



From Angle Stacks to Fluid and Lithology Enhanced Stacks

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Summary

Seismic amplitudes contain some additional information about lithology and pore-fluid in the reservoir. By combining intercept and gradient stacks, an optimal seismic stack can be designed to provide maximum discrimination between either fluids or lithologies. This paper will detail the workflow of computing intercept and gradient from a combination of near-mid-far angles stacks. Then define background/shale trend angle from intercept and gradient data at the reservoir. With this trend (angle), fluid and lithology enhanced stacks were generated to verify the fluid contact and lithology/facies changes in the reservoir across the entire seismic survey.

Introduction

Near-mid-far angle/offset stacks are very common dataset available for interpreter nowadays. These are key inputs for calculating AVO attributes where pre-stack gathers are not available or in areas of noisy data. Figure 1 shows how the partially stacked traces have much less noise than the raw gather. A common crossplot of AVO intercept and gradient attributes help to separate the lithology and fluid responses from the background trend. By combining intercept and gradient stacks along an angle of rotation, fluid and lithology stacks can be produced. The key parameter to generate the fluid and lithology stacks is the fluid angle. This angle is typically defined by the apparent V_p/V_s ratio of the background or shale trend on the crossplot. Figure 2 Shows background trend and pay sands AVO response in crossplot.

The fluid stack is an optimal stack for enhancing fluid effects in the seismic data. This stack is used to highlight hydrocarbon reservoirs. A lithology stack is an optimal stack for enhancing lithology variations where fluid effects are removed or reduced. This stack is used for mapping instances of sand.

Method

The methods presented here demonstrate how to rotate and compute intercept and gradient stacks from a combination of near-mid-far angle or offset stacks.

Step 1: Generate intercept and gradient data

With access to prestack gathers, intercept-gradient data can be dynamically generated. An advantage to calculating intercept and gradient from the gathers is that this method provides a degree of confidence in the quality of data being analyzed. The disadvantage to using the gathers is that the method is not very robust in the presence of noise and the gathers require a great deal of disk space. Without access to prestack gathers, a practical technique is to generate intercept-gradient volumes from near-mid-far angle or offset stacks. This technique has proven to be robust even in noisy data areas. Figure 3 shows a cartoon of calculating intercept “A” and gradient “B” values from near-mid-far angle stacks amplitude.



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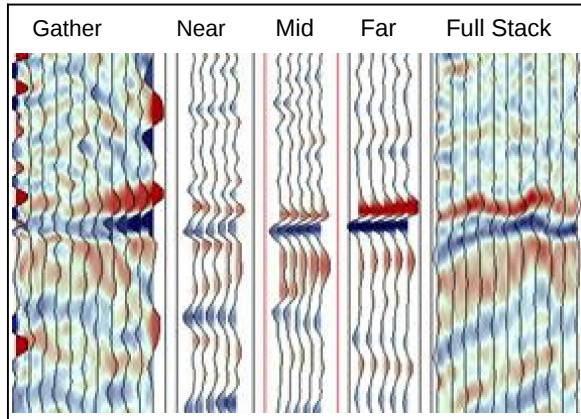


Figure 1: Prestack gather on the left, partial stacks in the middle, and the full stack on the right. The partial stacks exhibit a strong class 3 AVO response with the noise greatly reduced from the gather.

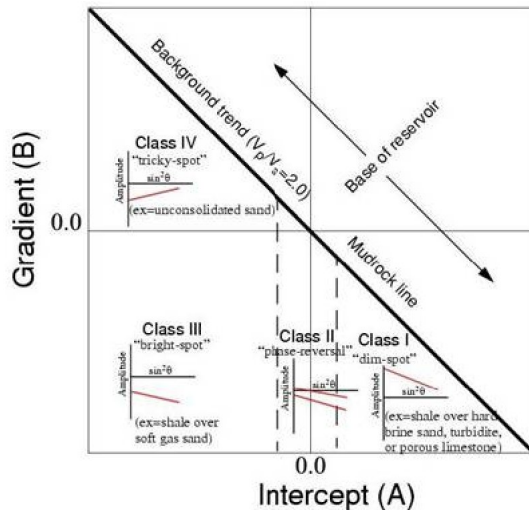


Figure 2: Intercept and Gradient crossplot: Background trend (Mudrock line) and AVO response from hydrocarbon rocks. (From Rutherford Williams classification, 1989)

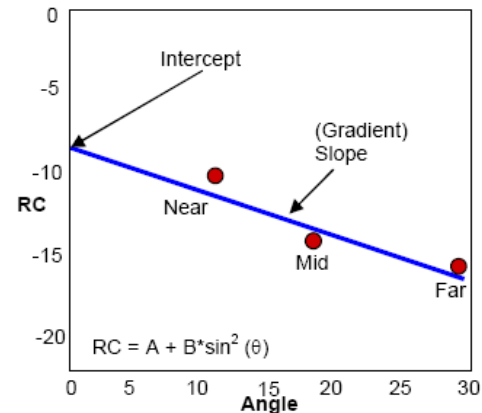


Figure 3: Intercept and Gradient calculation from a linear regression of the amplitudes across near-mid-far stacks

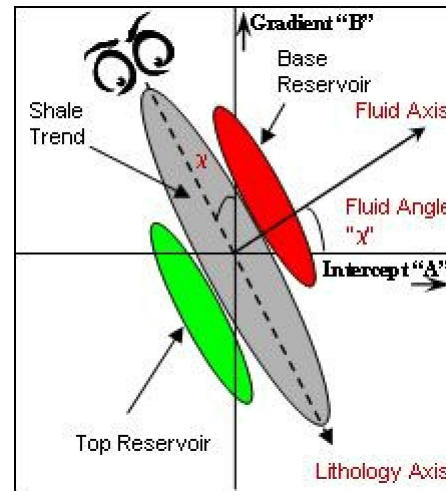


Figure 4: Background/Shale Trend = Lithology Axis, Fluid Axis is perpendicular to Lithology Axis. Fluid Angle ϕ is angle between shale trend and vertical axis.

Step 2: Obtaining the "angle" of the background trend

In crossplot analysis, a customized mudrock or background trend line of the input intercept-gradient data for a particular reservoir can be defined. All hydrocarbon-filled rocks should plot to the left of this line. This line will normally pass through the origin, though it could be offset slightly. This line becomes the lithology axis. The fluid axis is perpendicular to the lithology axis and (normally) passes through the origin. Fluid angle ϕ is typically defined as the angle between background trend and the vertical axis (gradient axis), Figure 4. The amplitude and slope of the real seismic data is often vastly different from the modeled data. This makes it necessary to scale the real data to the modeled synthetic data. Fortunately this step can be done automatically by using AVO analysis software.



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Step 3: Generate fluid and lithology stacks

Once the background trend has been well defined, intercept and gradient data can be transformed into "fluid" and "lithology" data through a simple coordinate axis rotation. Given a user-selected rotation angle (fluid angle) α , the fluid volume and lithology volume are computed from the intercept volume and the gradient volume through the following equations:

$$\begin{aligned} \text{Fluid stack} &= \text{Intercept} * \cos(\alpha) + \text{Gradient} * \sin(\alpha) \\ \text{Lithology stack} &= -\text{Intercept} * \sin(\alpha) + \text{Gradient} * \cos(\alpha) \end{aligned}$$

where α = rotation angle (fluid angle)

The above rotation separates fluids and lithologies along constant intercept or gradient values. Depending on the rotation, different lithologies or different fluids attributes can be maximized in the "rotated stack" section. Figure 5 shows the affects of Fluid and the Lithology rotation. AVO anomalies due to fluids are typically identified as those points that lie far from the background trend (usually below and to the left of it). Hence, creating fluid and lithology volumes simplifies identification of AVO anomalies, as they stand out as strong (typically negative) values on the fluid volume. The lithology volume serves primarily as a check, as a true AVO anomaly will appear on the fluid volume but will not have a corresponding anomaly on the lithology volume. Figure 6 shows an enhanced fluid and lithology stack output.

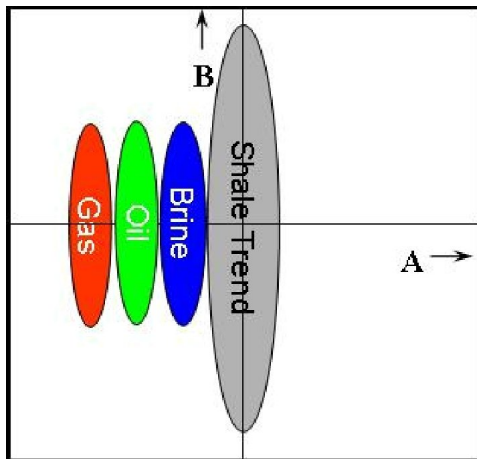


Figure 5: Fluid rotated stack. The same fluid has the same intercept value. The same lithology has the same gradient value.

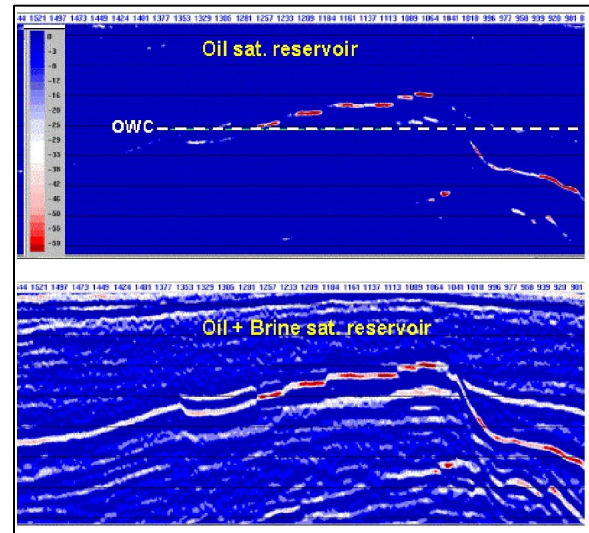


Figure 6: Example of fluid enhanced stack (Top) highlight the Oil saturated reservoir as the bright amp (red color) above the OWC. A combination of fluid and lithology enhanced stacks (Bottom) shows the whole reservoir including brine sands (white color) and oil saturated sands. (Data courtesy of Statoil)

In theory the lithology stack will not contain any bright spots at the target because the bright spot is related to the presence of hydrocarbon and not a change of lithology. The fluid stack should highlight bright spots and fluid contacts quite clearly. The fluid stack can be thought of as the difference between the actual stack and the stack if all the data were in a water-saturated state. For the lithology stack, typically the higher the amplitude the higher the quality of sand in the reservoir. The full-fold stack is just a linear combination of the fluid and lithology stacks.

Examples

Figure 7 is an example using data from the Heidrun field in the Norwegian North Sea. The discovery was based on the gas bright-spot poststack amplitude and the crest of the structure. The hydrocarbon pay sands are shown as AVO Class III response. Intercept and gradient was computed from near-mid-far angle stacks and are then automatically scaled to match the well data. Seismic background/shale was represented by windows of 30ms bellows the top reservoir to calibrate to modeled synthetic. This case the fluid angle is measured about 28° . Fluid and lithology stacks were generated using the rotation angle of 28 degree for entire 3D seismic survey. The fluid stacks output result displays much better continuity higher amplitude value in the pay zone in comparison to normal full-stack section. High amplitude cutoff shows consistent with the OWC in the reservoir.



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Conclusions

When calculating intercept and gradient attributes, input gathers are assumed to be NMO-corrected to align primary events. Multiple energy and other forms of coherent noise, as well as random noise, will degrade the AVO analysis. The problems caused by random noise can be reduced by calculating intercept and gradient from near-mid-far angle/offset stacks. Crossplot analysis of AVO intercept and gradient helps to map out specific fluid or lithology characteristics across the entire seismic survey. Once mapping of a specific fluid or lithology characteristic has been defined, the computer can process the entire 3D volume for that specific characteristic as seismic stack volumes that enhance fluid contacts or lithology changes.

Intercept and gradient volumes can be also inverted to acoustic and gradient impedance volumes. Those are then used to generate fluid and lithology impedance volumes in an extended elastic impedance form.

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