The New Method of the Sweet Spot Discrimination and Predictive Production in North American Shale Oil*

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Abstract

The cost of horizontal drilling and hydraulic fracturing in shale oil and gas development is very high. In order to improve economic benefits, the research on sweet spot discrimination needs to be carried out immediately. This paper first analyzed that the main factors of sweet spot in North American shale included total organic carbon content, rock brittleness, porosity and fracture. Then rock physics analysis was the key of sweet spot discrimination, while the quantitative logging interpretation of reservoir parameter is the basis of rock physics. For the logging quantitative evaluation problem in North American shale, a kerogen-corrected logging model has been used, and the core technology and flowchart of reservoir quantitative evaluation in shale oil and gas based on elemental capture spectroscopy logging have been built. The interpretation results in block A and block B in North America are of high precision by using the new evaluation method of logging. Based on logging interpretation results, rock physics analysis has been carried out, and the results showed that the porosity was the key factor of affecting yield in block A. Because P-wave impedance can characterize porosity effectively, the technology combination of prostack inversion and fracture analysis is used to predict sweet spot of shale in block A. The result was used to guide drilling deployment and fracturing design and shale oil and gas yield is greatly improved. The total organic carbon content and rock brittleness are the key factors of shale oil and gas production in block B. So prestack simultaneous inversion technique was used to solve the problem of sweet spot discrimination in block B. Drilling results confirmed that the shale oil and gas yield in sweet spot region was very high. Thus, rock physics is the core and key of sweet spot discrimination.

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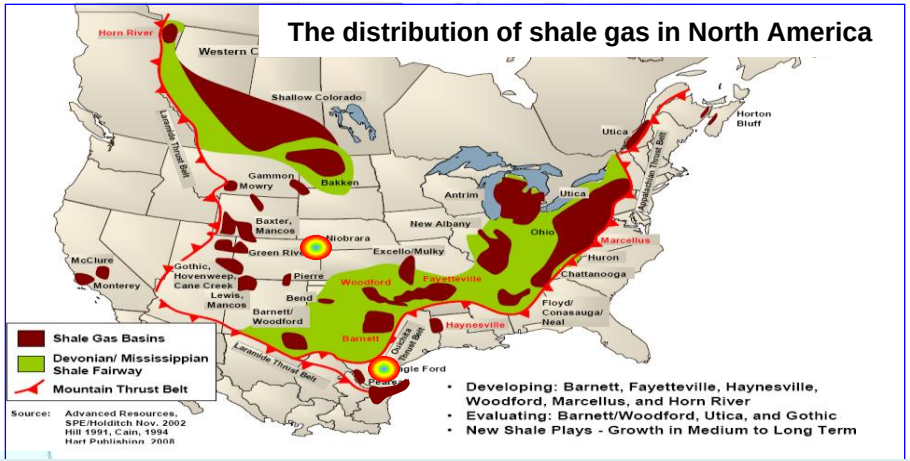
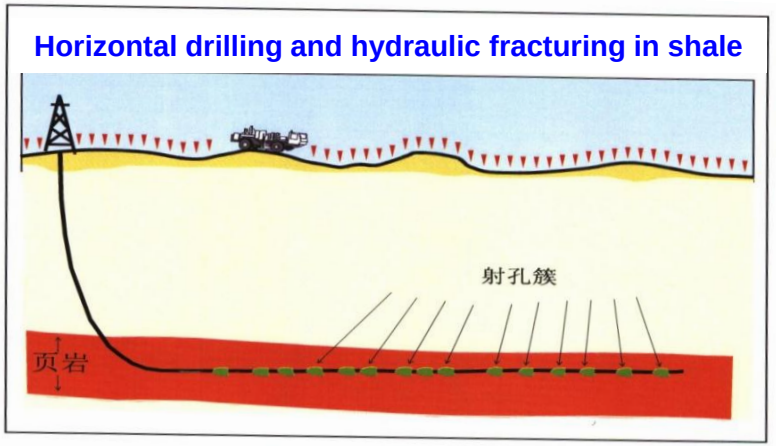
June，2016

Main Contents

- Introduction
- Technologies and application
- Conclusions

Challenges of Development in Shale





In some shale blocks of North America, such as EagleFord and Niobrara ,Some research work has been carried out in CNOOC.

Nowadays, the costs of horizontal drilling and hydraulic fracturing are increasing in shale oil and gas development. In order to improve economic benefits, it is necessary to carry out the research on sweet spots discrimination immediately.

Main Factors of Sweet Spots

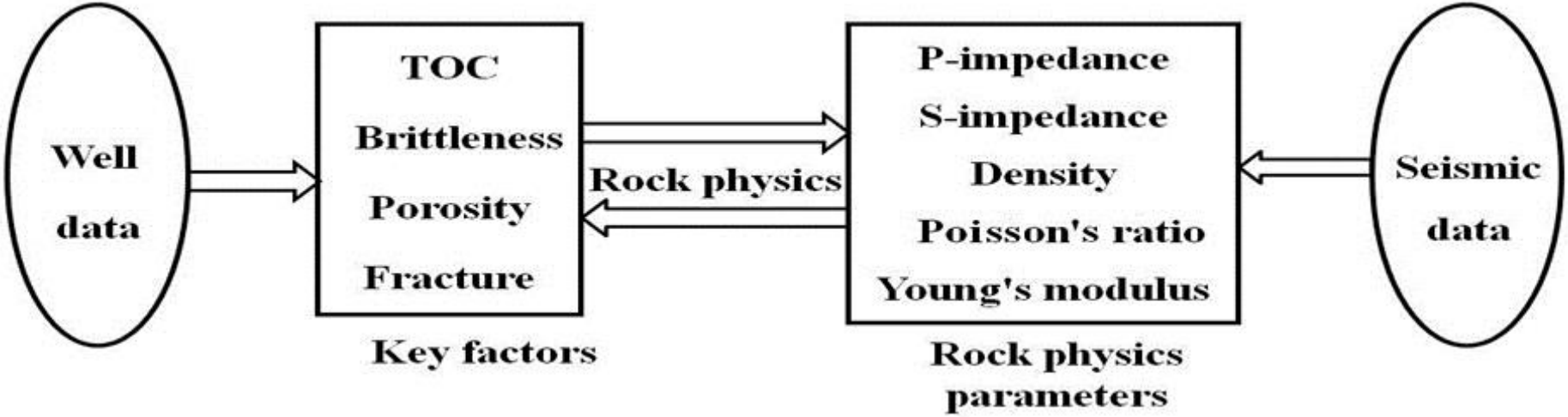
Sweet spots mean the area with higher production of oil and gas in shale.

The main factors of sweet spots in North American shale oil and gas are as follows:

- **Total organic carbon content (TOC) is preferably higher than 2.5%-3.0%;**
- **Rock brittleness is higher, and brittle mineral content is higher than 30%-40%;**
- **Porosity is higher than 4%;**
- **Reservoir fractures are relatively well developed.**

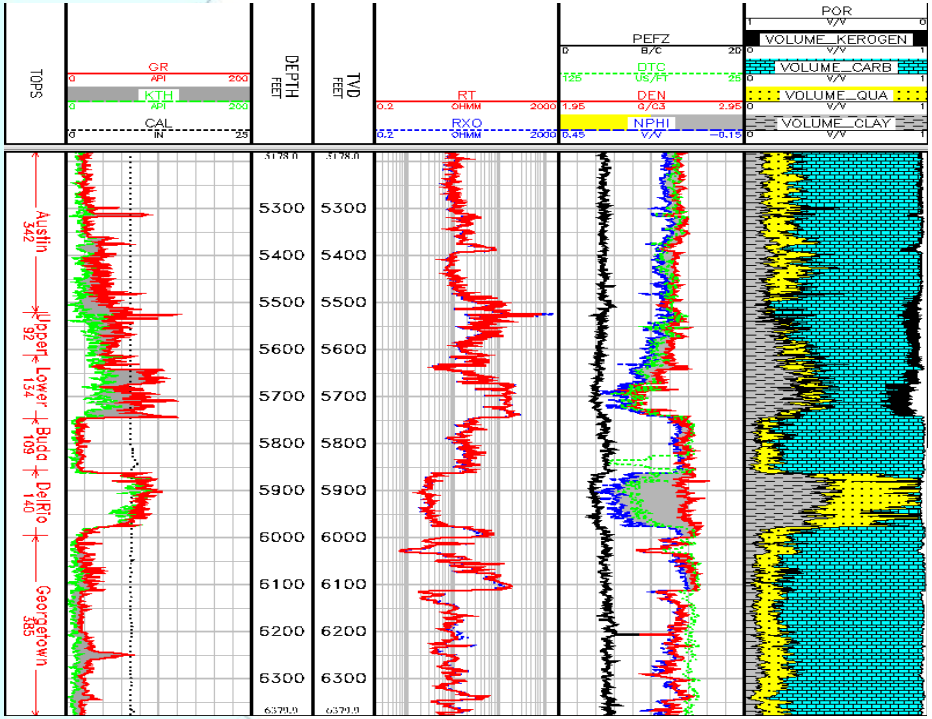
How to Predict Sweet Spots?

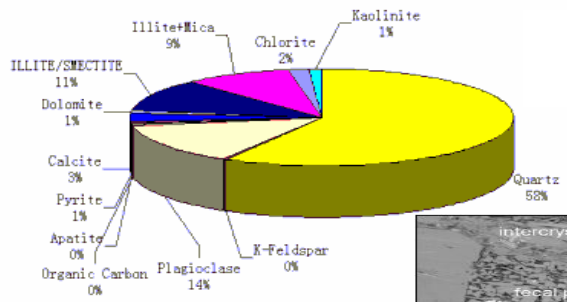
The relationship between crucial factors and rock physical parameters has been built by using well data; And some geophysical methods will be selected to obtain rock physical parameter volumes.



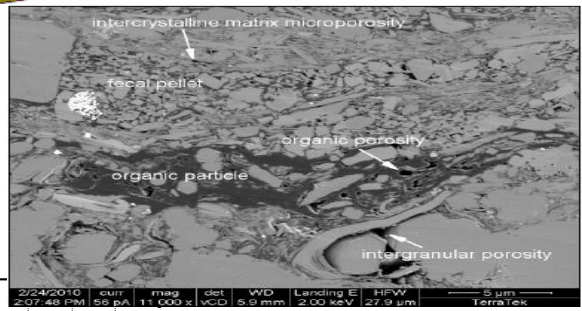
Next we shall see several problems in above process.

Difficult Logging Evaluation

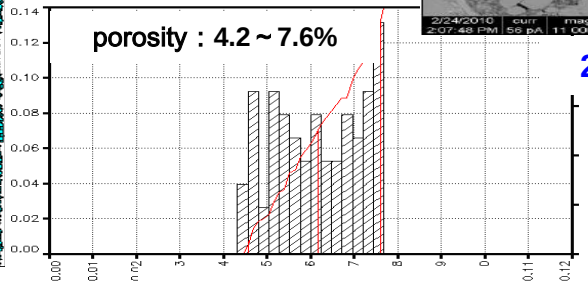




1.The complex mineral compositions in shale



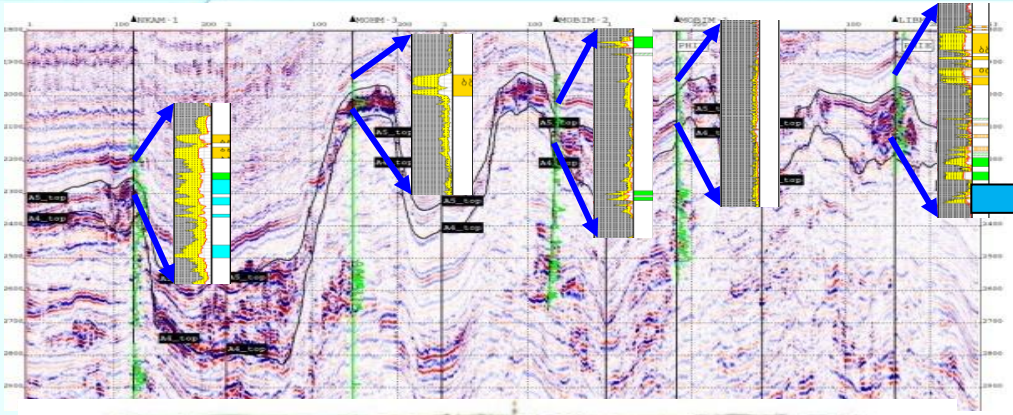
2. Rich in organic matter



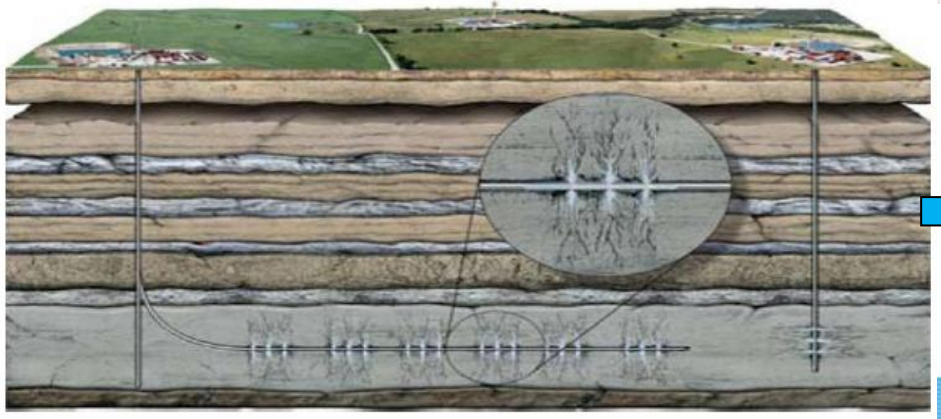
3. Low porosity

Ambiguous Relationship

Between key properties and rock physical parameters in shale



Lithology
Porosity
Fluid
Thickness



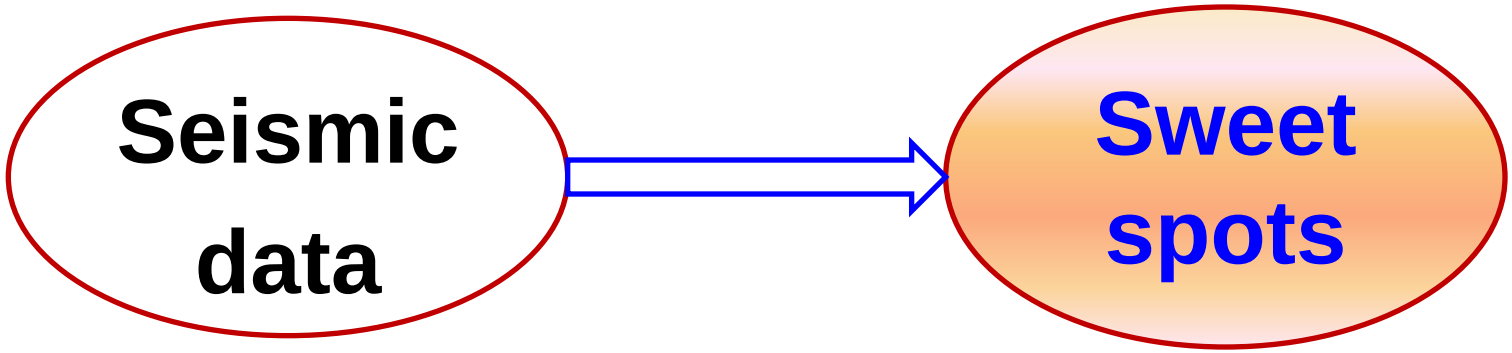
TOC
Brittleness
Prosity
Thickness

?

Rock physical parameters

P-impedance
S-impedance
Density
Possion ratio
Lame - constant
Young's-modulus

Undefined Technical Workflow of sweet spots discrimination by using seismic data.



It is a new topic that how to predict sweet spots in shale by using seismic data. A technical workflow should be established for solving such problem.

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- Introduction
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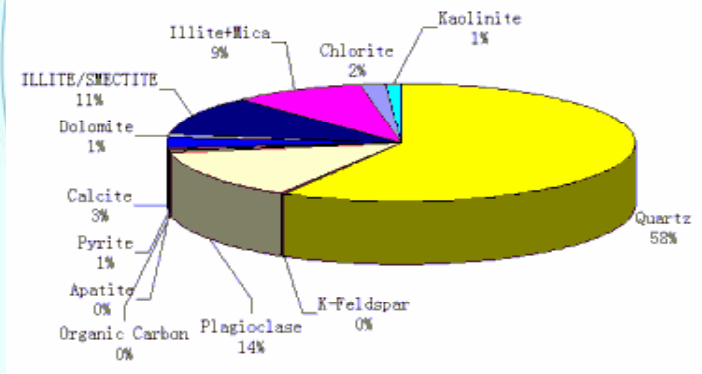
Related Technologies

- A kerogen-corrected logging model has been used, and the flowchart of quantitative evaluation based on geochemical logging has been built in shale.
- Technology combination of post stack inversion and fracture analysis has been used to predict sweet spots of shale in block EagleFord .
- On the basis of rock physical analysis, prestack simultaneous inversion technique was used to solve the problem of sweet spots discrimination in block Niobrara.

A kerogen-corrected logging model has been used, and flowchart of quantitative evaluation based on geochemical logging has been built in shale.

➢It is rich in organic matter,which influences well logs greatly. So conventional logging porosity model is no longer valid in shale.

The mineral composition in shale



The kerogen-corrected logging model

$$\rho_{\log} = \underbrace{\rho_{matrix}\left(1-\phi-V_{TOC}\right)}_{\text{Frame response}} + \underbrace{\rho_{fluid}\,\phi}_{\text{Fluid response}} + \underbrace{\rho_{TOC}\,V_{TOC}}_{\textit{TOC response}}$$

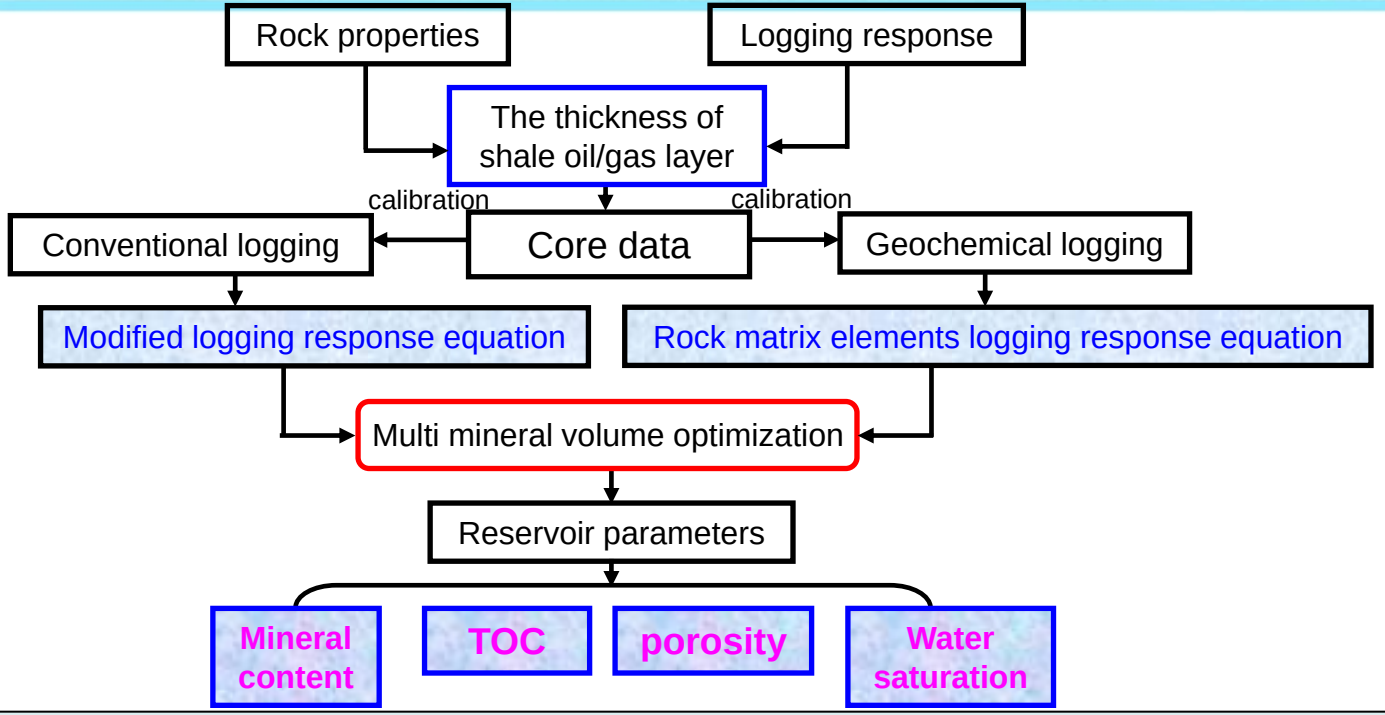
■ well curves :

GR+RHOB+NPHI+DT+Pe+Rt+DWAI+DWCA+DWFE+DWSI

conventional logging curves — Geochemical logging curves

Flowchart of Quantitative Evaluation

based on geochemical logging



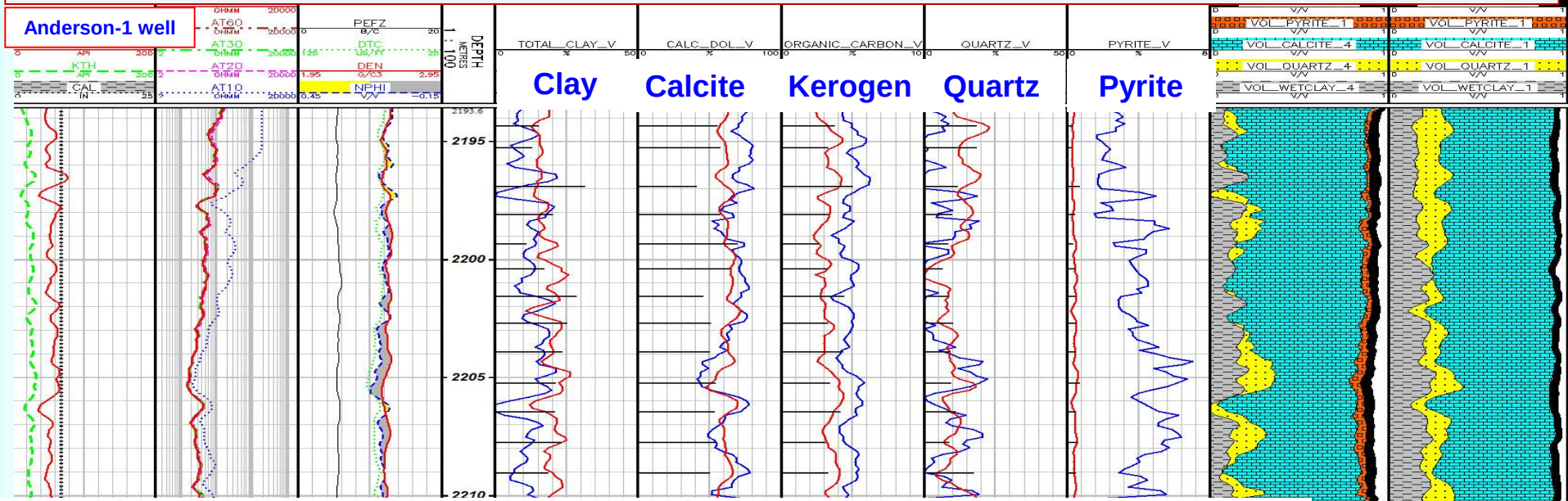
➢**The quantitative reservoir evaluation flowchart of reservoir parameters have been built. It was used to process real well data of shale.**

Improved Interpretation Accuracy

Formation components: Calcite + Quartz + Clay + Kerogen + Pyrite + Oil + Water

Conventional model： GR+RHOB+NPHI+DT+Pe+Rt

Geochemical model： GR+RHOB+NPHI+DT+Pe+Rt+DWAI+DWCA+DWFE+DW

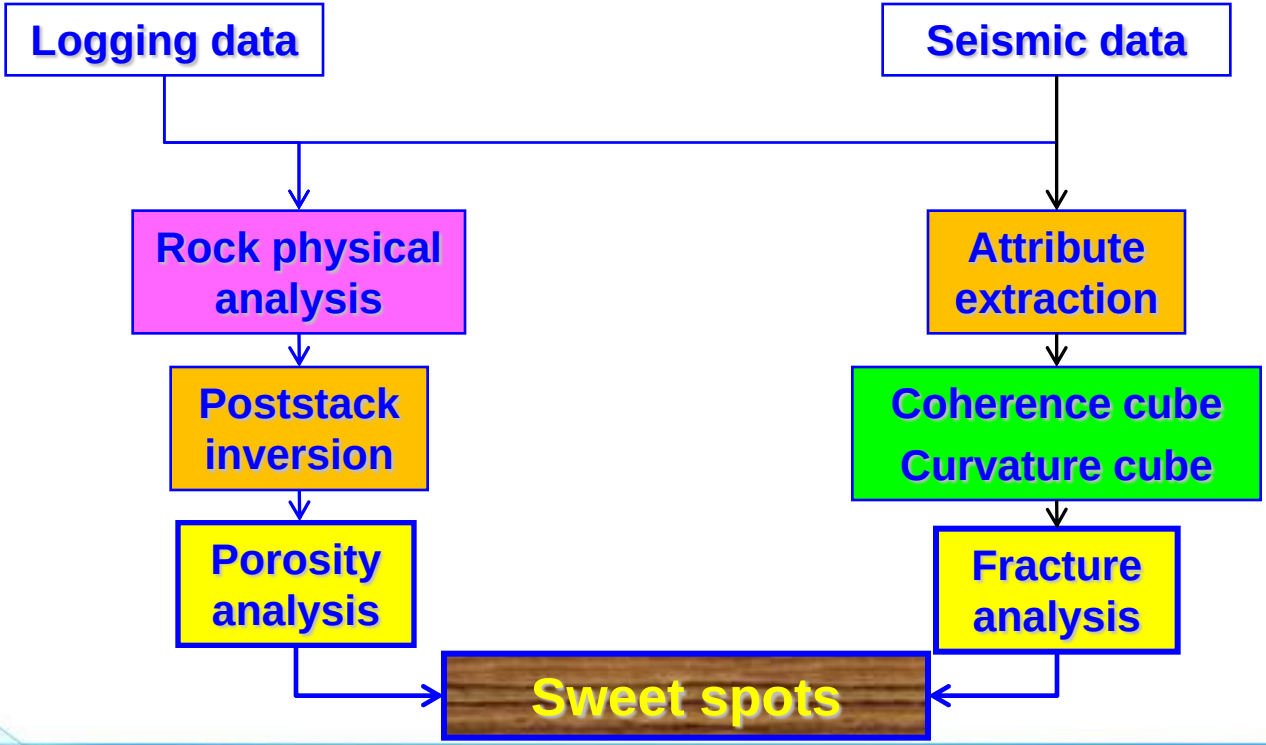


Blue: the result from **Conventional model** ; **Red :** the result from **Geochemical model** ;

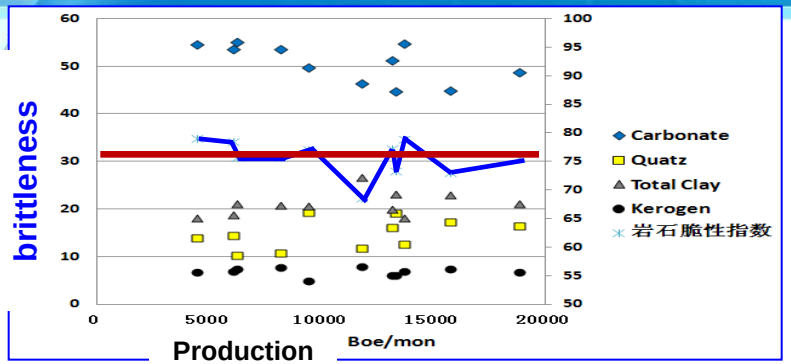
Technology combination

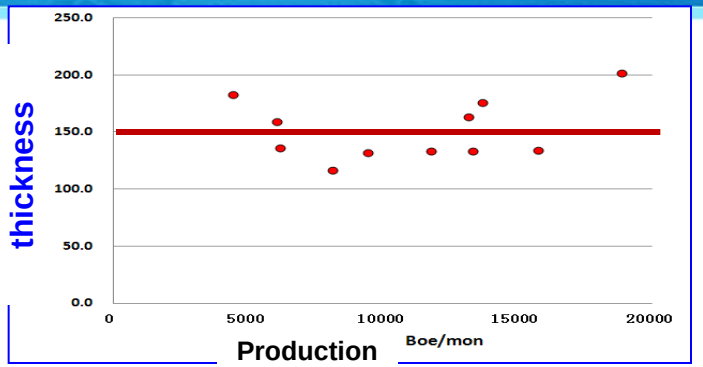
of poststack inversion and fracture analysis

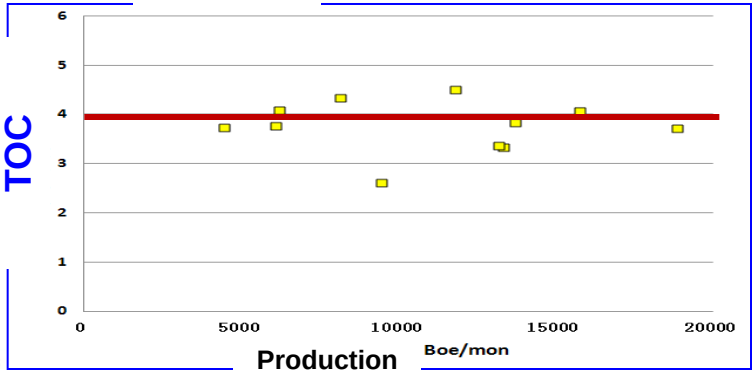
has been used to predict sweet spots of shale in EagleFord .

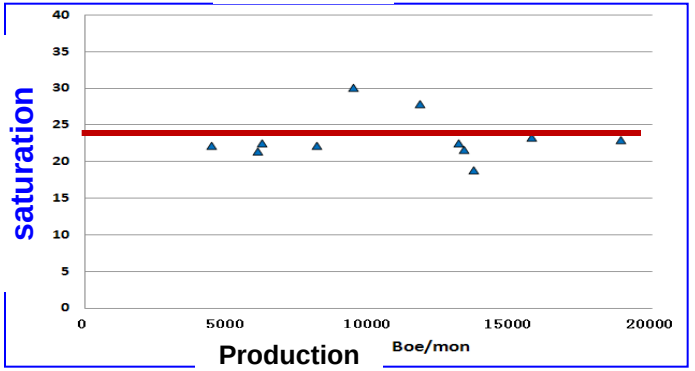


Production and Reservoir Parameters in EagleFord



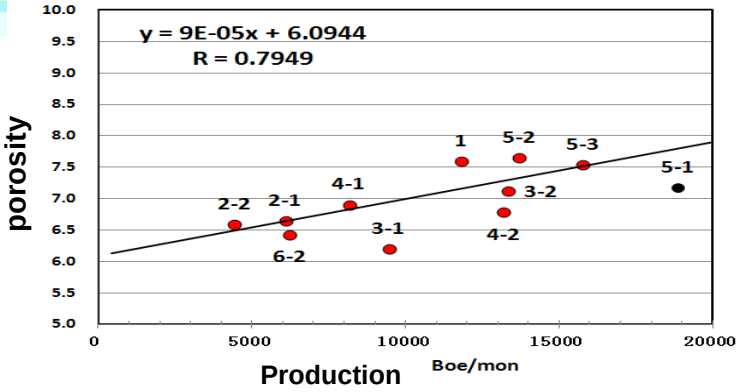


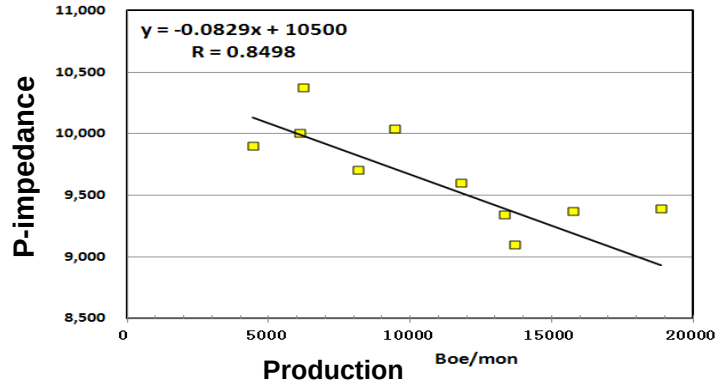


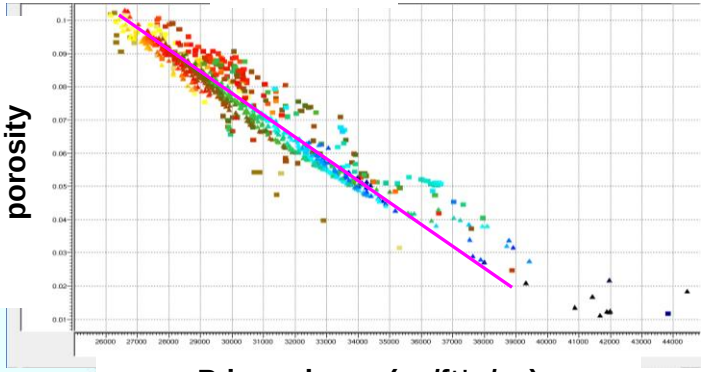


In EagleFord, the distributions of rock brittleness, thickness, TOC and water saturation are relatively stable, which has little effect on shale oil/gas production.

The Key of Sweet Spots: P-impedance



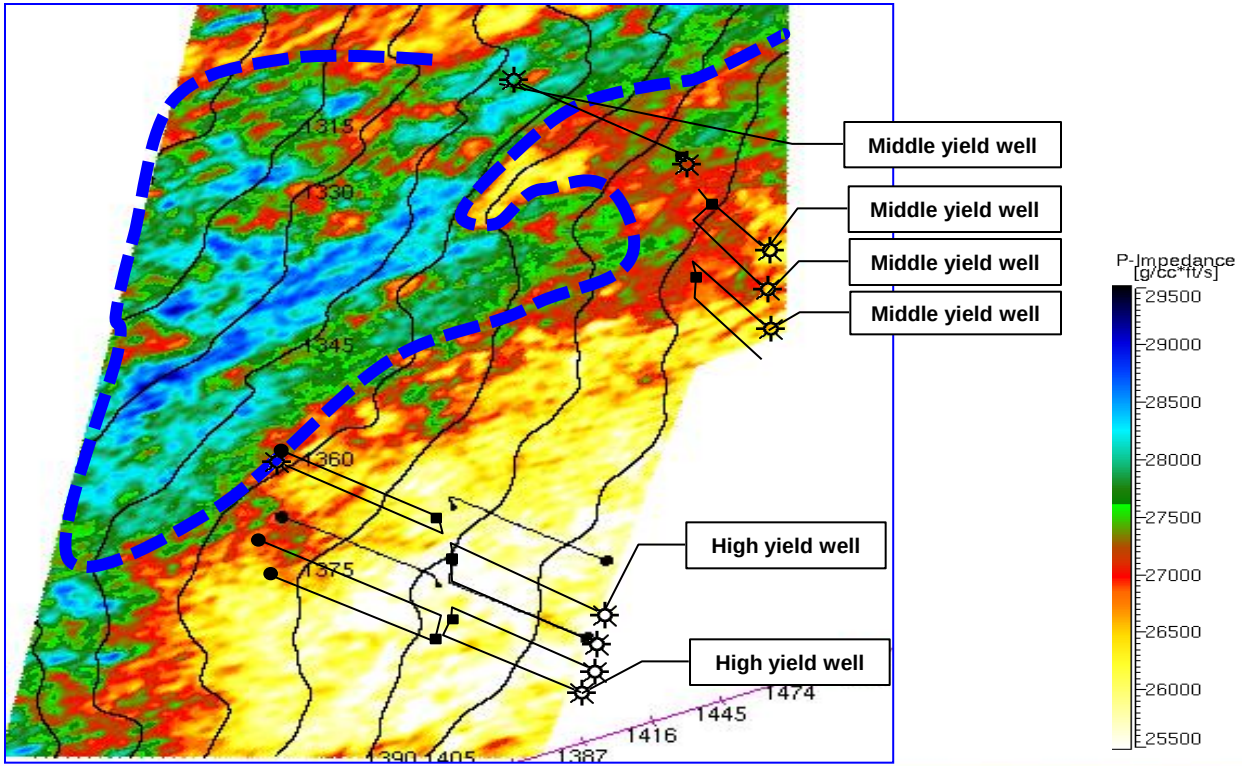




- ✓ **Porosity is the key geological factor that influences the production .**
- ✓ **P-wave impedance can characterize porosity effectively.**
- ✓ **P-wave impedance from poststack inversion can be used to predict the region with higher oil and gas yield.**

P-impedance

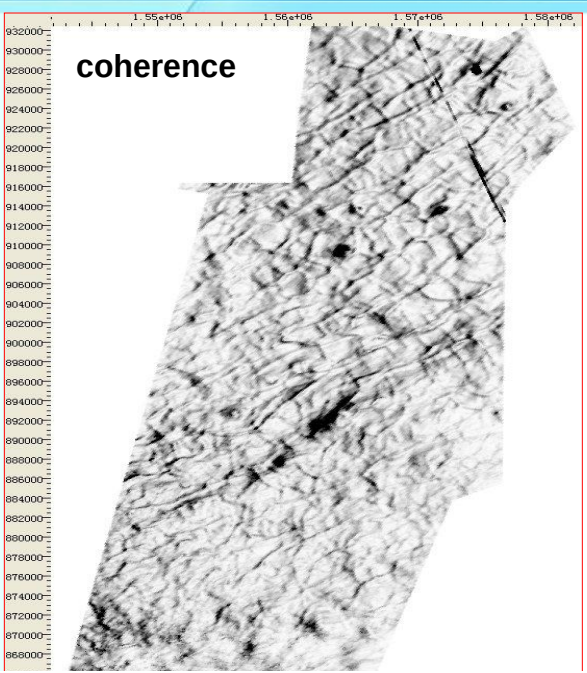
Has a Good Correlation with Yield in EagleFord

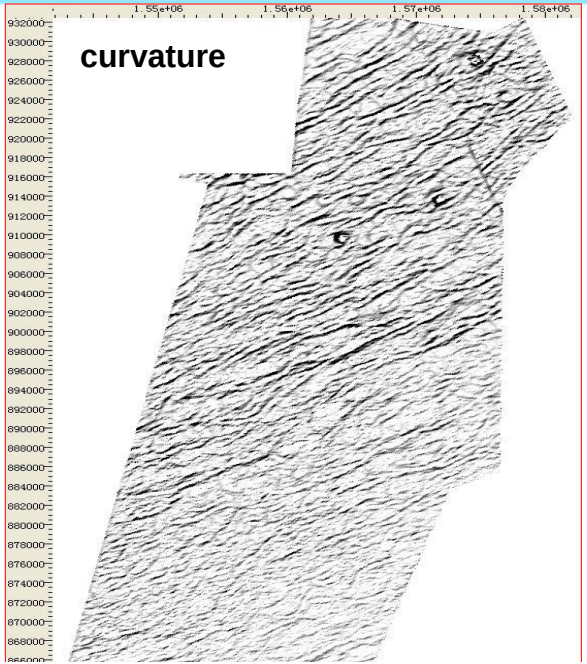


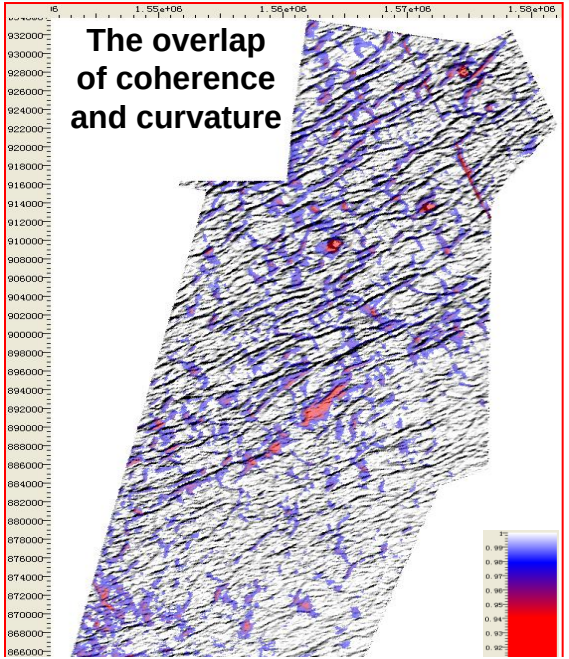
Higher yield wells correspond to Lower P-impedance

Predicting Fracture Distribution

Using Coherence and Curvature



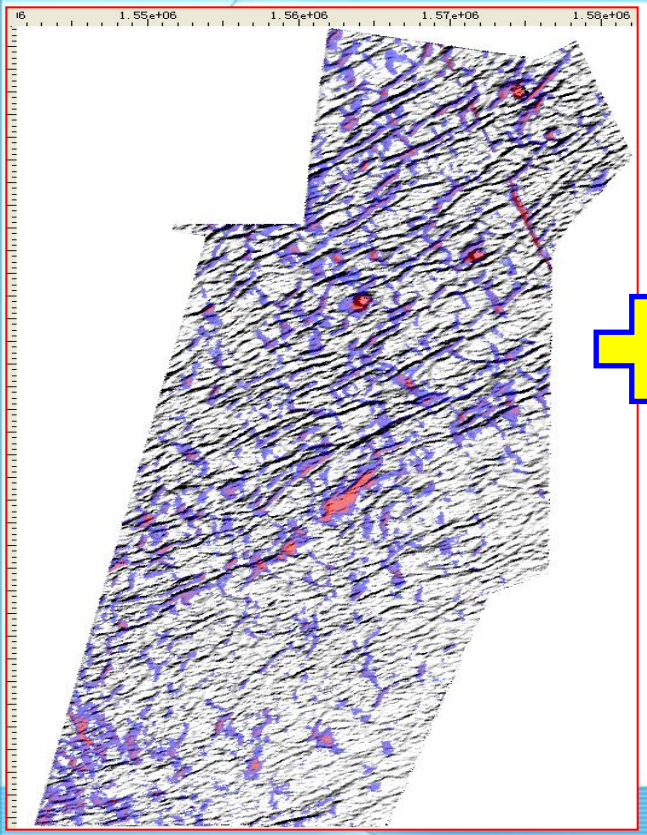


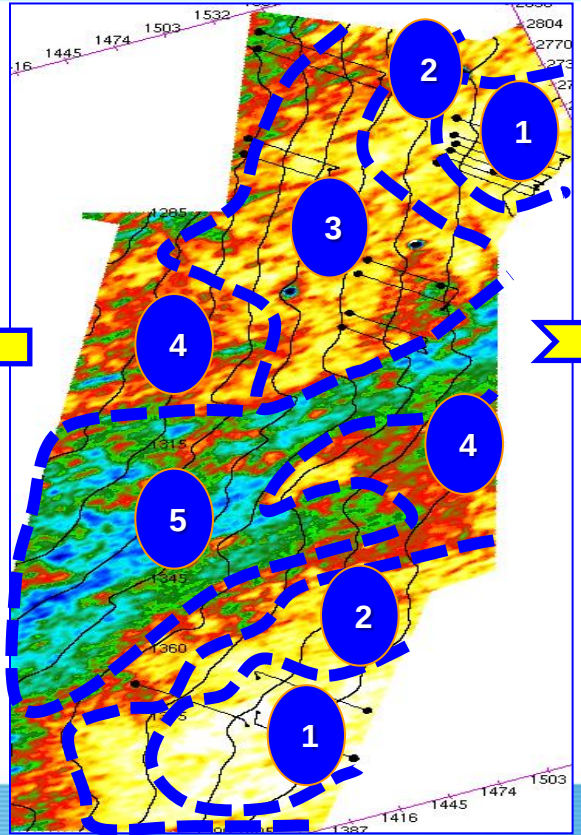


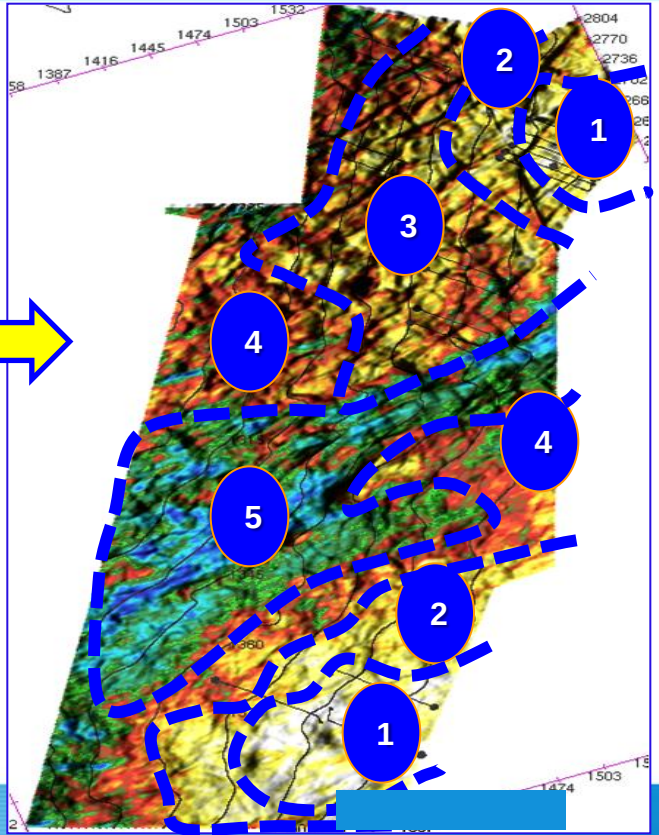
The result shows that fracture orientations are mostly North East. If drilling direction is substantially perpendicular to the direction of fracture, it is easy to form mesh seam and improve oil and gas production.

Sweet Spots

Predicted by The Overlap of Fracture and P-impedance

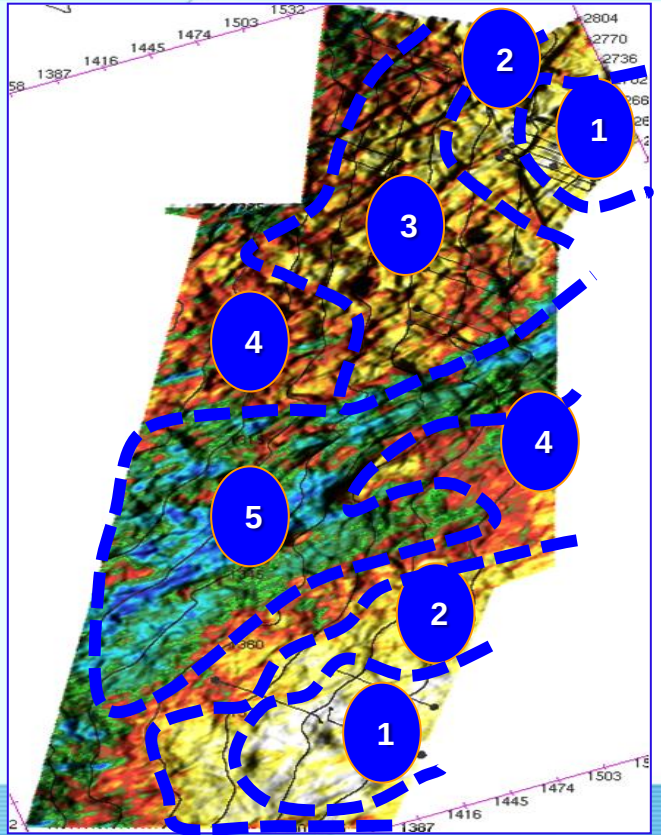




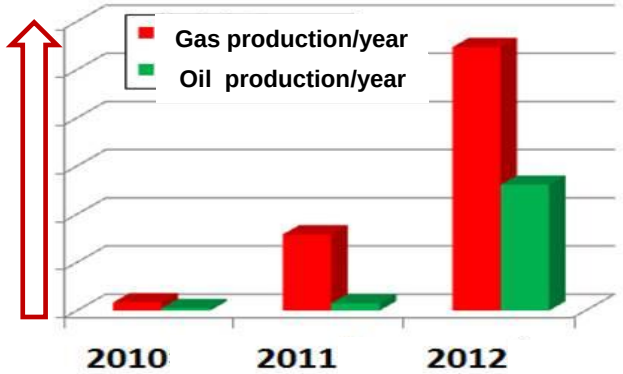


Yield improved

by sweet spots prediction result in EagleFord



In 2012, the sweet spots prediction result was used to guide drilling deployment and fracturing design in EagleFord. And shale oil and gas yield is greatly improved through the new drilling wells.

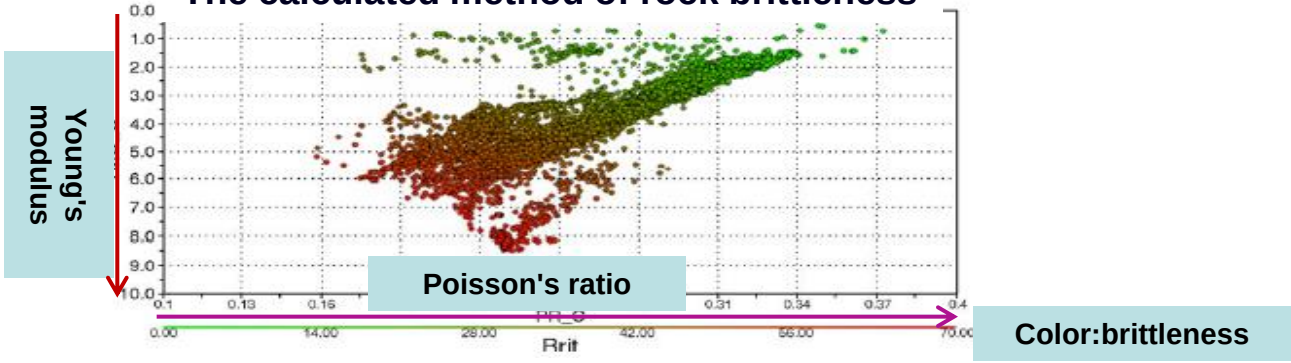


The change of production from 2010 to 2012 in EagleFord

On the basis of rock physical analysis, prestack simultaneous inversion technique was used to solve the problem of sweet spots discrimination in block Niobrara.

TOC and rock brittleness are the key factors of exploration and development in shale.

The calculated method of rock brittleness

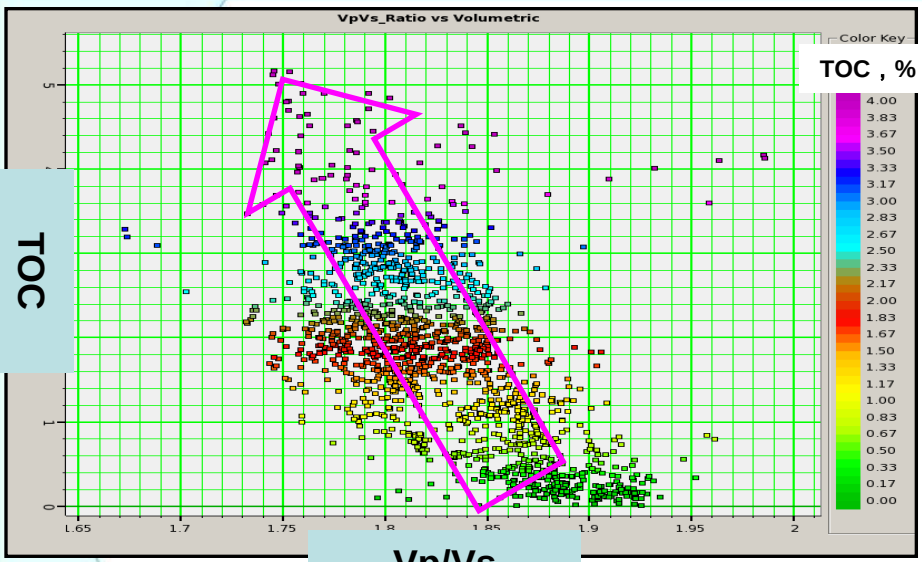


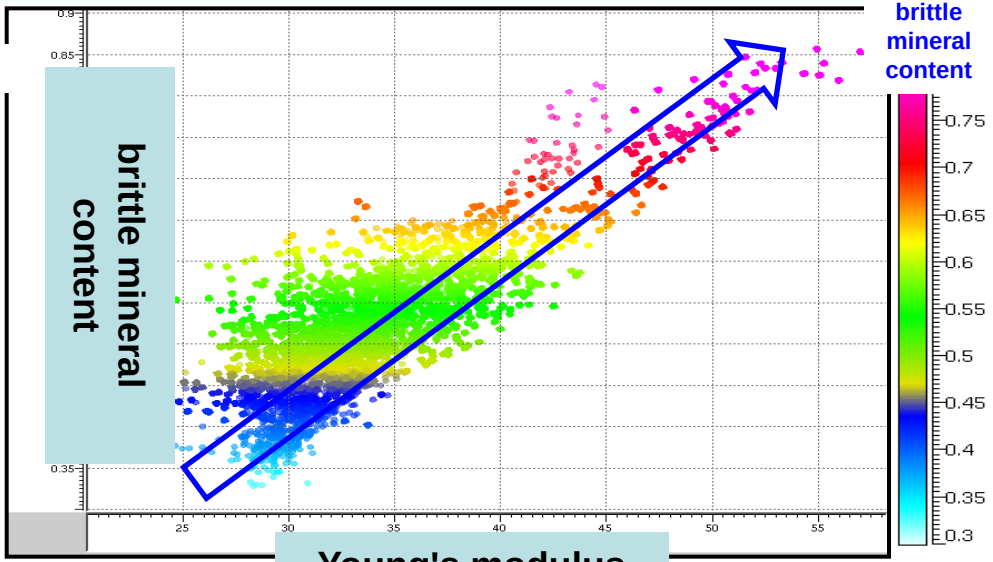
There are two kinds of methods to calculate rock brittleness:

(1) Brittleness index (Rick Rickman et.al., 2008). It is proportional to the Young's modulus, and it is inversely proportional to the Poisson's ratio;

(2) Brittle mineral content.

Rock Physical Analysis in Niobrara





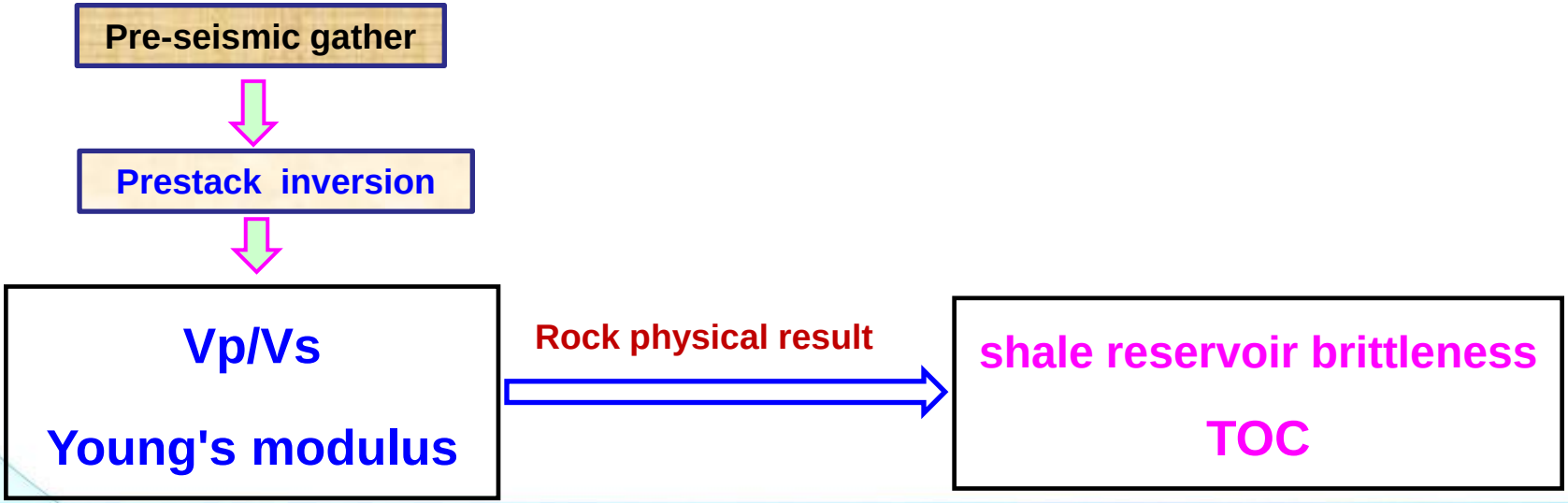
The conclusions of crossplots are as follows:

As values of TOC increases, the lower Vp/Vs will be.

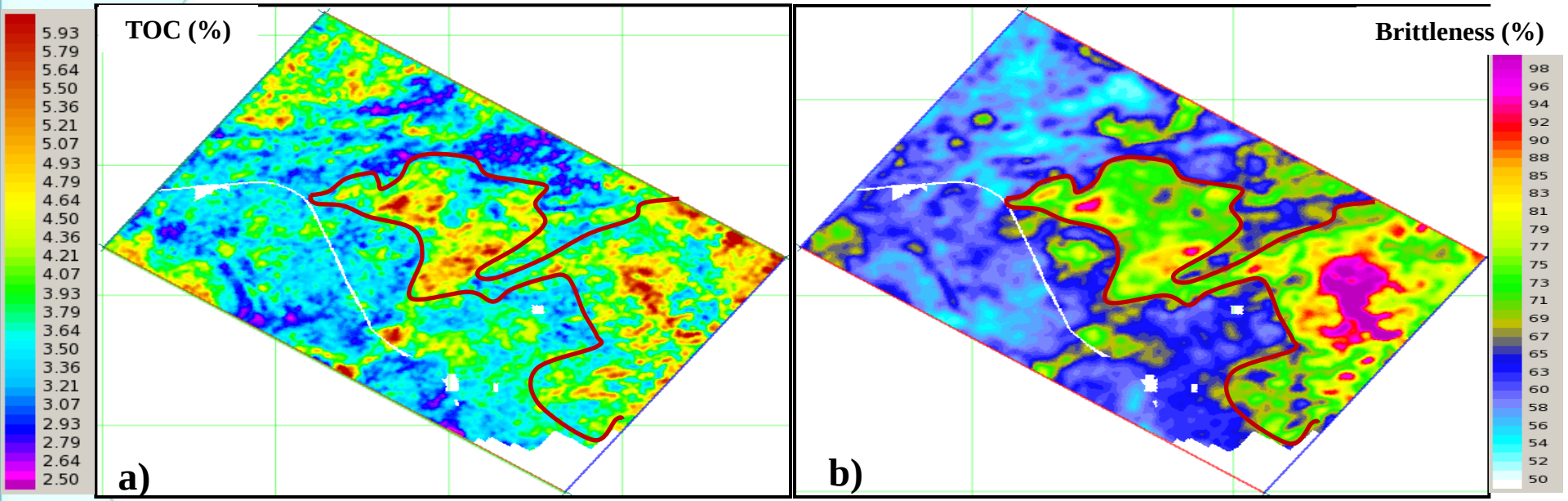
As brittle mineral content increases, the higher Young's modulus will be.

The Result Obtained by Prestack Inversion

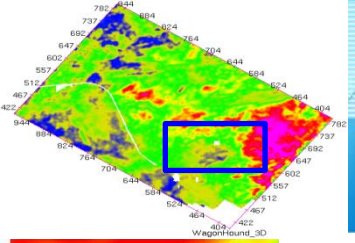
Vp/Vs and Young's modulus sets were obtained by using prestack simultaneous inversion. And then, shale reservoir brittleness and TOC were derived from above rock physics relations.



Plane Maps of TOC and Brittleness in Niobrara

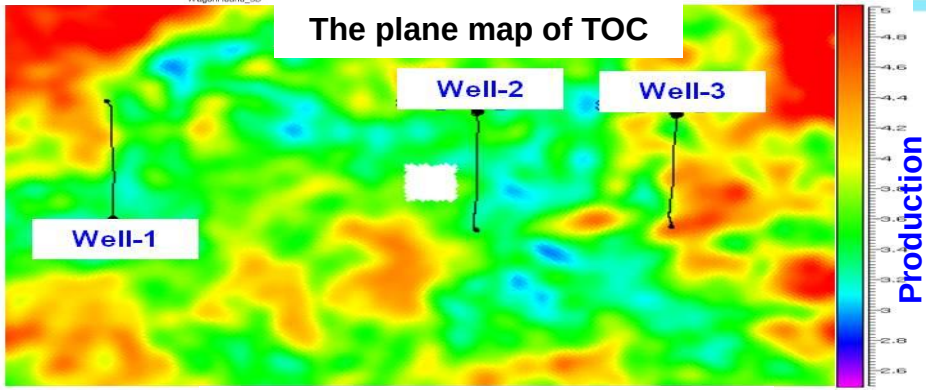


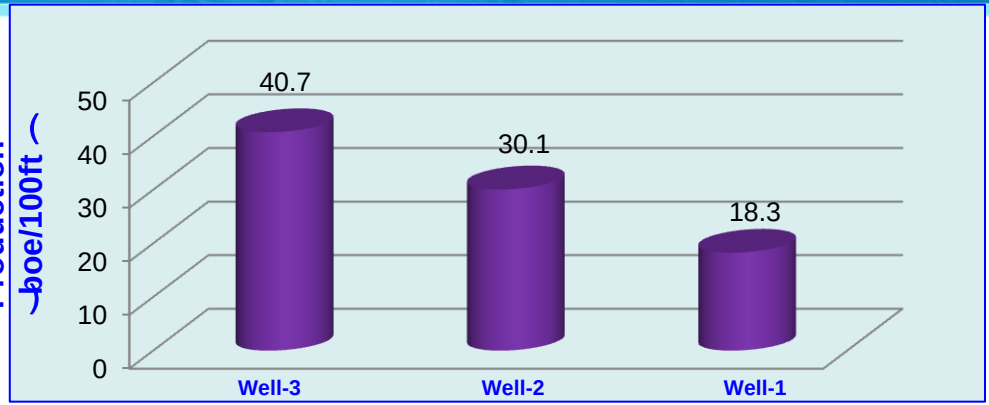
TOC is slightly higher in the centre and Eastern of the area ; and the rock brittleness is also higher in centre and Eastern, where is good at hydraulic fracturing treatments. So the centre and Eastern are the sweet spots of shale in Niobrara.



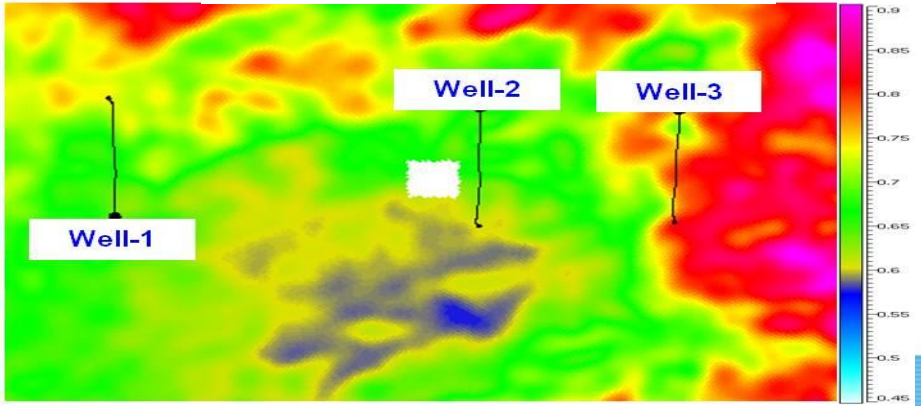
Production Factors in Niobrara

The plane map of TOC





The plane map of brittleness



In well-3, TOC and brittleness are higher than well-1 and well-2. So its production is highest.

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Conclusions

- Sweet spots discrimination technique has been used well in the North American shale.
- The basic idea is as follows: First, the relationships between key properties and rock physical parameters are established by logging data at different shale blocks, and then some appropriate geophysical techniques will be selected to predict sweet spots of shale.
- Therefore, rock physics is the core and key of sweet spots discrimination in shale, and quantitative logging evaluation of reservoir parameters is the basis of rock physics analysis.

Thanks for your attention ...