The Geophysical Corner is a regular column in the EXPLORER, edited by Satinder Chopra, chief geophysicist for Arcis Seismic Solutions, Calgary, TGS, Canada, and a past AAPG-SEG Joint Distinguished Lecturer.

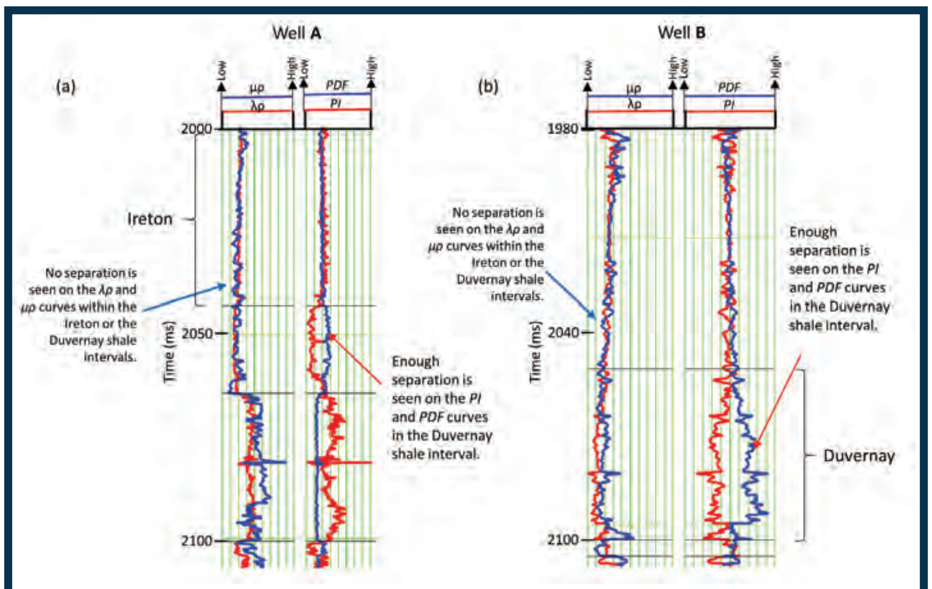

Figure 1: Comparison of λρ – μρ and PI-PDF well log curves. On scaling the curves such that they are seen to overlay for the background lithology, no separation is seen on the λρ – μρ curves in the Ireton and Duvernay shale sections while enough separation is seen on the PI and PDF curves for well (a) A and (b) B.

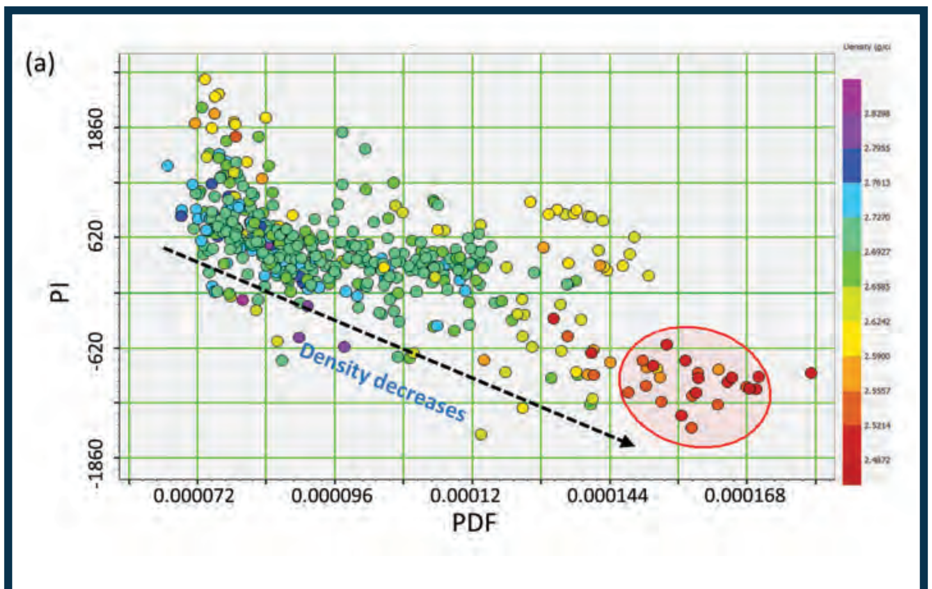

Figure 2(a): Crossplot of PI vs PDF attributes computed for well log data for the time interval shown in figure 1, color-coded with density. It is noticed that density decreases in the direction of the black arrow. Points corresponding to low density (high PDF, low PI) are enclosed in the red polygon as they show the characteristics of a source rock.

Poisson Impedance Application to Shale Resource Characterization

By RITESH KUMAR SHARMA and SATINDER CHOPRA

The main goal for shale resource characterization is usually the identification of sweet spots, which represent the most favorable drilling targets.

Such sweet spots can be identified as those pockets in the target formation that exhibit high total organic carbon (TOC) content, as well as high brittleness. This is based on the fact that the higher the TOC in a formation, the better its potential for hydrocarbon generation, and the higher the brittleness, the better its fracability.


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The TOC content is usually determined from well log data and calibrated with the available core data. But such a determination can only be made at the location of the wells, even though we wish to determine this property in a lateral sense.

We thus turn our attention to seismic data. As there is no direct way of computing TOC using seismic data, we adopt indirect ways for doing so.

Separating Gas Sand Reservoir From Background Lithology

TOC changes in shale formations are expected to influence the P-velocity (V_P), S-velocity (V_S) and density (ρ) of those formations. Consequently, it should be possible to detect changes in TOC from surface seismic response through the impedance inversion process.

During the last decade, prestack impedance inversion has been used to compute the P-impedance (I_P), S-impedance (I_S), V_P/V_S and density attributes, amongst others. Of course, the robust determination of density from seismic data requires very long-offsets and noise-free data, which are seldom available. So as to avoid this stringent requirement for determination of density, usually product-attributes are computed. Examples of such attributes are λρ, μρ, κρ and Eρ, where λ and μ are the Lame's constants, ρ is the density, κ is the bulk modulus or the incompressibility, and *E* the Young's modulus of the rock.

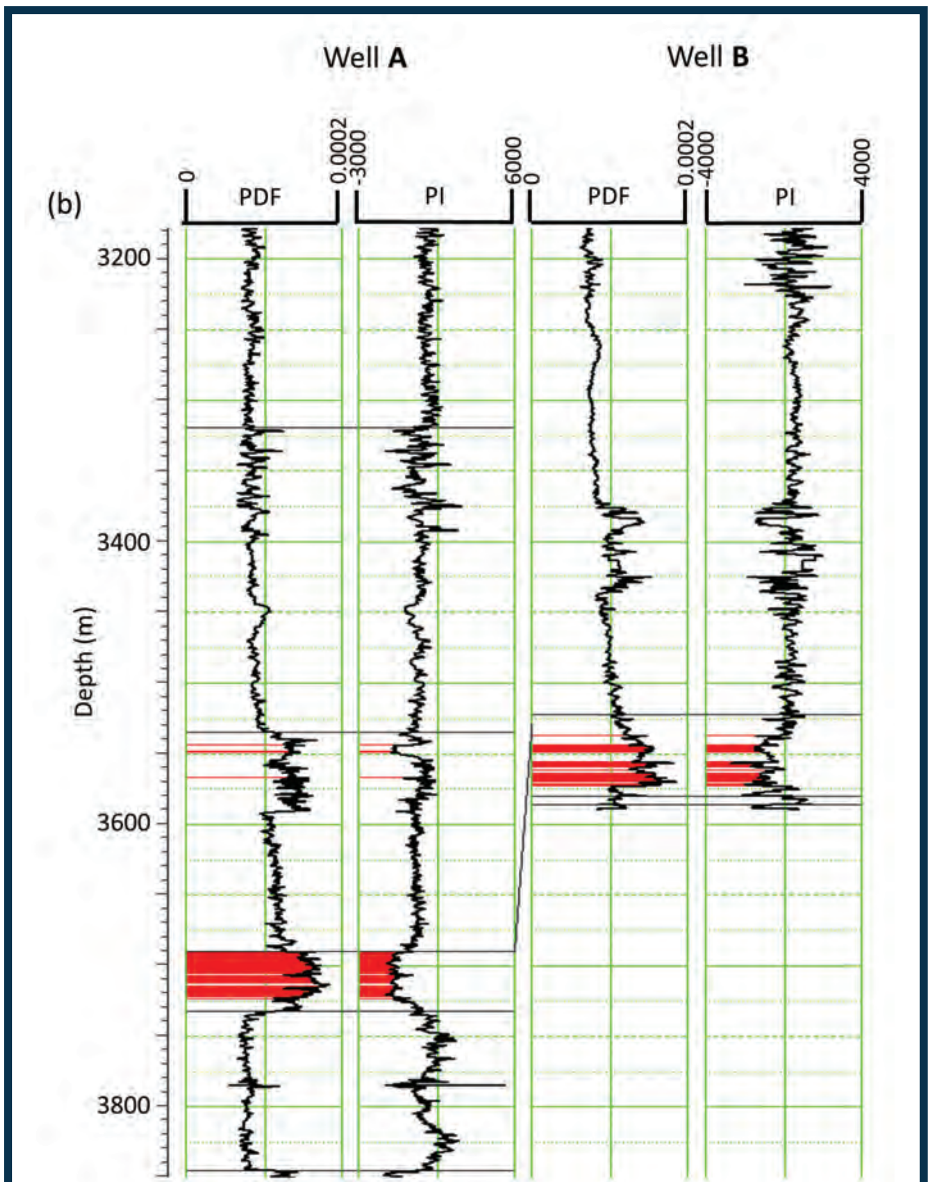

Figure 2(b): Back projection of enclosed points on the well log curves shows that these points are coming from the Duvernay zone for both the wells.

In the case of conventional reservoirs, it is usually noticed that on a crossplot of I_P vs I_S, the cluster of points coming from a gas sand reservoir tend to separate out from the cluster that represents the background lithology. The extent of separation between such clusters depends on the impedance contrast between the litho-fluid and the background lithology.

Enhanced separation between clusters of points representing gas sands and those that represent the background lithology is sought by crossplotting other combinations of seismic attributes such as λρ and μρ. Gas sands usually exhibit lower values of λρ and high values of μρ, and are generally seen to exhibit a somewhat better cluster separation, though it may not be always the case. In the latter case, an interesting attribute called "Poisson impedance" (PI) has been suggested to work better. Mathematically, *PI* is given as $PI = I_P - cI_S$, where the index c describes the optimum rotation of the cluster of points in the I_P vs I_S crossplot space for obtaining better litho-fluid discrimination. The value of '*c*' is determined as the inverse of the slope of the regression line on an I_P vs I_S crossplot. *PI* shows better discrimination of pay sands from the background lithology.

With this done, we may still be faced with the issue of variation in sand quality, i.e. the ability to separate clean sands from shaley or dirty sands. For this purpose, another attributes known as *Poisson dampening factor* (*PDF*) was introduced and is mathematically given as:

$$\frac{D}{\rho} = \frac{I_P + \sqrt{2} I_S}{2\,(I_P^2 - I_S^2)}$$

A crossplot of *PI* vs *PDF* is found to be interesting as it helps with lithology discrimination and extended characterization of sand quality. Good quality or clean sands exhibit high values of *PDF* and low values of *PI*.

Application to the Duvernay Formation

Armed with all this information about *PI* and *PDF*, we decided to apply it to an unconventional reservoir, i.e. the Duvernay Formation of central Alberta, Canada. The Duvernay shale play has been recognized as the source rock for many of the large Devonian oil and gas pools in Alberta, including the early discoveries of conventional hydrocarbons near Leduc, south of Edmonton, Canada. We began with the well log data and crossplotted different attributes, which can be derived seismically. The commonly considered pairs of attributes for the purpose are I_P - I_S, λρ – μρ, I_P – V_P/ V_S, etc. As discussed above, for conventional gas sand reservoirs, λρ and μρ pair of attributes is found to be superior to the I_P - I_S pair, or some other attributes in terms of fluid and lithology

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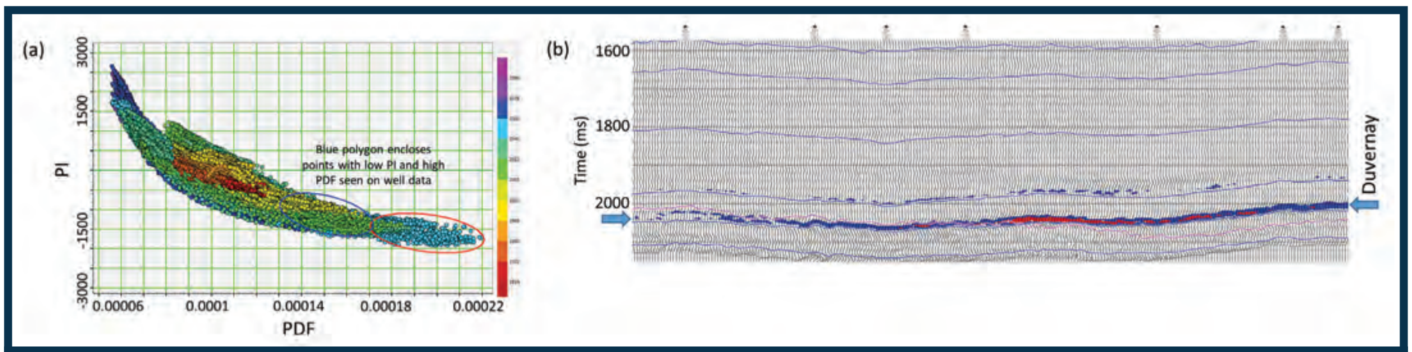

Figure 3: (a) Crossplot of PI and PDF attributes derived from post-stack joint inversion along an arbitrary line that passes through the different wells over a zone that covers the Duvernay formation. Blue polygon encloses points with low PI and high PDF seen on well-log data for the Duvernay formation. Points enclosed by red polygon show lower values of PI and higher values of PDF than the values of points enclosed by blue polygon. (b) Back projection of these two polygons shows the prospective zone in the Duvernay shale.

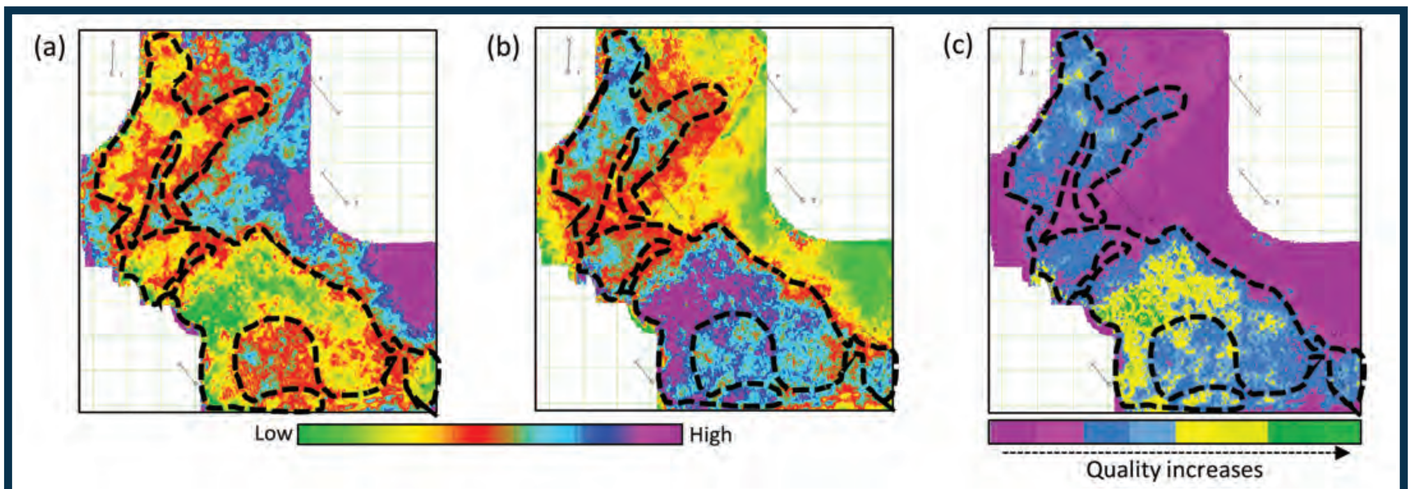

Figure 4: Horizon slices from (a) PI and (b) PDF attribute volumes averaged over a 10 ms-window above the Duvernay base horizon. As low PI and high PDF correspond to the Duvernay formation, the presence of Duvernay formation has been mapped laterally as indicated with the black outline. However, within the Duvernay formation the quality of it is shown in (c).

discrimination. We make a comparison of λρ - μρ with *PI - PDF* attributes. Figure 1 shows this comparison. The panels to the left in figures 1a and b show the λρ (red) and μρ (blue) curves for wells A and B. The curves are scaled in such a way that they overlay each other for the background lithology (in the present case the zone marked above the Duvernay formation).

In the Duvernay zone (source rock), we expect lower λρ values and somewhat higher values of μρ, compared with a non-source rock. However, we do not notice this on the λρ and μρ curves in figures 1a and b. On the right panels in figure 1a and b, we have plotted *PI* and *PDF* curves, again scaled so that they overlap in the background litho-intervals as for the λρ and μρ curves. Notice that the *PI* and *PDF* curves show a crossover separation in the Duvernay intervals in the two wells with respect to the background litho-intervals. With this encouraging observation, we crossplotted *PI* and *PDF* for both the wells for the same intervals, color-coded with density values and is shown in figure 2. Data points corresponding to very low density correspond to high *PDF* values and low *PI* values, which may be considered favourable for source rocks. To ascertain the location of these points on the log curves, we enclose some points on the crossplot in a polygon and back-project them on the log curves. Notice in figure 2b, the data points come from the Duvernay zone in both the wells.

We now turned our attention to deriving the *PI* and *PDF* attributes from seismic data. As these attributes are a function of I_P and I_S, we need to compute both these attributes using simultaneous or joint impedance inversion. Both these types of impedance inversion technique have been discussed by the authors in an earlier GeoCorner article (July 2015). We picked up post-stack joint inversion data for the present study, which uses the *PP-* and *PS*-stacked data from a multicomponent seismic survey over the area.

Employing the *P*-impedance and *S*-impedance low-frequency impedance models, and the appropriate wavelets

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from the two seismic datasets in the broad zone of interest, the *P*- and *S*-impedance attributes are derived.

Figure 3a shows the crossplot of inverted *PI* and *PDF* along an arbitrary line passing through different wells over a zone that broadly covers the Duvernay interval. The overall shape of the cluster of points seen on this crossplot is similar to the equivalent crossplot obtained with well log data shown in figure 2a.

The cluster of points enclosed in the blue polygon are those that exhibit low *PI* and high *PDF* values on the log data for the Duvernay formation. The points enclosed in the red polygon show lower values of *PI* and higher values of *PDF* than the points enclosed in the blue polygon.

Analogous to the conclusions that we draw from such crossplots for conventional plays, we notice that as we go from the blue to the red polygon, the quality of shale should improve. The back projection of these two polygons on the seismic line shows the location of these points and as shown in figure 3b we observe these points highlighting the Duvernay interval. What we conclude here is that the red zone represents better quality shale that the blue zone. The presence of quartz (sand) in the clay decreases its density, which may lead to an increase in *PDF* values associated with it. Higher content of quartz enhances its brittleness, and thus the better quality of shale we refer to has a reference to its brittleness. The red zone thus may be considered being more brittle than the blue zone.

As we desire to identify sweet spots in a lateral sense over the interval of interest on a 3-D volume we generate horizon slices of *PI* and *PDF* over a 10 ms window above the base of the Duvernay interval, and are shown in figures 4a and b. We interpret low *PI* and high *PDF* values as corresponding to the Duvernay zone based on the above-mentioned observations, and are shown enclosed within a black outline.

Finally, based on the values of *PI* and *PDF* we compute the quality of the Duvernay shale, shown in figure 4c. The magenta color corresponds to the background trend, and the quality of the shale increases as we go from dark blue to light green colors.

In conclusion, thus we have demonstrated the characterization of the Duvernay shale in terms of *PI* and *PDF* attributes in a qualitative way, both on well log and seismic data. We suggest the application of the above workflow for characterization of other shale plays and also ascertain how well the predictions are met on drilling.

We thank Arcis Seismic Solutions, TGS, for allowing us to present this work.

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of geothermal generating systems for different types of geothermal resource. At a few locations (e.g., Larderllo, Italy; The Geysers, California), the resource is dry steam at a temperature greater than 300 degrees. The steam is fed directly to a turbine, which turns a generator to produce electricity. More commonly the resource is water at a temperature of greater than 360 degrees, which is flashed to water and steam at the surface. The steam is fed to a turbine, which turns a generator to produce electricity and the water is injected back into the reservoir to maintain reservoir fluid volume. For both dry-steam and flashed-steam power plants, more than one stage may be connected in series with the steam pressure decreasing at each stage.

For geothermal resources with temperatures lower than about 350 degrees, a binary system is used. In the binary system the geothermal fluid passes through a heat exchanger where a secondary fluid with a lower boiling temperature than water is vaporized. The geothermal fluid is then reinjected back into the reservoir. The vaporized secondary fluid drives a turbine that turns a generator to produce electricity. The secondary fluid is cooled before returning to the heat exchanger resulting in a back-pressure on the turbine. Two types of secondary fluid are used in operating binary power plants, organic refrigerants, (the organic rankine cycle, or ORC), and a mixture of two components, typically ammonia and water (the Kalina Cycle).

Economic geothermal power generation systems are currently sited on geothermal resources with sufficient permeability to produce adequate flow to maintain the energy transfer required for the electricity production. Experimental systems have been explored in a few countries in which permeability has been enhanced by hydraulic fracturing or similar techniques (enhanced geothermal systems, or EGS), but these systems are still in the investigation stage.

Some geothermal waters, especially with magmatic heat sources, have a high mineral content with solutes that can include economic concentrations of silica, zinc, lithium, manganese, gold, silver and some rare earth minerals. After the heat has been extracted from the geothermal fluid, one or more of these minerals may be extracted, increasing the economic return of the geothermal operation.

Direct use of geothermal resources and geothermal power production make valuable contributions to the mix of renewable but they are geographically limited to where high temperatures are near the surface or where the use justifies the cost of drilling.

Ground-source heat pumps may be used at almost any location where space heating and/or cooling, and even hot water and refrigeration are required.

Heat pumps are not an energy source and consume electricity. However, the energy savings that result from replacing most conventional heating and cooling systems with ground-source heat pumps would make a large reduction in the quantity of electricity needed to be generated. The most efficient and cleanest electricity is the electricity that does not need to be generated.

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