Integrating Micro Seismic and Conventional Seismic Data for Characterizing Fracture Network: A California Case Study

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OUTLINE

- Introduction
- Optimized passive seismic survey design
- Microseismic derived property estimation
- Seismic derived property estimation
- Hybrid FZI* attributes for identifying fractures
- Integrated interpretations through case study
- Conclusions

* Fracture Zone Identifier
PROBLEM DEFINITION

Motivation?

- Enhanced cross-disciplinary technology applications.
- How to work in highly data constrained & geologically challenging environments?
- Novel workflows to tackle said challenges.
- Maximize/ optimize use of available data.
- Improved algorithms to support analysis.

Fracture zone characterization

MEQ – Seismic joint interpretation

Improved velocity models

Discontinuity mapping

4D characterization framework
CHARACTERIZATION WORKFLOW

- 3D seismic
  - Data conditioning
  - Dip steered filtering
  - Well to seismic ties
  - Seismic attribute analysis
  - Multi-attribute/ANN
  - Reservoir property estimates

- Passive seismic
  - Data formatting
  - Auto-picking
  - Phase detection
  - Event locations
  - Tomographic inversion
  - COSGSIM
  - \( V_p \) & \( V_s \) (high resolution)

- Inversion uncertainty
- Estimation uncertainty
- Rock properties

- A-priori information on fracture zones
- Well Logs
- Image logs/production data, etc.
- Fracture zone identification framework

- ANN classification algorithm
- FZI maps
PASSIVE ARRAY OPTIMIZATION

QF = W₁ × QF₁ + W₂ × QF₂ (W₁ = 1.0 & W₂ = 0.0)

QF = W₁ × QF₁ + W₂ × QF₂ (W₁ = 0.0 & W₂ = 1.0)
LOCATION & VELOCITY INVERSION

Sample Vp and Vs maps at 1 Km depth level after SimulPS run
IMPROVED VELOCITY MODELS

Better estimate velocity (primary) based on seismic derived impedance (secondary)

Microseismic Data

- $V_P$ & $V_S$
- Normal Score Transformation

Seismic Data

- Impedance Maps

COSGSIM

- Normal Score Transformed $V_P$ & $V_S$
- Primary Variable

Final $V_P$ Realizations

Final $V_S$ Realizations

$V_P$ Realizations (Gaussian Domain)

$V_S$ Realizations (Gaussian Domain)

Inverse Normal Score Transformation
COSGSIM – INPUTS & RESULTS

**VP at depth of 1 km**

**VS at depth of 1 km**

**VP simulation error**

**VS simulation error**
ROCK PROPERTY ESTIMATES

\[ \mu = \rho V_S^2 \]
\[ \lambda = V_p^2 \rho - 2\mu \]

Mavko et al., 2003

\[ V_E^2 = \frac{V_S^2(3V_P^2 - 4V_S^2)}{(V_P^2 - V_S^2)} \]
\[ V_K^2 = V_P^2 - \frac{4}{3} V_S^2 \]

Tokosoz et al., 1981

\[ F_E = \frac{(b - b_r)}{b_{\text{max}}} = e^{\alpha V_E} \]

Rutqvist et al., 2003

\[ K = \lambda + \frac{2\mu}{3} \]
\[ E = \frac{9K\lambda}{3K + \mu} \]
\[ \sigma = \frac{\lambda}{2(\lambda + \mu)} \]

Beer et al., 2009

\[ \Delta_N = \frac{4e}{3g(1 - g)} \]
\[ \Delta_T = \frac{16e}{3(3 - 2g)} \]

Hsu et al., 1993

\[ g = \left( \frac{V_S}{V_P} \right)^2 \]
PROPERTY ESTIMATION

Normalized fracture aperture expandability - $F_E$

[3D diagrams showing fracture aperture expandability across depth and inline directions.]
3D SEISMIC DERIVED ATTRIBUTES

density

discontinuity

frequency
CHARACTERIZATION FRAMEWORK

Martakis et al., 2006; Berryman et al., 2002; Berge et al., 2001; Boitnott, 2003, Downton et al., 2008

Effective pressure

↑ Vp & K

Fracture opening

↑ V_E & ↓ K

Fluid Saturation

↓ Vs or ↑ Vp/Vs & σ

Fractures

↓ Vp & Vs

Lithification

↑ Vp/Vs, μ & K or ↓ σ

Porosity

↓ Vp/Vs & K

Pore pressure

↓ Vp

Fracture density

↑ Δ_T

Gas

↓ Vp, Vs & K
HYBRID FZI ATTRIBUTE

TRAIN

FZI_3

TEST

FZI_4
MAPPED FRACTURE ATTRIBUTES

\[ k_{Fi} \]

\[ FZI_{3,4} \quad F: \quad k_{Fi} = n_{fn} FZI_A^3 / 12 \Delta T_n, \ V_{En} \]
OUTPUT UNCERTAINTIES

INVERSION

COSGSIM ($V_p$)

COSGSIM ($V_s$)

FZI UNCERTAINTY
MAPPED FRACTURE ATTRIBUTES
FRACTURED ZONES ($V_E$, $\Delta_T$ & FZI$_4$)

Horizon 3 (Testing)

$V_E$

$\Delta_T$

FZI$_4$
DISCONTINUITY INTEGRATED FZI

FZI_4 integrated with discontinuity at 500m & 1000m depths
DISCONTINUITY INTEGRATED FZI
DISCONTINUITY, $V_E$ & EDGE
FZI, STRESS GRADIENT, & EDGE
RESULTS & CONCLUSIONS

- Introduced workflow to use passive & active seismic data to characterize fractures in unconventional settings.

- Highlights:
  - High resolution velocity modeling with poor MEQ data quality (using seismic derived constraints & geostatistical simulation).
  - Framework for improved passive seismic survey design
  - Geomechanical property estimates for fracture zone identification using available rock physics framework (valid for sedimentary systems).
  - Introduction of newly defined hybrid “FZI” attributes to delineate fractured zones.
  - Framework for integrated analysis & interpretation to better understand reservoir behavior & plan future field development.
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QUESTIONS?