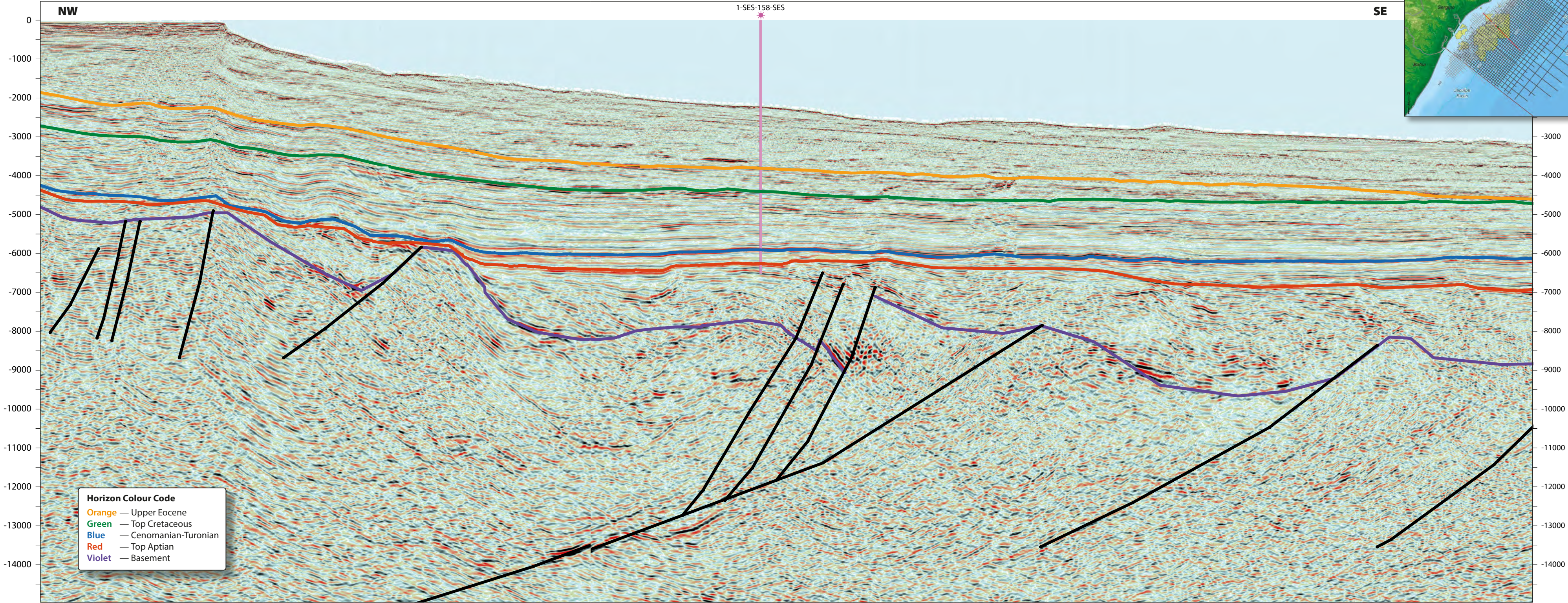
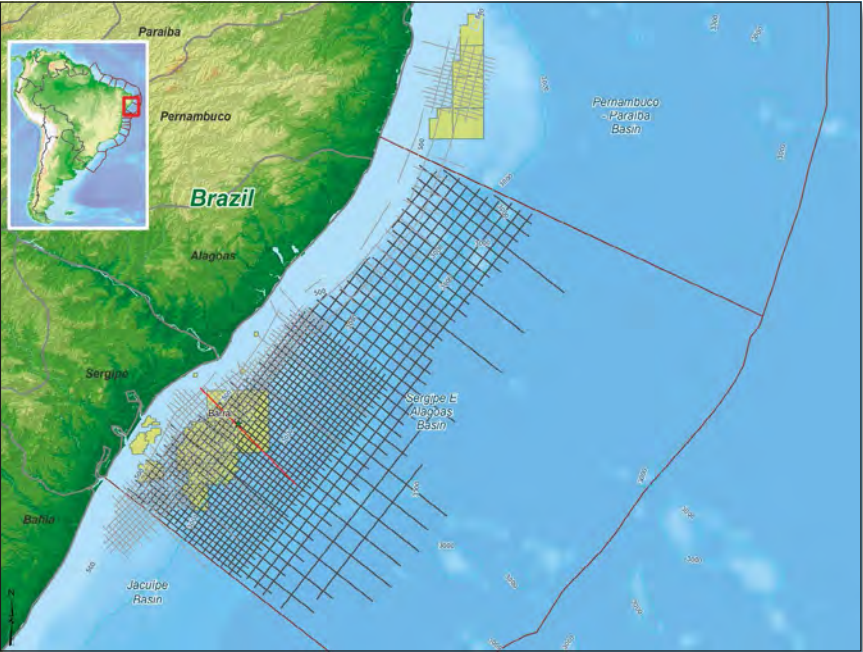


Sergipe Basin, Brazil:

DHIs from Calibrated AVO Stacks

Amplitude variation with offset (AVO) techniques are valuable tools that assist exploration, development and production teams to identify hydrocarbons in clastic depositional settings. The clastic reservoirs in the Sergipe Basin offshore Brazil are well suited for quantitative interpretation, best illustrated by the classic bright spot which can be observed on the accompanying section at a depth of 4,700m near the well bore. The recent announcement by the Brazilian energy regulatory agency ANP that the Sergipe Basin is likely to be included in Round 13 suggests that there will be considerable opportunity for additional prospecting in this basin. AVO techniques will prove to be important both for prospecting and for reducing drilling risk as the exploration cycle expands and progresses to development in the Sergipe Basin.

Pre-stack depth migrated section through the Barra discovery well



AVO Signatures Help Identify Hydrocarbons

MIKE SAUNDERS and **DAN NEGRI**, Spectrum; **CHRISTOPHER ROSS**, Cross Quantitative Interpretation; **SCOTT BOWMAN**, Petrodynamics

In the relatively mature Sergipe Basin, AVO anomalies can be used to highlight prospective anomalies and eliminate leads and prospects without such indicators.

The Sergipe Basin is a relatively mature hydrocarbon province on the north-east coast of Brazil, comprising 44,370 km², both onshore and offshore. The onshore portion of the basin (12,620 km²) is considered mature, with over 2 Bbo in place and 816 wells drilled since 1935. However, Petrobras has made several discoveries since 2010, including the 2010 Barra well (1-SES-158) and the subsequent Barra 1 appraisal well (3-SES-165). The wells targeted oil- and gas-charged Maastrichtian sandstones that display readily identifiable AVO anomalies on 2D seismic profiles.

Spectrum re-processed 8,200 km of seismic data in 2013, using modern pre-stack time and depth imaging algorithms. The 2D seismic data was acquired with an 8 km streamer in 1999, providing a wide range of reflection angles for quantitative interpretation. The re-processing illustrates clear images of stratigraphic features within the prospective section, and numerous potential AVO anomalies are evident. Two profiles near the 1-SES-158 Barra discovery well were selected and the digital logs from this well were incorporated into the analysis.

The Barra discovery well was drilled in September 2010, reaching a depth of 6,510m in 2,341m of water.

Permeability and porosity conditions in the reservoir are excellent between 4,650m and 4,750m, where drill stem tests indicate gas and condensate are present in commercial quantities. The sandstones encountered in the Barra well are approximately 80m thick, and well tests indicate a high porosity gas-charged reservoir.

AVO Attributes

For mid to high porosity sandstones encased in shales or mudstones, gas and light oil saturated sandstones can be identified using amplitude versus offset (AVO) techniques with high-quality, long-offset seismic data.

Examination of available well data shows that the sandstone in the Barra well does have 25% to 33% porosities, with velocities that are equivalent to or slightly faster than shale velocities and sand densities that are less than the shale densities. AVO modelling indicates a Class 2 to Class 3 AVO response depending on the thickness of the sand modelled. AVO attributes computed from the models indicate that the enhanced gradient (FNxF) and scaled Poisson's ratio change (SPR) attributes should be diagnostic for sands of sufficient thickness.

SPR change is the weighted sum of the AVO intercept

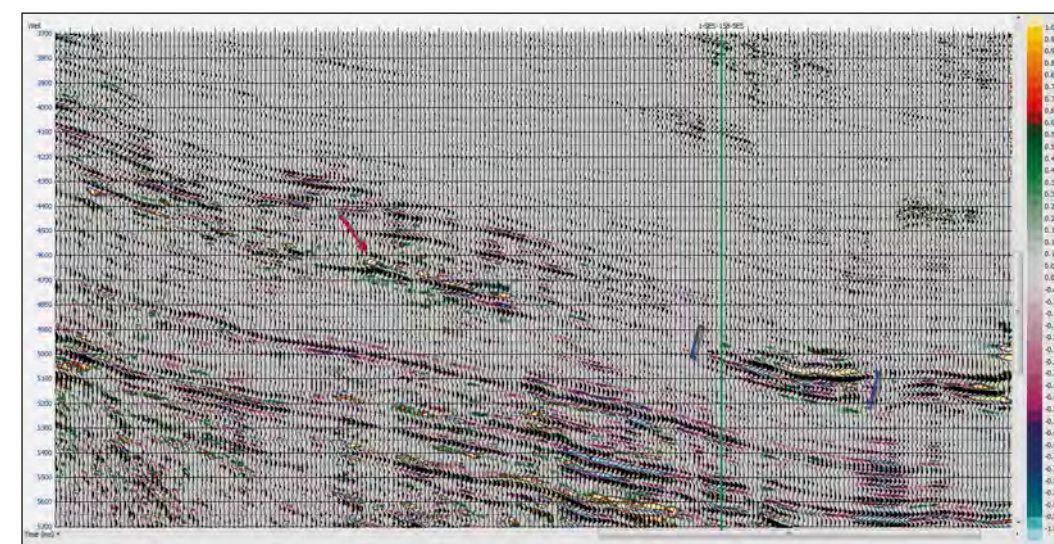
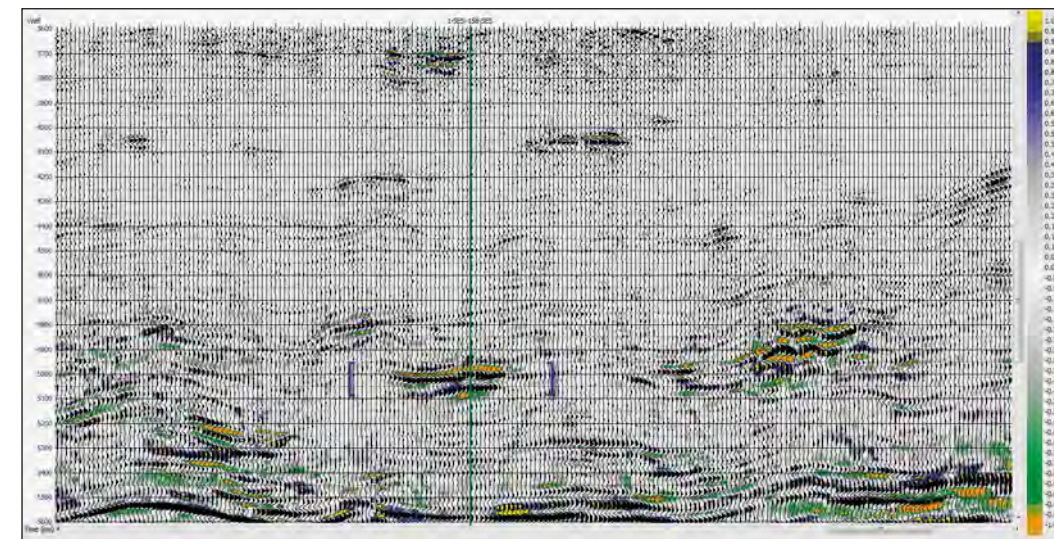
and gradient, where the weighting is determined by the background V_p/V_s ratio of the geology. The SPR attribute is a fluid factor AVO attribute that should illuminate hydrocarbon-saturated reservoirs and marginalise wet- or brine-saturated reservoirs. The FNxF attribute is computed by calculating the difference between the far angle stack and the near angle stack, and multiplying the difference by the far angle stack. Angle ranges are used in place of offset ranges so they are optimised for the geology and objective depth.

For the purpose of determining whether AVO attribute stacks can identify potential hydrocarbon reservoirs, we look at 2D seismic profiles that tie the Barra discovery well. For each of these profiles we compute an SPR and FNxF stack, both of which should show visible anomalies for the high porosity, gas-saturated sands found in the Barra discovery well.

Seismic Examples

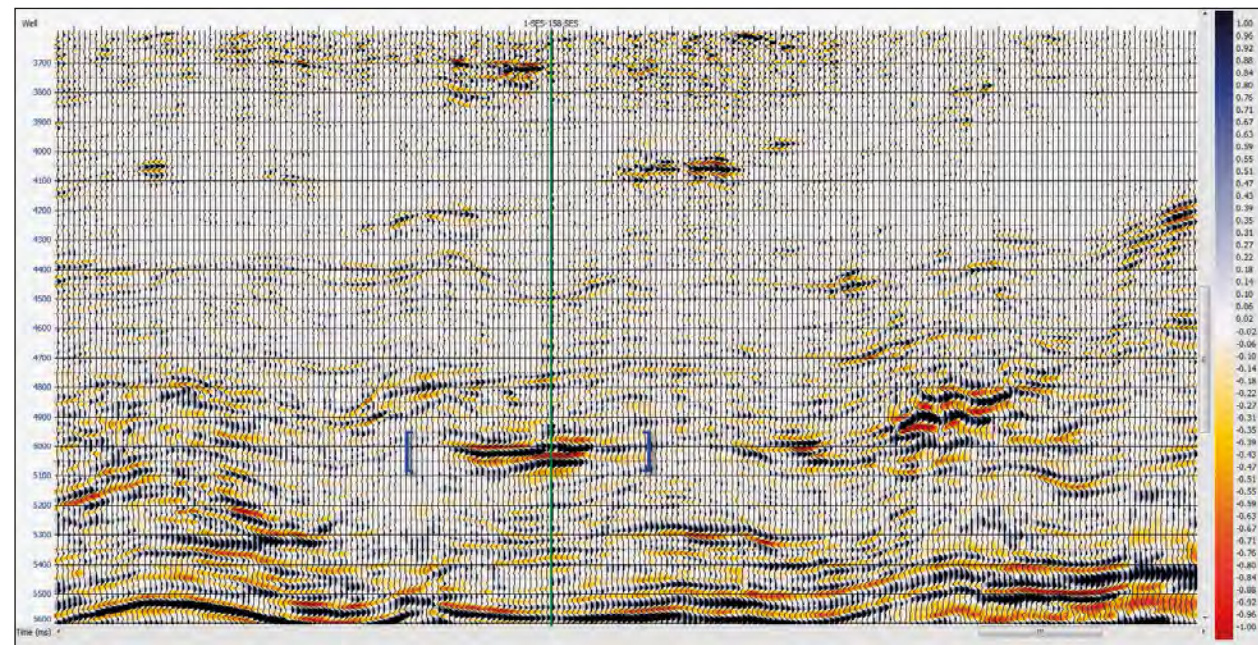
Line 21 is a strike line near the Barra 1 well. The top figure above shows the full stack in wiggle trace and the SPR change attribute in variable area. For a hydrocarbon-saturated reservoir the SPR attribute should show a minimum at the top of the reservoir signifying a relative decrease in Poisson's ratio (a decrease in V_p/V_s), and a positive SPR amplitude at the base of the reservoir assuming sufficient thickness to isolate the top and base of the sand. The event and overlaying attribute on the profile are quite similar to what has been described, with a strong negative SPR amplitude corresponding to the trough on the migrated stack amplitude and the positive blue-yellow SPR amplitude underlying the full stack peak.

In the lower figure this up-dip anomaly has the paired peak-peak character on the FNxF attribute, which typically



Comparing the SPR and FNxF AVO for Line 21. Top: the SPR change AVO attribute is a fluid factor which illustrates hydrocarbon-saturated sands when properly calibrated. High porosity, gas-saturated sands produce an anomalous trough-peak (orange-yellow) SPR character, which is observed on the bracketed event. Bottom: the FNxF AVO attribute is a fluid-indicator that is positive for mid-to-high-porosity gas-saturated sands. For thick gas-saturated sands, a double positive (yellow-yellow) FNxF is observed in the down-dip portion for the upper leg of the anomaly.

AVO conditioned stack using 4° to 32° after noise attenuation and residual move-out corrections. The multi-legged seismic amplitude anomaly of interest is bracketed at 4,980 to 5,100 ms. Projected well position is shown by the green well path.



corresponds to hydrocarbon-saturated reservoirs. This display also presents the known hydrocarbon-saturated reservoir with a single peak over a weak mix of positive and negative FNxF responses. The lack of a double peak in this instance might be attributed to the multi-legged nature of the event (a more complex sand body) and interference effects that may be negating the increase in amplitude versus offset on the base of the sand or other subjacent sands.

Hydrocarbon Charge Identified

Based on the available well data and the 2D profiles covering this basin, AVO anomalies from SPR and FNxF attributes can identify hydrocarbon charge in sandstone reservoirs, for thick sands with 18% or higher porosity. This screening process will not necessarily eliminate other geologies with lower V_p/V_s ratios: it will, however, highlight prospective anomalies and cull out leads and prospects that do not exhibit AVO signatures associated with hydrocarbons. ■