Utilizing full waveform inversion from shallow to deep.

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FWI in the forefront of Production

A more detailed look at what’s down there

In 2004, scientists had to guess at the size and shape of the salt dome beneath Atlantis, and knew little about the earth under the dome. Then, last year, BP scientists developed a new algorithm and used the company's supercomputer to produce a more accurate image of the salt dome and minerals under it. British oil major BP has discovered 200 million barrels of oil in a hidden cache in the Gulf of Mexico, thanks to a technological breakthrough allowing the company to see beneath geological formations that had befuddled oil exploration for decades.

Original rendering drawn by hand guesstimating data on salt dome.
Source: BP

Salt dome more Ocean Sea accurately rendered bed
Houston Chronicle
3-Dimensional Problem of Subsalt Imaging

- Full Azimuth Acquisition
- Accurate Structural Picture
- Best imaging of Salt-Sediment Interface
Prospecting Without Seismic and Depth Imaging

What will you find?
Prospecting Without Seismic and Depth Imaging

What will you find?

This
Prospecting Without Seismic and Depth Imaging

What will you find?

This or This
Full Waveform Inversion (FWI)

FWI: data fitting based model building process

- applicable to data with rich transmission (long-offset)
  - plenty successful FWI applications in field
  - limited penetration depth

- more challenging with reflection, mainly because:
  - reflection-driven gradient not amenable for kinematic update
  - strong nonlinearity & many false local minima
Two Modes of FWI Gradient

FWI gradient has both low- & high-wavenumber components

transmitted energy

\[ S_1 \ast R_1 \]

reflected energy

\[ S_2 \ast R_2 + S_3 \ast R_3 + S_2 \ast R_3 + S_3 \ast R_2 \]
Key Challenges to Successful Inversion

- Key to inversion with transmission:
  How to mitigate local-minima issue? (objective selection)

- Keys to inversion with reflection:
  (1) How to promote low-wavenumber updates?
  (2) How to mitigate local-minima issue?
Method: Reflection based FWI (RFWI)

Two essential components:

- Born modeling based gradient kernel
  - to explicitly compute low-wavenumber components from reflection

- Kinematics oriented objective functions
  - to achieve correct updating direction
Low-wavenumber Gradient from Reflection

Gradient based on Born modeling

\[
\left( \frac{\partial \delta p}{\partial \nu} \right)^T d_r = S_2 \ast R_3 + S_3 \ast R_2
\]

\[
\left( \frac{\partial \delta p}{\partial \nu} \right)^T d_r = \text{src\_bg} \ast \text{rcv\_scat} + \text{rcv\_bg} \ast \text{src\_scat}
\]
Difference between FWI approaches

Reflections included in FWI

Reflection Based FWI
Initial Velocity Provided
LS-FWI Inverted Vp (7 and 10 Hz)
Velocity Model Building Approach

Conventional FWI (early arrivals)

Salt Body Interpretation
Regional Lines with 1D initial model for FWI
Regional Lines with Adjustive FWI update from 1D initial velocity model
Velocity Model Building Approach

RFWI Updates
Input velocity to RFWI
RFWI Update with Velocity Overlay

Suspect salt missing
Summary & Conclusion

Two essential components of RFWI:

1. model decomposition & Born modeling based optimization
2. objective function: emphasize on measuring kinematic difference between observed and predicted reflections

Reflections can be used to build macro model

Robust inversion workflow (Cycle skip mitigation {FWI + RFWI} + LS FWI) for velocity model determination.