# High-End Imaging: Moving closer to rock properties estimation

Sharp Reflections GATHERing, Leiden, October 23, 2023 Bertrand Caselitz, PGS Imaging Chief Geophysicist



In recent years, there has been a notable adoption of high-end imaging technology, leading to substantial enhancements in quality.

The progress in processing technology has yielded more precise products for quantitative interpretation and could significantly accelerate processing project turnaround time.

High-end processing technology are inversion-based techniques that can be split into 2 groups:

### Full Waveform Inversion

Rock properties estimation: Velocity, anisotropy, absorption, ... Wave equation Refractions, reflections, full wavefield Raw, processed input data

### Least-Squares Migration

Reflectivity (recovery)

Kirchhoff, wave equation Reflections, Multiples, both Input: Processed data and velocity, anisotropy, ...

PGS

Processing seismic has been a sequential process (and still is).



## Full Waveform Inversion (FWI) Concept







Updated FWI model (resulting in a better phase match)

Refractions (bananas) are FWI best friends !

PGS



Derivatives of the FWI Velocity model - pseudo-reflectivity

Getting reliable velocity model, assuming density

Phase-driven cost functions (TLFWI, TWE-FWI, DM-FWI, ...) – Not sensitive to amplitude difference between recorded data and modelled data.

Use the full wavefield (refractions, reflections including multiples) – illumination, S/N, turnaround reduction

Only invert for velocity. Assumption on other properties as multi-parameters inversion is very challenging (parameters leakage)

FWI Image has very good S/N. It is equivalent to intercept. Broadband (low and high frequencies).

No pre-stack information.

### FWI image example





FWI Velocity model

LS-RTM using FWI Velocity model

FWI Image

Towards high-fidelity imaging: Dynamic Matching FWI and its application, TLE, Feb 2023, Y. Huang



Use of elastic wave equation instead of acoustic wave equation.

Still only inverting for Vp only.

Assumption on Vs and density

Main improvements around high velocity bodies (better phase) – halos reduction

### Elastic FWI image example





Enhancing salt model resolution and subsalt imaging with elastic FWI, TLE, March 2023, Z. Zhang

## Multi-parameter FWI (PGS Ultima)





### Multi-parameter FWI (PGS Ultima)





*The* goal of seismic inversion is to both estimate the *velocity* model and predict the *reflectivity*, <u>without damaging either</u>. This simultaneous inversion is built into a single framework with minimum data processing.

### *Ultima* Simultaneous inversion workflow = Multi-parameter FWI





Key aspects:

- Full wavefield modeling engine using Vector reflectivity
- Scale separation: velocity & impedance kernel



### Simultaneous inversion with scale separation: FWI + LS-RTM



## Initial velocity model – depth slice, 3400m





Slide 13

## Ultima velocity model – depth slice, 3400m







## Ultima reflectivity model / LS-RTM



### Multi-parameter FWI – Resolution comparison





Next-generation resolution through multi-parameter FWI imaging, TLE Jan 23, T. Rayment et al.

### Fault Shadow Imaging Challenge – Norwegian Sea



#### **Fault Shadow**



Application of simultaneous inversion (FWI and non-linear LSRTM) for improved imaging, Eage 2023, A. Pankov

### Relative Density from Ultima

From simultaneous inversion for velocity (V) and reflectivity (R) we derive impedance and density







Relative density from Ultima

Application of simultaneous inversion (FWI and non-linear LSRTM) for improved imaging, Eage 2023, A. Pankov

## Multi-parameter FWI with angle gather output

### *Ultima* Final Velocity





### *Ultima* Full Stack





*Ultima* Angle Gathers





### *Ultima* Partial Stacks



+



8.0

### Intercept - 2 terms 3 angles





## Gradient - 2 terms 3 angles





### Relative density comparison 4520m





Derived from ratio multi-parameters FWI output

## Relative Vp/Vs







### Summary

- Latest FWI technology developments have challenged the sequential way to process seismic data
- FWI Image is a 'pseudo' reflectivity supporting structural interpretation
- Elastic FWI further improves the FWI Image but minor uplift on migrated image
- Multi-parameter FWI allows to invert for velocity and 'true' reflectivity
- Pre-stack data can be output from multi-parameter FWI leading to elastic properties derivation
- Future: Elastic multi-parameter FWI, Full parameters inversion, Joint PP-PS FWI, ...





#### COPYRIGHT

The presentation, including all text, data, photographs, drawings and images (the "Content") belongs to PGS ASA, and/or its subsidiaries ("PGS") and may be protected by Norwegian, U.S., and international copyright, trademark, intellectual property and other laws. Accordingly, neither the whole nor any part of this document shall be reproduced in any form nor used in any manner without express prior written permission by PGS and applicable acknowledgements. In the event of authorized reproduction, no trademark, copyright or other notice shall be altered or removed. © 2023 PGS ASA. All Rights Reserved.

#### A Clearer Image