The Marrying of Petrophysics with Geophysics Results in a Powerful Tool for Independents

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While the application of new geophysical and petrophysical technology separately can make an impact on the bottom line for the independent, the combination of the technologies which has become know as Seismic Petrophysics is a much bigger bang for the buck.

Independents benefit from advanced seismic technologies by using an integrated rock-property based solution to maximize results in exploration, well planning, drilling, production, and reservoir management. The key to success is to understand the rocks with tools to interpret and define lithology, porosity, fluids, pore pressure and reservoir quality; providing seismic data in a geologically meaningful and multi-disciplinary format.

The integration of well logs with seismic data is challenging because they are presented in different domains. Well logs are displayed in units of microseconds/ft, gm/cc, gapi, ohm-m, etc., while seismic is displayed in terms of reflectivity. When inversions are carried out to put seismic into a more log-similar domain, acoustic impedance is often chosen. This seems somewhat odd since well logs through Petrophysical Analysis are inverted to lithology, porosity and fluids.

Why then take the seismic data to the starting well log domain and not to the final point? All of the measurements have one thing in common: the rocks. So ideally all of the measurements should be placed into the rock domain - that is lithology, porosity and fluids. Then the process can be thought in terms of rock-based integration.

The presented process will first describe how seismic data can be inverted into the lithology, porosity and fluid domains in a similar way that well log analysis is conducted. The results then are integrated with the well log analysis in terms of rocks.

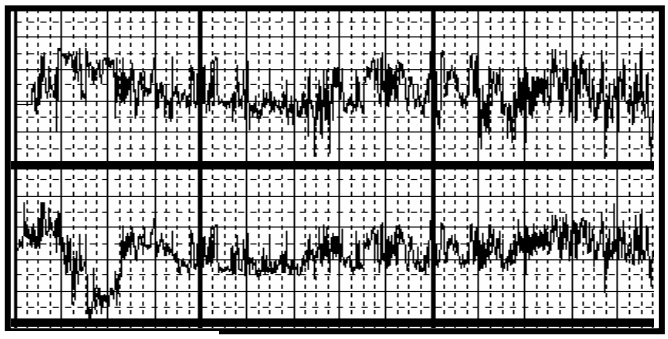

Figure 1

Reviewed separately, a neutron log or a density log would not accurately identify sands, shales or gas zones. (*Figure 1*) By overlapping the density log and the neutron logs in compatible scales on the same track, pieces of information come together to fill in the puzzle. When the two log curves cross over, gas is indicated. When the two log curves are separate, shale is likely present. When the two log curves are on top of each other, sand can be found. And the porosity is the average of the two – what is known as crossplot porosity.

A crossplot can also be developed by putting the neutron points on the x-axis and the density points on the y-axis, resulting in a blob of data. The meaning of the blob is revealed by referencing a chart book. The result is shale, sand, gas and porosity.

By taking a simple petrophysical workflow, it is possible to crossplot a neutron log and a density log to calculate lithology, porosities, and fluids. *(Figure 2)*

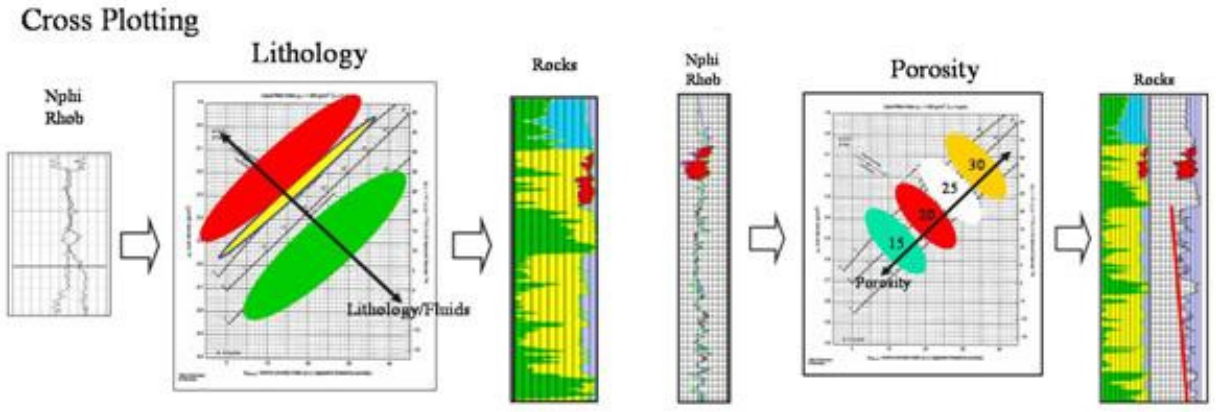

Figure 2

In petrophysical analysis, the neutron and density combination allows for the separation of lithology and fluids from porosity. This works because neutron and density are independent from each other and both respond to lithology, porosities, and fluids.

A similar technique can be applied to the seismic data; however, two independent seismic sections are needed instead of one. That problem can be solved by using AVO (amplitude variation with offset), a technology that has existed since the mid 1980's.

The acquisition of seismic data results in the sampling of each surface point at many different angles. The variation of amplitude with offset can thus be analyzed, resulting in zero offset (P) and AVO gradient (G) sections, two independent seismic measurements. *(Figure 3)* Conventionally, all the gathers are added up or averaged to create the full offset stack resulting in just one measurement, which would be similar to adding the neutron log to the density log.

These two sections provide the equivalent of two well logs in the logging world. A crossplot is created by putting P on the X-axis and G on the Y-axis and plotting all the points. The resulting crossplot blob is equivalent to that created by the neutron and density logs so a chart book is needed to understand the blob in terms of lithology, porosities, and fluids.

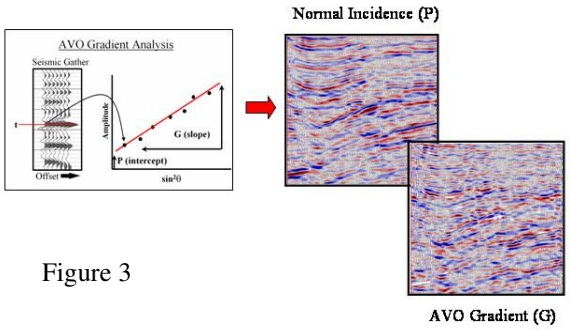

Figure 3

To create this chart book, a lot of modeling was required. Conventional seismic modeling is conducted by using the well logs to make synthetics then changing the well logs to sand the synthetics change. However, that does not help because the relationship between well logs and synthetics is not what is of interest. Rather, what is desired is the relationship between rocks and synthetics/seismic.

Log analysis is about the relationship between logs and rocks. Seismic models relate logs to seismic. Therefore, the math already exists to relate rocks to synthetics/seismic. Studying how rocks influence seismic reveals what seismic is telling us about rocks.

In modeling, lithology derived from the well logs is used to create the synthetic seismic gathers. As the lithology changes, the modeled seismic gathers also change. This allows for the creation of thousands of modeled responses of different rocks. From these responses, gathers are created, then P and G sections are created, then finally all rock responses are plotted into P/G crossplot space. *(Figure 4)*

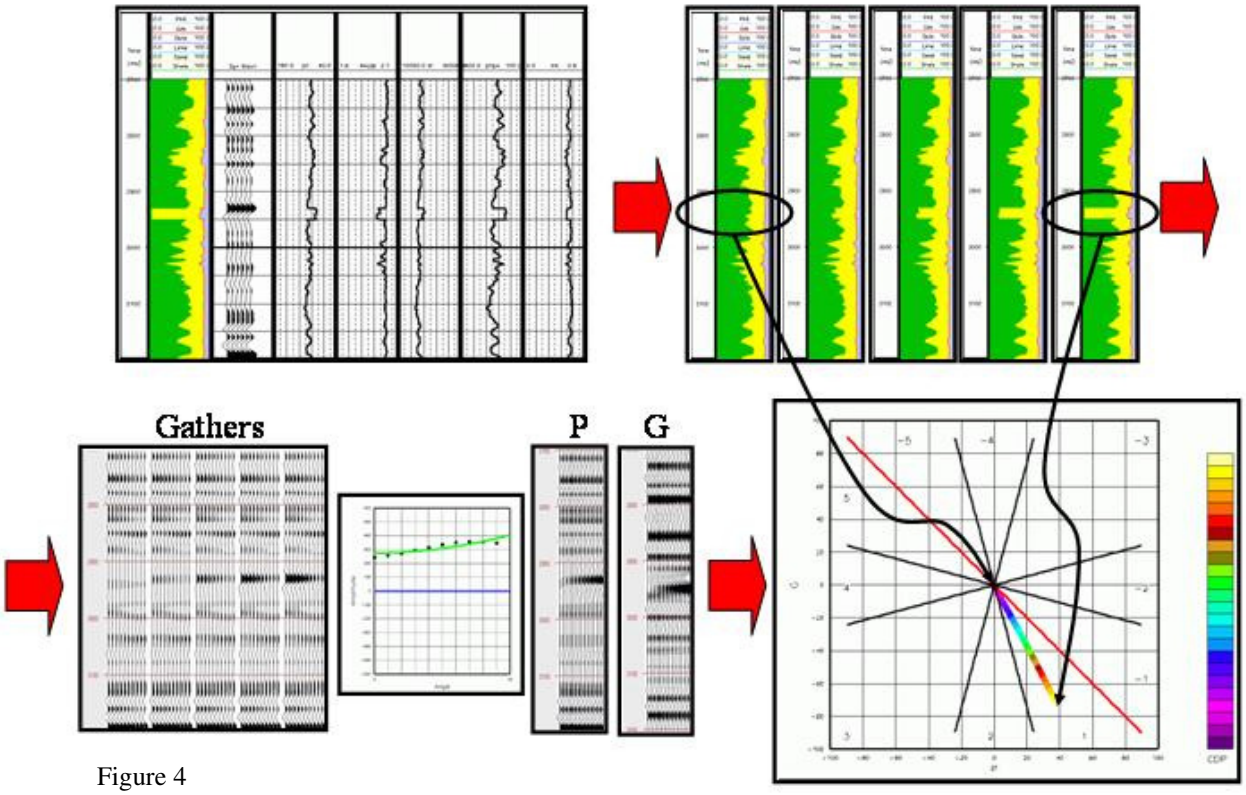

Figure 4

The location that a given shale/sand interface point will plot depends on the properties of the sand and shale. After studying many models it becomes evident that, as the sand becomes cleaner, the point plots further from the origin. Add gas to the sand, and the distance increases in generally a southwesterly direction. Change the porosity, and the direction changes. In other words, porosity acts in an orthogonal way to lithology and fluids. This is similar to what happens with a neutron/density log crossplot.

After studying thousands of different models and hundreds of different data sets, it is easy to figure out what is important in crossplot space:

1. *Elliptical distance from the origin*

The crossplot is elliptical by nature, and its elliptical distance from the origin is a function of lithology, fluids, and thickness. *(Figure 5)*

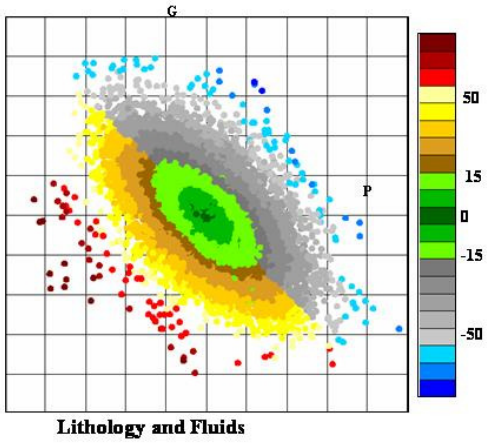

Figure 5

2. *Direction*

Direction is a function of porosity and whether the sand is blocky or laminated. Together these help infer the depositional facies. Direction is called AVO type and is divided into 10 different types form 5 to -5 as shown. *(Figure 6)*

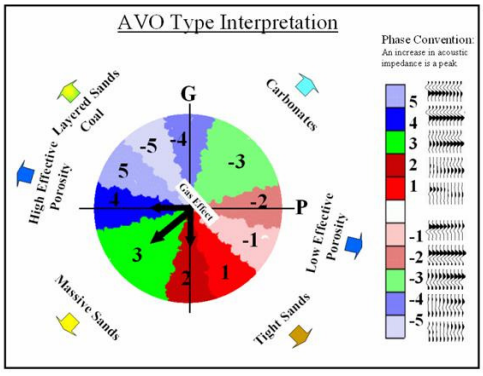

Figure 6

The lithology fluid section (elliptical distance) gives insight into the rock's lithology contrast, fluid contrast, and thickness. The AVO-type section (direction) provides insight into the rocks porosity and depositional facies. From this information it is easy to pinpoint the best well position.

With distance and direction being the important attributes, the volumes can easily be scanned and mapped for the seismic characteristics that will best reduce risk in a given area. This is demonstrated below *(Figure 7)* in the sections and horizon maps of Lithology and Fluids along with the AVO Types from a commercial gas discovery.

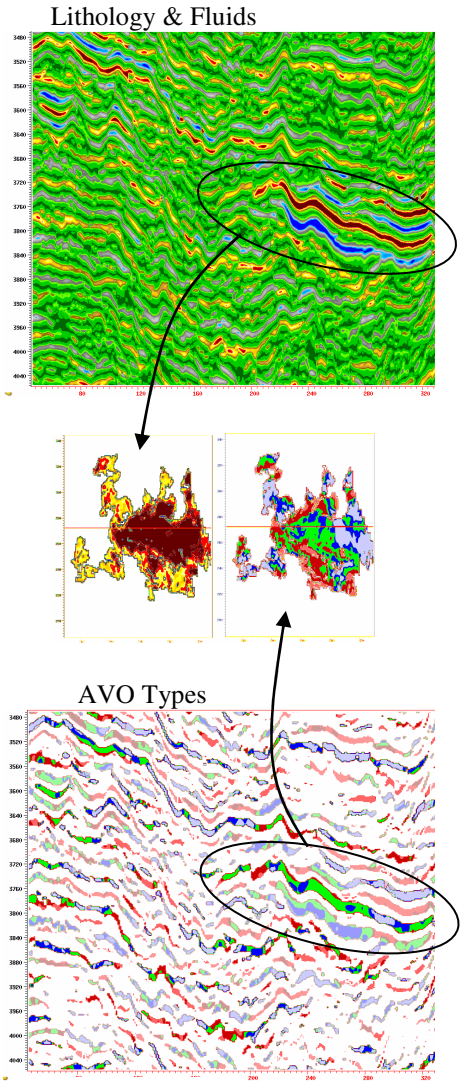

Figure 7

Summary

These technologies allow independents to more easily and accurately find and develop reserves with tools that are useful throughout the lifecycle of a project. The marrying of petrophysics with geophysics results in a science we term seismic petrophysics. The goal is to understand the petrophysical information that seismic data brings to the table. This starts with a good understanding of the rocks. Because the seismic data is in terms of lithology, porosities, and fluids, not velocities and densities, this information can be used by not only geoscientists, but also drillers and reservoir engineers to provide exploration companies with a more strategic and precise model for finding and developing hidden oil and gas reservoirs.