# [PS]Applying Rock Physics towards Seismic Characterization: Case Study from an Unconventional Resource, Neuquén Basin, Argentina*

**Teresa Santana[1], R. Weger[2], Silvana Gandi[1], Alejandro D´Odorico[1], and Ariel Kautyian[1]**

Search and Discovery Article #41886 (2016)**
Posted September 26, 2016

*Adapted from poster presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016


[1]Gerencia de Subsuelo E&P YPF S.A., Buenos Aires, Argentina, South America (teresa.santana@ypf.com)
[2]Center for Carbonate Research CSL, University of Miami, Miami, FL, USA (rweger@rsmas.miami.edu)

## Abstract

Calibration of seismic amplitudes to known rock properties is the ultimate goal of quantitative interpretation (QI) permitting seismic reservoir characterization away from well control. This paper presents a case study of a mature onshore field within the Neuquén Basin, Argentina where an integrated workflow for QI was defined and implemented with the aim of delineating potential areas for further development. The study area is covered by 3D seismic data and 14 wells with a complete set of elastic logs, providing the basis for quantitative analysis along the Quintuco-Vaca Muerta reservoir section, a complex Upper Jurassic to Lower Cretaceous mixed carbonate-siliciclastic system. A summary of the work performed with reference to rock properties and rock physics over a particular layer is used as an example in this paper. 3D seismic data was reprocessed following a workflow tailored towards QI to preserve relative amplitudes and stable phase across the entire survey. Sensitivities for incident angles were performed during processing to obtain the optimal angle stack design, from 10° to 40°, as the input for simultaneous inversion. Fourteen wells, with complete elastic log information, were used for AVA wavelet estimation and low frequency model construction. A four component multi-mineral petrophysical model was calibrated with neutron induced elemental spectroscopy tools and XRD core data. Porosity and hydrocarbon saturation were afterwards calculated and calibrated with NMR data. Rock physics diagnostics were conducted to find a model that correctly represents the elastic behavior of the rocks in the study area. The Friable Shale rock physics model, a modified version of Dvorkin and Nur's Friable Sand model (Dvorkin and Nur, 1996), is designed with the ability to consider different, including clay rich, mineral combinations and their variability with respect to internal rock stiffness. This makes it a versatile rock physics model for use in unconventional settings. A fine-tuned porosity-based parametric rock physics template was defined in the P and S impedance elastic domain. The use of this rock physics model was crucial to classify seismic inversion results into elastic facies and, finally, to define potential areas for further development.

# APPLYING ROCK PHYSICS TOWARDS SEISMIC CHARACTERIZATION: CASE STUDY FROM AN UNCONVENTIONAL RESOURCE, NEUQUÉN BASIN ARGENTINA

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*Teresa Santana*, R. Weger**, Silvana Gandi*, Alejandro D´Odorico*, Ariel Kautyian**

** Gerencia de Subsuelo E&P YPF S.A. (teresa.santana@ypf.com))*

*** Center for Carbonate Research CSL, University of Miami USA (rweger@rsmas.miami.edu)*

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## 1- ABSTRACT

***CALIBRATION* OF SEISMIC AMPLITUDES** TO KNOWN **ROCK PROPERTIES** IS THE **ULTIMATE GOAL OF QUANTITATIVE INTERPRETATION (QI)** PERMITTING ***SEISMIC RESERVOIR CHARACTERIZATION* AWAY FROM WELL CONTROL**.

THIS PAPER PRESENTS A CASE STUDY OF A **MATURE ONSHORE FIELD** WITHIN THE **NEUQUÉN BASIN, ARGENTINA** WHERE AN **INTEGRATED WORKFLOW FOR QI** WAS DEFINED AND IMPLEMENTED WITH THE **AIM OF DELINEATING POTENTIAL AREAS FOR FURTHER DEVELOPMENT**. THE STUDY AREA IS COVERED BY 3D SEISMIC DATA AND 12 WELLS WITH A COMPLETE SET OF ELASTIC LOGS, PROVIDING THE BASIS FOR QUANTITATIVE ANALYSIS ALONG THE **QUINTUCO-VACA MUERTA RESERVOIR** SECTION, A **COMPLEX UPPER JURASSIC TO LOWER CRETACEOUS MIXED CARBONATE-SILICICLASTIC SYSTEM**.

A SUMMARY OF THE WORK PERFORMED WITH REFERENCE TO **ROCK PROPERTIES** AND **ROCK PHYSICS** OVER A PARTICULAR LAYER IS USED AS AN EXAMPLE IN THIS PAPER.

**3D SEISMIC DATA** WAS REPROCESSED FOLLOWING A ***WORKFLOW TAILORED TOWARDS QI*** TO PRESERVE RELATIVE AMPLITUDES AND STABLE PHASE ACROSS THE ENTIRE SURVEY. SENSITIVITIES FOR INCIDENT ANGLES WERE PERFORMED DURING PROCESSING TO OBTAIN THE OPTIMAL ANGLE STACK DESIGN, FROM 10° TO 40°, AS THE INPUT FOR **SIMULTANEOUS INVERSION**. **12 WELLS**, WITH **COMPLETE ELASTIC LOG** INFORMATION, WERE USED FOR AVA WAVELET ESTIMATION AND LOW FREQUENCY MODEL CONSTRUCTION. A **FOUR COMPONENT MULTI-MINERAL PETROPHYSICAL MODEL** WAS **CALIBRATED** WITH **NEUTRON INDUCED ELEMENTAL SPECTROSCOPY** TOOLS AND **XRD CORE** DATA. **POROSITY AND HYDROCARBON SATURATION** WERE AFTERWARDS CALCULATED AND **CALIBRATED WITH NMR DATA**.

**ROCK PHYSICS DIAGNOSTICS** WERE CONDUCTED TO FIND A MODEL THAT CORRECTLY REPRESENTS THE ELASTIC BEHAVIOR OF THE ROCKS IN THE STUDY AREA. THE **FRIABLE SHALE ROCK PHYSICS MODEL**, A **MODIFIED VERSION OF DVORKIN & NUR'S FRIABLE SAND MODEL (DVORKIN AND NUR, 1996)**, IS DESIGNED WITH THE ABILITY TO CONSIDER DIFFERENT, INCLUDING CLAY RICH, MINERAL COMBINATIONS AND THEIR VARIABILITY WITH RESPECT TO INTERNAL ROCK STIFFNESS. THIS MAKES IT A **VERSATILE ROCK PHYSICS MODEL** FOR USE IN **UNCONVENTIONAL SETTINGS.**

A **FINE-TUNED POROSITY-BASED PARAMETRIC ROCK PHYSICS TEMPLATE** WAS DEFINED IN THE **P AND S IMPEDANCE ELASTIC DOMAIN**. THE USE OF THIS ROCK PHYSICS MODEL **WAS CRUCIAL** TO **CLASSIFY SEISMIC INVERSION** RESULTS INTO **ELASTIC FACIES** AND, FINALLY, TO **DEFINE POTENTIAL AREAS FOR FURTHER DEVELOPMENT**.

## 1- OBJECTIVES AND WORKFLOW

**ESTABLISH RELATIONSHIPS BETWEEN**
**ROCK PROPERTIES AND THEIR ELASTIC RESPONSE**
**USING ROCK PHYSICS FOR RESERVOIR CHARACTERIZATION**
**TO DELINEATE AREAS FOR FURTHER DEVELOPMENT**

**QUANTITATIVE INTERPRETATION ULTIMATE GOAL:**
**QUANTIFICATION AND CALIBRATION OF SEISMIC AMPLITUDES TO ROCK PROPERTIES FOR RESERVOIR CHARACTERIZATION**

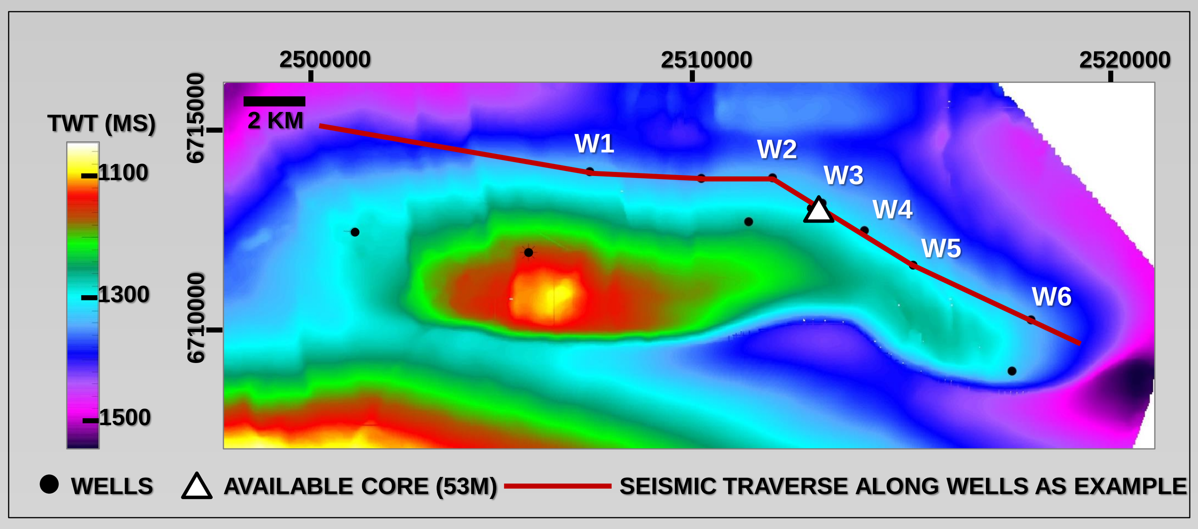
**GEOLOGY**
STRUCTURAL AND STRATIGRAPHIC FRAMEWORK
BASIN MODELING
PETROLOGY, CORE ANALYSIS
MINERALOGY

**QI PETROPHYSICS**
WELL DATA CONDITIONING
MULTI MINERAL MODELING
ROCK AND FLUID PROPERTIES
FLUID SUBSTITUTION
ROCK PHYSICS

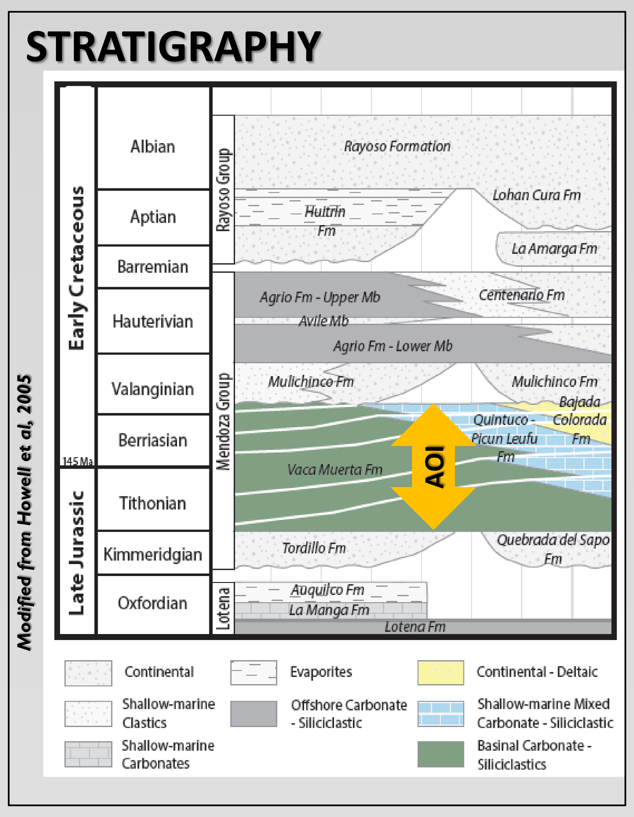
**QI GEOPHYSICS**
SEISMIC DATA CONDITIONING
GEOPHYSICAL INTERPRETATION
SEISMIC INVERSION
SEISMIC CHARACTERIZATION
QI INTERPRETATION

## 2- CASE STUDY: LOCATION AND GEOLOGY

**TIME STRUCTURE MAP – BASE VACA MUERTA**



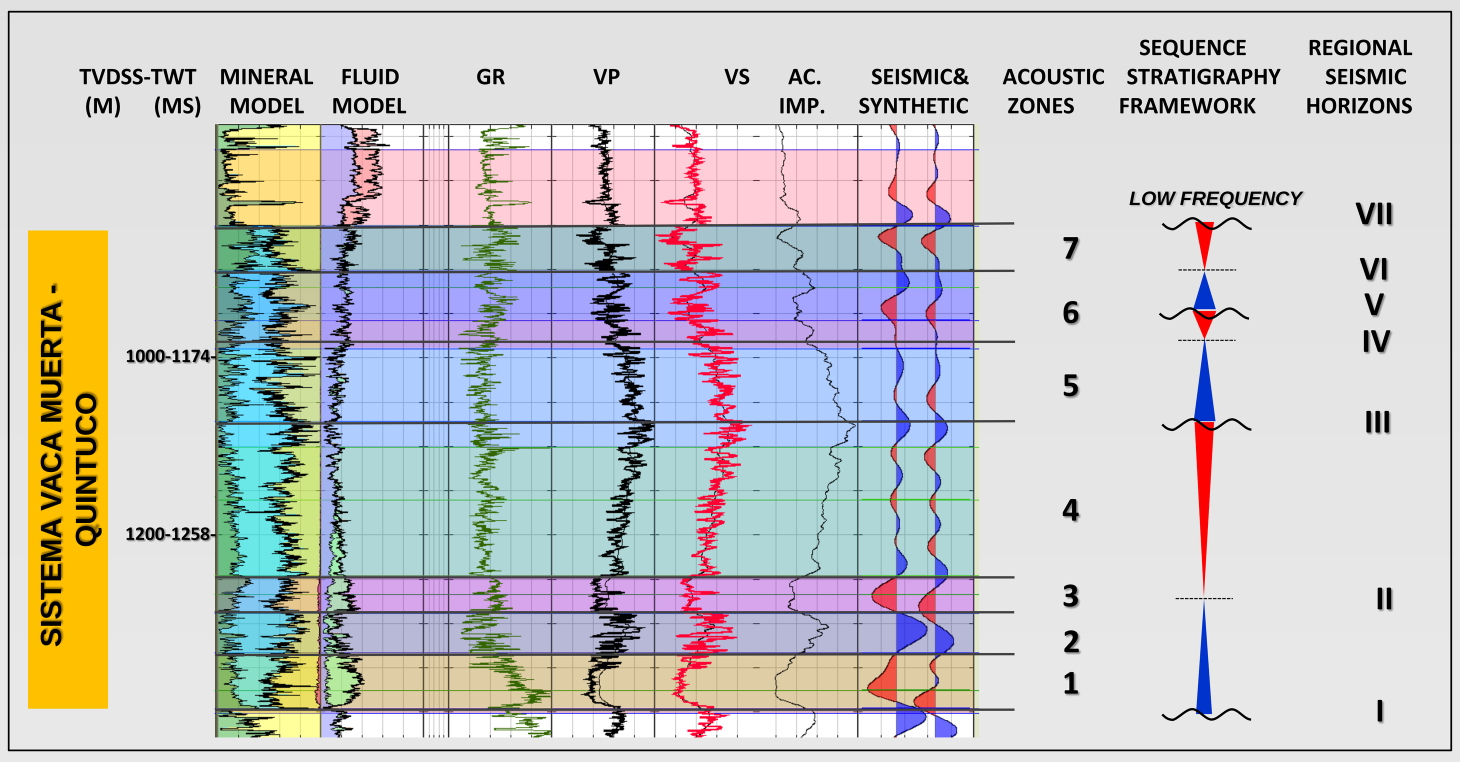
**STRATIGRAPHY**



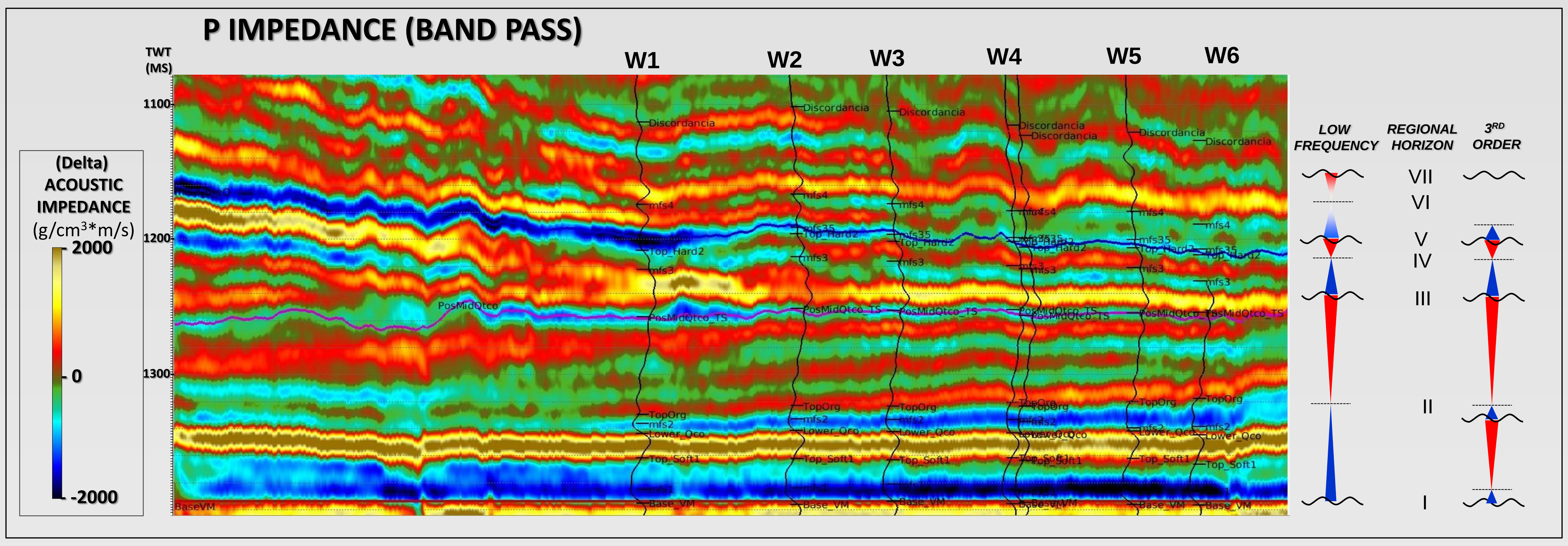
**DATA AVAILABILITY**
✓3D SEISMIC DATA REPROCESSED FOLLOWING A WORKFLOW TAILORED TOWARDS QI INCLUDING ANGLE STACK, FROM 10° TO 40 ° FOR SIMULTANEOUS INVERSION
✓12 WELLS, WITH COMPLETE SET OF ELASTIC LOGS
✓1 CORE (53M) OVER INTERVAL OF INTEREST

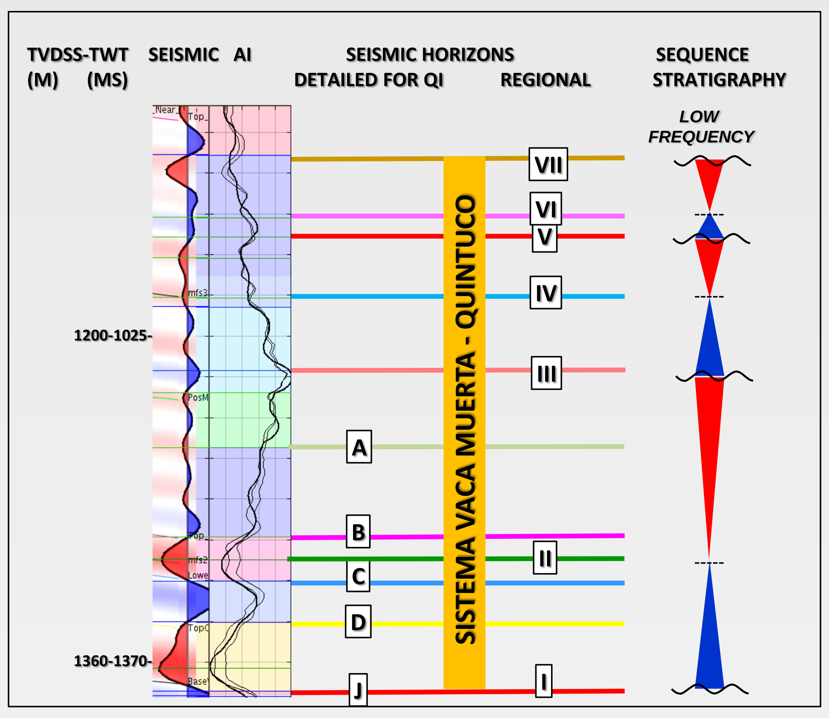
**OBJECTIVE RESERVOIR:**
UPPER JURASSIC LOWER CRETACEOUS
*QUINTUCO VACA MUERTA*
SILICICLASTIC CARBONATE SYSTEM

## 3- STRATIGRAPHIC FRAMEWORK



**P IMPEDANCE (BAND PASS)**



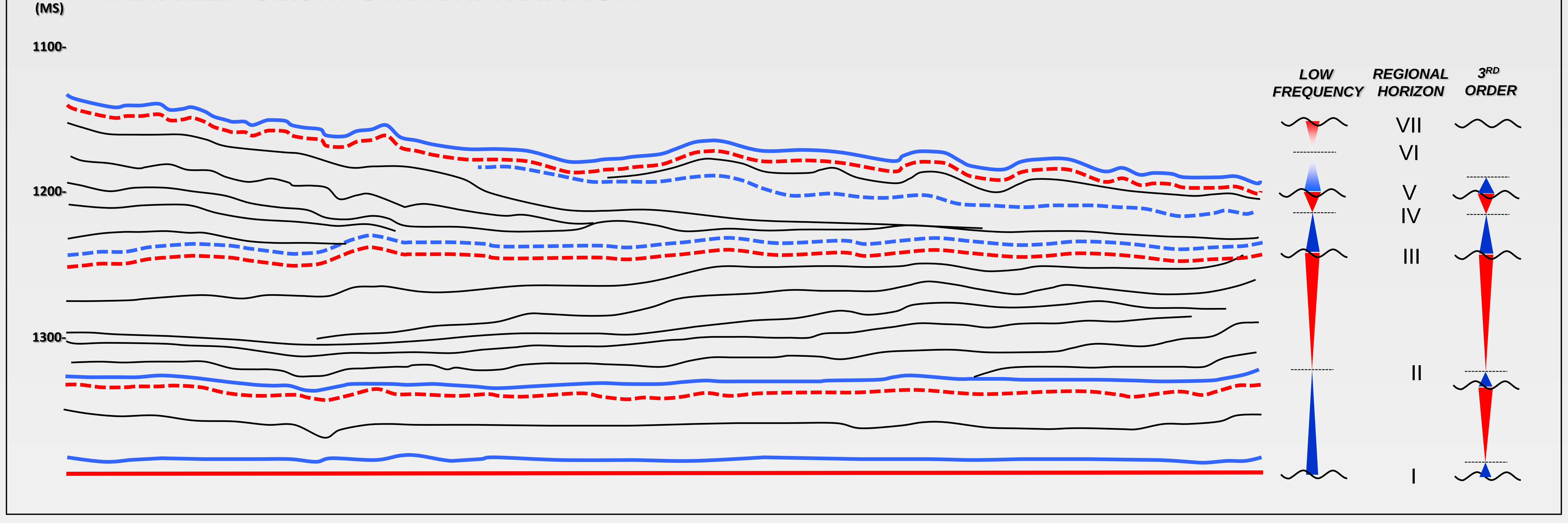


**INTEGRATION OF SEISMIC INTERPRETATION AND SEQUENCE STRATIGRAPHY FRAMEWORK AT DIFFERENT SCALES**

**DETAILED SEISMIC INTERPRETATION FOR QI PERFORMED IN AREA OF INTEREST TO DEFINE ZONES FOR ROCK PHYSICS ANALYSIS**

**SEVEN ACOUSTIC ZONES IDENTIFIED**

**DETAILED SEISMIC INTERPRETATION**



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** Center for Carbonate Research CSL, University of Miami USA (rweger@rsmas.miami.edu)

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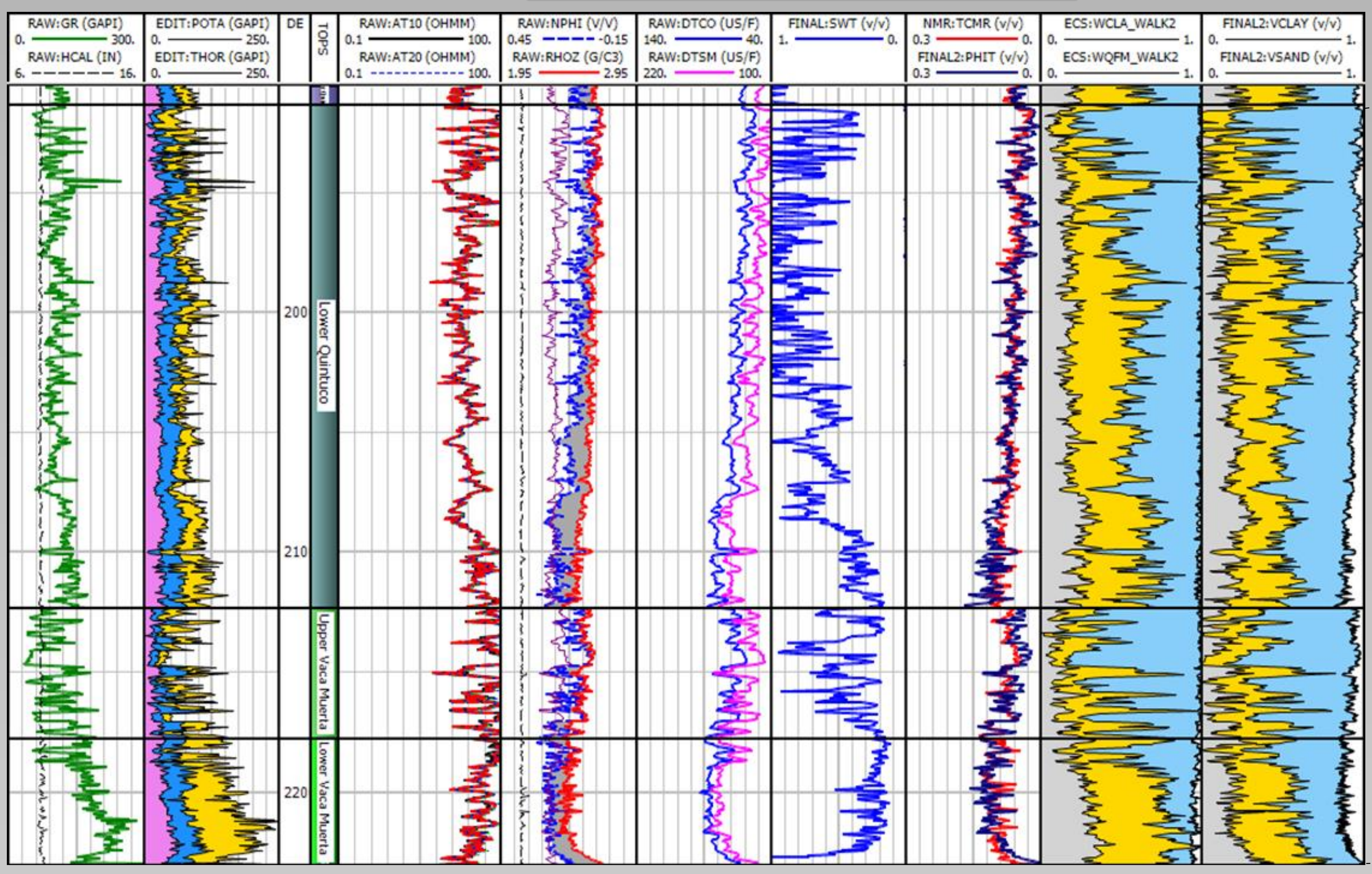
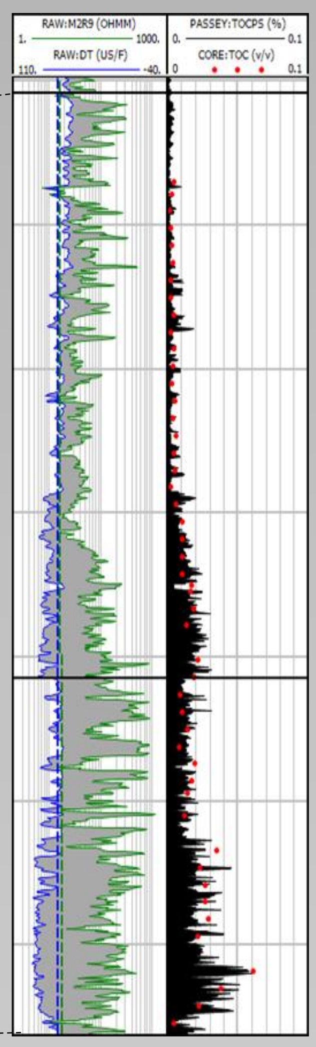
## 4- PETROPHYSICAL MODEL

### MULTI MINERAL MODEL



### TOC USING QUINN PASSEY´S METHODOLOGY

$$TOC = \left[ log_{10}\left(\frac{R_T}{R_{bl}}\right) + 0.02\,.(\Delta t - \Delta t_{bl}) \right].10^{(2.297-0.1688\,.LOM)}$$

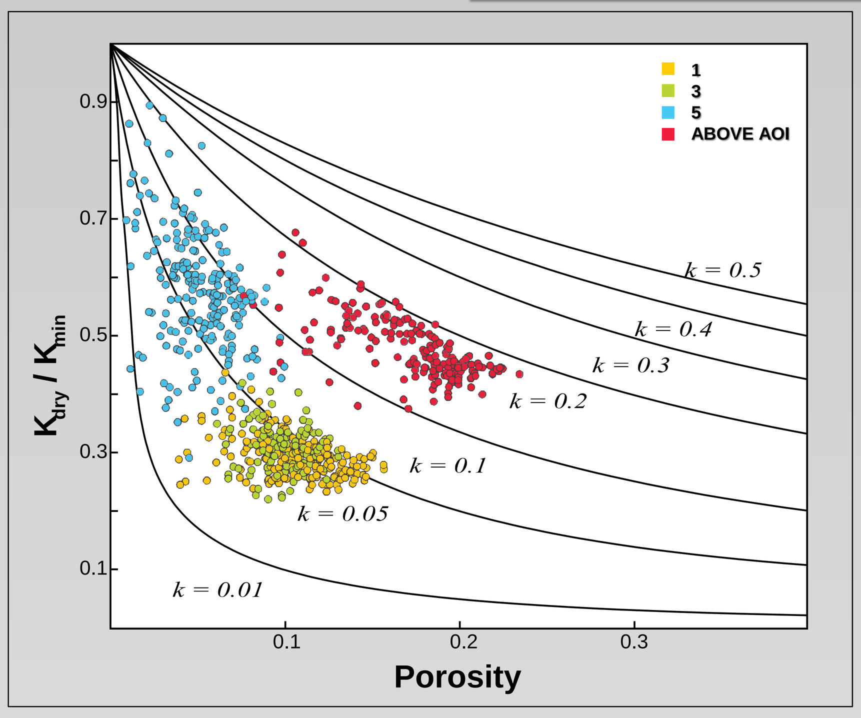
✓THREE-COMPONENT MULTIMINERAL MODEL INCLUDES CARBONATES, CLASTICS (QZ + PLAG + FK) AND CLAYS

✓MINERAL VOLUME FRACTIONS MATCH ELEMENTAL CAPTURE SPECTROSCOPY LOG TRENDS

✓TOC IS CALCULATED INDEPENDENTLY THROUGH PASSEY´S EQUATION AND *CALIBRATED* AGAINST CORE MEASURED TOC

✓MODEL TOTAL POROSITY *FITS* NMR TOTAL POROSITY

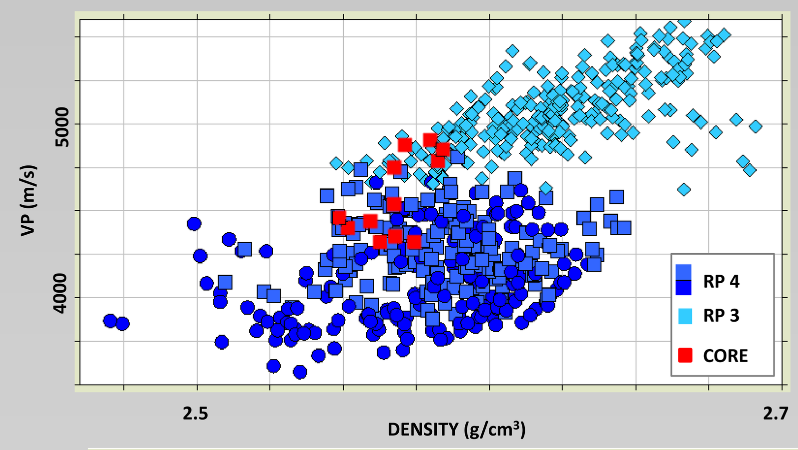
### GASSMANN FLUID SUBSTITUTION

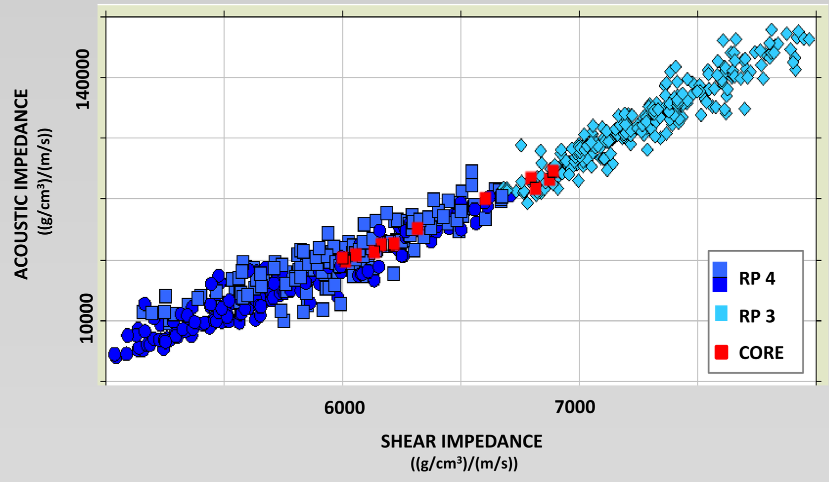


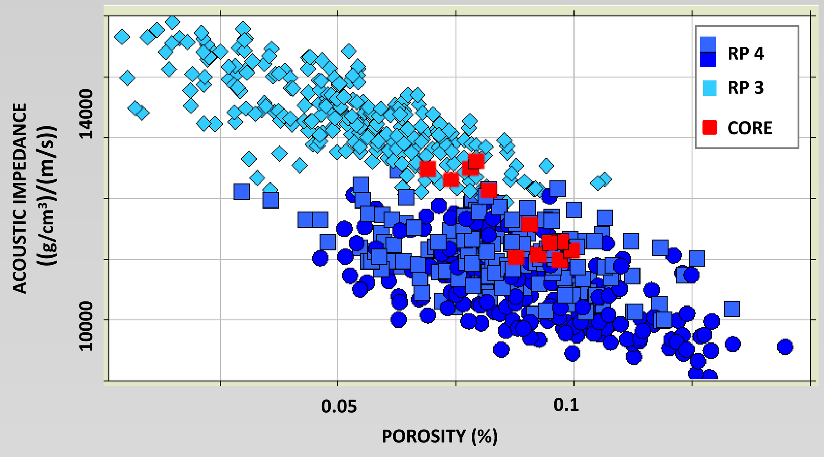

✓REASONABLE VALUES OF $K_{DRY}/K_{MIN}$, WITH RESPECT TO PHYSICALLY POSSIBLE VALUES AND GEOLOGICALLY APPROPRIATE VALUES FOR DIFFERENT TYPES OF ROCKS IS OBTAINED FROM DIFFERENT STRATIGRAPHIC SECTIONS

### ACOUSTIC PROPERTIES CALIBRATION

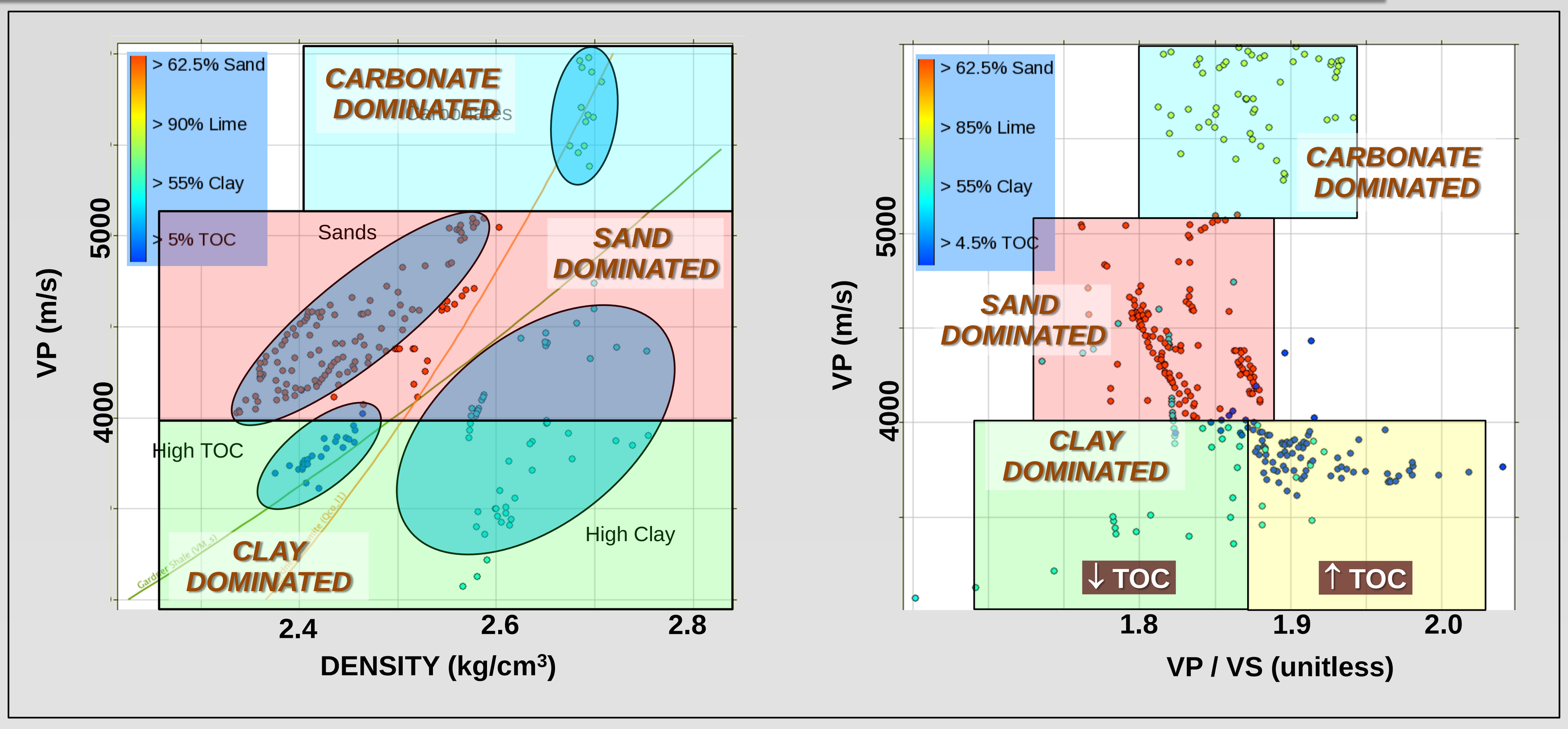
LIMITED CORE DATA IS AVAILABLE FOR CALIBRATION



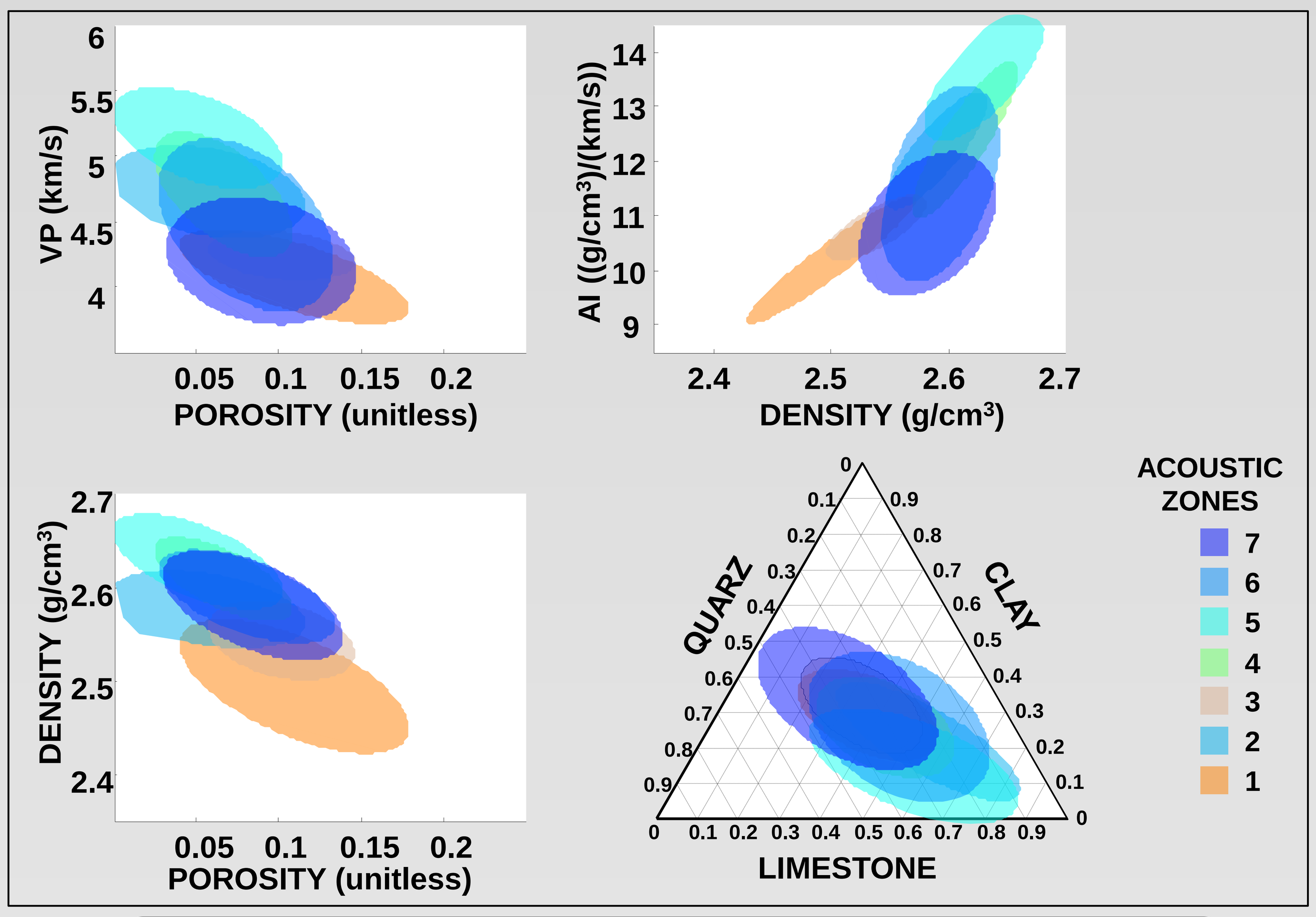




## 5- END MEMBERS AND TREND ANALYSIS

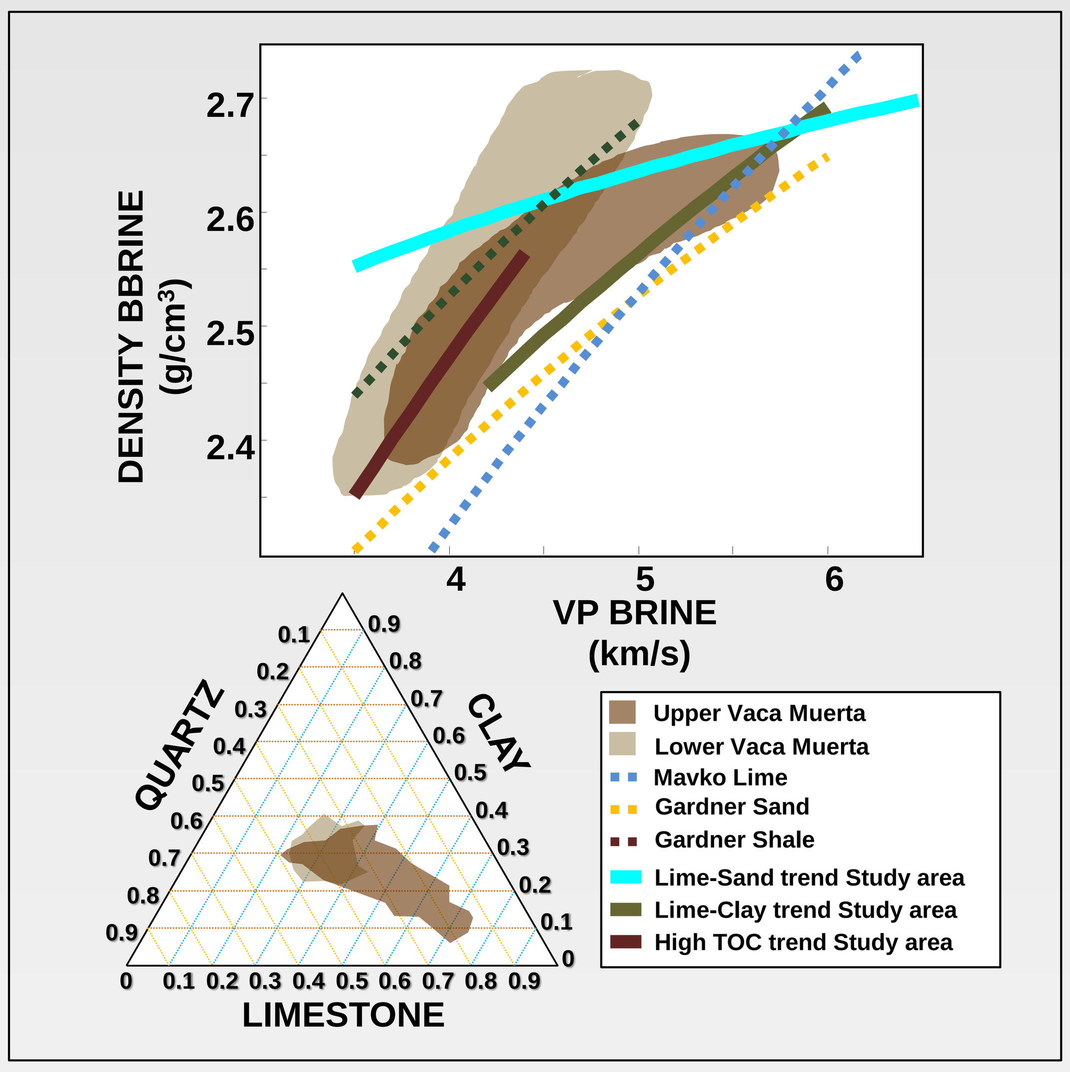



VELOCITY-DENSITY CROSS PLOT SHOWS CLEAR SEPARATION BETWEEN LIMESTONES, SANDSTONES, CLAYS AND HIGH TOC INTERVALS

IN ADDITION TO DENSITY, VP/VS RATIO CAN BE USED TO DISTINGUISH HIGH FROM LOW TOC IN CLAY RICH INTERVALS



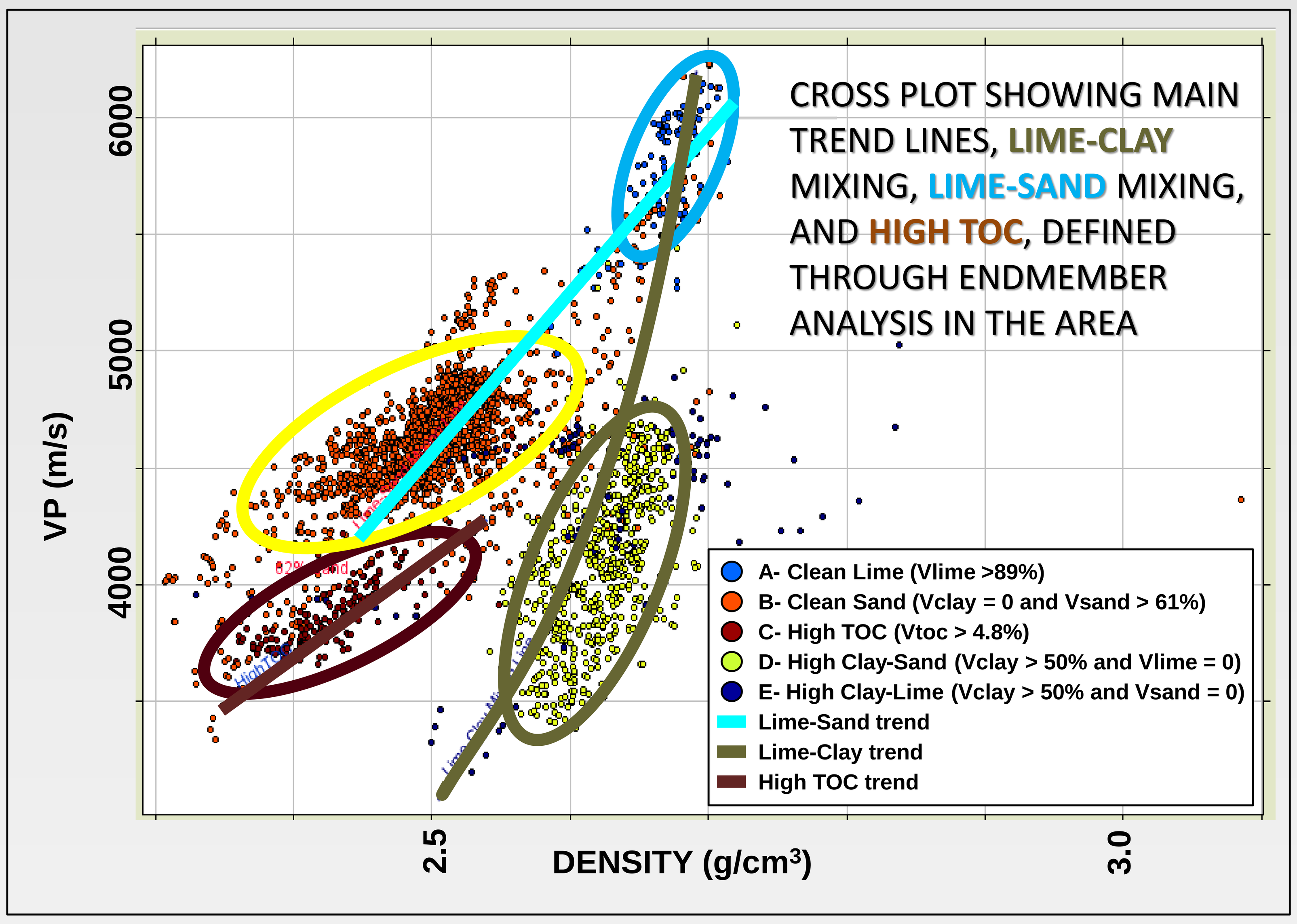

SEVERAL ZONES OVELAY IN THE ELASTIC DOMAIN ZONES WILL BE REGROUPED FOR RP ANALYSIS




LOWER VACA MUERTA SHOW A CLEAR TOC RICH TREND AND A FAIRLY STABLE 30/30/30 CLAY, LIMESTONE, AND SANDSTONE DISTRIBUTION

IN CONTRAST, UPPER VACA MUERTA EXHIBIT A TREND CHANGE FOLLOWING THE LIME-CLAY MIXING LINE CHARACTERISTIC IN THIS AREA

*ACOUSTIC PROPERTIES* CHANGE DRIVEN BY AN INCREASE OF LIME VOLUME TO *UP TO 70%*




CROSS PLOT SHOWING MAIN TREND LINES, LIME-CLAY MIXING, LIME-SAND MIXING, AND HIGH TOC, DEFINED THROUGH ENDMEMBER ANALYSIS IN THE AREA

# APPLYING ROCK PHYSICS TOWARDS SEISMIC CHARACTERIZATION: CASE STUDY FROM AN UNCONVENTIONAL RESOURCE, NEUQUÉN BASIN ARGENTINA

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## 6- ROCK PHYSICS MODELING

### SELECTING THE ROCK PHYSICS MODEL

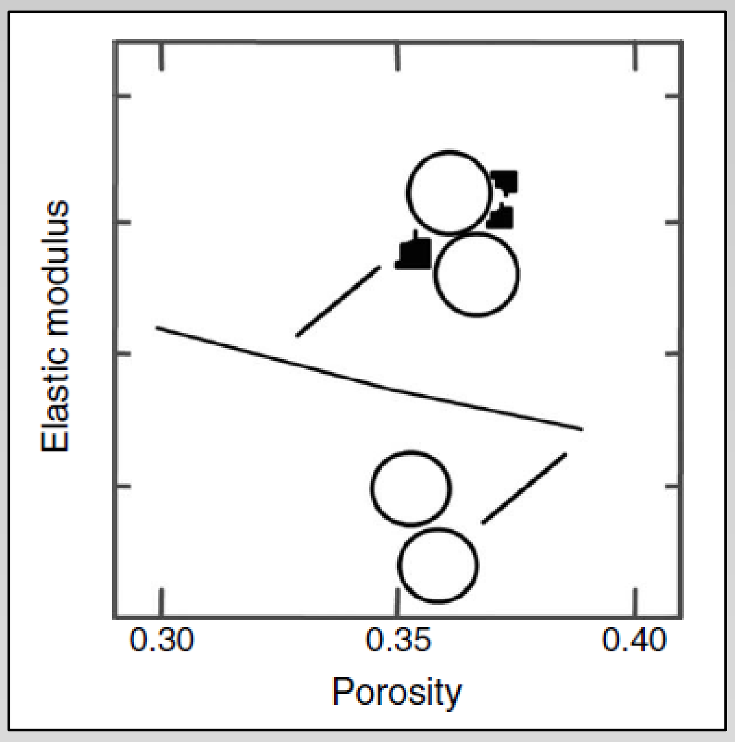
### FRIABLE SHALE MODEL

**FRIABLE SHALE MODEL** IS A MODIFIED VERSION OF THE ***FRIABLE SAND MODEL*** *(AVSETH ET AL, 2005)* WITH THE ABILITY TO CONSIDER DIFFERENT, INCLUDING **CLAY RICH**, **MINERAL COMBINATIONS** AND THEIR **VARIABILITY WITH RESPECT TO INTERNAL ROCK STIFFNESS**

THIS MODEL OPERATES AS A **TWO COMPONENT MINERAL SYSTEM** IN WHICH MATERIALS OF DIFFERENT GRAIN SIZE AND DIFFERENT MINERALOGY CAN BE MIXED

**INDIVIDUAL COMPONENTS** CAN BE SUBSTITUTED BY VIRTUALLY **ANY** APPROPRIATE DESCRIPTION OF **MODULI AND DENSITY**

**FRIABLE SAND MODEL**

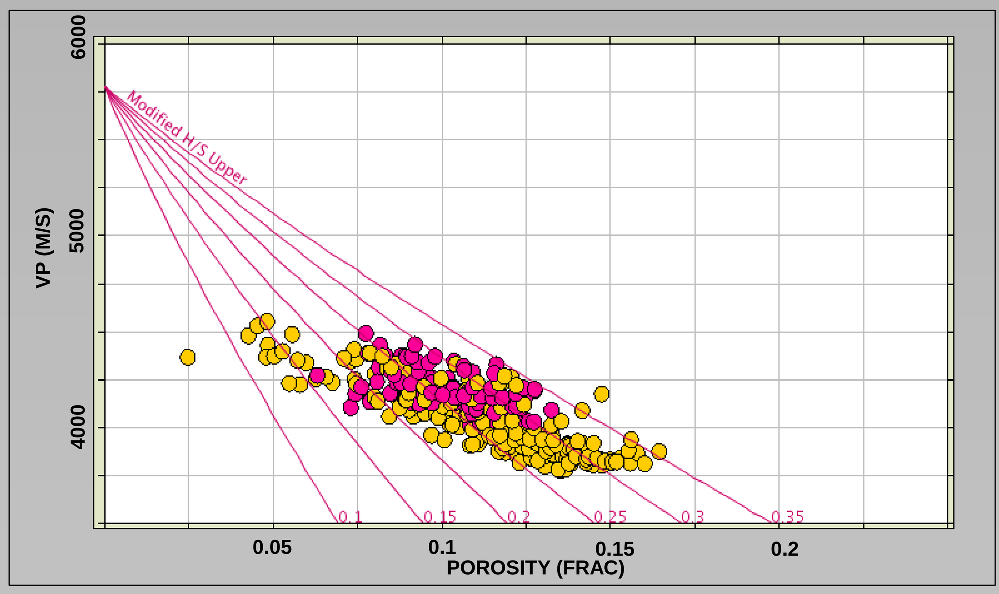


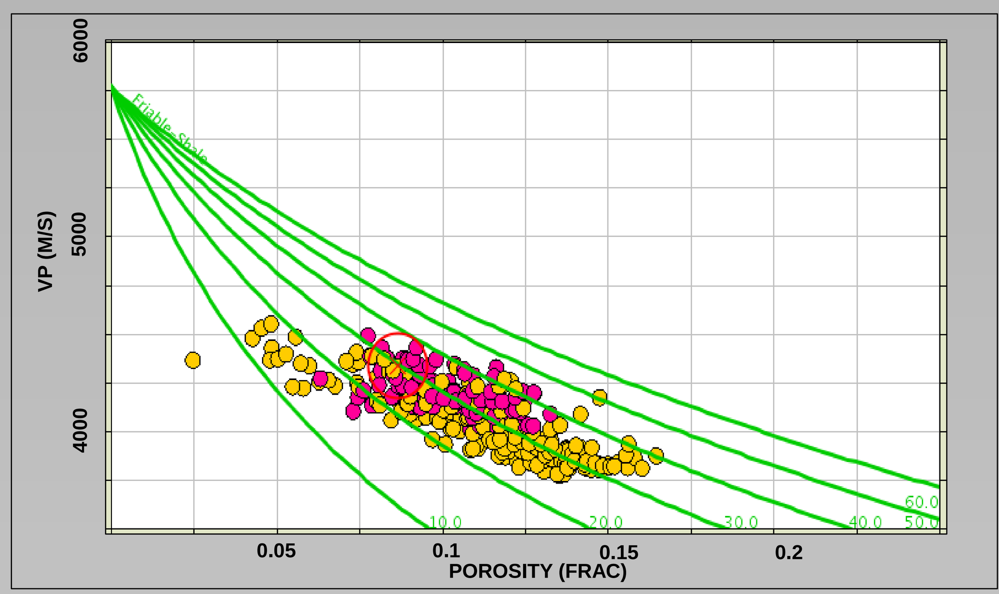

***ELASTIC MODULUS INCREASES SLIGHTLY WITH DETERIORATING SORTING AND ASSOCIATED***

**EFFECTIVE PRESSURE, FLUID SATURATION, AND MINERAL COMPOSITION** ARE HELD **CONSTANT**, WHILE **CRITICAL POROSITY, COORDINATION NUMBER AND SHEAR REDUCTION** FACTOR ARE **OPTIMIZED** USING **FORWARD & REVERSE MODELING**

### ADJUSTING PARAMETERS

### CRITICAL POROSITY AND COORDINATION NUMBER SENSITIVITY

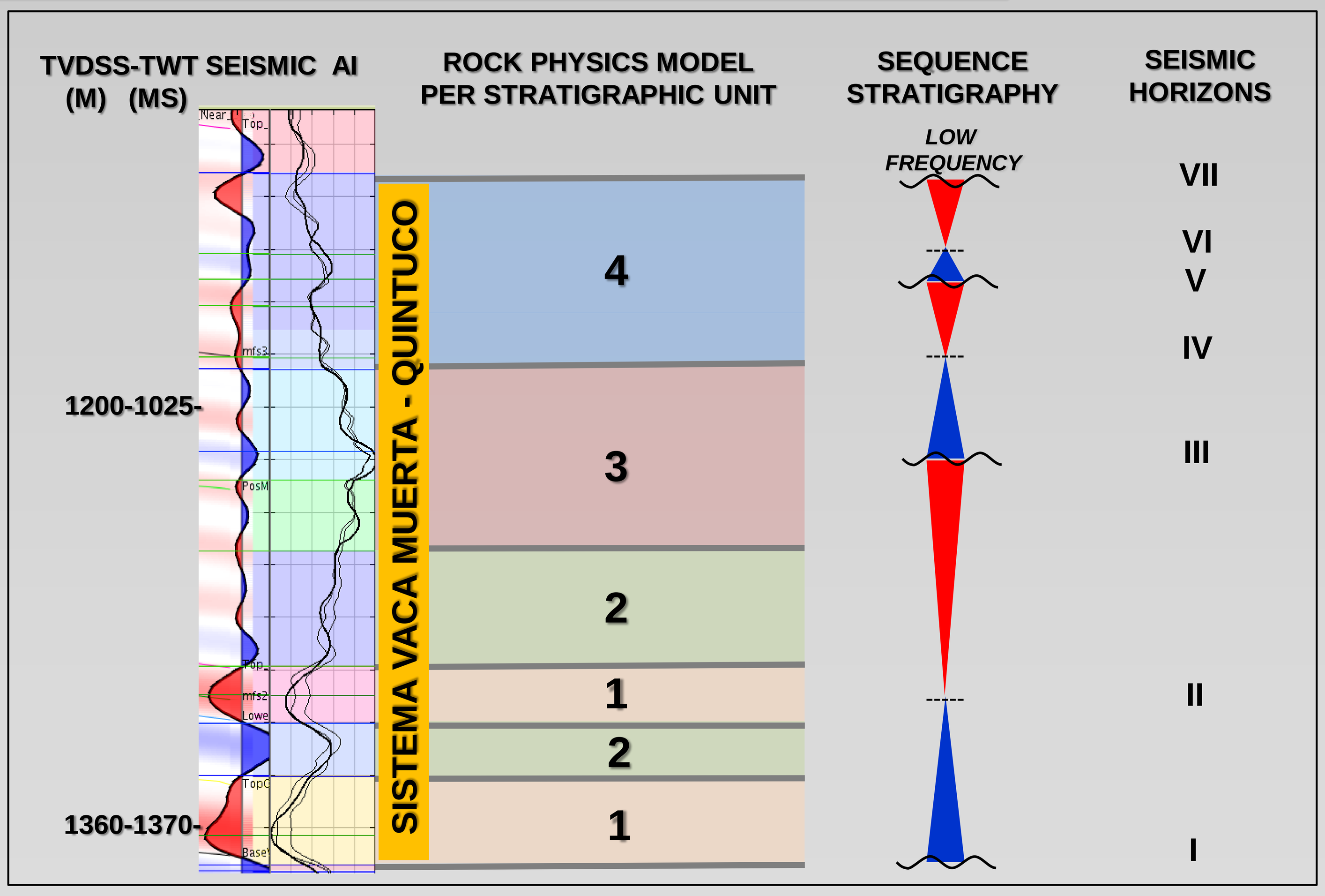



**>COORDINATION NUMBER, STIFFER ROCK**

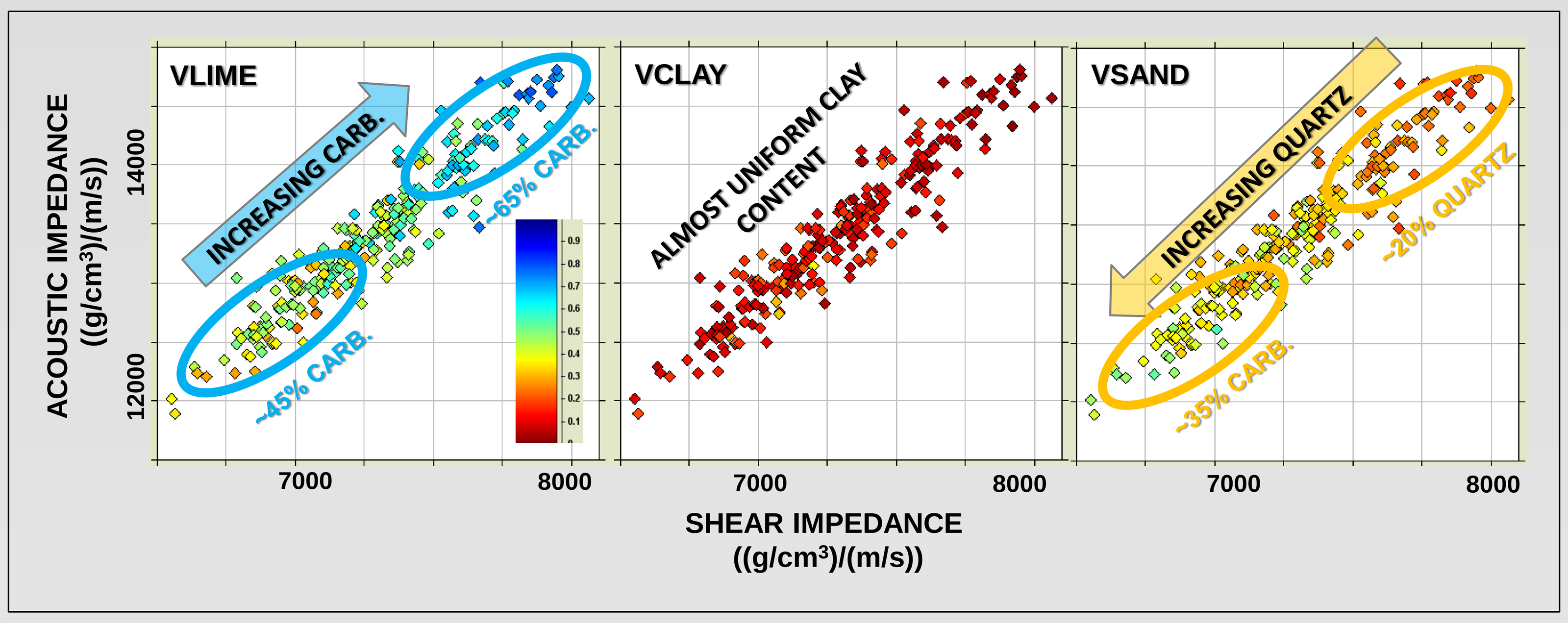
**FROM A *GEOLOGICAL POINT OF VIEW*, COORDINATION NUMBERS (CN)** CAN BE INTERPRETED AS VARIATION IN **PORE COMPLEXITY** OR THE **DEGREES OF LAMINATIONS AND/OR FINE LAYERING** INDICATING *VARIABILITY IN **ROCK STIFFNESS/FRIABILITY*** PRESENT IN THE ROCK

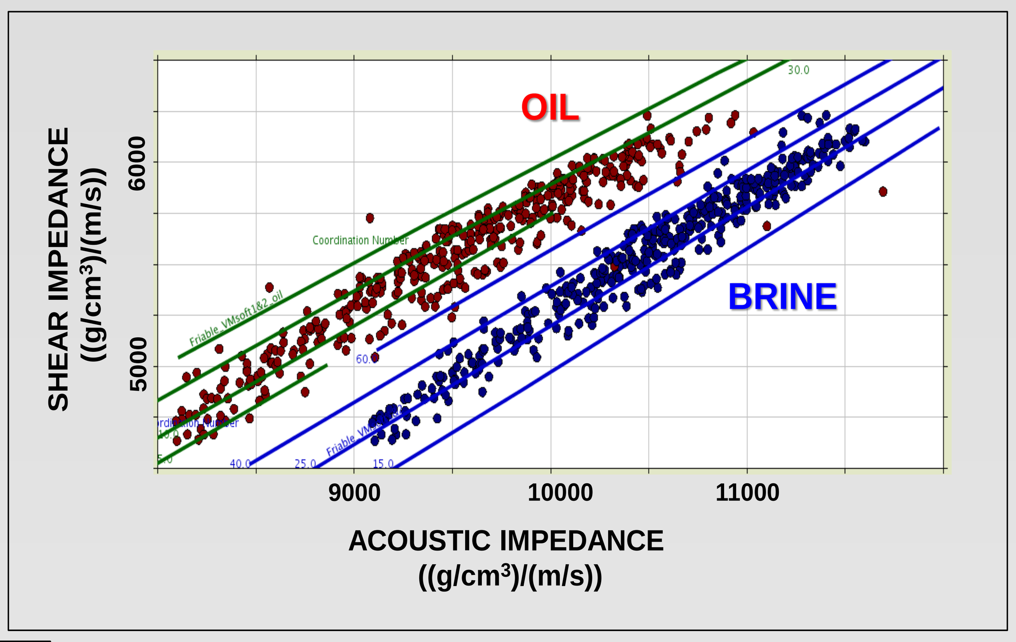
## 7-FINAL LAYERS IN STUDY AREA

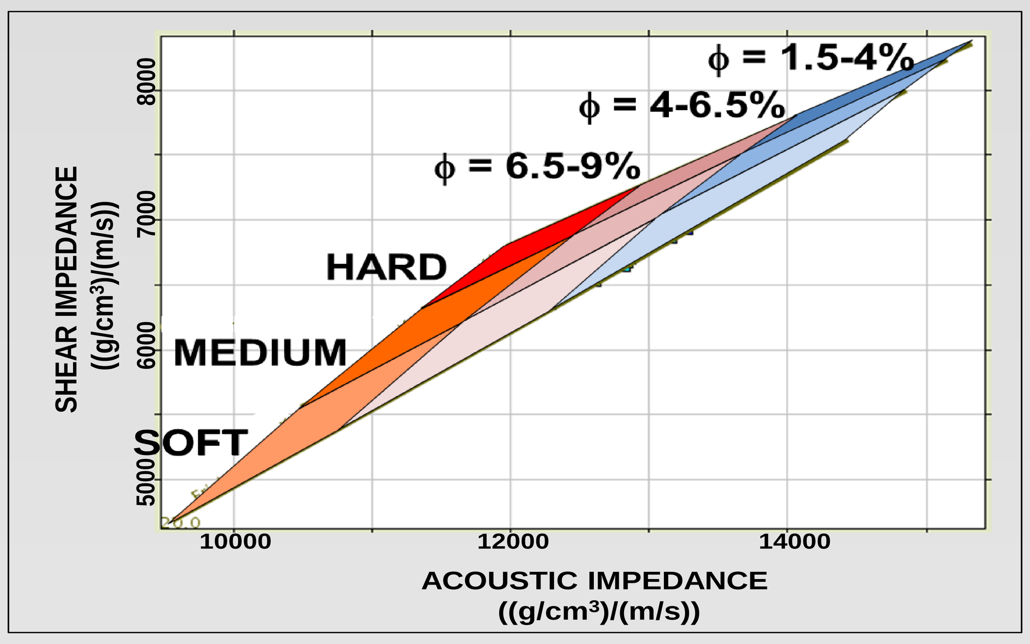



**FOUR ZONES** WERE DEFINED **WITHIN INTERVAL OF INTEREST** BY COMBINING LAYERS WITH SIMILAR ELASTIC PROPERTIES

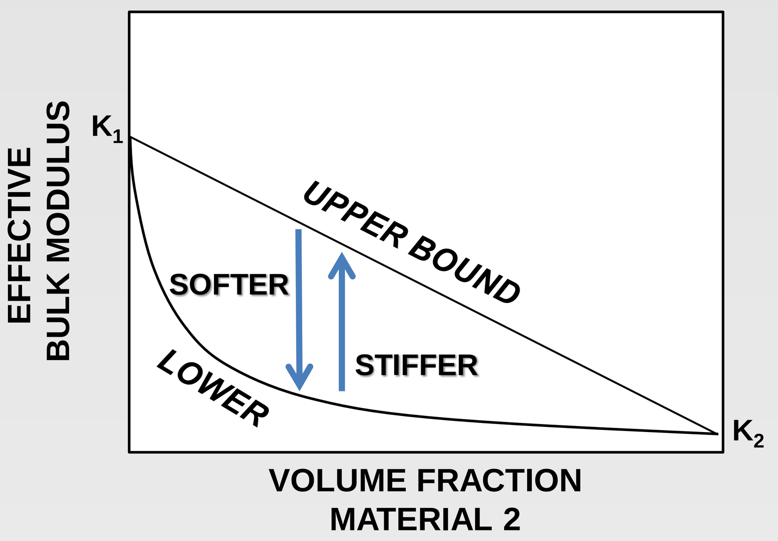
## 8- ROCK PHYSIC MODEL APPLICATION (EXAMPLE)




| | $K_0$ | $MU_0$ | DENSITY |
|---|---|---|---|
| QUARTZ | 48 | 28 | 2.65 |
| CALCITE | 73 | 30 | 2.73 |
| DRY CLAY | 66 | 25 | 2.85 |



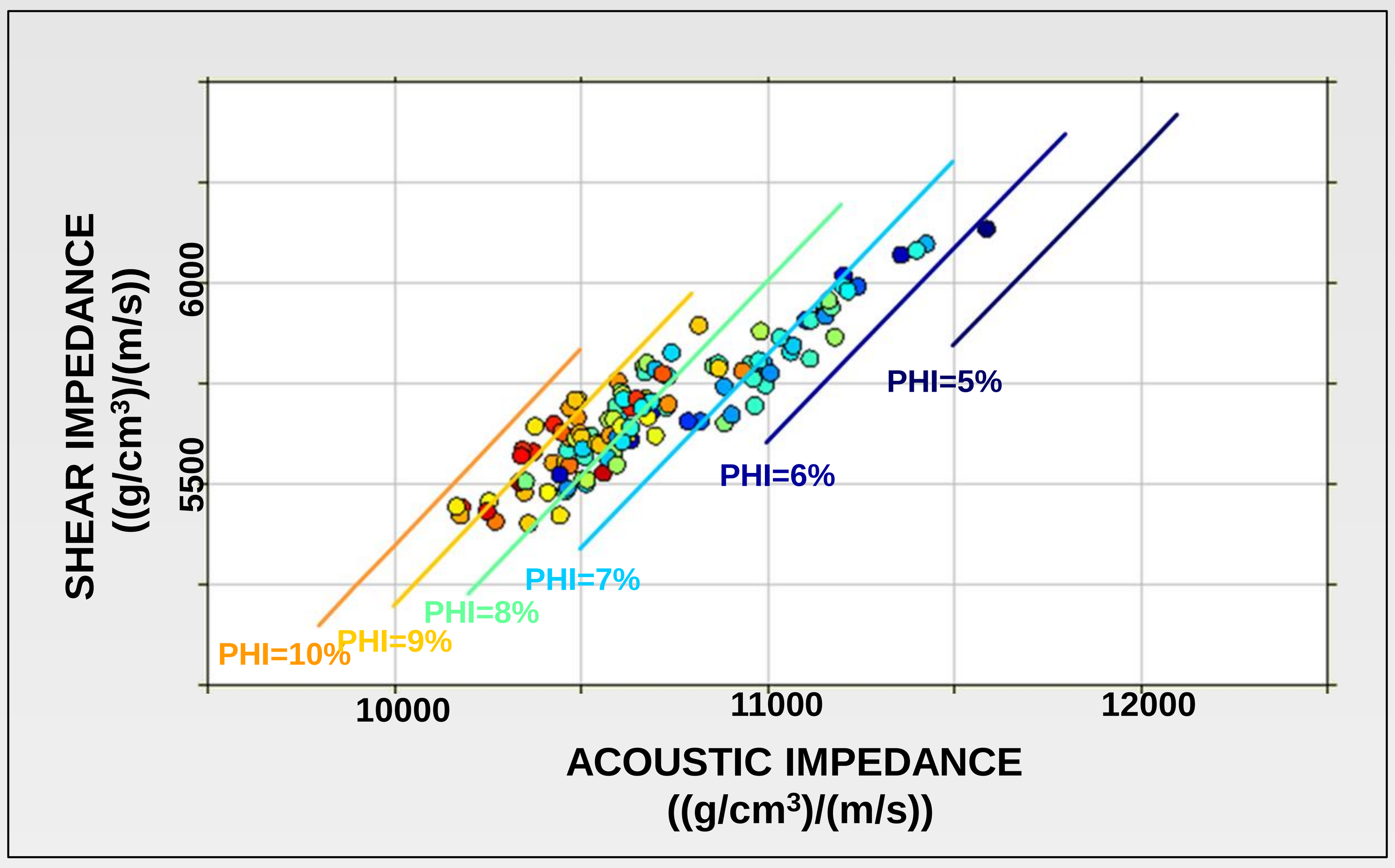

VOIGT $M_V = \sum_{i=1}^{N} f_i M_i$

REUSS $\frac{1}{M_R} = \sum_{i=1}^{N} \frac{f_i}{M_i}$

| CLAY = 15% | | | |
|---|---|---|---|
| VOIGT-REUSS AVERAGE (50/50) | | | |
| | $K_0$ | $MU_0$ | DENSITY |
| CLAY + QUARTZ | 50.37 | 27.53 | 2.68 |
| CLAY + CALCITE | 67.00 | 27.38 | 2.75 |

THE **MODEL** ASSUMES THAT **ONE ENDMEMBER** IS DEFINED AS A **MINERAL UNDER EFFECTIVE PRESSURE CONDITIONS**, AND THE **OTHER ENDMEMBER** IS DETERMINED BY THE **MINERAL MODULI OF A SECOND MATERIAL AT ZERO POROSITY AT THE HASHIN-SHTRIKMAN LOWER BOUND** (AVSETH ET AL. 2005)

**NINE AREAS** DEFINED IN TERMS OF **VARYING POROSITY** AND **ROCK STIFFNESS** IN THE **ACOUSTIC** AND **SHEAR IMPEDANCES** DOMAIN




RPT IS ***SUPERIMPOSED*** ON THE **BACKUS FILTERED BRINE SUBSTITUTED** LOG VALUES OF **ACOUSTIC AND SHEAR IMPEDANCES**

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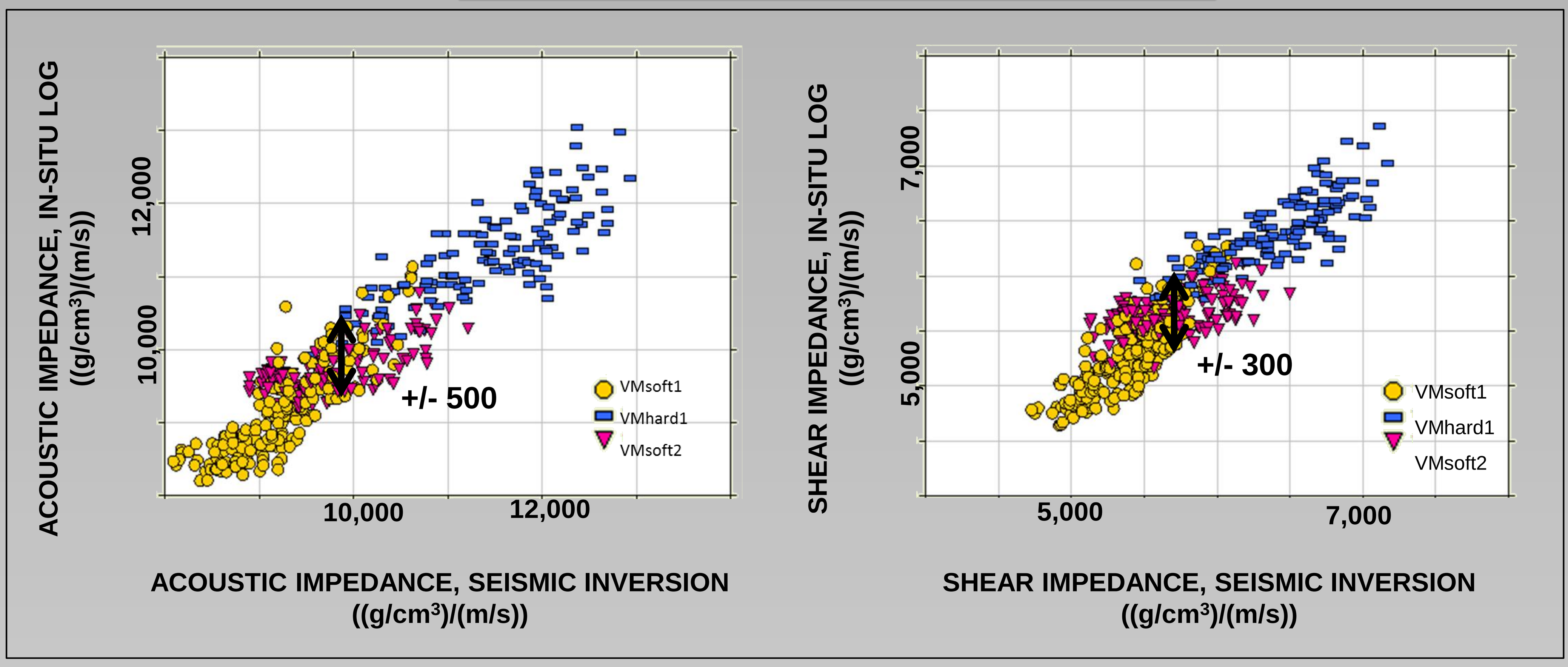
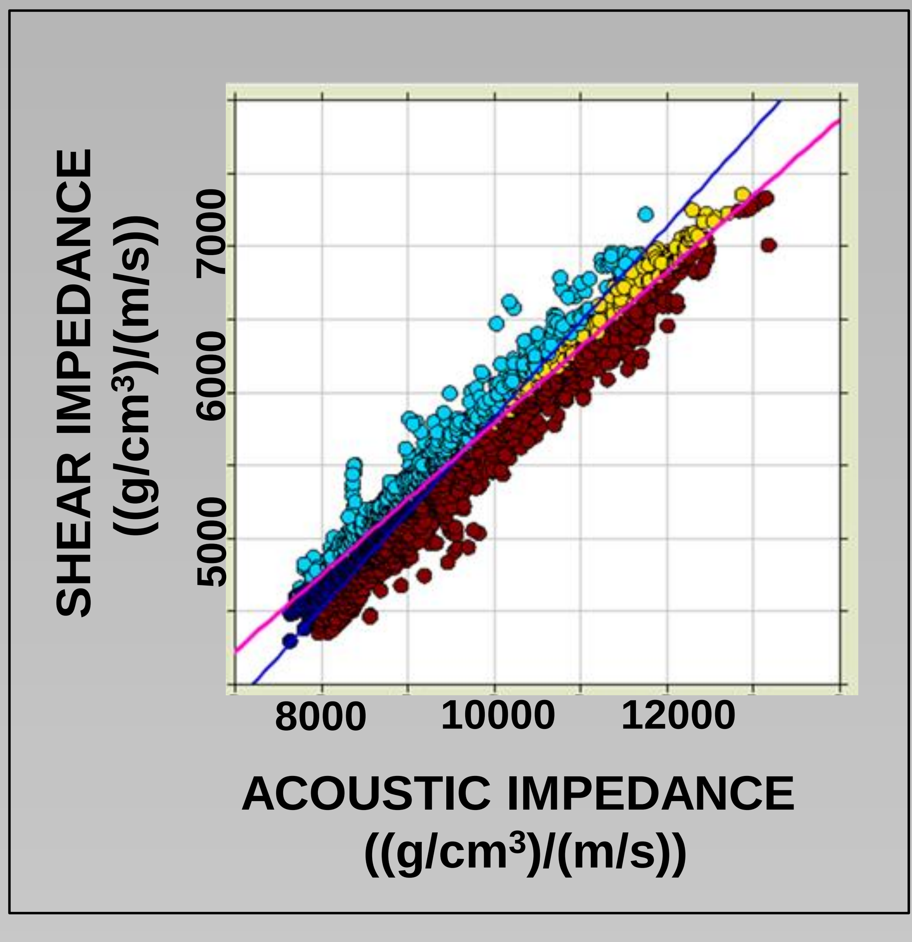
## 9- ROCK PHYSICS MODELING APPLICATION TO SEISMIC DATA (EXAMPLE)

### SEISMIC INVERSION UNCERTAINTIES



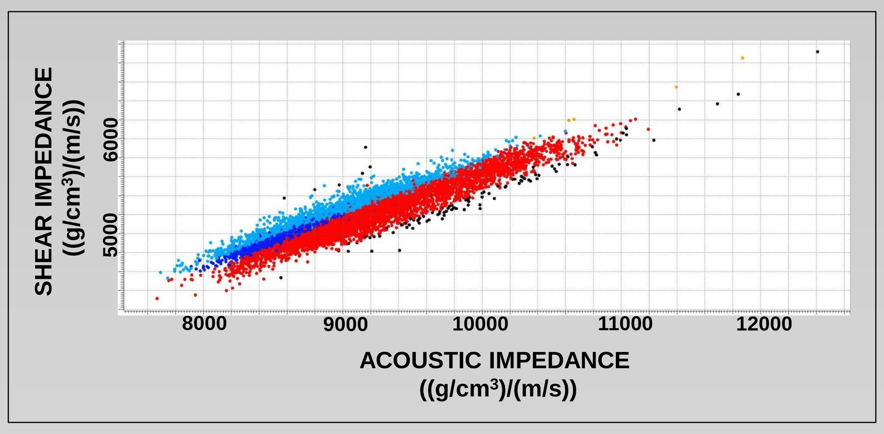

### LITHO TYPES

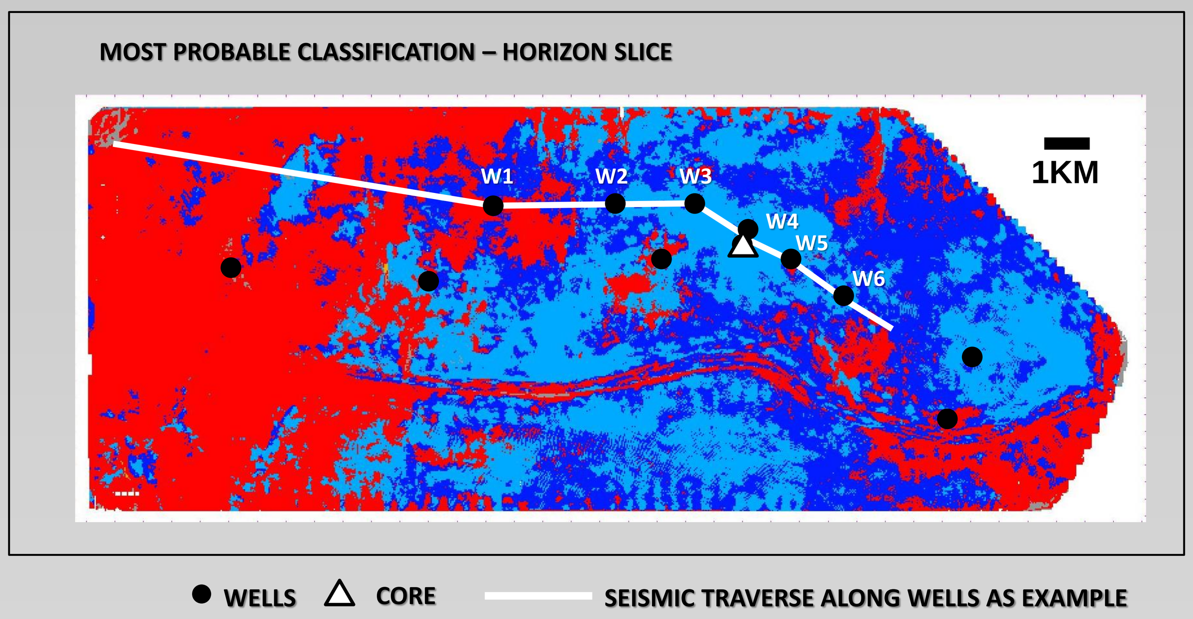
MODEL BASED, "LITHO-TYPES" IN FORM OF WELL LOGS WERE OBTAIN BY APPLYING THE FRIABLE-SHALE MODEL TO BRINE SUBSTITUTED AI-SI WELL DATA




**ACCEPTABLE DISPERSION** IN THE **CORRELATION** BETWEEN **INVERTED SEISMIC** AND **WELL LOG** IS OBSERVED IN ORDER **TO CLASSIFY INVERSION** DATA *USING* THE ***PROPOSED ROCK PHYSICS MODEL***

### BAYESIAN CLASSIFICATION



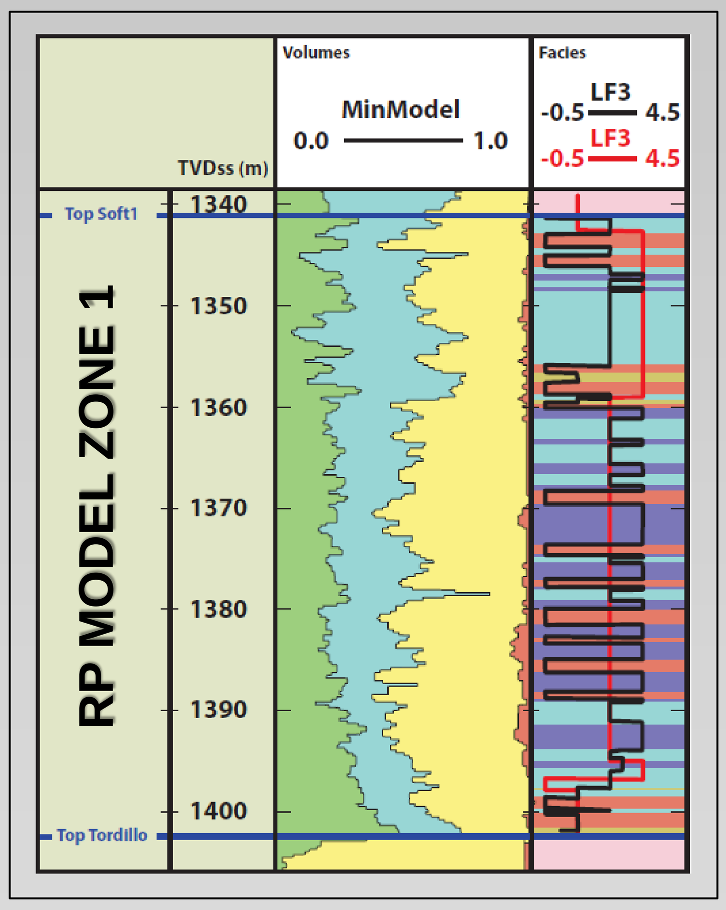



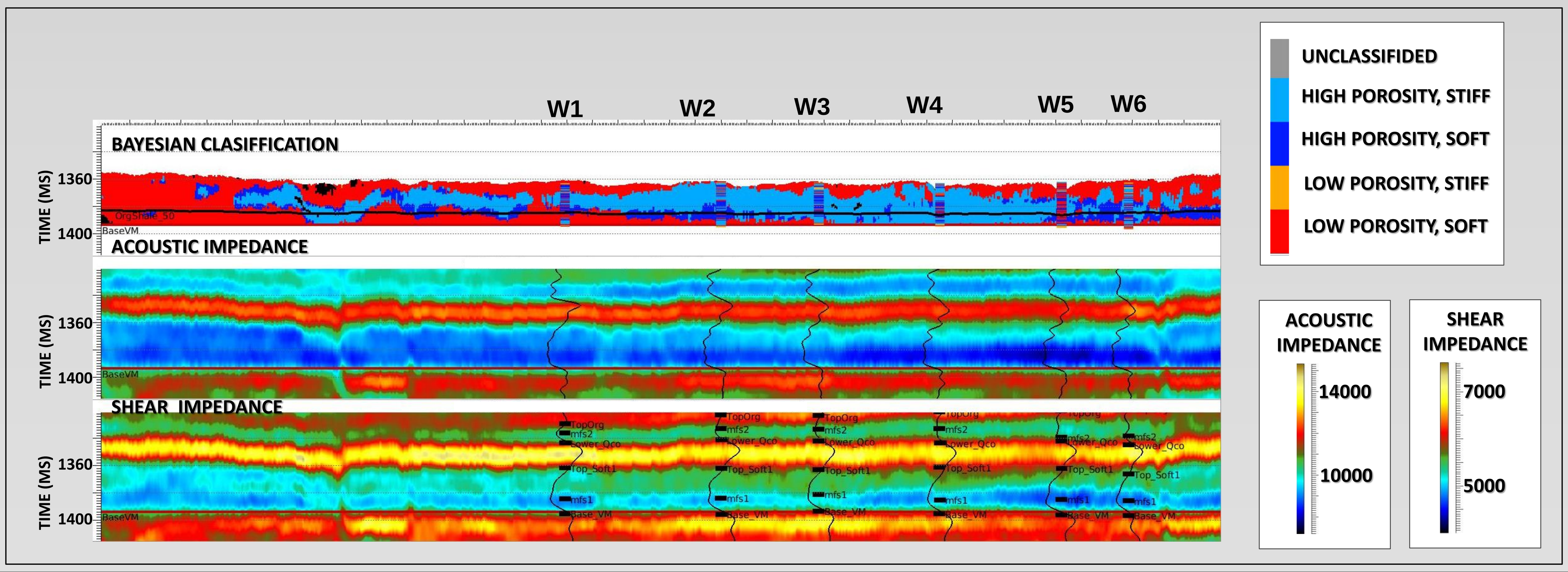

### UPSCALING

FOUR "LITHO-TYPES" DEFINED

-HIGH AND LOW POROSITY (CUTOFF AT 9%)

-HIGH AND LOW ROCK STIFFNESS (CUT OFF AT CN 30)




IDENTIFICATION OF FOUR AREAS WITH VARIOUS **RESERVOIR PROPERTIES (HIGH-LOW POROSITY, HIGH-LOW STIFFNESS)** WERE IDENTIFIED AFTER APPLYING THE **PROPOSED ROCK PHYSICS TEMPLATE (RPT)**

***NO PRODUCTION DATA*** IS YET AVAILABLE ***TO CALIBRATE*** THE RESULTS

## 10- CONCLUSIONS

- ✓ THE **FRIABLE SHALE ROCK PHYSICS MODEL**, A **MODIFIED VERSION OF DVORKIN & NUR'S FRIABLE SAND MODEL (DVORKIN AND NUR, 1996)** WAS SELECTED AND USED FOR THE PRESENT WORK. THE MODEL HAS THE ABILITY TO CONSIDER DIFFERENT, INCLUDING **CLAY RICH**, MINERAL COMBINATIONS AND THEIR VARIABILITY WITH RESPECT TO INTERNAL ROCK STIFFNESS.
- ✓ THIS MODEL DESCRIBES **MORE THAN 80% OF DATA** FOR THE **QUINTUCO VACA MUERTA SYSTEM** IN THE STUDY AREA.
- ✓ THE **PROPOSED RPT**, BASED ON QUALITY CONTROLLED WELL LOG DATA AND CALIBRATED ROCK PHYSICS MODELING **CAN BE USED FOR QUICK IDENTIFICATION OF RESERVOIR PROPERTIES**, SUCH AS **POROSITY**, ON SEISMIC INVERSION CROSS PLOTS (P. AVSETH ET AL, 2014).
- ✓ THE APPLICATION OF THE **RESULTING RPT** INCLUDING PARAMETERS ADJUSTMENTS FOR A PARTICULAR LAYER IS SHOWNS AS EXAMPLE.
- ✓ FACIES DEFINITION IN THE ELASTIC DOMAINS, BASED IN **WELL LOG DATA** AND ROCK PHYSICS TEMPLATES, **ARE CRUCIAL TO CLASSIFY SEISMIC INVERSION RESULTS**. LITHO-TYPES WERE DEFINED AND RPT APPLIED TO A PARTICULAR LAYER.
- ✓ THE **PROPOSED FINE-TUNED POROSITY-BASED ROCK PHYSICS TEMPLATE** DEFINED IN THE **P AND S IMPEDANCE ELASTIC DOMAIN** CAN BE USED TO **DEFINE FACIES AND THEIR PROBABILITIES** USING A CLASSIFICATION TECHNIQUE, BASED IN A BAYESIAN FORMULATION, WITH THE ULTIMATE GOAL OF **DEFINING POTENTIAL AREAS FOR FURTHER DEVELOPMENT** IN THE STUDY AREA.

## ACKNOWLEDGEMENTS

WE WOULD LIKE TO THANK YPF S.A. FOR THE PERMISSION TO PRESENT THIS WORK. SPECIAL THANKS TO OUR COLLEAGUE G. GODINO FOR THE REVIEW OF SOME FIGURES

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