Full Waveform Inversion for Complex Near-Surface Imaging Using SEG SEAM II Synthetic Model*

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Abstract

The Earth's complexity near the surface introduces many challenges in land seismic exploration. In arid areas such as much of the Middle East, karst features and unconsolidated sediments make the problem more difficult by introducing a complex velocity contrast, and complex anisotropy and attenuation problems, in addition to strong scattering of surface and body waves that interfere with the imaging of deeper structure. In this article, we tested and applied Full Waveform Inversion as a high-end technology in velocity model building and seismic wave migration for imaging complex near-surface structure having small-scale geological features using the Arid SEAM Phase II synthetic model.

Full waveform inversion for complex near-surface imaging using SEG SEAM II synthetic model

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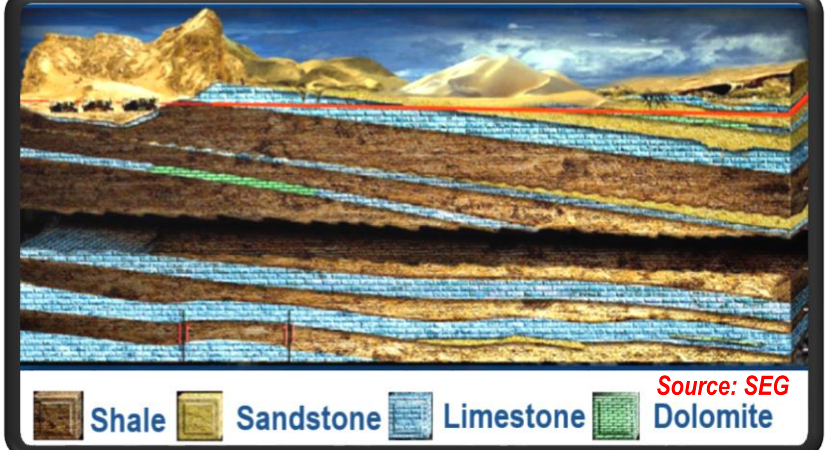


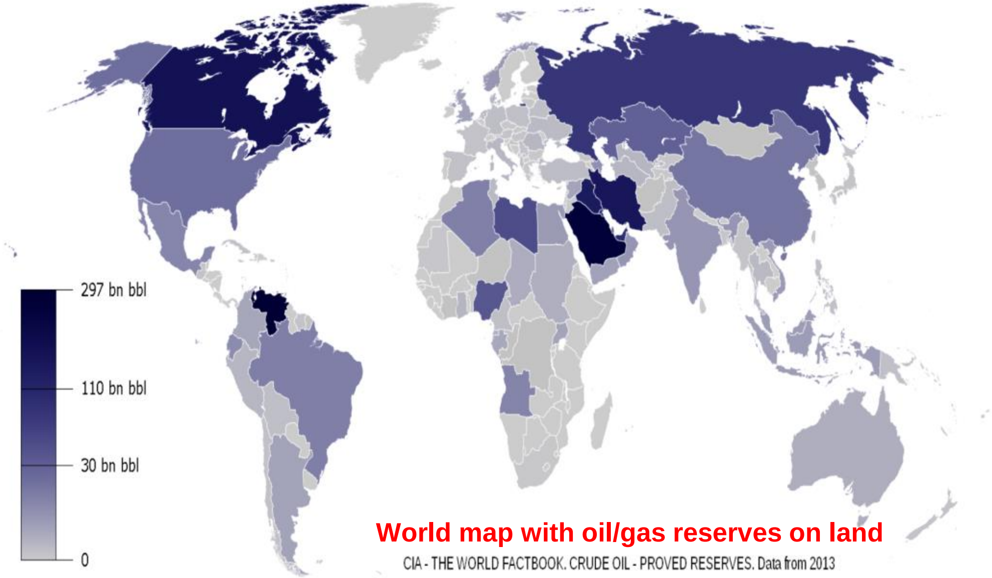
Motivation

Approximately 2/3 of the remaining conventional oil and gas reserves are on land.

Growing challenges of land hydrocarbon exploration place increasing demands on accurate, high resolution 3D seismic images to identify unconventional and low relief reservoirs with small extension.

Traditional geophysical tools for near-surface velocity reconstruction such as refraction and diving wave tomography have limited success for cases with near-surface velocity inversion and strong lateral heterogeneity.

Drilling optimization and efficiency decreases in karstic areas.



World map with oil/gas reserves on land

CIA - THE WORLD FACTBOOK. CRUDE OIL - PROVED RESERVES. Data from 2013

Outline

- Problem definition & research objectives
- Shallow geology of Arabian Gulf & SEG SEAM Phase II Arid Model
- FWI theory, workflow & Challenges
- Seismic data processing & Initial model building
- Acoustic FWI on viscoelastic
- Conclusions

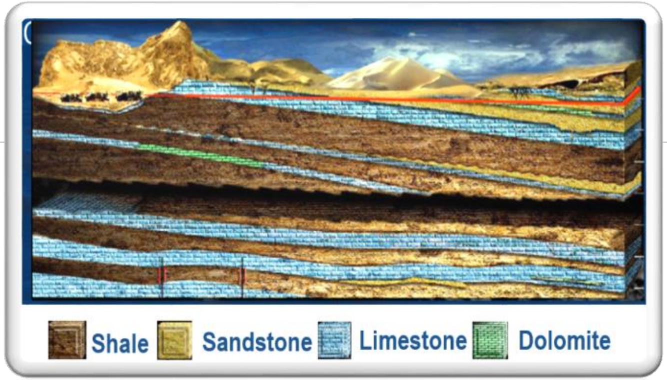
Problem Definition

Complex near-surface geology

- Karst
- Low velocity unconsolidated sediments
- Stream channels
- Hard outcrop refractors

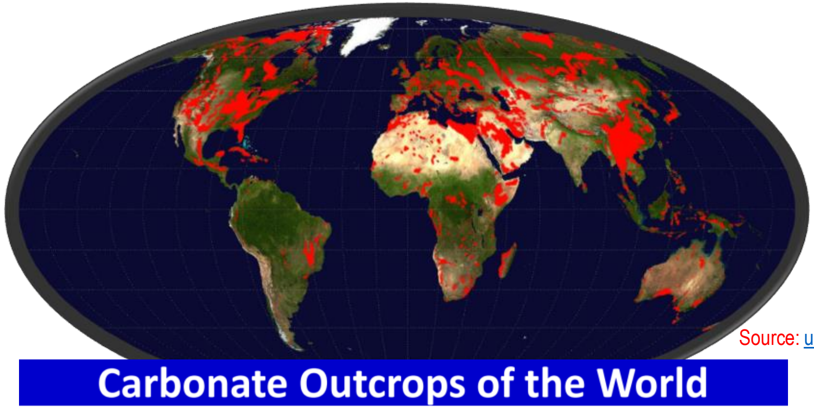
Problems caused by these complexities

- Scattering of seismic energy
- Distorting and degrading images of underlying structures.



Source: SEG

In case of intercalated thin beds of Carbonates and Dolomite (high velocity) and Sandstone and Shale (low velocity), refraction and diving wave tomography won't define low velocity layers.



Source: ulrichstill

Karst is an **irregular limestone region** with sinkholes, underground streams, and caverns largely shaped by the dissolving action of water on carbonate bedrock (usually limestone, dolomite, anhydride or marble).

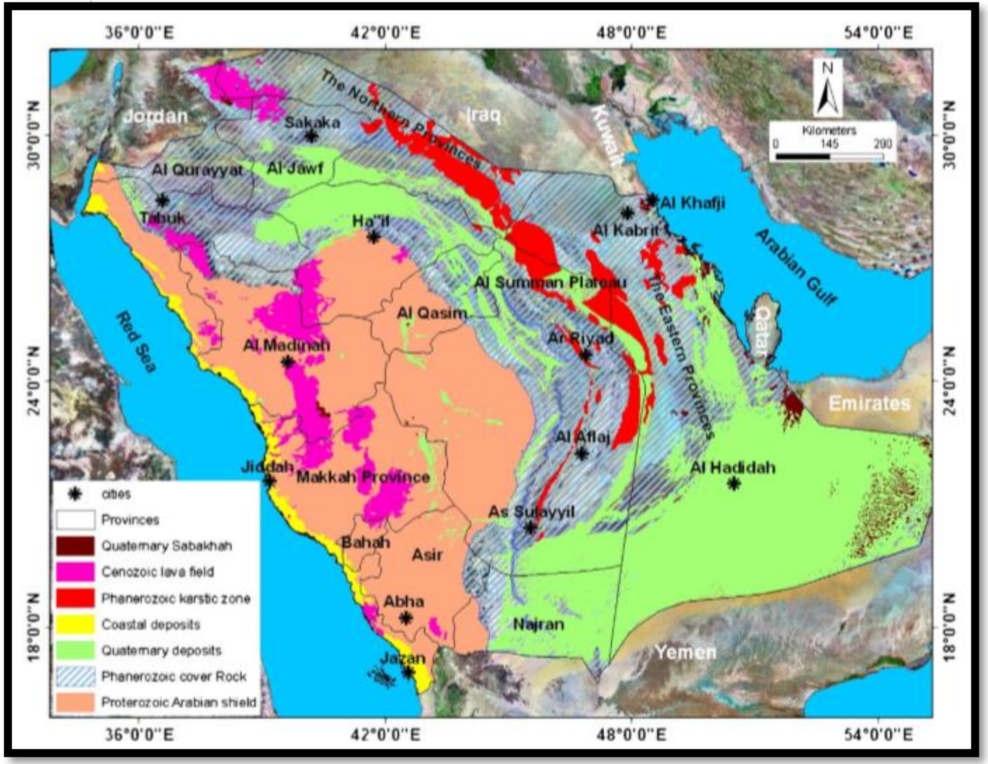
Research objectives

The primary objective is to use FWI to better characterize the near-surface zone:

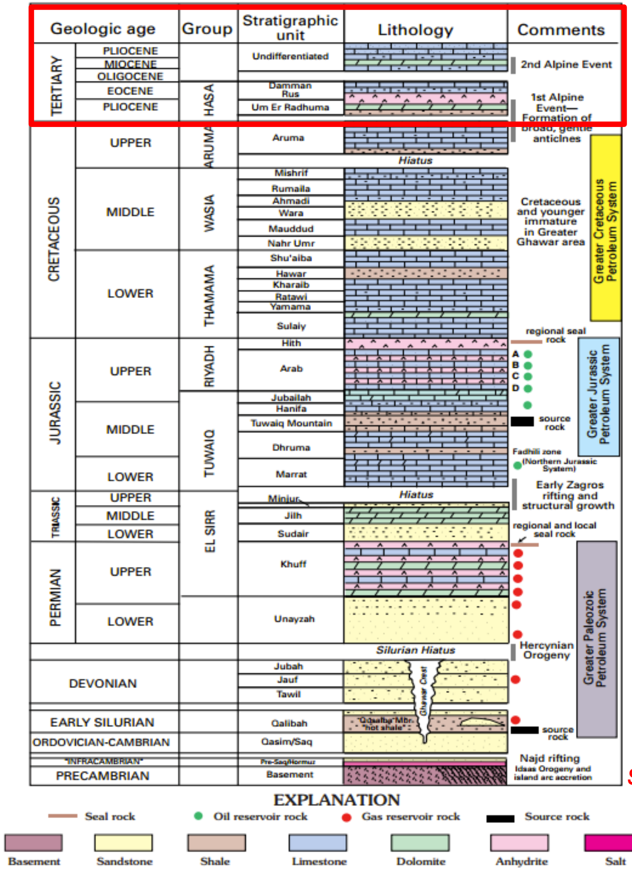
1. Examine if FWI can accurately reconstruct models of small shallow geological features with strong velocity contrast

2. Assess subsurface imaging improvement

Arabia Peninsula - near-surface geology



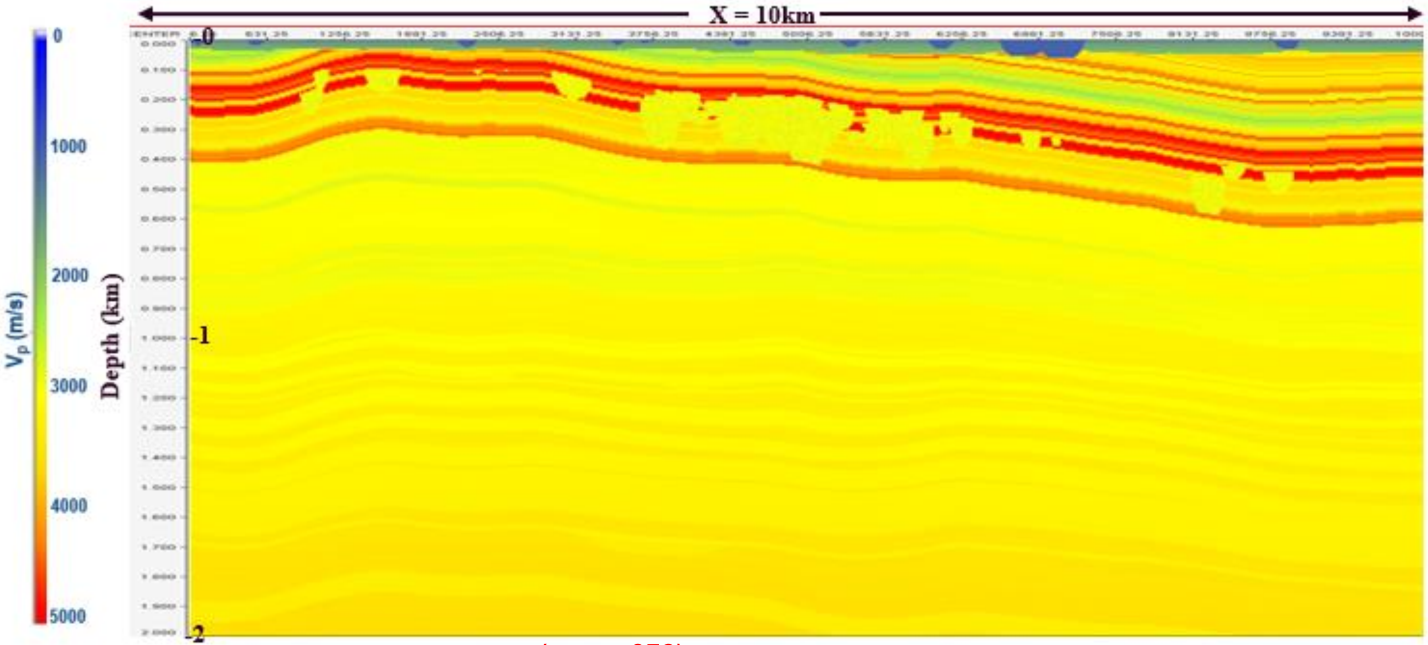
Source: SGS



Source: USGS

SEAM Phase II – Arid model

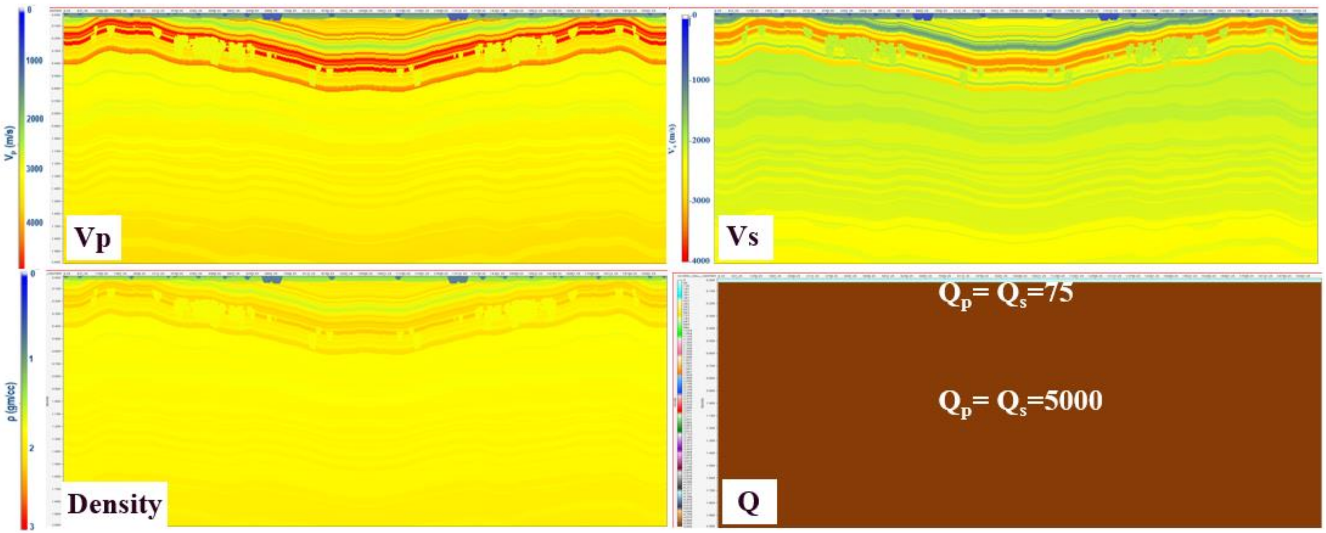
The Arid SEAM Phase II model exhibits the same reservoir and stratigraphy as the unconventional SEAM (Barret) model, but replaces the first 500 meters with complex near-surface features encountered in desert terrains like the Arabian Peninsula. In such terrains, features including karst, wadis, stream channels and low velocity unconsolidated sediments in the near-surface introduce strong velocity contrasts.

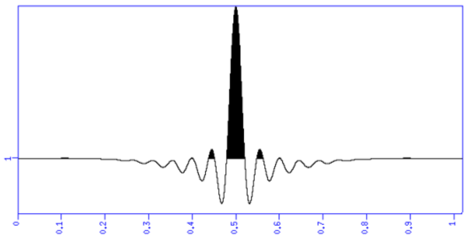


(source: SEG)

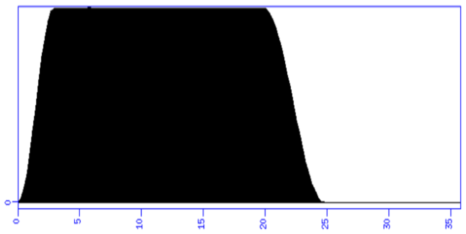
Simulation of viscoelastic data by FDM

Modeling inputs are Vp, Vs, Rho, Qp and Qs of the SEAM II arid model and a Klauder source wavelet.





Klauder wavelet with 3-20Hz



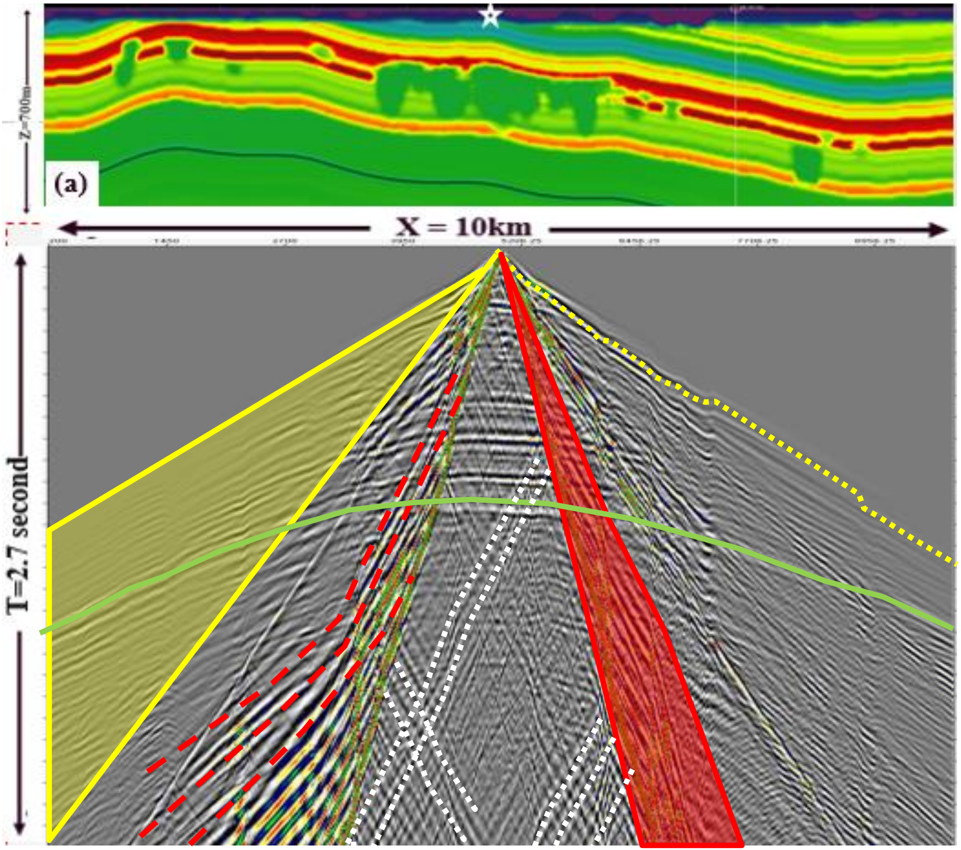
Correlation between seismic wavefield and the near surface velocity

1. First arrivals show complex static issues that are correlated with shallow karst locations in the velocity model.

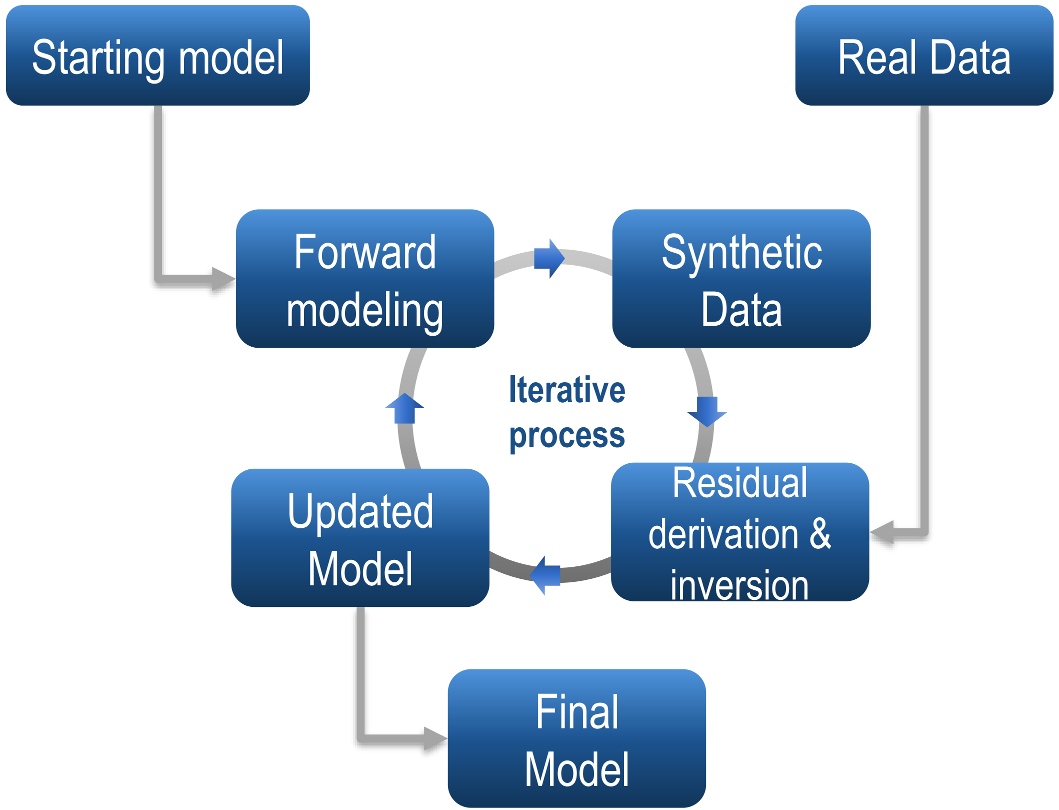
2. Dispersion of surface waves confirms the presence of strong velocity variations.

3. All hyperbolic energies below the green line are multiples and/or S-wave reflections.

4. Scatting on seismic correlates with karst locations in the velocity model.



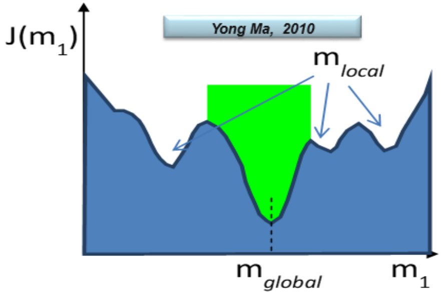
FWI – general workflow



FWI - Challenges

FWI is plagued by the local non-linearity issue which depends on

- The closeness of the starting model to the true (unknown) model
- Availability of low frequency and far offset in the recorded data



Additional challenges associated with applying FWI to land data

- Strong near-surface effects such as attenuation, ground roll, and scattering due to rapid geological variations
- Elastic FWI is challenging because we have to invert for density, P-wave velocity, and S-wave velocity simultaneously as well as modeling low-velocity surface and S-waves.
- Viscoelastic FWI is even more challenging because we have to invert for density, P-wave velocity, S-wave velocity, Qp and Qs simultaneously at all frequencies of the recorded data.

Apply acoustic FWI on land seismic data which is dominated by elastic energy.

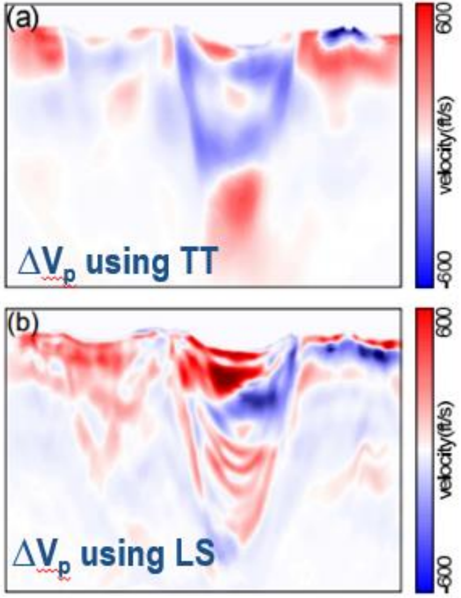
Elements of a successful acoustic FWI on land data

Before FWI

1. Use seismic data processing to eliminate non-acoustic energy.
2. Using surface wave inversion (SWI) and manual velocity picking to build an accurate initial velocity r

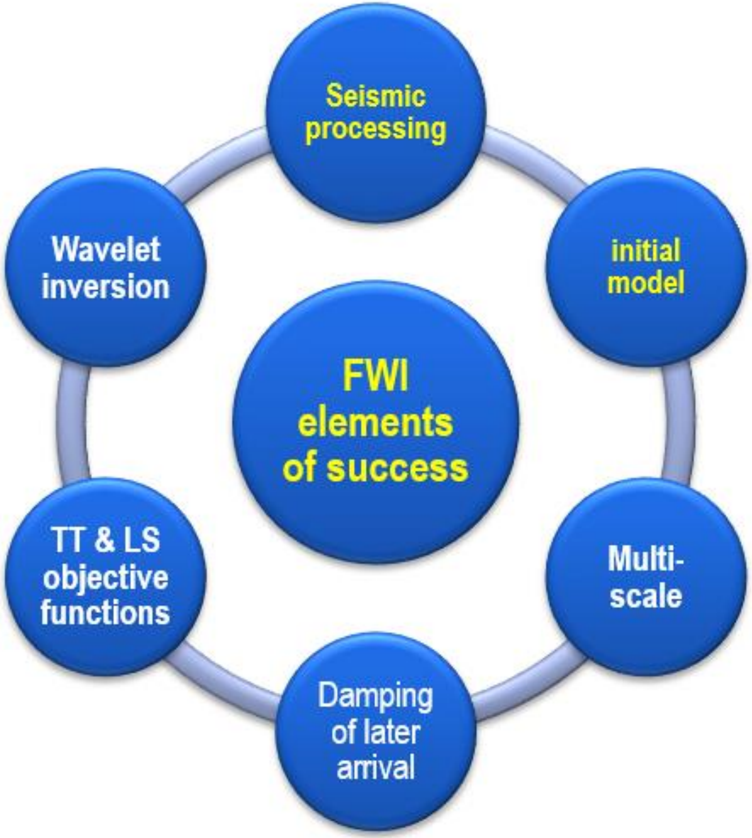
During FWI workflow

1. Estimate the wavelet from the input data at each frequency band.
2. Start with the lowest frequencies and gradually increase the bandwidth of the data.
3. Start with early arrivals and include deeper ones gradually.
4. Use travel time (TT) objective function followed by least square (LS) objective function.



Jiao, 2015

Elements of a successful acoustic FWI on land data



Before FWI

1. Use seismic data processing to el
2. Using surface wave inversion (SW

During FWI workflow

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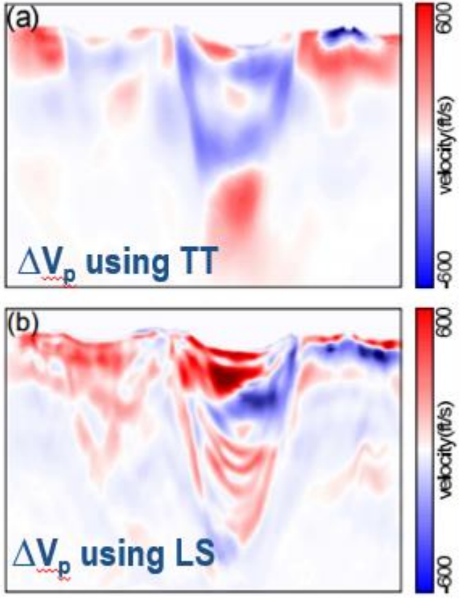
4. Use travel time (TT) objective funct



Jiao, 2015

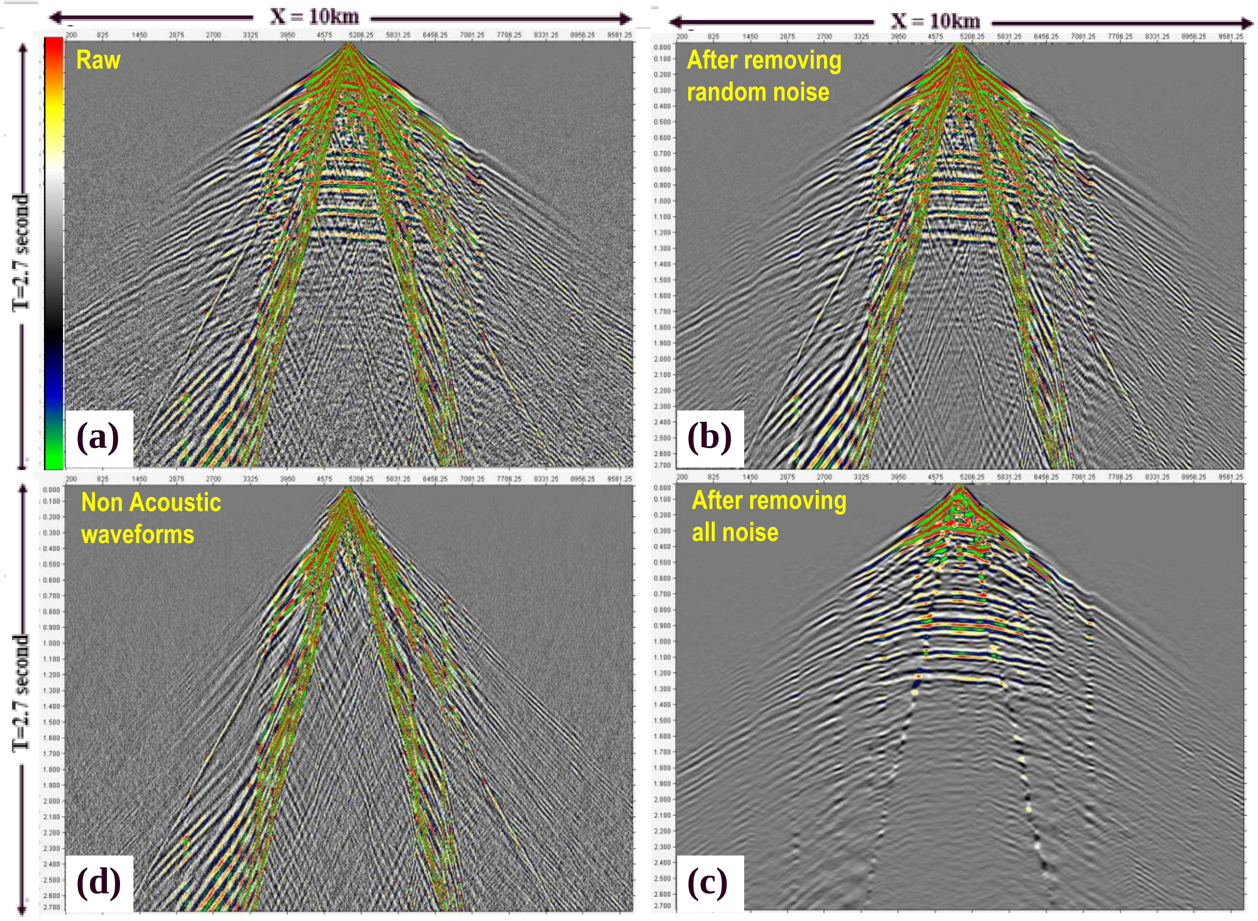
Viscoelastic modeling parameters

Parameter	Value
Type of forward modeling	Viscoelastic (Vp, Vs, Rho, Qp, Qs)
Wavelet	Klauder (3-20 Hz)
Free-surface multiple	included
Noise	included
Maximum frequency	25Hz
Acquisition geometry	20km 2D line with SI=25m & RI=12.5m

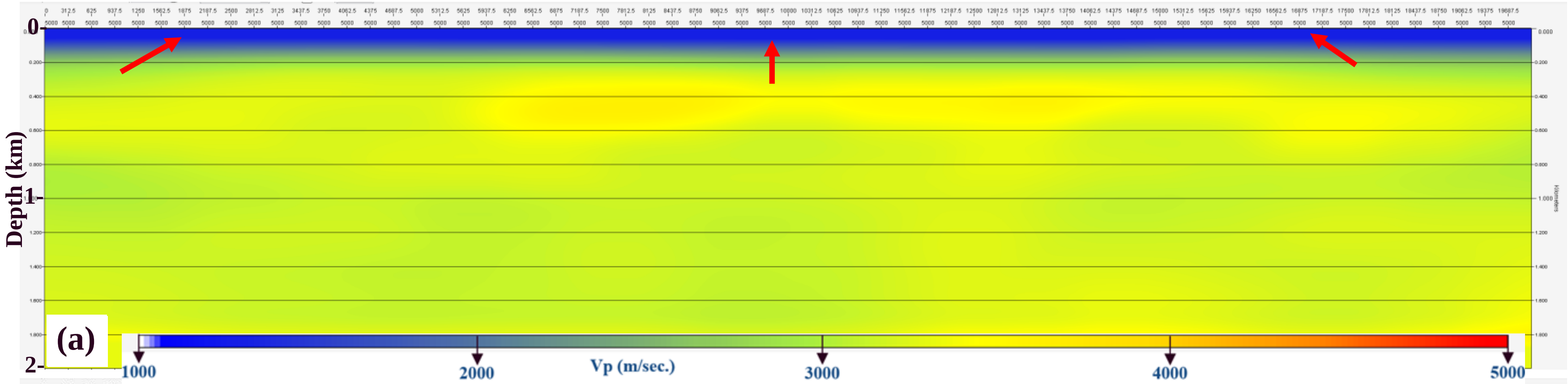
Noise attenuation to eliminate non-acoustic energy

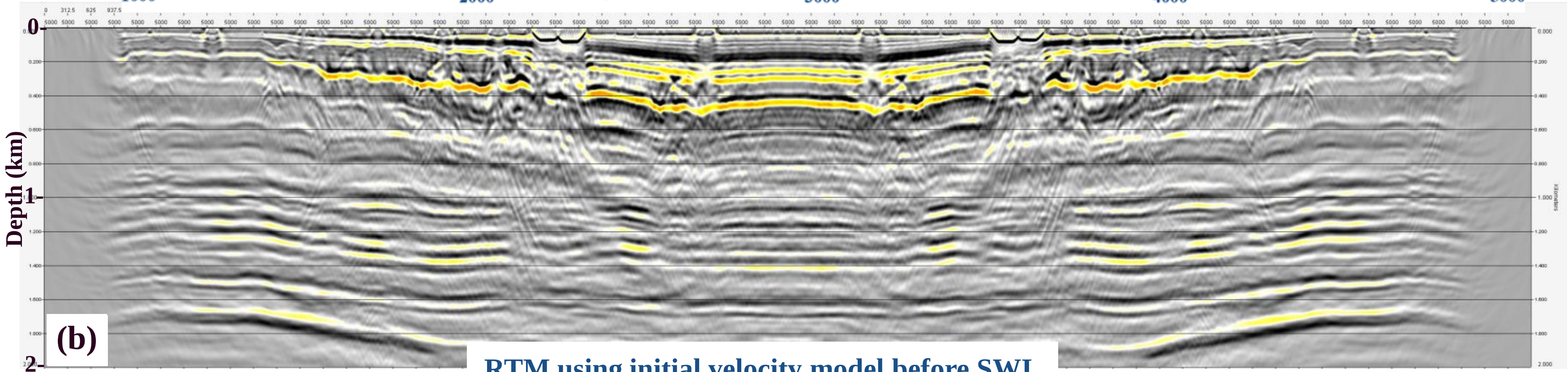
Noise attenuation processing workflow

- BPF (2-60Hz)
- FX-Decon
- Dip filter



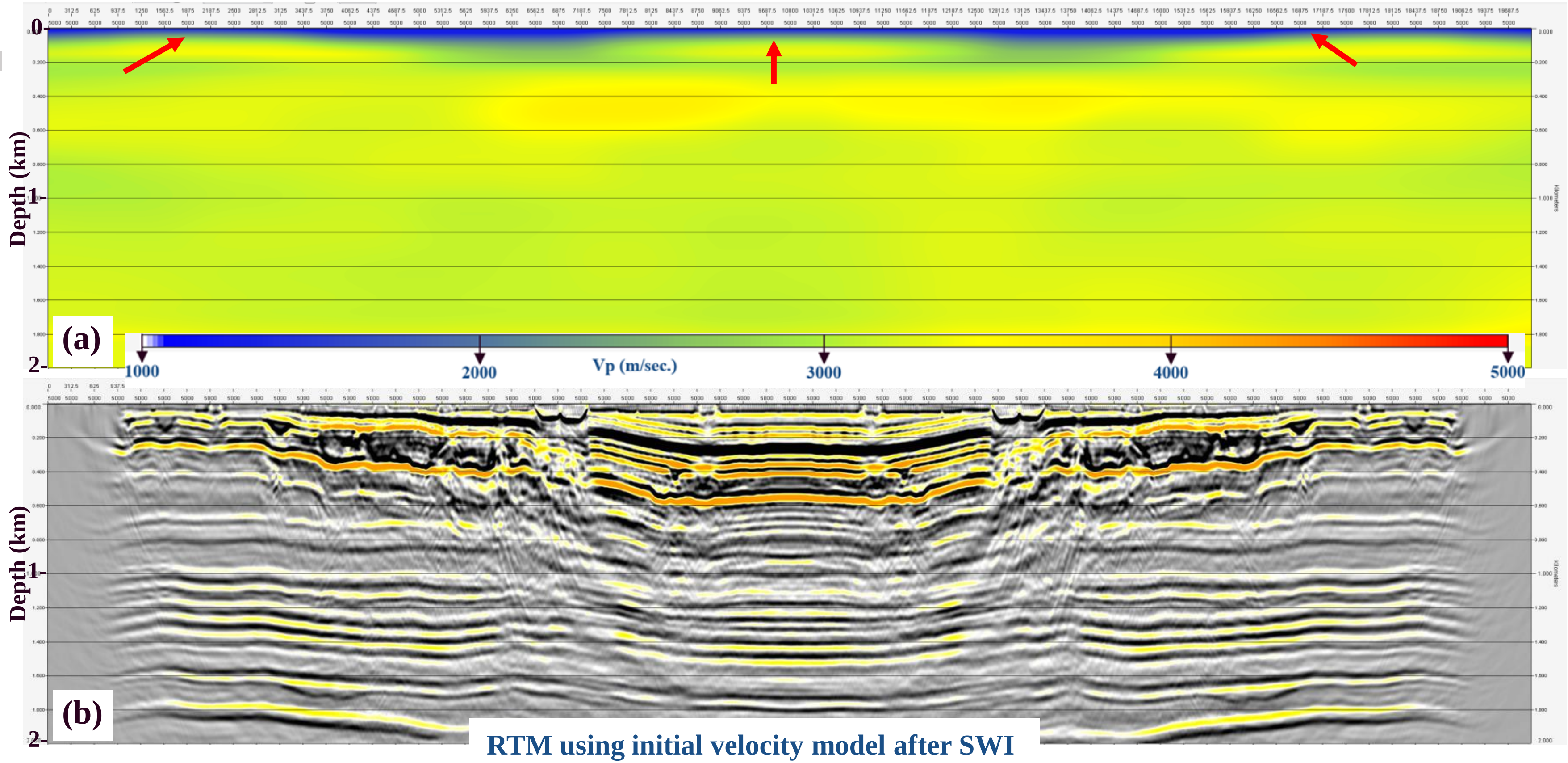
Manually-picked velocity model



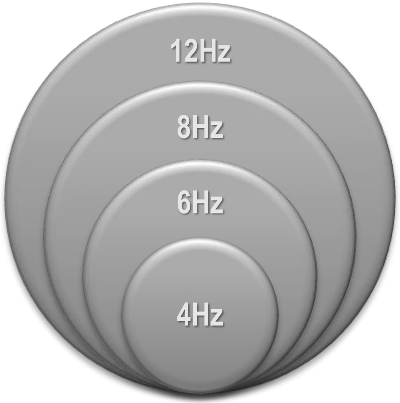


RTM using initial velocity model before SWI

Manual picked velocity model + SWI

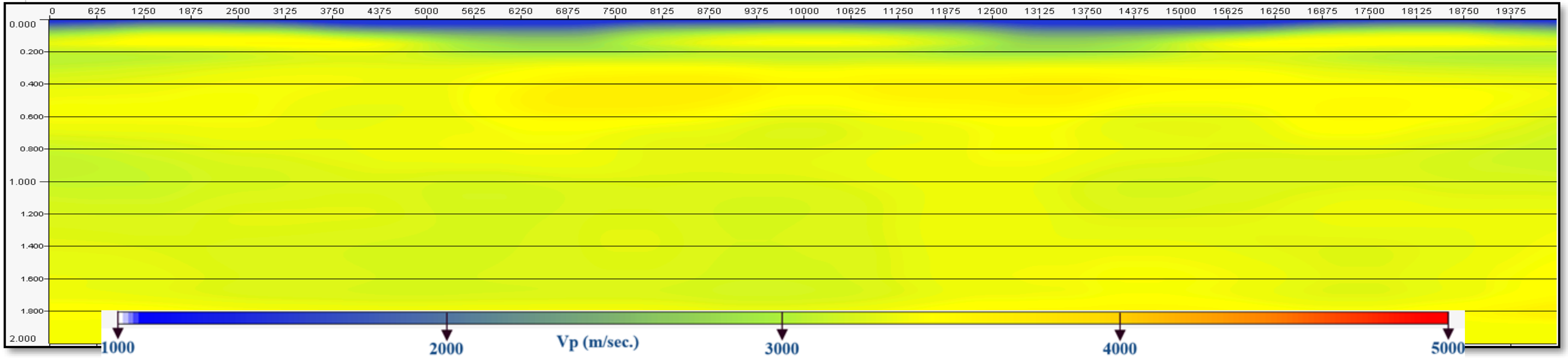


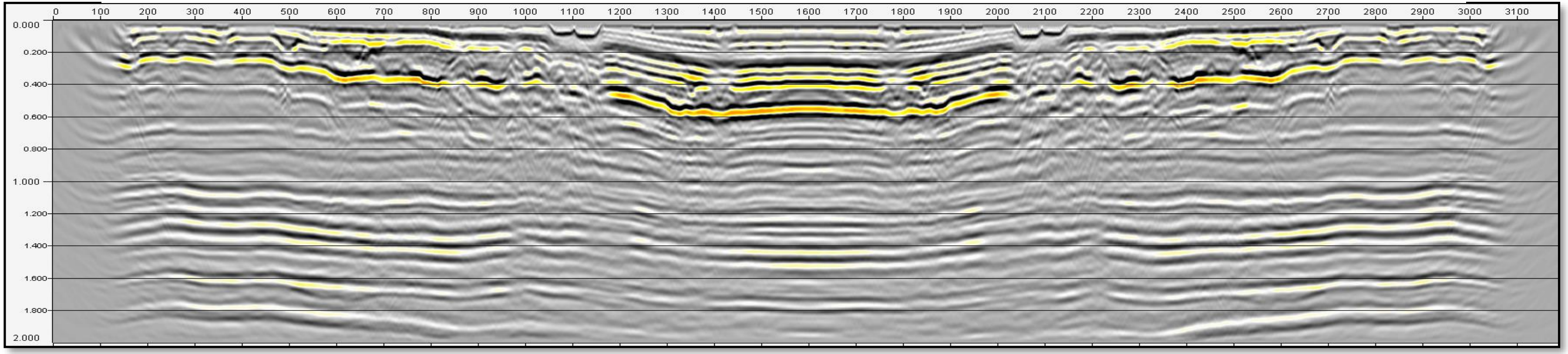
Acoustic FWI on viscoelastic synthetic data



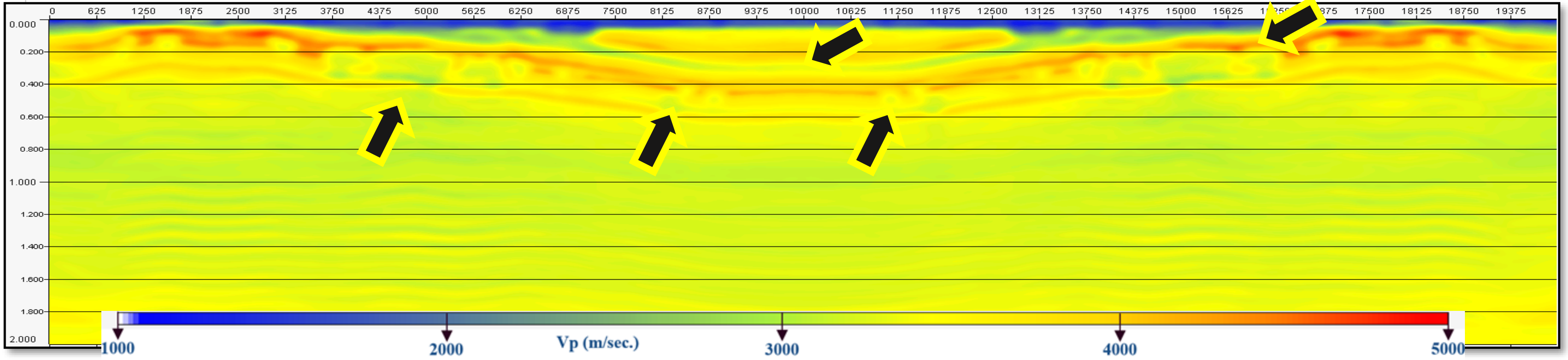
Peak frequency	Frequency band	Inverted energy	No. of iterations	Objective function
4	1-7	Refraction	4+6	TT+LS
6	1-11	Refraction	3+5	TT+LS
8	2-14	Refraction + Reflection	5+6	LS
12	2-21	Refraction + Reflection	6+6	LS
40 iterations, each iteration has 3 forward modeling and one migration				

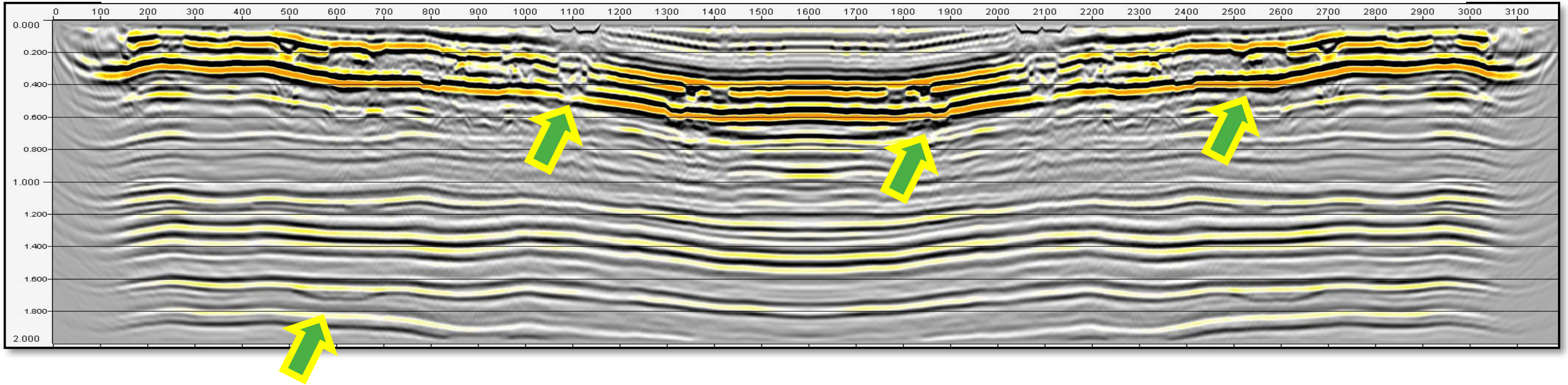
Initial model



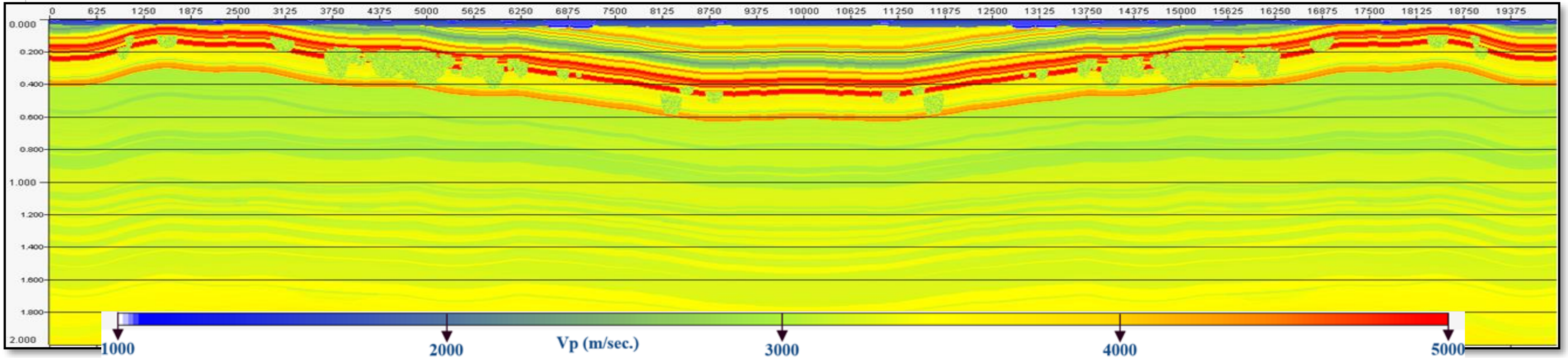


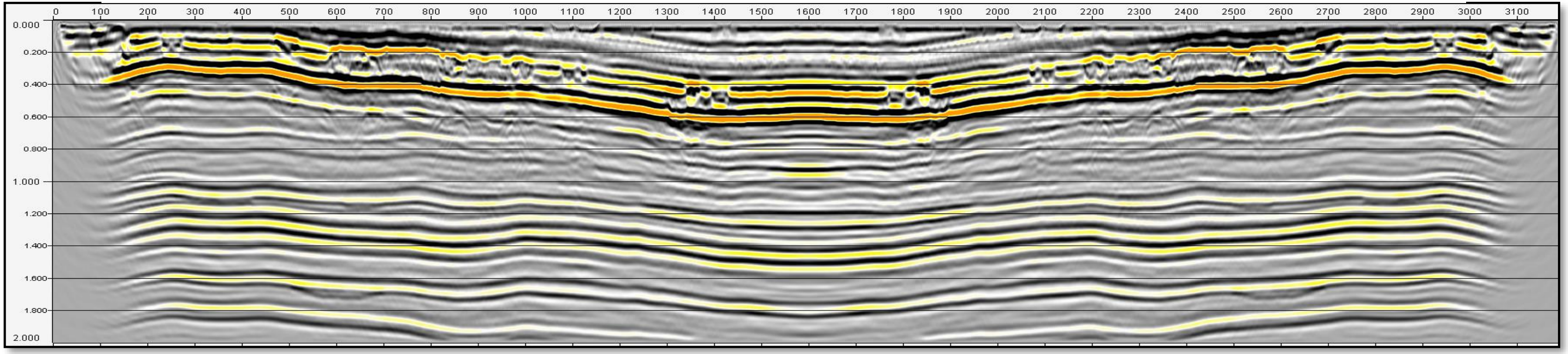
Estimated model by FWI (peak freq. =12Hz)





True model


0 625 1250 1875 2500 3125 3750 4375 5000 5625 6250 6875 7500 8125 8750 9375 10000 10625 11250 11875 12500 13125 13750 14375 15000 15625 16250 16875 17500 18125 18750 19375
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
1.800
2.000
1000
2000
Vp (m/sec.)
3000
4000
5000


0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500 2600 2700 2800 2900 3000 3100
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
1.600
1.800
2.000

Conclusions

➢ **Data pre-conditioning helped in estimating a more accurate near-surface model which made using acoustic FWI on an originally viscoelastic data effective.**