

Amplitude Versus Offset Classification (AVOC): parameterisation and interpretation uncertainties

Introduction

AVO classes (Rutherford and Williams, 1989; Castagna and Swan, 1997) are defined in the reflectivity domain for top gas sand reflectors. With the introduction of coloured inversion (Lancaster, 2000), relative impedance volumes have become widely used, as they resemble geological data more closely than reflectivity data, making interpretation easier. Consequently, AVOC is often applied in the impedance domain to highlight sand bodies rather than reflectivity boundaries. This paper discusses AVOC pitfalls, including the advantages and disadvantages of using AVOC in either the reflectivity or impedance domains, as well as the uncertainties associated with AVOC parameterization.

Definitions and Method

The AVOC theory is based on the AVO response of a top sand reflector within a binary sand/shale lithology model in the reflectivity domain (see Figure 1). Class 1 sands exhibit a strong positive amplitude at near offset (or intercept) that decreases with offset. Class 2 sands have a dim or near-zero amplitude at near offset which increases significantly at far offset. Class 2 is further subdivided: Class 2p shows a small positive amplitude at near offset, with a polarity reversal at mid and far offsets, while Class 2 has a dim negative amplitude at near offset that becomes more strongly negative at far offset. Class 3 sands exhibit a negative amplitude at near offset that becomes increasingly negative with offset. Finally, class 4 sands display a strong negative amplitude at near offset, with minimal change across offsets.

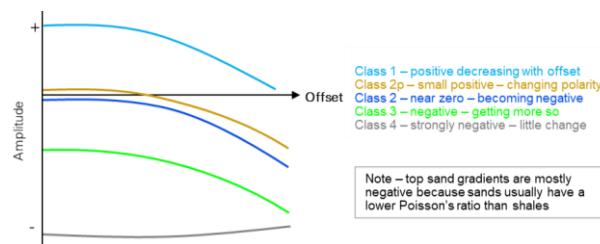


Figure 1 AVOC definition after Rutherford and Williams (1989) and Castagna and Swan (1997).

To generate an AVOC volume from a seismic gather, these steps are typically followed:

- Generate Intercept (Int) and Gradient (Grad) Volumes from the Seismic Gather (Figure 2a):** For each seismic sample, derive intercept and gradient values by applying a linear fit of the reflection coefficient (Rpp) versus the sine-squared of incident angles (up to a maximum incident angle of 30 degrees) (G. Mavko et al., 2009). Repeat this process for all time samples in the gather to produce complete Int and Grad volumes. If applying AVOC in the impedance domain, use Coloured Inversion (Lancaster, 2000) to convert these Int and Grad volumes into Acoustic Impedance (AI) and Gradient Impedance (GI) volumes.
- Define AVOC areas in Int and Grad (Castagna and Swan, 1997) or AI and GI Crossplot Spaces (Figure 2b):** In crossplot spaces, define AVOC parameters to distinguish sand Classes. Define an ellipse to be used as a mask, to exclude random noise, background shale, and wavelet side-lobes. Define positive slopes for the Class 2 to Class 3 boundary and negative slopes for the Class 1 to Class 2p boundary. AVOC in the impedance domain is defined similarly to the top sand AVOC in the reflectivity domain; note that while AVOC parameters apply to both top and base sand reflectors in the reflectivity domain, in the impedance domain sand bodies are defined without explicit top and base boundaries.
- Apply AVOC areas to Generate the AVOC Volume:** Using the AVOC areas defined in step (b), classify each sample in the intercept and gradient volumes or the AI and GI volumes generated in step (a) to produce the final AVOC volume.

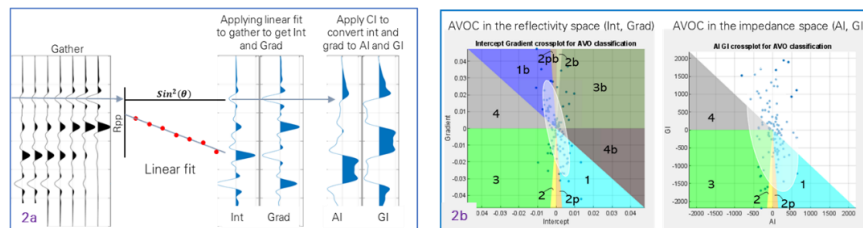


Figure 2: a) Generating Int, Grad and AI, GI from seismic gather b) AVOC parameterisation.

AVOC Parameterization Uncertainties

AVOC results are sensitive to parameter choices, particularly class boundaries and background noise definitions, for which no standard solution exists. Thus, optimization of those elements is often required to allow reliable insight into litho-fluid facies. Figure 3 illustrates a simple binary lithology model with gas sand and wet sand, bounded by identical shale layers in the overburden and under-burden. In this model, Int and Grad (or AI and GI) represent band-limited synthetic data with no noise or multiples, and the expected AVOC is Class 3 for the gas sand interval and Class 1 for the wet sand interval.

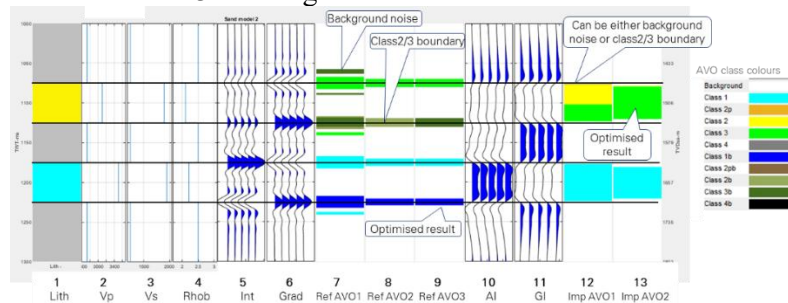


Figure 3 AVOC parameterisation example. Different slopes and background noise definition give different AVOC results

Columns 7, 8, and 9 in Figure 3 display AVOC results in the reflectivity domain. The first parameter set, shown in column 7, results in background noise near the top and base of the AVOC gas sand and wet sand intervals. The second parameter set, with different class boundaries, shown in column 8, yields inconsistent AVOC at the top and base of the gas sand, where they should be the same. Finally, column 9 shows the optimized parameters, resulting in consistent AVOC at both the top and base of each sand interval, with no background noise.

In the impedance domain, results are shown in columns 12 and 13. Column 12 (first parameter set) shows two AVOC bodies within the gas sand interval and some noise near the top. In contrast, column 13 shows the optimized result, where each sand body has a single AVOC, although the top and base of the AVOC bodies are slightly misaligned.

Why does noise appear in the AVOC reflectivity domain, despite the input data being noise-free? And why are the top and base AVOC boundaries more precise in the reflectivity domain than in the impedance domain? This is due to wavelet side lobes. In the reflectivity domain, side lobes are primarily located near the top and base of reflectors, making them easier to remove. However, in the impedance domain, wavelet side lobes contribute more significantly to the boundaries of sand bodies, which complicates noise removal. As a result, removing these side lobe effects does not impact AVOC precision in the reflectivity domain but can reduce boundary accuracy and thickness precision in the impedance domain.

AVOC Interpretation Uncertainties

AVOC interpretation may be a useful method to help determine lithology or fluid type (Avseth et al., 2003, Foster et al., 2010), but it should always be integrated with seismic rock property data for reliable

results. Generally, AVO Classes reflect varying degrees of consolidation, which can correlate with age and burial depth (Avseth et al., 2003). Class 3 typically indicates a shallower, poorly consolidated reservoir; Class 1 represents a well-consolidated reservoir, common in carbonate or hard sand formations; and Class 2 falls between these extremes, often associated with moderately consolidated sandstone reservoirs. Theoretically, AVOC can provide insights into sand quality or fluid content. For instance, in some geological settings, gas sands may exhibit Class 3 AVO behaviour, while wet sands, with similar rock quality may show Class 1 characteristics.

In practice, AVOC interpretation is challenging and comes with significant uncertainties. AVO theory is based on a simple binary model of shale-sand-shale, but real subsurface environments are far more complex, involving variable reservoir properties such as porosity and multiple lithologies - such as sand, shaley sand, silt, carbonate, soft shale, and hard shale - and interference effects between bodies. For example, a low porosity gas sand may have a similar class response as a high porosity brine sand. Additionally, AVOC applies not only to sand bodies but also to shale bodies, especially those with unique properties, like source rocks.

Figure 4 illustrates the uncertainty in interpreting AVOC data. In this model example, the sequence progresses from Class 3 at the top, through Class 1 (top and base) in the middle, down to a Class 2 top at the bottom. A naive interpretation might suggest that the top layer with Class 3 represents gas sand, above a wet sand in the middle (Class 1), with potential for gas in the bottom layer (the Class 2 top). However, the lithology column on the left reveals that: (1) the top layer indeed corresponds to Class 3, (2) the middle layer with Class 1 is actually a gas-bearing shaley sand, and (3) the bottom layer shows Class 2 AVO even though it is shale over shale.

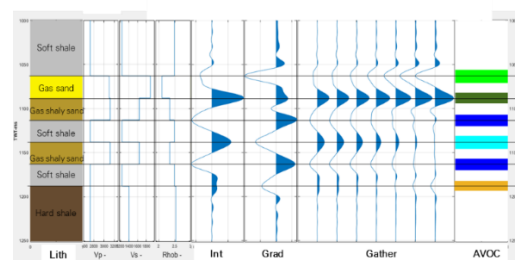


Figure 4 An example of complex AVOC interpretation

This example highlights that real AVO Classes are more complex than theoretical models suggest. AVOC at the top and base of a sand body will vary depending on surrounding formations, and AVOC alone cannot reliably define lithology or fluid content. Integrating AVOC with other data is essential for accurate interpretation.

A key question in AVOC interpretation is whether to use reflectivity or impedance data. While AVOC is defined in reflectivity (specifically for top sand reflectors), AVOC in impedance seems simpler and aligns more closely with geological layering. In reflectivity, the interpretation can be ambiguous; for example, a strong negative intercept with a positive gradient could represent Class 4 if at a top sand boundary but might indicate Class 1 if at a base sand boundary. Often, AVOC volumes alone do not provide clear information about sand interval location. Could the ambiguity in reflectivity be reduced in the impedance domain, where AVOC is applied to bodies rather than boundaries? Does this make AVOC in impedance more straightforward?

Figure 5 compares AVOC in both domains. In model A (left), a simple binary model with thin and thick sand layers, AVOC in the reflectivity domain shows Class 3 at the top and base of both layers. AI-GI bodies in this binary model display similar AVO characteristics to the intercept and gradient top sand boundaries; however, in impedance domain, the Class 3 body for the thin sand layer is misaligned due to side-lobe effects, and the Class 3 body for the thick sand is not well defined due to amplitude variations across the thicker sand body because of band limited data.

Model B (right) demonstrates a more complex scenario, with soft shale at the top, followed by shaley gas sand, shaley wet sand, and hard shale at the bottom. This setup has different overburden and underburden characteristics, making interpretation challenging. In reflectivity, the top of the shaley gas sand

layer shows Class 1 AVO, while its base shows Class 3. The base of the shaley wet sand layer appears as Class 4. In the impedance domain, because of the non-binary model, interpretation appears simpler but is misleading, showing only Class 1 for the shaley gas sand and no AVO response for the shaley wet sand (interpreted as background noise). It also displays Class 4 within the hard shale body, which could be misleadingly interpreted as a sand body with Class 4 AVO.

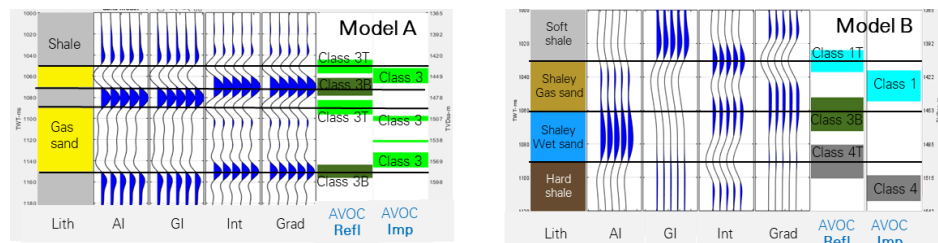


Figure 5 AVOC in different domain. AVOC in impedance domain is strong affected by wavelet sidelobes and potential bias result.

Conclusions

AVOC can be valuable, but it should be part of an integrated interpretation alongside other volumes, such as lithology, fluid volumes, or Vsand volume from stochastic inversion. Observations from AVOC volumes should always be combined with rock physics insights, interpretations from other seismic data, the geological model, and available drilling or production data. AVOC volumes alone are not reliable for predicting lithology or hydrocarbon presence.

The reflectivity domain is recommended for AVOC interpretation. In the reflectivity domain, given adequate resolution and data quality, binary geology will typically show the same AVOC Class at both the top and base of sand layers. The absence of this pairing could indicate a more complex, non-binary geological setting. In such cases, AVOC in the impedance domain can be misleading, as it always shows a single Class or no AVOC (background noise) in a body and may fail to accurately represent thick sands. A reflectivity-based AVOC volume will be better suited to identifying the top and base of thicker sands. Defining AVO slopes and the size of the background noise ellipse mask is not straightforward. When creating an AVOC volume, carefully validate the parameters by conducting quality control at well locations to ensure optimal parameterization. Also, verify seismic data quality: if gradient data quality is poor, the AVOC volume will likely be unreliable.

Acknowledgements

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