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PSNew Attribute for Determination of Lithology and Brittleness*

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Abstract

The discrimination of fluid content and lithology in a reservoir is an important characterization that has a bearing on reservoir development and its management. For the unconventional reservoirs, such as shale gas formations, besides other favorable considerations that are expected of them, it is vital that reservoir zones are brittle. Brittle zones fracture better and fracturing of shale gas reservoirs is required for their production. Amongst the different physical parameters that characterize the rocks, Young's modulus (E) is a measure of their brittleness and can characterize such stiffer pockets in shales and some practitioners have demonstrated the determination of Young's modulus from seismic data by way of inversion. One limitation of such an approach is the requirement of density, which as stated above is difficult to derive from seismic data, unless long offset information is available.

Considering the importance of an attribute that could yield information on the brittleness of a reservoir as well as be a good lithology indicator, we propose a new attribute, Eρ, which is the product of Young's modulus and density. This is different from the conventionally used attribute, μρ, where μ is the shear modulus. We begin by first comparing the derived μρ and Eρ curves for a well in northern Alberta and showing how the Eρ curve emphasizes the variation corresponding to lithology change more than in the μρ curve.

For implementation of this analysis on seismic data, we considered a gas-impregnated Nordegg member of the Jurassic Fernie Formation of the Western Canadian Sedimentary Basin. It consists of predominantly brownish, greyish and black shales. These "shales" vary from siliceous rich cherts and dolomites to carbonate rich shale. Due to the complex geology of the reservoir in the Nordegg, differentiating the lithology and fluid content is a challenge. Thus, as the first step, simultaneous impedance inversion was run on the pre-conditioned 3-D seismic data to obtain P-impedance and S-impedance volumes, which are then transformed into μρ and Eρ volumes as, discussed above. We notice that not only does Eρ attribute have a higher level of detail than the μρ attribute, the sandstone presence exhibits lower Eρ values, whereas the availability of

dolomitic siltstone exhibits higher values. The new attribute (Eρ) should not only be a good lithology indicator, but one that intensifies the variation in lithology as well.

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Summary

The discrimination of fluid content and lithology in a reservoir is an important characterization that has a bearing on reservoir development and its management. For the unconventional reservoirs, such as shale gas formations, besides other favorable considerations that are expected of them, it is vital that reservoir zones are brittle. Brittle zones frac better and fracing of shale gas reservoirs is required for their production. Amongst the different physical parameters that characterize the rocks, *Young's modulus (E) is a measure of their brittleness*. Attempts are usually made to determine this physical constant from well log data, but such measurements are localized over a small area. For studying lateral variation of brittleness in an area, 3D seismic data needs to be used. Computation of Young's modulus from seismic data requires the availability of density (ρ). The computation of density in turn requires long offset data, which is usually not available. In this study, we propose a new attribute ($E\rho$) in the form of a product of Young's modulus and density. For a brittle rock, both Young's modulus and density are expected to be high, and so the $E\rho$ attribute would exhibit a high value and serve as a brittleness indicator. As well, we demonstrate the usefulness of this new attribute for litho-fluid detection, when it is used in conjunction with the product of bulk modulus and density.

Introduction

The properties that have a direct impact on the relevant elastic constants are *bulk modulus*, *shear modulus*, and *Young's modulus*, amongst others. Bulk modulus (κ) is a measure of a material's resistance to change in volume and is known as incompressibility. It is treated as a porosity indicator. Shear modulus (μ) is measure of rigidity of a rock or resistance to deformation taken in a shear direction and is treated as a lithology indicator. Further, Young's modulus (E), also known as stiffness modulus is a measure of the stiffness of the material of the rock. Historically, on the basis of these physical properties, geoscientists have attempted to delineate the fluid and lithology content of a reservoir.

In the absence of density, efforts have been made for characterization of a reservoir in terms of lithology and fluid content. For this purpose, *Ip* and *Is* are used for litho-fluid discrimination as *Ip* is sensitive to fluid, whereas *Is* is not. Goodway et al (1997) proposed the determination of rock physics parameters such as Lame's constants (λ and μ) from *Ip* and *Is* and demonstrated that as λ (sensitive to pore fluid) and μ (sensitive to the rigidity of the rock matrix) may be difficult to isolate from seismic data, but $\lambda\rho$ and $\mu\rho$, where ρ is density, can be easily determined from *Ip* and *Is*. Besides, these attributes show better discrimination of lithology and fluids in the $\lambda\rho - \mu\rho$ crossplot space. Russell et al (2003) proposed the use of the more generalized fluid term (ρf), instead of just the $\lambda\rho$ attribute. Likewise, Katahara (2001) investigated the application of $\kappa\rho$ attribute using well data, for enhancing the detection of fluid. More recently, Dabagh et al (2011) have shown a comparison of $\kappa\rho$ and $\lambda\rho$, and that $\kappa\rho$ comes out as a superior attribute for fluid detection.

Objectives

1. We propose a new attribute ($E\rho$) in the form of a product of Young's modulus and density as a brittleness and lithology indicator.
2. We describe it as a scaled version of the $\mu\rho$ attribute and can be derived seismically.
3. Clusters in crossplot space for $\kappa\rho$-$E\rho$ corresponding to lithofluids are seen better discriminated than similar clusters in *$\kappa\rho$-$\mu\rho$ space*.

The stiffness of a rock is an important property, especially important for shale gas reservoirs where fracing is employed for stimulation. Stiffer shales frac much better than ductile ones and enhance the permeability of those zones. Thus, Young's modulus can characterize such stiffer pockets in shales.

Considering the importance of a lithology indicator as well as an attribute that could yield information on the brittleness of a reservoir, we propose a new attribute, $E\rho$, which is the product of Young's modulus and density. While $E\rho$ accentuates lithology detection in terms of brittleness, $\kappa\rho$, intensifies fluid detection. $E\rho$ facilitates a new domain, wherein fluid-lithology discrimination can be achieved in a significant way.

Methodology

Young's modulus (E) is the measure of stiffness of a rock and can be defined in terms of bulk modulus (κ) as

$$E = 3\kappa(1 - 2\sigma)$$

where σ is the Poisson's ratio and can be written in terms of *P*-wave velocity and *S*-wave velocity as follows:

$$\sigma = \frac{v_p^2 - 2v_s^2}{2v_p^2 - 2v_s^2}$$

Substitution of this equation into the first one and manipulating yields

$$E\rho = \mu\rho\,\frac{3I_p^2 - 4I_s^2}{I_p^2 - I_s^2}$$

Thus, once we compute *Ip* and *Is* using seismic impedance inversion, $E\sigma$ can be derived directly.

For brine sands, *vp/vs=2*, it can be shown that $E\rho = 8/3(\mu\rho)$.

Examples

1. We now demonstrate the computation of $E\rho$ from well log and seismic data, and show its practical importance.

In Figure 1, we show a comparison of the $\mu\rho$ and $E\rho$ curves for a well in northern Alberta. Notice, the $E\rho$ curve emphasizes the variation corresponding to lithology change more than in the $\mu\rho$ curve.

For ease in interpretation, we segment the input log curves and the results shown in Figure 2 stand out nice and clear.

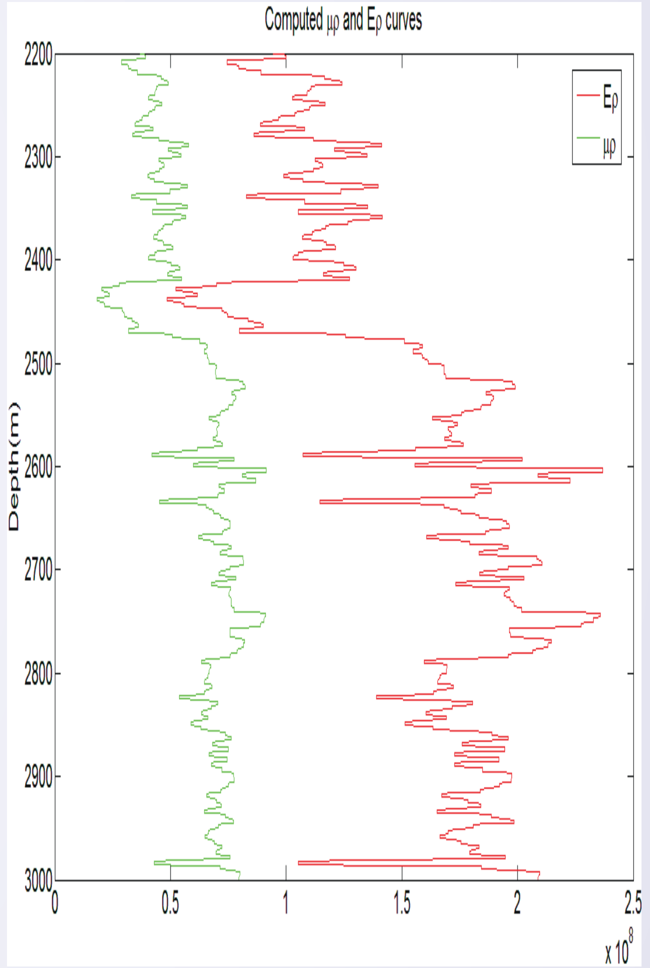

Figure 1

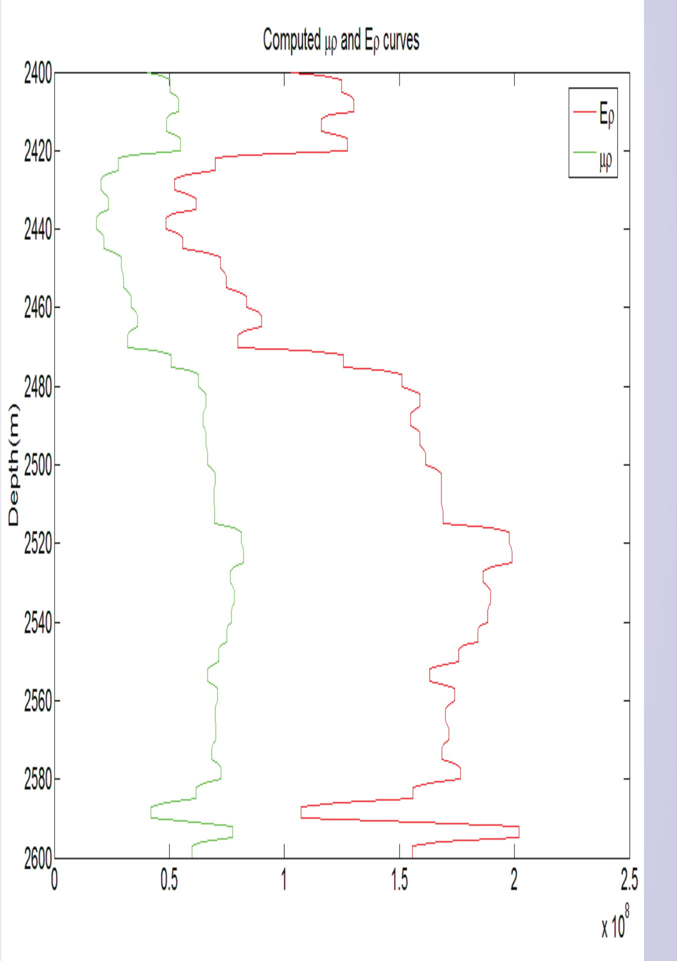

Figure 2

$E\rho$ curves emphasize the variation corresponding to the lithology change much better than than the $\mu\rho$ curve.

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2. For implementation of this analysis on seismic data, we considered a gas-impregnated *Nordegg member of the Jurassic Fernie formation* of the Western Canadian Sedimentary Basin.

The Nordegg member of the Fernie formation varies throughout the WCSB. It consists of predominantly brownish, greyish and black shale's. These "shales" vary from siliceous rich cherts and dolomites to carbonate rich shale.

Due to the complex geology of the reservoir in the Nordegg, differentiating the lithology and fluid content is a challenge. The Nordegg – Montney interface is a regional unconformity which seperates the Jurassic and Triassic strata in the area. The Montney formation is composed of fine grained siltstone grading to fine grained sandstones, with limited shale content. There is a diagenetic dolomitic overprinting on the siltstones and sandstones.

Thus, as the first step, simultaneous impedance inversion was run on the pre-conditioned 3D seismic data to obtain P-impedance and S-impedance volumes. Next, these impedance volumes were transformed into $\mu\rho$ and $E\rho$ volumes as discussed above.

In Figures 3 a and b, we show segments of vertical sections from the $\mu\rho$ and $E\rho$ volumes respectively. Apparently, we notice *$E\rho$ has a higher level of detail than the $\mu\rho$ attribute*. The upper parts of the figures exhibit lower values of the attributes as they correspond to the sandstone presence, whereas the higher values are seen in the lower part, verifying the availability of dolomitic siltstone in this zone.

The time slices of $\mu\rho$ and $E\rho$ attributes taken for the Montney formation are illustrated in Figures 4a and b, respectively, the arrows indicating the points where very noticeable information on lithology is clearly seen on the section.

Crossplots shown in Figures 5 and 6 also show the advantanges of using $E\rho$ attribute.

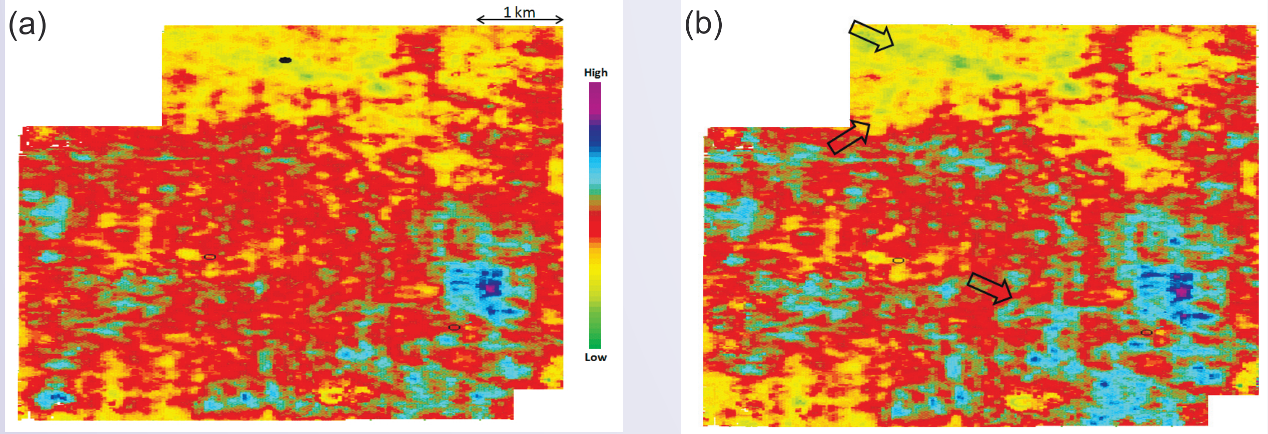

Figure 4: Time slices from the (left) $\mu\rho$ and (right) $E\rho$ attribute volumes taken at the Montney level. Notice, $E\rho$ displays more emphasized detail pertaining to lithology. Arrows indicate the pockets where lithologic information is seen more emphasized than others.

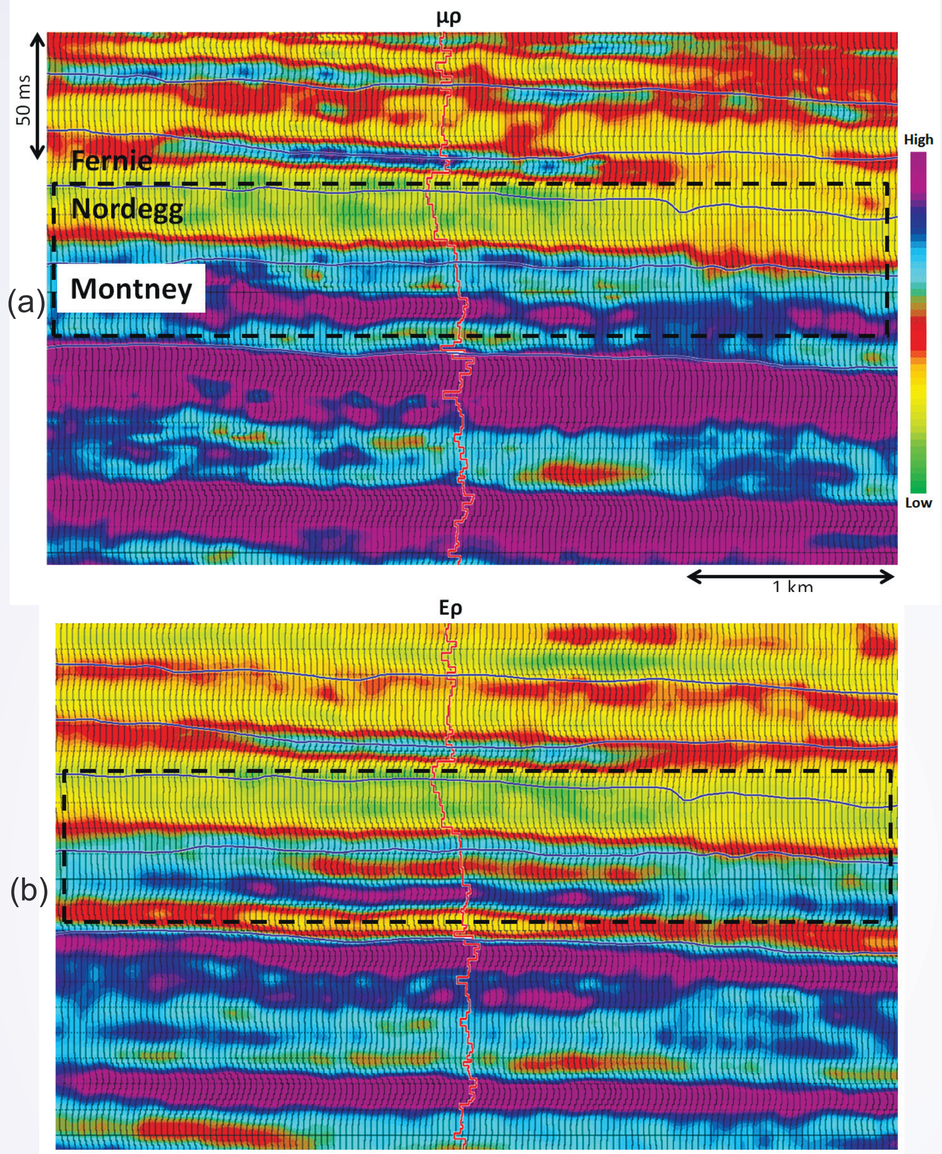

Figure 3: Comparison of $\mu\rho$ section (above) and $E\rho$ section (below), which illustrates the detailed lithology information seen on the $E\rho$ section compared with the $\mu\rho$ section, especially in the rectangular highlighted area.

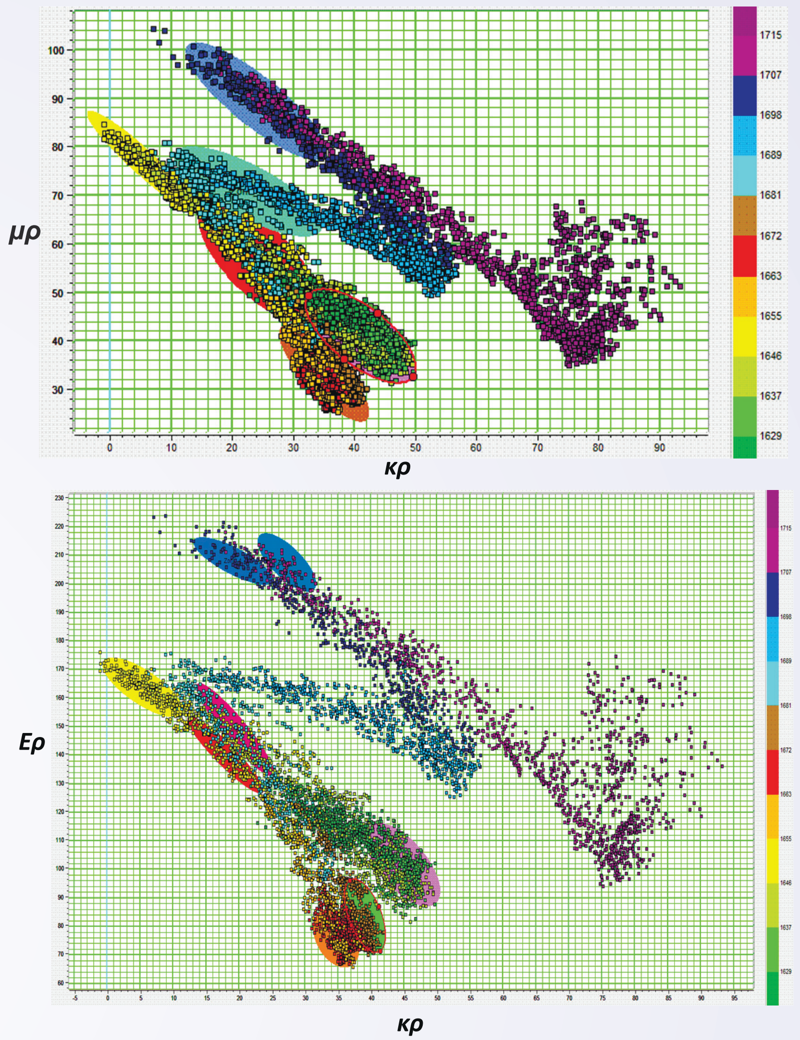

Figure 5: Crossplot of (above) $\kappa\rho - \mu\rho$ and (below) $\kappa\rho - E\rho$ with clusters covering the Ferni, Nordegg and the Montney formations. Notice, the clusters corresponding to these formations are seen much better separated in the lower crossplot than the one above.

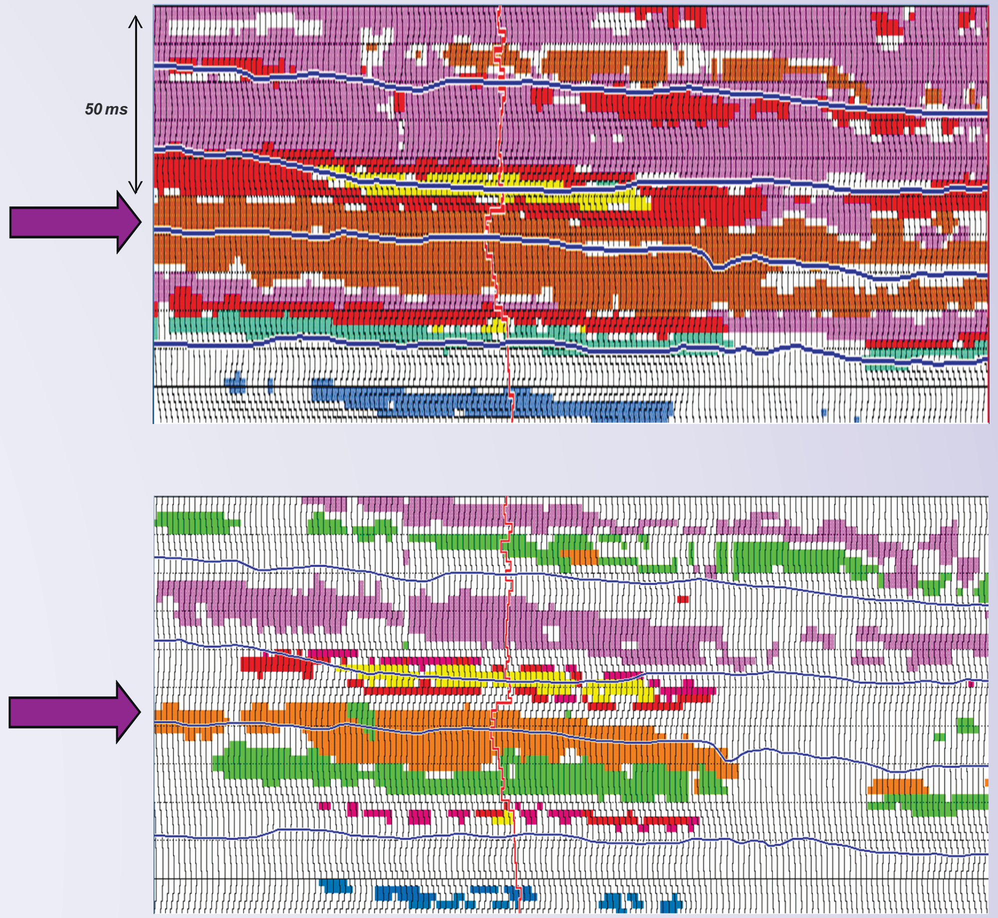

Figure 6: Back projection of cluster points enclosed in polygons as seen on the crossplots for (above) $\kappa\rho - \mu\rho$, and (below) $\kappa\rho - E\rho$. Notice, the upper and lower part of the Montney formation is distinguishable. Ferni and Nordegg formations are also seen as showing variation within their own zones.

References

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3. We now discuss the application of *E*-rho as a brittleness indicator attribute. Brittleness has an important application in shale resource plays in terms of fracing, as brittle formations frac better.

Usually Young's modulus is used for characterizing subsurface formation in terms of brittleness. However, this requires knowledge of density, which is seldom available. Instead of just Young's modulus, we can derive *E*-rho from seismic data, which does not require the knowledge of density. For doing this the first thing to do is to make sure that *E*-rho is similar to the Young's modulus (*E*).

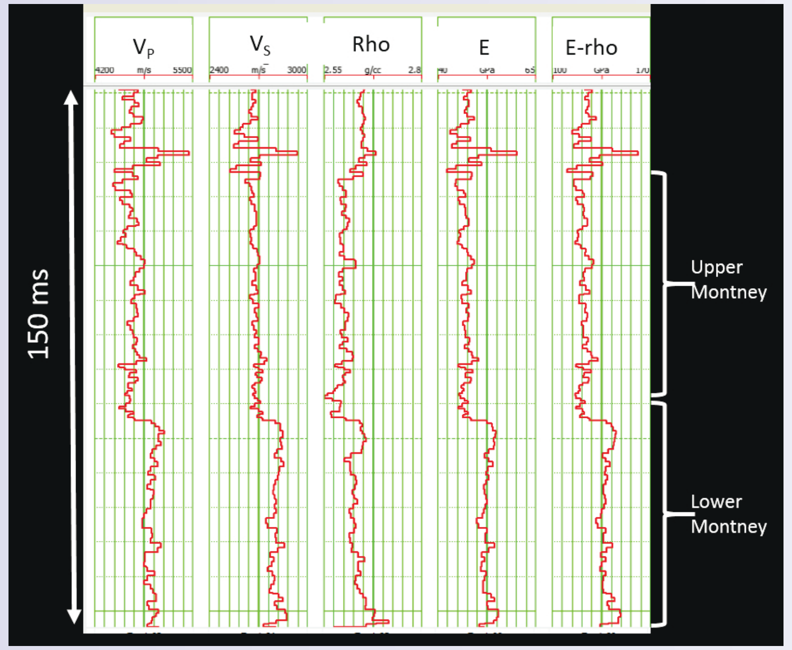
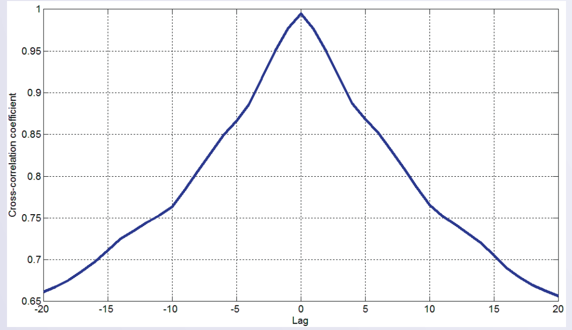


Figure 7: Display of log curves as well as the derived curves *E* and *E*-rho for a broad zone of interest covering the Lower and Upper Montney Formation in British Columbia, Canada. As we notice, the *E* and *E*-rho curves are very similar.

We can authenticate this observation by cross-correlating the two curves and would then expect to have maximum correlation at zero lag for high similarity. We notice this in the adjoining figure.



Having shown the similarity of *E* and *E*-rho at the well location, we now derive these attributes from the seismic data and show how close they are.

To carry out this exercise we needed to get hold of a seismic dataset that had large offsets, so that density could also be computed, and used in order to derive *E*.

In Figure 8 we show the angle information overlaid on the seismic gathers and angles up to 49 degrees were selected for density computation.

A representative density section is shown in Figure 9, which shows lower values of density in the Upper Montney Formation, as expected. The overlaid density curve is seen to match well with the inverted density.

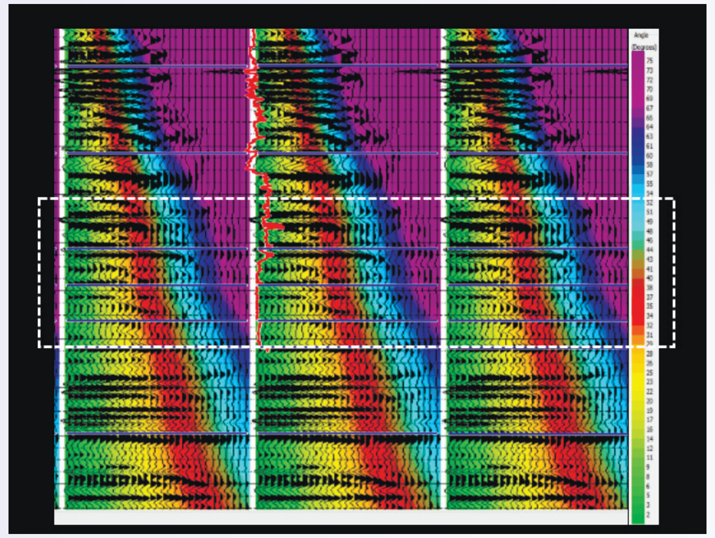


Figure 8: Angle information in colour overlaid on seismic gathers. The range of angles selected for density inversion is up to 49 degrees.

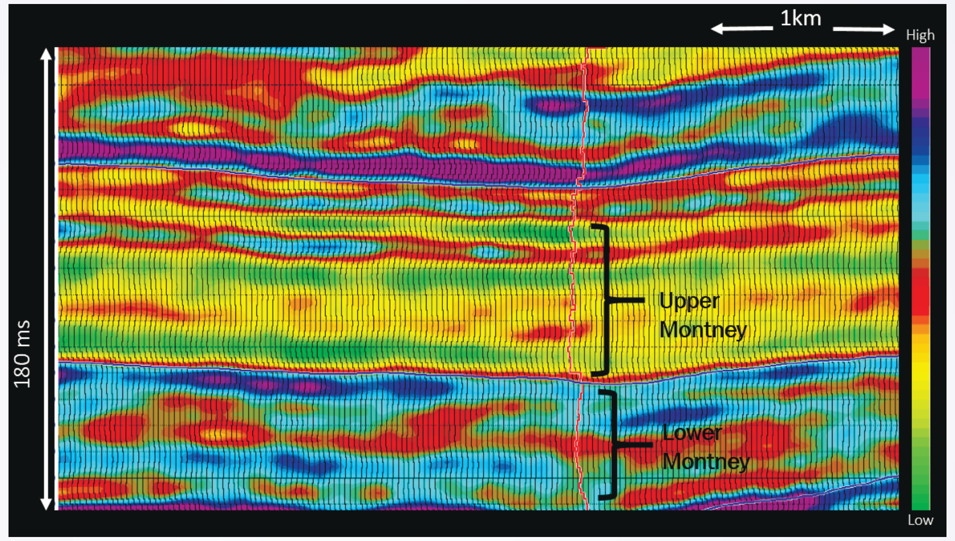


Figure 9: A representative density section computed from simultaneous inversion. Low values of density are seen in the Upper Montney Formation, and the overlaid density curve also shows good correlation.

Conclusions

1. The proposed *new attribute (Eρ)* in the form of a *product of Young's modulus and density, is a good brittleness and lithology indicator*.
2. Using well log and seismic data we have demonstrated that *E and E-rho yield similar results*.
3. This attribute (*E*-rho) *can be derived seismically* and have shown that we can *determine the brittleness of a formation* with it.
4. *Clusters in κρ – Eρ crossplot space* corresponding to the litho-fluids are seen to be *discriminated better than between similar clusters in the κρ – μρ space*.

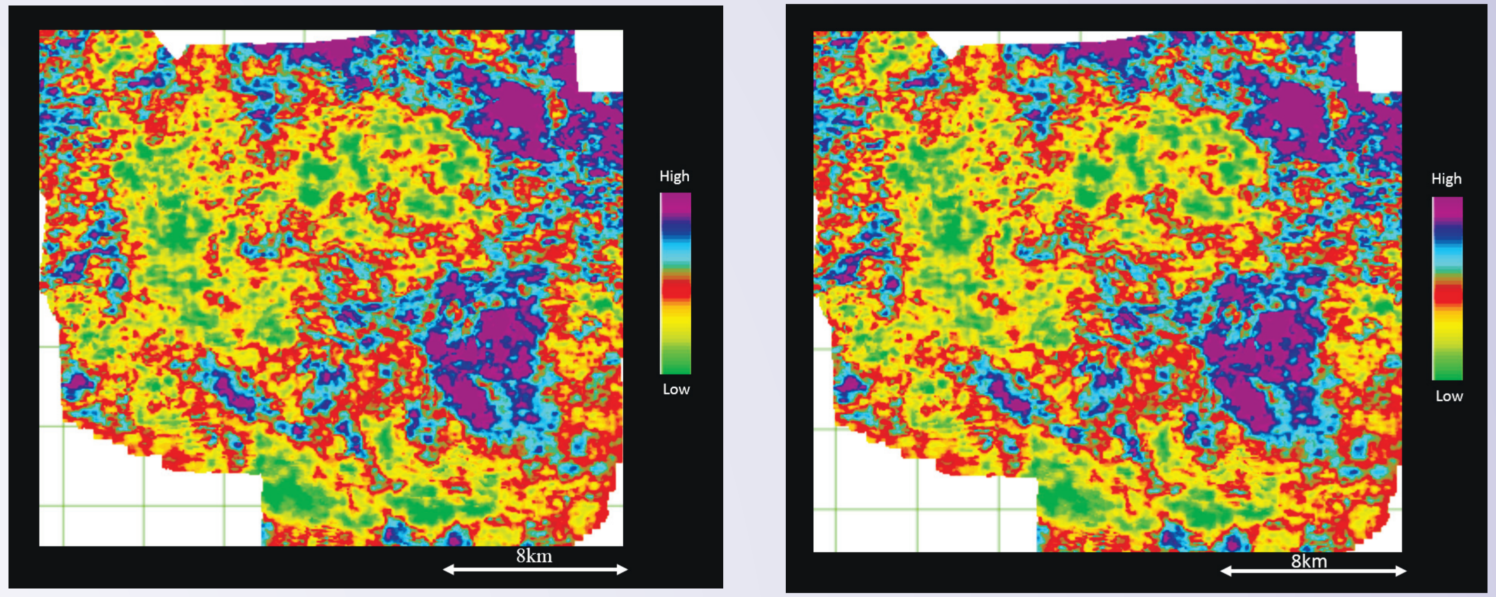


Figure 10: Time slices from within the Upper Montney Formation averaged over a 10 ms window from (left) the Young's modulus volume, and (right) the *E*-rho volume. Apparently, the two are very similar.

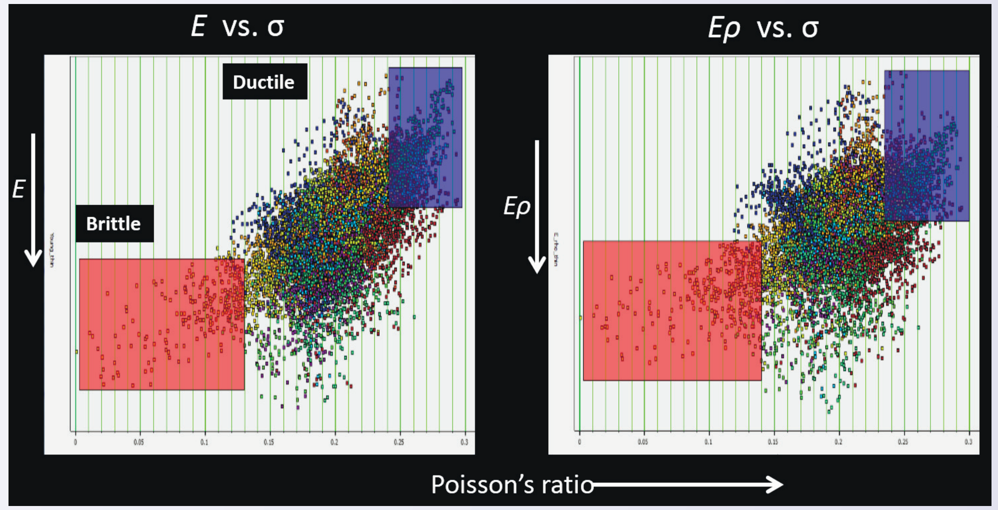


Figure 11: Crossplots between (left) *E* and Poisson's ratio and (right) *E* - rho over a zone that includes the Upper Montney Formation. Notice the similarity between the cluster points. Two polygons corresponding to the brittle (red) and ductile (blue) zones are drawn on thes crossplots and the selected points are back projected on to the seismic shown in Figure 12.

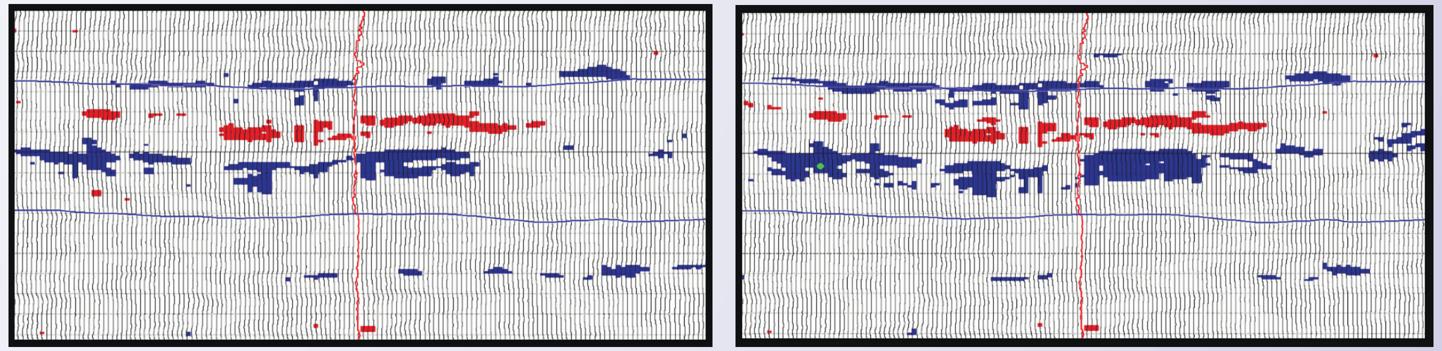


Figure 12: Back projection of points selected by polygons in Figure 11.