Integrated Characterization of Unconventional Upper Jurassic Reservoir in Northern Mexico

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Introduction

This field in Northern Mexico was explored as conventional resource during past decades. Recently it has been redirected by Pemex to shale unconventional play category based on the potential of Upper Jurassic source rock formation, correlated with the Haynesville shale in USA. In unconventional plays stimulation of the reservoir by hydraulic fracturing is the primary mechanism used to increase hydrocarbon production rates, thus making wells economically viable. The main goals of this project were to estimate for target formation the distribution, abundance and maturity of organic matter as well as the susceptibility for fracking. This was achieved by means of parameters such as TOC, brittleness, natural fracture distribution and orientation, and principal in situ stresses orientation. This required the integrated geoscience analysis workflow shown in figure 1 comprising mainly:

- Multimineral petrophysical evaluation integrating organic system with inorganic compounds.
- Seismic analysis for providing image and accurate angle/azimuth dependent reflectivity.
- Stratigraphic and structural analysis to generate the geological framework.
- Characterization of TOC and brittleness. Rock physics based integration of petrophysical analysis and seismic attributes.
- Characterization of fracture and stresses from borehole images & full azimuth seismic analysis.

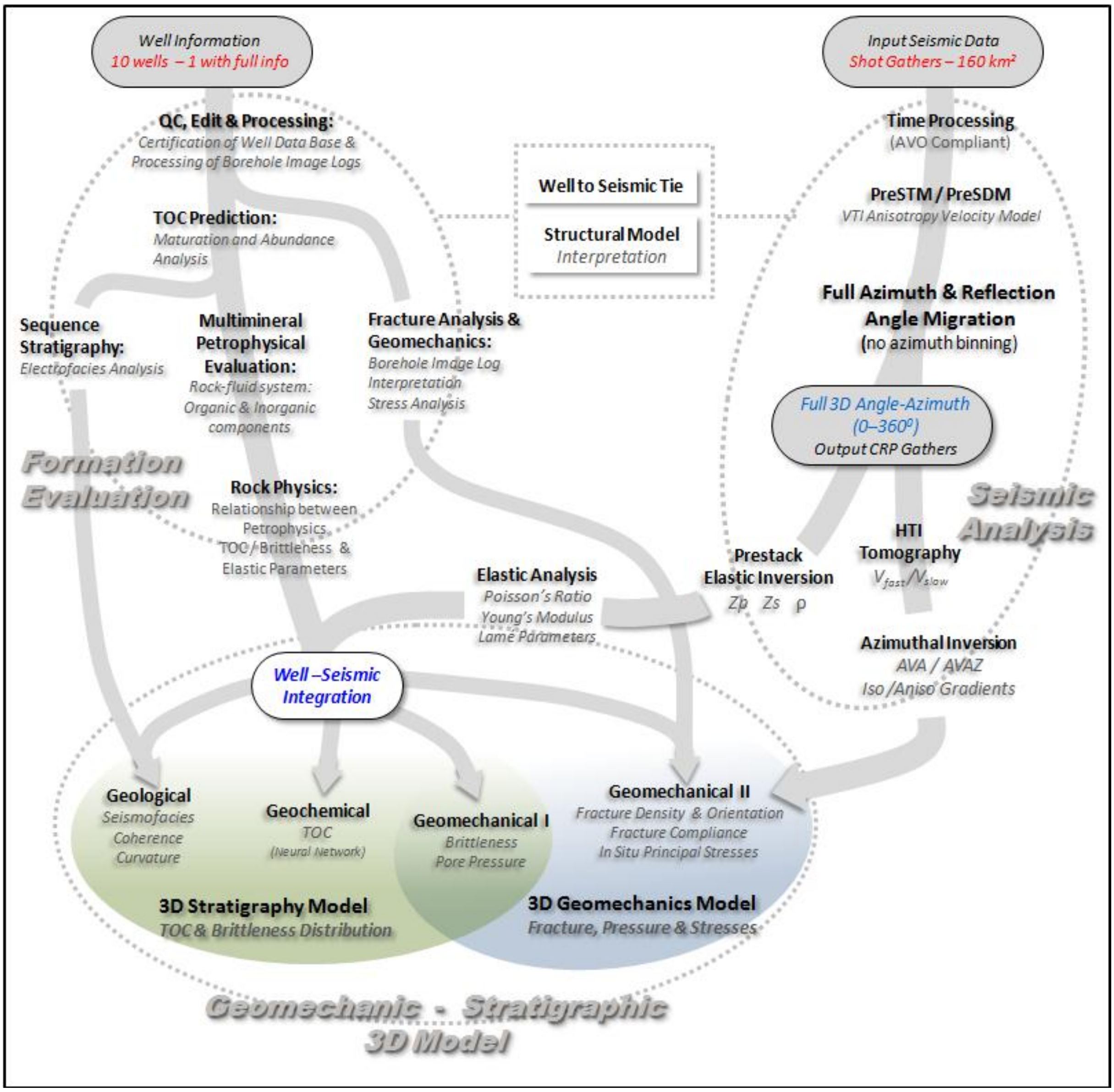

Figure 1 *Unconventional characterization workflow specifically designed for this project*

Geology and Unconventional Formation Evaluation

The sedimentation of the target formation developed in a passive margin and was controlled by remnants of the Paleozoic uplift known as Tamaulipas arch. The anoxic environment allowed the preservation of organic matter and the production of kerogen. The bottom is enriched in detritic quartz and calcite, indicating shallow conditions with low presence of organic matter and high brittleness. On the top, conversely, organic matter was preserved with highest TOC at the maximum flooding surface.

Formation evaluation for unconventional reservoir characterization faces two key challenges: the porous system definition and the estimation of the formation susceptibility to increase permeability through fracking in order to drain the hydrocarbon trapped in the rock. In this context, reservoir porosity is dominated by the effect of the maturation of the organic matter while the role of the inter grain effective porosity turns insignificant. Core samples were the key for both the calibration of TOC prediction and the selection of the most appropriate methodology for TOC estimation according to the type, maturity and abundance observed in the area. Multimineral petrophysical analysis, out of conventional logs, capture spectroscopy, magnetic resonance and preliminary TOC [Passey, 1990] provided a model that integrated organic and inorganic systems of the rock, calibrated with pyrolysis and petrophysical analysis on the core. The borehole resistive image helped in: a) definition of stratigraphic model through texture analysis (electrofacies) and b) structural interpretation for fracture and stresses analysis, used for calibration of the azimuthal seismic study. The dipole sonic led to a full set of elastic rock properties that enabled the correlation with the petrophysical parameters, thus underpinning the parameterization of the seismic predictions. Out of ten wells only AK-1 has the complete set of information on the target to carry out the analysis just described. The remaining nine wells were drilled well before the 70´s and their conventional log sets required major editing and standardization effort. After that, the petrophysical model generated in AK-1 was extended to the rest of the wells, thus having a formation evaluation model consistent throughout the whole set.

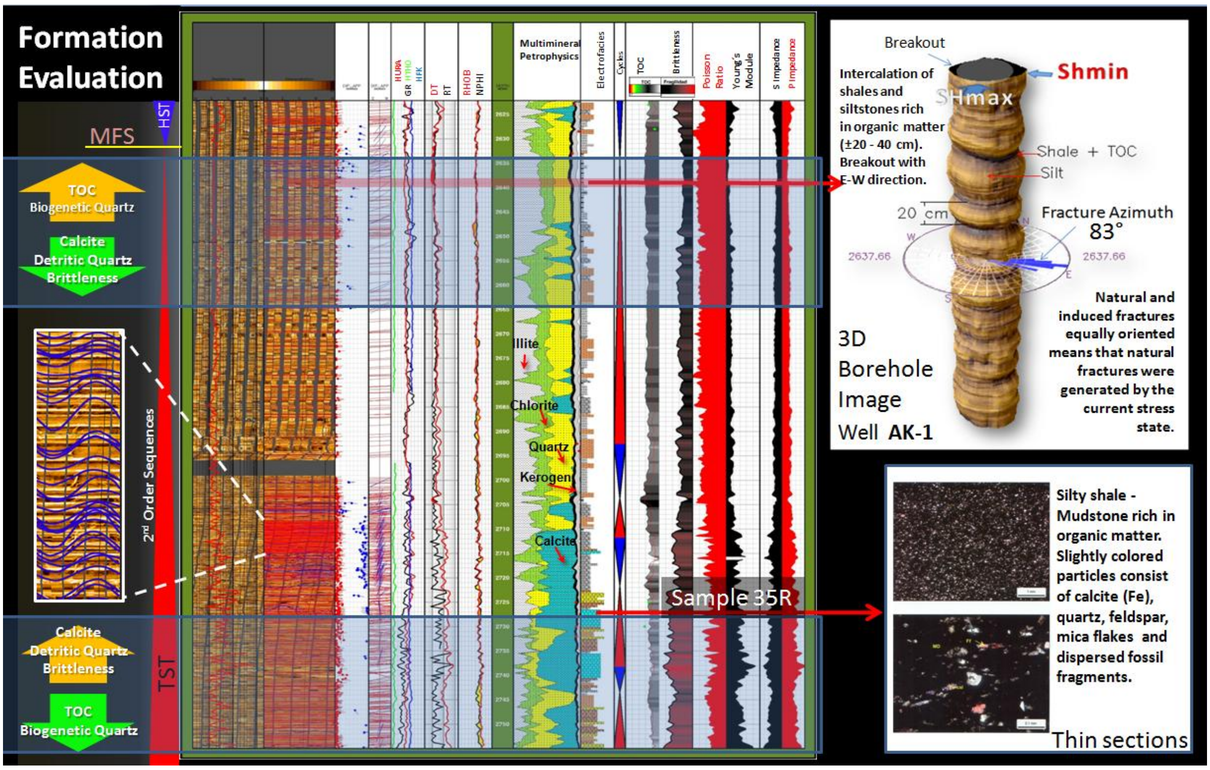

Figure 2 *Description of target formation. The sequence (Upper Jurassic) is part of a transgression system (Pindell 2001, Goldhammer 1999) related to the opening of the Gulf of Mexico -late Kimmeridgian and Tithonian.*

Continuous local azimuth-angle migration. HTI analysis

The available seismic on this area is an azimuth-rich 160 sq km conventional land survey. The active patch implies up to 24 degree reflection angle illumination on the 3.5km-deep target and more than 35 degrees in the higher velocity overburden. An AVAZ compliant processing sequence was applied, including band specific noise attenuation procedures in the shot, receiver and cdp domains.

The following VTI anisotropic PSDM workflow resulted in a calibrated depth image. High rate sampled reflection angle-azimuth CRP gathers were obtained from full azimuth local angle domain depth migration & analysis suite EarthStudy 360® [Koren et al., 2008]. Azimuthal tomography [Koren et al., 2010] and AVAZ [Rüger et al., 1998] were used to analyze the HTI signal on the resulting 3D gathers. Significant HTI effects were found both on amplitude and traveltime variation with azimuth at the target formation as shown on figure 3. Partial angle stacks derived from pre-conditioned 3D angle-azimuth gathers were the input for simultaneous inversion. Fracture density and orientation from AVAZ analysis were input to stress and fracture analysis and interpretation. The sharp velocity plunge that identifies the top of the reservoir decreases maximum reflection angle. This weakened the estimation of the density and related attributes which called for external input for a reliable inversion of density-related parameters.

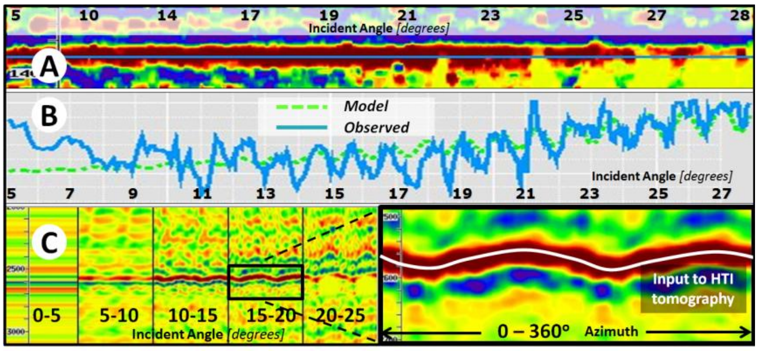

Figure 3 *A) target on azimuth-angle gather. B) amplitude vs. Rüger model (estimated). C) Azimuthal move out on target.*

Integrated 3D Seismic Driven Characterization

The sequence applied combined prestack simultaneous inversion (Tonellot et al. 2001), seismofacies classification, neural network prediction and fracture/stress state estimation. The goal was to support quantitative interpretation with a set of attribute volumes for the characterization of the target formation as non-conventional gas producer. The formation evaluation provided with hard data for model calibration. It also provided rock physics relationships between reservoir rock properties and elastic parameters that guided the derivation of the volumes. Brittleness and TOC cubes account for

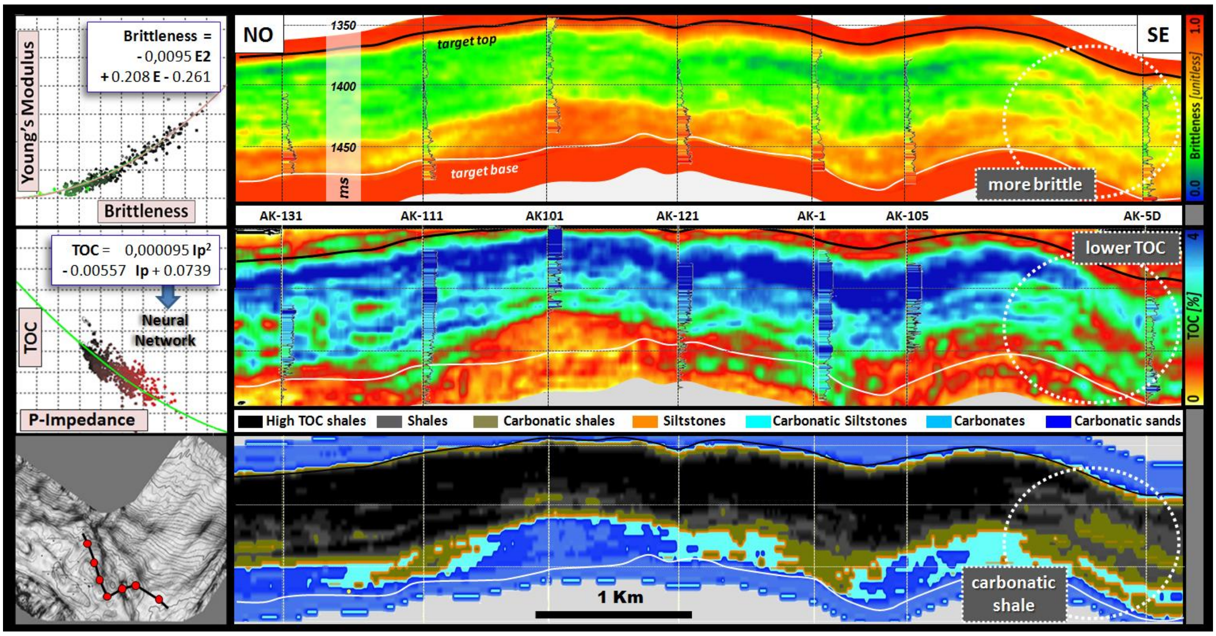

Figure 4 *From top to bottom: brittleness and TOC -including well profiles- and seismofacies. High TOC shales facies(black) correlates with ductile and high organic content zones (dark blue) while carbonatic shale facies(green) does with more brittle and poorer in TOC zones. Crossplots on left show the rock physics equations used for attributes derivation. TOC/quartz-carbonates balance is a key to understand reservoir performance.*

the susceptibility to fracking and the producing potential of the formation respectively; seismofacies helped to interpret reservoir geomechanical and geochemical properties within the stratigraphic model. These volumes, extracted along an arbitrary section through the wells are shown in figure 4. Given that TOC and brittleness are of capital importance to evaluate source rocks as a reservoir an iterative procedure including neural network prediction optimization was applied.

The formation needs to be fractured to produce so we must know whether and how it will fracture. Brittleness is related to fracability while the in situ stress state predicts the way the formation will fracture. Normal fracture compliance -estimated from fracture density-, together with linear slip theory (Schoenberg et al., 1995) and principal stresses formulation (Gray, 1995) allowed horizontal maximum and minimum principal in situ stress volumes derivation. The ratio between both stresses governs the type of pattern that the induced fractures will follow. After calibrating them with

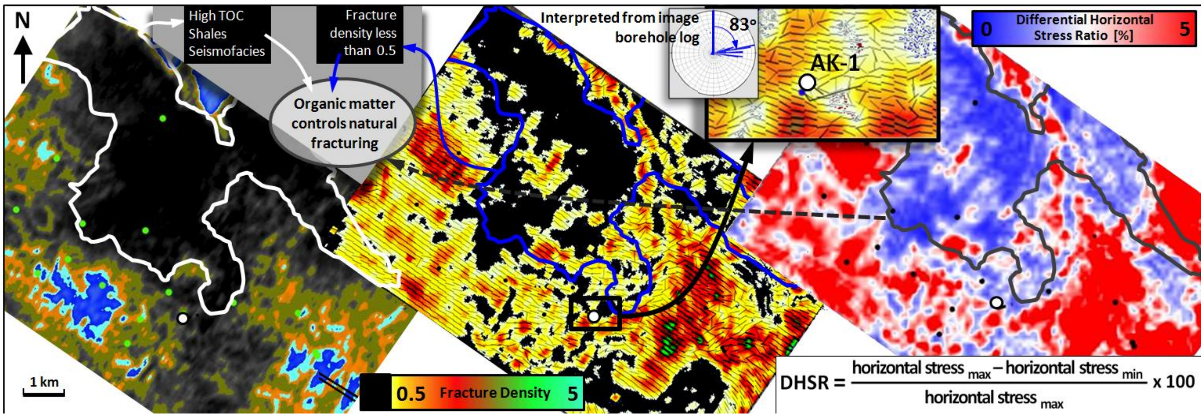

Figure 5 *Maps extracted 20 ms above base of reservoir. Sismofacies (left), fracture density and orientation (center) and DHSR (right). AK-1 neighboring fracture orientation detail (upper) showing good matching with 83° well record.*

geomechanical results in well AK-1, they were put under the form of differential horizontal stress ratio (DHSR). High values of DHSR suggest oriented fractures while low values are associated with network style patterns. Both situation are discriminated by a value of DHSR of 2.5%, supported by natural fracture patterns as there is no microseismic available so far on this project. See figure 5.

Conclusions

TOC and brittleness were predicted for the target with correlations of 0.88 and 0.92 respectively.

There is a remarkable consistency between TOC/brittleness volumes and seismofacies.

Formation evaluation led to a better brittleness prediction than Rickman formula.

TOC and density -key for brittleness estimation- had to be enhanced by neural network prediction.

The seismic survey was not wide azimuth, however fracture information could be successfully extracted as shown by the correlation with borehole image interpretation.

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