the Energy to Lead

Introduction to Novel Fracture Attributes using Geophysical and Petrophysical Data for Unconventional Reservoir Characterization

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Gas Technology Institute

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Reservoir Monitoring Consortium Semi-Annual Review Meeting

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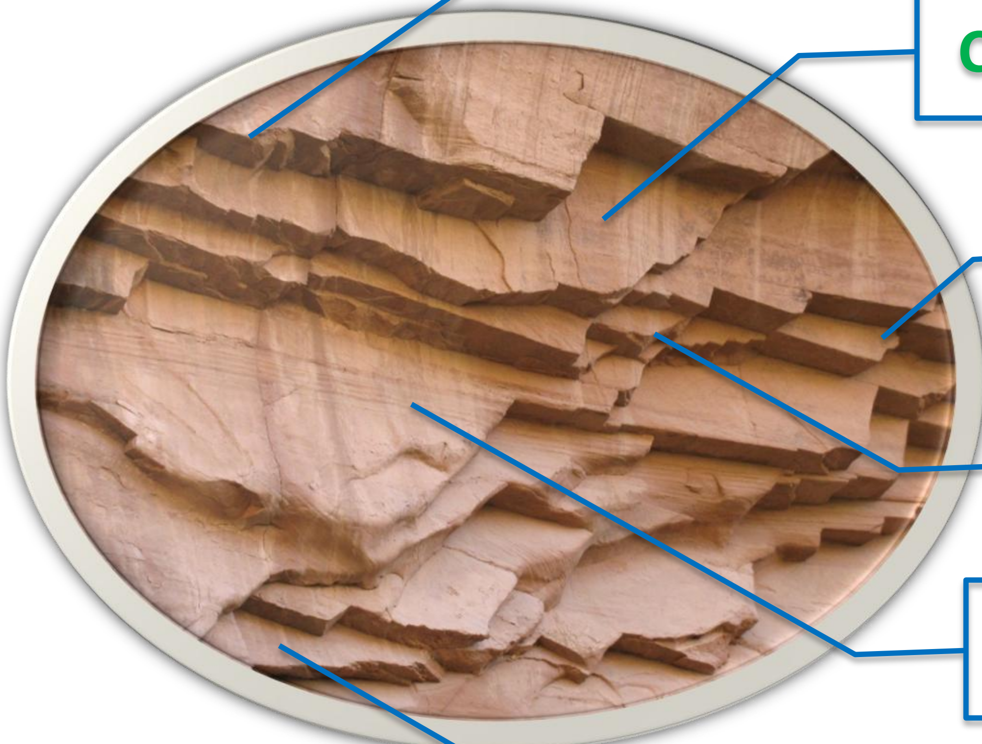
AGENDA



Introduction

Characterization Workflow

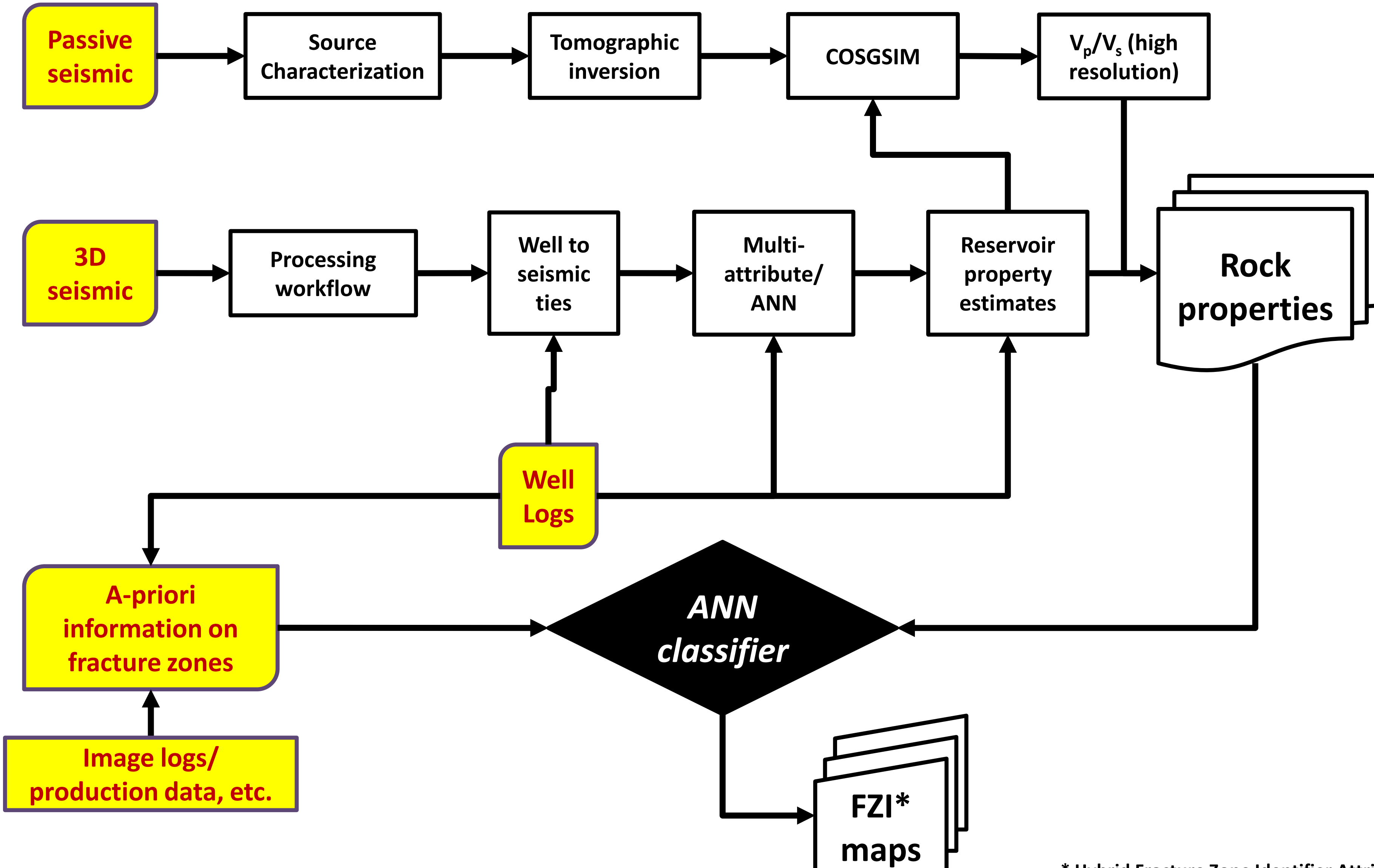
Reservoir Property Estimation

Fracture detection framework

Hybrid fracture attributes

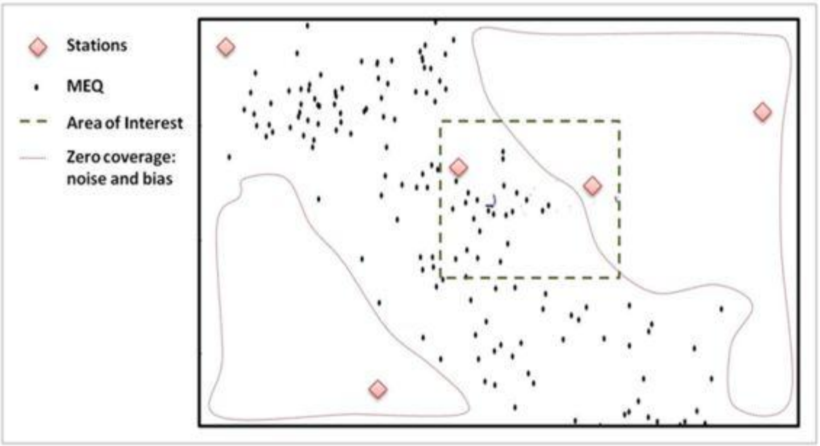
Interpretations

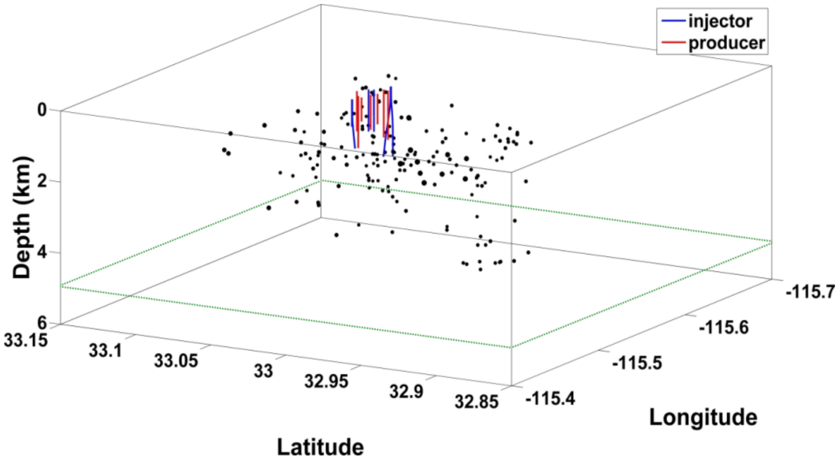
WORKFLOW

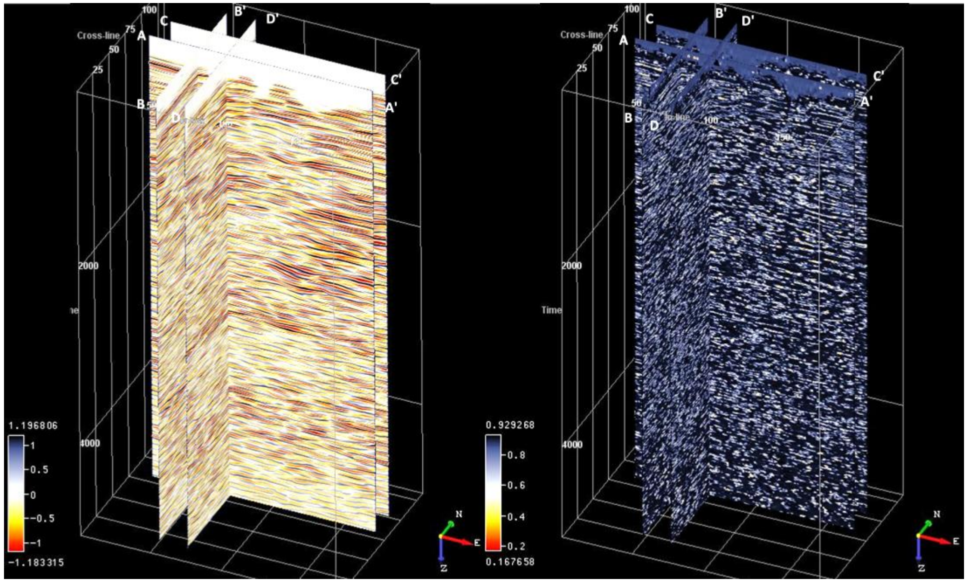


* Hybrid Fracture Zone Identifier Attribute

DATA QUALITY ISSUES



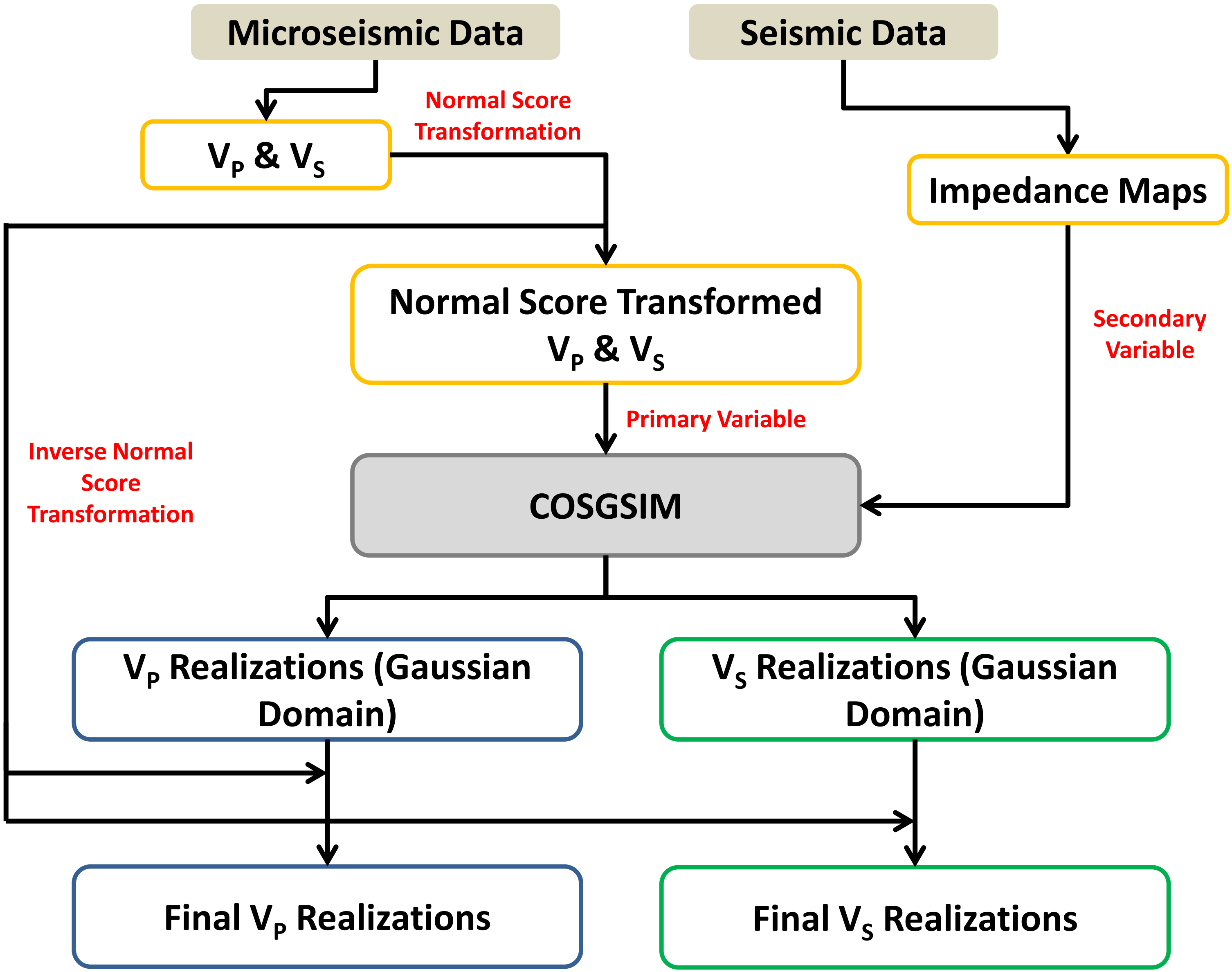


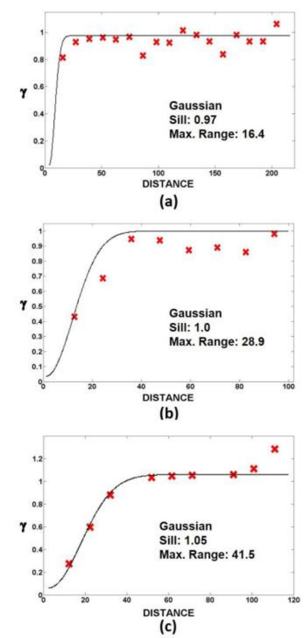


SOLUTION

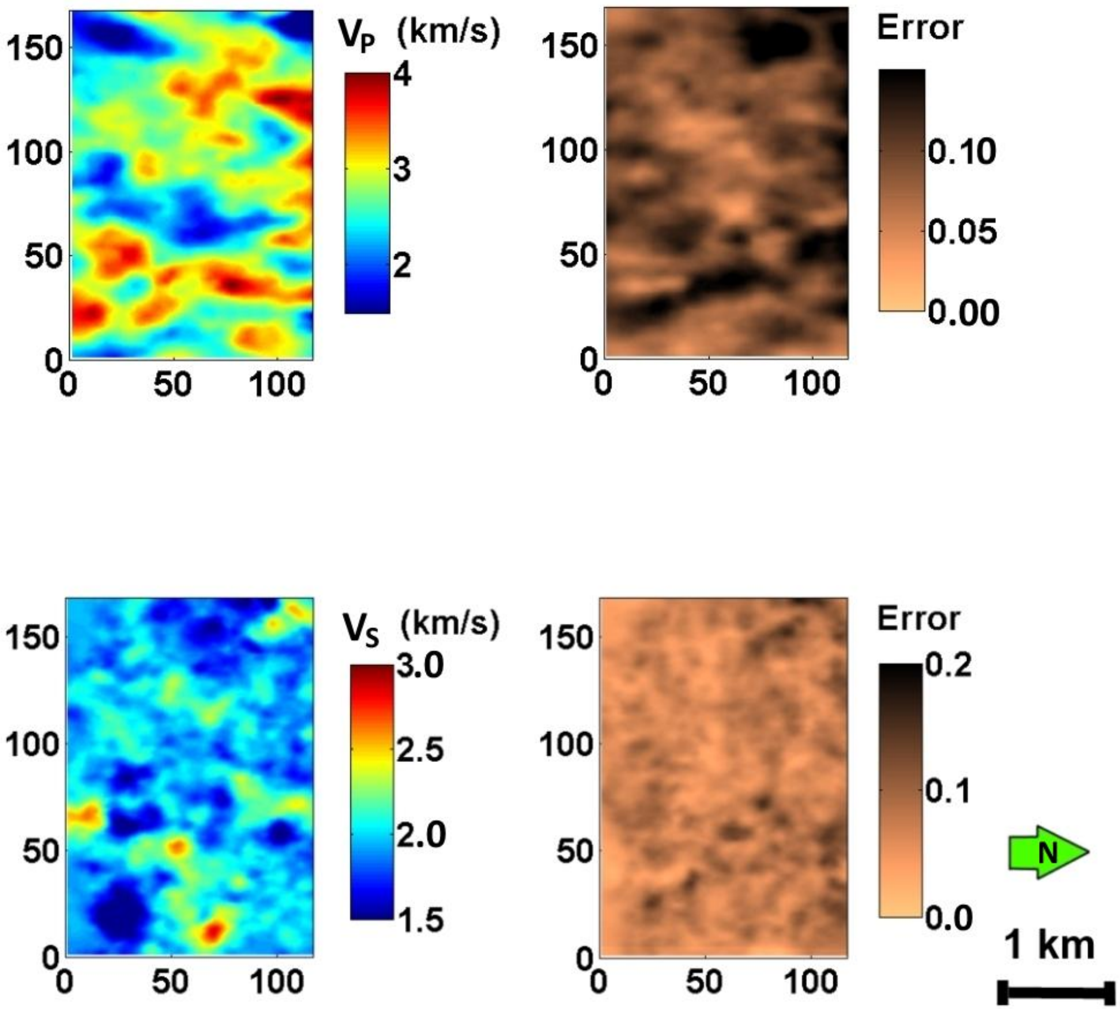
- Estimate velocities with higher resolution
- Reduce estimation uncertainty with improved workflow
- Incorporate secondary information to improve mapping
- Sequential Gaussian Co-simulation

STOCHASTIC MODELING WORKFLOW



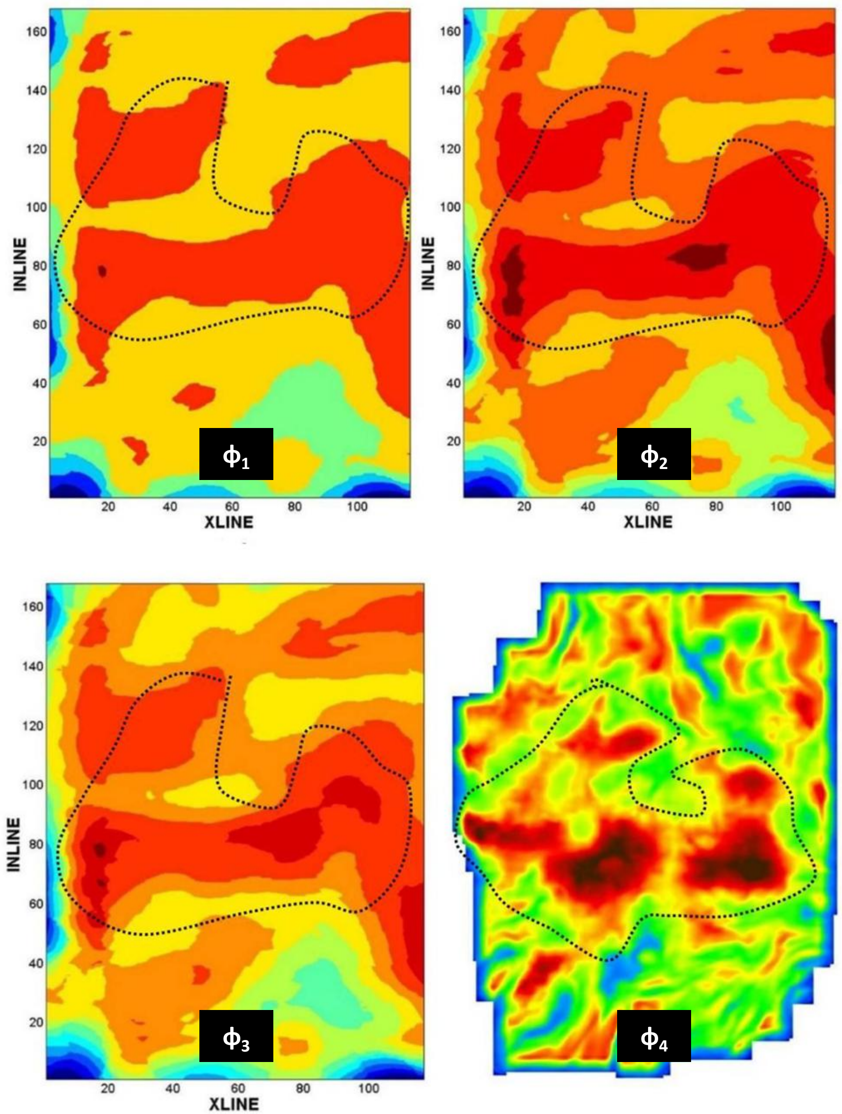


V_P & V_S – SIMULATION RESULTS



- Original sparse velocity maps using SimulPS
- Grid spacing for sparse velocity model – 12 X 16 X 9 (500 m grid separation)
- Data specific to study area extracted from SimulPS inversion grid as required
- Simulation error computed using normalized standard deviation (%age) over all realizations (~ 1000)
- Final property map selected based on minimized least squared error

ϕ ESTIMATION – VALIDATION OF MODELS



$$\phi_1 = [(V_m - V_P)]/[V_P(V_m - V_f)]$$

$$V_P = (1-\phi)^2 V_m + \phi V_f$$

$$\phi_2 = \left\{(2V_m - V_f) - \sqrt{[V_f^{\,2} + 4V_m(V_P - V_f)]}\right\}/(2V_m)$$

$$\rho = 0.23 V_P^{0.25}$$

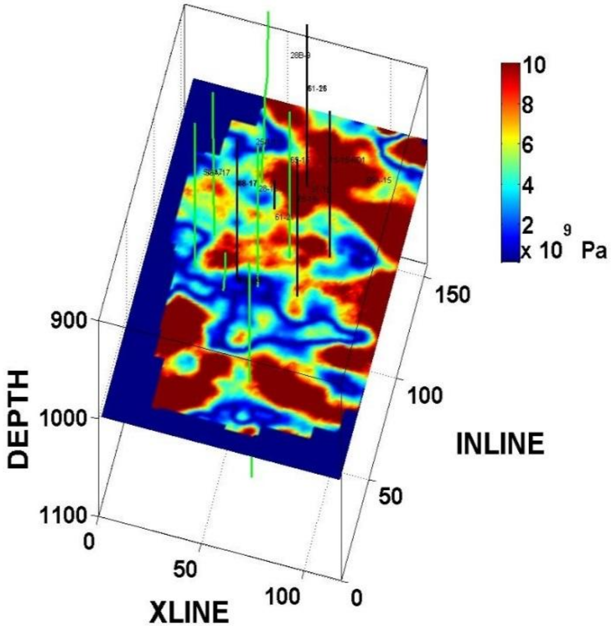
$$\rho = (1-\phi)\rho_m + \phi\rho_f$$

$$V_P = \left\{\left[(1-\phi)\,\rho_m + \phi\rho_f\right]/0.23\right\}^4$$

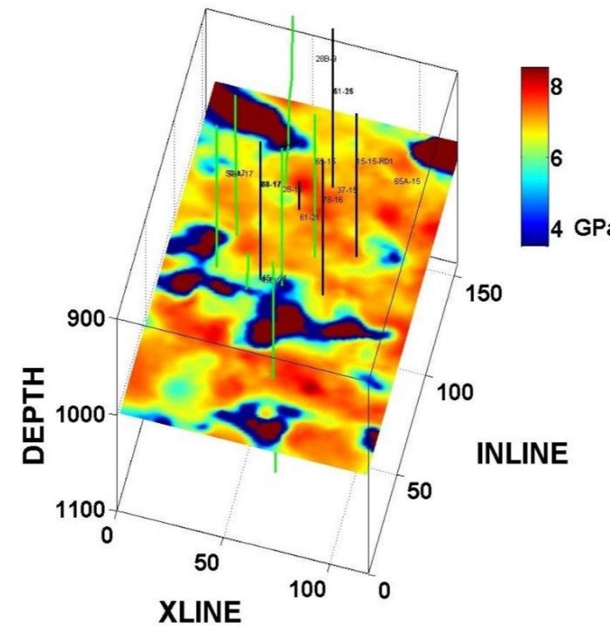
$$\phi_3 = \left[\rho_m - 0.23(V_P)^{1/4}\right]/(\rho_m - \rho_f)$$

ϕ_4 shows seismic derived porosity map (using well log controls).

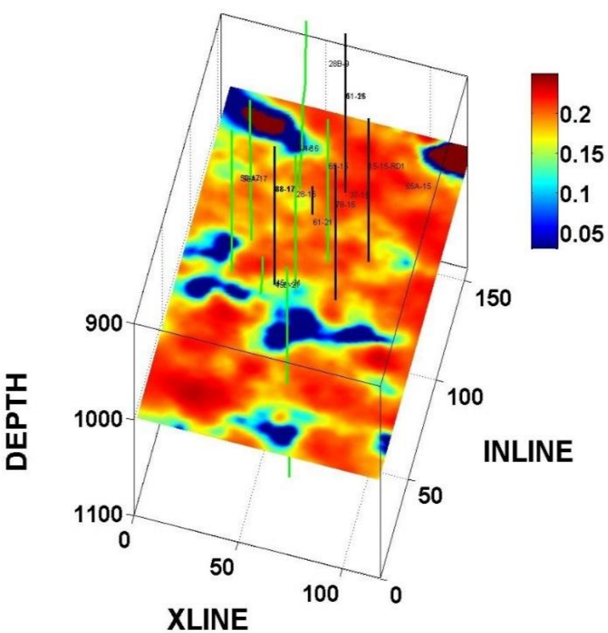
MICROSEISMIC DERIVED PROPERTIES



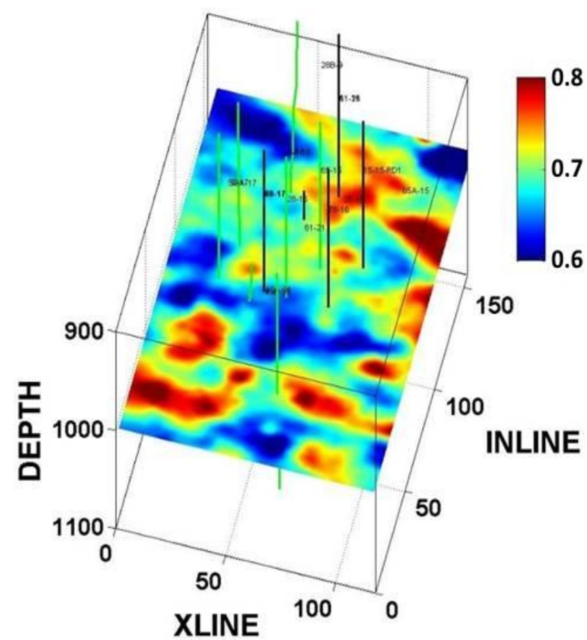
$$K = \lambda + \frac{2\mu}{3}$$



$$V_E{}^2 = \frac{V_S{}^2\left(3V_P{}^2 - 4V_S{}^2\right)}{\left(V_P{}^2 - V_S{}^2\right)}$$



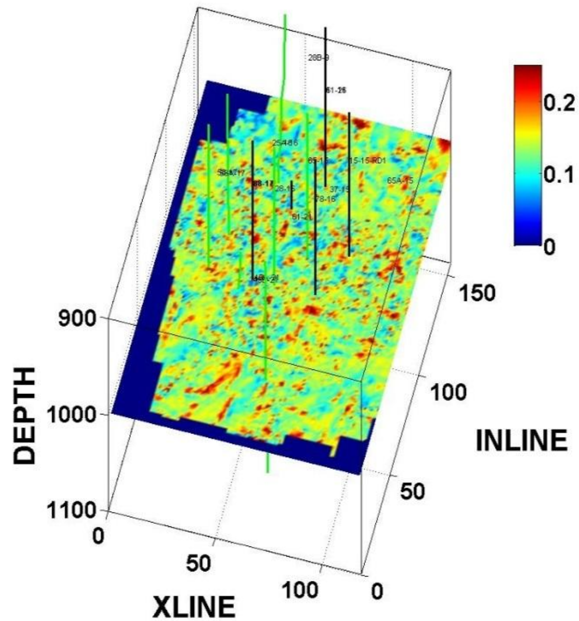
$$\sigma = \frac{\lambda}{2(\lambda + \mu)}$$



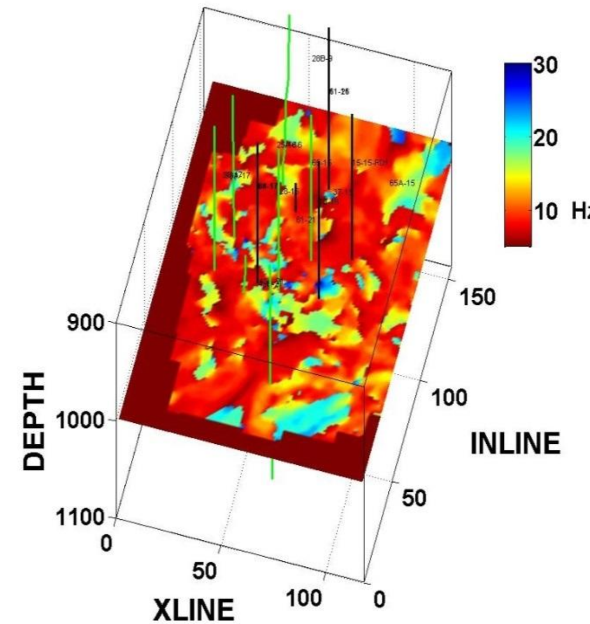
$$\Delta_T = 16e/(3(3 - 2g))$$

$$g = (V_S/V_P)^2$$

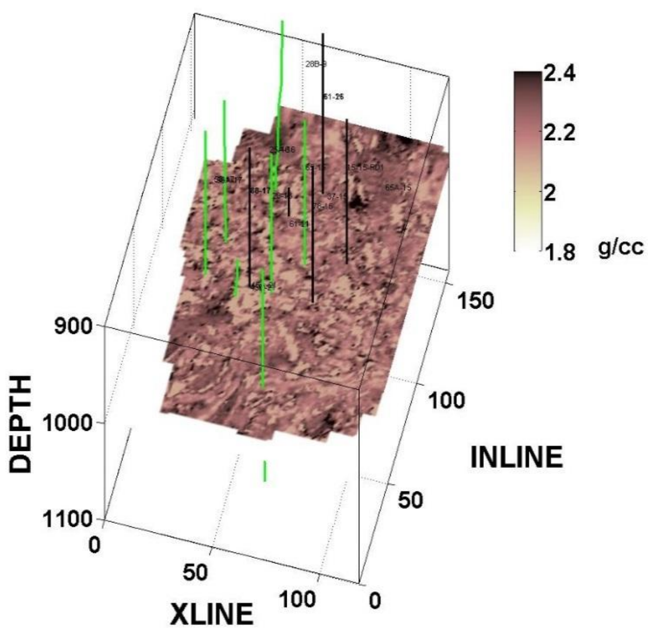
3D SEISMIC DERIVED ATTRIBUTES



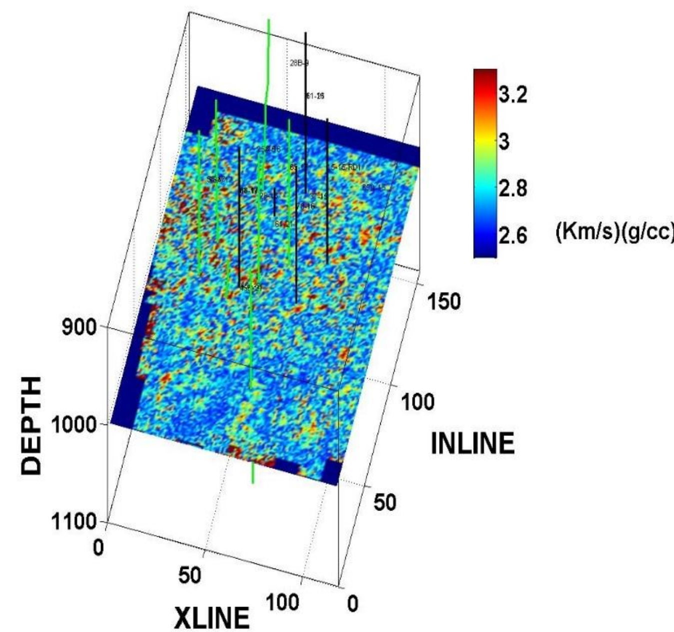
Log Derived Porosity



Instantaneous Frequency

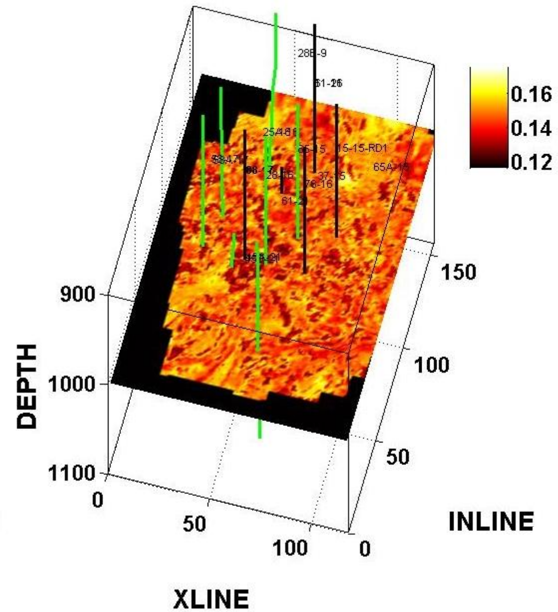


Log Derived Density

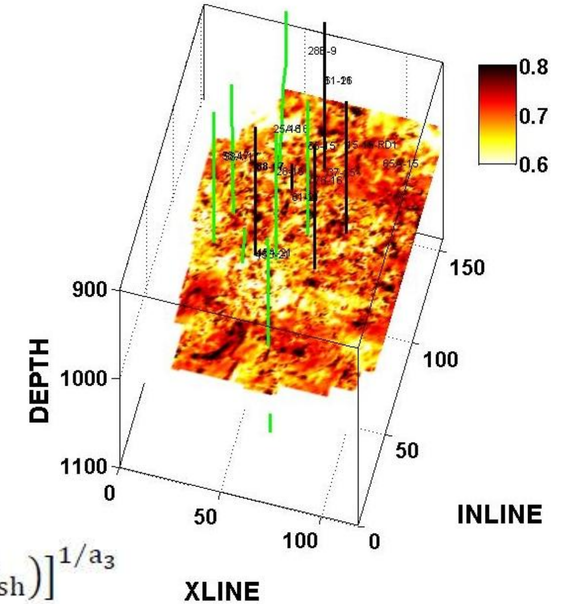


Acoustic Impedance

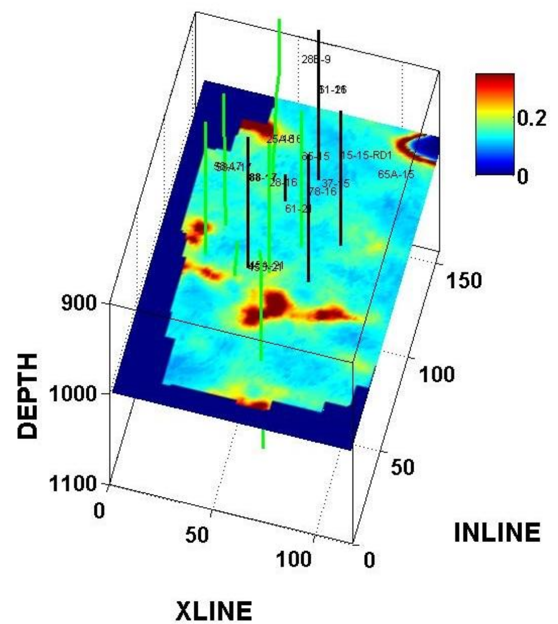
HYBRID ATTRIBUTES



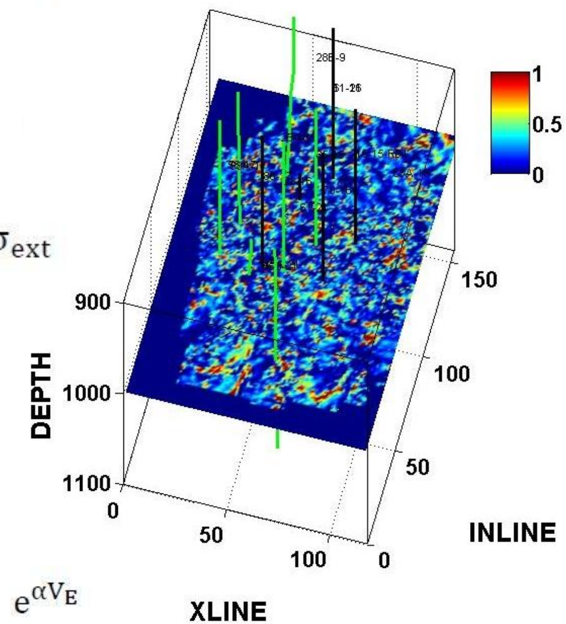
$$\sigma_1 = g \int_0^z \rho(z')dz'$$



$$P_p = \sigma_1 - \left[(1/a_4) \times \left(V_p - a_1 + a_2\phi + a_3V_{sh}\right)\right]^{1/a_3}$$

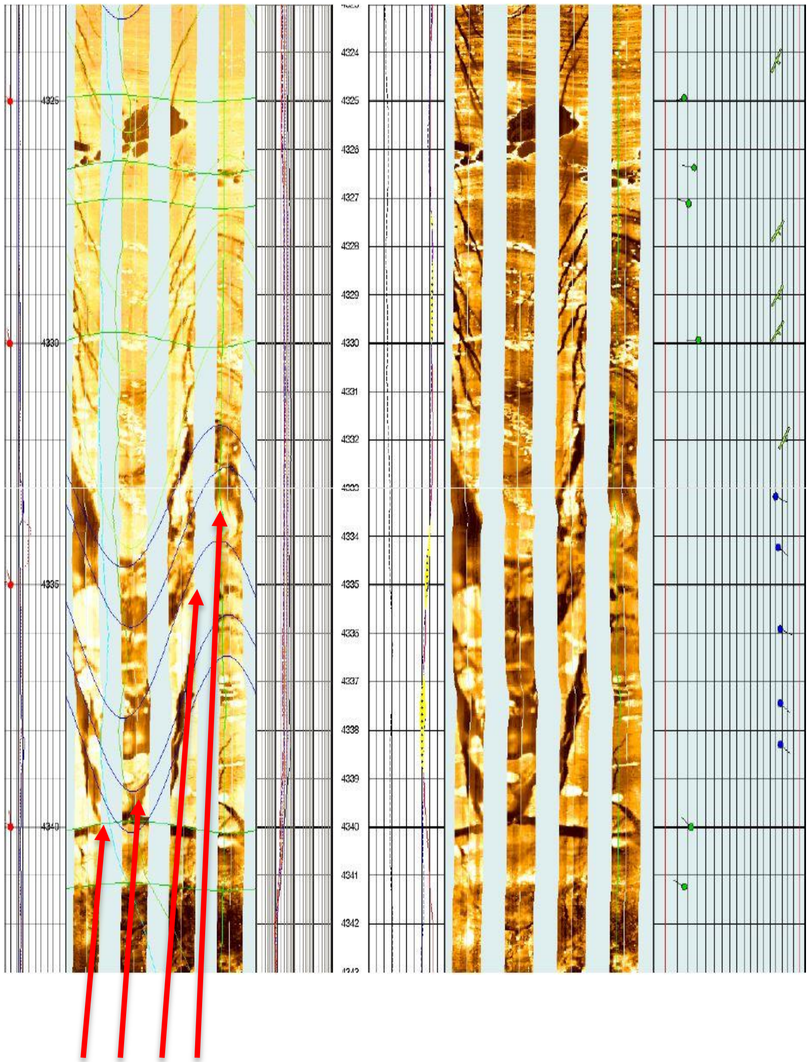


$$\sigma_{min} \cong [\nu/(1-\nu)] \times \left(\sigma_1 - \alpha P_p\right) + \alpha P_p + \sigma_{ext}$$

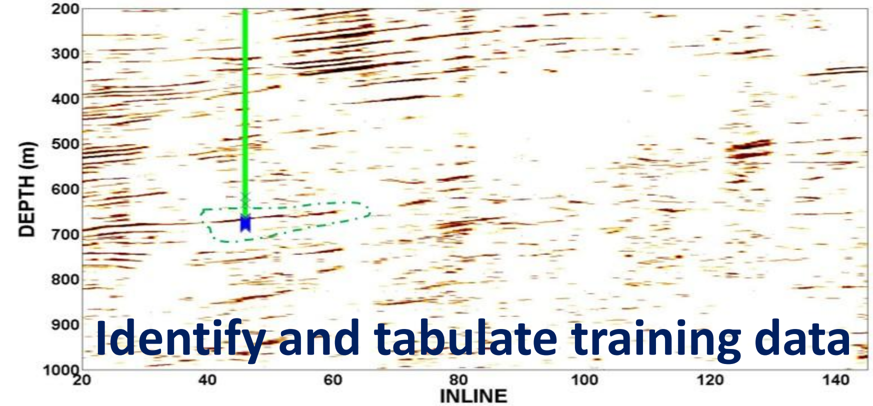


$$F_E = (b - b_r)/b_{max} = e^{\alpha V_E}$$

FRACTURE ZONE DETECTION FRAMEWORK



Identify fractures & generate fracture logs



Fluid Saturation — $\downarrow V_S$ or $\uparrow V_P/V_S$ & σ

Fracture density — $\uparrow \Delta_T$

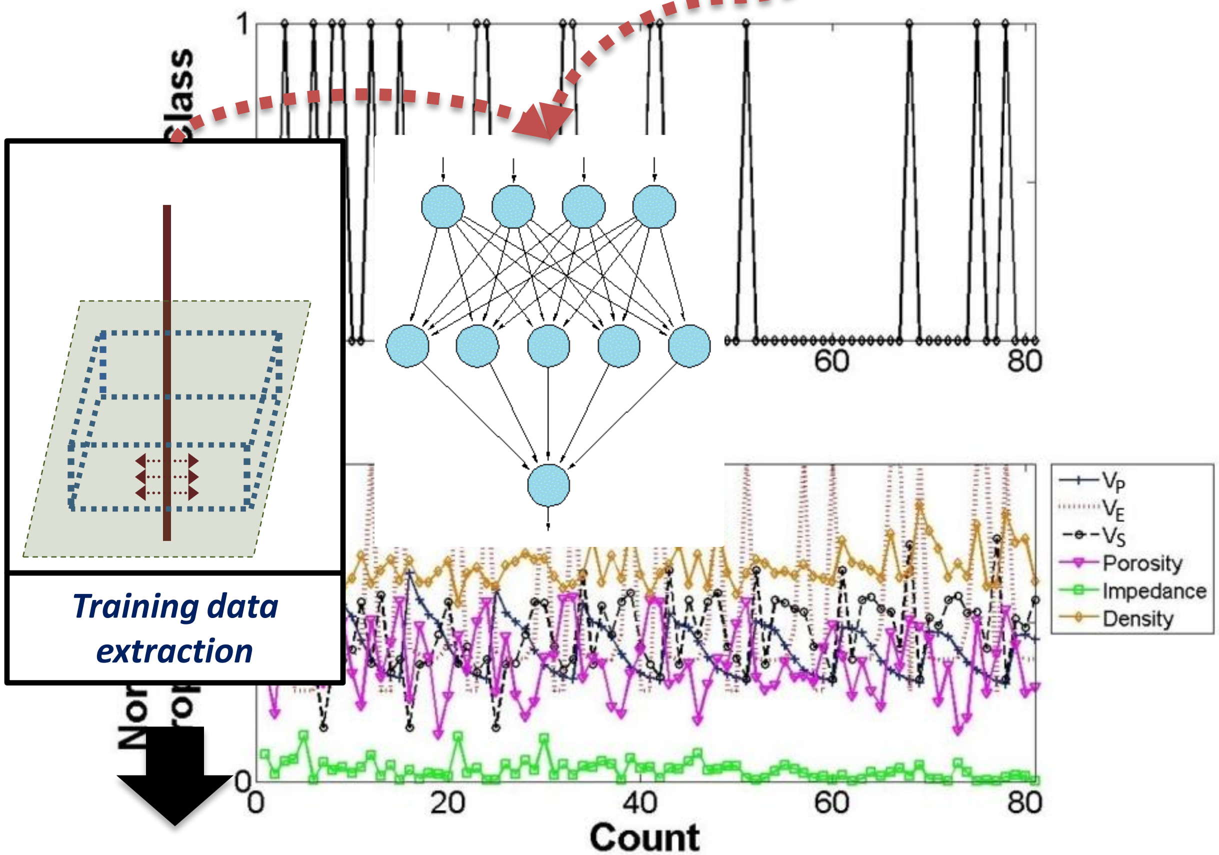
Fracture presence — $\downarrow V_P$ & V_S

Fracture opening — $\uparrow V_E$ & $\downarrow K$

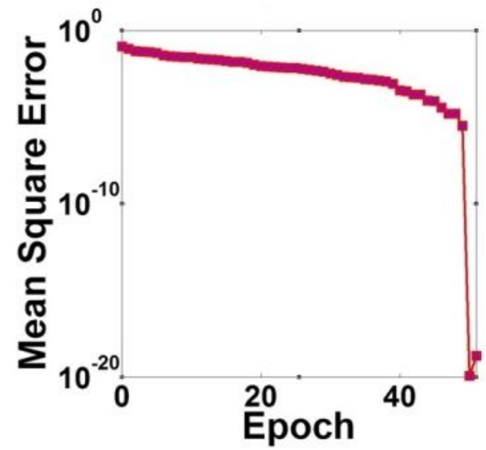
Establish model framework

HYBRID FZI ATTRIBUTE MAPPING (ANN)

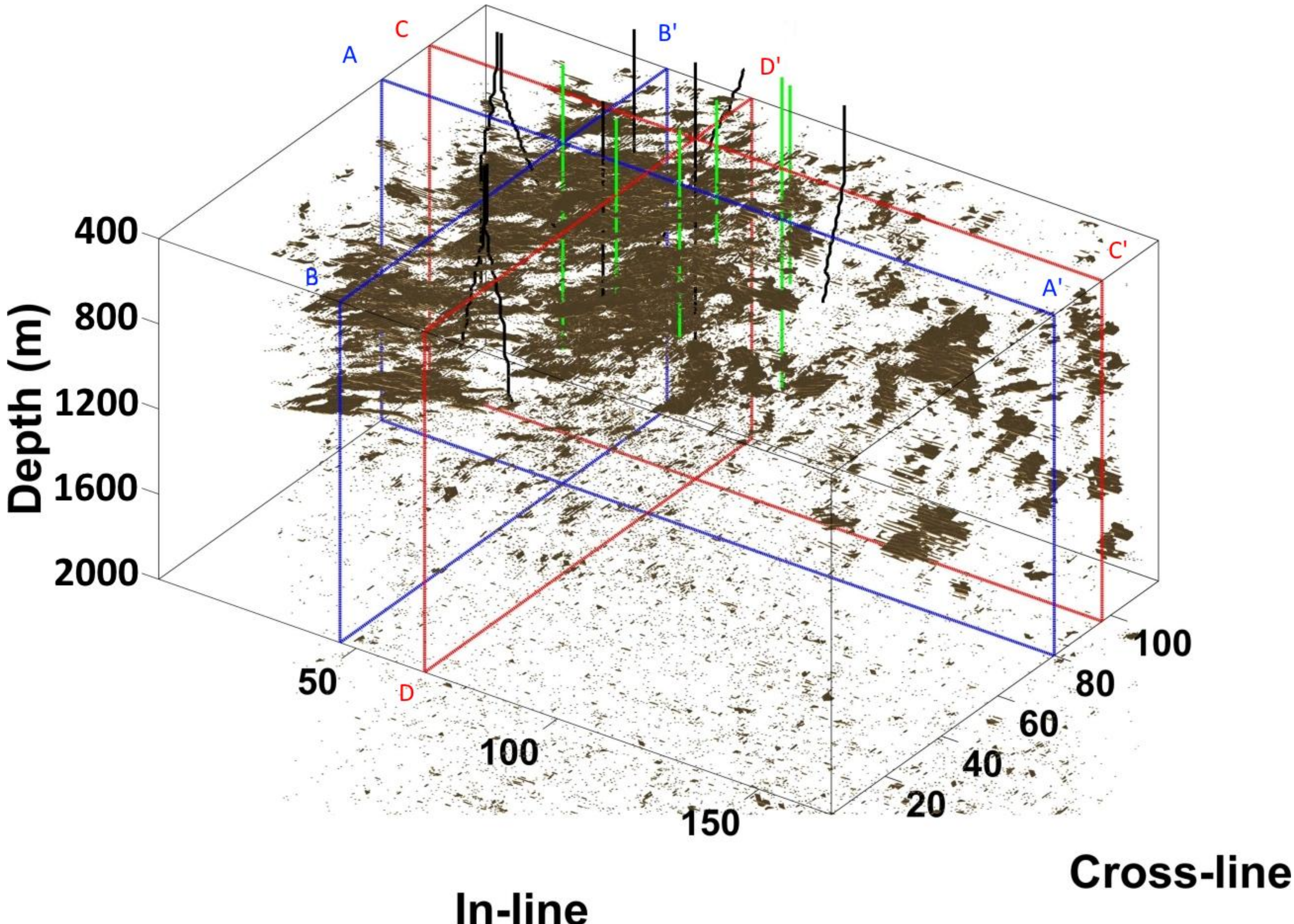
$$FZI_n = F\{\phi_n, Z_n, V_{Pn}, V_{Sn}, \rho_n, V_{En},\}$$



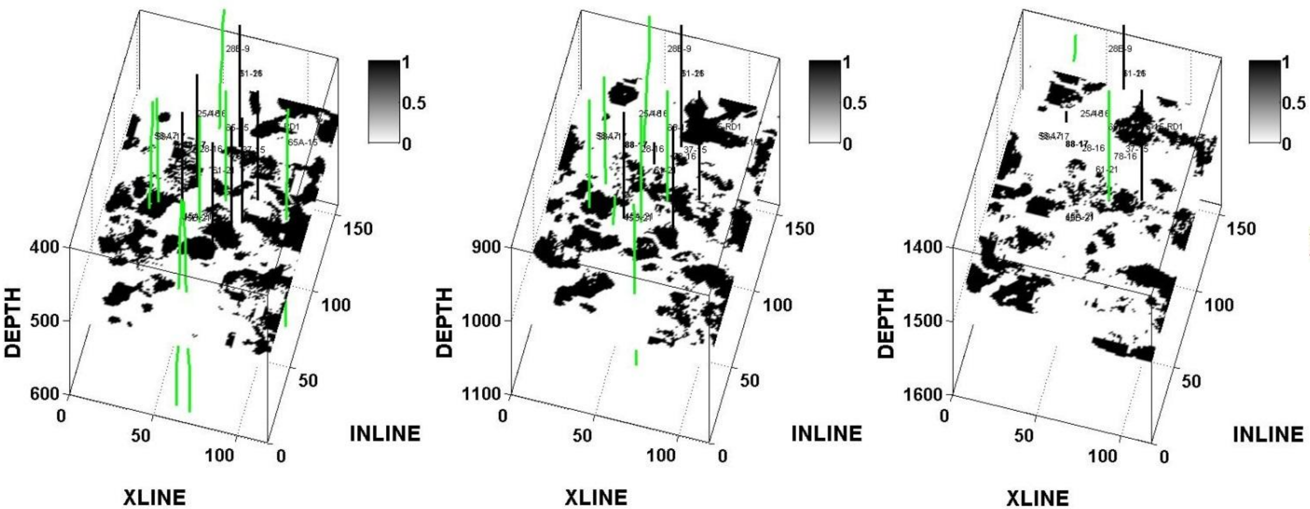
FZI



FZI ATTRIBUTE MAPPING (3D DISTRIBUTION)



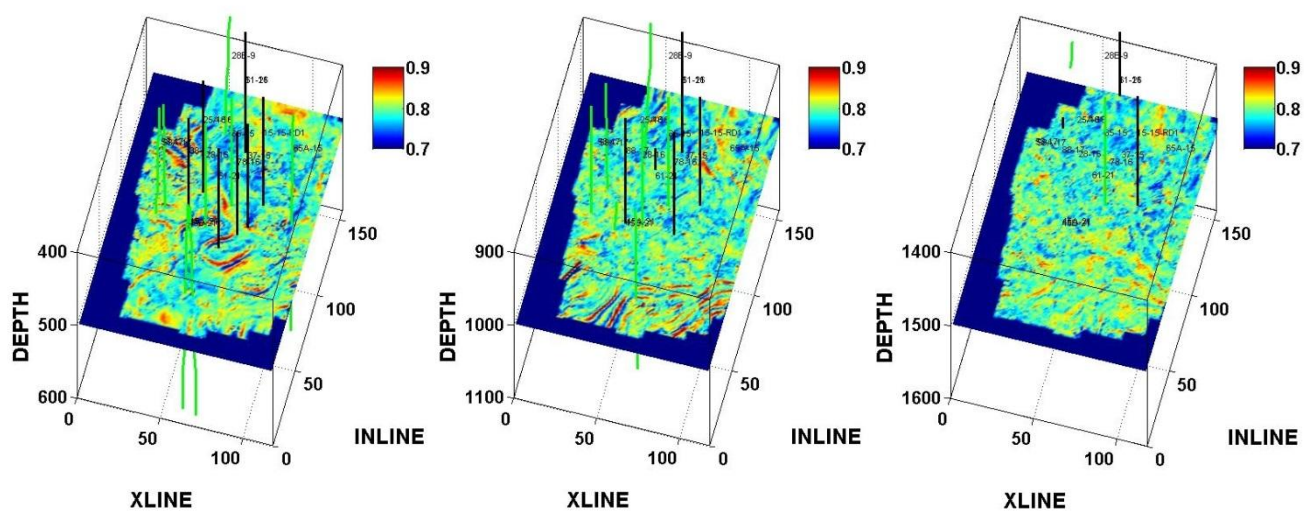
FZI ATTRIBUTE MAPPING (DEPTH SLICE)



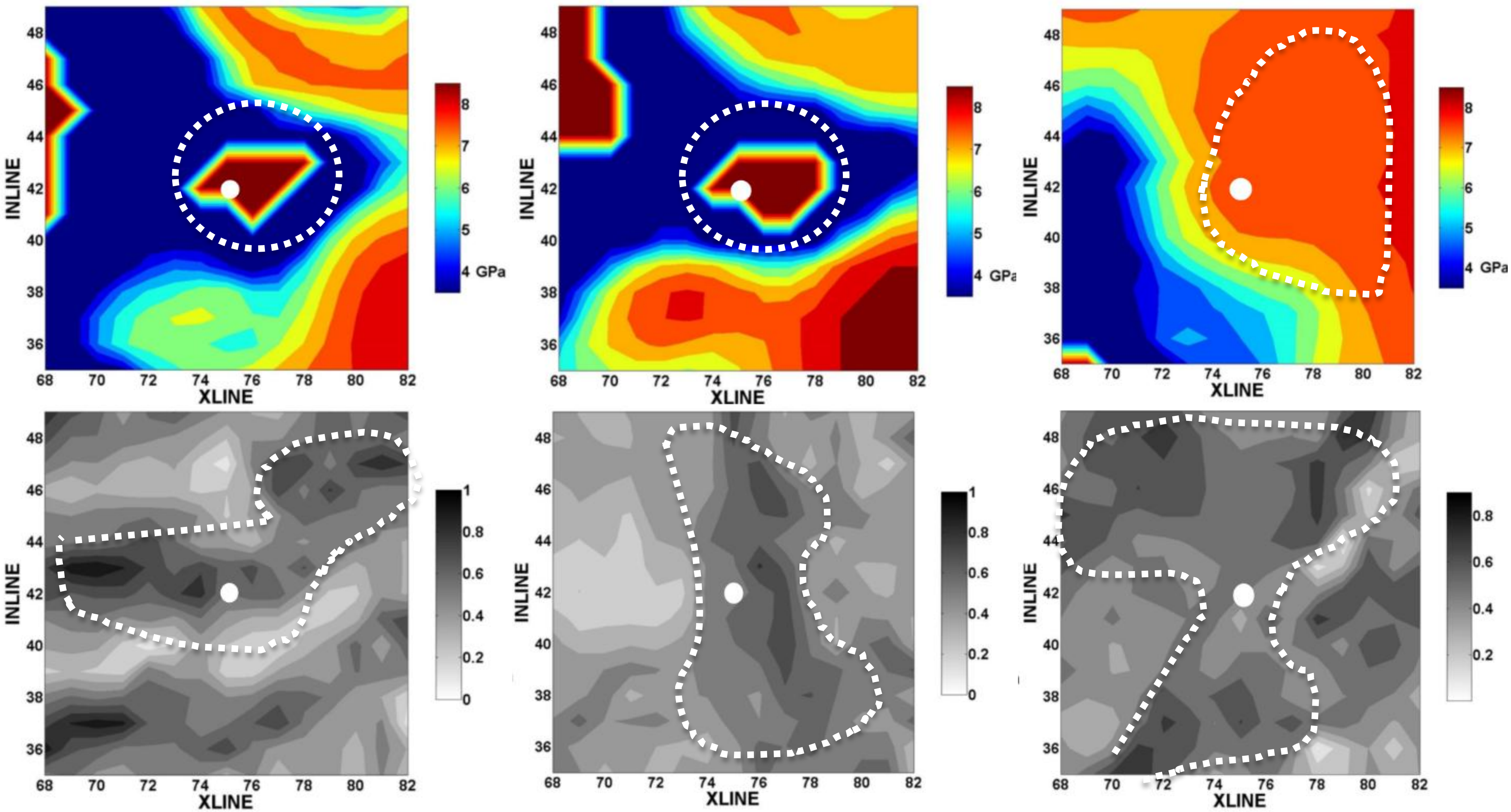
$$FZI_{3,4} = F\{\phi_n, AI_n, \rho_n, V_{Pn}, V_{Sn}, \Delta_{Tn}, V_{En}\}$$

$$FZI_A = f(\phi_n, f_n, Z_n, F_{En})$$

$$k_{Fi} = n_{Fn} FZI_A{}^3/12$$



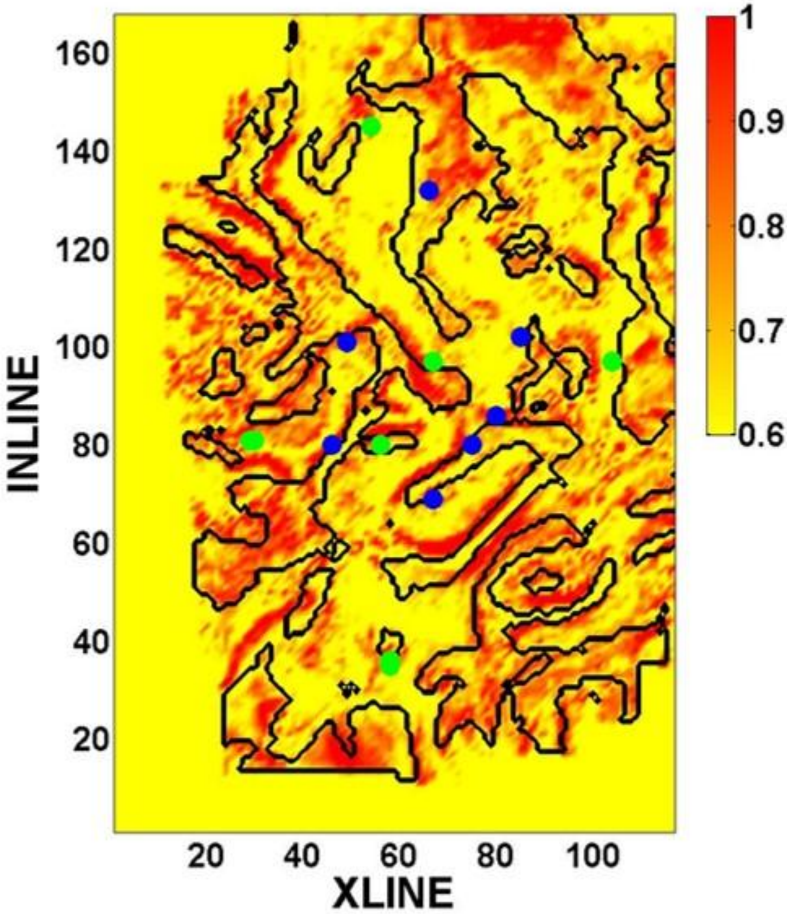
IMPACT OF INPUTS ON MODELING



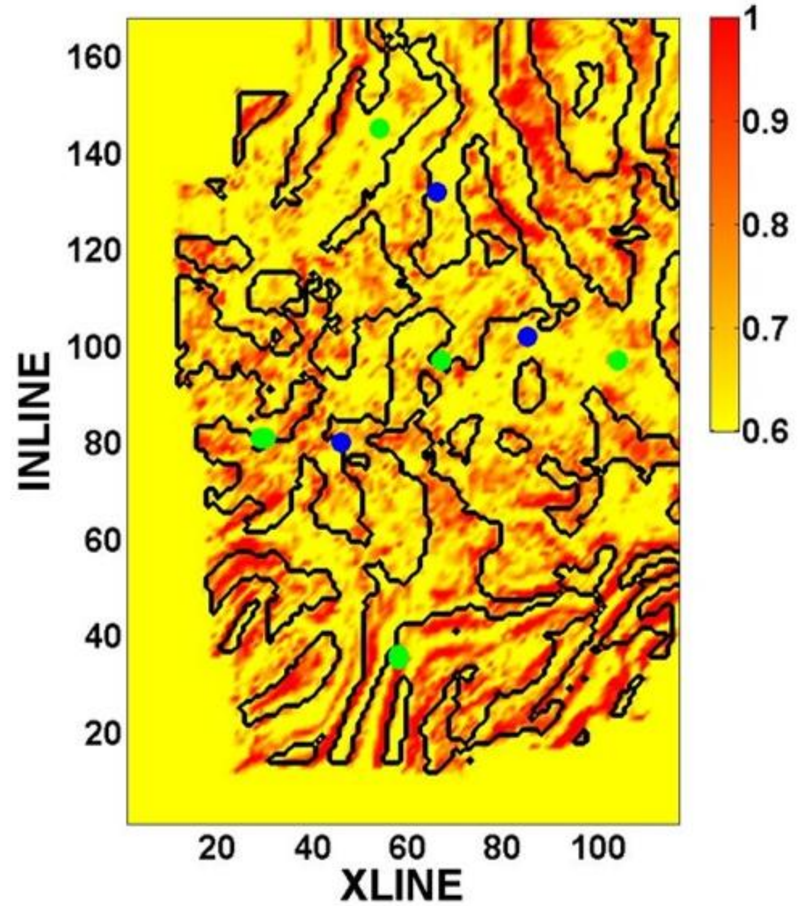
High extensional stress and high FZI values mapped at horizons of interest along two wells with known conductive fractures. We observe high V_E to map with high FZI close to wells but not necessarily at other locations (due to dependence on other properties)

INTERPRETATION (1)

Z = 0.5 km

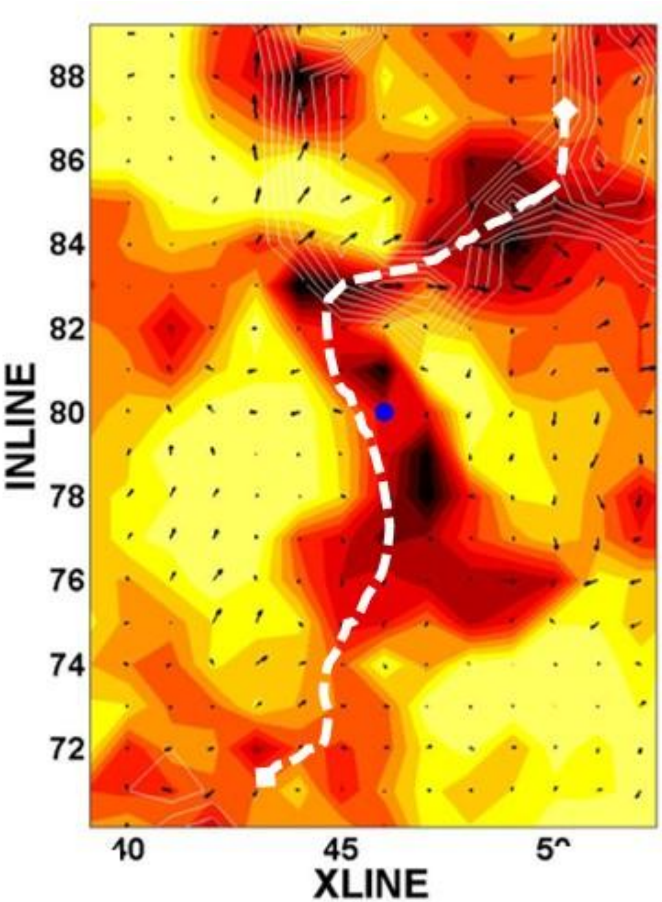


Z = 1.0 km

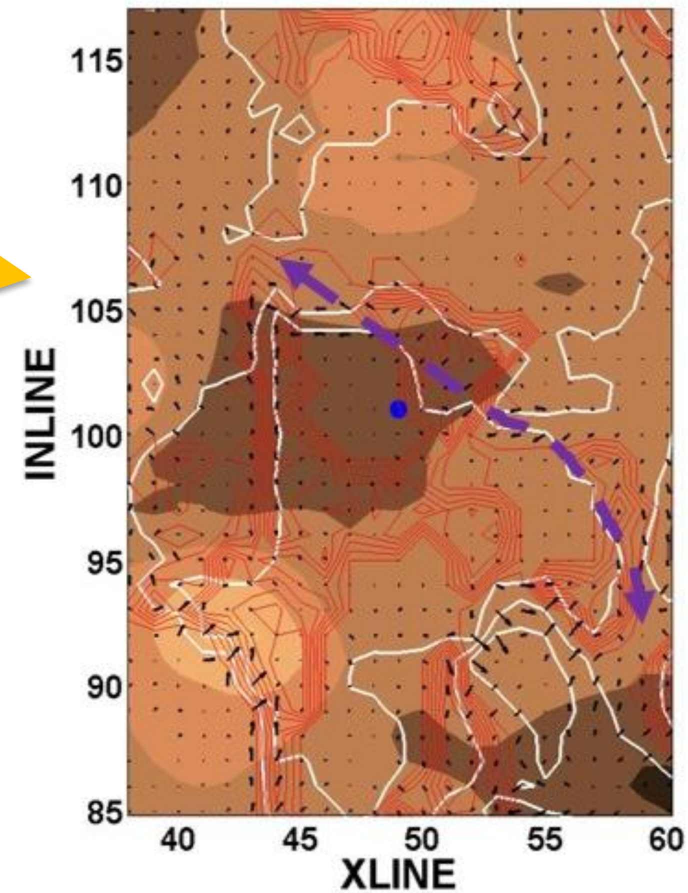


FZI with discontinuity derived from 3D seismic data used to identify and validate flow regimes close to known injectors and producers. Some wells align with major edge boundaries and/ or are within high FZI zones at the depths indicated.

INTERPRETATION (2)

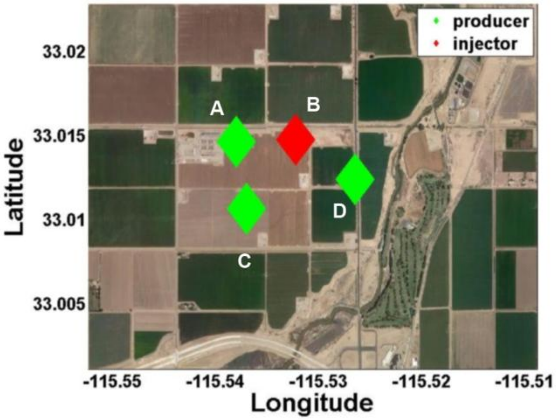


Extensional stress, discontinuity, edge and gradient mapped close to sample wellbore at horizon of interest. We observe major change in stress close to identified edge boundaries flanked by major discontinuities.

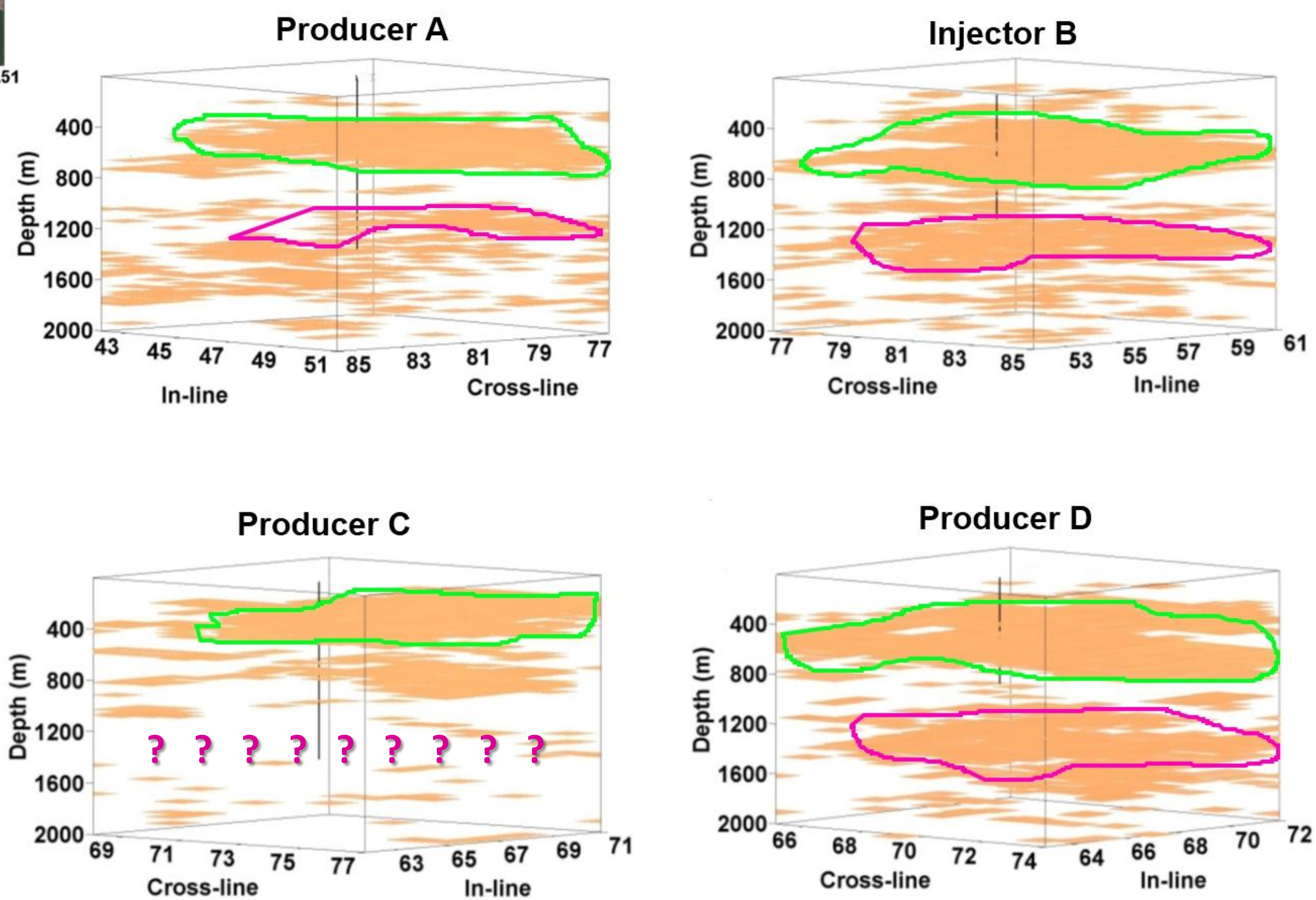


FZI mapped with discontinuity and extensional stress (vector) map. We observe major changes in stress regime close to identified discontinuities along with potential flow regime close to wellbore at horizon of interest.

INTERPRETATION (3)



Near wellbore distribution of FZI for producers A, C & D and injector B. Flowing intervals for most wells at Z > 1100m.



Mapping highlights the possible reason for observed low flow throughput for well B.

OBSERVATIONS & CONCLUSIONS

- ✓ Low resolution passive seismic can be used as a reservoir characterization tool.
- ✓ It can supplant information from conventional 3D reflection seismic data and provide a method for time lapse analysis.
- ✓ Various properties can be predicted by means of neural-networks and other hybrid AI algorithms.
- ✓ COSGSIM provides a useful tool to improve on the relatively low resolution of microseismic derived compressional and shear velocity estimates.
- ✓ New hybrid FZI attributes show promising results in identification of potential zones of interest for future development and for reservoir diagnostics.
- ✓ Other properties such as pore pressure, effective stress, fracture aperture, fracture orientation, fracture permeability, etc. can also be predicted by following a similar methodology provided relevant physical models are available for mapping.

FURTHER READING

- Maity, D., F. Aminzadeh, 2015, Novel fracture zone identifier attribute using geophysical and well log data for unconventional reservoirs: Interpretation, 3(3), T155–T167. http://dx.doi.org/10.1190/INT-2015-0003.1

- Maity, D., 2013, Integrated reservoir characterization for unconventional reservoirs using seismic, microseismic and well log data: Ph.D. thesis, University of Southern California. http://digitallibrary.usc.edu/cdm/ref/collection/p15799coll3/id/294857

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QUESTIONS

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COMMENTS…