New 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, $E\rho$, which is the product of Young's modulus and density. This is different from the conventionally used attribute, $\mu\rho$, where $\mu$ is the shear modulus. We begin by first comparing the derived $\mu\rho$ and $E\rho$ curves for a well in northern Alberta and showing how the $E\rho$ curve emphasizes the variation corresponding to lithology change more than in the $\mu\rho$ 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 $\mu\rho$ and $E\rho$ volumes as, discussed above. We notice that not only does $E\rho$ attribute have a higher level of detail than the $\mu\rho$ attribute, the sandstone presence exhibits lower $E\rho$ values, whereas the availability of
dolomitic siltstone exhibits higher values. The new attribute (Ep) should not only be a good lithology indicator, but one that intensifies the variation in lithology as well.
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Summary

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 $\kappa\rho$-Ep corresponding to lithofluids are seen better discriminated than similar clusters in $\kappa\rho-\mu\rho$ space.

Objectives

- 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.

Methodology

- For a brittle rock, both Young's modulus and density are expected to be high, which accentuates lithology detection in terms of brittleness, $\kappa\rho$, intensifies fluid detection.
- Young's modulus ($E$) is a measure of stiffness of the material of the rock.
- We describe it as a scaled version of the $\mu\rho$ attribute and can be derived seismically.

Examples

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

- In Figure 2, we demonstrate the computation of $E\rho$ from well log and seismic data, and show its practical importance.

Introduction

- The discrimination of fluid content and lithology in a reservoir is a significant challenge in the oil and gas industry. For the unconventional reservoirs, such as shale gas formations, besides other favorable considerations that are expected of them, it is vital that reservoir zones be brittle. Brittle zones frac better and thus improve the performance of shale gas reservoirs. For this purpose, a technique to identify brittle zones is critical.

- Amongst the different physical parameters that characterize the rocks, $\lambda\rho$ of Young's modulus from seismic data requires the availability of density ($\rho$). 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 ($E$) and density ($\rho$). The proposed attribute is insensitive to the variation of density, thus it can be easily computed from seismic data.

- 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 ($\lambda\rho$) is a measure of their brittleness and is treated as a porosity indicator. Further, $E\rho$ can also be considered as a stiffness modulus.

- Historically, on the basis of these physical properties, geoscientists have attempted to delineate the fluid and lithology content of a reservoir.

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

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 frac, 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 ($E$).

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.

Conclusions

1. The proposed new attribute (Ep) 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 (Eρ) can be derived seismically and have shown that we can determine the brittleness of a formation with it.
4. Clusters in $\kappa\rho$ – $E\rho$ crossplot space corresponding to the litho-fluids are seen to be discriminated better than between similar clusters in the $\kappa\rho$ – $\mu\rho$ space.