Challenges in AVO compliance and calibration in West Africa: Geology versus Imaging

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Summary

Reprocessing legacy 3D seismic data with modern broadband imaging workflows has become a powerful tool for improving structural resolution and amplitude fidelity in frontier and mature basins alike. However, enhanced seismic detail does not necessarily translate into improved exploration decisions, particularly when evaluating Amplitude Versus Offset (AVO) and Amplitude Versus Angle (AVA) responses calibrated to borehole data.

Higher-fidelity data often reveal geological complexities previously unresolved in legacy volumes, enabling more robust rock-physics-based AVO calibration and reducing uncertainty in the discrimination of lithological versus fluid-related anomalies when using attributes such as relative extended elastic impedance (rEEI) and relative elastic reflectivity (rEER).

This paper outlines an integrated, iterative workflow that combines modern broadband reprocessing, rigorous AVO quality control, rock physics analysis, and attribute screening to assess whether amplitude fidelity improvements are real and fit for purpose (Figure 1). Case studies from offshore the Republic of Ghana, the Republic of Guinea, Sierra Leone, and Côte d'Ivoire demonstrate how modern broadband reprocessing, including deghosting and full waveform inversion (FWI), stabilizes pre-stack seismic responses and improves well to seismic ties. The results highlight that improved imaging shifts exploration uncertainty away from data quality and toward genuine geological risk, enabling more reliable AVO driven prospect evaluation across regional seismic datasets.

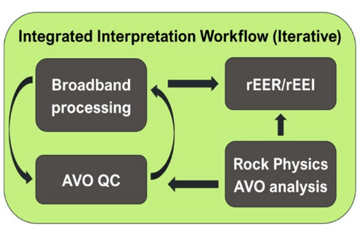

Figure 1: Integrated iterative workflow for AVO stability broadband seismic that is fit for purpose for target mapping and high fidelity for rock physics calibration.

Methodology

Broadband signal recovery is a central objective of modern seismic reprocessing, as improved bandwidth directly impacts both vertical resolution and amplitude stability across offset and angle. Deghosting removes spectral notches caused by interference between primary and ghost reflections at the source and receiver, enabling recovery of both low and high frequency energy (Rickett et al., 2014).

This broader effective bandwidth improves wavelet stability and enhances the interpretability of amplitude-versus-offset behavior, particularly at higher angles where legacy data often suffer from bandwidth loss and phase instability. The combined application of demultiple, deghosting, and FWI produces seismic gathers with stabilized moveout and phase, forming a robust foundation for subsequent AVO analysis (Figure 2) and impedance domain attribute generation.

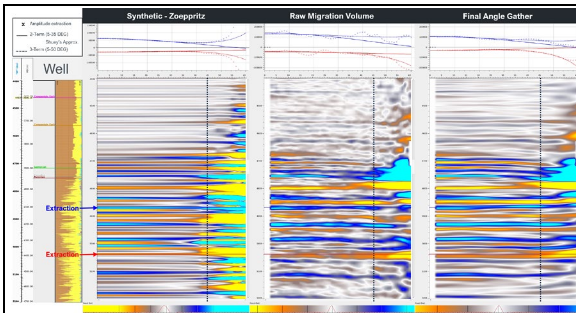

Figure 2: Iterative AVA QC across the processing flow assesses the stability of AVO responses at the calibration well by comparing the borehole synthetic with successive gather versions, ensuring that the final AVA product is robust and geologically meaningful.

The resulting improvement in amplitude consistency is observed not only at well locations but across the entire survey, supporting reliable regional screening for AVO anomalies. Once amplitude behavior has been validated, reflectivity can be inverted to impedance using the rEER and rEEI methodology with a flat background model, which minimizes wavelet dependence and improves inversion stability (Harris and Young, 2024). This approach allows anomalies to be evaluated without reliance on low frequency models derived from wells and supports efficient, large-scale screening of 3D seismic volumes (Figure 3).

The geophysical validity of the rEER and rEEI methodology in clastic basins -including areas with limited borehole control- has been successfully demonstrated in multiple global applications. A notable example is the Isabella field in the Gulf of America, where subtle indications of anomalous seismic amplitudes were observed on the full stack response, whilst the inverted rEEI at 45ºθ or 27ºχ attribute cube provided a clear, lateral coherent anomaly that correlated to the 35m oil column of the Isabella discovery well (Went and Hedley, 2023).

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Although the mapping of the seismic amplitudes is valid and correct on fit-for-purpose data sets, the conclusions drawn from that interpretation can be ambiguous, and these first examples motivate the need for an integrated workflow that combines rock physics calibration, AVO quality control, and impedance-domain attribute analysis.

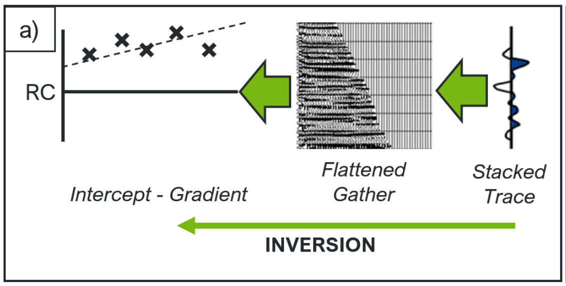

Figure 3: Inversion workflow from reflectivity post stack rEEI volume that allows to map anomalies that can be calibrated with rock physics interpretation of target reservoirs at the borehole location (modified from Went and Hedley 2023)

Examples

To demonstrate the advantages of the integrated AVO analysis workflow at an early stage of seismic imaging or interpretation studies, we showcase the different stages across several studies from offshore West Africa.

The first part of the study focuses on borehole data, rock physics interpretation, and the tie from geophysical logs to geophysical attributes in seismic volumes.

Well data from boreholes offshore the Republic of Guinea, Côte d'Ivoire, and the Republic of Ghana illustrate how amplitude-based interpretation is non-unique when faced with geological complexities such as anomalous mineralogical effects in the clastic pore space - even when modern seismic data are available.

The examples from offshore the Republic of Guinea and the Republic of Ghana illustrate why this distinction is critical. Most clearly shown in the mature Tano Basin offshore Ghana, which is well calibrated, with textbook AVO responses in clean sands with high contrast, where increasingly ambiguous behavior observed near volcanic extrusives likely reflect pore-space modifications that significantly reduce elastic and seismic contrasts between brine-, oil-, and gas-filled reservoirs.

The second part of the study establishes how such an integrated approach, when applied after successful AVO QC of the input datasets, can confirm and validate interpretation from seismic attributes by correlating with rock-physics-based AVO analysis from available borehole data, using examples from Sierra Leone, Côte d'Ivoire, and the Republic of Ghana of independently mapped leads and possible targets that can be correlated with tested locations of exploration wells.

In Sierra Leone, modern reprocessing combined with rigorous AVO QC establishes a robust foundation for interpretation, validated by shallow gas accumulations highlighted by the rEER attribute that evolve from ambiguous responses on legacy data to consistent class IV behavior on reprocessed partial-angle attributes (Figure 4).

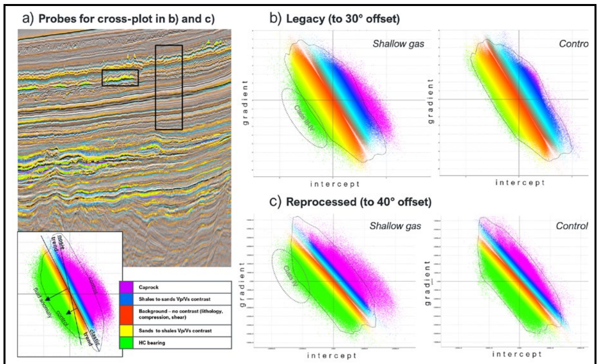

Figure 4: a) Shallow gas offshore Sierra Leone as marked on the seismic section with the rEER overlay on reprocessed full stack depth-to-time domain has been evaluated alongside a control probe over shale/clastics. The cross-plot of intercept vs. gradient over both probes shows an anomaly, on the legacy data set (b) as an indiscernible class III-IV response, whereas on the reprocessed depth-to-time ultra-far angle stacks the anomaly clearly moves to a class IV anomaly (c).

In Côte d'Ivoire, impedance domain attributes such as rEEI provide an effective bridge between well-scale rock physics understanding and regional exploration scouting. By reducing sensitivity to wavelet effects and evaluating seismic responses in a domain closely linked to intercept–gradient behavior, these attributes enable subtle reservoirs and fluid effects to be mapped where conventional full stack amplitudes are insufficient. This demonstrates the practical value of integrated workflows in areas of limited well control and subtle impedance contrast.

Conclusions

The West African case studies demonstrate that modern broadband seismic reprocessing fundamentally shifts the nature of AVO and AVA interpretation. While advances such as deghosting, advanced demultiple, and FWI consistently improve pre-stack amplitude stability and bandwidth (Sirgue et al., 2010), enhanced data quality does not automatically lead to simpler or less ambiguous interpretation. Instead, improved imaging often reveals

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geological complexity that was previously unresolved in legacy datasets, shifting the primary source of uncertainty from data quality to subsurface geology and rock physics variability.

Across all basins examined, systematic AVO quality control is critical for establishing whether reprocessed seismic data are fit for purpose for quantitative interpretation. Metrics such as spectral consistency, near–far correlation, and intercept–gradient stability provide objective evidence that the assumptions underlying AVO theory are satisfied. Once this compliance is demonstrated, residual ambiguity in amplitude behavior can no longer be attributed primarily to processing artefacts and must instead be interpreted in terms of lithology, reservoir quality, diagenesis, and pore space evolution (Avseth et al., 2010).

The Sierra Leone and Côte d'Ivoire case studies demonstrate how an integrated interpretation workflow successfully manages increased subsurface complexity and translates improved data fidelity into exploration value. Importantly, these improvements extend beyond individual well locations, supporting reliable regional screening with confidence in amplitude fidelity.

Taken together, the case studies show that modern imaging workflows fundamentally shift the focus of exploration uncertainty. Legacy seismic data often masked geological complexity through limited bandwidth, unstable amplitudes, and incomplete offset coverage, resulting in seemingly cleaner data but ultimately masking key risks associated with reservoir quality, diagenesis and pore space evolution, potentially leading to misinterpretations. Modern broadband reprocessing removes many of these limitations. Ultimately, modern imaging does not simplify the subsurface; although the resulting datasets are fit for purpose from a geophysical perspective and more sensitive to geological variability.

Where borehole and modern seismic data independently may provide a more precise interpretation, interpreting with renewed accuracy is only feasible by adopting integrated workflows early and iteratively, rather than treating them as a post-processing validation step.

Finally, integrated and iterative interpretation workflows provide a structured and scalable approach to recognizing this shift and to derisking exploration decisions. Exploration teams can leverage improved seismic fidelity to better understand geological complexity, place amplitude anomalies in their correct context, and make more informed, risk-aware exploration decisions.

Acknowledgements

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