Spectral Detection of Attenuation and Lithology

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Overview

• Introduction
• Spectral detection of changes in lithology and stratigraphy
• Spectra detection of attenuation
• Examples: Canada, Indonesia, Australia
• Time-frequency analysis
• Conclusions
Introduction

• Traditional seismic interpretation methods rely heavily on amplitude analysis for quantifying reservoir parameters.
• AVO and seismic inversion technologies have been developed to help improve, support and verify seismic interpretation.
• Frequency content is another important source if information in seismic data.
• Spectral analysis as discussed in this presentation refers to tools used for the examination of the frequency content of times series data.
• The presentation will discuss two complementary ways of employing spectral analysis for hydrocarbon reservoir mapping: detection and tuning
Seismic Spectral Elements

Consists of several components:
- Wavelet
- Reflectivity
- Noise

Seismic response

\[ \text{Seismic}(t) = \text{Wavelet}(t) \ast \text{Reflectivity}(t) + \text{noise}(t) \]

Time Domain

\[ \text{Seismic}(f) = \text{Wavelet}(f) \times \text{Reflectivity}(f) + \text{noise}(f) \]

Frequency Domain

Seismic attribute analysis uses information extracted from the seismic data or its constituents.
Spectral Signatures

Lithological:
- Reflectivity-induced, e.g.
  - Tuning effects (pinch-outs).
  - Time thickness changes (sand/shale ratio, porosity, gas).
  - Faults and Fractures

Petrophysical:
- Primarily wavelet-induced (Attenuation)
  - Attenuation is a function of fluid viscosity, permeability and temperature.
  - Generally, gas attenuates more than oil and oil more than water.
  - Reflectivity may be affected by attenuation as well.
Spectral Detection of Lithology

Often, spectral patterns are more distinct than waveform patterns.
Devonian Pinnacle Reef Example:
Wavelet above - $|W_a(f)|$

Wavelet below - $|W_b(f)|$

Attenuation = \frac{|W_b(f)|}{|W_a(f)|}
4D Monitoring: Cold Lake


- Power Spectra above the reservoir shows good spectral repeatability between the two surveys.
- Below the reservoir higher frequency attenuation is evident in the production cycle.
4D Monitoring: Cold Lake (85% quantile frequencies)

- Power spectra for time window above the reservoir show high repeatability for production and injection surveys.
- High frequency attenuated zones during oil production correlate spatially with the 15 CSS wells for spectral window below reservoir.
- High frequency attenuated zones correlate with velocity sag anomalies.
- Most probable cause of high frequency attenuation is gas saturation in reservoir.
The Tubridgi Gas Field is located 30 Km west-southwest of Onslow W.A. in the onshore portion of the Carnarvon Basin. The hydrocarbons are entrapped in a northeast trending anticlinal structure with broad, low relief evident only in depth mapping of seismic two-way-times. The Early Cretaceous and Mungaroo reservoirs are sealed by the Cretaceous Muderong shale.
Tubridgi: Spectral Attenuation Validation

Image on the left is a composite showing panels of spectral attenuation (color) and wavelet spectra (grey), taken from seismic data ties with 16 boreholes. Note that there is a greater than 90% correlation with the presence of hydrocarbons and the higher frequency seismic attenuation. Follow-up drilling of six wells in the field over a period of several years continued to demonstrate the relationship between high frequency attenuation and the presence of hydrocarbons.
Discovered in 1996, the Perseus gas field was drilled in 131 m of water and started production in 2001. The Athena field was discovered in October 1997 and is an extension of the North West Shelf Gas project’s Perseus gas field.
The Badak field was discovered in 1972 and a seismic line templating the field is shown. Hydrocarbons are trapped in a large anticlinal structure in stacked accumulations at depths from 1100 to 3600 metres. The spectral example shown in this study examines a zone of productive Upper Miocene sandstone reservoir around 1700 metres below the surface.
• The attenuation spectra shows an attenuation anomaly between 20-50 Hz.
• The presence of hydrocarbons in the Miocene Sandstone reservoirs at the Badak field appears to have caused measurable attenuation of higher seismic frequencies.
• The attenuation measurement was made from geophysical archived stacked seismic data.
Spring Grove: Surat Basin Qld Australia

“A Major Play In The Surat – Bowen Basin”
Talk presented by Dr Howard Brady, CEO of Mosaic Oil NL, to PESA NSW Tuesday March 9th 2004

Target reservoir is a Permian aged sandstone reservoir. Initial well drilled crestally on structure failed to encounter reservoir sand at target level (D&A).

Play concept: better sand development off paleo-high. Which flank would be the better location to test this play concept?

Spectral attenuation showed an anomaly on the eastern flank of the structure. Subsequent well location suggested by this anomaly was an oil well (no associated gas). The field has expected recoverable reserves of around one million barrels.
Time Frequency Analysis

- Provides better time localization of the frequency content of seismic data
- First Technique utilized STFT which is basically a sliding window FT. Resolution depends on the length of the window. Both low and high frequencies would have same analysis bandwidth (i.e. higher frequencies more accurately resolved than lower frequency).
- The Gabor transform is one of the earliest implementations of the STFT with a Gaussian window
- Wigner-Ville distribution provides high resolution time-frequency analysis employing a quadratic transform obtained by instantaneous correlation of the signal. This approach suffers from interference resulting from its quadratic nature.
- Note that geology and wavelet effects are not separated in time frequency distributions.
The Wigner-Ville Distribution: Cross Term

A signal composed of two modulated Gaussians (Gabor atoms)

WV distribution of above signal. Notice the interference term.

- Decomposing the signal into time-frequency wavelets addresses the cross-term problem.
- The time-frequency distribution of the signal is obtained by adding the Wigner-Ville distribution of the individual components.
Time Frequency Analysis: Applications

1. Detection of changes in lithology.
2. Detection of coherent noise.
3. Crude attenuation indicator.
Conclusions:

- Target-oriented spectral attribute analysis can provide an effective indicator of change within the zone of interest.
- Depending on the analysis method, the results can provide an indicator of changes in geomorphology or pore-fluid.
- Demonstrated several examples of spectral attenuation in both oil and/or gas reservoirs.
- These spectral attenuation signatures have been observed and documented by the authors and collaborators over many oil and gas accumulations on 2D/3D/4D seismic data worldwide at depths from 200 to 3000 meters in Cenozoic, Mesozoic and Paleozoic aged section in clastic, carbonate and fractured reservoirs.
- Time-Frequency analysis is more indicative of changes in geomorphology than pore-fluid content.