz



Bandpass Filter (0-1-11-12) Hz

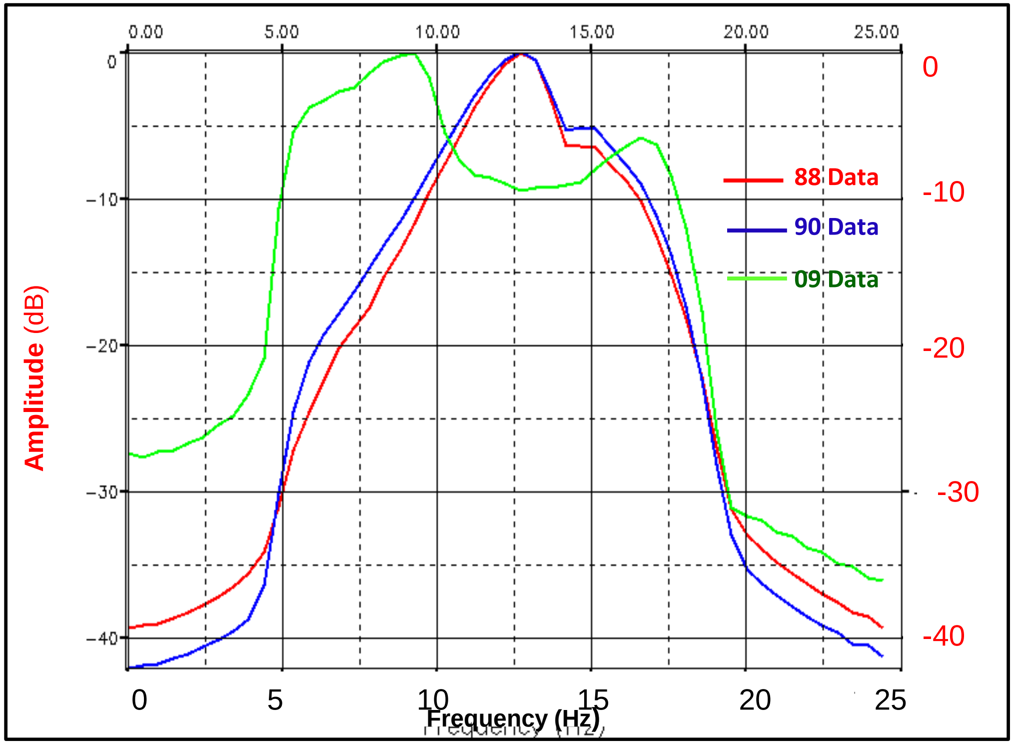


Bandpass Filter (0-1-12-13) Hz



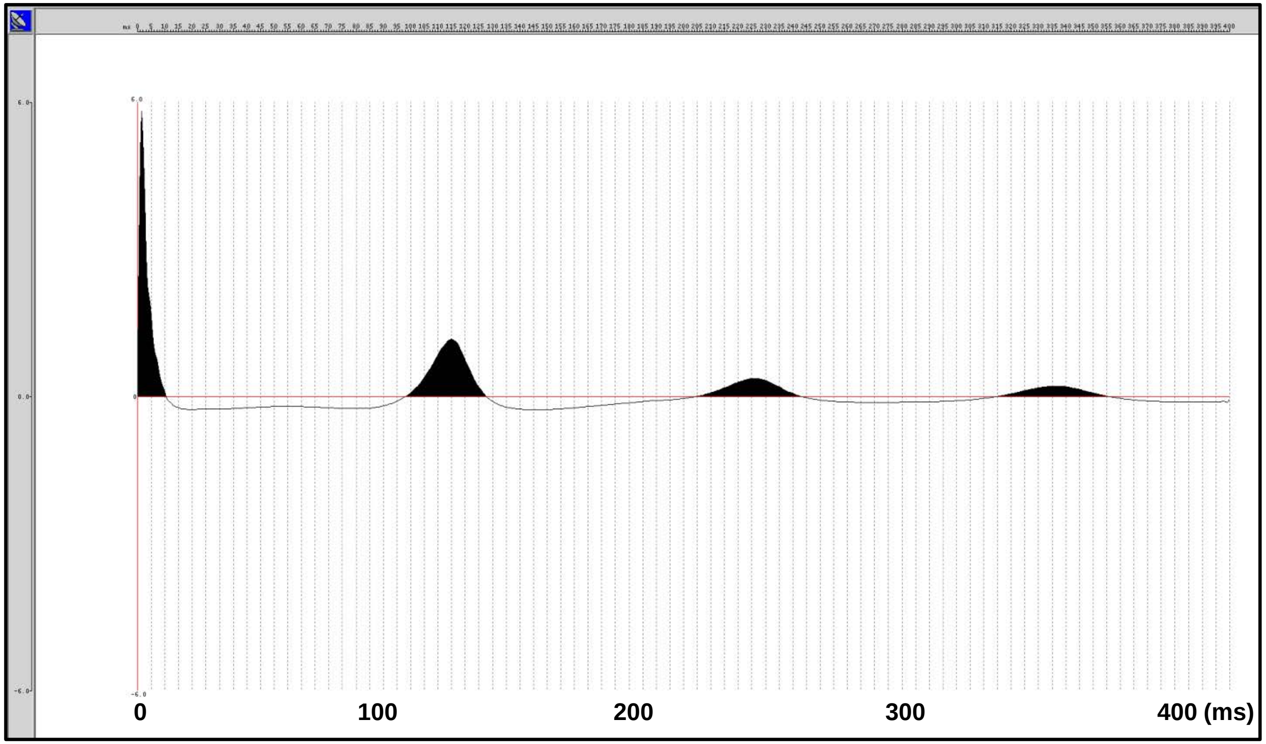
I. FWI Frequency Range Conclusion: (11Hz-12.5Hz)

- 88, and 90 data had a Butterworth filter applied during acquisition (10Hz-(18Db/oc)- 350Hz (90 Db/oc)). Therefore, frequencies below 10Hz had no reliable signal for inversion.
- For 88 and 90 data, the inversion frequency range is: **11Hz-11.5Hz-12-12.5Hz** (8 iteration each)
- 09 data were not used due to swelling noise



Amplitude Spectrum for 88, 90, and 09 data after a (4-6-15-20Hz) bandpass filter applied

II. Wavelet Modeling

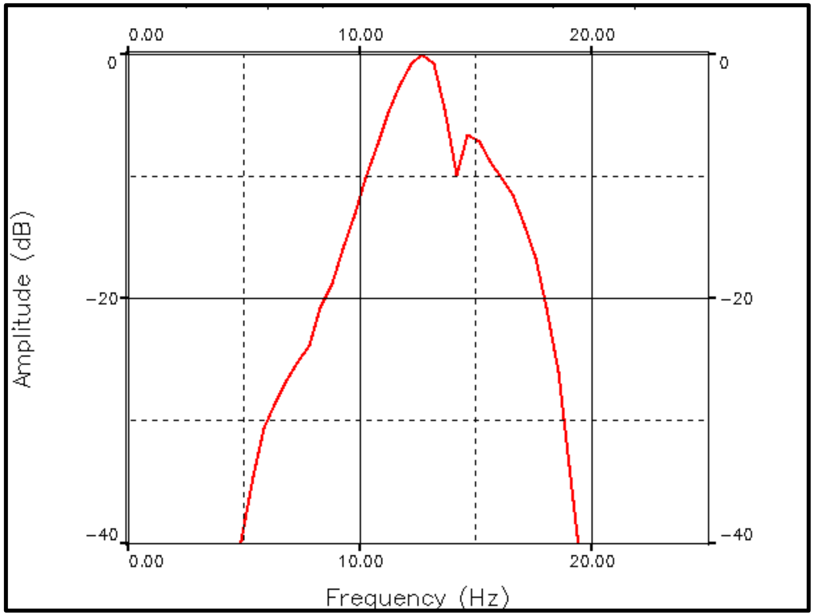


Starting wavelet was Modelled in Nucleus with following parameters:

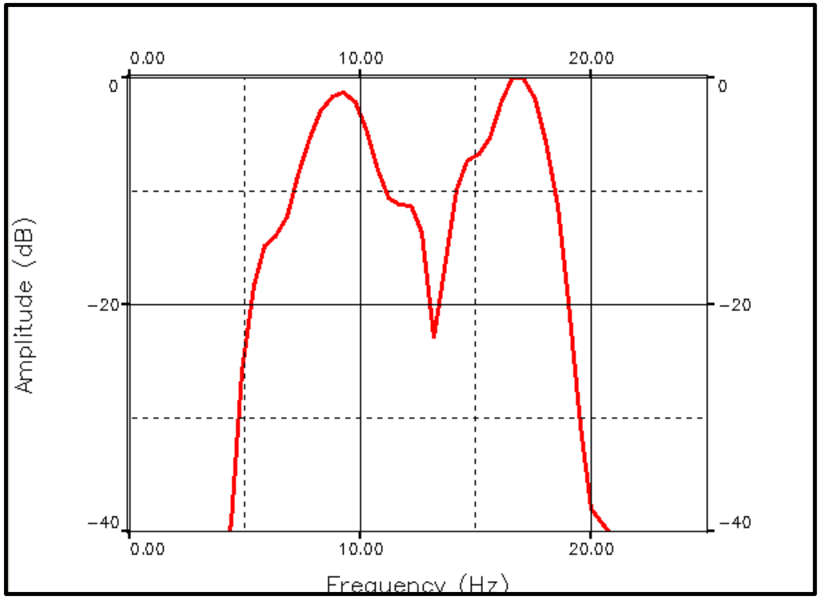
- 4 airgun cluster
- Individual Gun-size: 40 cubic inches
- 50 cm spacing
- Firing pressure: 2000 psi
- Filter: 10Hz(18 db/oc)-360 Hz (360 db/oc)

Wavelet Modelling:
Field Data Vs. Synthetics using modelled wavlet

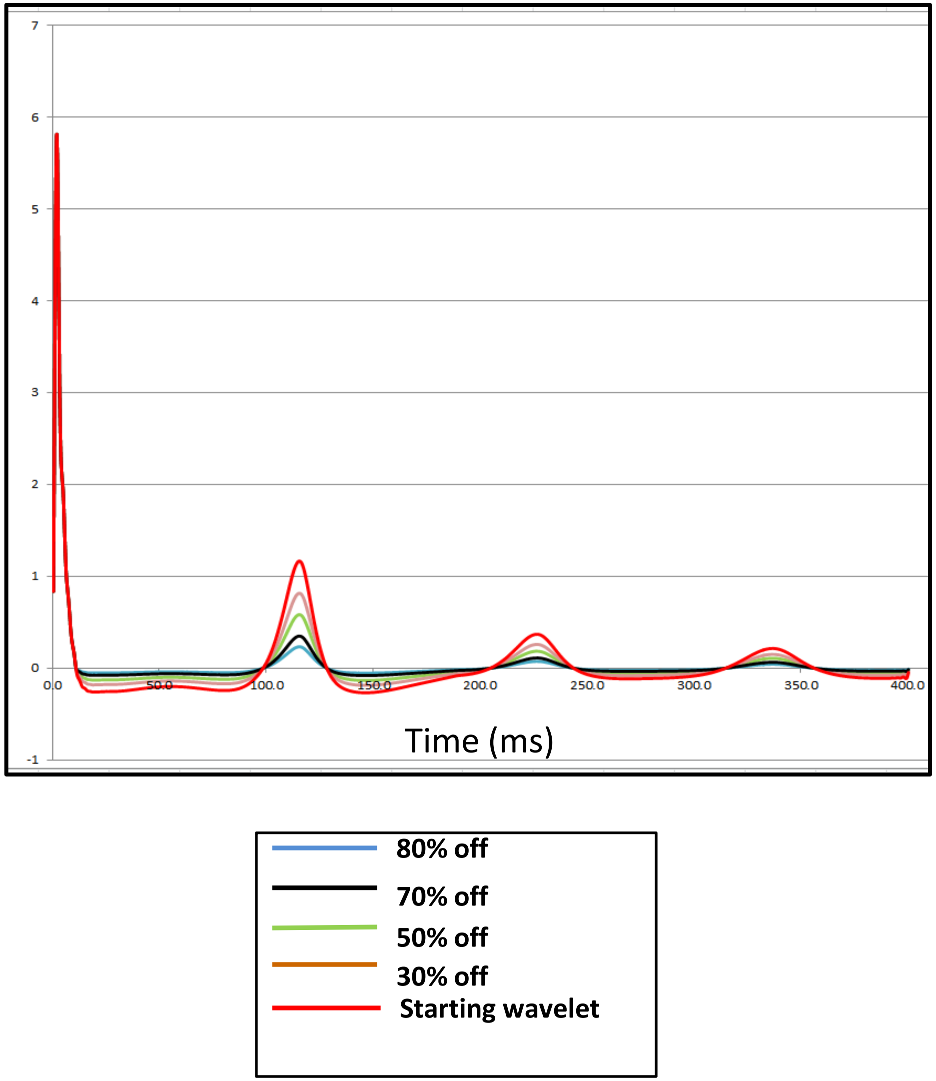
Amp. Spect. of Field Data(1988) with Bandpass filter (4-6-15-20)

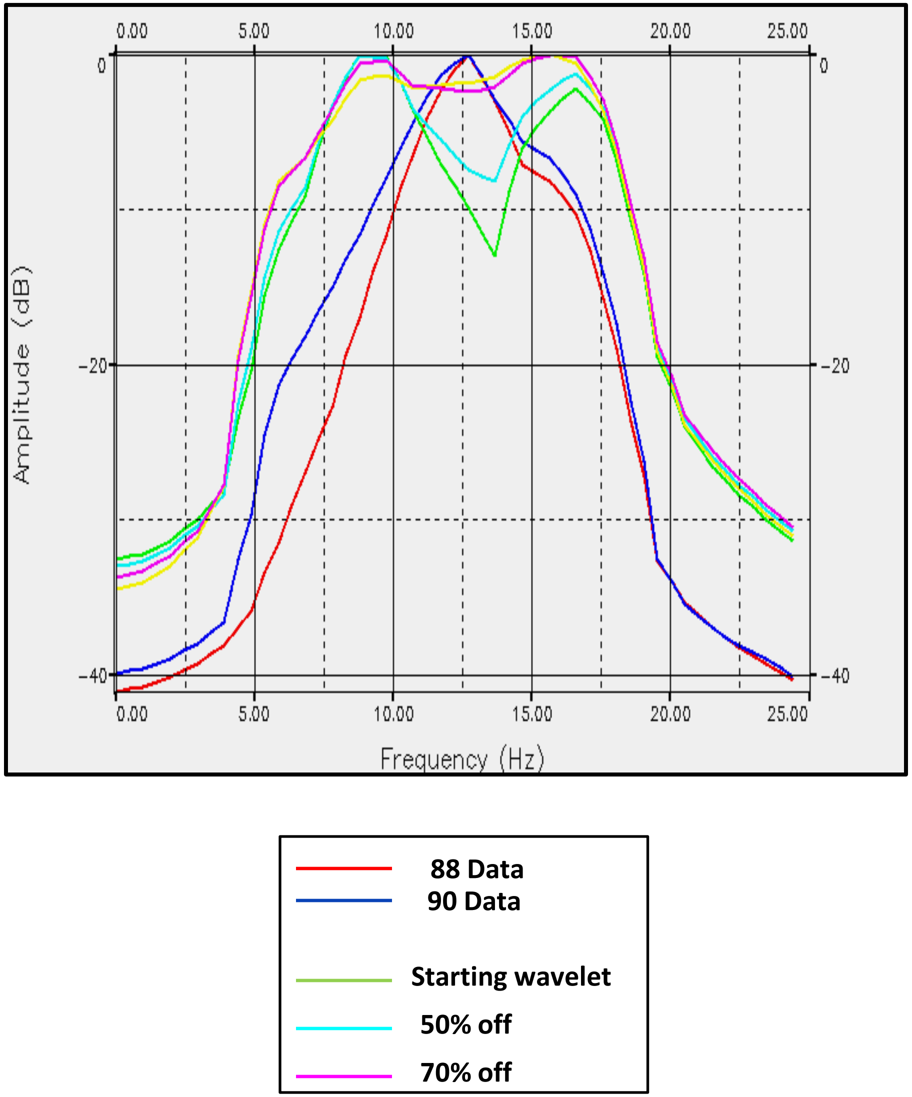


Amp. Spect. of Synthetics using the starting wavelet (Bandpass filter (4-6-15-20))

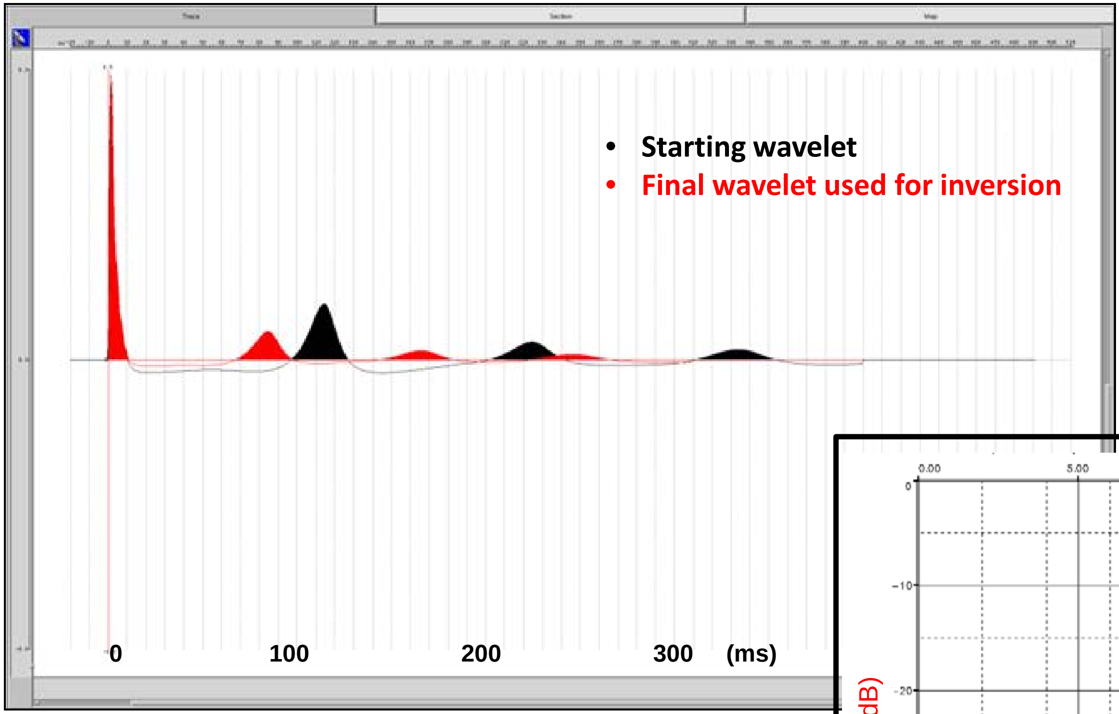


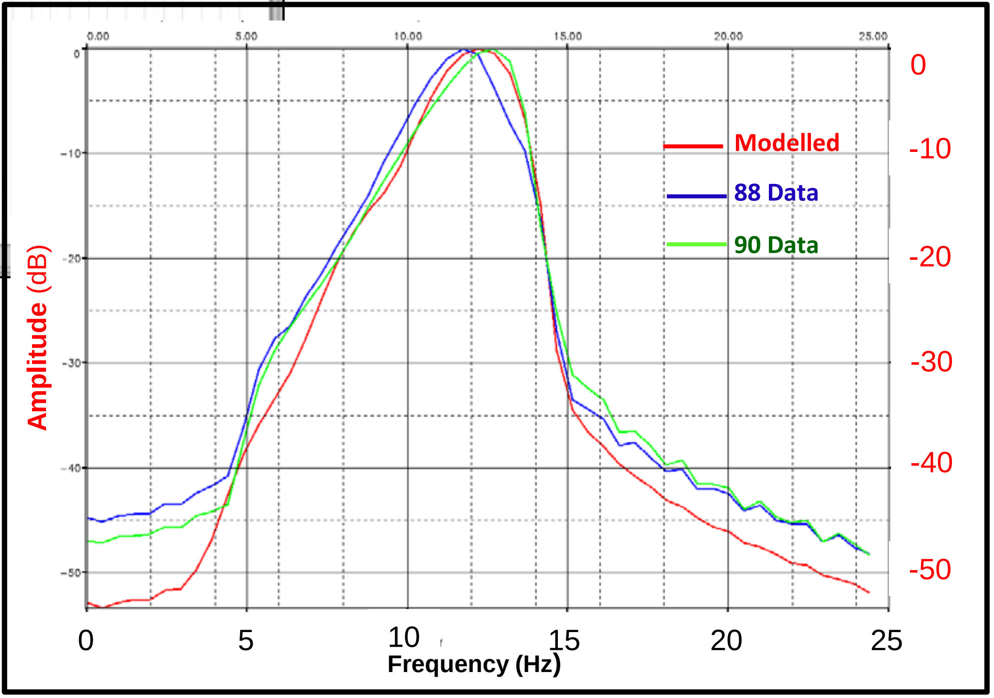
Bubble Scaling-Down (P/B ratio Increase)





II. Wavelet Modeling





2 corrections applied to the starting wavelet:

1. **Bubble energy was reduced by (50%)**

2. **Bubble period was shorten to 81ms instead of 117ms in starting wavelet**

➔ **Nice match with seismic is obtained**

III. Initial Velocity Models (#1, #2, and #3) + Forward Modeling

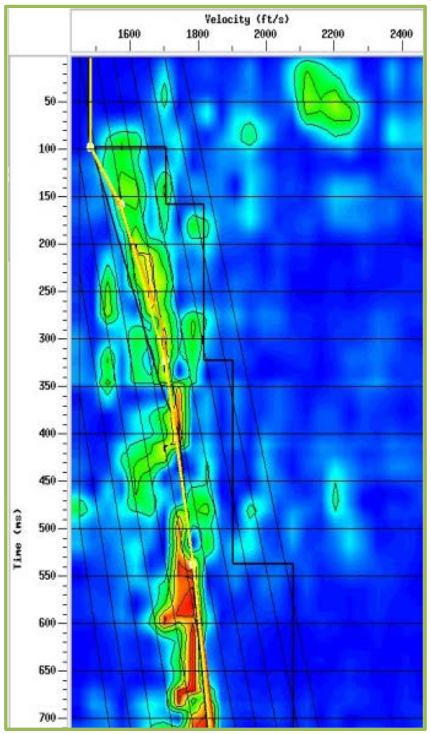
Review of Initial Velocity Model Building:

STEP 1: Stacking (RMS) velocity picking (Time)

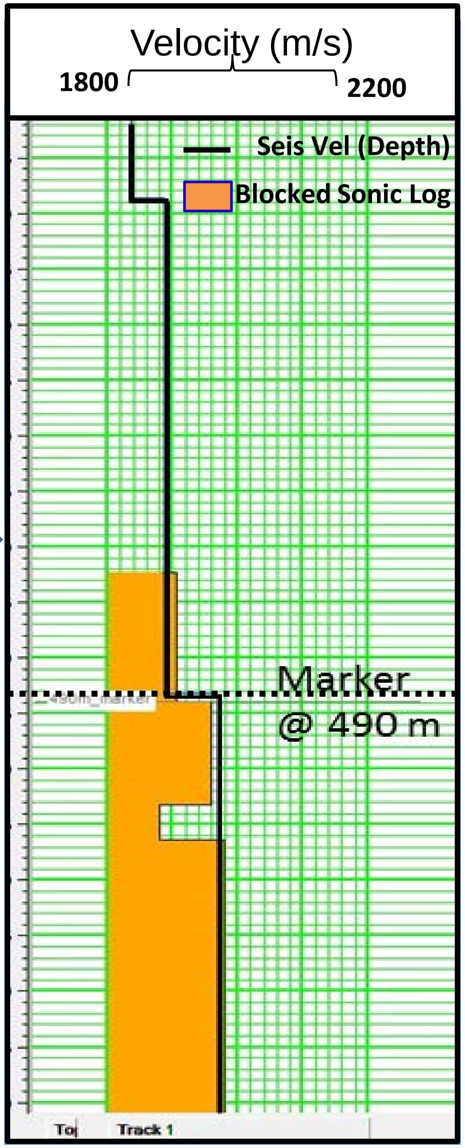
STEP 2: Convert RMS velocity to interval velocity using Dix Equation (Depth)

STEP 3: Convert Interval Velocity (blocky) to Average Velocity (smooth) *

1



2



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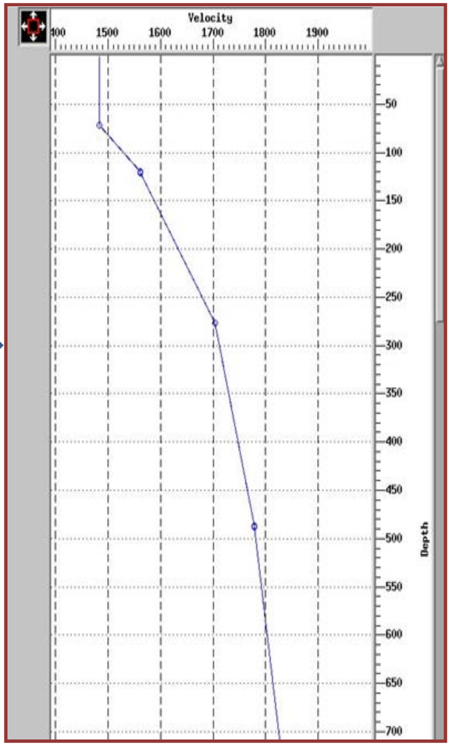
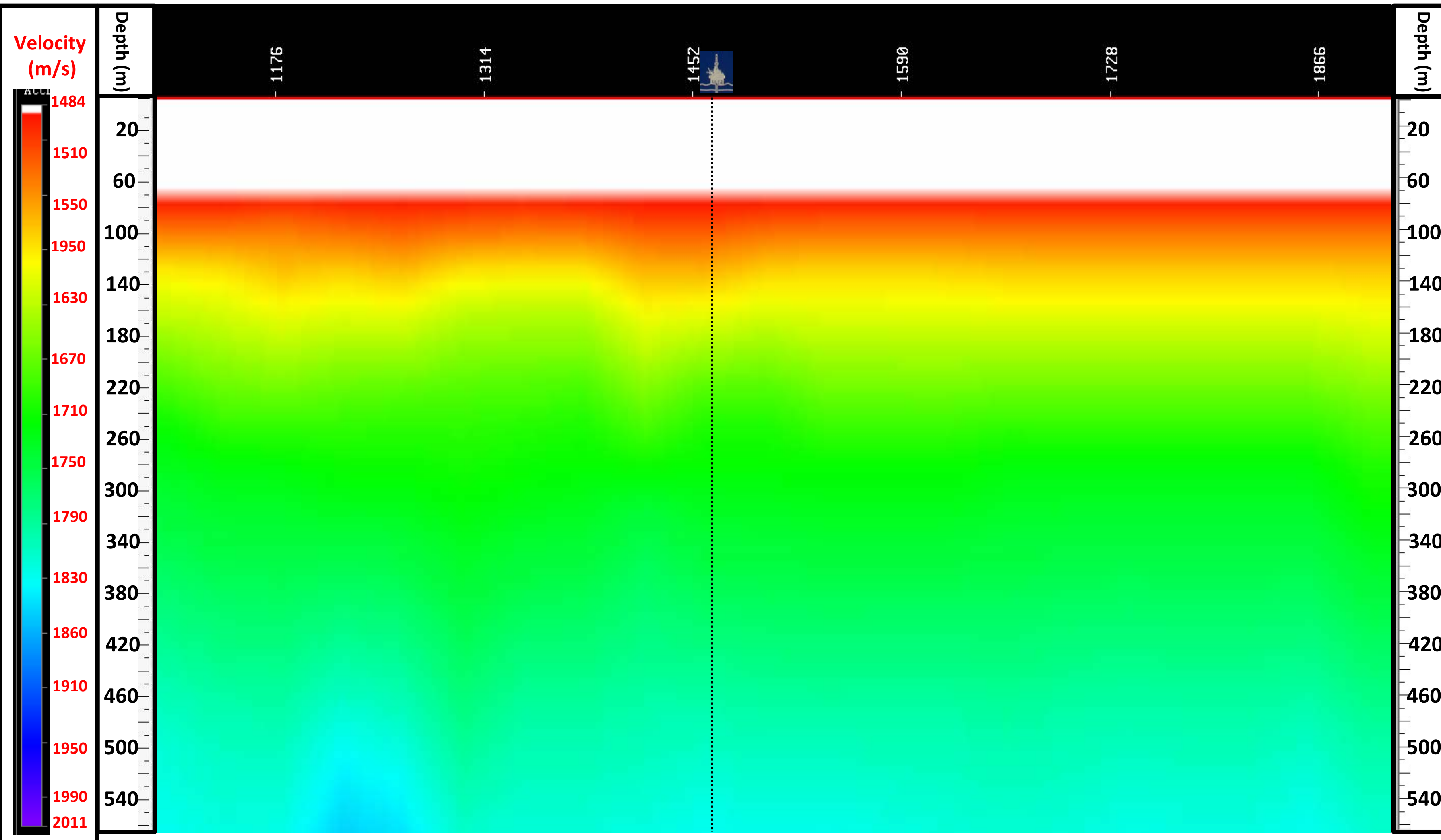


Seismic Interval velocity (depth) matches sonic log,

Initial model # 1 (In depth)



Well-14 Projected Location

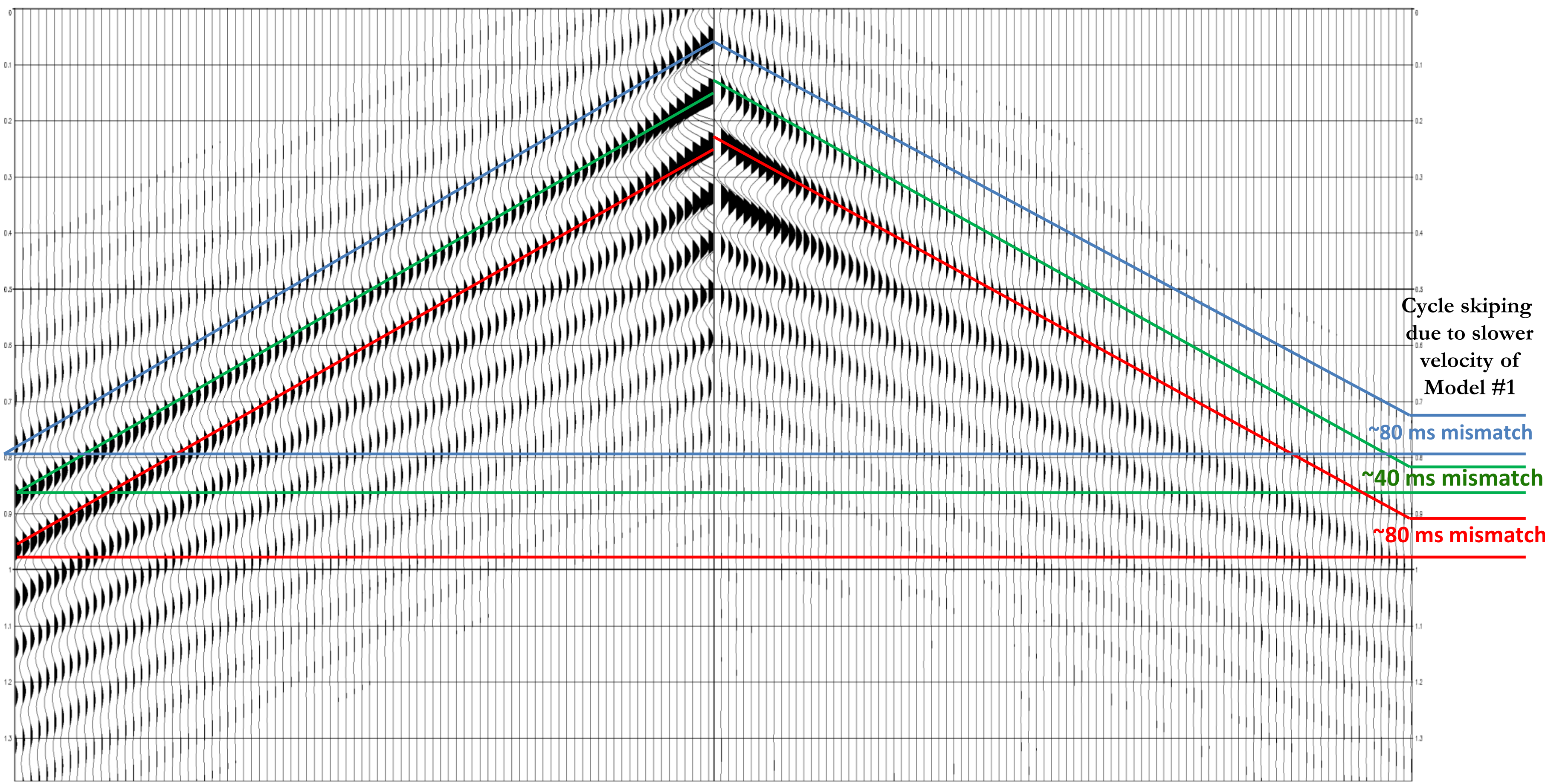
Synthitics generated using initial Model #1

Vs

90 data

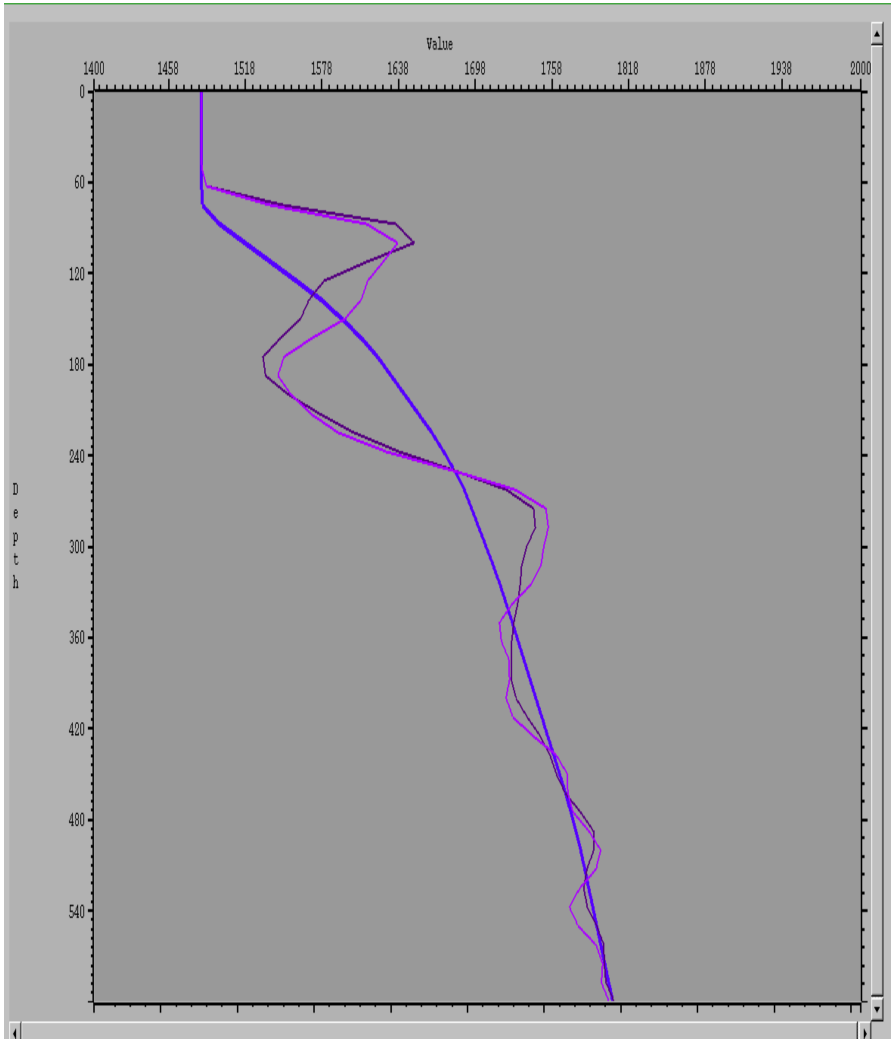
(both with bandpass filter 0-1-13-15),

large mismatch at far offset causing cycle skiping due to slow velocity in initial model#1



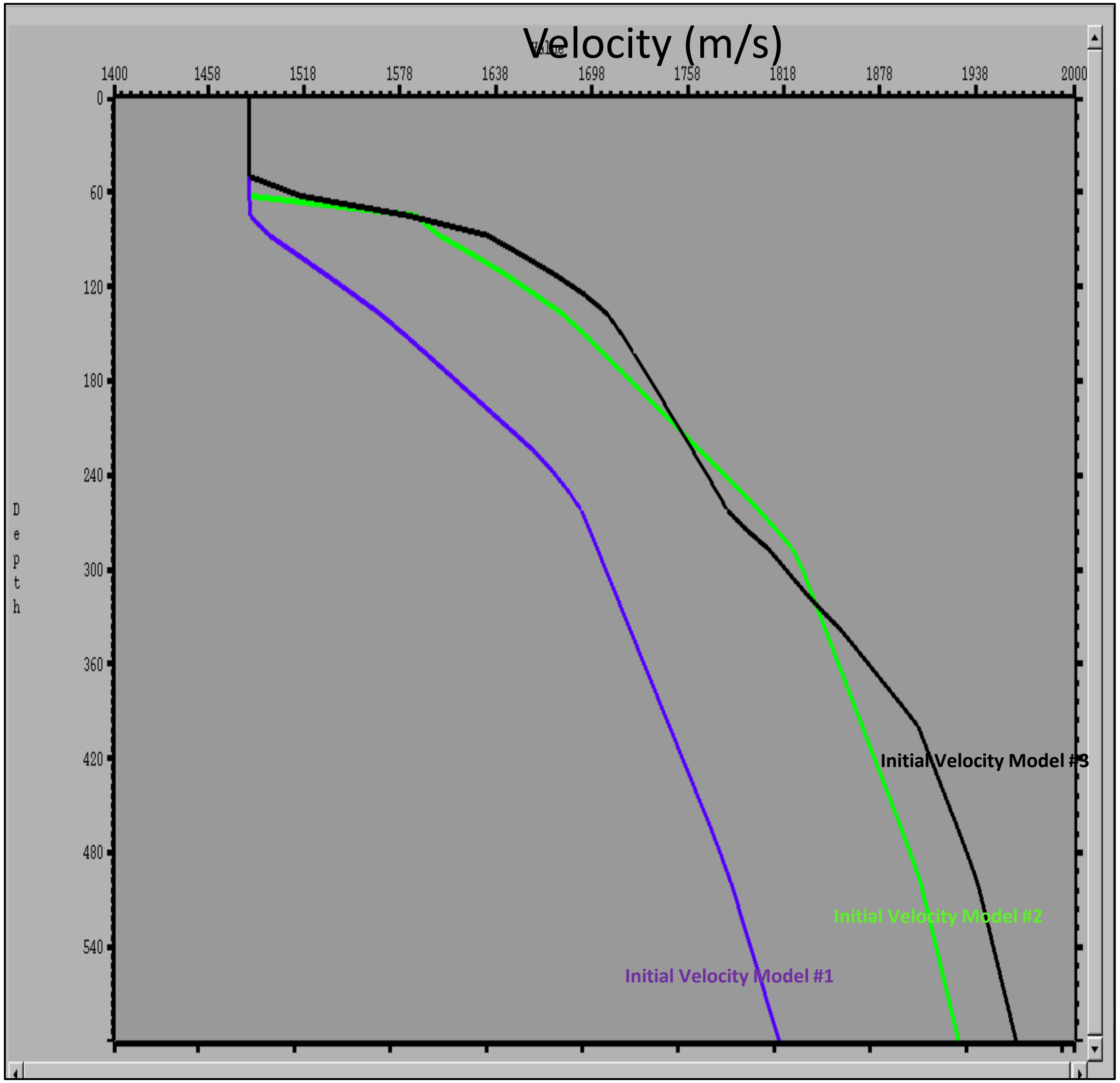
Synthitics **Field Data**

QC: One Vp Trace Inversion Test: Initial Vs Inverted



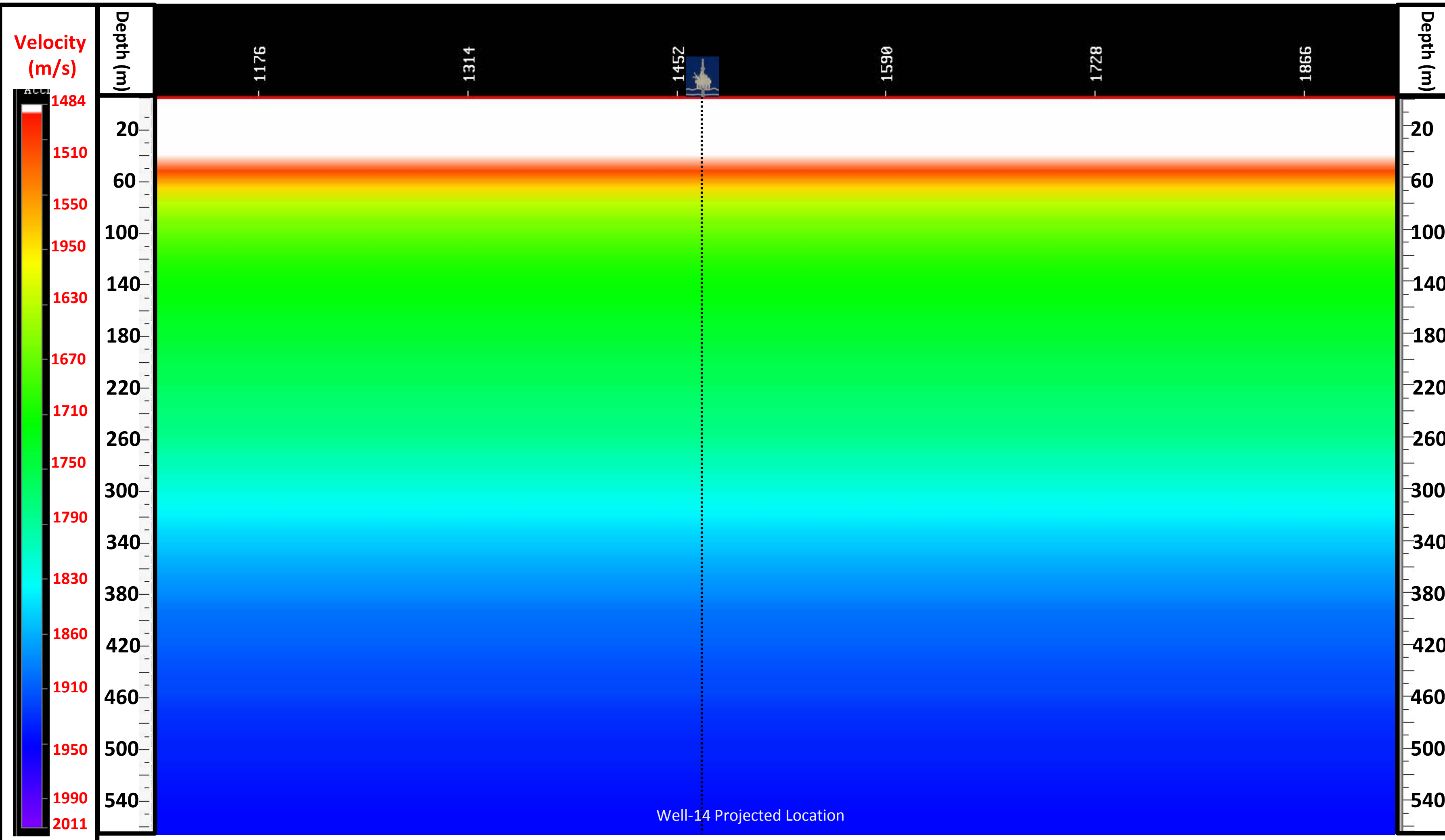
Comparison of the 3 Initial models:

As can be seen in forward modeling results generated using the 3 initial models (slides 23-24) , Model#3 gives the best fit with field data. Synthetic #1, #2 models results in far-offsets cycle skipping (time-shift mismatch between field and synthetics up to 80ms).



Initial Velocity Model #3: Input for Inversion#3

Created by multiplying the original initial velocity model (slow) by depth-variable increaments (6-9%). Water velocity kept unchanged. The synthitics produced using this model matches the field data reasonably well. Therefore, Inversion #3 is most realiable up to this point.



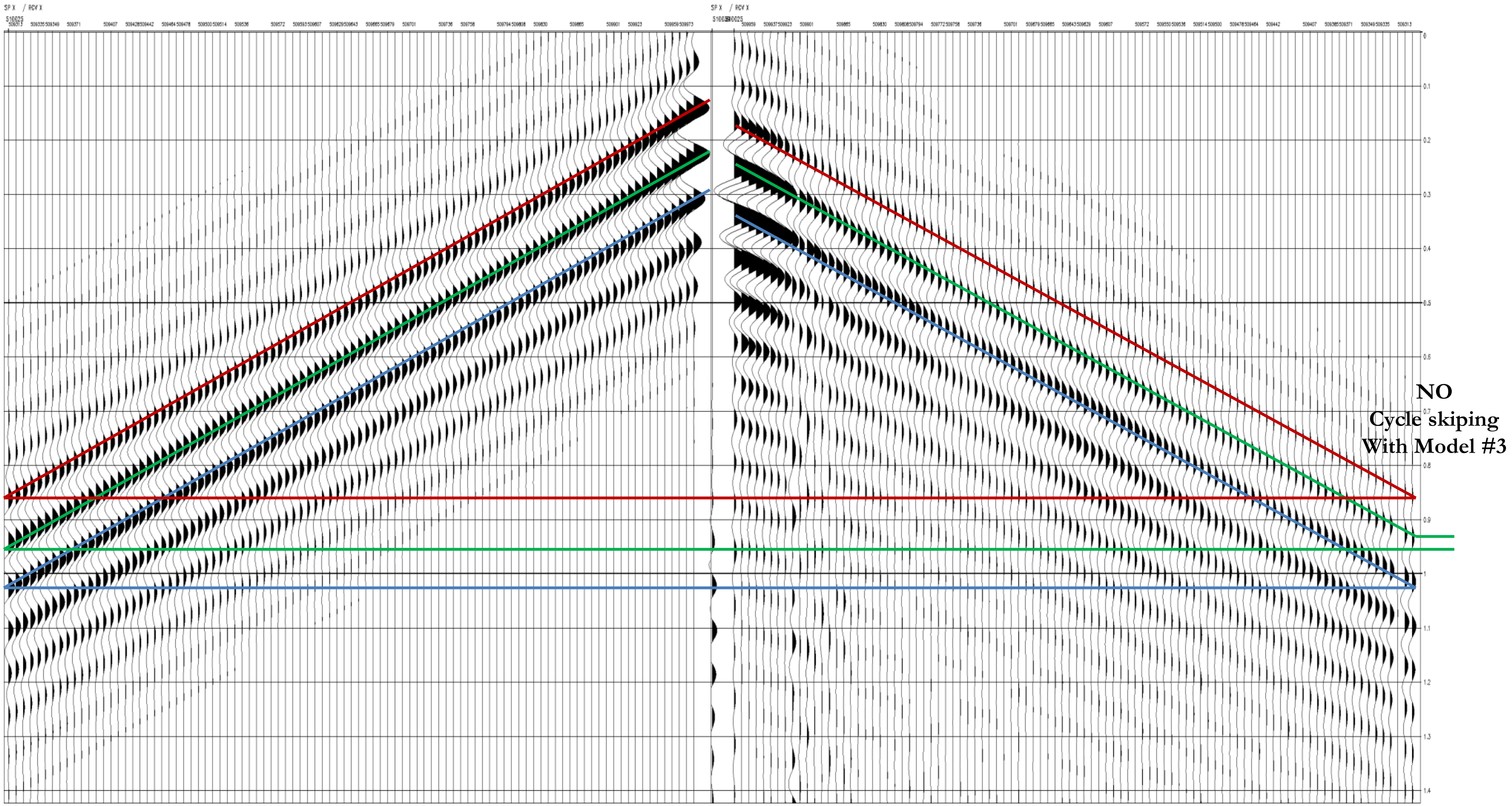
Synth Initial <u>model #3</u>

Vs

88 data (shot location-center of line)

(both with bandpass filter 0-1-13-15)

No Cycle Skipping



Synthitics

Field Data

Forward Modeling Conclusions

- Initial Velocity Model #3 produces synthetics that matches the field data reasonably well with no cycle skipping.
- Some events had a slight mismatch in near offset as well as far offset, but not to the extend it causes cycle skipping.
- Initial Model is still an area of improvment

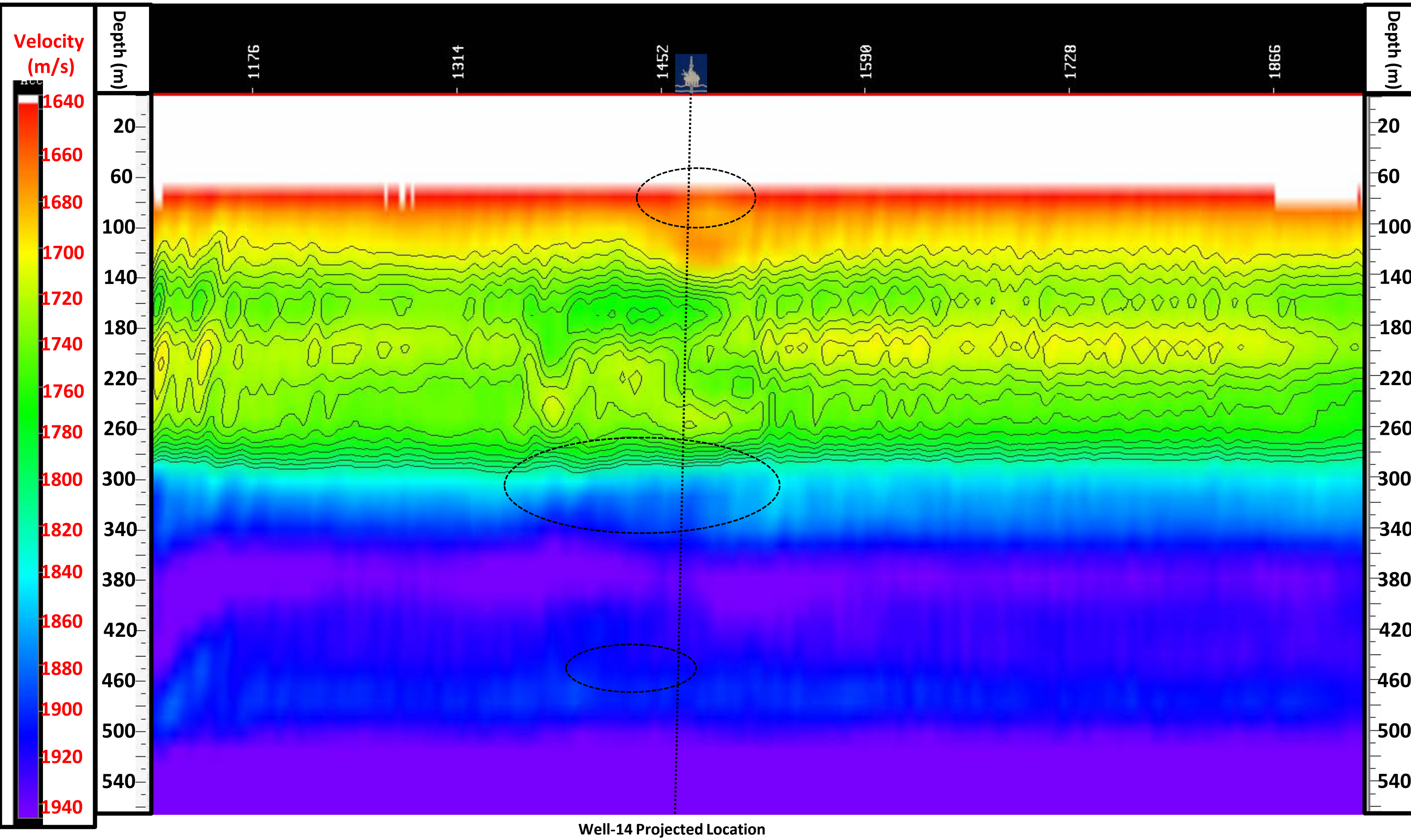
PART 2:

FWI Results (88 & 90 Data) & Discussions

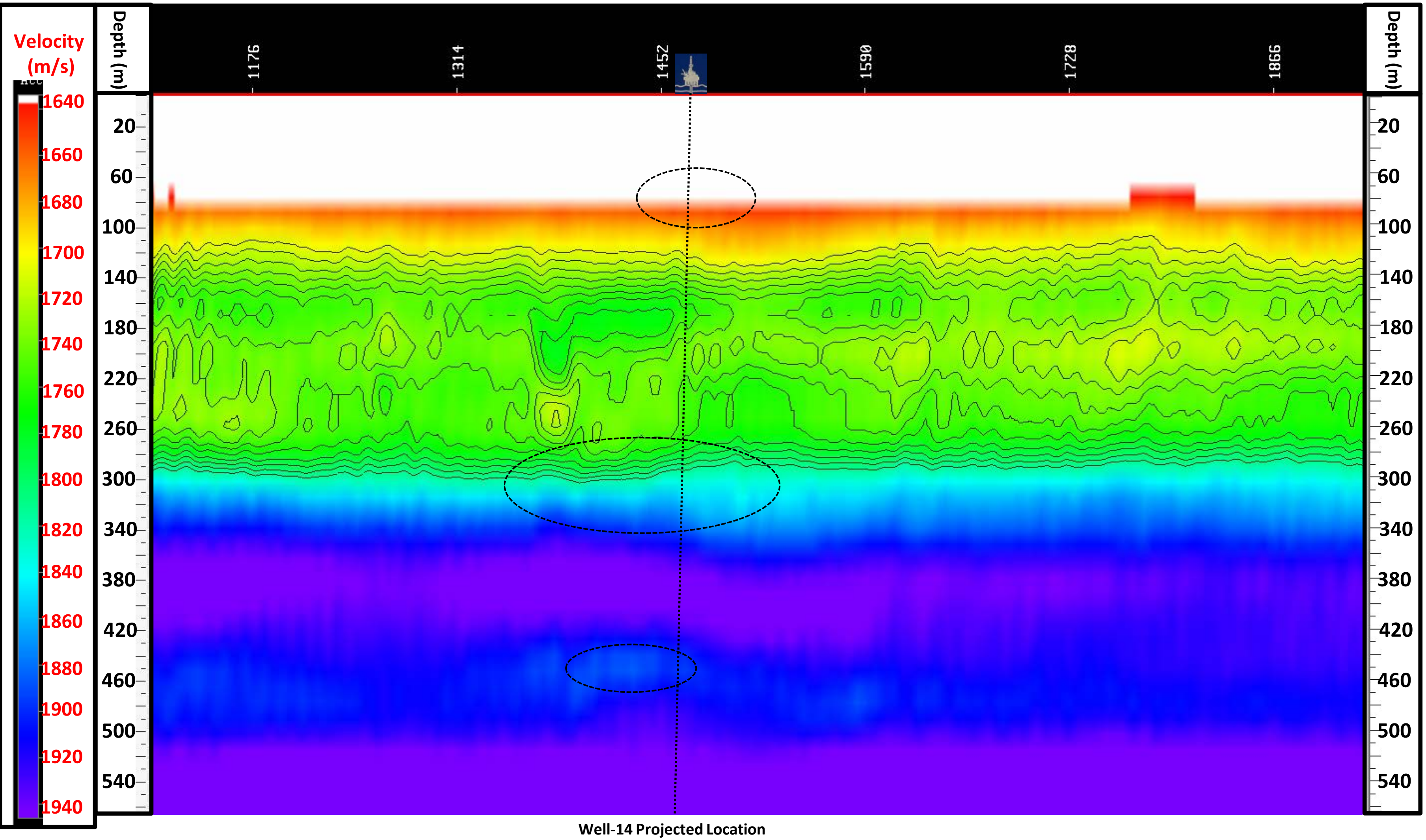
The method used is acoustic, finite difference, time domain method that updates the P-wave velocity using linearized least squares inversion process (adjoint-wavefield approach).

*(**Ratcliffe, et. al, 2011,** Full Waveform Inversion: a North Sea OBC case study, SEG, Expanded Abstract)

88 Inverted Velocity (iteration 16)

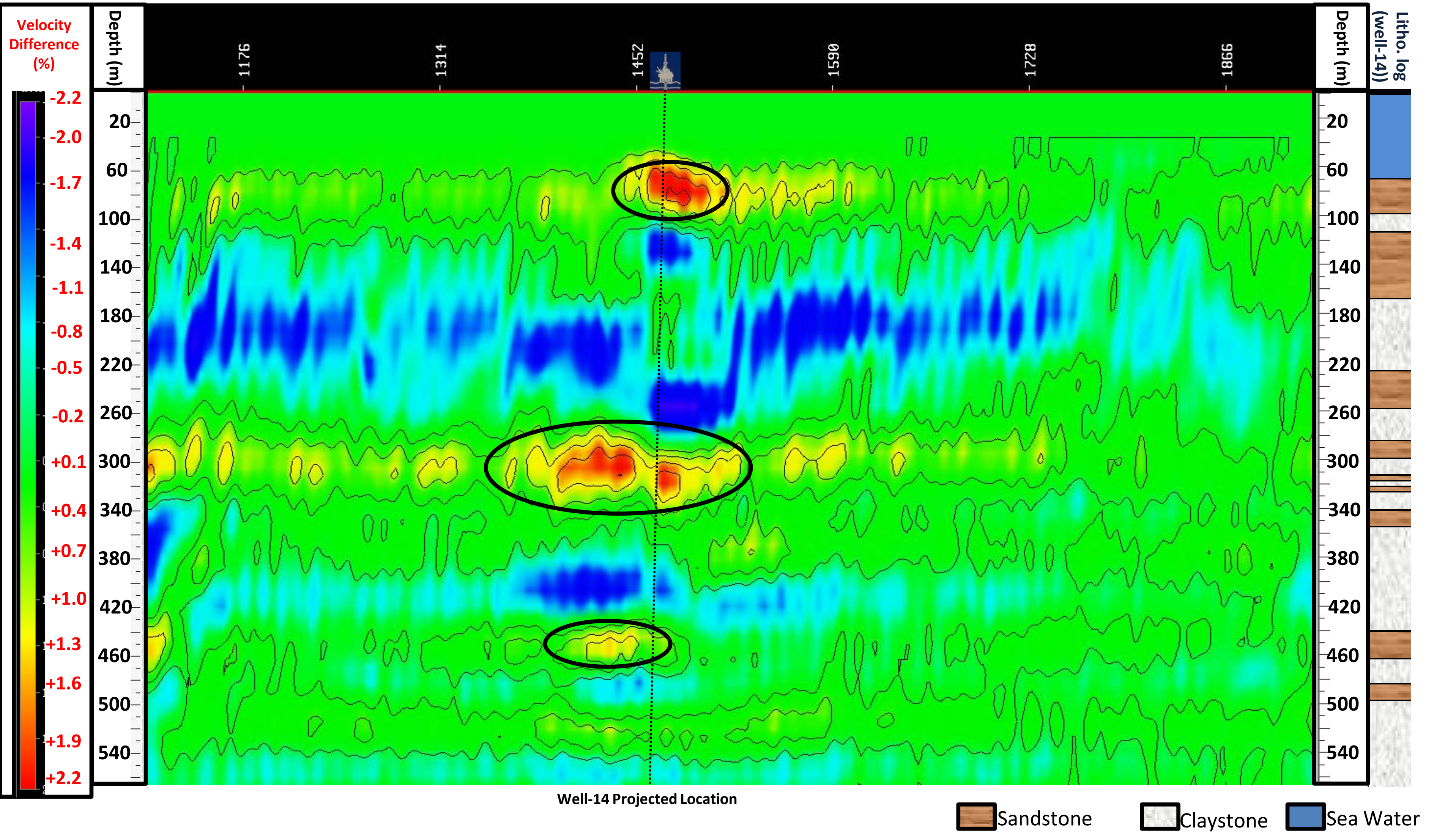


90 Inverted Velocity (iteration 16)

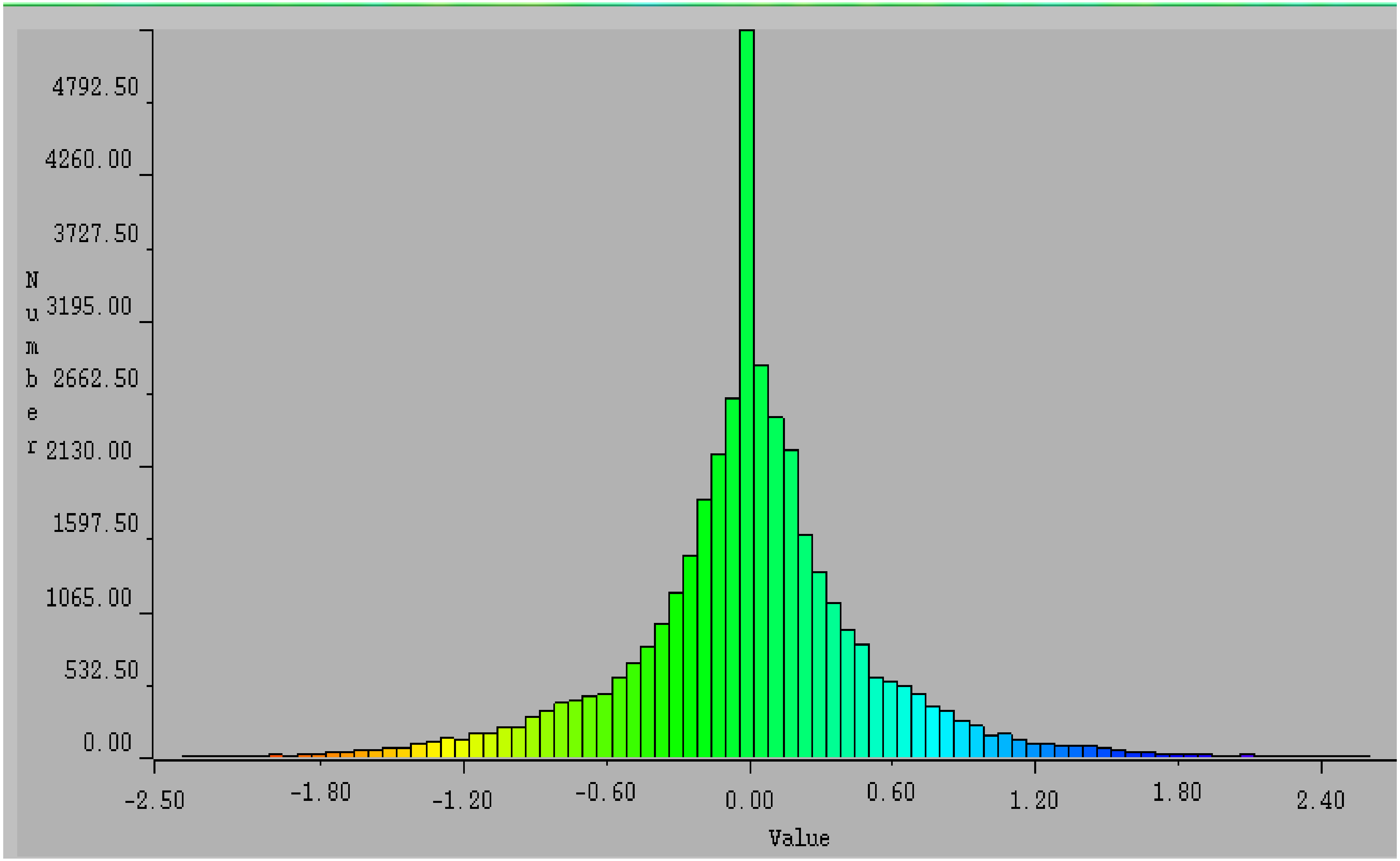


Velocity Difference (%) = ((88 vel. minus 90vel.)/88vel)x 100:

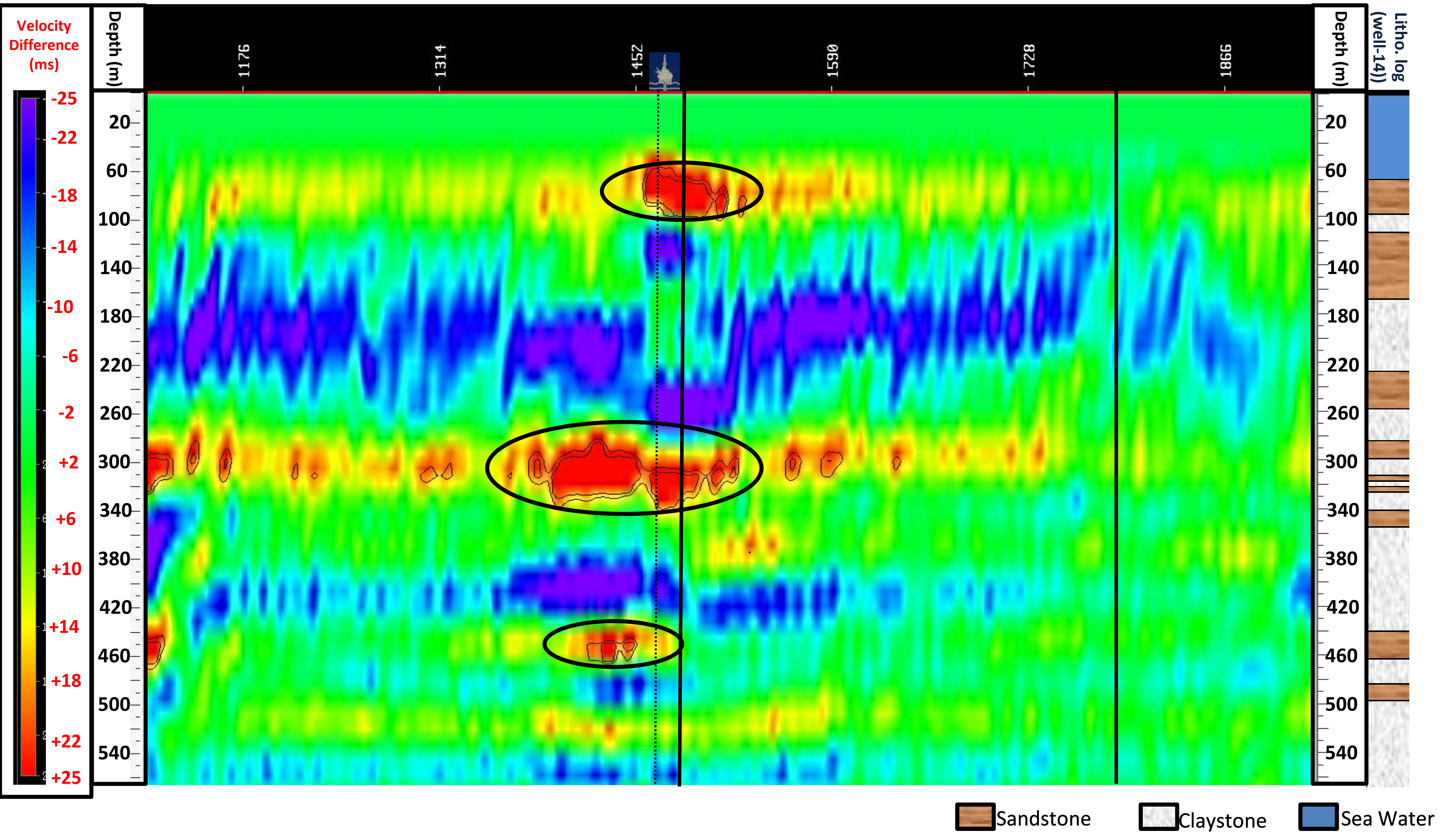
Red anomalies means 90 data is slower (gas present)



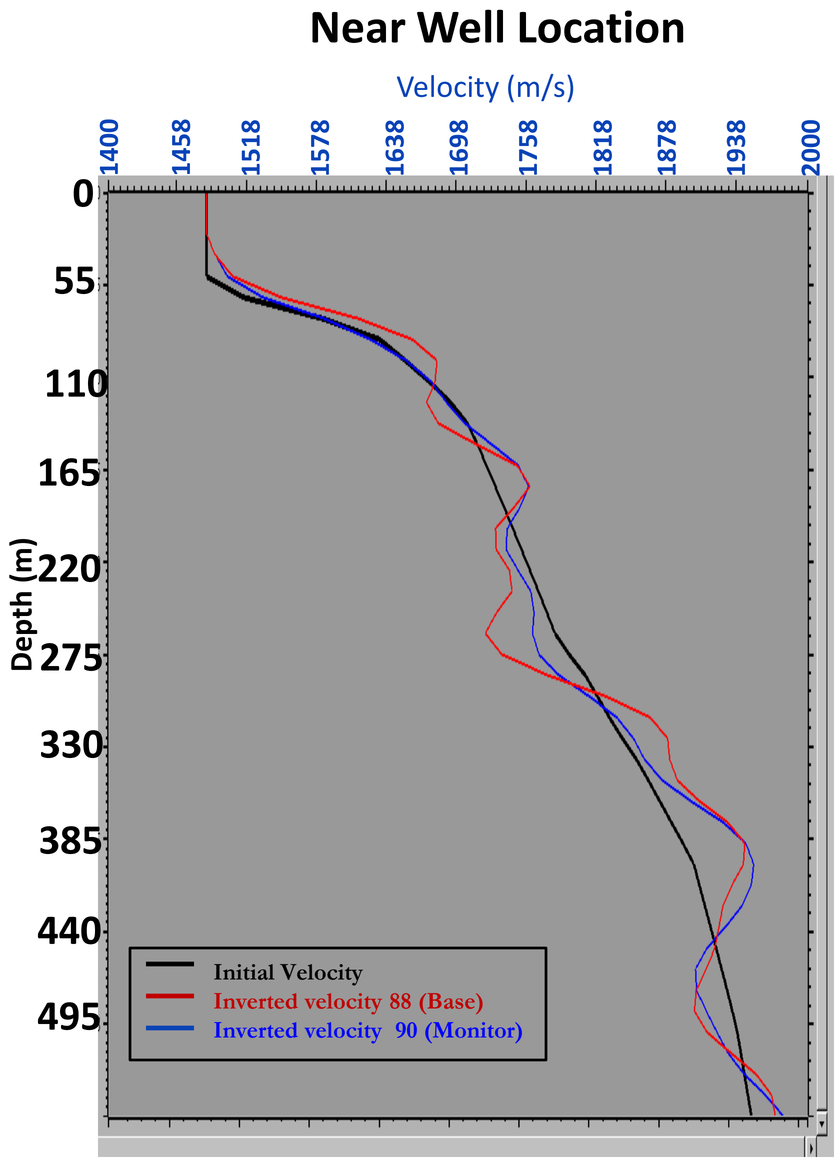
Difference (%) Histogram

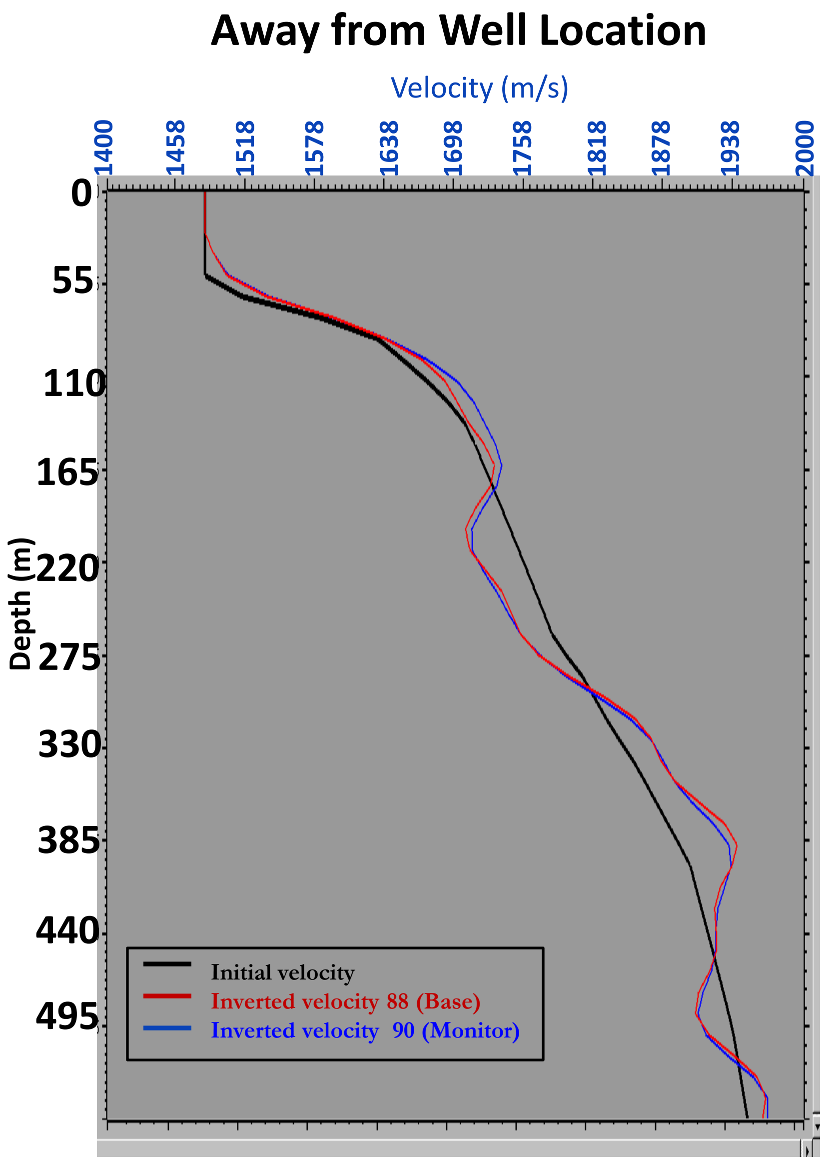


Inversion #3: Velocity Difference (m/s)
(88 vel minus 90 vel)
3 interesting anamolies indecating gas migration

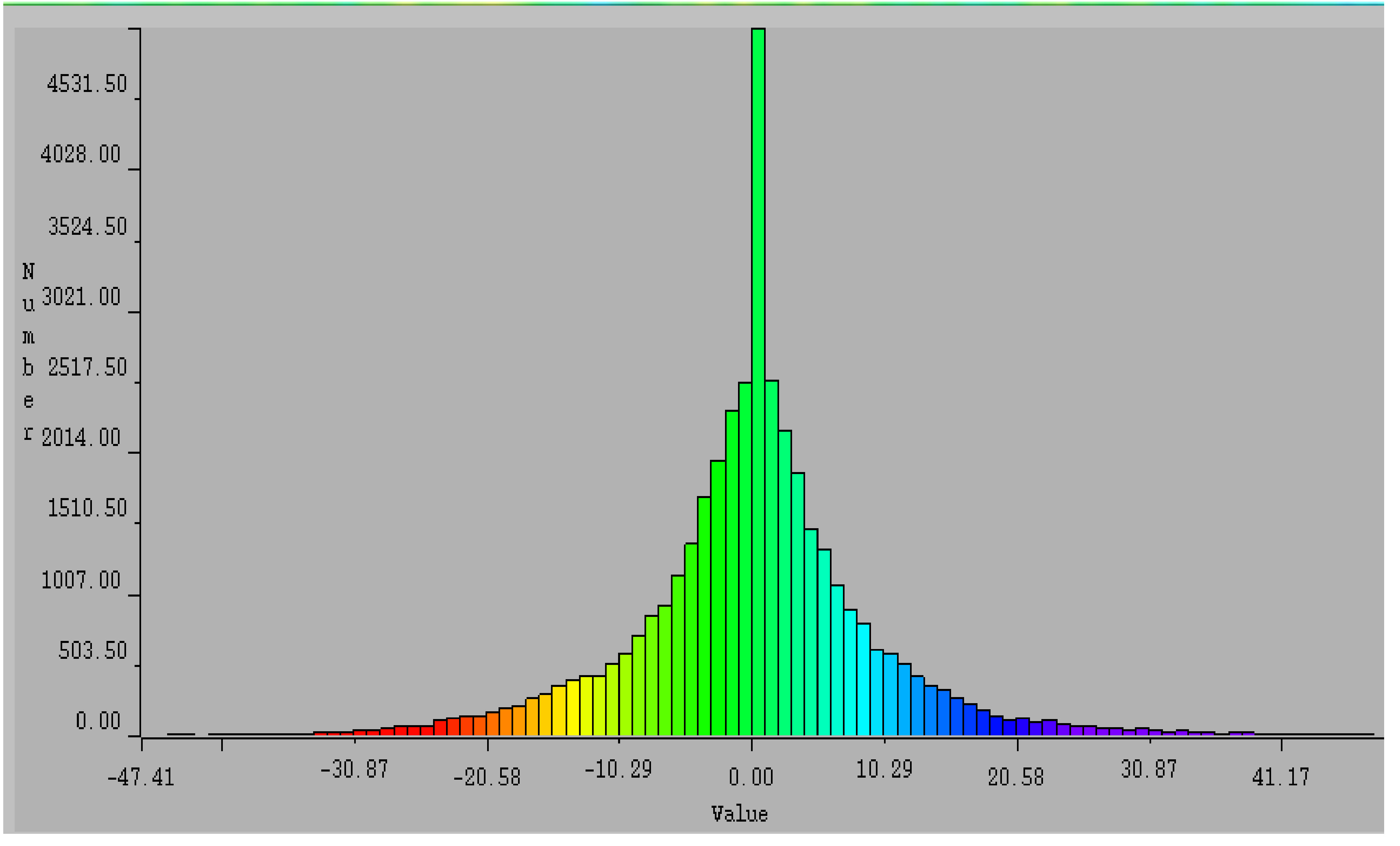


Vertical Velocity Profile





Histogram of Velocity Difference (m/s)



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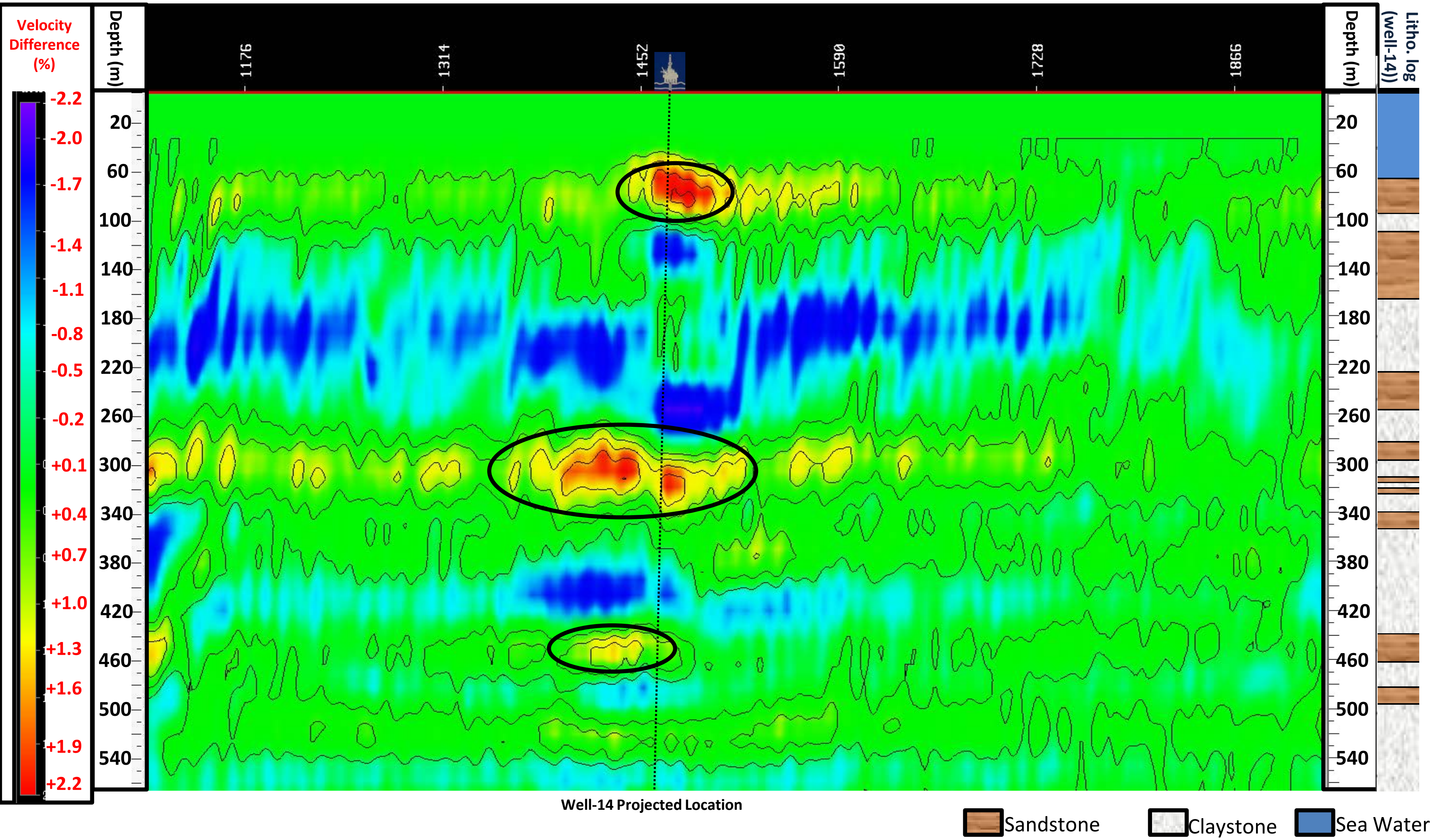


QC: Lateral Extent Vs. Time-shift

$$\Delta t \approx -l \frac{\Delta V_2}{V^2}$$ (Hossain and Landrø, 2011)

- **Sea-bed Anamoly:**

$$\Delta t \approx 279\,(m)\,\frac{40\,(\frac{m}{s})}{1640^2} \approx 4.1 \text{ ms}$$

- **Anamoly at Depth 300 m**

$$\Delta t \approx 507\,(m)\,\frac{30\,(\frac{m}{s})}{1770^2} \approx 4.8 \text{ ms}$$

Inversion-Results Conclusions

- With FWI we were able to detect small velocity differences (~30 m/s – 2.5%)
- FWI shows 3 velocity anomalies that indicates gas migration into sand layers
- On the other hand, the inversion results shows unexpected anamolies: indicating 88 data has lower velocity which doesn’t agree with the gas migration scenario.

Future Improvments

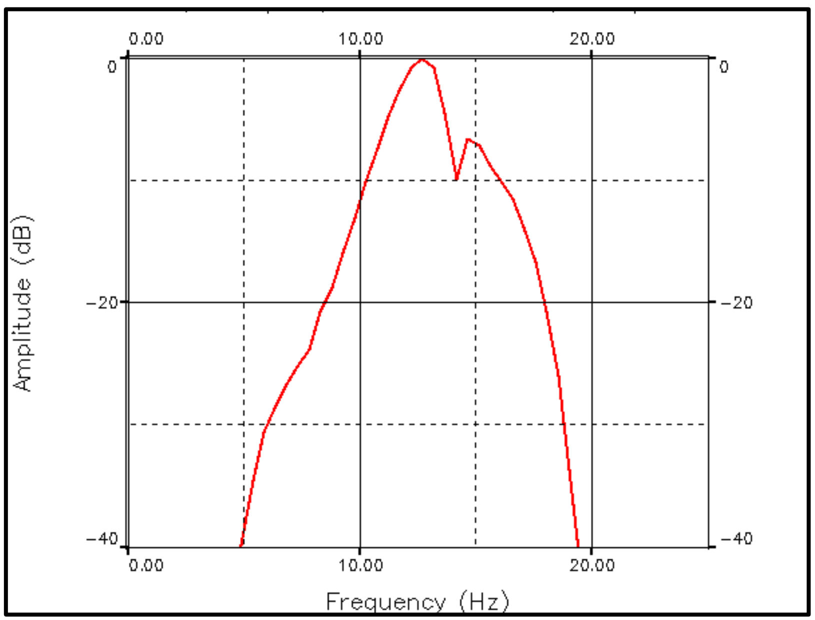
- Initial velocity model
- Incorporated density & anisotropy as an input for inversion.

Acknowledgments

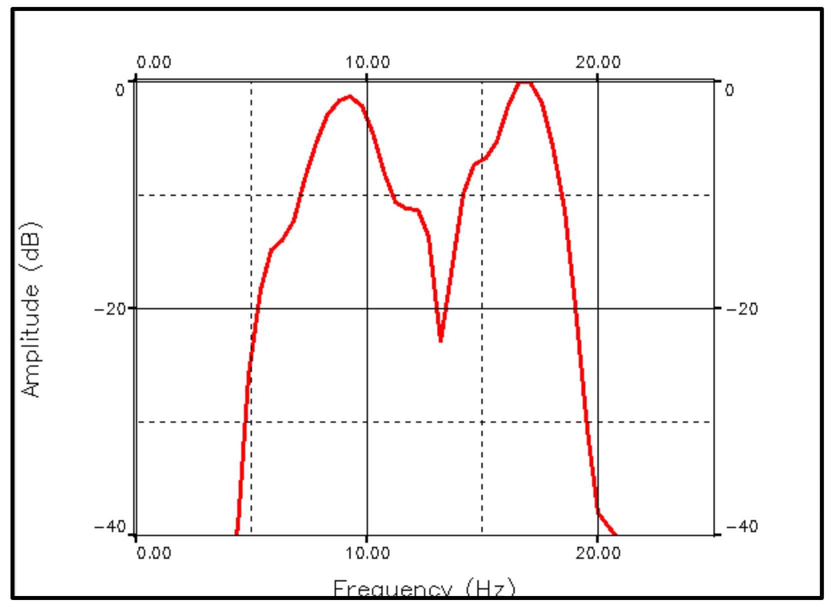
- **CGGVeritas;** Vetle Vinje & Andrew Ratcliffe
- **Statoil** and **Total** for permission to use the data
- **LOSEM-Consortium partners** for financial support **:** BayernGas, BP, Det Norske, CGGVeritas, Lundin, Statoil and Total
- **Saudi Aramco** for financial support of my PhD

Wavelet Modelling

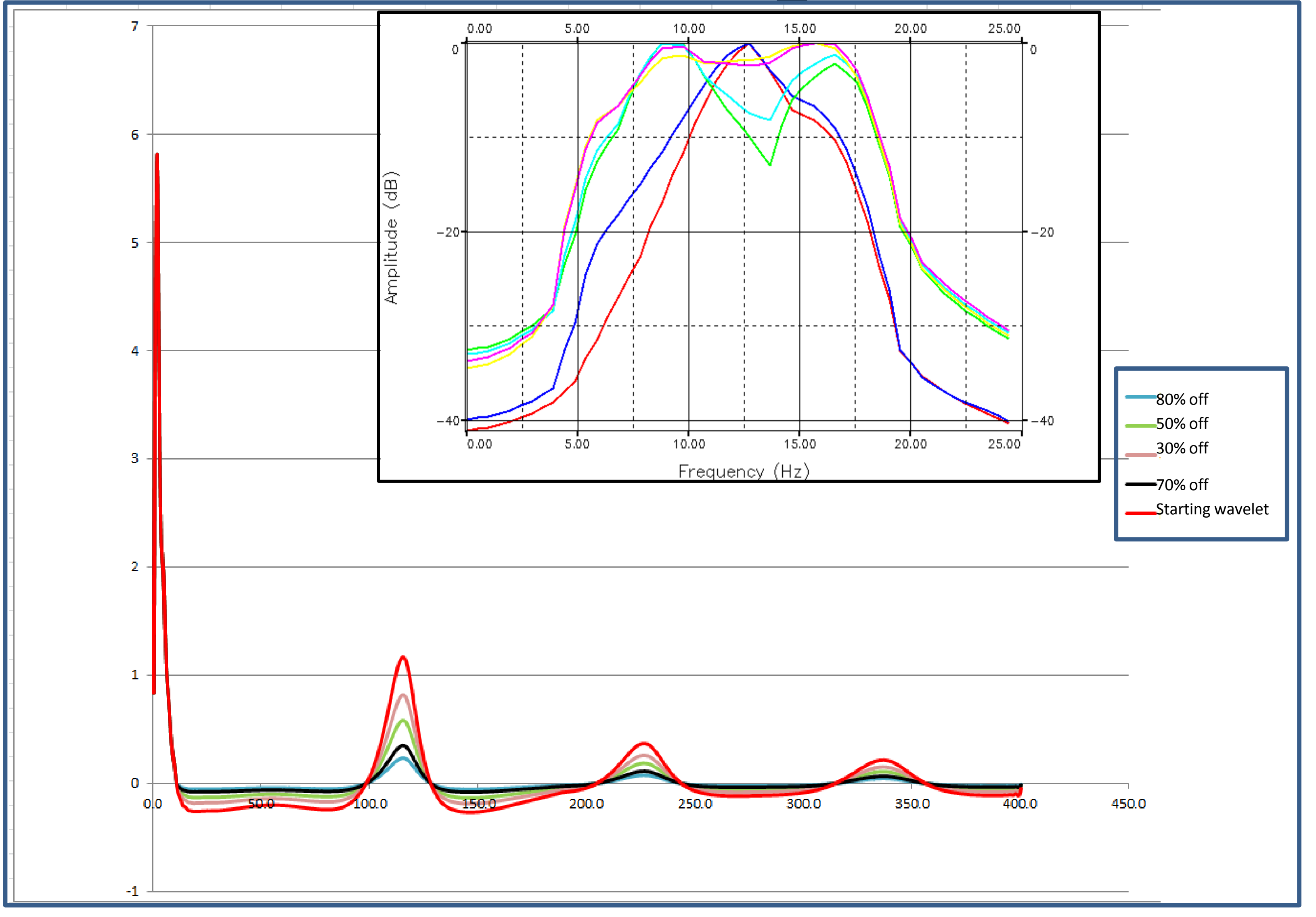
Amp. Spect. of Field Data(1988) with Bandpass filter (4-6-15-20)

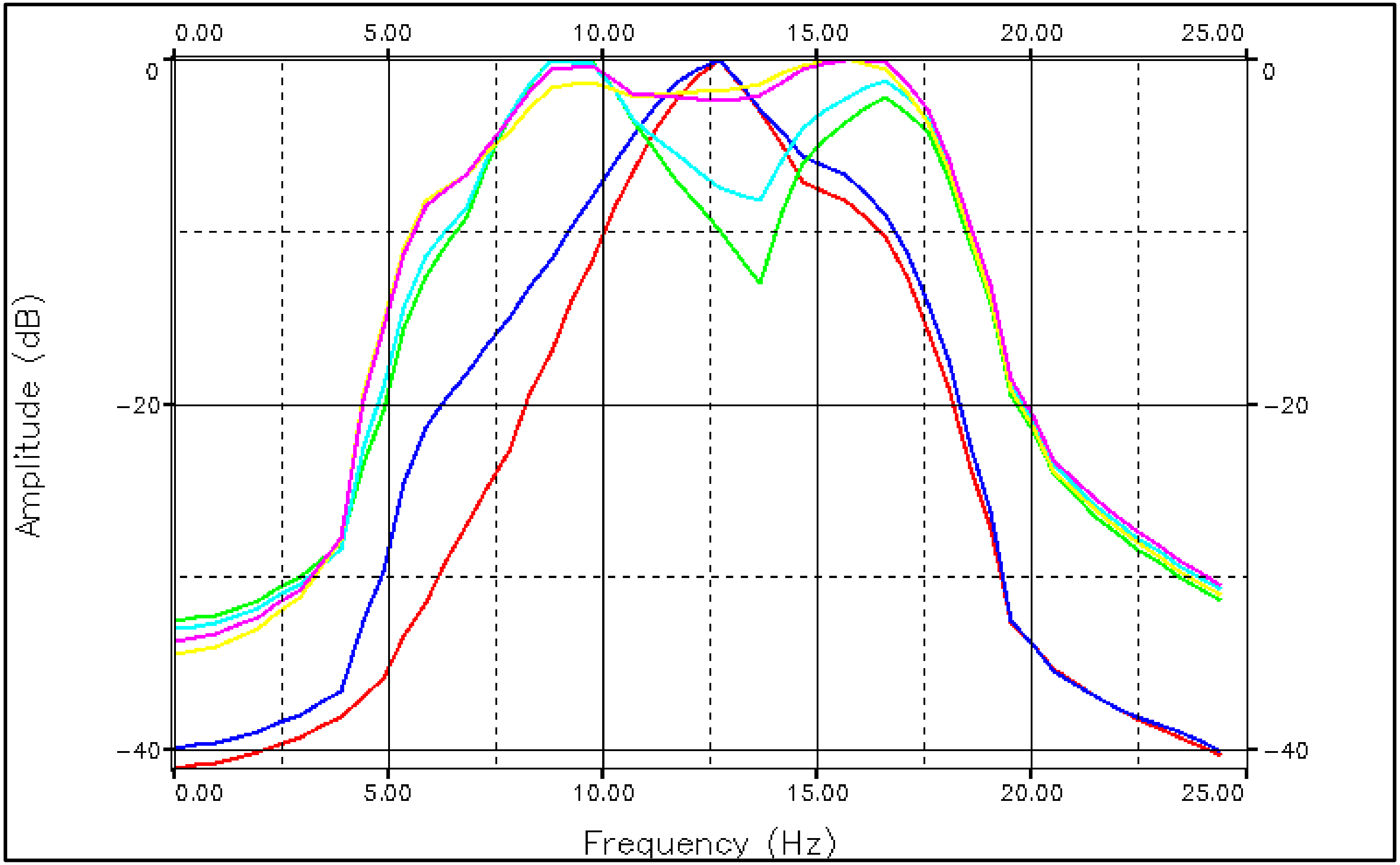


Synthetic Data with starting wavelet



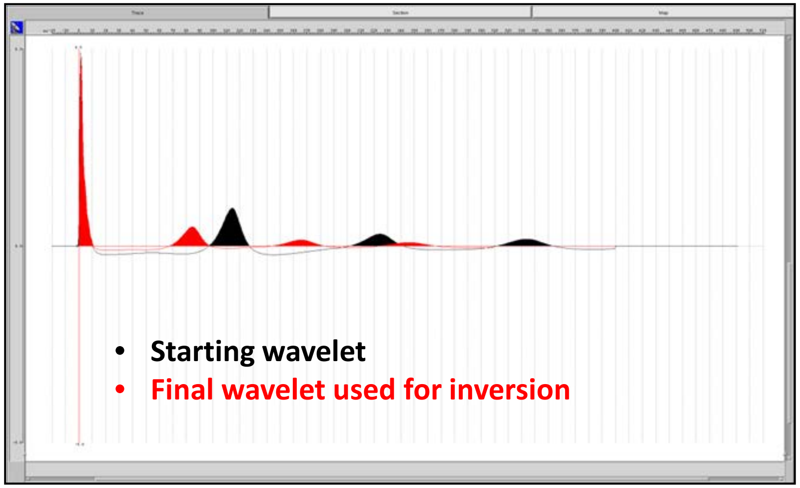
Bubble Scaling-Down

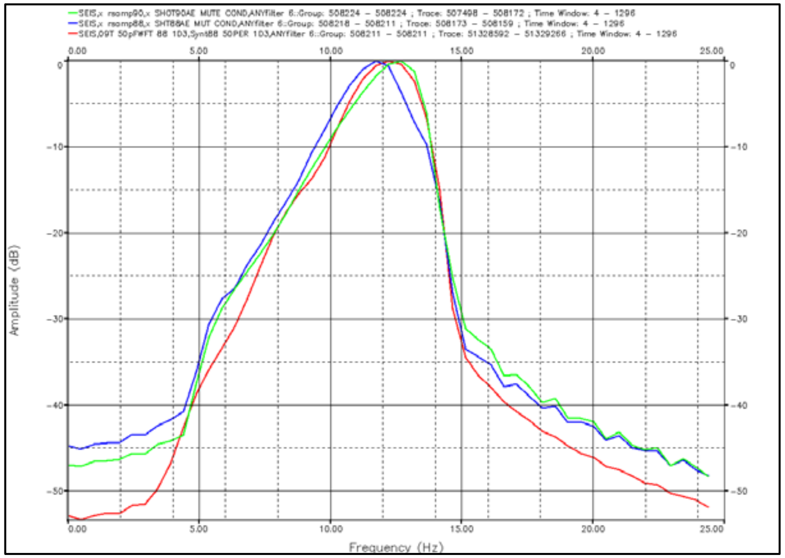




0.00
5.00
10.00
15.00
20.00
25.00
0
-20
-40
Amplitude (dB)
Frequency (Hz)

II. Wavelet Modeling





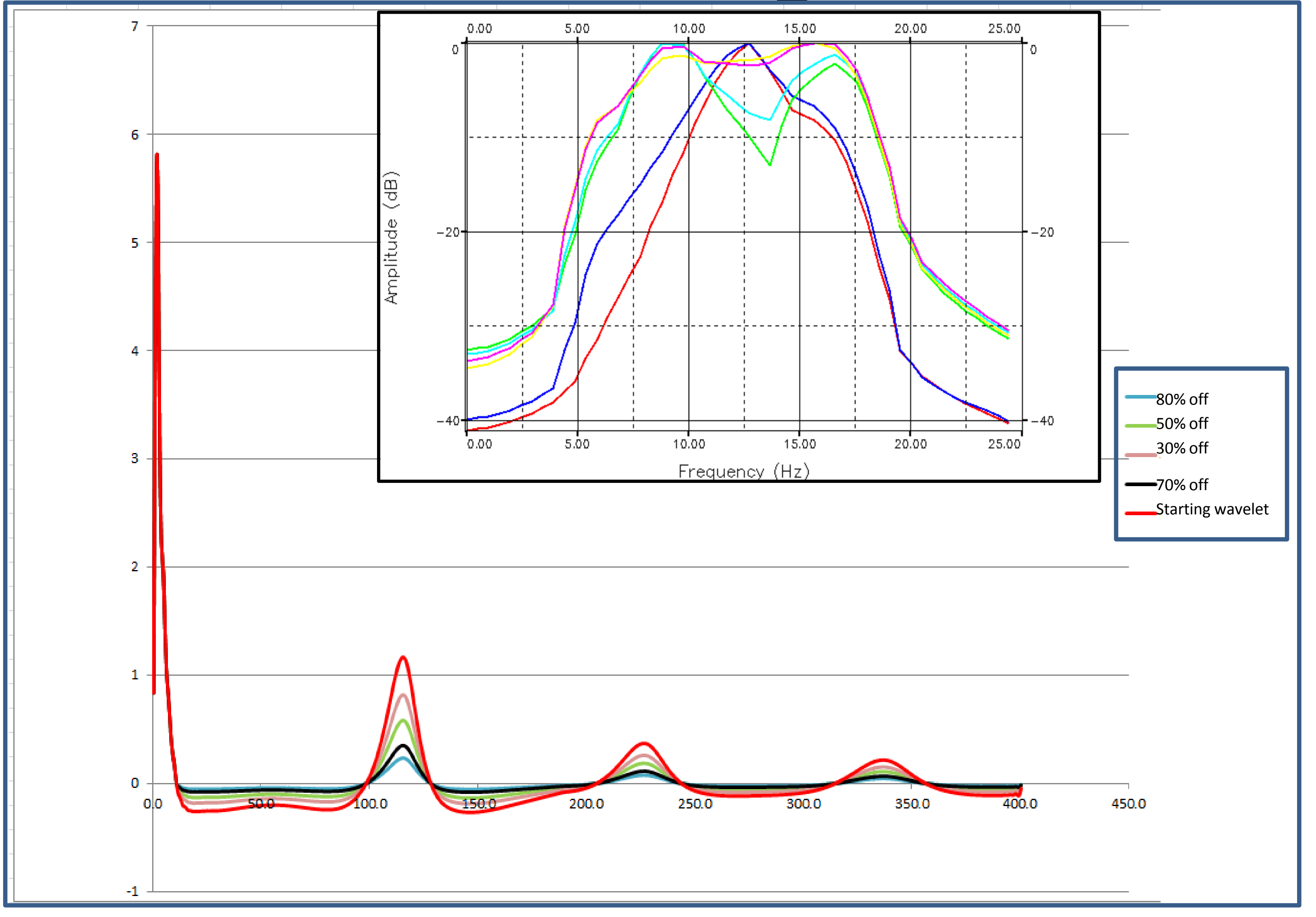
The follwoing corrections applied to the starting wavelet:

1. Bubble energy was reduced by (50%)

2. Bubble period was shorten to 81ms instead of 117ms in starting wavelet

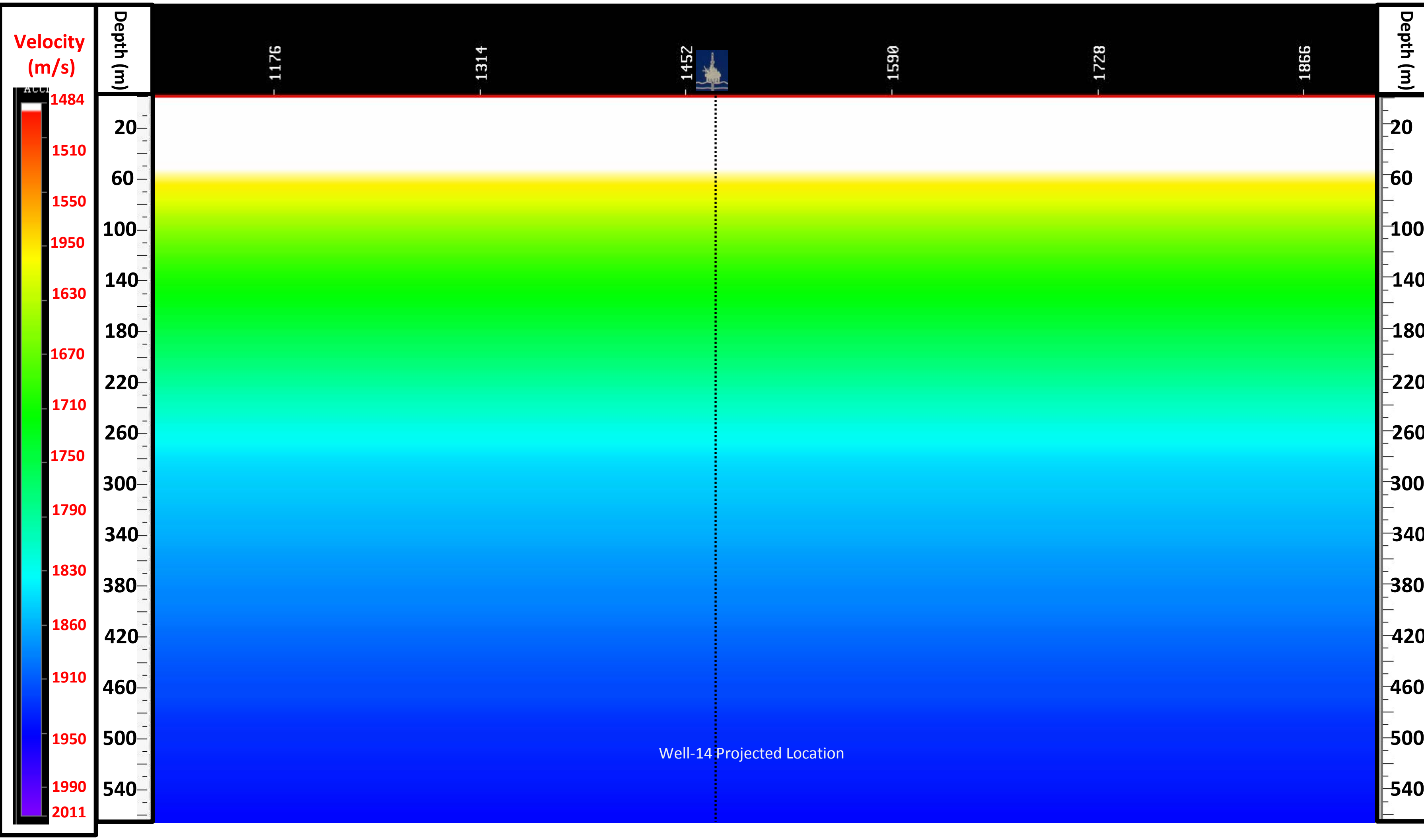
➔ **Nice match with seismic is obtained**

Bubble Scaling-Down

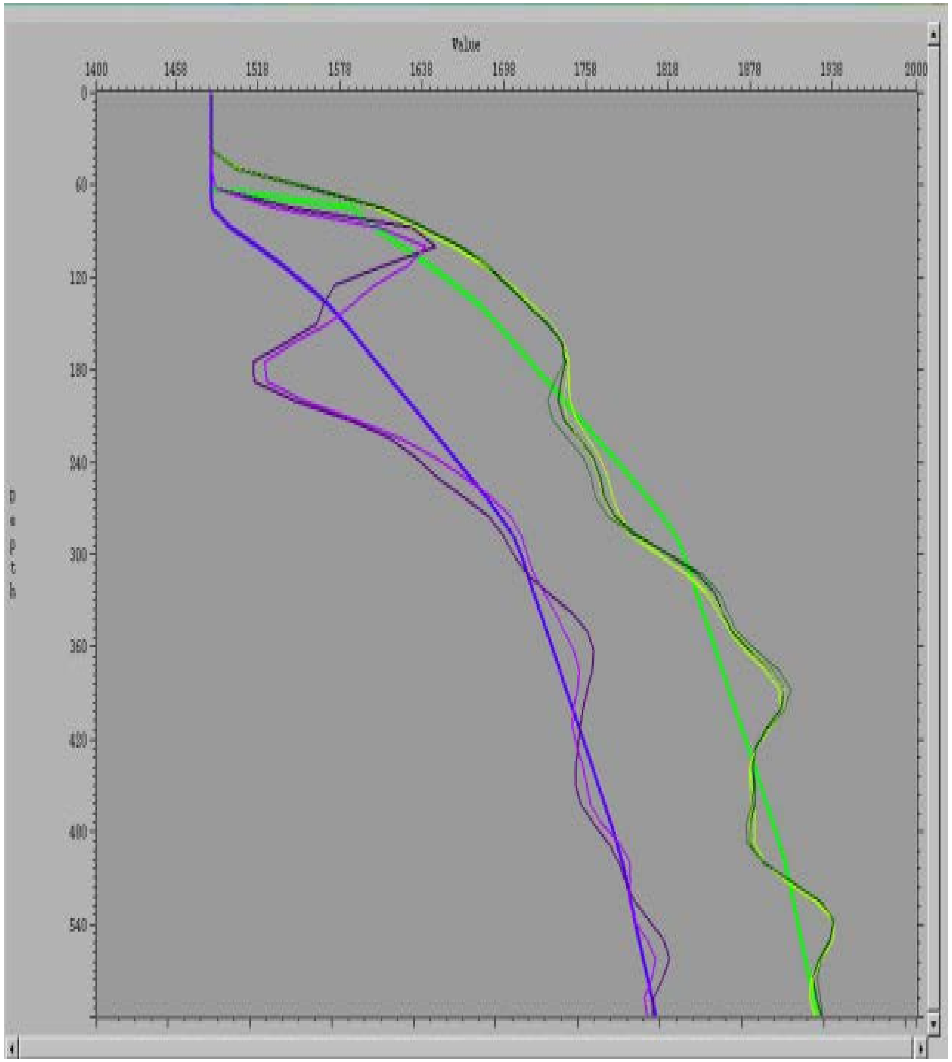


Initial Velocity Model #2: Input for Inversion#2

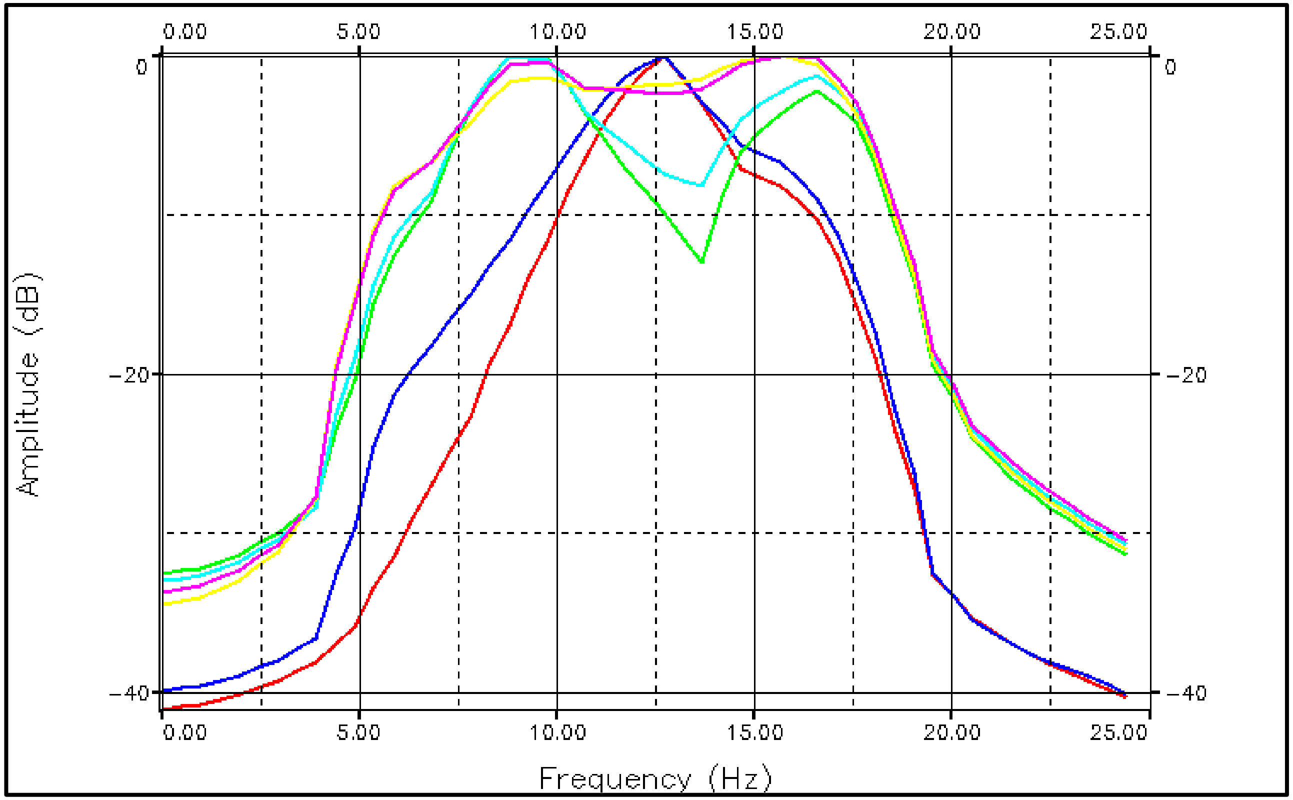
To compensate for improper smoothing, this model was created by multiplying the original initial velocity model (slow) by 1.07 (7% increment). Water velocity kept unchanged. However wasn't good enough.



Inversion #1 & #2:



Amplitude Spectrum Comparison:
Field data Vs Modelled Data with Different Primary/Bubble ratio



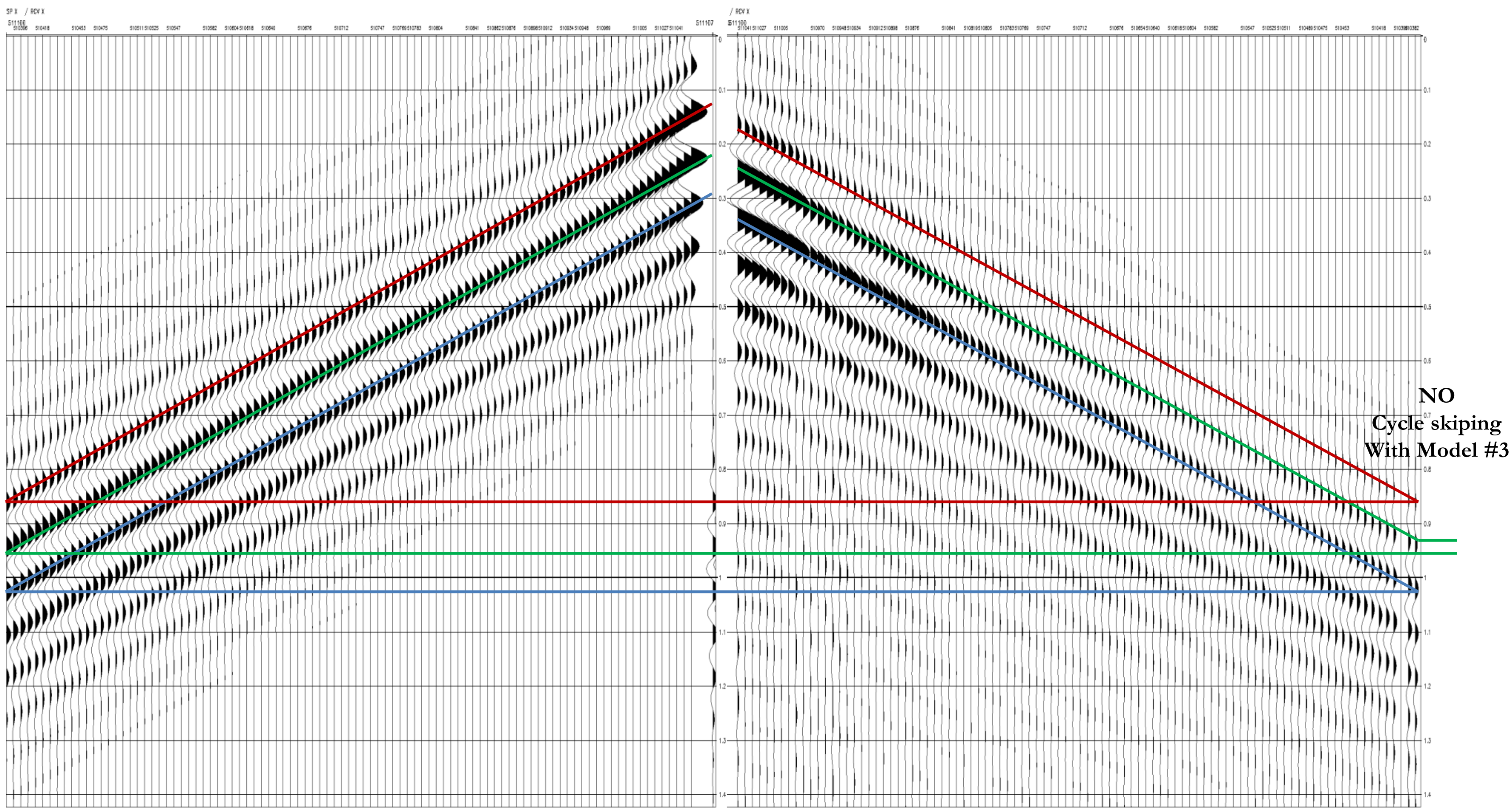
Synth Initial <u>Model #3</u>

Vs

88 data (shot location-Eastren Side of line)

(both with bandpass filter 0-1-13-15)

Again, No Cycle Skipping



Synthitics

Field Data

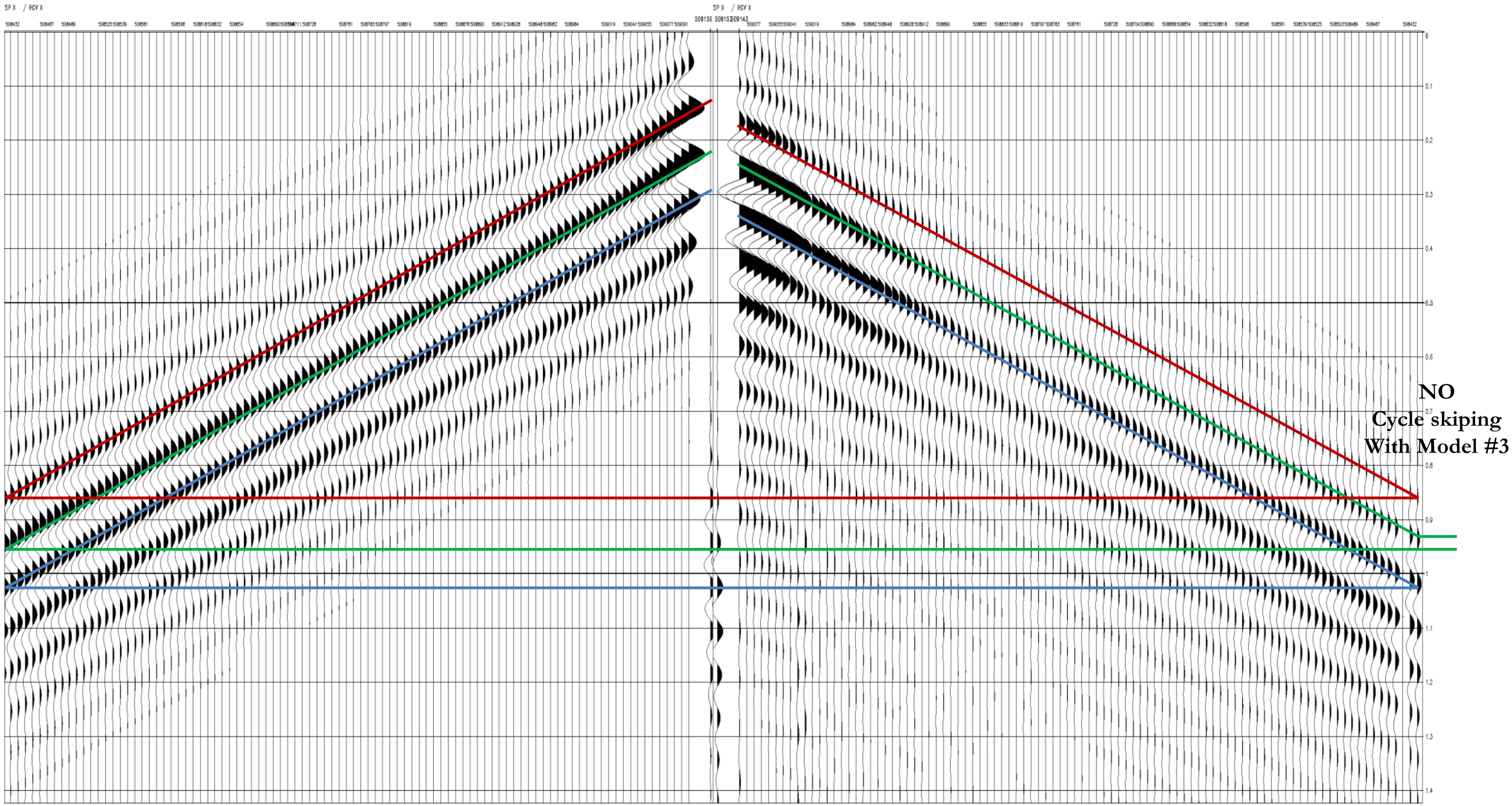
Synth Initial Model #3

Vs

88 data (shot location-Westren Side of line)

(both with bandpass filter 0-1-13-15)

Again, No Cycle Skipping



Synthitics

Field Data