QUIMIOESTRATIGRAFÍA APLICADA AL ESTUDIO Y PROGNOSIS EN RESERVORIOS NO CONVENCIONALES TIPO SHALE

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Agenda:

- Objectives
- Introduction
- Technology - Methodology
- TOC correlation
- Inorganic geochemistry, Geostatistics & Seismic
- Core Inorganic geochemistry, Geostatistics & image logs
- Geochemical-Geostatistical Geosteering model
- Conclusions

KEY TOOLS FOR BLACK SHALE EVALUATION: GEOSTATISTICS AND INORGANIC GEOCHEMISTRY APPLIED TO VACA MUERTA FORMATION, NEUQUEN BASIN, ARGENTINA

Authors:

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** Larriestra Geotecnologías S.A.
GEOCIENCIA DE VANGUARDIA

Soft Inorganic Geochemistry

- **Larriestra, C., 2011**, **"Geochemical Well Logging by Geostatistical Integration of Cutting and Well Log Data", Int. Association of Mathematical Geosciences, Annual Meeting** 5-9 Set, Salzburg, Austria, 2011.

- **Larriestra, C. 2013**, **"Soft Inorganic Geochemistry: A New Concept for Unconventional Resources Modeling", AAPG 2013, Annual Convention**, May 19-22, 2013, Pittsburgh, PA.

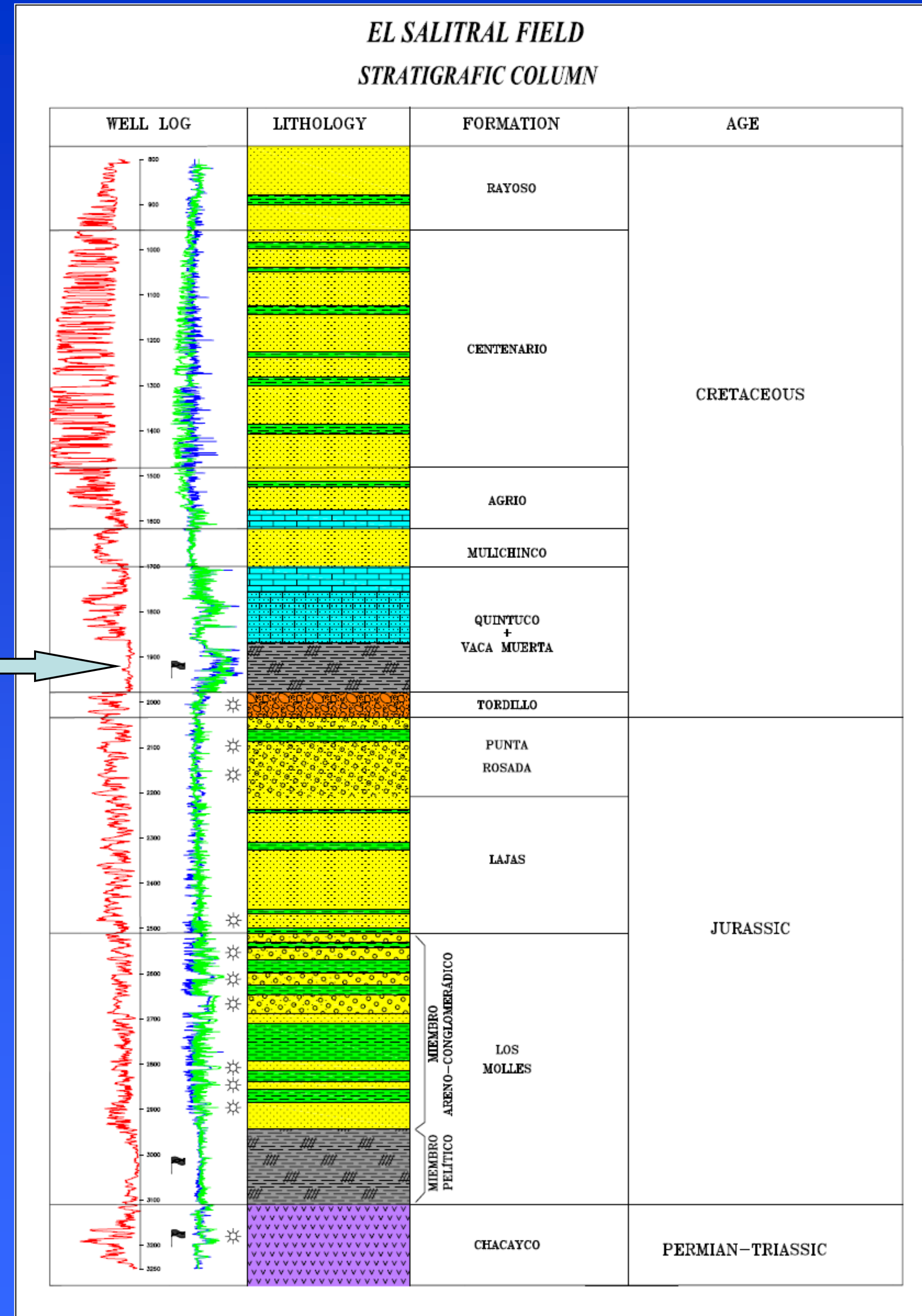
Soft Inorganic Geochemistry

<u>Concept</u>

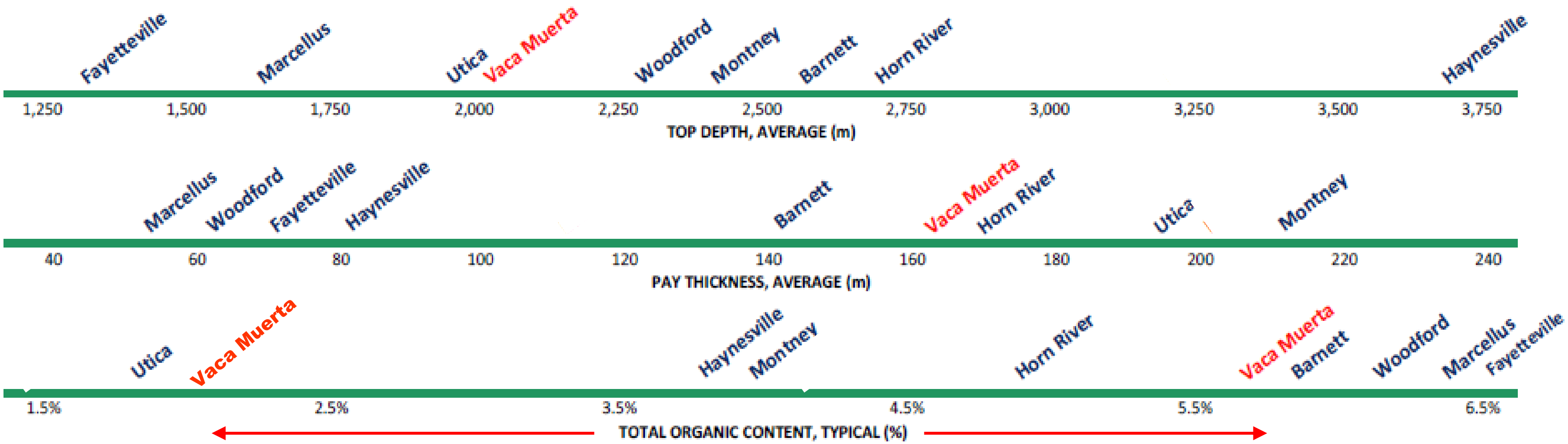
Soft inorganic geochemistry is defined as the spatial modeling of geochemical data which *prioritizes the amount of data*, *their spatial relationship and their relationship with other data types* (geological and geophysical data) over the *individual chemical analysis accuracy*.

STRATIGRAPHY

Marine – Marl? / Mudstone – Organic rich

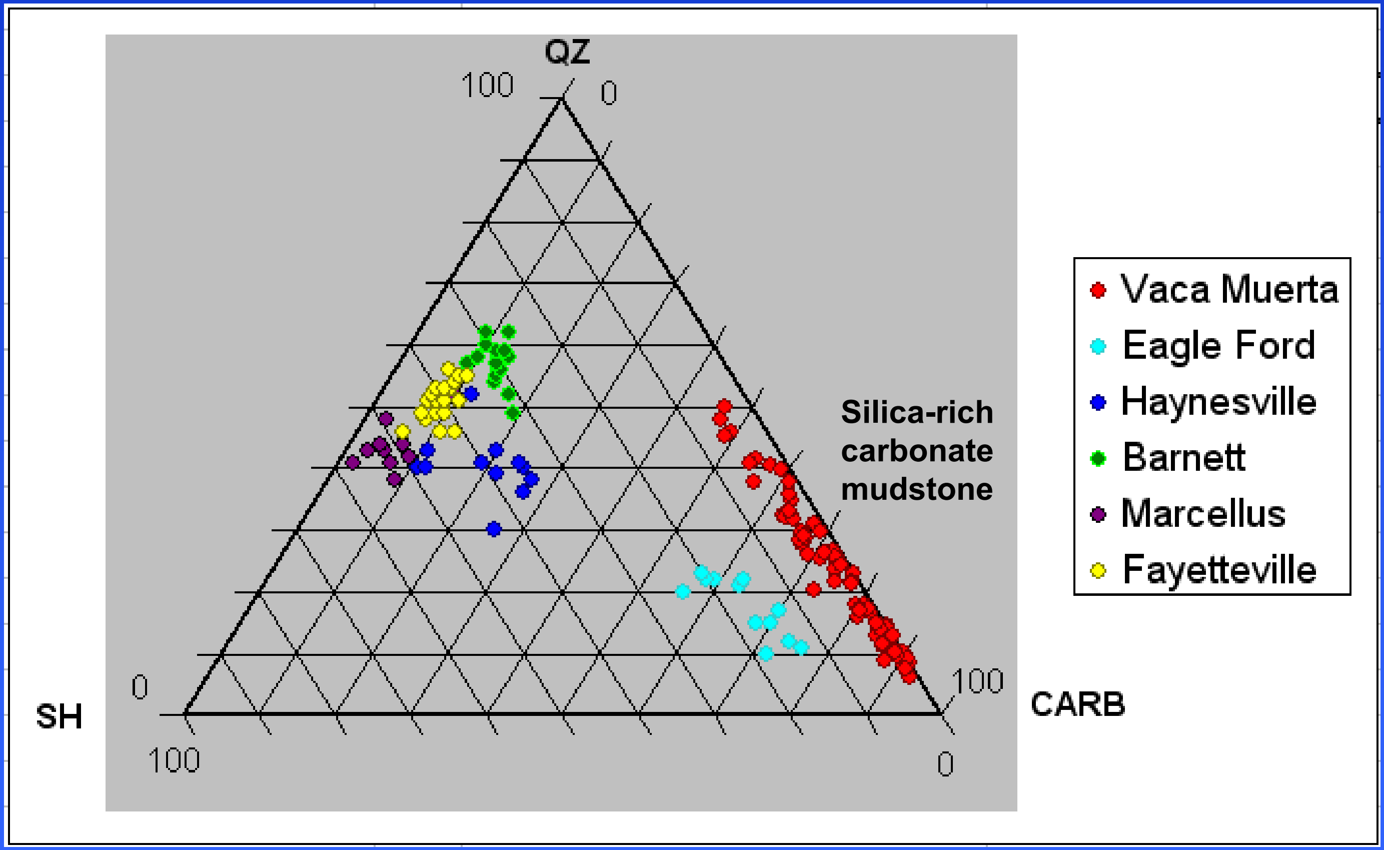


VACA MUERTA IN CONTEXT WITH OTHER SOURCE ROCKS



VACA MUERTA MINERALOGY

IN CONTEXT WITH OTHER SOURCE ROCKS



WORKFLOW

DATA ACQUISITION

- ***Non Destructive XRF analysis* of ALL cutting samples**
- ***Destructive analysis* ICP-MS, XRD and TOC (3% to 5% of samples)**

The XRF recording is make on Sample Storage site

↓

DATA CALIBRATION

↓

WIRELINE – GEOCHEMICAL LOGS CORRELATION

↓

GEOCHEMISTRY & SEISMIC INTEGRATION

↓

3D MODELS FOR TOC, ANOXIC FACIES & CHEMICAL ELEMENTS

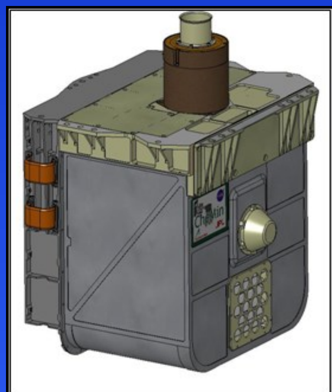
↓

BRITTLENESS & SEDIMENTARY INDICATORS

DATA ACQUISITION

TECHNOLOGY Developed for Mars Rover Curiosity

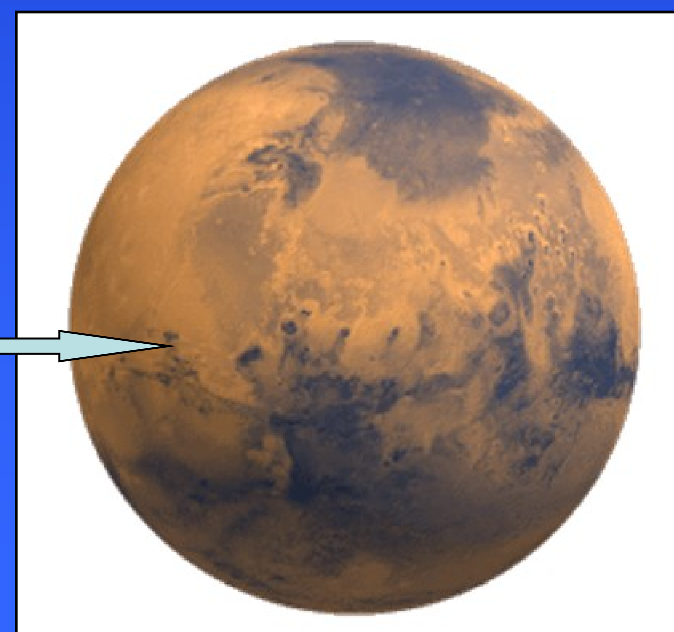
Jet Propulsion Laboratory
California Institute of Technology



XRD

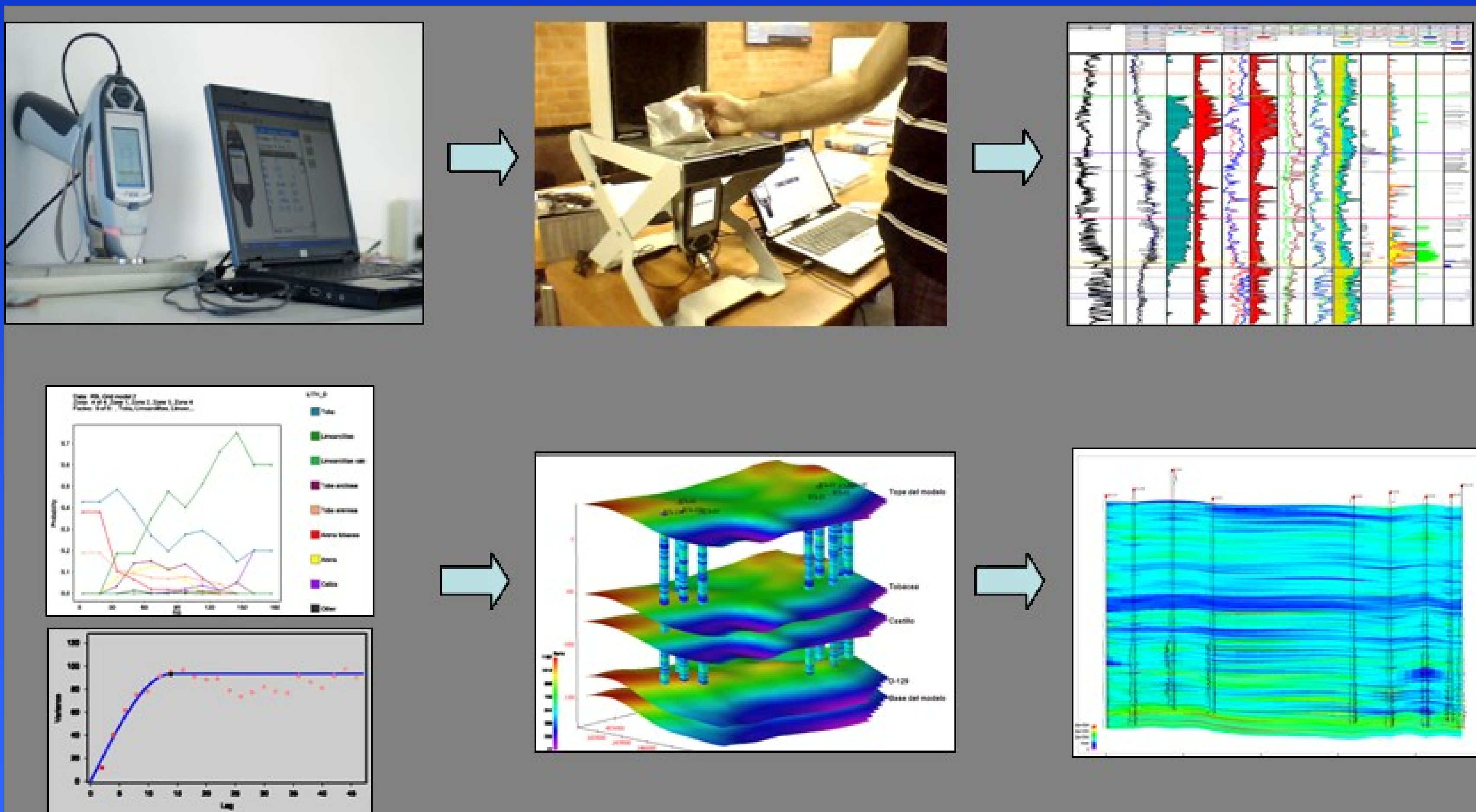
XRF

Mars Rover Curiosity



DATA ACQUISITION and PROCESSING

METHODOLOGY: XRF ANALYSIS OVER CUTTINGS (58 wells, +4300 samples)



Majority : Fe, Mn, Ca, K, S
Minority : Zr, Sr, Rb, Ti, Ba
Trace: Mo, U, Th, Pb, Se, As, Hg, Zn, W, Cu, Ni, Co, Cr, V, Sc, Cs, Te, Sb, Sn, Cd, Ag, Pd

DATA CALIBRATION: Hand Held XRF vs. ICP-MS results

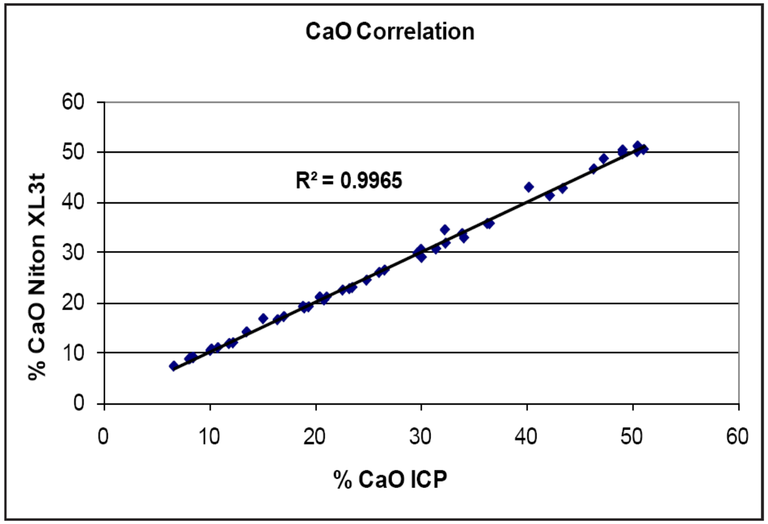


Figure 2. Correlation between CaO values measured by Niton XL3t Series analyzer and ICP-MS

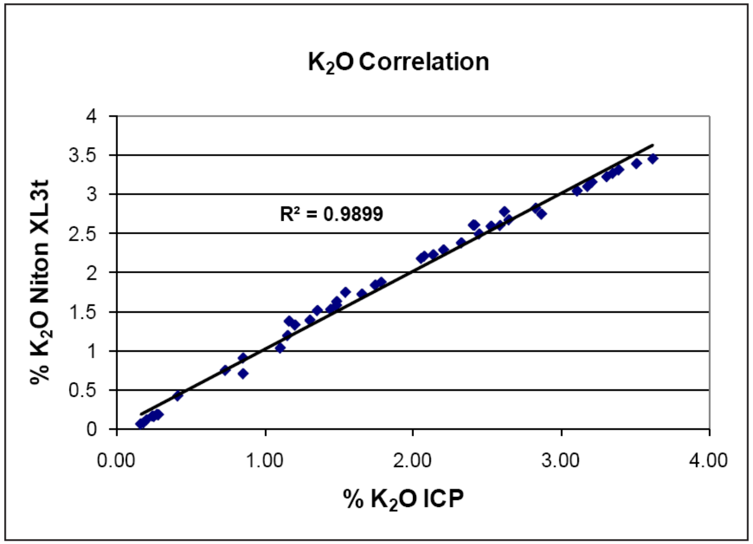
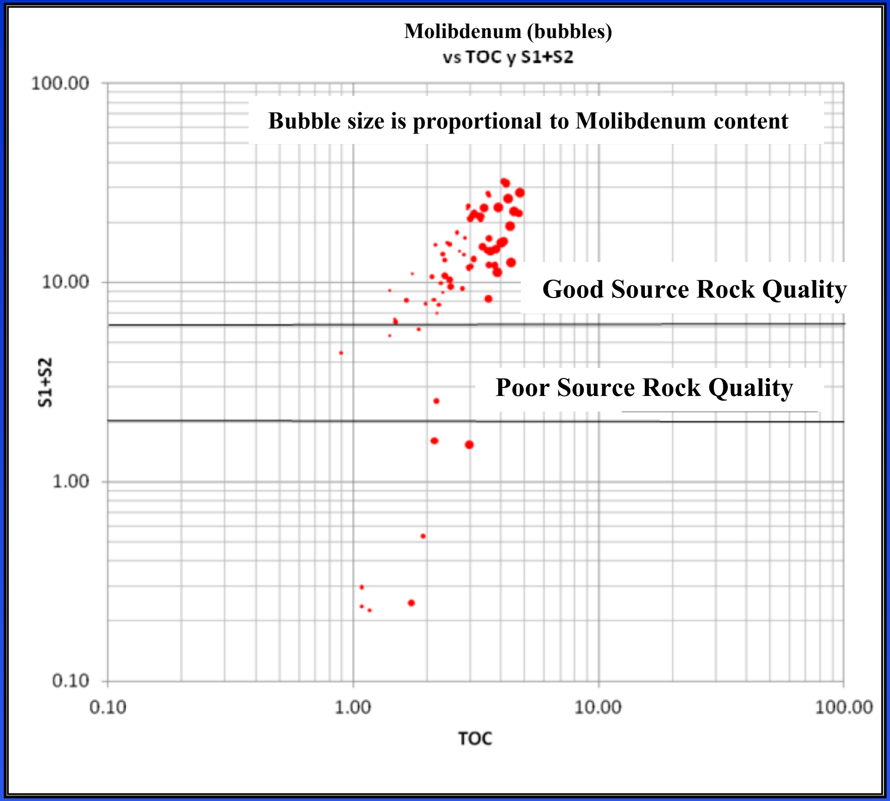


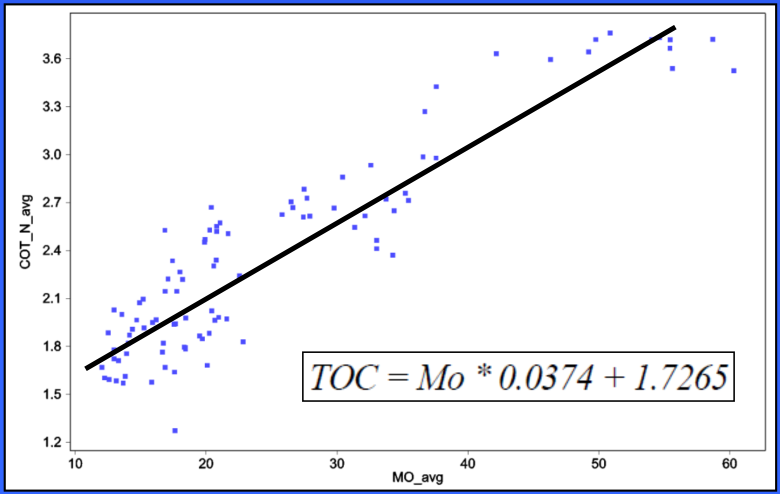
Figure 3. Correlation between K2O values measured by Niton XL3t Series analyzer and ICP-MS

Other Calibration References
US Geological Survey Standards

AGV-2	Guano Valley Andesite 2 (andesite)	USGS
SCo-1	Cody Shale 1 (shale)	USGS
SRM 001d	Argillaceous Limestone	National Institute of Standards and Technology

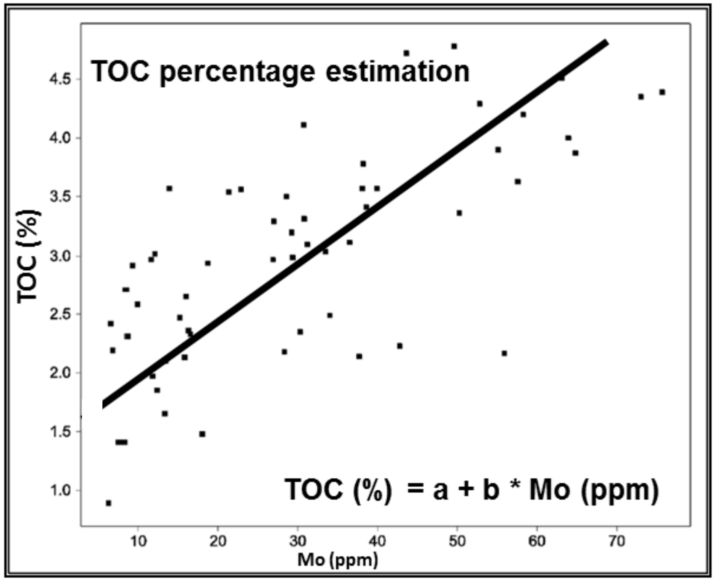


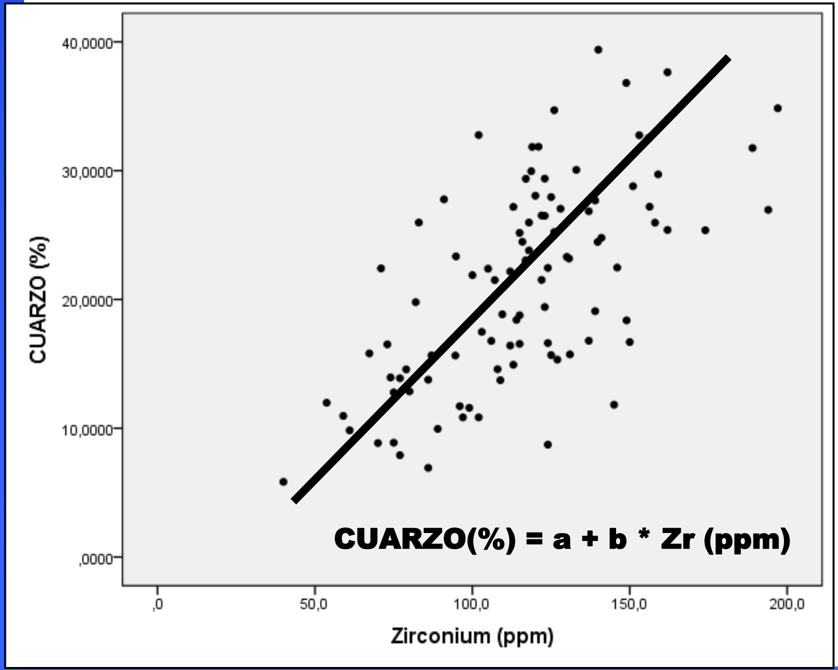
Best correlation corresponds to Mo

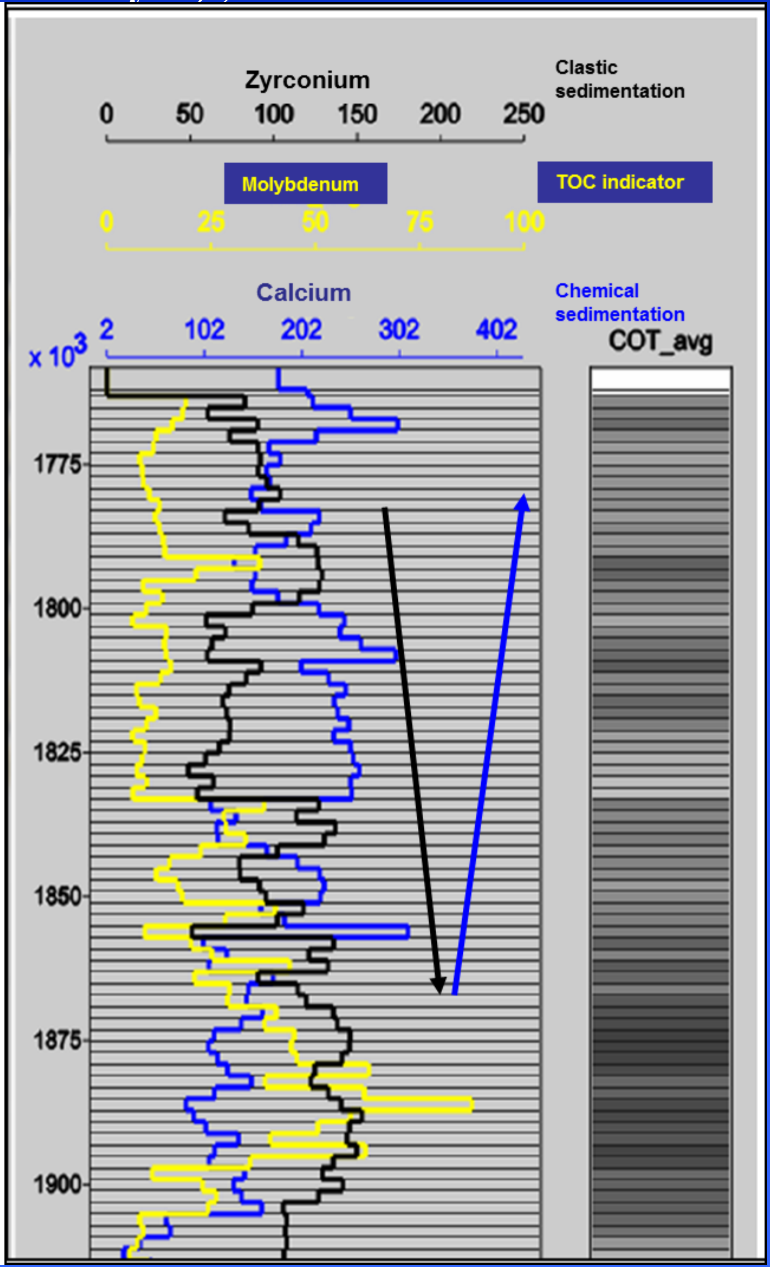


GEOSTATISTCAL DATA INTEGRACION

TRACE ELEMENTS (nondestructive analysis) ,MINERALOGY and TOC

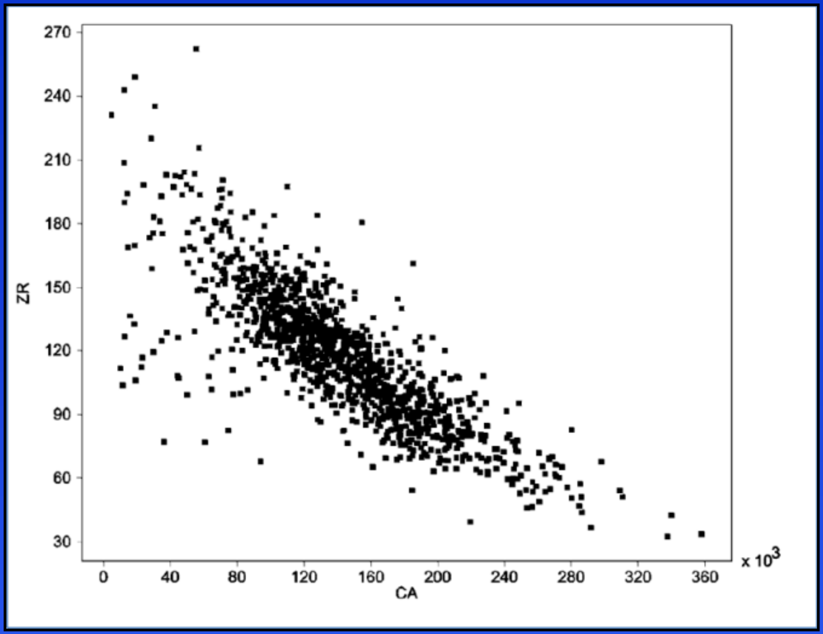




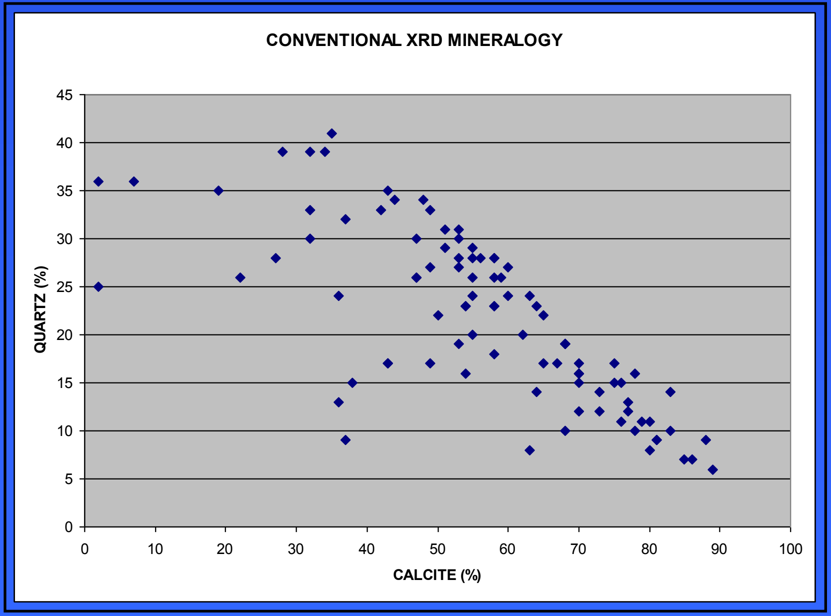


Other MINERALOGICAL and GEOCHEMICAL RELATIONSHIPS

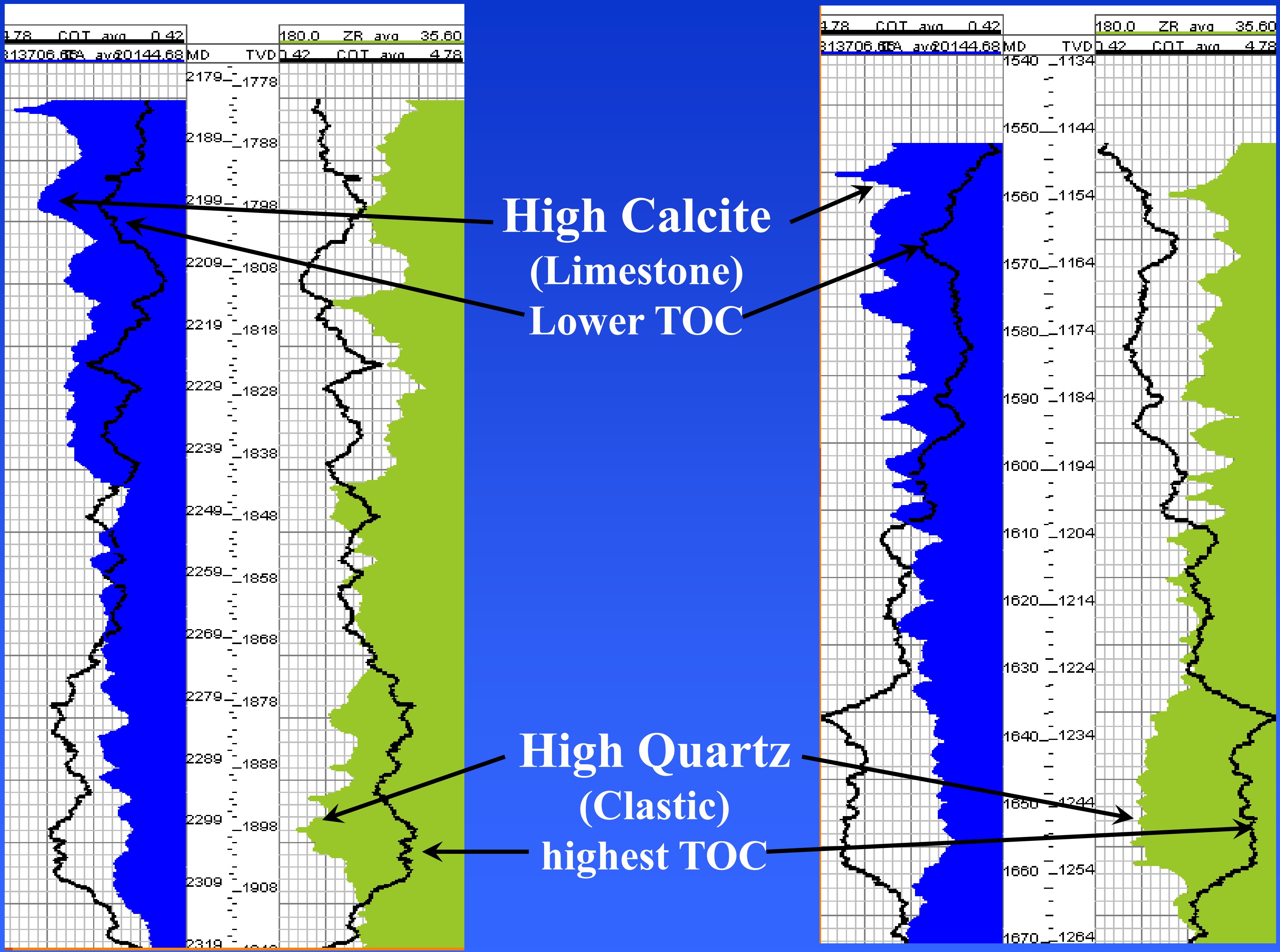
XRF DATA



XRD DATA



Vaca Muerta Fm.
Geochemical and Mineralogical Sweet Spots



GEOCHEMISTRY

&

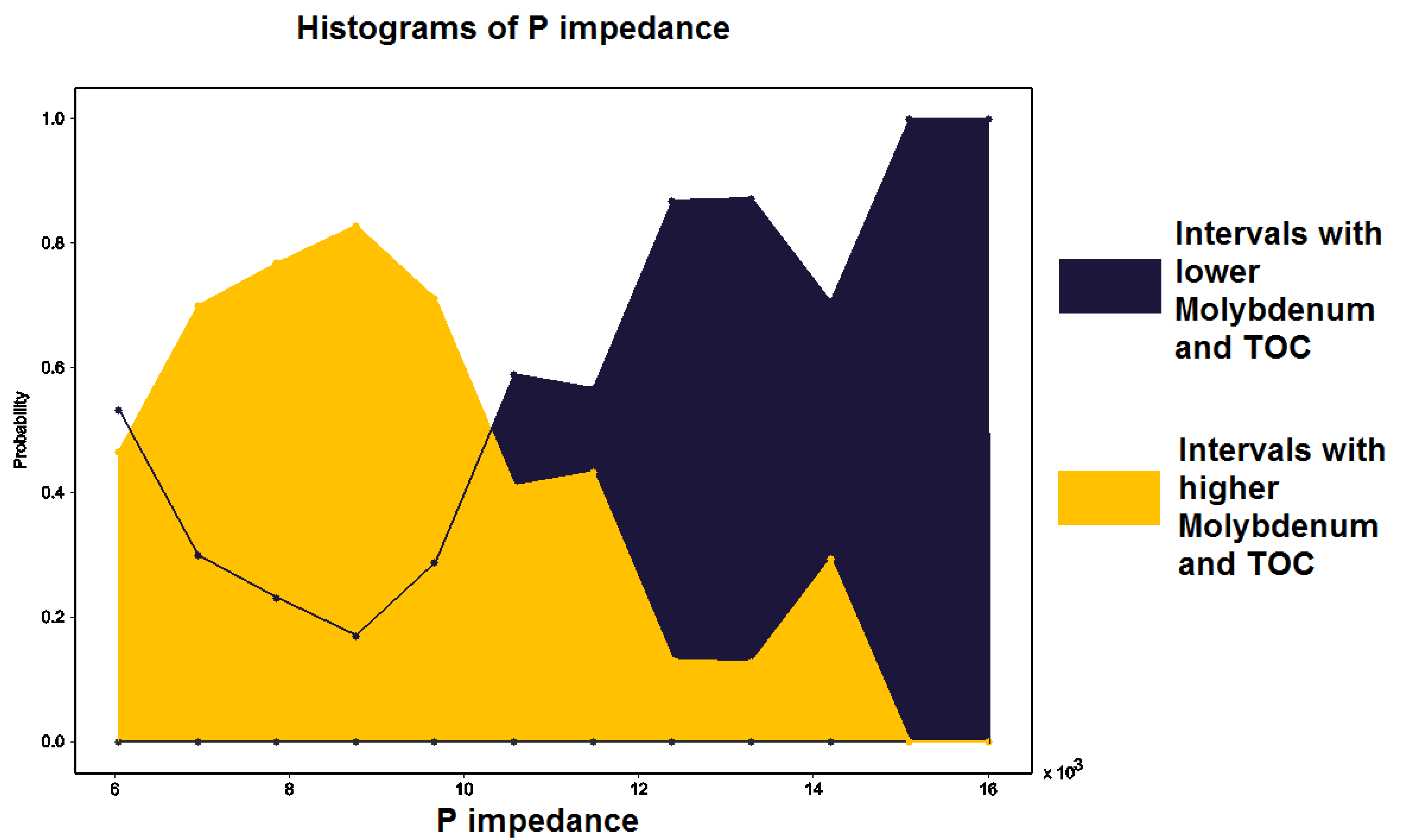
SEISMIC INTEGRATION

GEOCHEMISTRY, GEOSTATISTICS & SEISMIC

INORGANIC / ORGANIC GEOCHEMISTRY, GEOSTATISTICS, and its INTEGRATION with SEISMIC, allowed us to model different properties in the interwell space:

- Anoxic facies probability
- TOC
- Sedimentary indicators
- Brittleness indicators

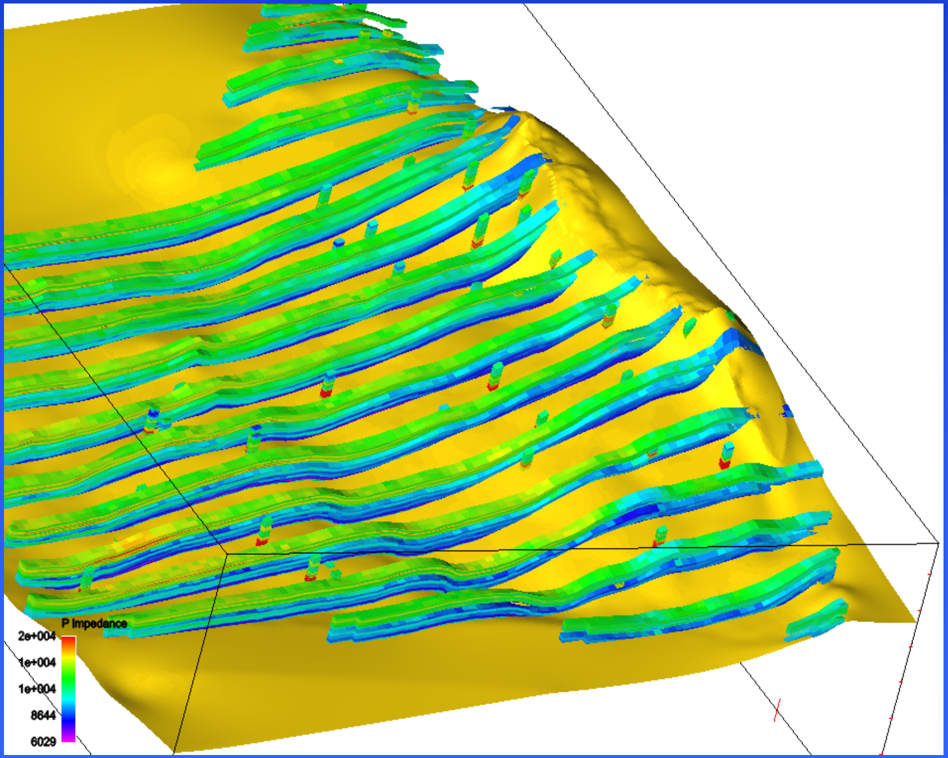
GEOCHEMISTRY & SEISMIC DATA INTEGRATION



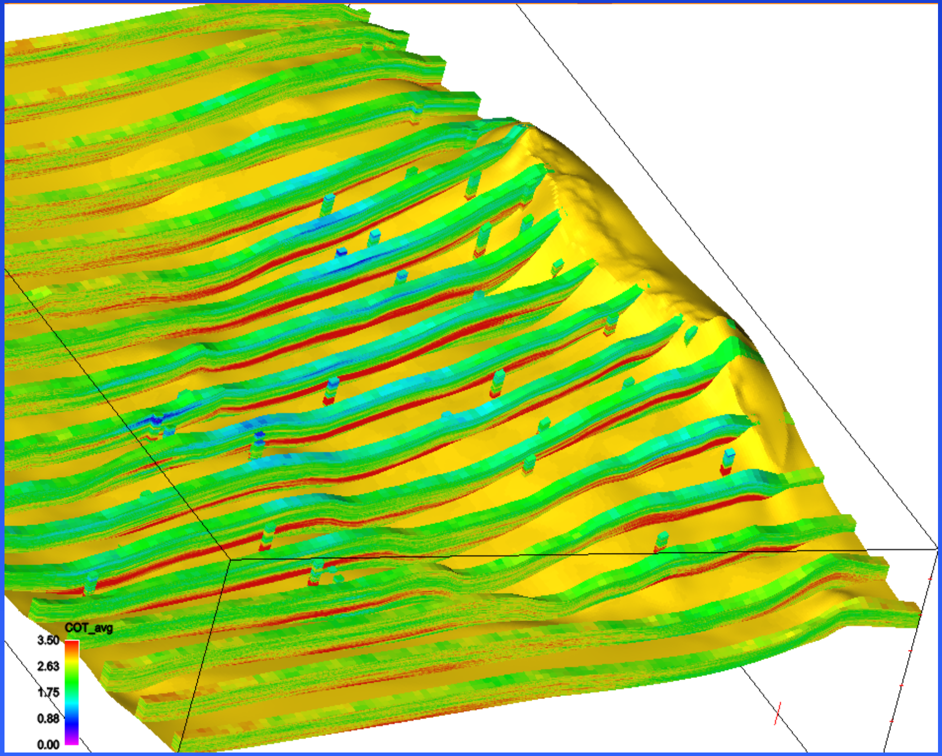
(From Nawratil, A., Gomez, H. y Larriestra, C., 2012, Key Tools for Black Shale Evaluation: Geostatistics and Inorganic Geochemistry Applied to Vaca Muerta Formation, Neuquén Basin, Argentina, AAPG ICE, September 15th – 19th 2012, Singapore)

Bayesian Cosimulation and anoxic facies propagation using P impedance in the interwell space

3D P impedance



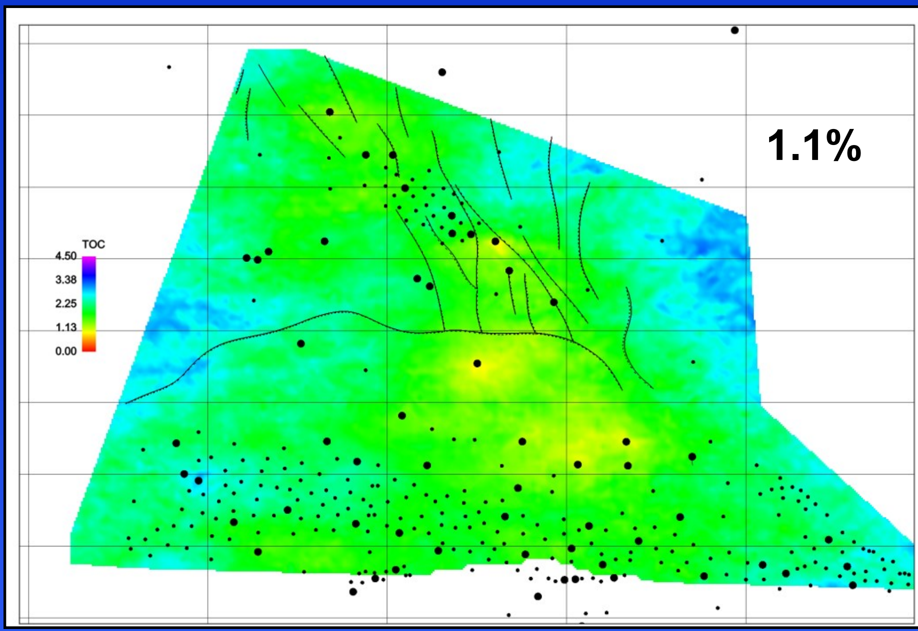
3D Cosimulated TOC



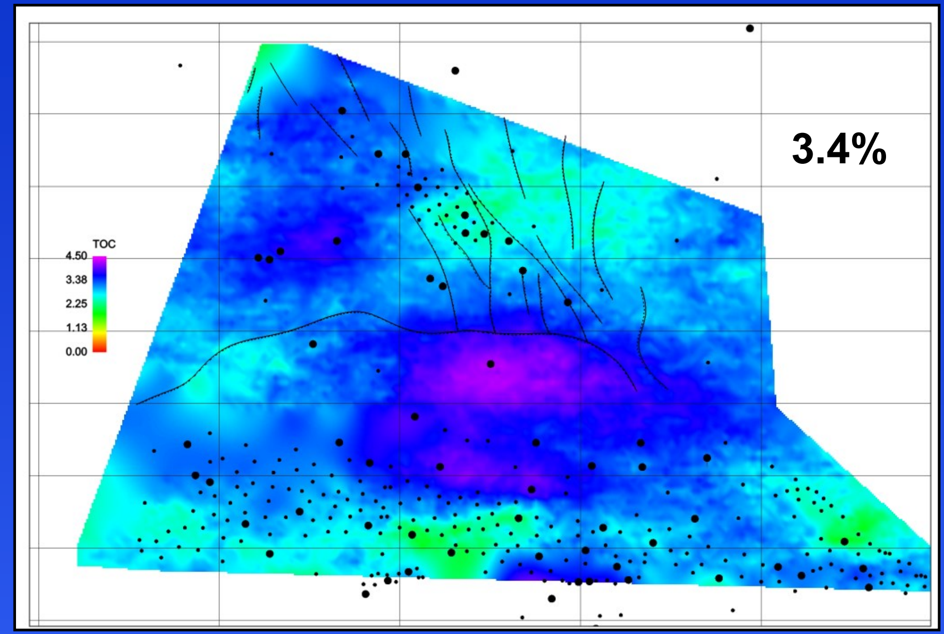
(From Nawratil, A., Gomez, H. y Larriestra, C., 2012, Key Tools for Black Shale Evaluation: Geostatistics and Inorganic Geochemistry Applied to Vaca Muerta Formation, Neuquén Basin, Argentina, AAPG ICE, September 15th – 19th 2012, Singapore)

VACA MUERTA TOC CHARACTERIZATION

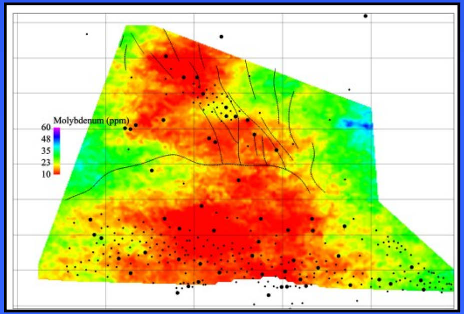
UPPER VM



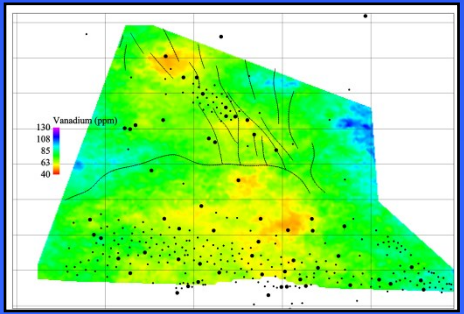
LOWER VM



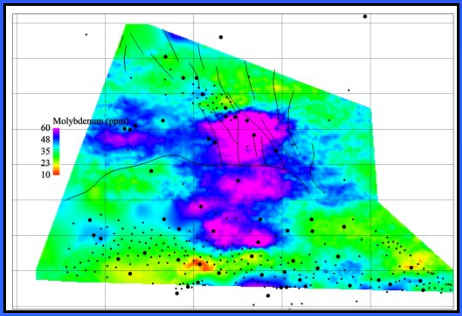
AV. TOC



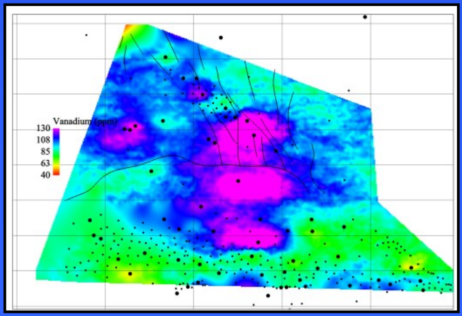
AV. Mo CONTENT



AV. V CONTENT



AV. Mo CONTENT



AV. V CONTENT

LVM shows higher TOC than UVM

AAPG Annual Convention & Exhibition 2014
6-9 APRIL HOUSTON

High Resolution Non-Destructive Chemostratigraphy of Vaca Muerta Fm: New Evidences of Black Shale Sedimentology Features

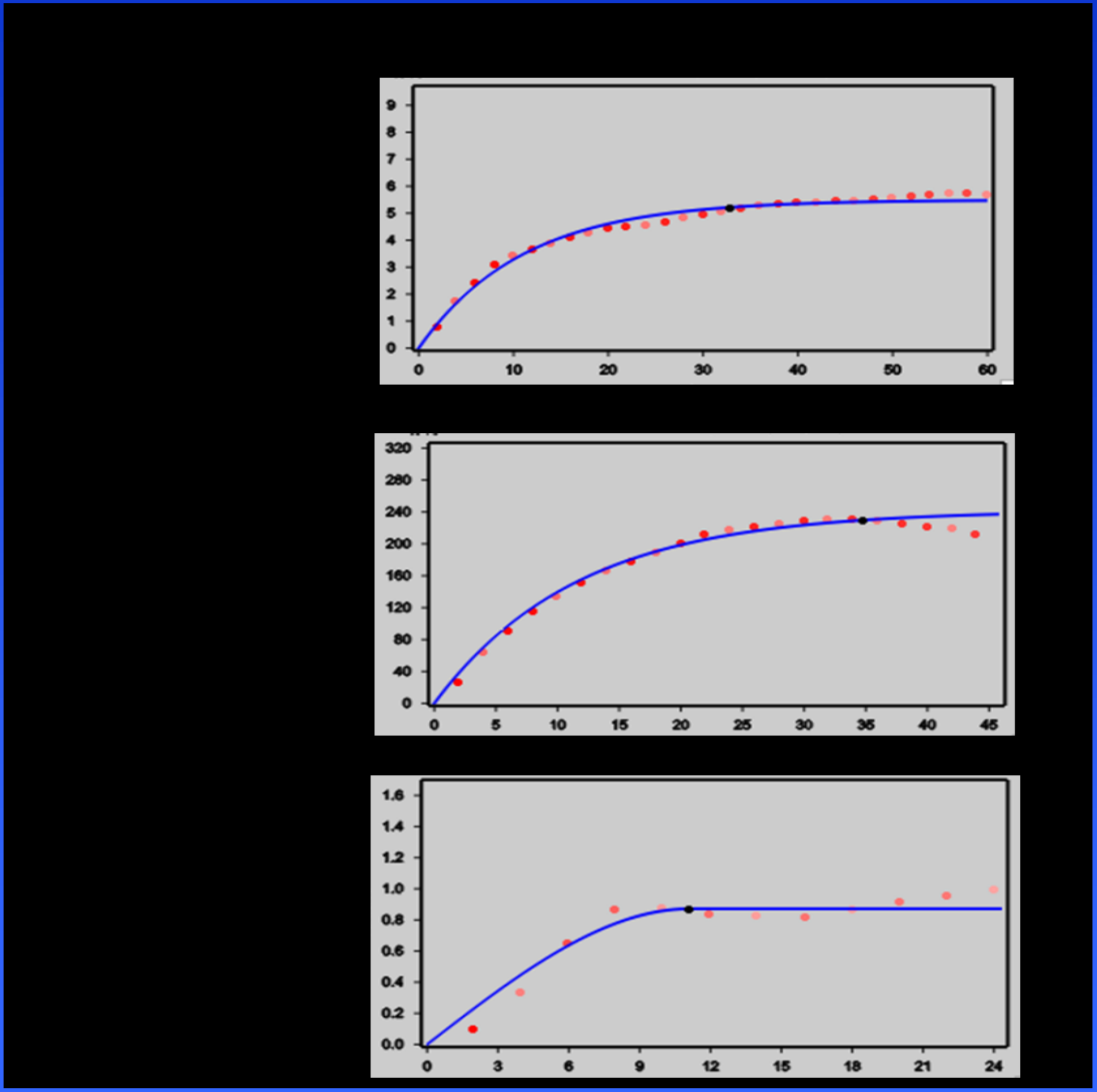
Claudio Larriestra and Roberto Merino

Larriestra Geotecnologías s.a.

Rovella Energía s.a.

GEOSTATISTICAL ANALYSIS

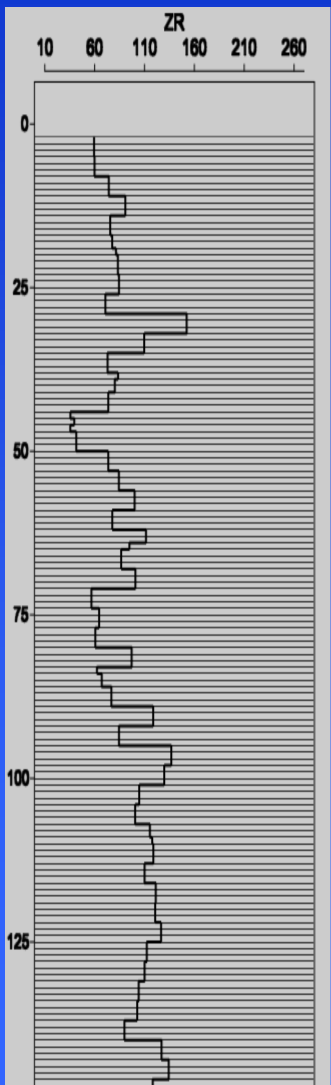
VARIOGRAM ANALYSIS in VERTICAL DIRECTION



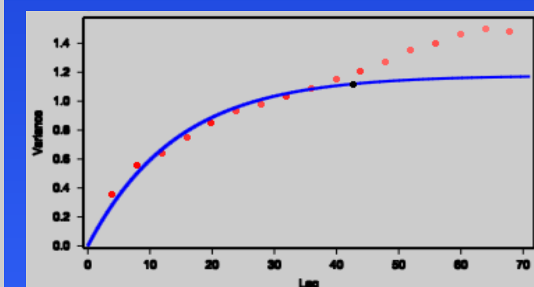
GEOSTATISTICAL ANALYSIS

VARIOGRAM ANALYSIS: ERROR DETECTION

NUGGET EFFECT

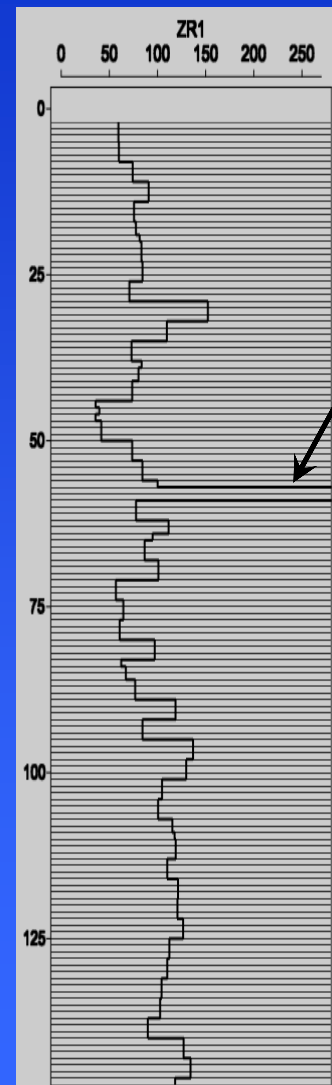


ORIGINAL LOG

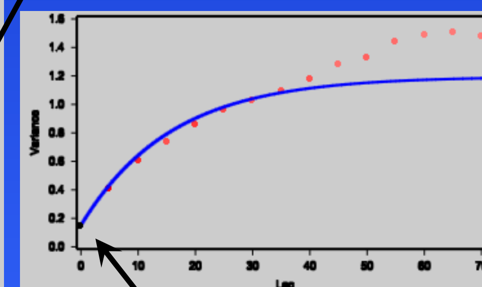


EXPONENTIAL

VARIOGRAM

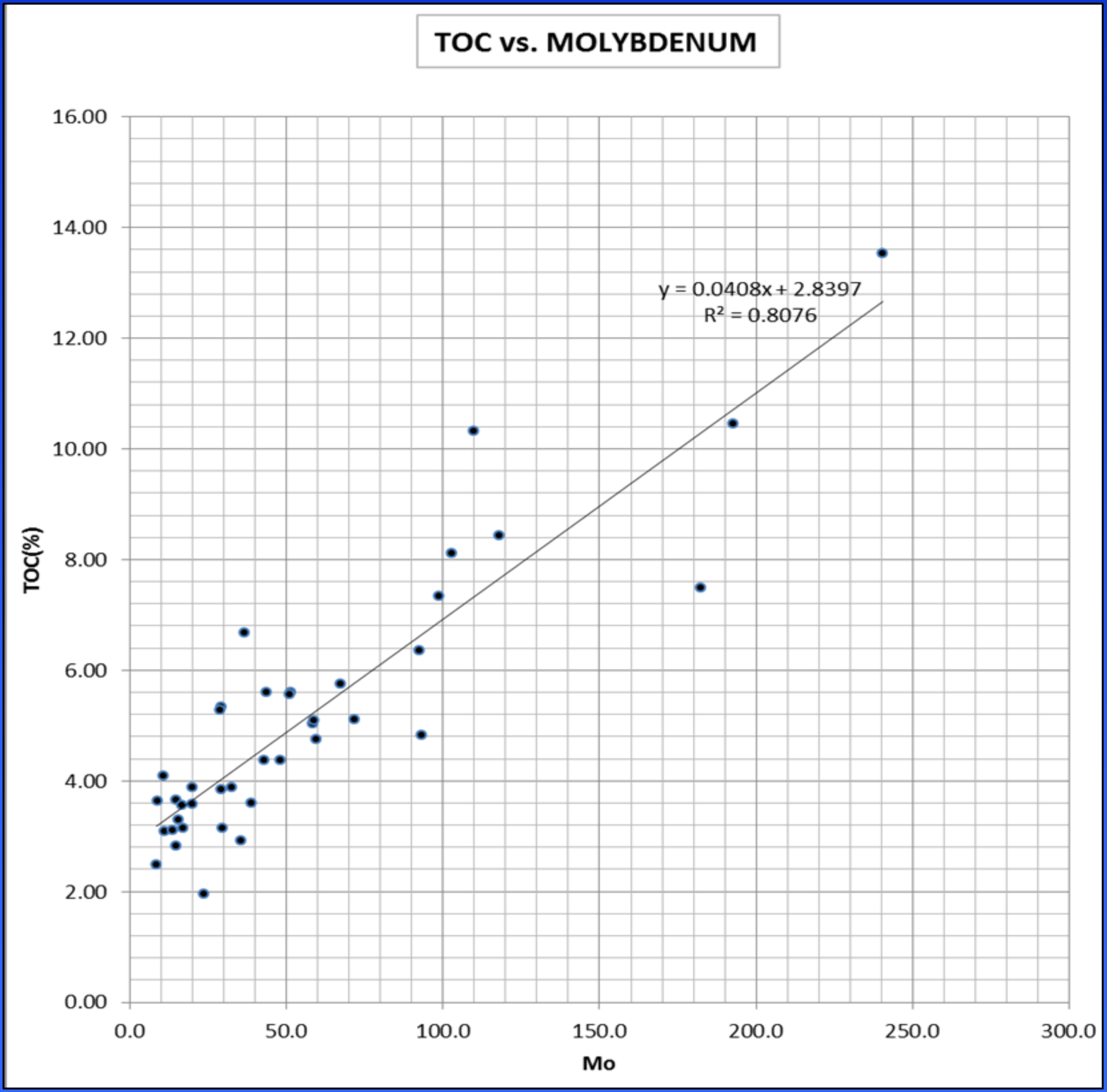


ANOMALOUS POINT

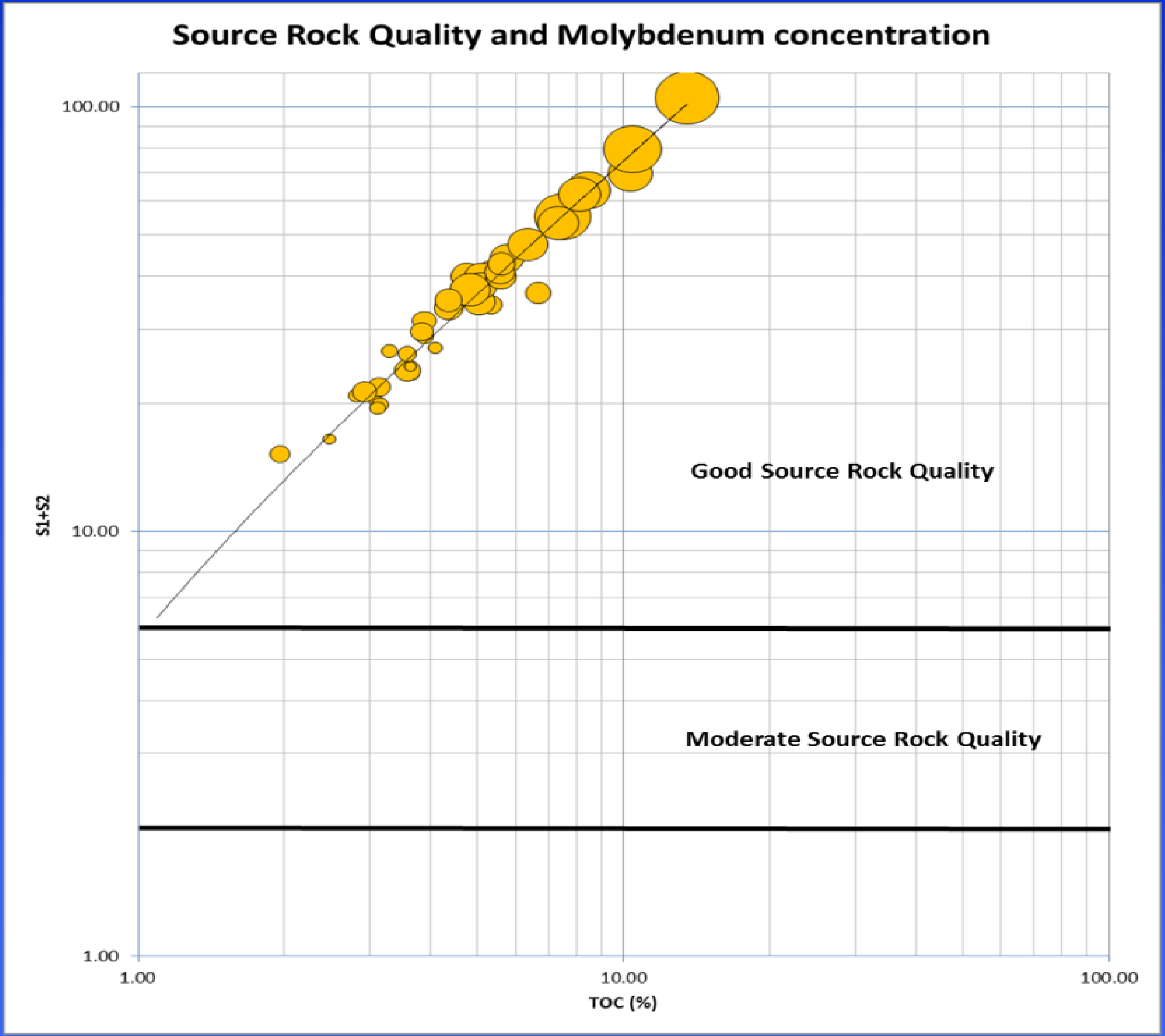


NUGGET EFFECT

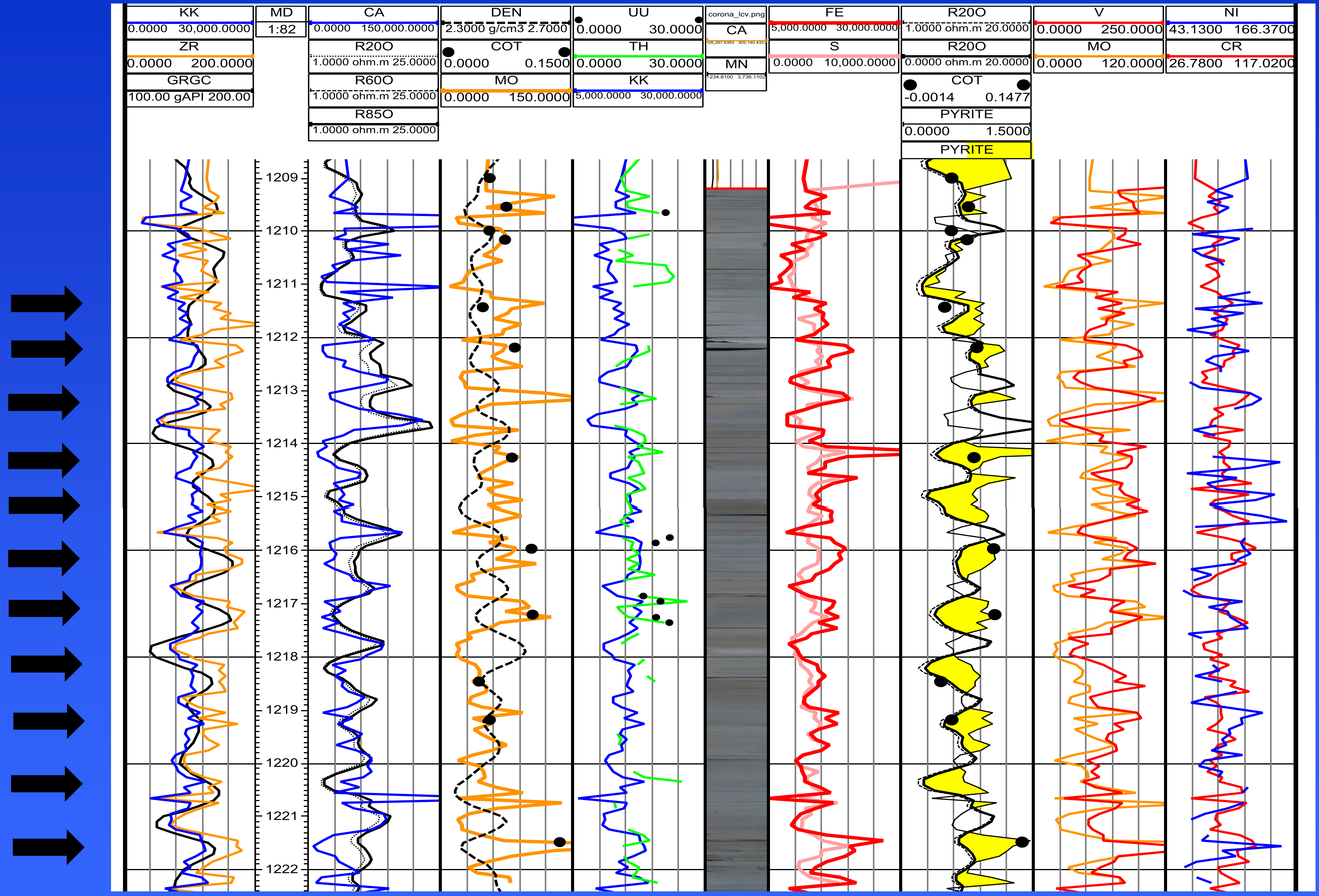
TRACE ELEMENTS
related to
ANOXIC EVENTS



ROCK SOURCE POTENTIAL
and
TRACE ELEMENTS

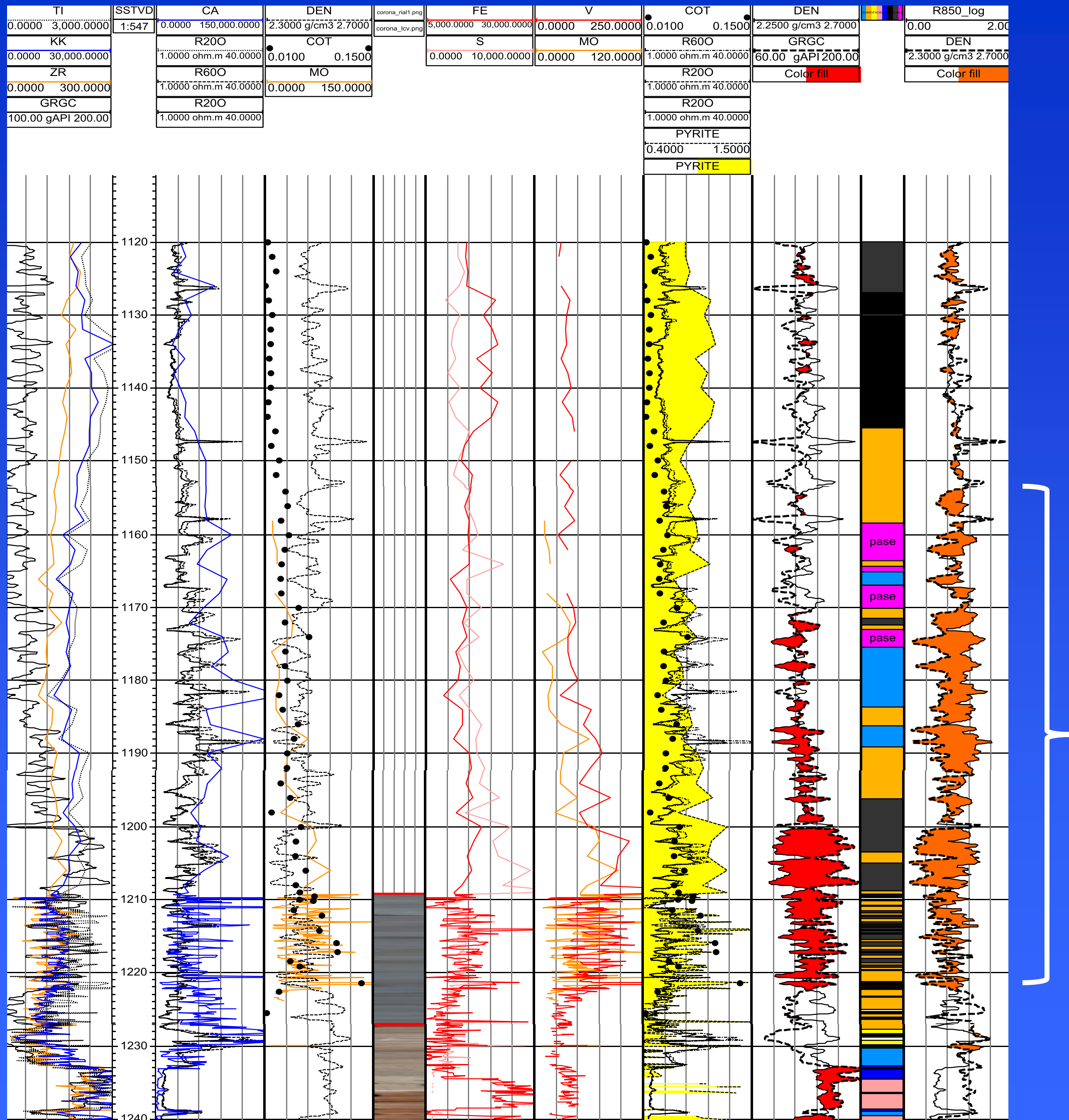


Vaca Muerta Core: Geochemical logging
Anoxic – Dysoxic intervals



Indicate low resistivity, low density, high TOC, high Molybdenum and high pyrite

Geochemical logging: Core and cutting: Net pay Thickness Evaluation



Net pay thickness from Passey et al. (1990) model

Net Pay thickness from Molibdenum-TOC model

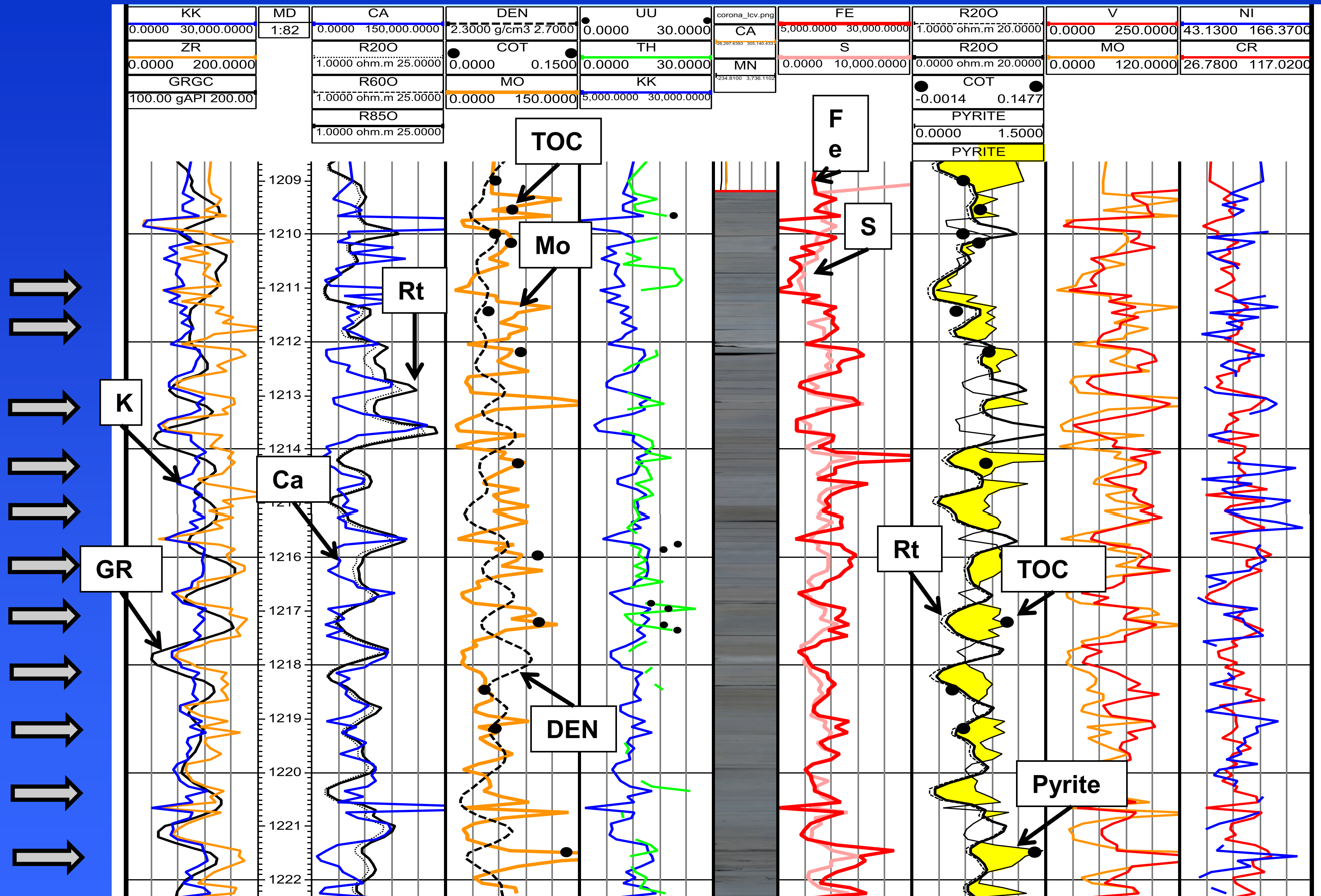
Gamma Ray / Density logs model is a good approximation

Unravelling Paradigms in Vaca Muerta Formation, Neuquén Basin, Argentina: The Construction of Geochemical Wellbore Images by Geostatistical Integration of Geochemistry and Conventional Log Data with Wellbore Resistivity Images

Claudio Larriestra[1], Roberto Merino[2] and Veronica Larriestra[3]

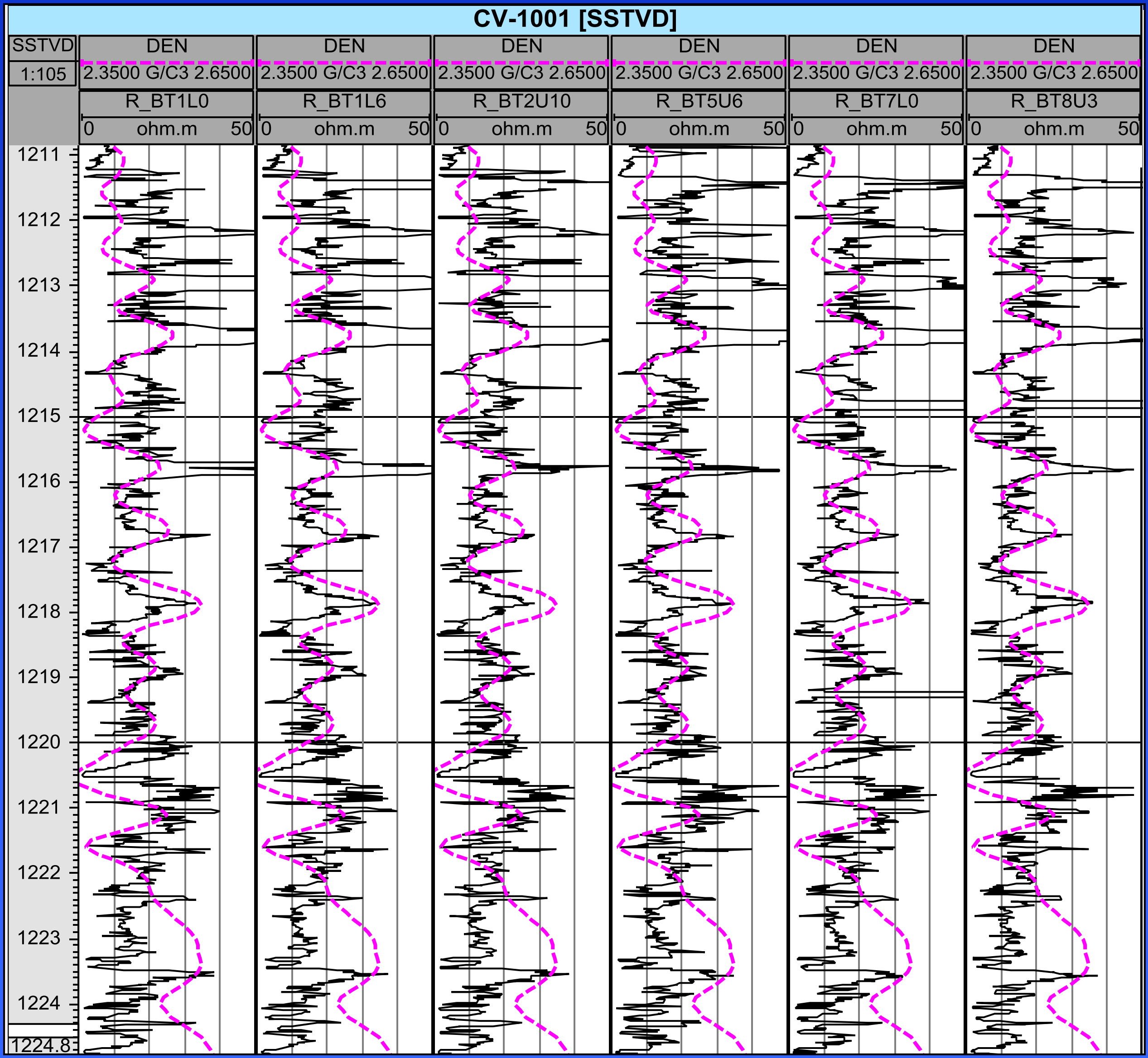
[1] YPF Tecnología S.A., Ensenada, Buenos Aires. Argentina
[2] Rovella Energía S.A., Buenos Aires, Argentina
[3] School of Defense, Ministry of Defense, Buenos Aires, Argentina

Vaca Muerta Fm. Core Geochemical logging
Anoxic – Dysoxic intervals

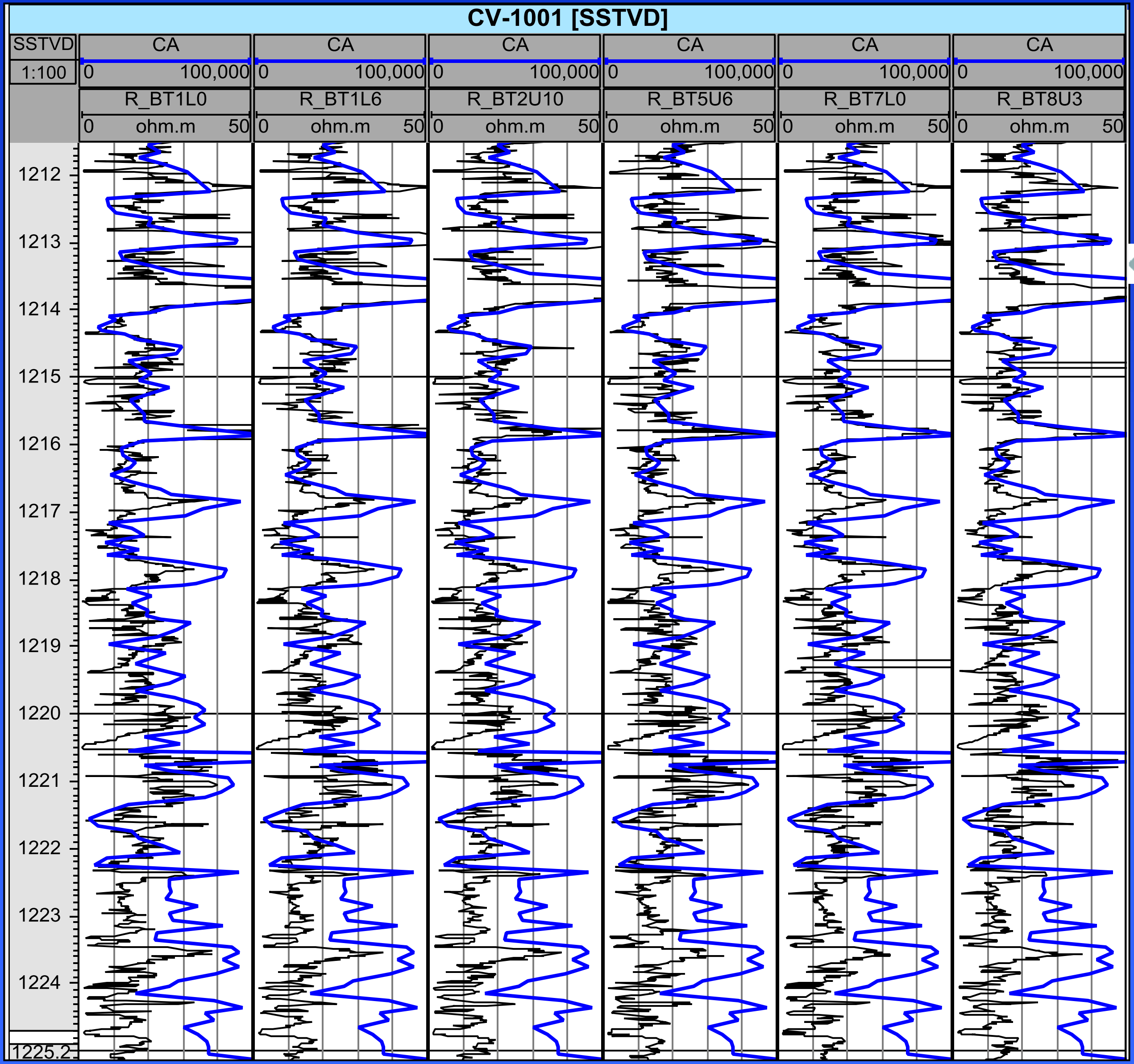


Indicate low resistivity, low density, high TOC, high Molybdenum and high pyrite

Spatial correlation between Density log and six buttons of Resistivity Image

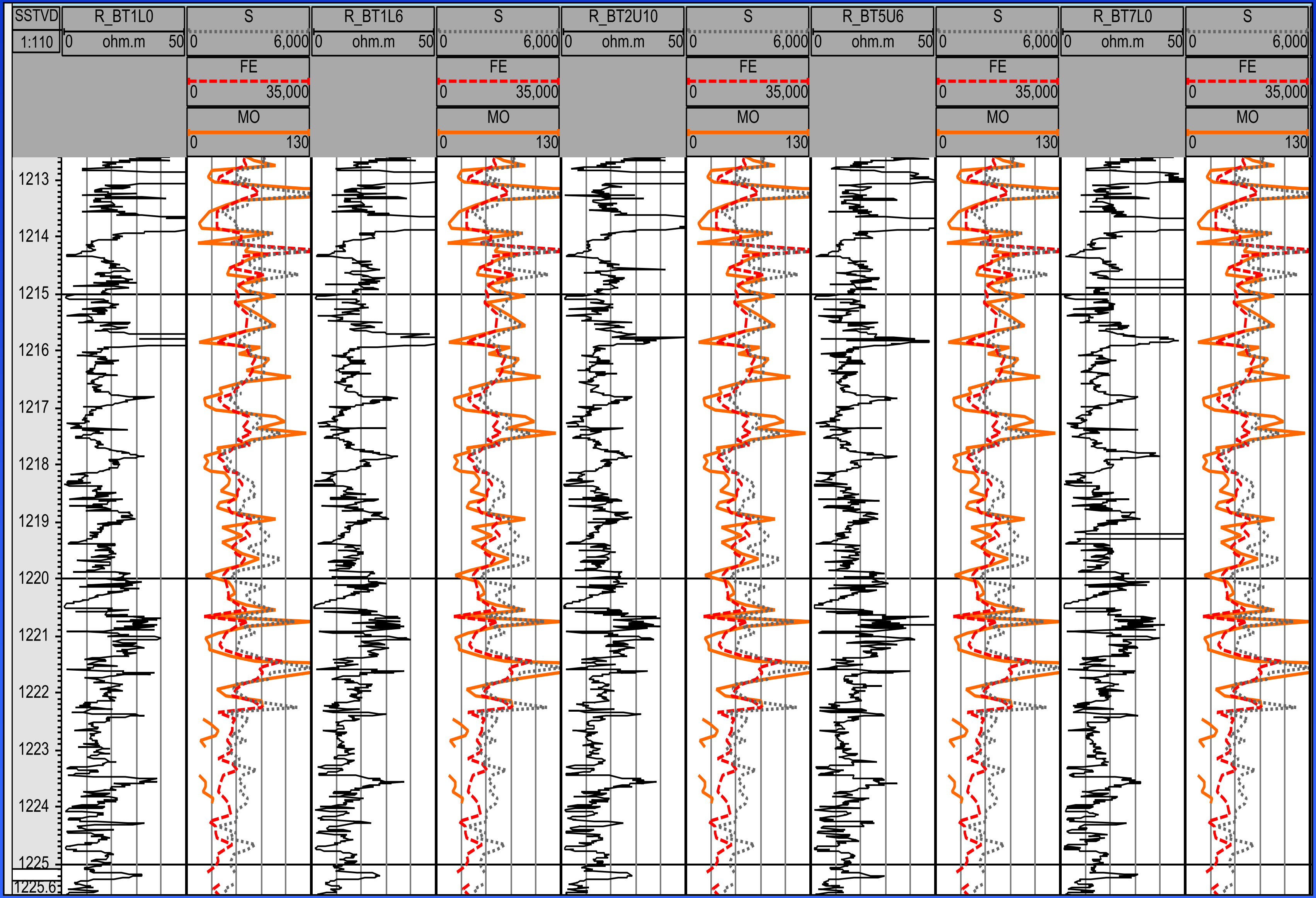


DIRECT spatial correlation between Calcium concentration (XRF) and six buttons response of Resistivity Image



Core recording each 10 cm.

INVERSE spatial correlation between Molybdenum, Sulfur and Iron concentrations (XRF) and several buttons response of Resistivity Image



DENSITY IMAGE GENERATION by 2D Sequential Gaussian Cosimulation

Density as *hard data* and *Resistivity Image* as *softdata*

Density data

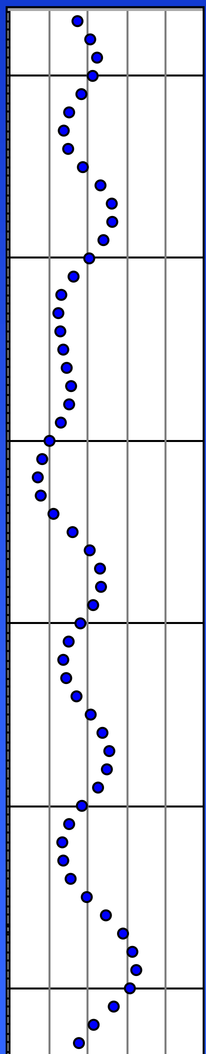
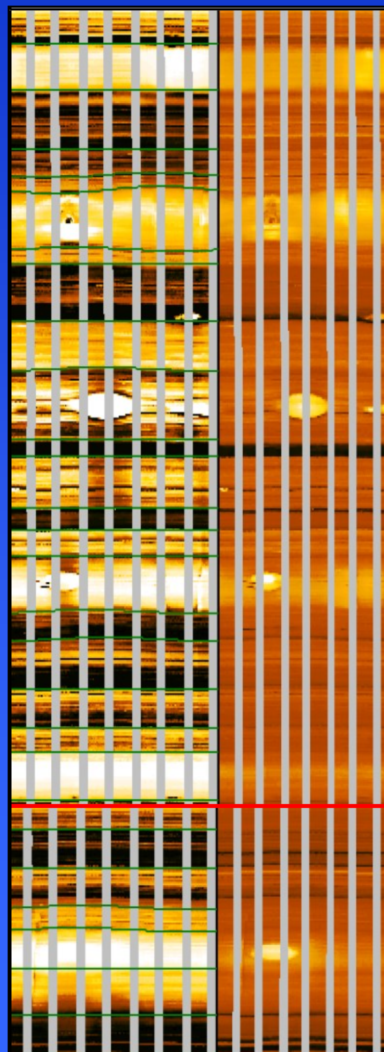


Image data



Processing

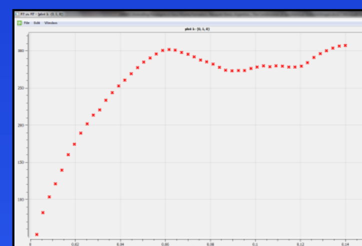
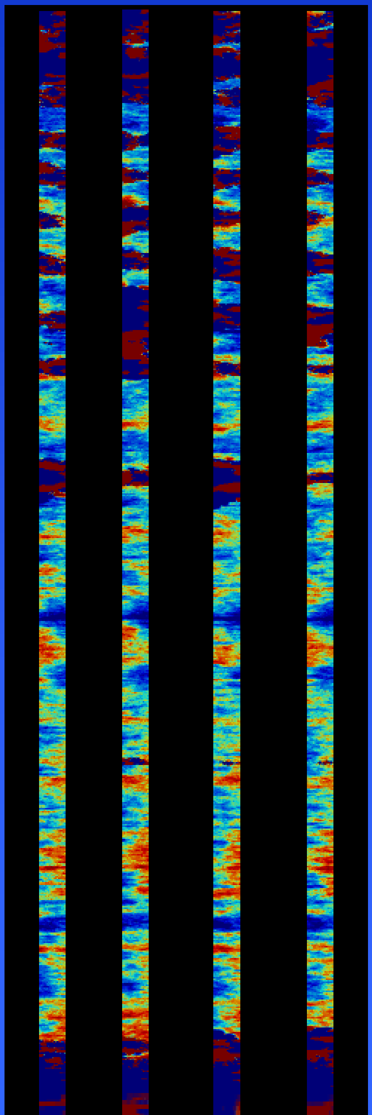
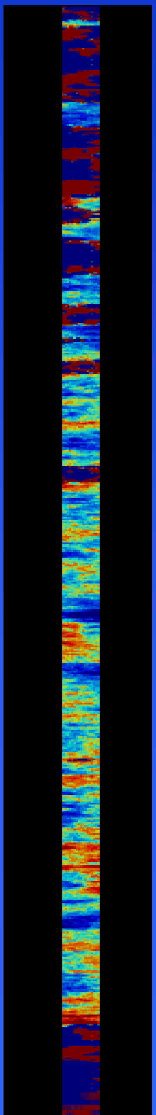


Image Variogram Analysis
Cosimulation with type II Markov model

N realizations

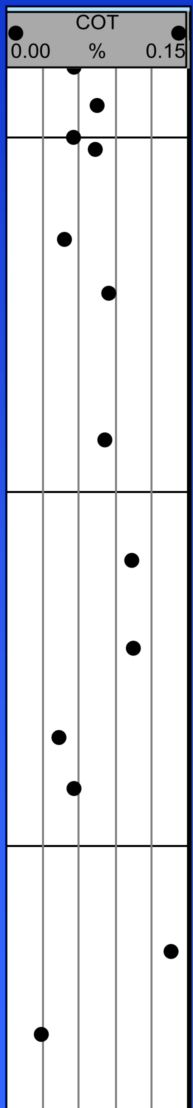


Average of N realizations

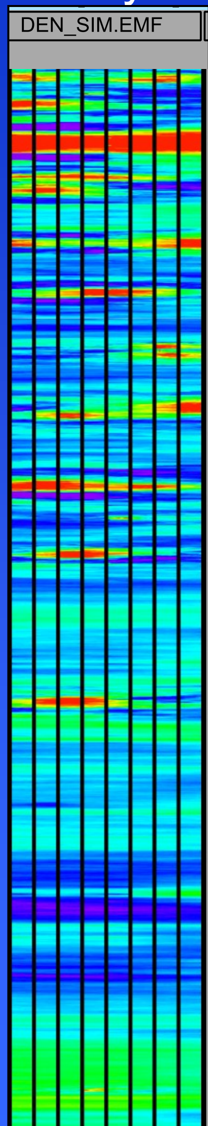


TOC IMAGE GENERATION by 2D Sequential Gaussian Cosimulation
TOC* from Pyrolysis as *hard data* and *Density Image* as *softdata

TOC data



Density Image



Processing of N realizations

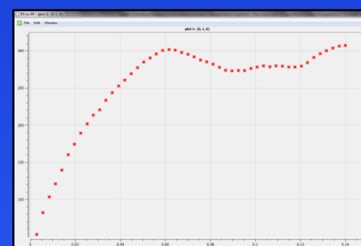
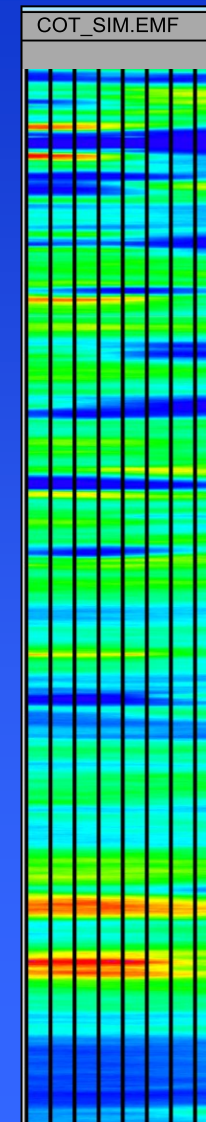
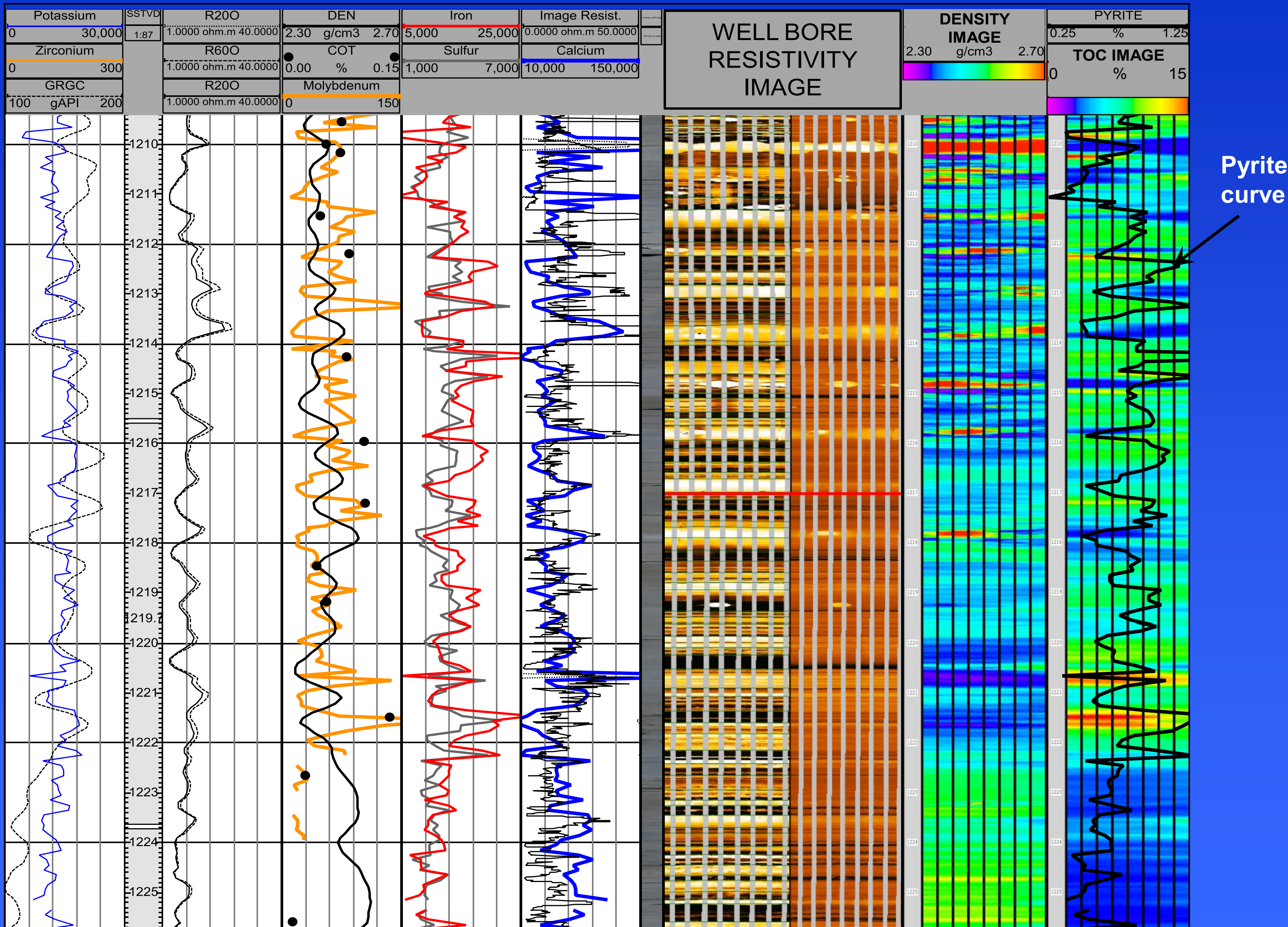


Image Variogram Analysis
Cosimulation with type II Markov model

TOC Image
Average of N realizations



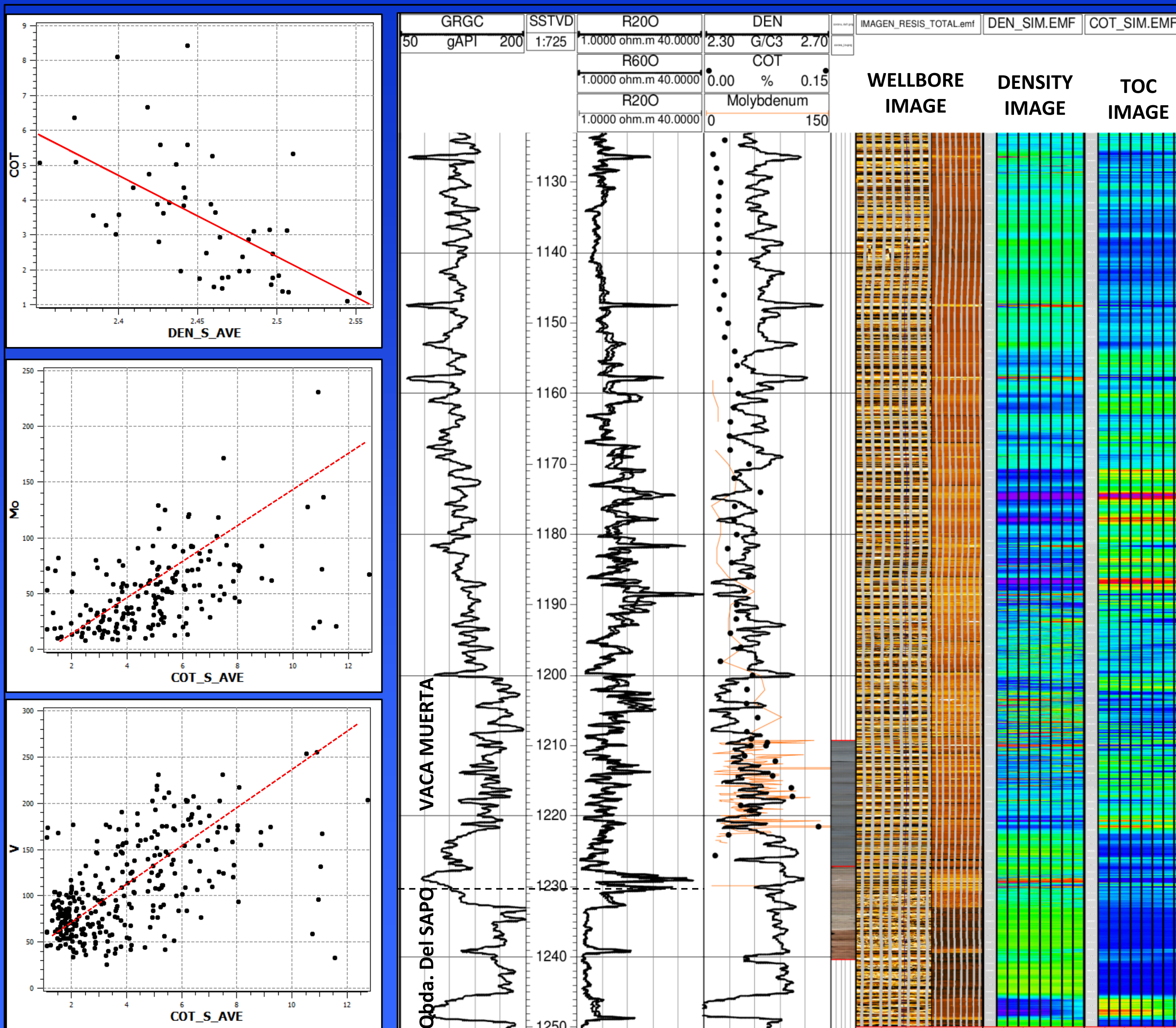
GEOSTATISTICAL MODEL of CORE DATA
Density and TOC images derived from Sequential Gaussian Cosimulation



Propagation of Geostatistical model to Vaca Muerta Fm.:Density and TOC Image Logs

Geochemical Validation

Geochemical Validation



Geostatistical model

INORGANIC GEOCHEMISTRY

&

GEOSTEERING

START HERE

Chemostratigraphic Characterization of the Vaca Muerta Formation in the Neuquén Basin, Argentina: Implications for Depositional Environment and Stratigraphic Distribution of Hydrocarbon Play Elements

Ryan D. Wilson[1], Robert Locklair[1], Ezequiel G. Pelegri[2], Hernan M. Reijenstein[3], Christopher J. Lipinski[1], James Bishop[1], Iván L. Noguera[2], Manuel Fantin[3], Claudio N. Larriestra[2]
1. Energy Technology Company, Chevron, Houston, TX, United States; 2. YTEG, Buenos Aires, Argentina; 3. Latin America Business Unit, Chevron, Houston, TX, United States.
RyanWilson@Chevron.com

Continue to Panel 2

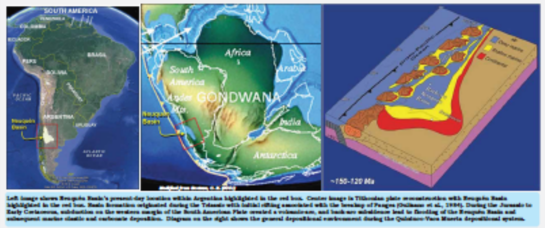
ABSTRACT

The Vaca Muerta Formation is an emerging unconventional resource play of Late Jurassic (Tithonian) to Early Cretaceous (Valanginian) age. Depositional sequences of mudstones with variable contributions from carbonates and clastics/volcaniclastics are found admixed throughout the succession. Vertical and lateral distribution of mudstone lithofacies indicate westward progradation of the system, resulting in temporal and geographic controls on hydrocarbon play element quality and distribution.

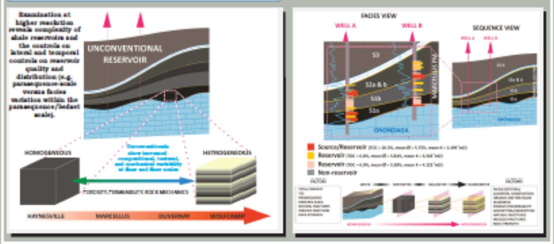
This study utilizes x-ray fluorescence (XRF) on drill cuttings and rotary sidewall cores (RSWC) for 3 vertical wells to enable high-resolution chemostratigraphic differentiation of mudstone packages within the Vaca Muerta. In addition, drill cuttings from a 1200 meter horizontal well were analyzed to assess lateral compositional variability. XRF measurements were calibrated to inductively coupled plasma mass spectrometry (ICP-MS), with significant agreement between the different instrument data ($r2=0.973$). On the basis of high-resolution chemostratigraphy, 5 disparate parasequence-sets were identified with characteristic chemical attributes and stratigraphic trends. Within the Lower Vaca Muerta, 2 parasequence-sets are recognized and show systematic thinning to the west reflecting decreased sediment flux away from carbonate source areas to the east. This is corroborated by a gradual decrease in Ca and an increase in Si and TOC westward (decreased dilution). Similar elemental trends are observed in the Upper Vaca Muerta. However, stratal architecture of 3 parasequence-sets shows a systematic thickening westward, suggesting erosion and/or sediment bypass with subsequent progradation to the distal areas of the basin. This is further evidenced by seismic toplap terminations (sequence boundary) at the Lower-Upper Vaca Muerta contact and progradational to aggradational parasequence stacking patterns.

This study aims to impact pre-drill decisions through delineating vertical and lateral variations in mudstone properties that are critical for reservoir characterization. Moreover, elemental ratios can be used to identify pay intervals, as well as to understand lateral continuity and potential geomechanical/frac barriers (i.e., Ca/Al, Si/Al, Ti/Al, Zr/Al). The results illustrate the importance of XRF chemostratigraphy in geosteering as well as facilitating subsurface characterization, resulting in more precise economics (P10/P50/P90) while reducing costs and uncertainty.

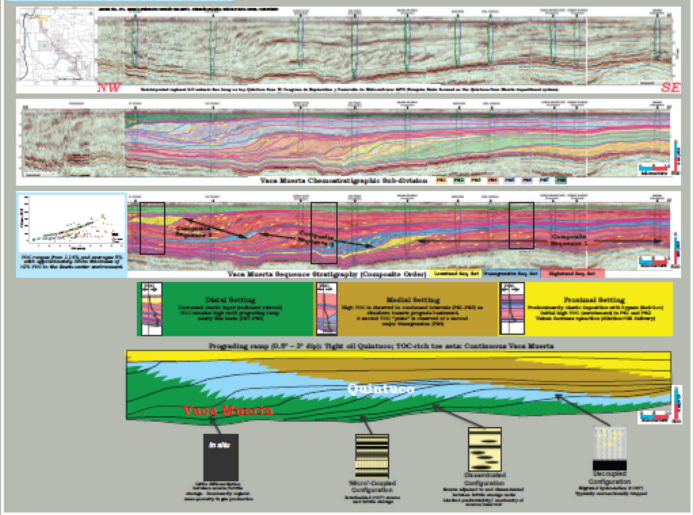
STUDY AREA



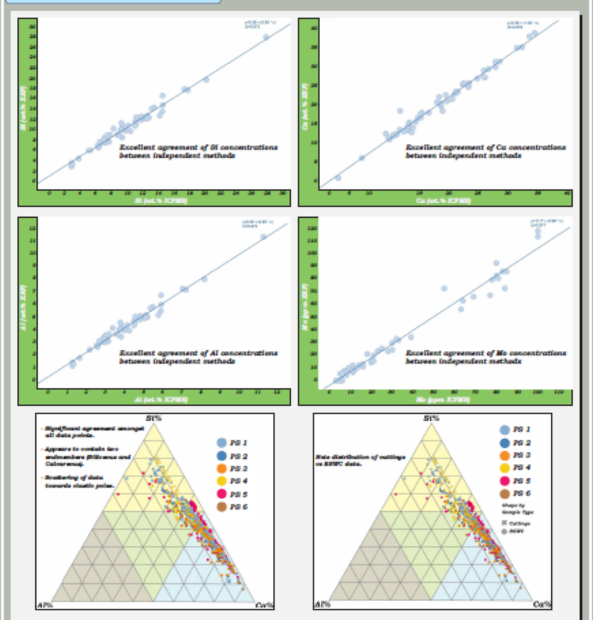
SCALING OF RESERVOIR PROPERTIES



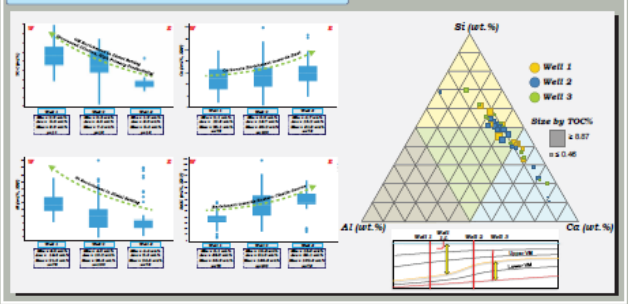
STRATIGRAPHIC FRAMEWORK



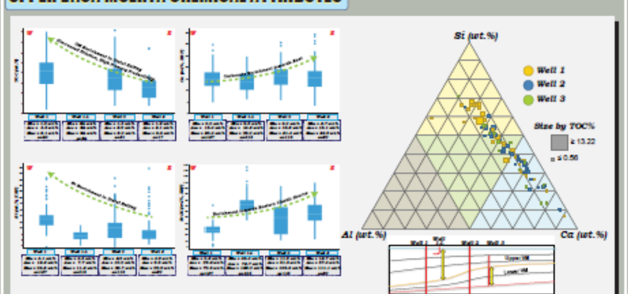
ICPMS vs XRF CALIBRATION



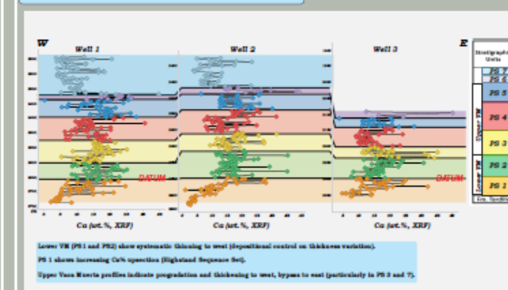
LOWER VACA MUERTA CHEMICAL ATTRIBUTES



UPPER VACA MUERTA CHEMICAL ATTRIBUTES



VACA MUERTA CHEMOSTRATIGRAPHY



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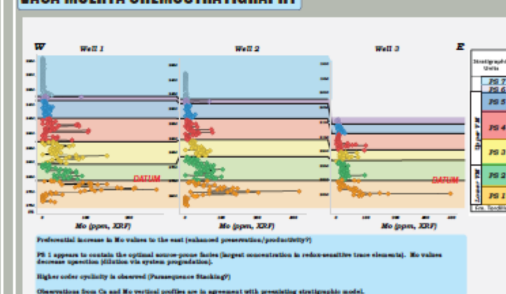
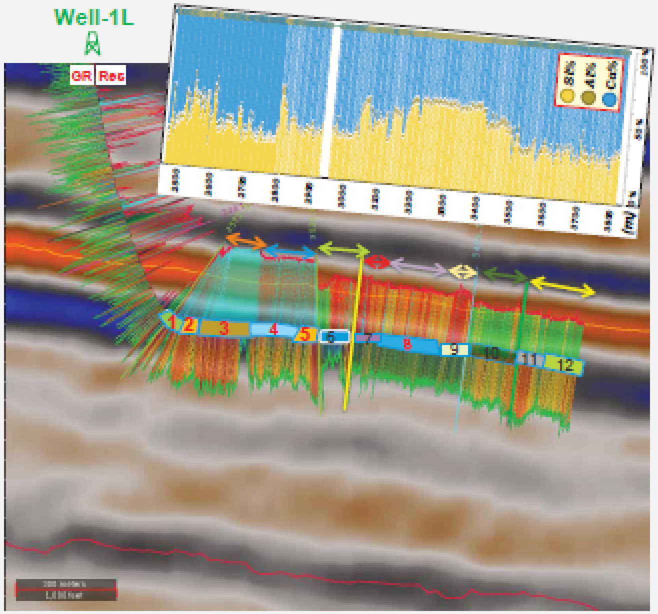
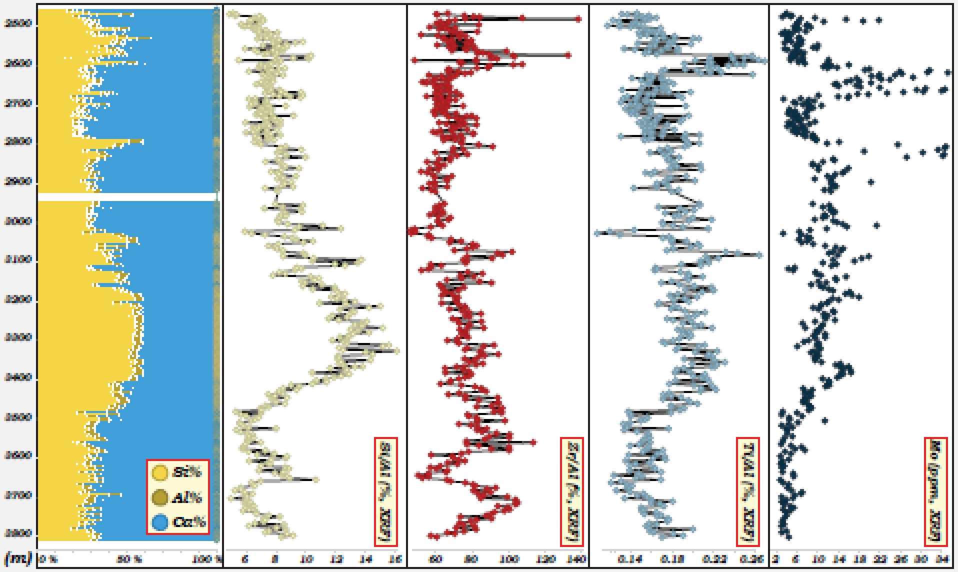


WELL 1-L CHEMOSTRATIGRAPHY

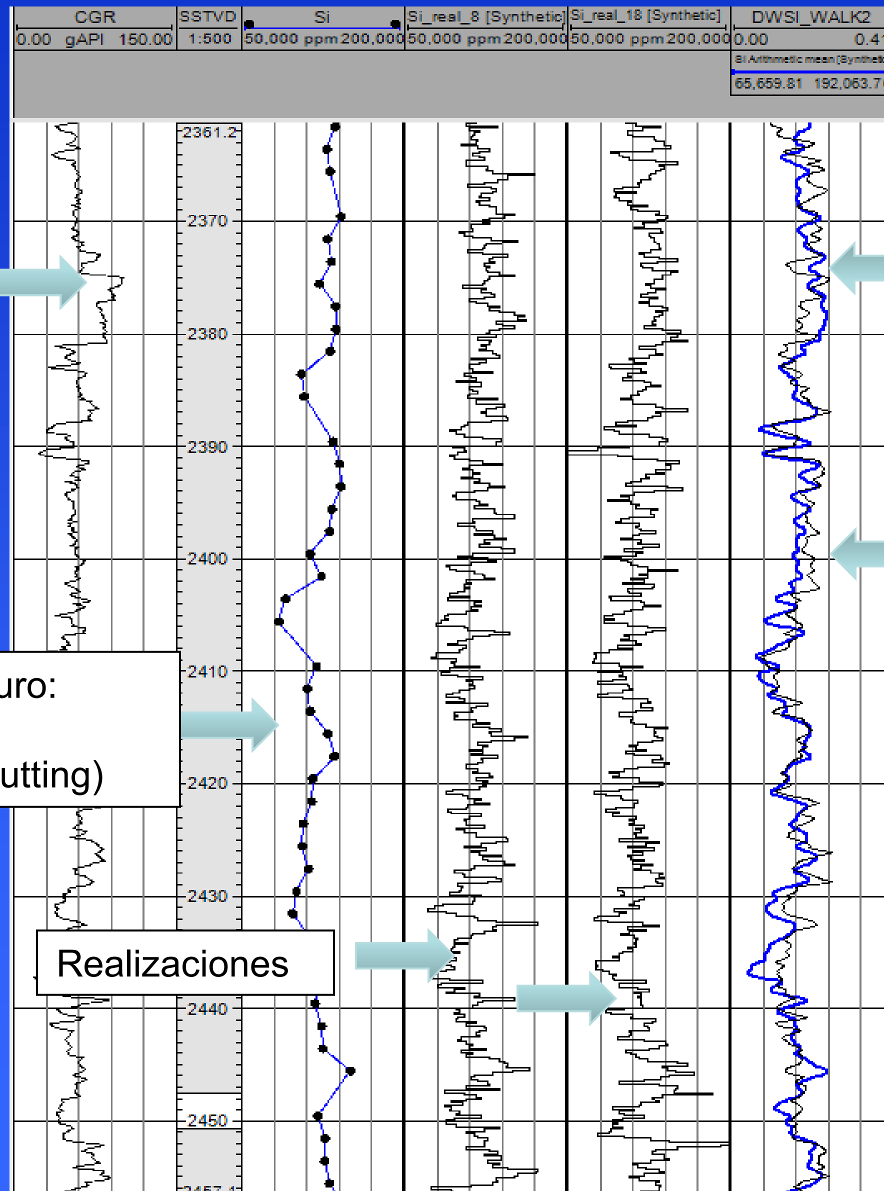




Intervals 1-3 (2630-2800 m MD) - Highest RT and lowest GR
Intervals 4-5 (2800-3050 m MD) - Second highest RT, low THC
Interval 6 (3050-3130 m MD) - High heterogeneity (GR-RT)
Interval 8 (3210-3390 m MD) - Medium RT, Higher FM and THC
Interval 9 (3390-3470 m MD) - Higher RT
Interval G (3470-3620 m MD) - Lower RT, Presence of limestones without oil traces
Interval H (3620-3810 m MD) - Lower RT, Presence of limestones with oil traces

All the defined intervals have shown interest to be completed.
The intervals have been defined based on:
1) Log Response (GR – RT)
2) Lithology (mudlog)
3) Gases interpretation (GC tracer)

PREDICCION de PERFILES tipo LITHOSCANNER mediante Simulación Secuencial Gaussiana de datos de FRX (cutting) y el perfil de Gamma Ray como softdata



Dato blando (Gamma Ray)

Dato duro: Silicio (FRX cutting)

Realizaciones

Silicio simulado: Promedio de 30 Realizaciones (azul)

Silicio registrado por perfil espectroscopía de neutrones (negro)

CONCLUSIONES

- La Quimioestratigrafia de cutting contribuye a una mejor descripción de los reservorios
- Puede ser integrada y modelada en 3D con la sísmica
- Los modelos quimioestratigráficos pueden ser aplicados a la geonavegación de pozos en reservorios tipo shale
- Brinda información no disponible en perfiles convencionales y permite reproducir perfiles geoquimicos tipo Lithoscanner
- Permite preservar el cutting debido a su carácter no destructivo
- Otras técnicas no destructivas pueden ser aplicadas con esta metodología

SPE International
Argentine Petroleum Section