Reservoir characterisation by application of a novel AVO anomaly imaging technique: Examples from Block 7, Offshore Mauritania

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Introduction

- Block 7 Offshore Mauritania,
  - operated by Dana Petroleum plc (a wholly owned subsidiary of KNOC)
  - water depths of 50 to 2500m.
  - 3D data shot in 2001 and 2005
  - 1600km² re-processed PSDM in 2008.
  - 3700km² re-processed PSDM in 2013
Introduction

• Four wells have been drilled by Dana and partners in Block 7;
  • Pelican-1 (2003)
  • Aigrette-1 (2007)
  • Cormoran-1 (2010)
  • Frégate-1 (2013)

• All four wells discovered hydrocarbons in Cretaceous slope turbidite deposits.

• The reservoir sands typically exhibit a class 2 to class 3 AVO response.

• Depositional model - thicker reservoir sands mainly deposited in
  • channel fairways
  • proximal levees
  • crevasse splays

Well test
AVO RGB Blending technique

Gather at gas sand illustrating AVO

AVO class diagram illustrating Near, Mid and Far stacks in colour (after Rutherford and Williams 1989).

Envelope attributes of 3 angle stacks

Red = Nears
Green = Mids
Blue = Fars

RGB blend = Near, Mid and Far

Amplitude

- Reflection Coefficient +

Angle (degrees)

Class 3

Class 2

Class 1
Step 1 – Compute Envelope attribute

Compute the Envelope attribute to prevent artefacts occurring during the RGB co-rendering of the Near Mid and Far cubes. Note that the sign of the amplitude is lost in this process.

Attenuation of higher frequencies in Far stack has some similarity to Frequency Decomposition RGB blending.
Step 2 – Create Horizon probe and select RGB display

• RGB blending 3 volumes in colour:
  • Red for Near
  • Green for Mid
  • Blue for Far

• Balance the background colours in the image.
• Background should be a fairly neutral colour so AVO anomalies stand out.
• Too much clipping (slider further to the left) makes highest amplitudes white.

Purely a qualitative technique, ideal for screening purposes.
Step 3 – Co-render the 3 Angle Stacks – using RGB Blending

Red = Nears

Green = Mids

Blue = Fars

RGB blend = Near, Mid and Far
Comparison: Full stack amplitudes vs Frequency Decomposition

- Full stack amplitude
- Frequency Decomposition - RGB blend 11-13-17 Hz

Derived from FULL Stack, hence no AVO information.

RGB blending of Frequency Decomposition data is an excellent tool for facies discrimination.
Comparison: Frequency Decomposition vs AVO RGB Blending

- RGB blending of Frequency Decomposition data is an excellent tool for facies discrimination.
- Derived from FULL Stack, hence no AVO information.

- Near-Mid-Far co-rendered in RGB also shows facies patterns.
- Adds discrimination of lithology and gas-filled sands in blue.
Calibration of seismic facies with core and log facies models

**Conceptual extended slope model**

- Extended slope mud-rich fine-grained submarine fan model (after Bouma, 1997)
- Abyssal Plain
- Shelf
- Fan Valley
- Sediment gravity flow systems
- Slumps
- Leveed channels
- Amalgamated channel fill
- Thin-bedded clean sandstones

**Levéed channel depositional model**

- Interchannel mudrocks
- Submarine channel sands
- Submarine sandlobe - crevasse splay sands
- Channel leveé heterolithics

**Seismic facies model**

- Depositional channel
- Erosional channel
- Levee and overbank
- Crevasse lobe

**Core-based channel model**

- Crevasse Lobe
- Interchannel mudrocks
- Depositional channel
- Channel leveé – proximal to distal
- Erosional channel
- Slumps and injection complex
Core facies and depositional environments

<table>
<thead>
<tr>
<th>Depositional channel – sandy high density turbidites</th>
</tr>
</thead>
<tbody>
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<td>Channel levee – heterolithic tracted turbidite sandstones and mudrocks</td>
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<td>Slumps and carbonate-rich melange</td>
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<td>Erosional Channel fill – sandy debris flows</td>
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Depositional channel – sandy high density turbidites

- Depositional channel – sandy high density turbidites
- Slumps and carbonate-rich melange
- Erosional Channel fill – sandy debris flows
- Channel levee – heterolithic tracted turbidite sandstones and mudrocks

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Calibration of core facies and depositional environments to seismic

Far Stack PSDM

- Depositional channel
- Erosional channel
- Levee and overbank
- Crevasse lobe
- Slumps
- Mass wastage complex
- Mudrocks

Outcrop analogue – Karoo Fm., South Africa

Fan 5 slope channel fill 45m thick 500m wide

AVO RGB display
Calibration of core facies and depositional environments to seismic.

- Far Stack PSDM
- Depositional channel
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Outcrop analogue – Karoo Fm., South Africa

Fan 5 slope channel fill 45m thick 500m wide
Field analogue comparisons – Lainsburg slope channels – Baviaans – Skielding Fan B

Thick bedded amalgamated sandstone unit – stacked massive $T_a$ turbidites in channel axis - 35m+ thick in axis - 1.2km lateral extent of channel complex

Medium bedded, non-amalgamated channel margin and overbank fines – dominated by $T_c$ and $T_a$ turbidites with thick-bedded climbing ripple laminated $T_c$

Shale rip-up clasts concentrated in lag deposit – bypass phase at channel base.

Slump folds in channel margin location – collapse and remobilisation of levee facies

Injected sandstone dykes and sills beneath main channel cut

Overbank fines – homogeneous mudrocks deposited from suspension

Good analogue for the slope channel complexes.

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Inline showing seismic facies

- High amplitudes drape over MTC
- High amplitudes within broad channel cuts
- High amplitudes in levee
- High amplitudes within erosional channel cut, possible shale filled channel
- High amplitudes outwith channel cut = crevasse lobe with mud-filled channel

1000 m
Inline showing seismic facies

**Simplified seismic facies**

- **Channel fill High amplitude seismic facies = sandy**
- **Channel fill Low amplitude seismic facies = heterolithic**
- **Lobe facies High amplitude seismic facies = sandy**
- **Mass Transport Complex = Chaotic seismic facies**

- High amplitudes drape over MTC
- High amplitudes in levee
- High amplitudes within broad channel cuts
- High amplitudes outwith channel cut = crevasse lobe with mud-filled channel

Low amplitudes within erosional channel cut, possible shale filled channel.
Horizon AVO blend

- Interchannel crevasse splays, gas filled
- Shale filled crevasse channel – low amplitude No AVO
- Multiple channel trends, cf anastomosing channel braid plain
- Discrete well defined channel belt
- Dark low amplitude – interchannel mudrocks
- Discrete well defined channel belt
A series of horizon parallel slices to illustrate the technique

- First set is a regionally mapped Upper Cretaceous horizon, moved downwards in 10m increments.
- This ensures that the image is reasonably parallel to the stratigraphic grain
- Could use iso-proportional slices, but this slows the process down to a snail’s pace
250 m above Horizon 5 circa 3.5km depth
180 m above datum Horizon 5
140 m above datum Horizon 5
100 m above datum Horizon 5
60 m above datum Horizon 5 – Main reservoir
At datum Horizon 5 – Regional mapped shale prone interval
Use in shallow hazard analysis

- The AVO RGB blend technique is also ideal for rapid screening for shallow gas hazards
Shallow Hazard Study Example 1: 280m below seabed

Shallow canyon fill with meandering channels showing blue colours indicating strong AVO response and likely shallow gas hazards.
Shallow Hazard Study Example 2: 550 mtr below seabed

AVO-RGB blend on the left, on the right an RMS amplitude extraction from a 40mtr window centered on the horizon from the full stack. Bright blue colours are caused by higher amplitudes on the far stack indicating a potential shallow gas hazard in the meandering channel, though not in the funnel shaped amplitude anomaly.
Conclusions

AVO RGB blending of the Near, Mid and Far angle stacks has a number of advantages:

- No specialist software required, we used Petrel, but SviPro or any package that allows RGB blending of 3 seismic cubes should work.
- required pre-processing is a simple envelope attribute computation.
- sedimentary bodies and AVO anomalies in one display.
- better description of seismic facies.
- aids in identifying potential hydrocarbon bearing reservoirs.

This makes AVO RGB blending an ideal tool for:

- rapid screening of large volumes for exploration.
- appraisal and development facies mapping and well planning.
- Shallow hazard identification
Acknowledgements