Identification and geological validation of AVO driven opportunities in frontier basins: examples from offshore Africa.

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Summary

2D and 3D seismic data from frontier offshore basins around Africa has been subjected to relative extended elastic impedance inversion (rEEI) to screen for AVO anomalies and to identify large, commercially attractive, undrilled opportunities. Since the process uses only information present within the seismic data, methods of testing the AVO anomaly are sought to confirm the validity of the proposed drilling opportunity. In frontier basins where some drilling has taken place, testing the results against previously drilled boreholes is one way to test that discoveries can be detected using rEEI. In undrilled or sparsely drilled basins, confirmation of the geological validity of the play and prospect (source, charge, reservoir, trap) takes on a more important role in derisking the opportunities. Multiple large opportunities, identified and tested using the above methods, are presented from frontier basins around South, West and East Africa.

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Introduction

Drilling in frontier basins typically requires identification of large prospective opportunities to offset the increased play risk when compared with more mature basins. This is particularly true where frontier basin opportunities occur in deep water settings where the cost of drilling and development increases substantially. Nevertheless, and despite the increased cost and risk, large undrilled billion-barrel scale opportunities still merit attention, and such discoveries continue to be made. In recent years very large play opening discoveries have been made, for example, in Guyana, Brazil, Ghana, Cote d'Ivoire and Namibia. Part of the challenge for companies considering entering frontier basins is to reduce the exploration risk sufficiently so that the balance is tipped in the favour of drilling the identified opportunities. Efficiently identifying opportunities over very large undrilled areas (1000's of sq. km) demands extracting maximum useful information present in existing 2D and 3D seismic surveys. An important part of that process involves efficiently exploiting the amplitude variation with offset (AVO) present within the data to identify opportunities in suitable plays. We use a globally applicable rock property model to guide interpretation and a relative extended elastic impedance inversion process (rEEI) to screen for opportunities over large areas. Following identification of an anomaly, a careful examination of the play and prospect is required to test the validity of the prospective feature. We present examples of several large opportunities in offshore African basins and highlight the methods we have used to validate and derisk them.

Methods

The rock physics model and relative extended elastic impedance inversion (rEEI) concept and method we test in this paper is summarised in Figure 1 and is described fully in Went *et al.* (2023). It requires generation of intercept and gradient impedances and mathematical reweighting of the two attributes to produce rEEIχ27, a rotation of the seismic data optimised for discrimination of siliciclastic lithology and fluid over most relevant depths of interest (typically 1000-3000 m). The elegance of the method allows the inversion to be performed relatively quickly over large areas. Examples from 2D and 3D surveys in Namibia, Mozambique and Liberia are presented.

Screening for AVO anomalies is a relatively straightforward process performed on a single volume, rEEIχ27. Anomalies that have already been drilled can be evaluated to test whether lithology and fluid predicted by seismic, match the results in the wells. This can be done either through a detailed well tie or, where well data is not released, through matching of well location and target zone information to the results of seismic inversion.

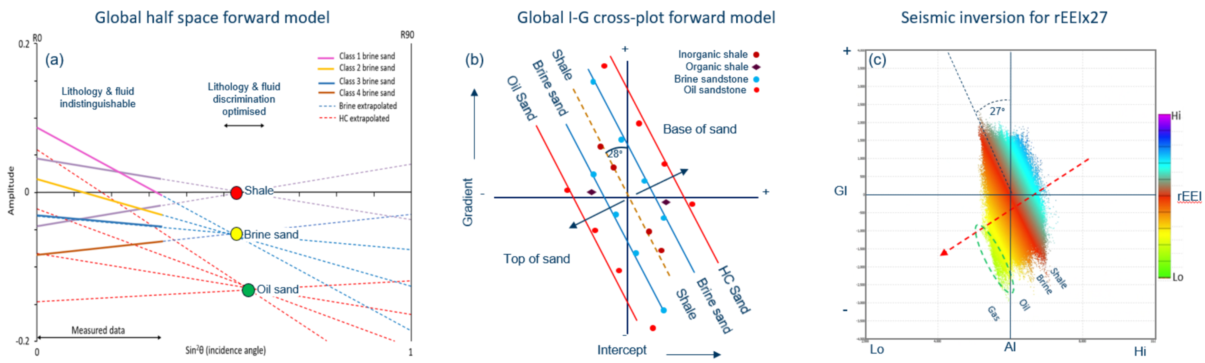

Figure 1. a) Half space forward models of intercept and gradient for globally typical, siliciclastic lithologies, highlight that lithology and fluid discrimination is optimised at a projected incidence angle of 45° (θ); b) the same data plotted on an intercept-gradient plot shows the discrimination occurs at a cross plot rotation angle (χ) of 27°; c) a relative seismic inversion for AI, GI and rEEI χ27 over a known

oil discovery show oil sands highlighted by low values of rEEI χ27 (in green) in the SW corner of the AI-GI cross plot (a and b after Went 2021, c after Went et al. 2025).

Results

Results of the elastic inversion for the 2D data over the Venus discovery in the Orange Basin in Namibia is presented in Figure 2. The oil is stratigraphically trapped in a reservoir formed in a submarine fan setting. The reservoir sits directly on the source rock, facilitating charge, and a seismic AVO anomaly is clearly displayed at the reservoir level on the rEEIχ27 volume which is displayed co-rendered with the stack. It is also clearly displayed on the AI-GI cross plots. It is clear from the results of the relative elastic inversion that the AVO in the 2D seismic data is capable of highlighting the discovery. In this case the ultimate geological validation is provided by the confirmatory well penetration.

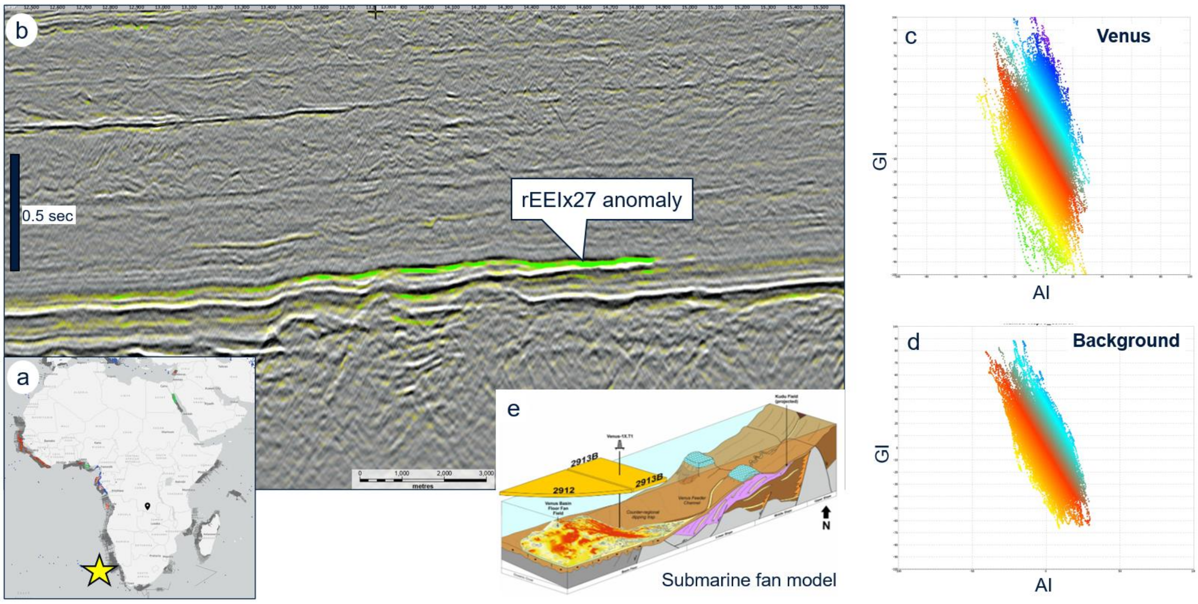

Figure 2. a) location of example in the Orange Basin, Namibia, SW Africa, b) 2D seismic section showing the full stack co-rendered with rEEIχ27 where all but the lowest values, shown in green, are rendered transparent; c) AI-GI cross plot colour coded by rEEIχ27, the oil sands at Venus are highlighted by the low green values of rEEI; d) AI-GI cross-plot representative of background strata; e) basin floor submarine fan reservoir and up-dip stratigraphic pinch-out model for Venus (from Impact Oil and Gas 2024).

Elastic inversion using the rEEI method was performed on selected lines from a 2D survey in the Angoche Basin (Figure 3). An rEEIχ27 anomaly (arrowed) is highlighted in a dip line and in an AI-GI cross-plot. The anomaly takes the form of an up-dip pinch-out, a common trapping configuration on passive margins. The intersecting cross-line provides additional evidence of the geology and a plausible explanation of the process controlling pinch-out. The anomaly, interpreted as gas-filled sandstone, sits at the base of a major incised canyon. The canyon cuts into well bedded, inclined strata interpreted as mounded contourite drift deposits. Whereas the contourite drifts move principally fine-grained sediment parallel to the slope, canyons transport sand as gravity flows directly downslope. Hence, the canyons cut into the previously deposited contourites providing the base and side seal to the pinch-out trap. The top seal is provided by muds (turbidite or contourite in origin) which back-fill the canyon, and the pinch-out occurs where base and top seals meet. In this case the location of the anomaly is geologically validated, since it is plausibly explained by the stratal architecture of the continental margin.

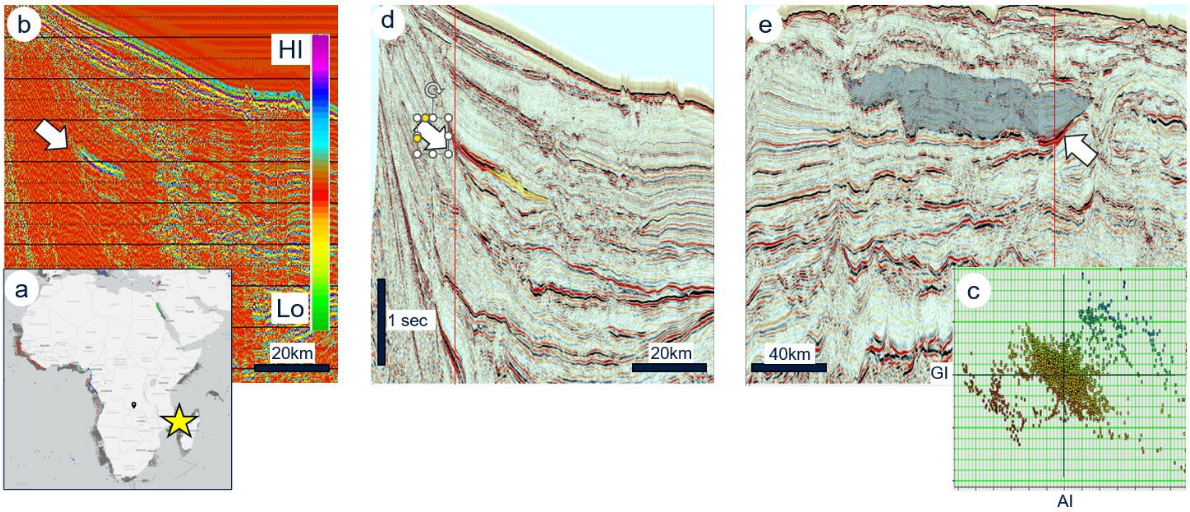

Figure 3. a) location of example opportunity in the Angoche Basin, Mozambique, East Africa; b) dip line showing rEEIχ27 anomaly (arrowed), c) AI-GI cross plot over the anomaly, showing the low and high values of rEEIχ27 that define the anomaly (brown = top of gas sand, blue = base of gas sand) d) dip line showing the appearance of the feature on the full stack, with an interpretation of the down-dip extension of the reservoir as brine filled sands, shown in pale yellow; e) anomaly is located at the base of canyon, interpreted to be back-filled with mud.

An example arbitrary line from 3D data in the undrilled Harper Basin, Liberia is presented in Figure 4. The line shows the full stack co-rendered with rEEIχ27 where all but the lowest values of rEEI, shown in green, are rendered transparent. This long line highlights two strong rEEIχ27 anomalies (arrowed), at approximately the same stratigraphic level, interpreted to be near Top Cenomanian.

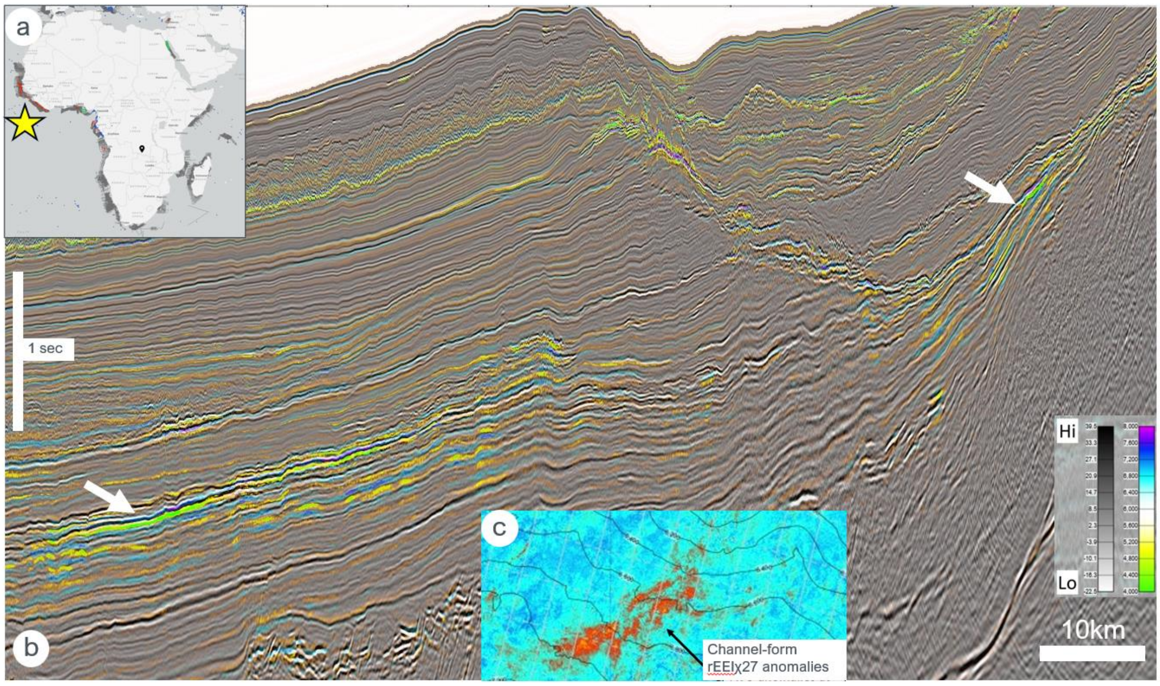

Figure 4. a) location of example in the Harper Basin, offshore Liberia; b) stack seismic section co-rendered with rEEIχ27 showing low values of rEEIχ27 in green, with two prominent anomalies present (arrowed); c) prominent AVO anomaly (red) distinct from background (light blue) is shown to be composed of channel form geometry features consistent with a slope channel or slope fan interpretation.

The larger of the two in the more basinward position is seen to be composed of multiple channel form anomalies (Figure 4c), consistent with an interpretation as slope channel deposits. The strata above the proposed reservoir bearing horizon is largely devoid of anomalies and shows a seismic character suggestive of mudstone deposition: it may form a regional seal. Both anomalies have analogues that have been successfully drilled in neighbouring and conjugate basins.

The down-dip anomaly is covered by a 2D line, which has also been subject to elastic inversion, and which shows an equivalent anomaly. It provides a further form of geophysical validation, since the same anomalous behaviour is present in two separate seismic experiments.

Conclusions

Validation of AVO anomalies in frontier basins such as those around Africa, can be performed by comparing the results of relative extended elastic impedance inversion (rEEI) with previous drilling, or via geological considerations which provide plausible explanations for the presence of the anomaly. This may include convincing explanations for the inevitable charging of reservoirs in certain plays or for the likely trapping of hydrocarbons in pinch-out traps in dip slope settings. When anomalies seen on elastic inversions are can be explained or supported through geological reasoning, the risks attendant in drilling frontier basin opportunities may be lowered sufficiently to make the prospects attractive, particularly if they are of substantial size.

Acknowledgments

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