Application of Simultaneous Inversion and Geomechanical Facies in the Characterization of an Unconventional Play*

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Abstract

The Vaca Muerta formation, covering approximately 30,000 square kilometers in Argentina's Neuquén Basin is a developing unconventional resource play. The giant Vaca Muerta shale oil and gas field has an estimated resource potential of 600+ billion barrels of oil and 1,000+ TCF of natural gas. Like other unconventional shale plays, horizontal drilling and hydraulic fracture stimulation are essential for economic viability. Main factors that can strongly influence the effectiveness of hydraulic stimulation are the distribution and values of horizontal stresses, elastic moduli and rock strength properties. This paper describe a workflow used to estimate elastic moduli, geomechanical facies and stresses in a 3D volume based on geological concepts, well-based 1D petrophysical and geomechanical models and pre-stack seismic inversion to estimate the lateral variation of elastic properties away from well control. The stress regime in the study area has two distinct environments, the normal pore pressure interval, covering all the overburden and the over-pressurized region, rich in hydrocarbons where the unconventional reservoir is allocated. The limit between these two distinct regions is a stratigraphical surface regionally continuous that delimits two sedimentary cycles deposited in different basin conditions (Figure 1). The workflow uses conventional, velocity based, pore pressure prediction estimation together with an isotropic assumptions for the estimation of the elastic properties from density, shear and compressional velocities. Horizontal stresses has been calculated at well locations assuming stress anisotropy and using elastic properties, pressure and tectonic strains following Cipolla et al 1994 approach and calibrating estimated curves with several mini-frac tests. The same set of assumptions used for the 1D Model at well locations is used for the estimation away of well control based on P and S wave velocities derived from pre-stack inversion and used as soft constrain in the static

model. The model is being used to select both the location of appraisal wells and the horizontal interval to be navigated based on stresses and brittleness variations

Selected References

Eberhart-Phillips, D., 1989, Active faulting and deformation of the Coalinga anticline as interpreted from three-dimensional velocity structure and seismicity: Journal of Geophysical Research, v. 94/13, p. 15565-15586: doi: 10.1029/89JB01390.

Mitchum, R.M., and M.A. Uliana, 1985, Seismic stratigraphy of carbonate depositional sequences, Upper Jurassic - Lower Cretaceous, Neuquén Basin, Argentina: in Bero, B.R., and D.G. Woolverton (eds), Seismic Stratigraphy: An Integrated Approach to Hydrocarbon Exploration, AAPG Memoir 39, p. 255–275.

Reijenstein, H.M., H. Posamentier, M.A. Fantín, F.G. Tomassini, and C. Lipinski, 2014, Vaca Muerta Seismic Stratigraphy and Geomorphology: Regional Architectural Trends for Unconventional Exploration: CONEXPLO - IX Congreso de Exploraicion & Desarrollo de Hidrocarburos, Web Accessed November 11, 2016, https://www.researchgate.net/publication/281110766_VACA_MUERTA_SEISMIC_STRATIGRAPHY_AND_GEOMORPHOLOGY_REGIONAL_ARCHITECTURAL_TRENDS_FOR_UNCONVENTIONAL_EXPLORATION

Stinco, L.P., and S.P. Barredo, 2014, Vaca Muerta Formation: An Example of Shale Heterogeneities Controlling Hydrocarbon Accumulations: Unconventional Resources Technology Conference, Denver, Colorado, 25-27 August 2014, p. 2854-2868.

Simultaneous Inversion and Geomechanical Facies in the Characterization of an Unconventional Play

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Chevron

human energy

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Exploring Frontiers in a Competitive Environment

Overview

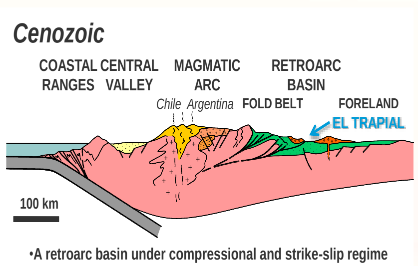
Presentation Contents

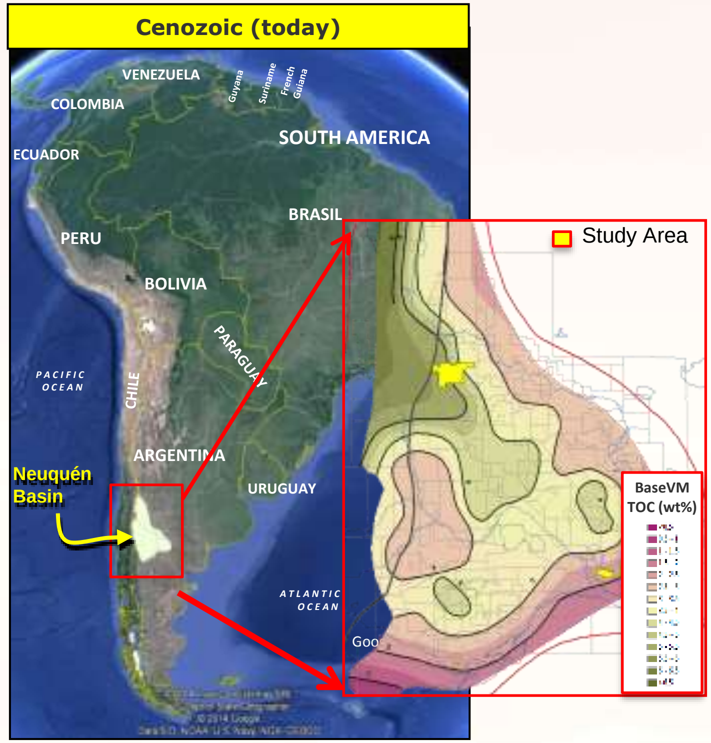
- Geological Framework
- Data Availability
- Seismic Information
- Initial Model
- Pre-Stack Inversion
- Spatial Distribution
- Mechanical Facies
- Pore Pressure
- 1D-MEM
- Static Modeling
- Conclusions

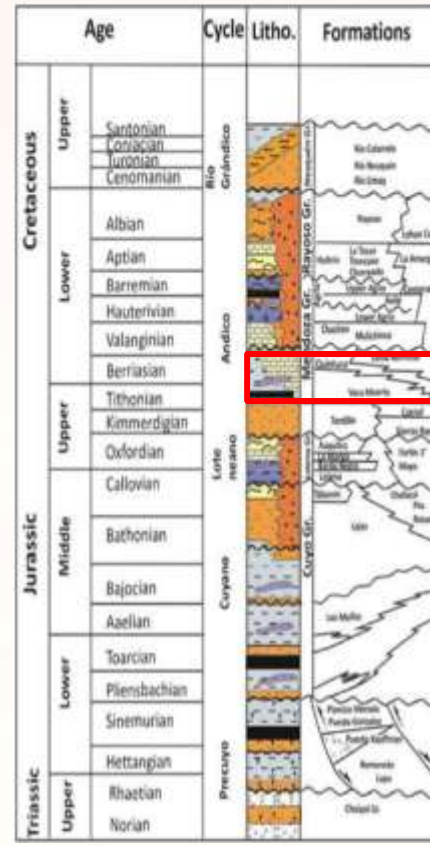
Scope

- Predict spatial changes in rock mechanical properties and stresses using 3D seismic and a regional calibrated 1D-MEM
- Identify non representative and potential hazard zones in the early exploratory stage.
- De-risk the project maximizing acquired information and use the workflow output for the planning of the pilot/appraisal phase

Geological Framework and Study Area







Modified from Mitchum & Uliana, 1985; Barredo & Stinco, 2014

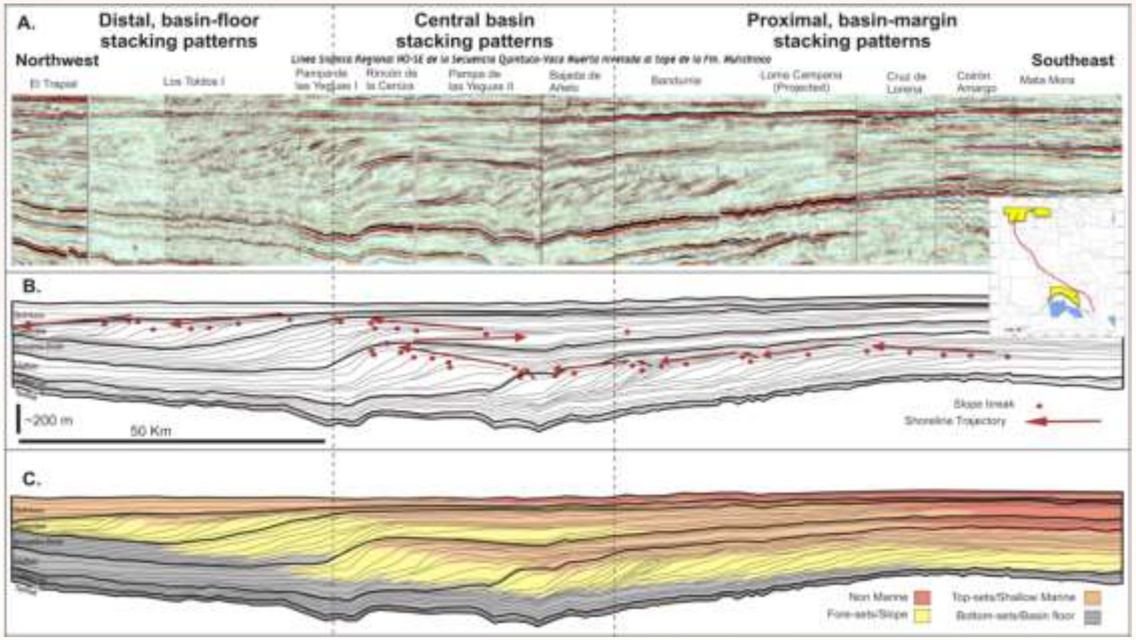
Country's most productive oil and gas basin

Early Triassic: Rift Phase – Back Arc Basin Formation

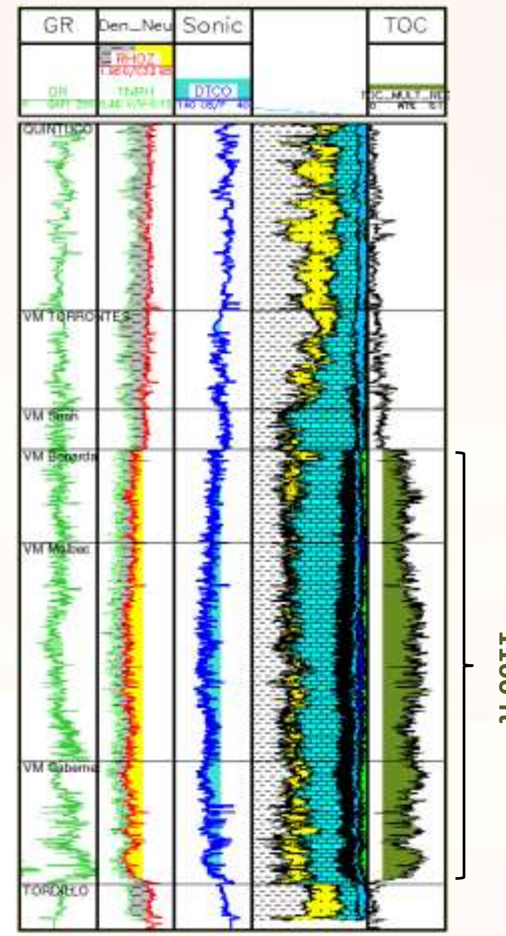
Late Triassic - Cretaceous: Thermal Sag Phase. 3 main sedimentary cycles.

Cenozoic: Andean compression uplifted + erosion

Vaca Muerta Stratigraphy and Type Log



Reijenstein et al., 2014



Target Section

PHIT > 5%
TOC > 2%
VCLAY < 40%

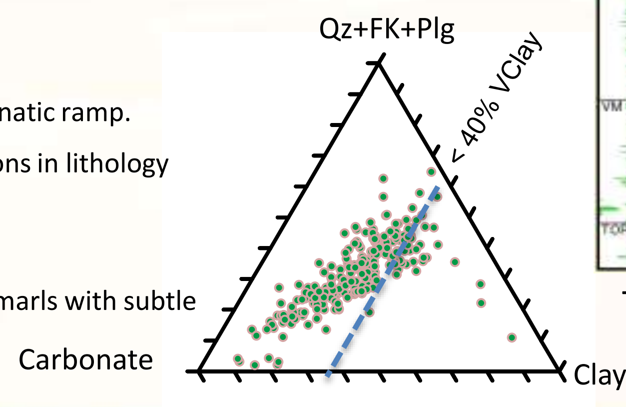
<u>Regional Stratigaphy</u>

Series of prograding sequences in a mixed clasitc/carbonatic ramp.

These sequences control the vertical and lateral variations in lithology and elastic parameters.

<u>VM Target</u>

Thick organic rich interval of overpressured shales and marls with subtle variations in composition



Data Availability

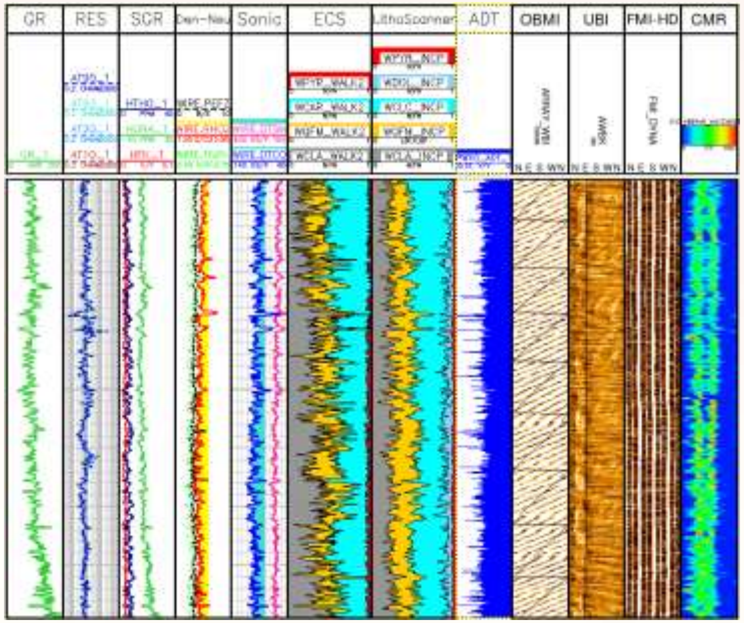
4 Exploration Wells

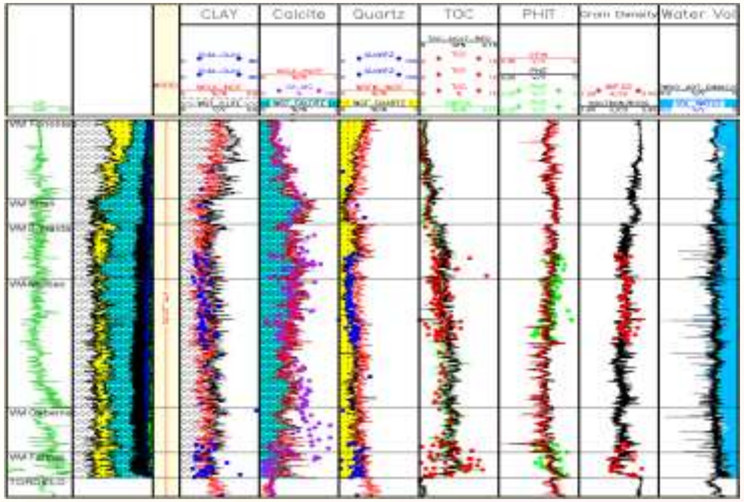
Last generation of Logging Tools including:

- High resolution spectroscopy
- Nuclear magnentic resonance
- Dipole Sonic
- High resolution dielectric tool
- Sonic Image logs
- Resistivity Image Logs

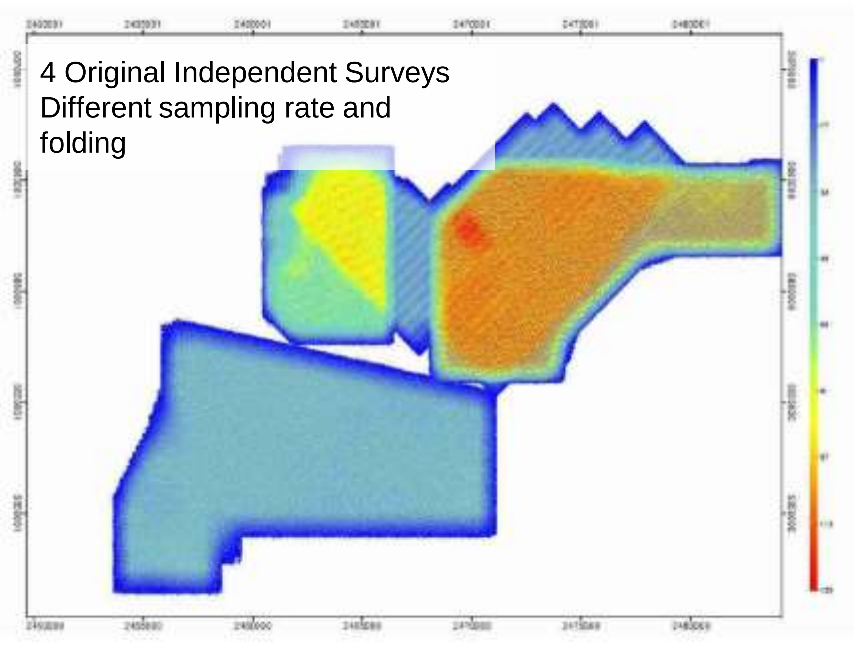
1200 ft of Cores among all wells

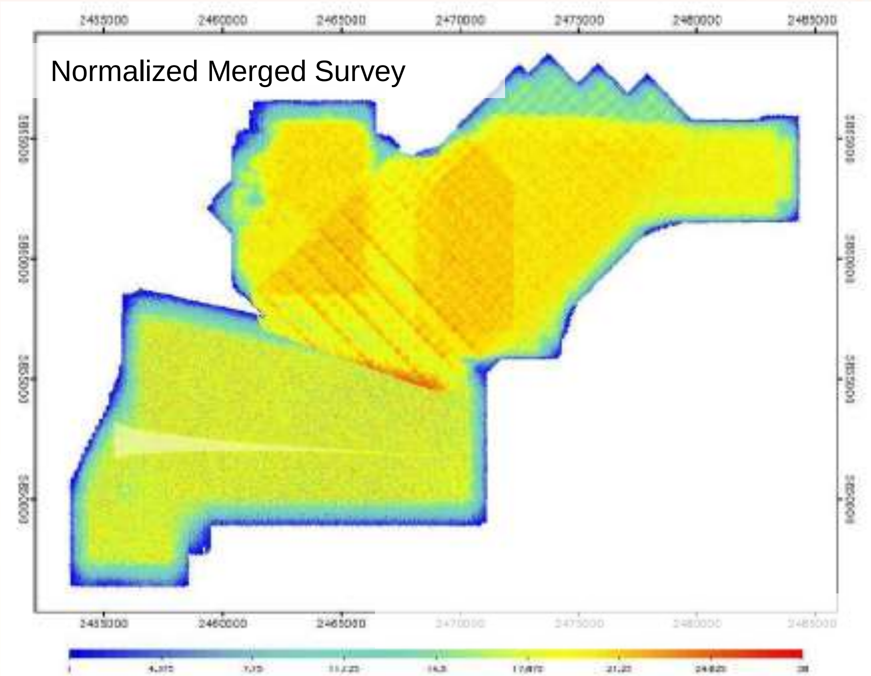
- Several Samples with anisotropic triaxial testing
- Hundreds of Laboratory determinations:
  - X-Ray difraction and X-Ray Fluorescence
  - Porosity and Geochemistry

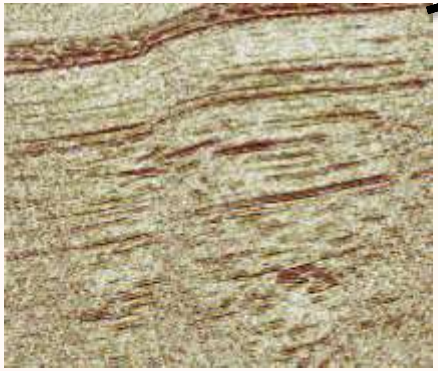




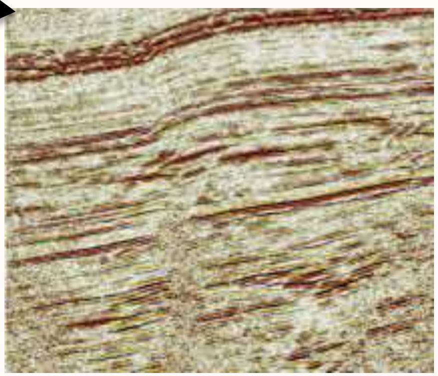
Seismic Information





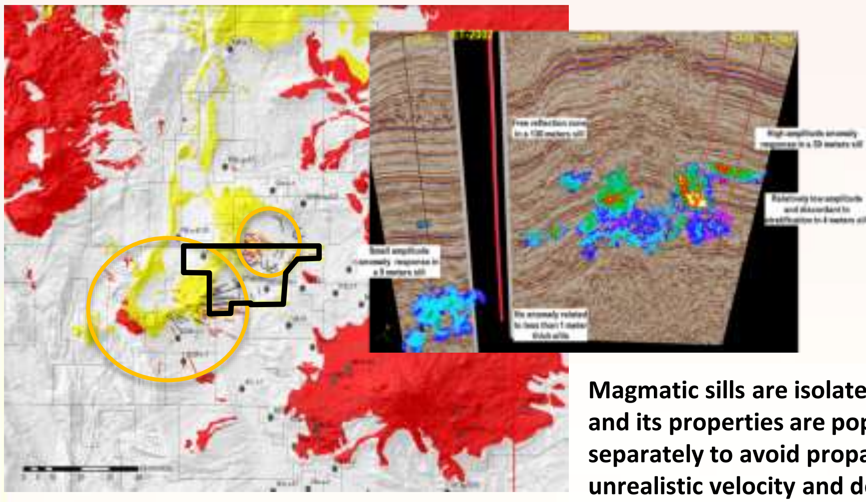


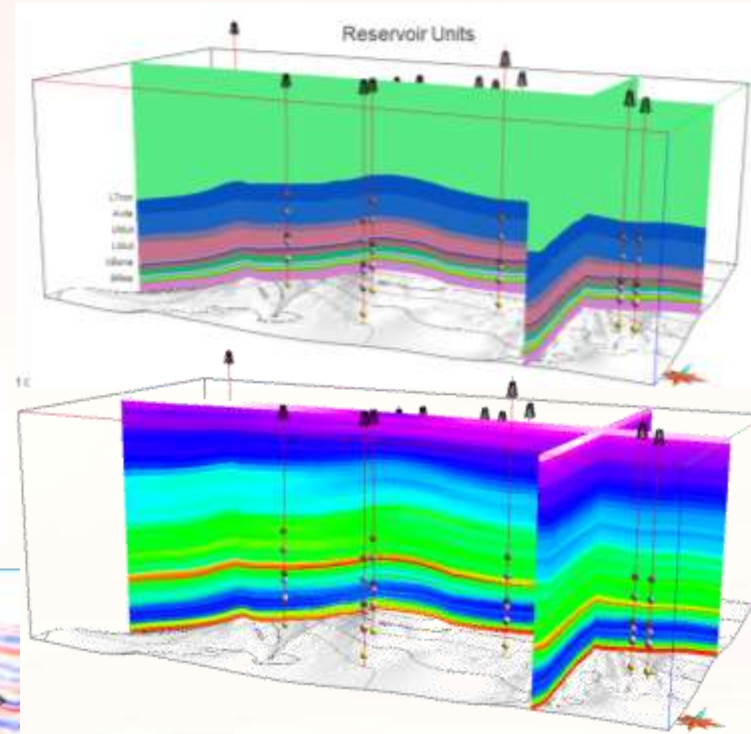
Deconvolution
Velocity Analysis/Static Corrections
Noise attenuation
Interpolation
Pre-Stack Time Migration (Kirchhoff)
RNMO
Synthetic AVO calibration @wells



Static Model and Magmatic Intrusions

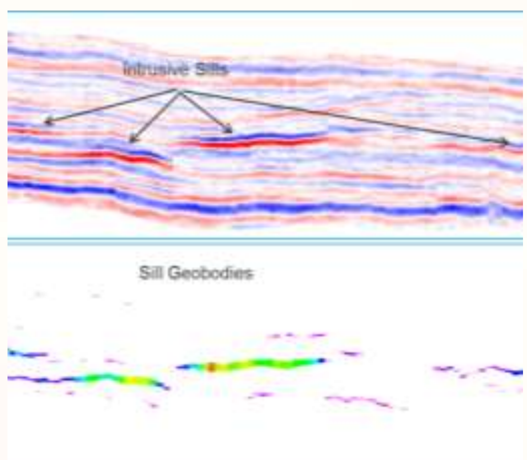
Stratigraphic Grid → Magmatic Intrusions Isolation → Velocity Model → Density Model



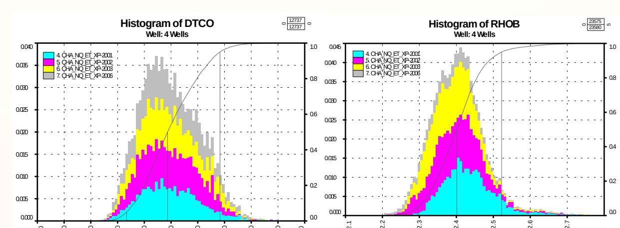


Magmatic sills are isolated in geobodies and its properties are populated separately to avoid propagation of unrealistic velocity and density away of well control.

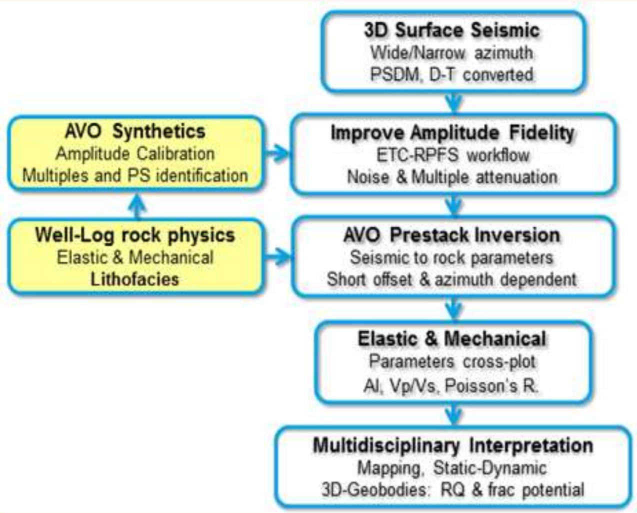
Simulated seismic for Sills: Hilbert's Attributes

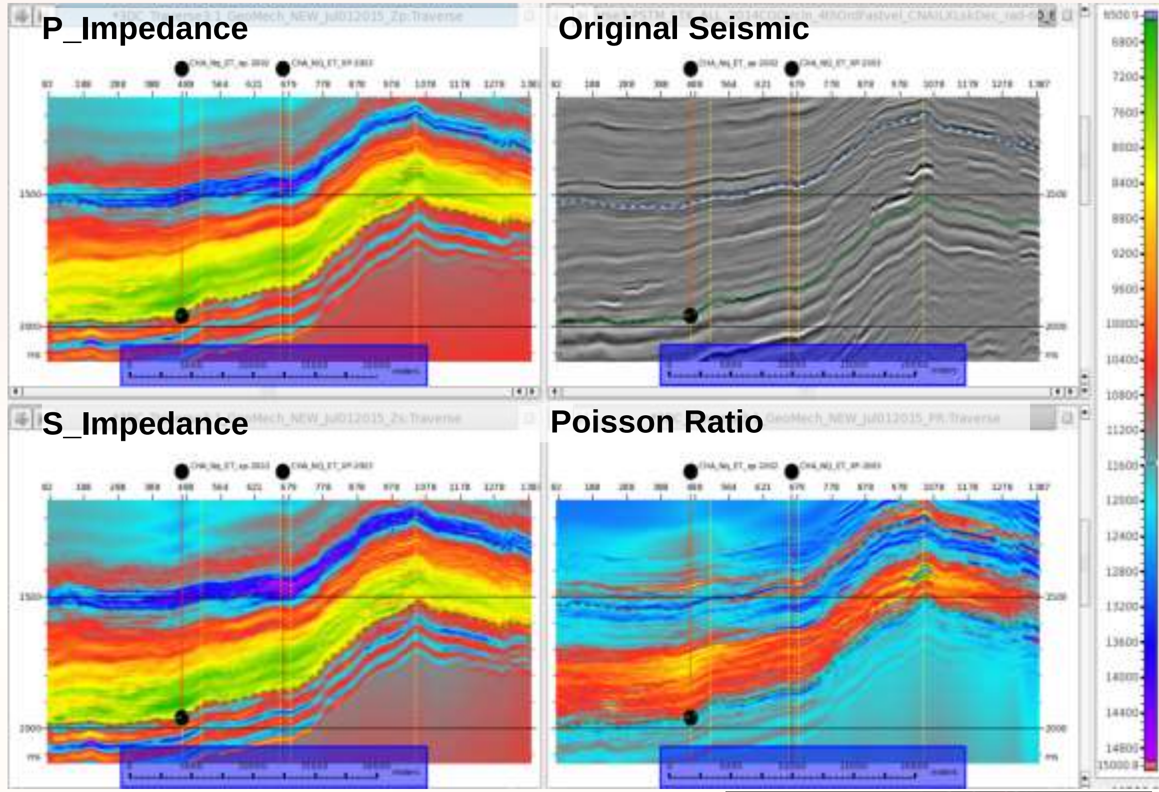


Magmatic Sills are characterized by high AI and strong reflectors

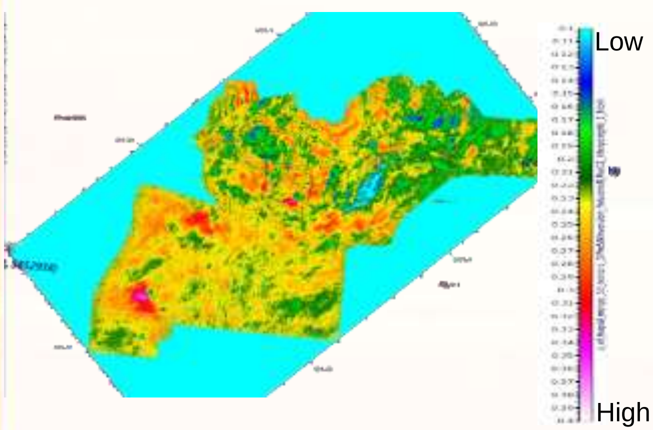


Simultaneous Pre-Stack Inversion





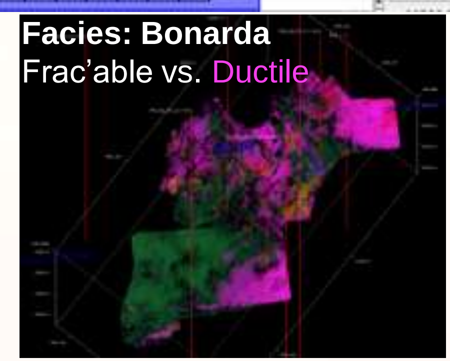
Poisson Ratio at Lower VM (Horizon Extraction)



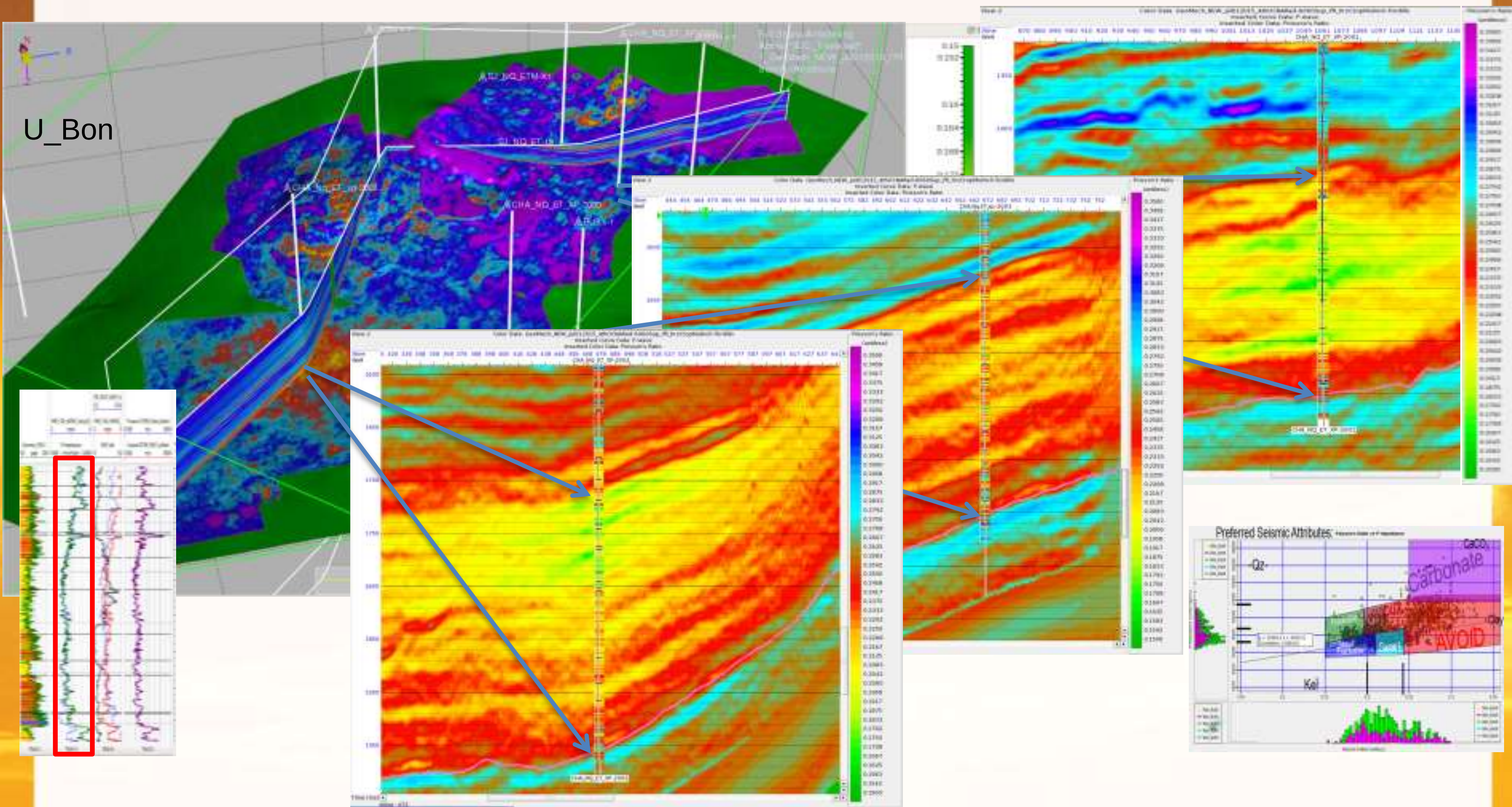
AI → Young

PR → CSS

Isotropic Dynamic properties



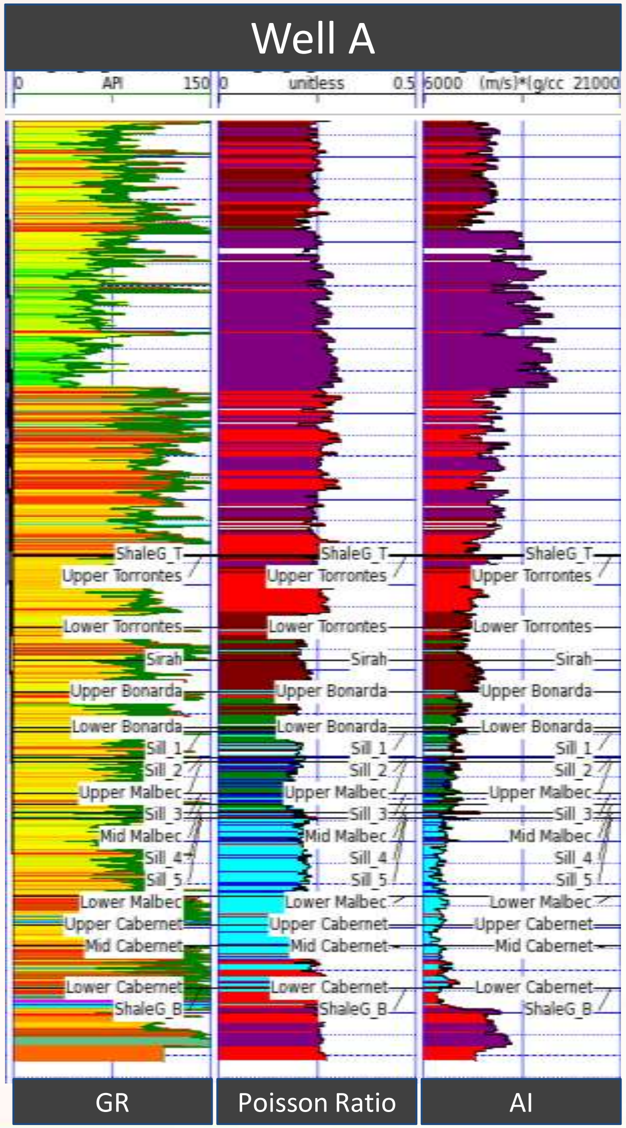
Spatial Distribution of Seismic Properties

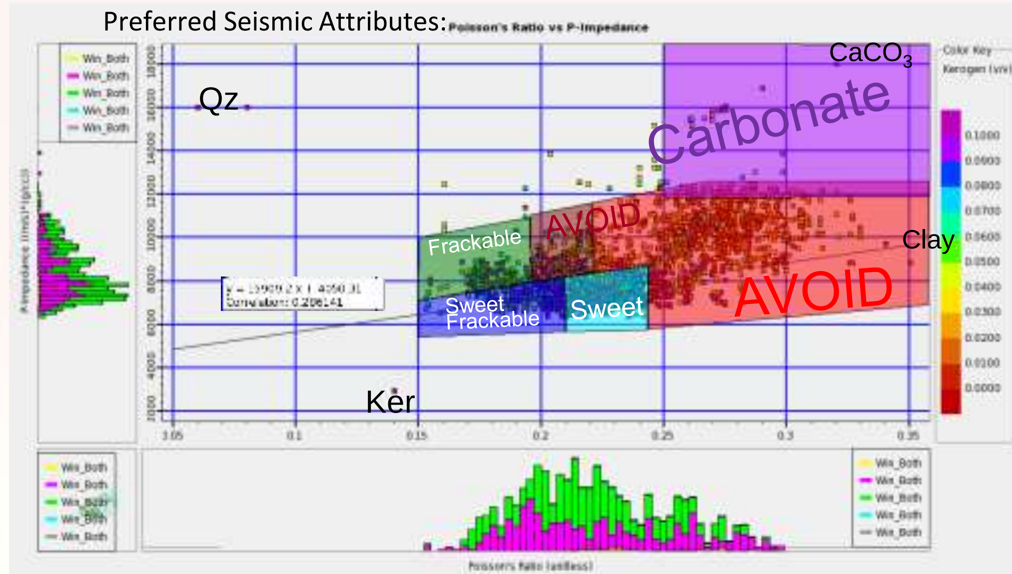


AI → Young Modulus
PR → Closure Stress Ratio (CSS)
Dynamic-Isotropic

Vertical and lateral variability captured by seismic attributes

Mechanical Seismic Facies





Avoid facies: Limestone, sills and high clay facies are not a completion target

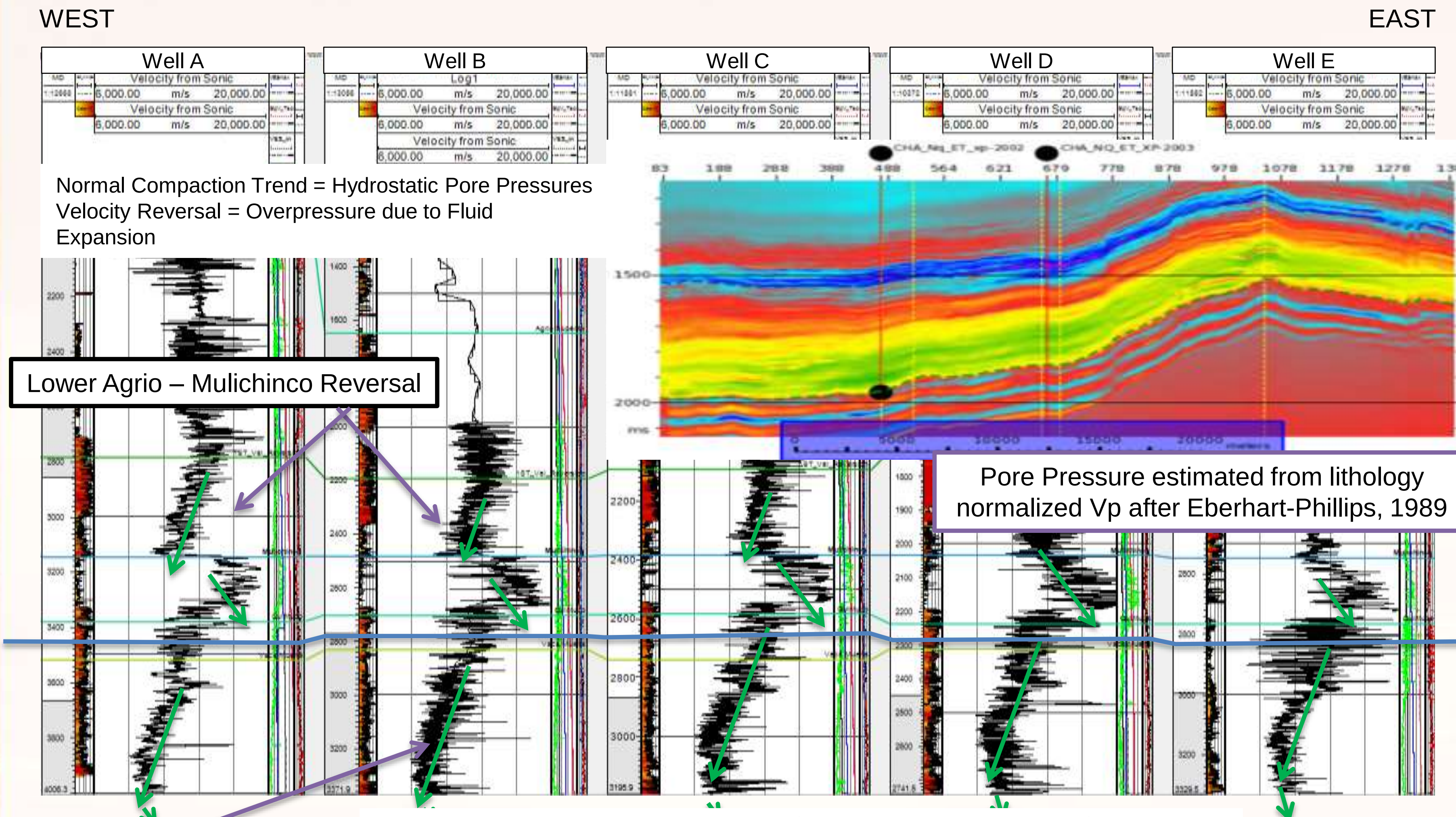
Kerogen rich facies: High TOC content may not be optimal for well landing & fracking

Frac facies: Low TOC content and frackable good for landing and completion; not in all wells.

Storage and Still frackable: Can be good for landing and completion with high TOC and high porosity.

Calibrated with FE, MEM and geological framework to identify core area
Similar to adjacent blocks

Pore Pressure



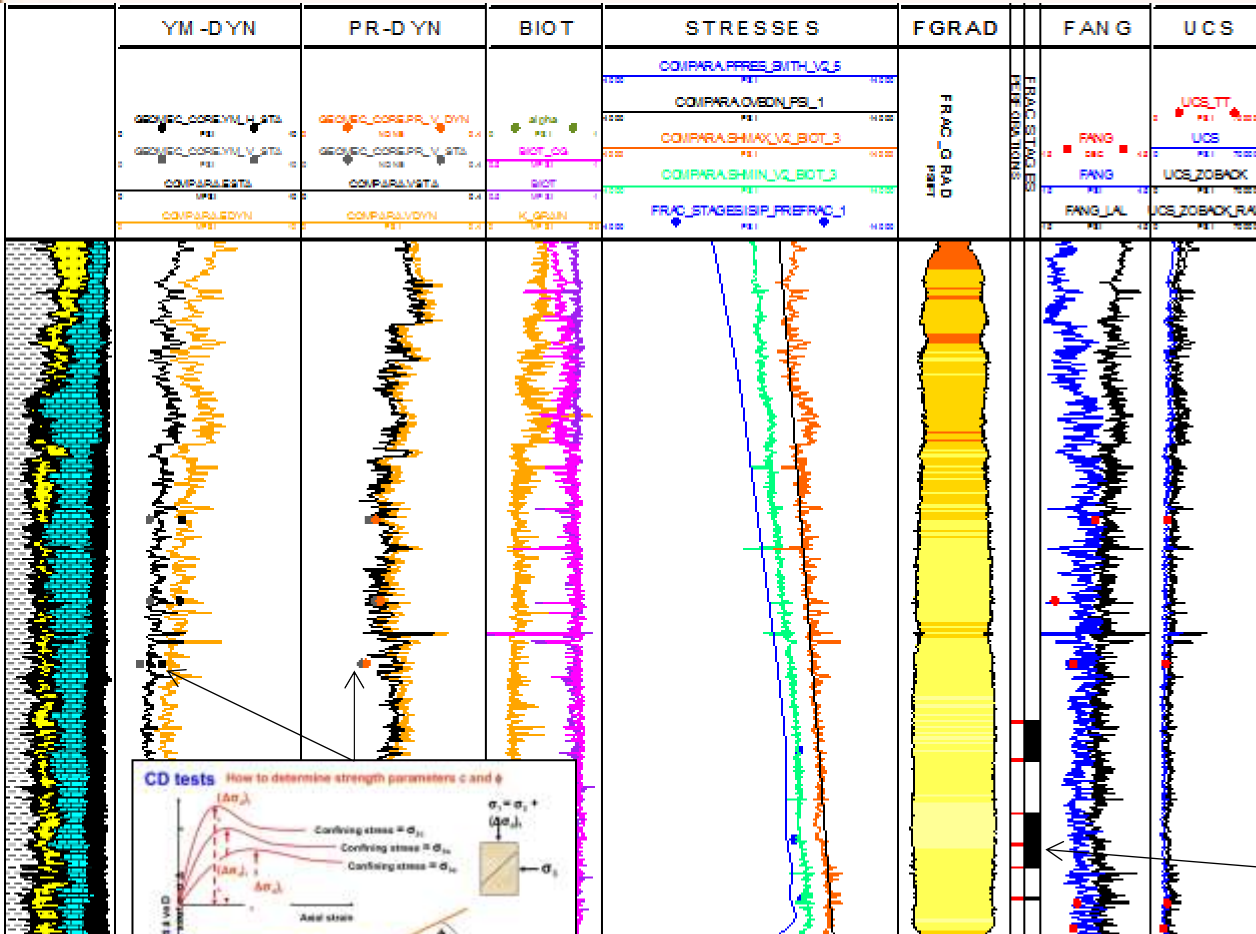
Vaca Muerta Reversal

1) $$DTnct = (DT_{MAX} - DT_{MIN}) * e^{(SLOPE*(DEPTH+EROSION))} + DT_{MIN}$$

2) $$V_o = a_1 - a_2*PHIT - a_3*VSH - a_4*CARB\_V$$

3) $$Vp = V_o + A \,.\, (\sigma_{max} \cdot (\frac{\sigma_{eff}}{\sigma_{max}})^{\frac{1}{U}})^{B}$$

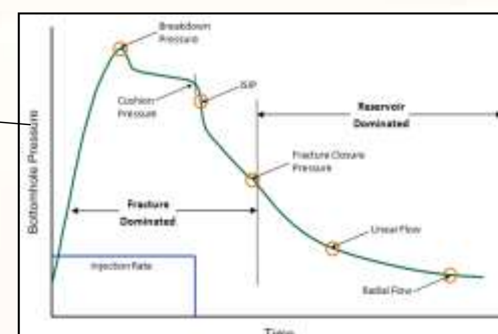
Regional 1D Mechanical Earth Model



- **MEM Tested with 18 wells**
- **Calibrated with triaxial and ISIPs**
- **Area: 3000 km2 (750,000 acres)**
- **Modified Eberhart-Phillips effective stress aproach**

$$\sigma_h = \alpha P_p + \frac{\nu}{1-\nu}\cdot(\sigma_v - \alpha P_p) + \frac{E}{1-\nu^2}\varepsilon_h + \frac{E\cdot\nu}{1-\nu^2}\varepsilon_H$$

$$\sigma_H = \alpha P_p + \frac{\nu}{1-\nu}\cdot(\sigma_v - \alpha P_p) + \frac{E}{1-\nu^2}\varepsilon_H + \frac{E\cdot\nu}{1-\nu^2}\varepsilon_h$$



Integration in the Static Model

Pore Pressure estimated from seismic velocity volume

↓

Overburden Pressure from interpolated density logs

↓

Pore pressure and Overburden Pressure gridded to 2-8 meters cell size

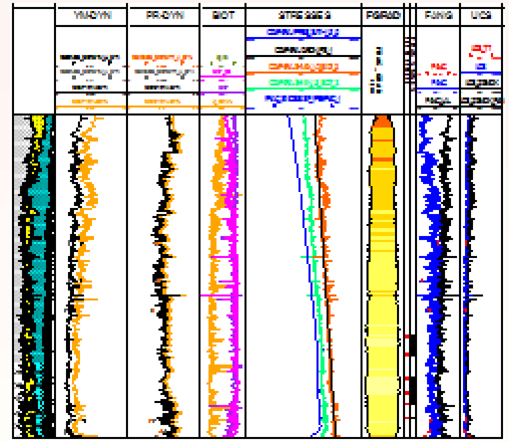
↓

Poisson Ratio estimated from 3D seismic (PR) (resampled)

↓

Tectonic strains are assumed constant and calibrated with minifracs & ISIPs

1D MEM

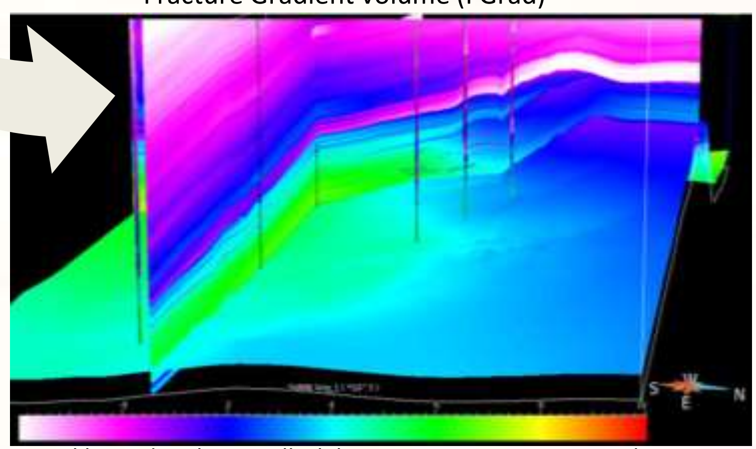


Horizontal Stress   CSS   *Vertical Stress*   *Tectonic Strains constant* $(V_{fast} = V_{slow})$

$$\sigma_h = \alpha P_p + \frac{\nu}{1-\nu}\cdot\left(\sigma_v - \alpha P_p\right) + \frac{E}{1-\nu^2}\varepsilon_h + \frac{E\cdot\nu}{1-\nu^2}\varepsilon_H$$

Geostistic guided by seismic

Fracture Gradient volume (FGrad)



Calibrated with 18 wells, lab measurements, micro and ISIP

Conclusions

- Last generation well log acquisition and core analysis was key to calibrate the petrophysical and the geomechanical model used to check the outputs of the seismic inversion
- Strong QC and interaction with processing company delivered a consistent and calibrated gather set and image.
- In exploration stage removing bias from the initial model before running inversion is critical to obtain reliable results.
- Acoustic Impedance is a valuable tool to detect and map the onset of overpressured zones in unconventionals.
- Poisson Ratio can be used as an indicator of brittle vs ductile zones and has been used for mechanical facies discrimination.
- Stress regime and anisotropy is as important as mechanical properties and can be roughly estimated from the static model after sampling the seismic facies as a guide.

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Chevron Argentina Business Unit

Chevron Africa and Latin America E&P


Thank you!
Questions?