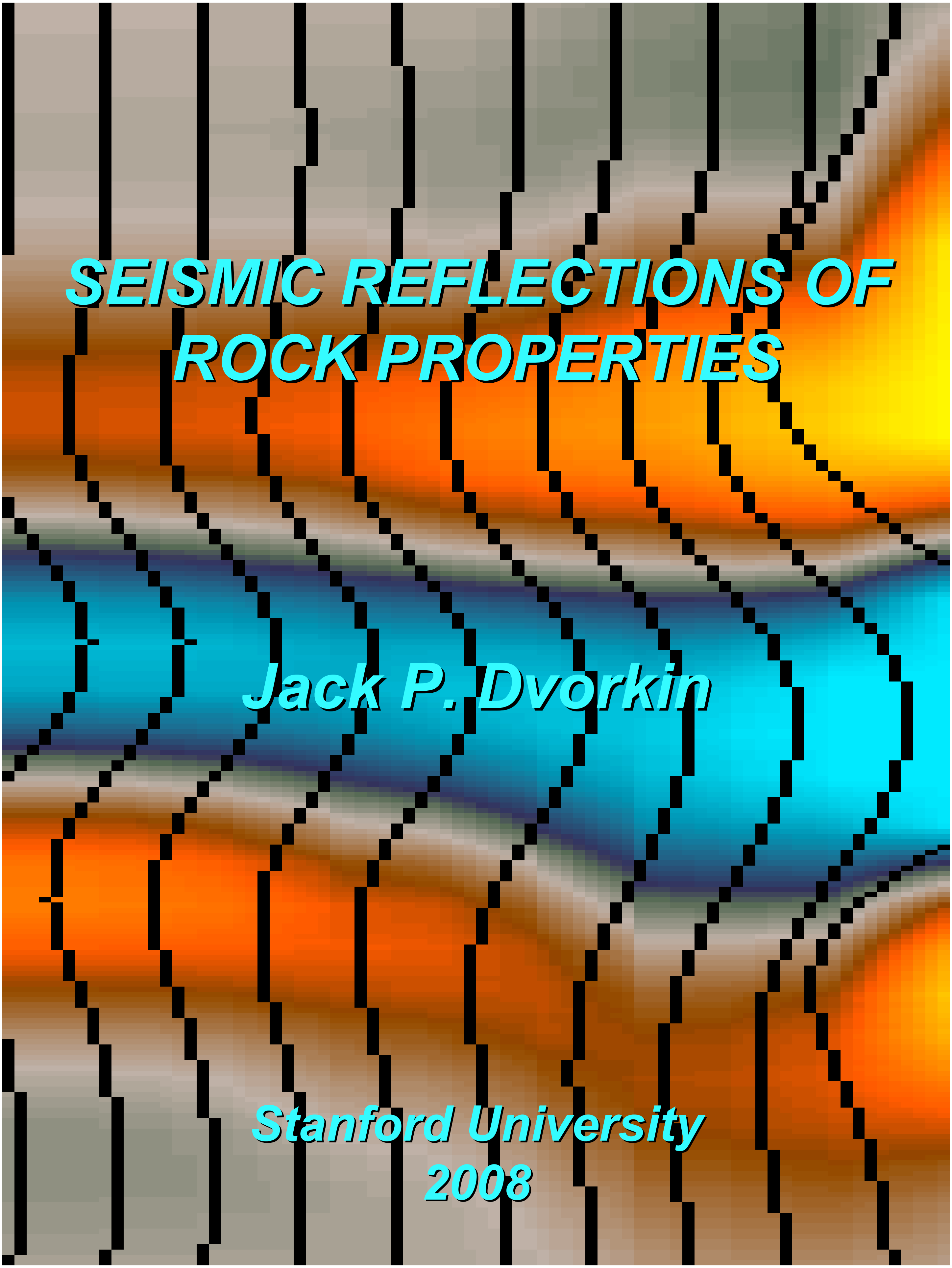

SEISMIC REFLECTIONS OF ROCK PROPERTIES

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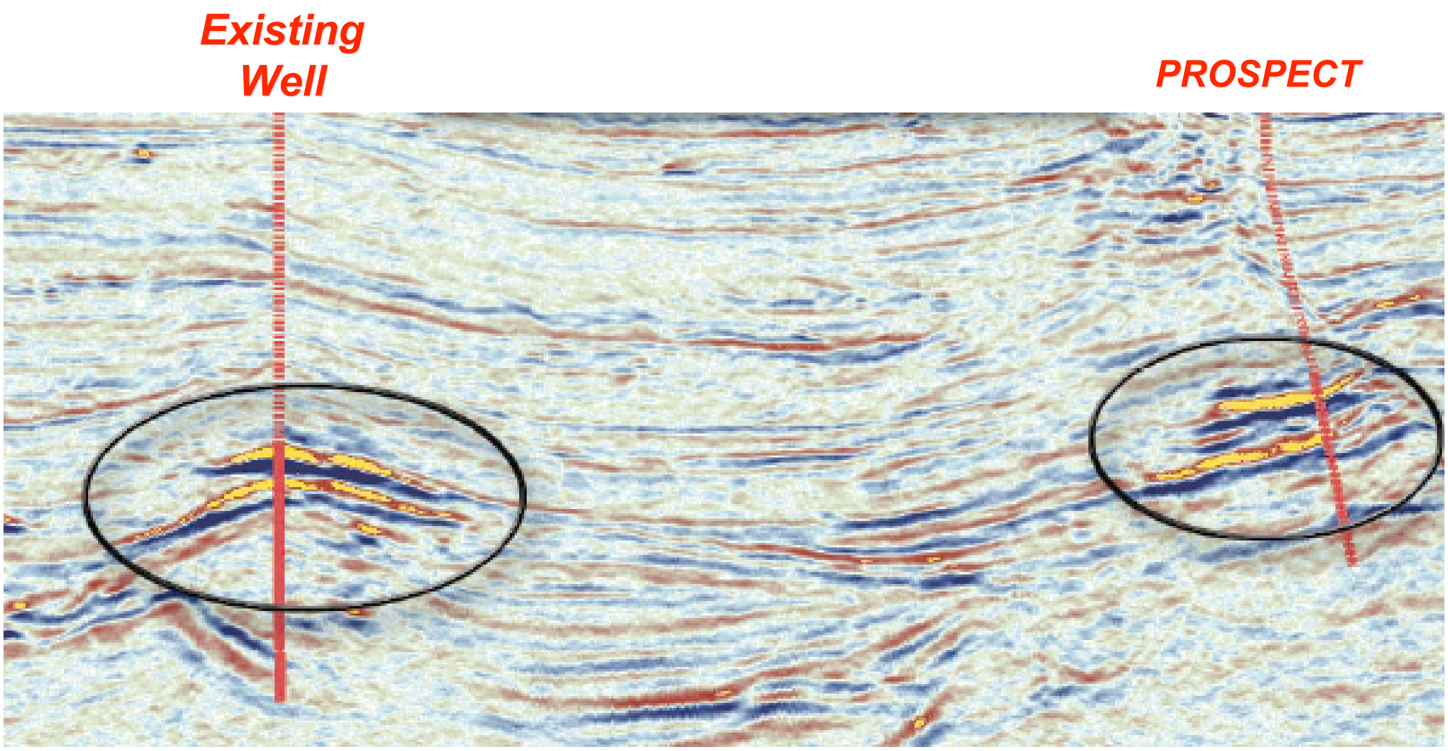
Stanford University
2008

1. Problem Formulation

MAIN QUESTION OF ROCK PHYSICS

How to Remotely Map Rock Properties and Conditions: Lithology, Porosity, Pressure, Saturation

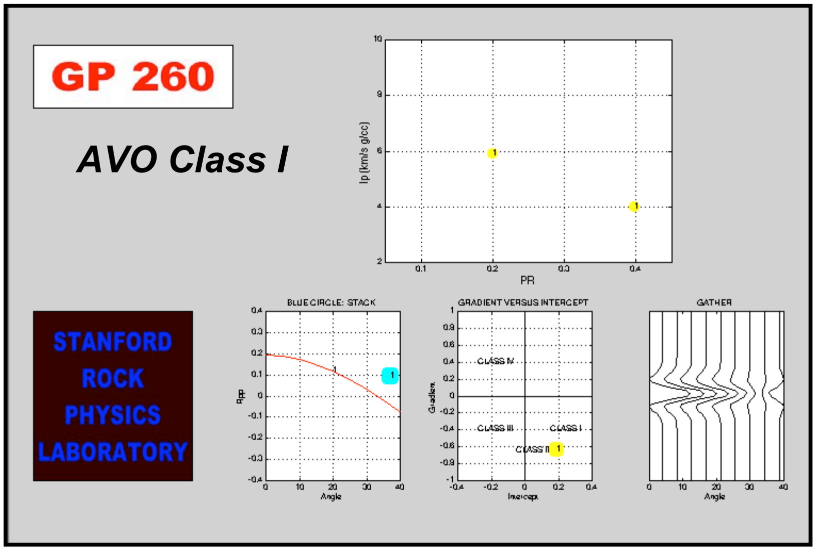
Rock and fluid prediction away from well control requires understanding of how rock's bulk and seismic properties are linked to each other and how they vary with geologic age, depth, and location.



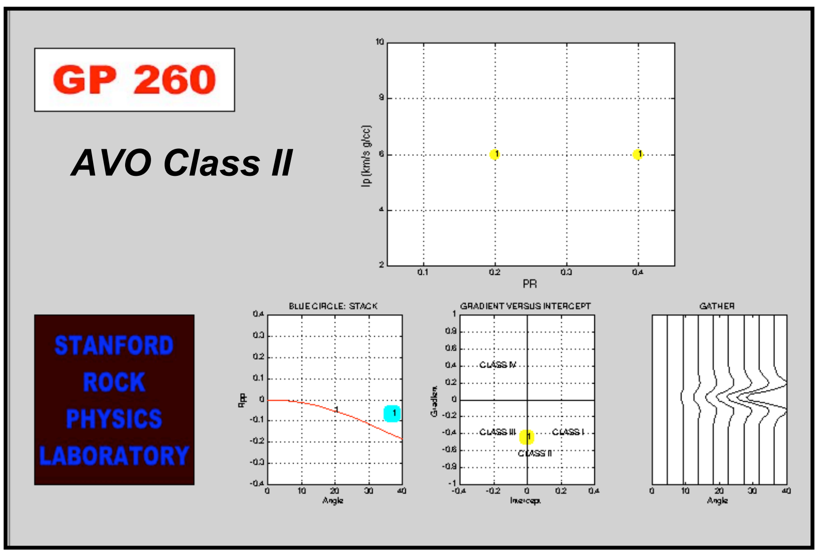
The main question of remote sensing is:
What reservoir properties may stand behind the seismic amplitude?

METHODS OF PREDICTION

Forward Modeling of Seismic Response



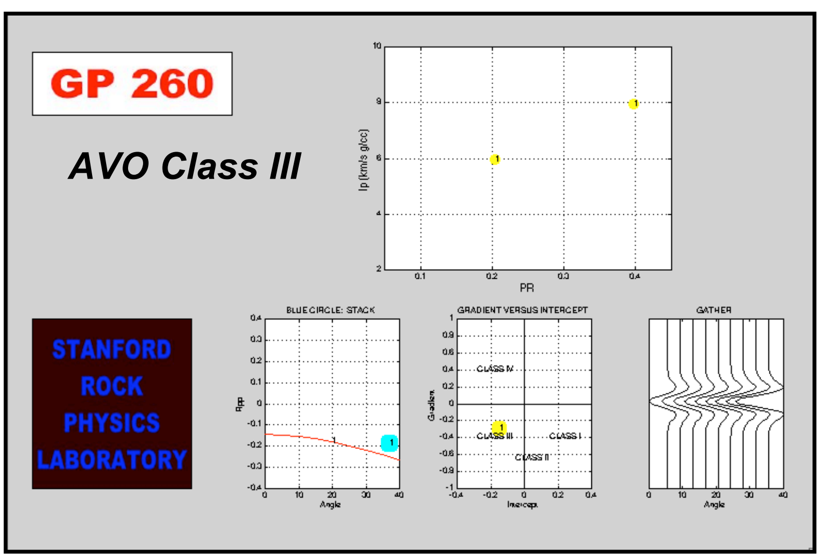
Depending on the selected elastic properties of the overburden and reservoir, we model various classes of AVO response.



Impedance and Poisson's Ratio

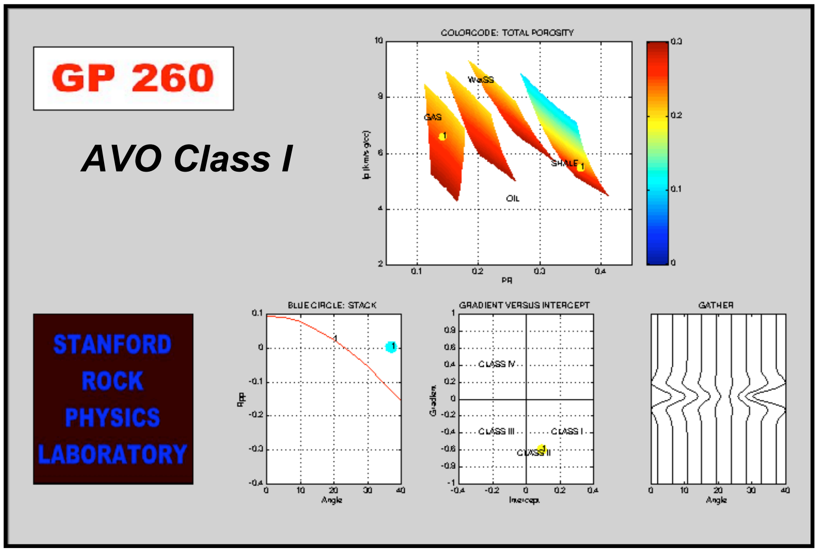
$$I_p = \rho_b V_p$$

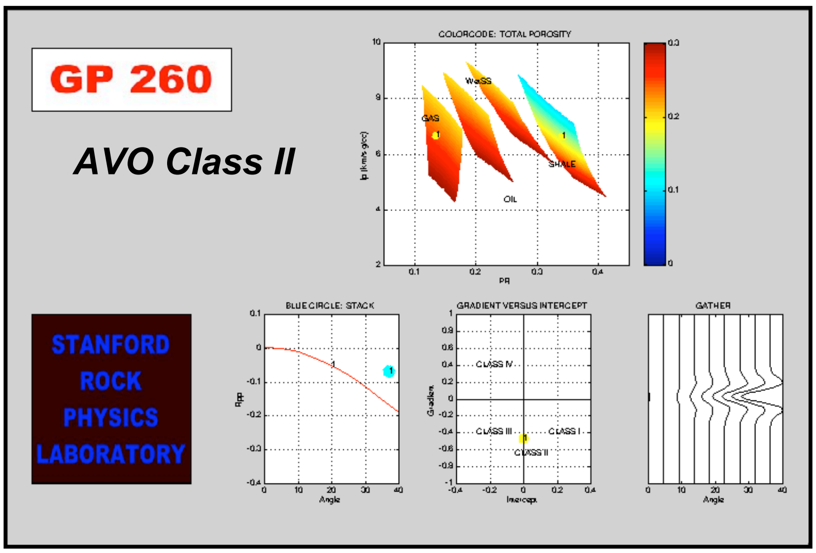
$$\mathrm{PR} \equiv \nu = \frac{1}{2}\frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1}$$

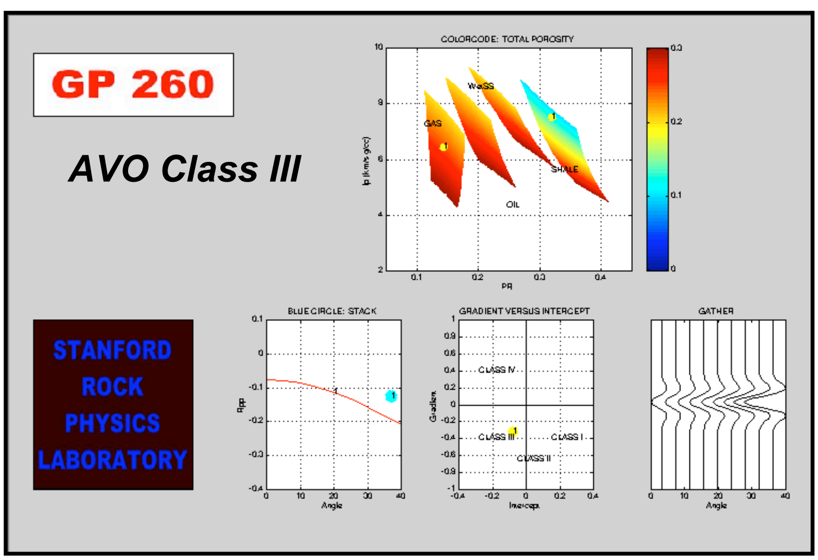


METHODS OF PREDICTION

Forward Modeling of Seismic Response from Rock Properties





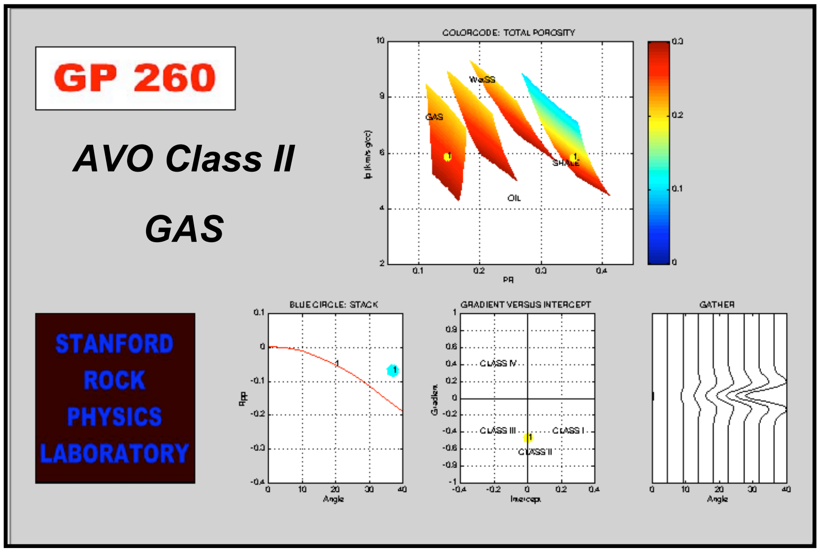


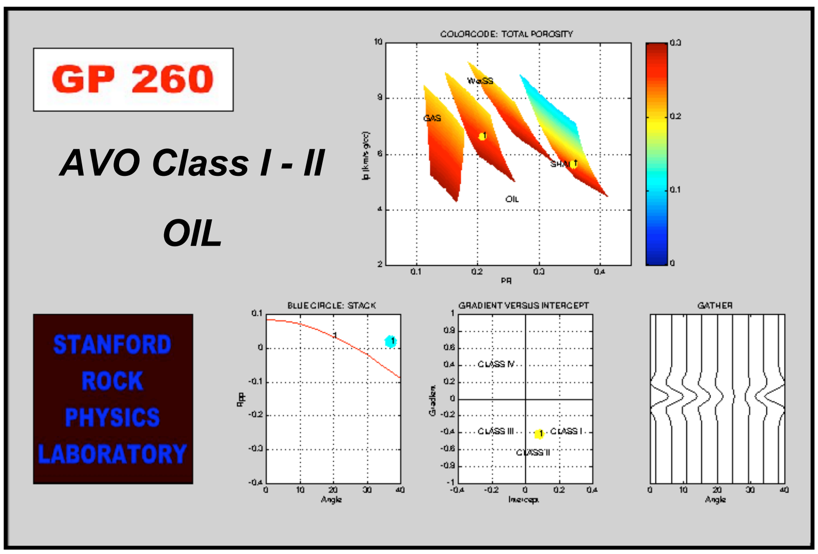
The AVO response changes with the compaction of shale which may be depth-driven.

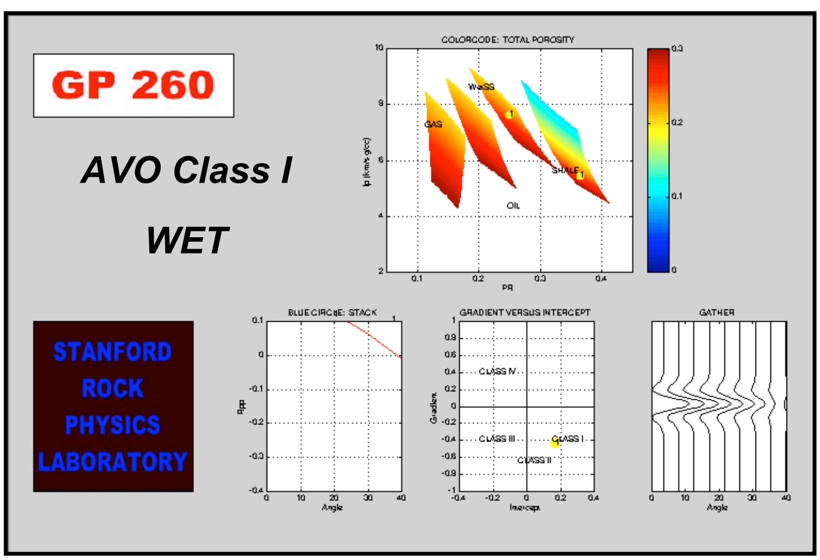
Shale compaction with increasing depth

METHODS OF PREDICTION

Forward Modeling of Seismic Response versus Fluid



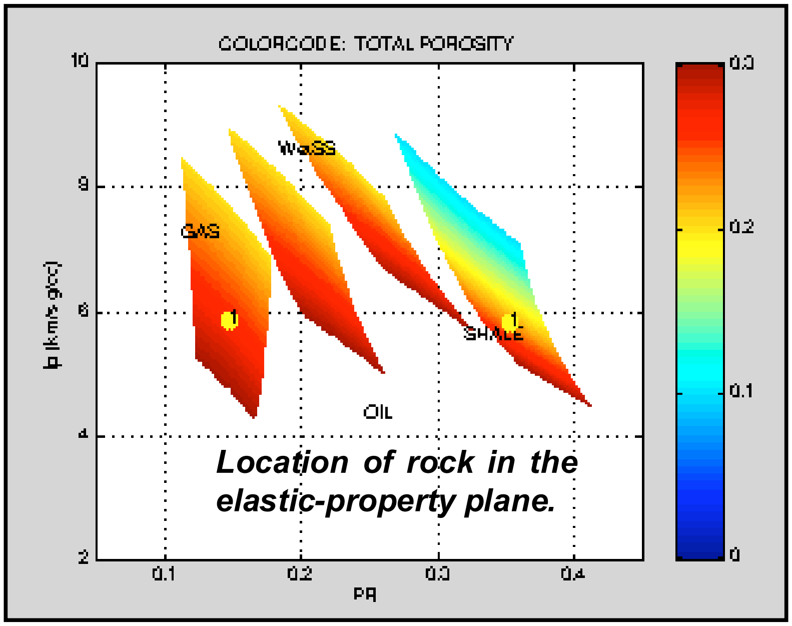




The AVO response changes with the pore fluid -- from gas to oil to water.

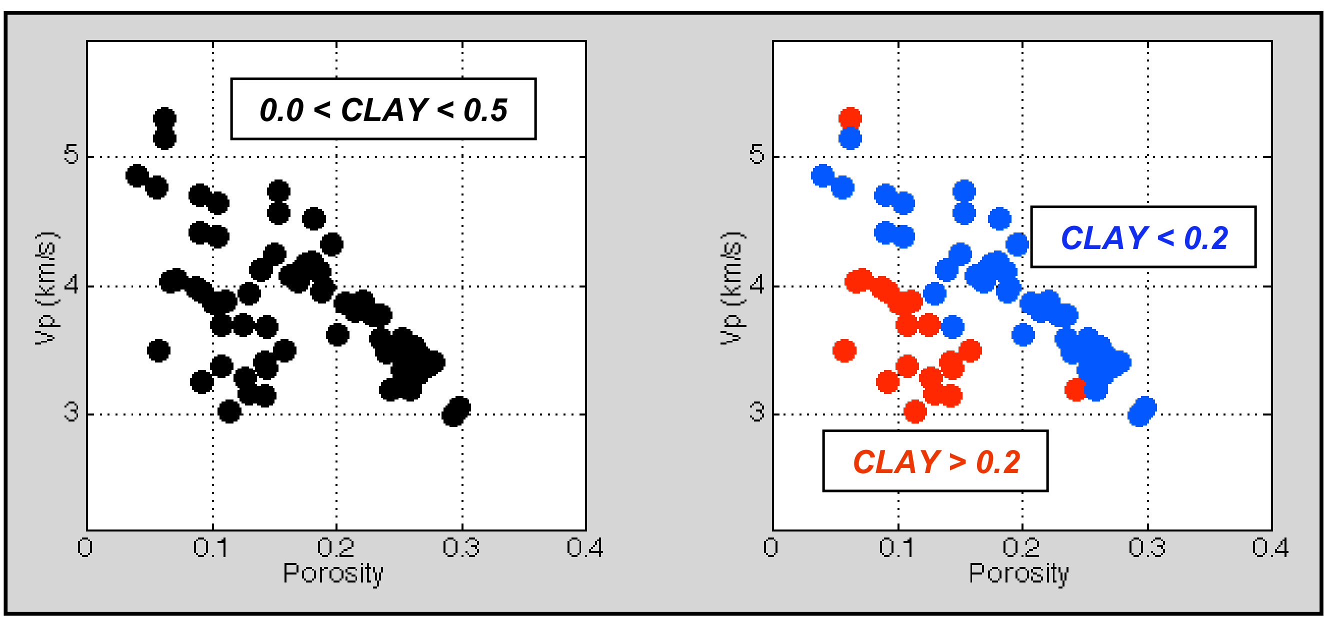
METHODS OF PREDICTION -- LAB

Relations between Lithology, Porosity, and Elastic Properties



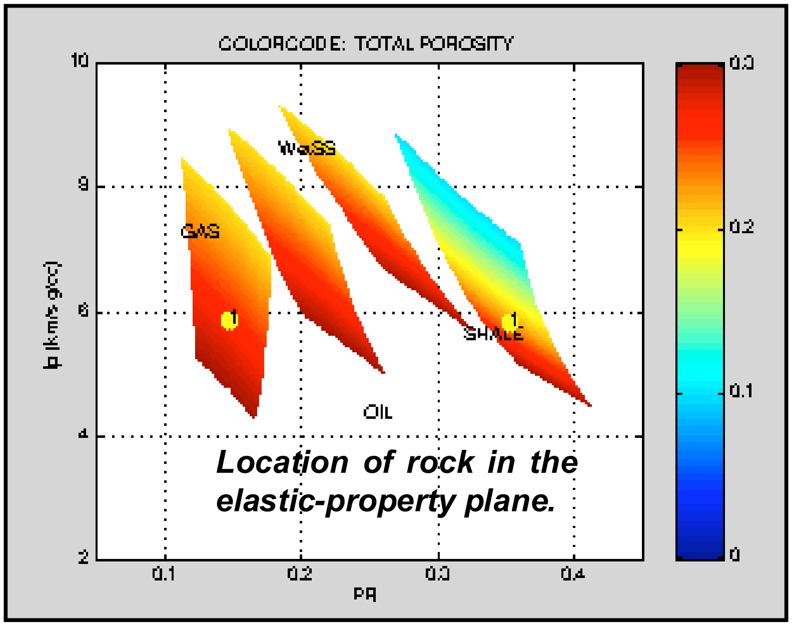
***Laboratory Measurements**. Han's (1986) laboratory data set includes over 60 sandstone samples of medium to low porosity and zero to 50% clay content. Shown below is a P-wave velocity versus porosity cross-plot for a subset of these data. The measurements shown below are for room-dry samples at 40 MPa confining pressure and atmospheric pore pressure (air).*

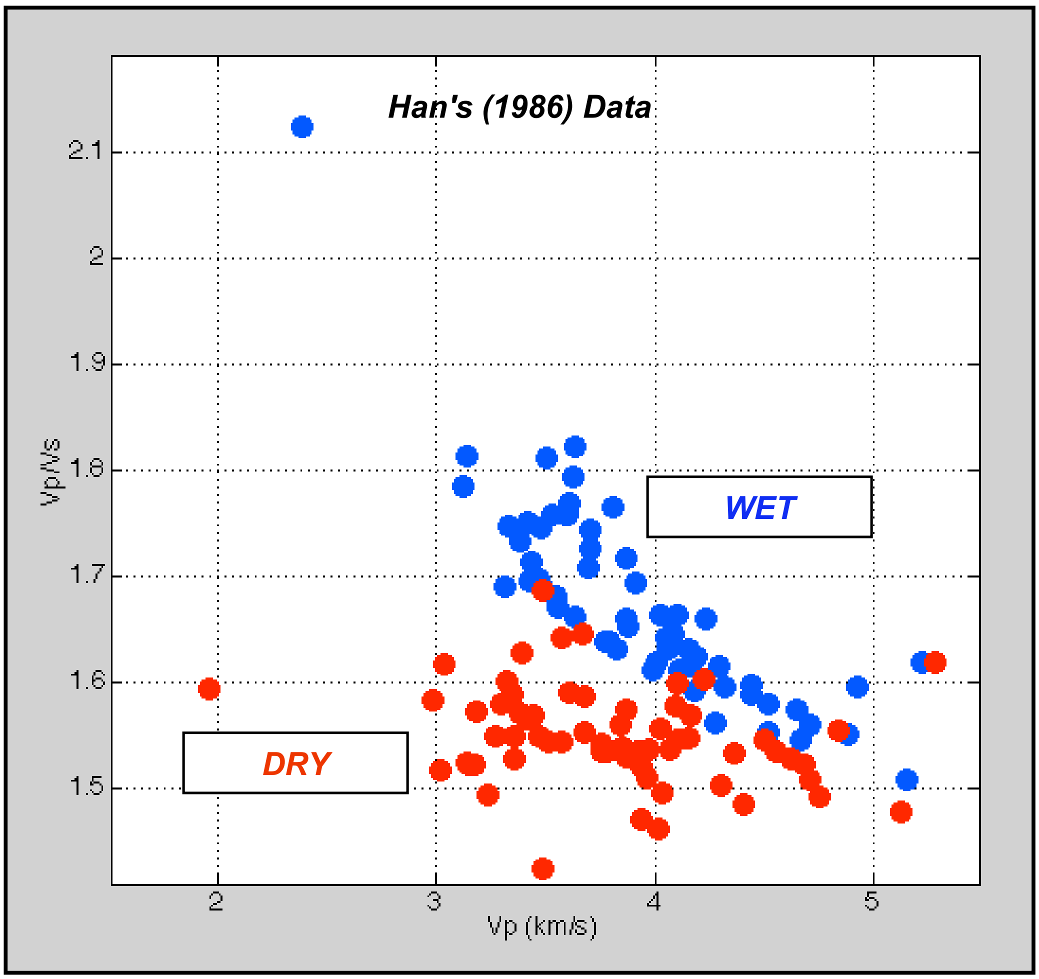
All data. ***Data color-coded by clay content.***



METHODS OF PREDICTION -- LAB

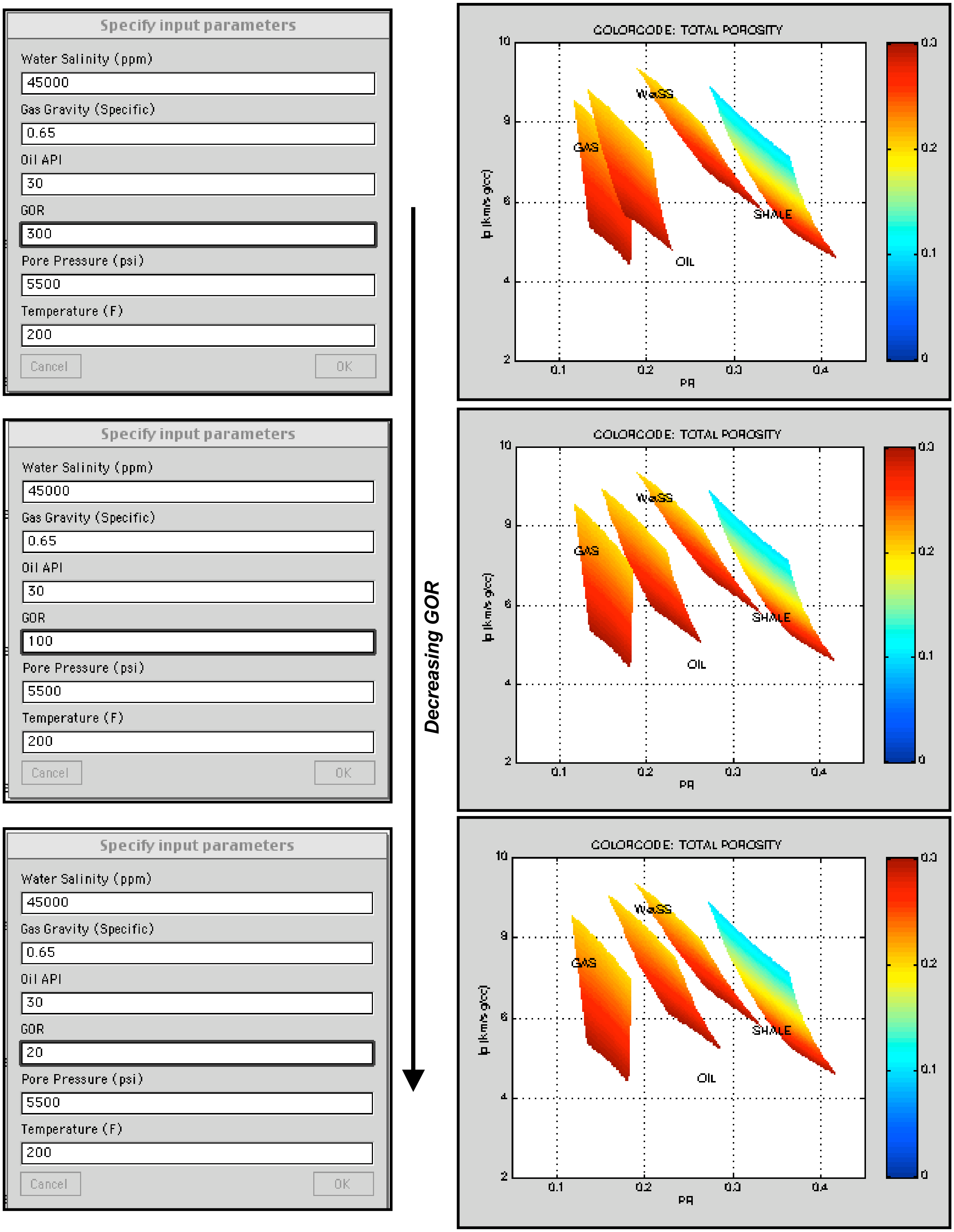
Relations between Fluid and Elastic Properties





EFFECTS OF OIL PROPERTIES

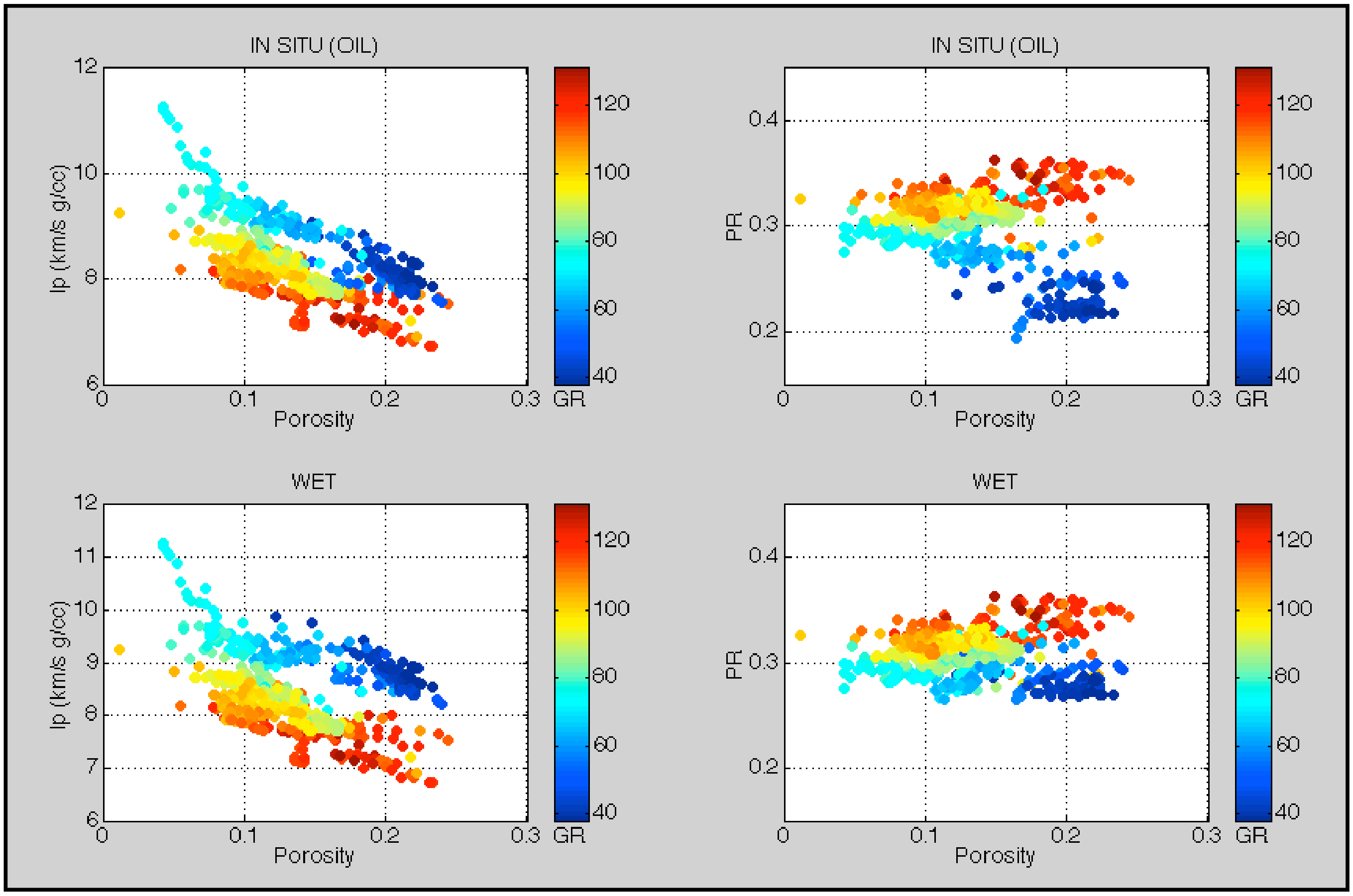
Oil Reservoir Response Depends on Oil API and GOR



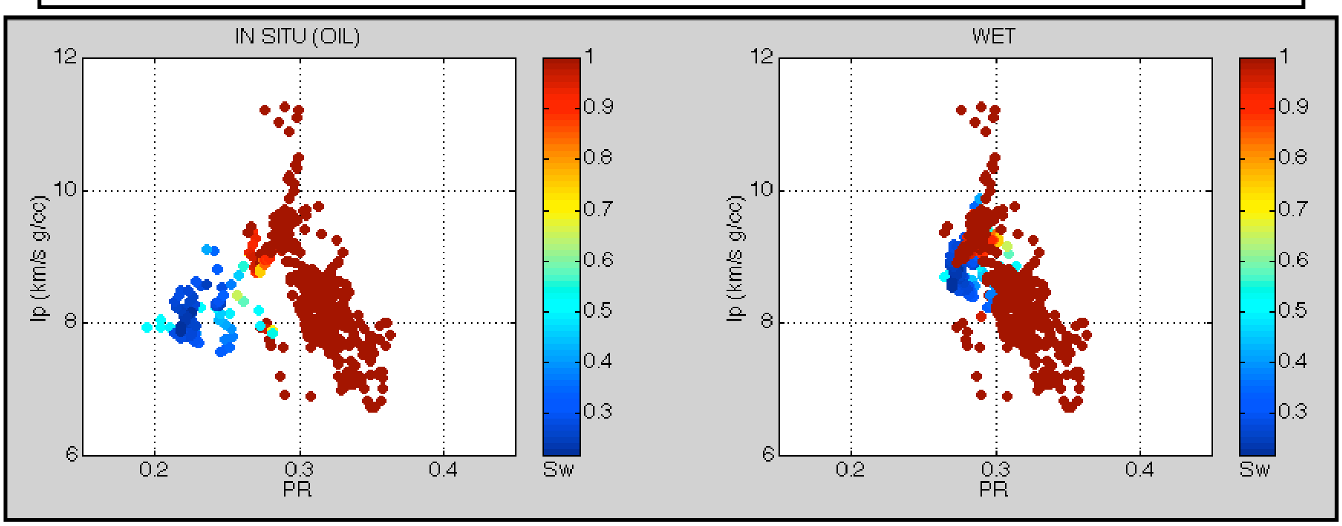
METHODS OF PREDICTION -- WELL

Relations between Lithology, Fluid, and Elastic Properties in Log Data

Sand/shale well in Alaska. Impedance and Poisson's ratio versus porosity. Top: at in-situ conditions, bottom: wet.



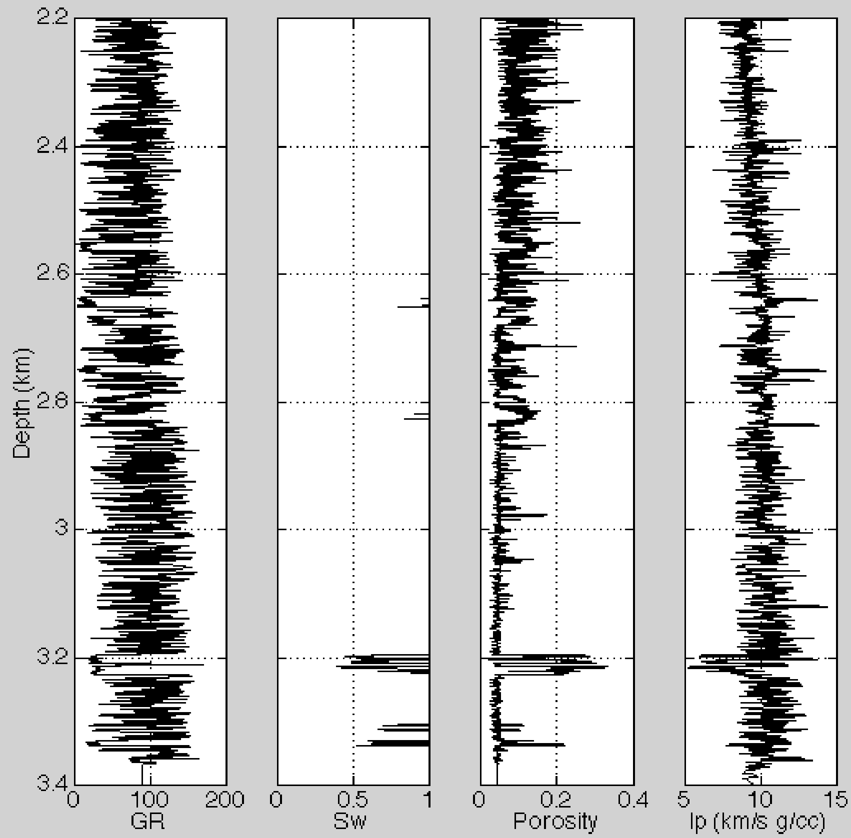
Impedance versus Poisson's ratio. Left: at in-situ conditions, right: wet.



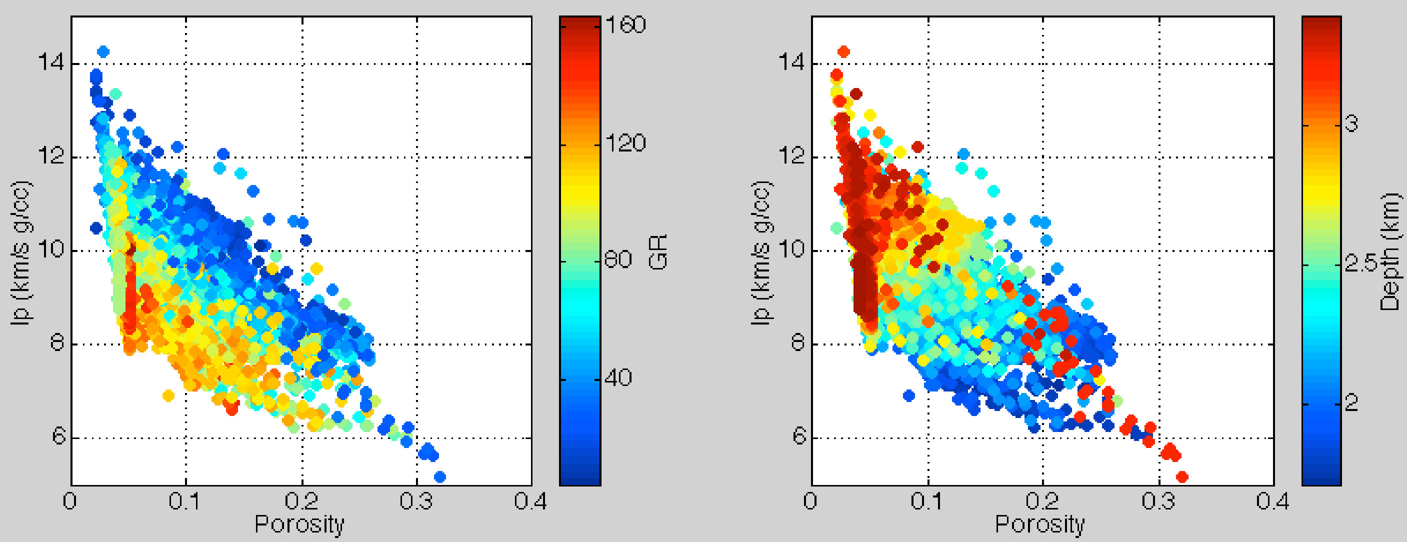
METHODS OF PREDICTION -- WELL

Relations between Lithology, Fluid, Depth, and Elastic Properties in Log Data

Sand/shale gas well offshore South Africa.



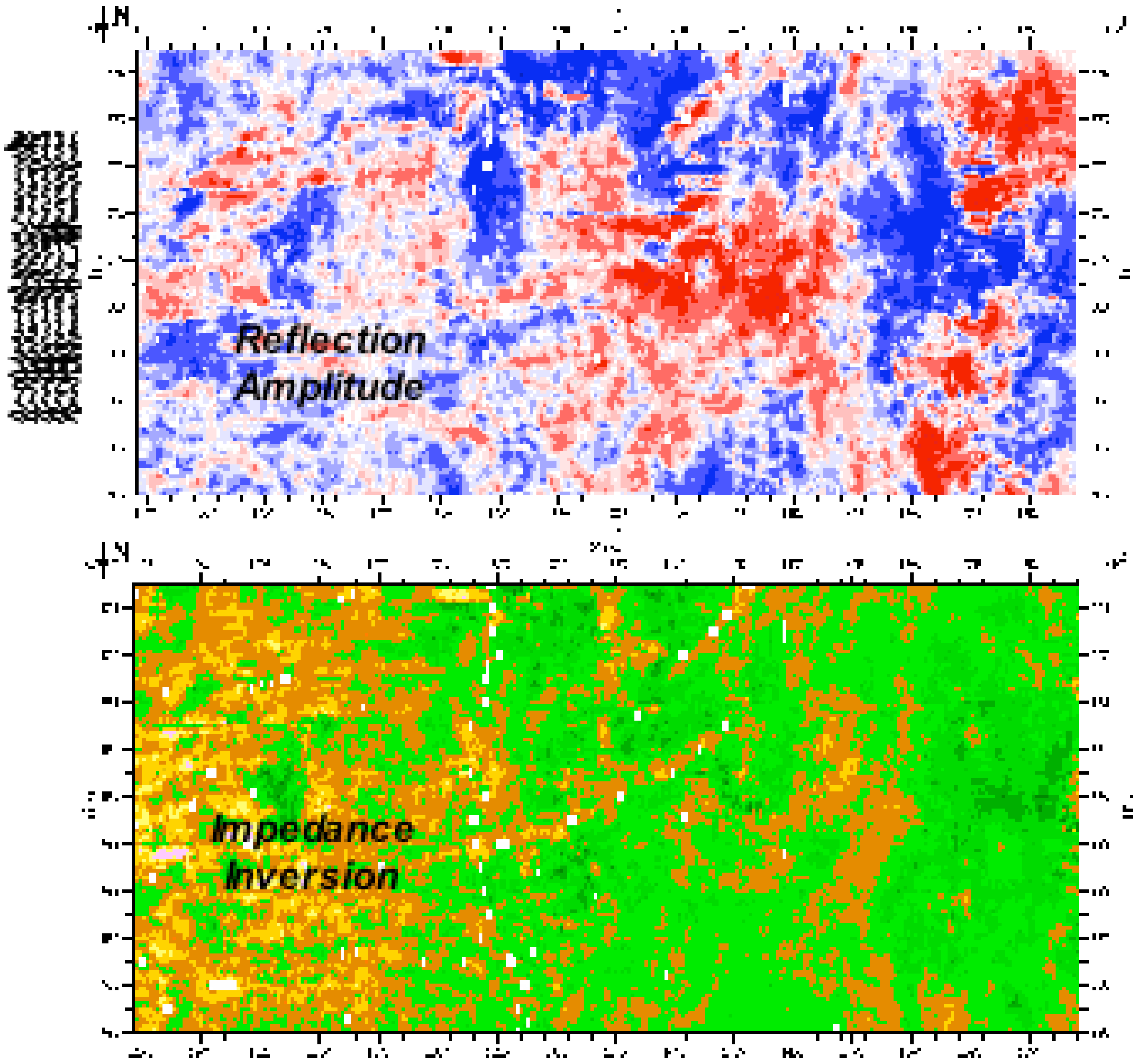
Impedance-porosity cross-plots show effects of clay (left) and compaction (right).



Finding Transforms and Applying them to Impedance Inversion

Reflection amplitude carries information about elastic contrast in the subsurface. Inversion attempts to translate this information into elastic properties within an interval.

These properties are important because we are interested in absolute values of lithology, fluid, and porosity within intervals.

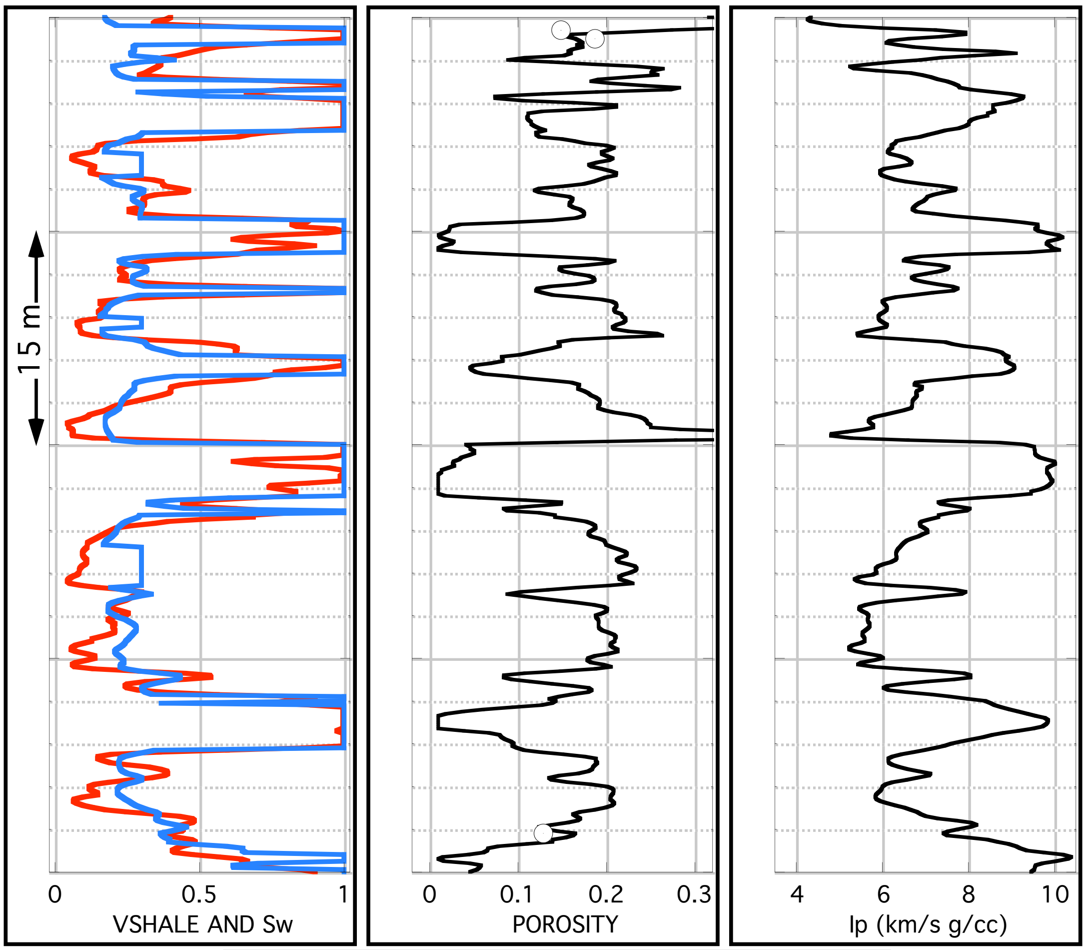


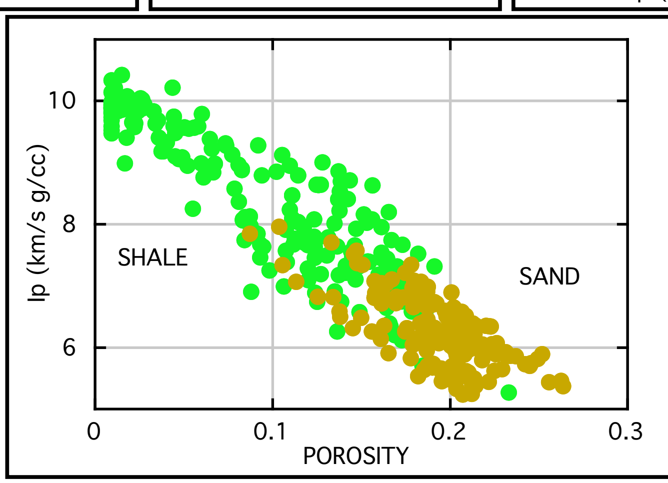
La Cira Norte -- Courtesy Ecopetrol and Mario Gutierrez

Finding Transforms and Applying them to Impedance Inversion

Log data can be treated as a result of a controlled experiment where various rock properties are measured in the subsurface. Shown below are VSHALE, total porosity, and Ip curves for a Colombian well drilled through Tertiary sand/shale sequence.

The Ip curve mirrors the porosity curve. This means that there is a relation between impedance and porosity.

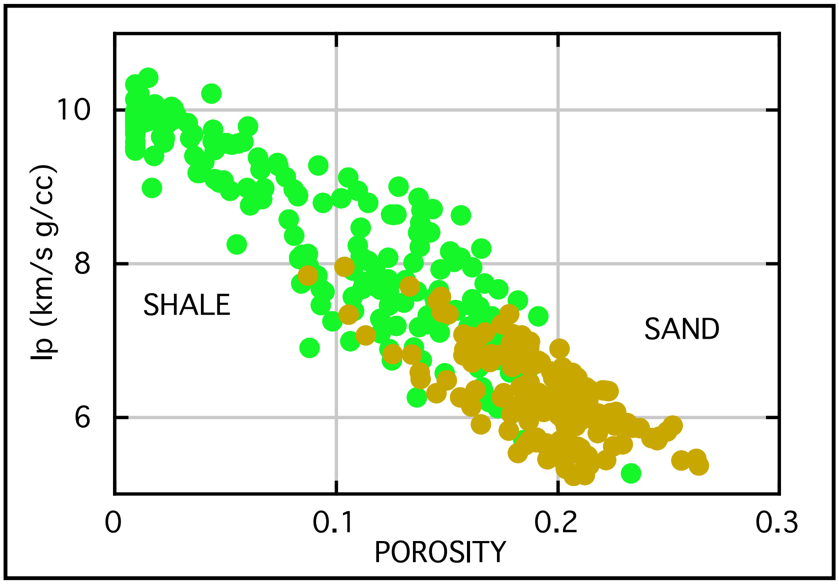




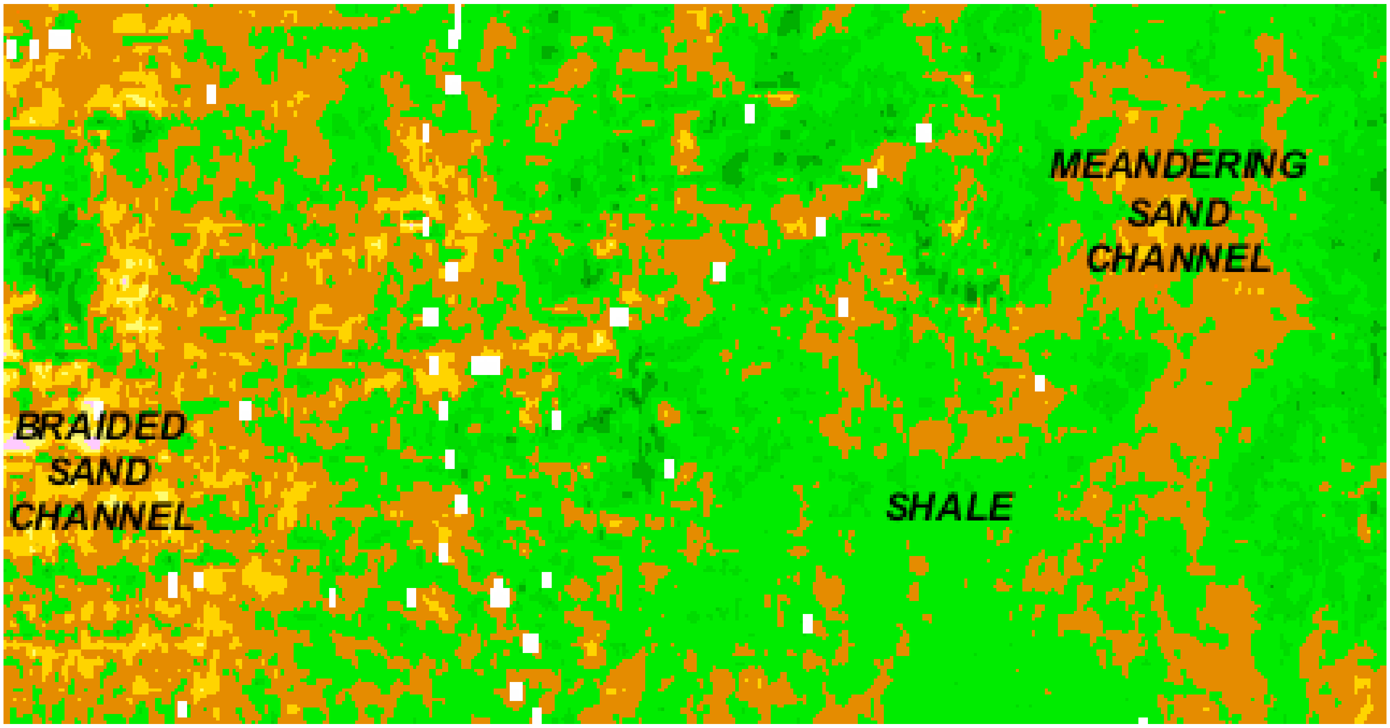
La Cira Norte -- Courtesy Ecopetrol and Mario Gutierrez

Finding Transforms and Applying them to Impedance Inversion

Impedance-porosity transform can be applied to impedance inversion volume to produce a porosity/lithology volume. Shown below is a La Cira field (Colombia) example.



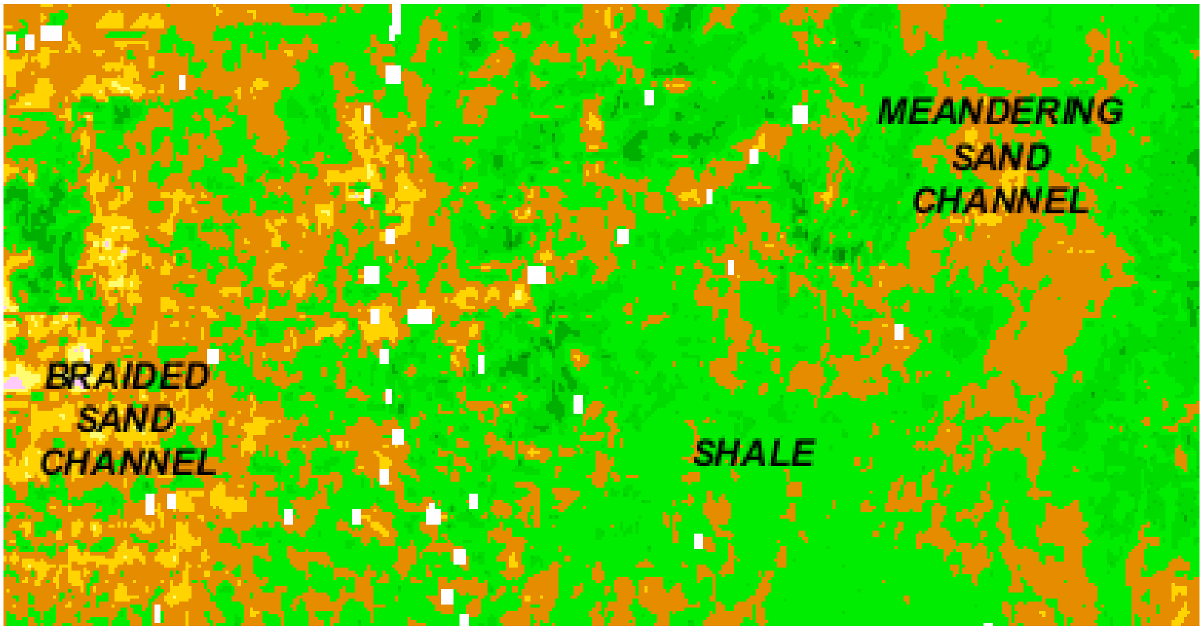
Porosity Strata Slice from 3D Seismic Data and Rock Physics Trend



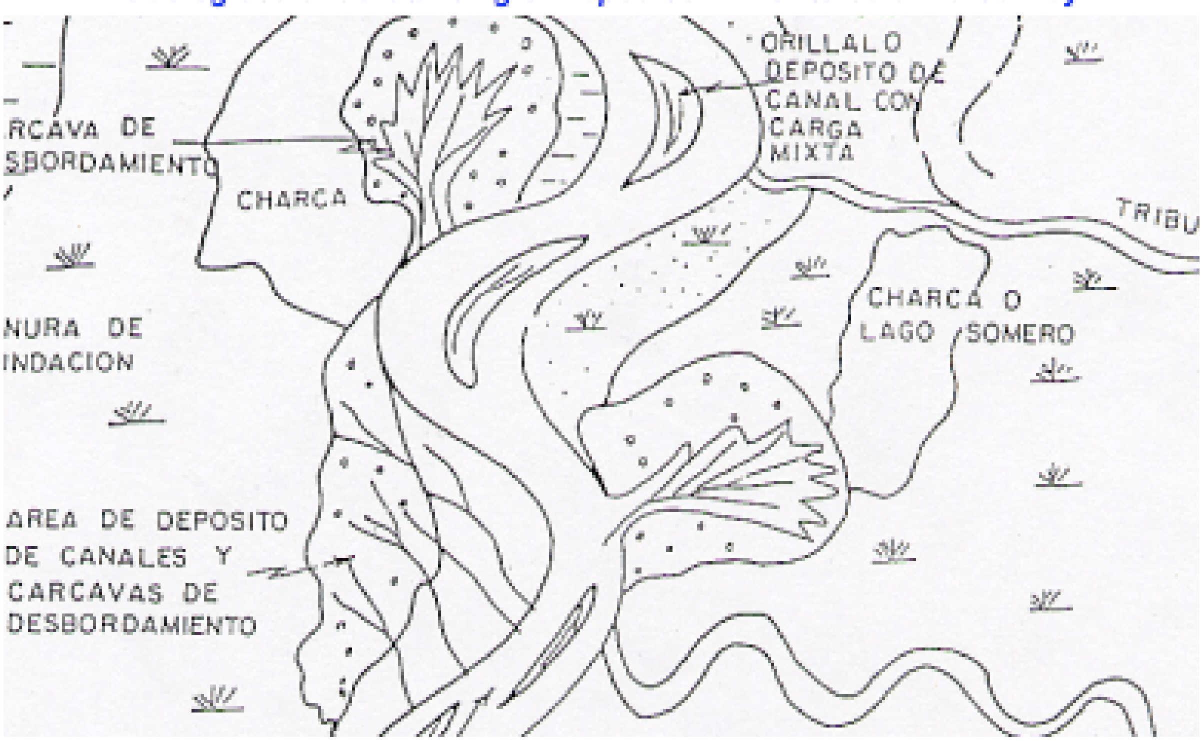
La Cira Norte -- Courtesy Ecopetrol and Mario Gutierrez

Finding Transforms and Applying them to Impedance Inversion

Stratigraphy and geology, in general, are important factors to be used to confirm mathematically derived reservoir descriptions.



Geologist's Understanding of Deposition Prior to Seismic Survey



La Cira Norte -- Courtesy Ecopetrol and Mario Gutierrez

Caveat of Scale

Thin sub-resolution layers produce smaller amplitude than thick layers. As a result, they produce smaller seismic impedance.

Applying an impedance-porosity transform to seismic impedance will produce a wrong porosity estimate.