Spectral Detection of Attenuation and Lithology

M. S. Maklad
Signal Estimation Technology Inc.

J. K. Dirstein*
Total Depth Pty Ltd.

*Presented by: jim@totaldepth.com.au

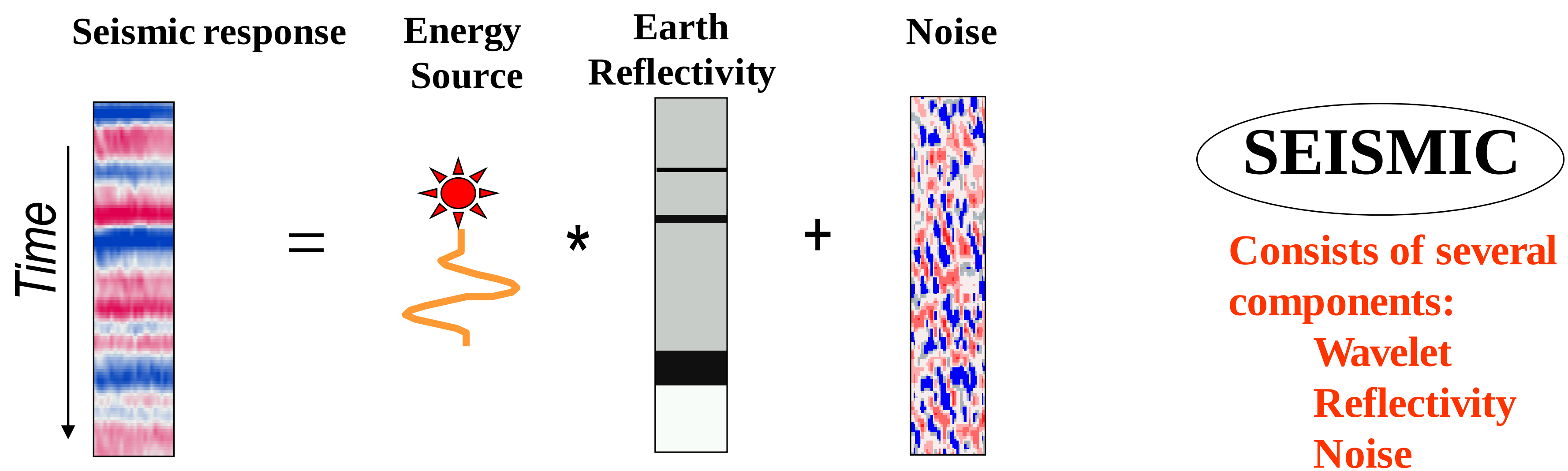
Overview

- 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



Time Domain

Seismic(t) = Wavelet(t) * Reflectivity(t) + noise(t)

Frequency Domain

Seismic(f) = Wavelet(f) X Reflectivity(f) + noise(f)

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

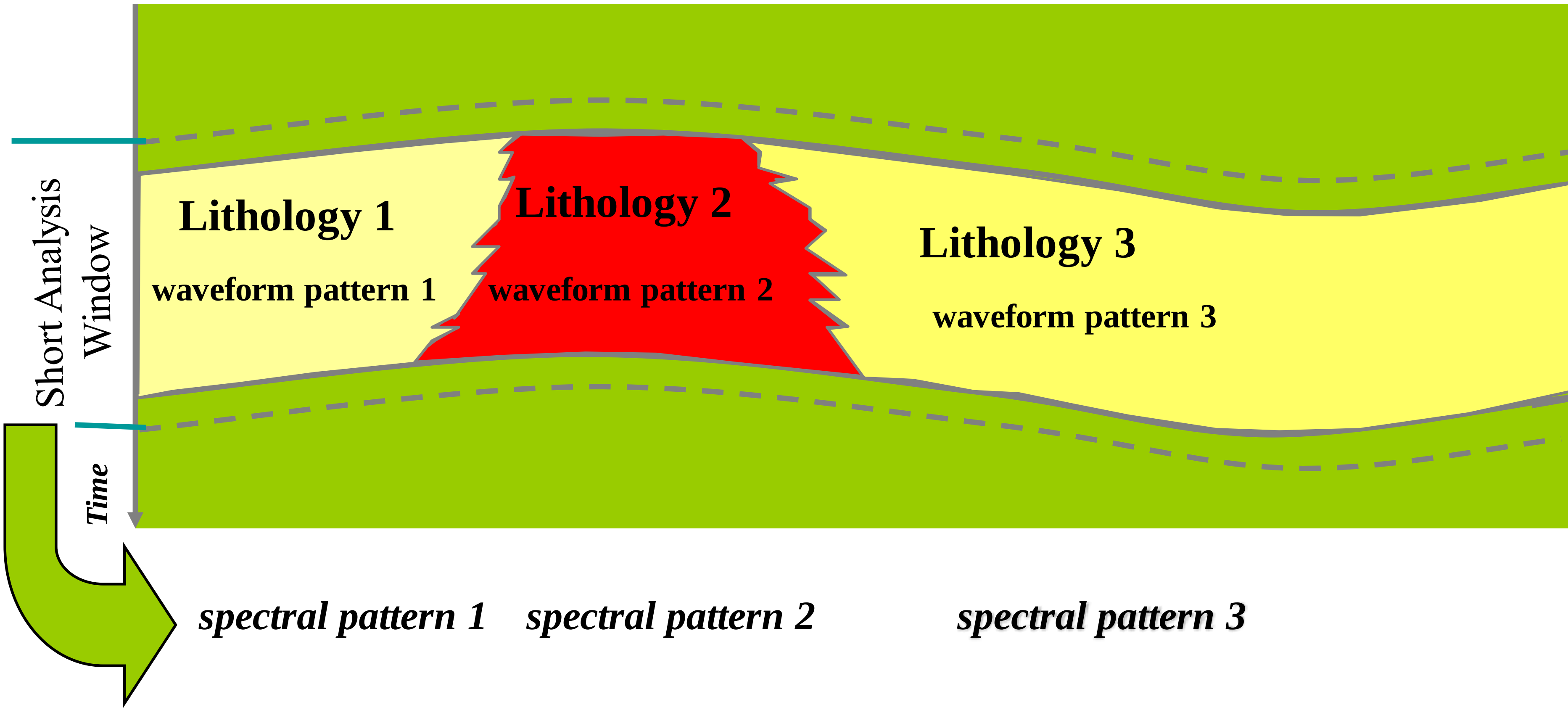
Petrophysical:

Primarily wavelet-induced

(Attenuation)

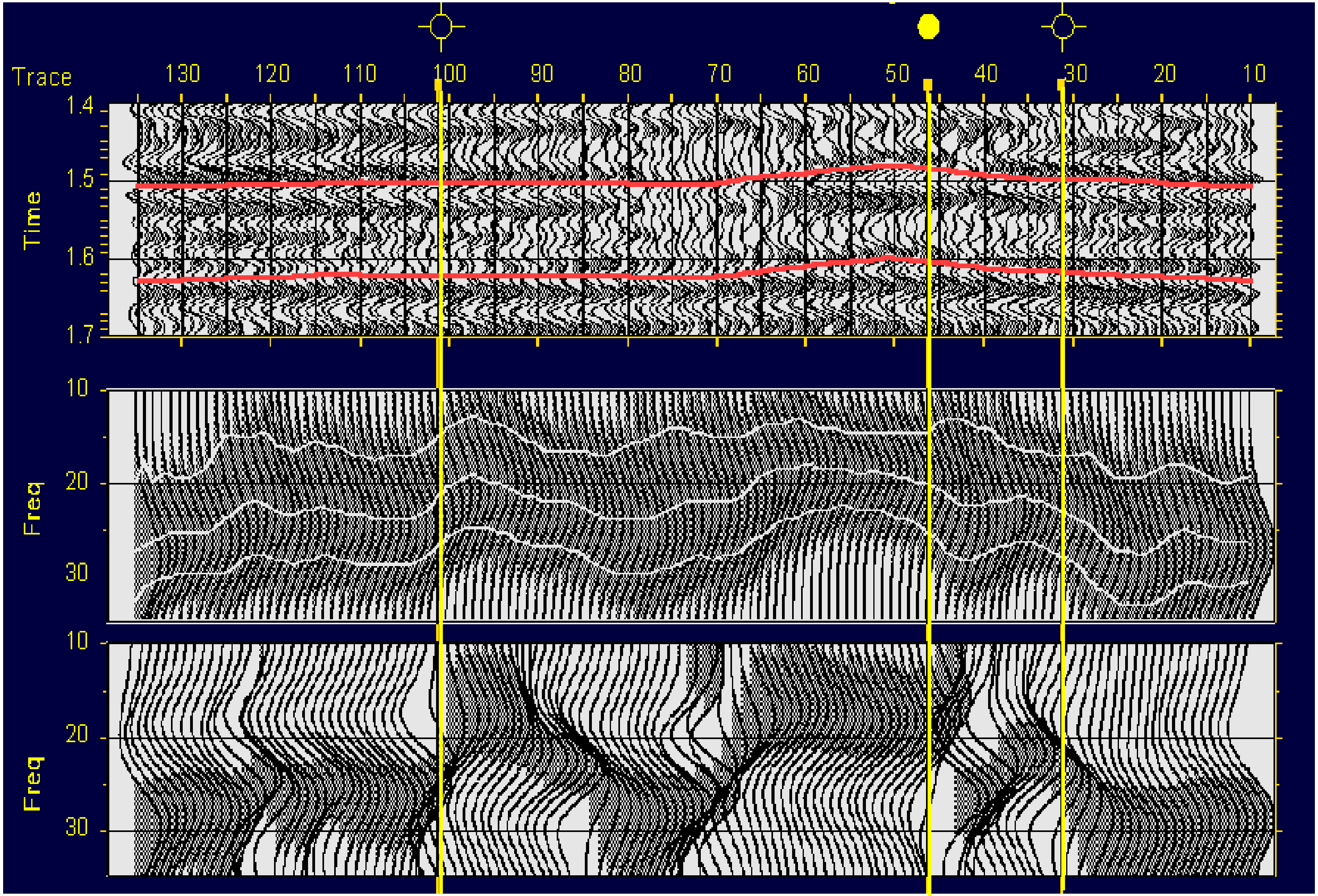
- Attenuation is a function of fluid viscosity, permeability and temperature.
- Generally, gas attenuates more than oil and oil more than water.
- Reflectivity may be affected by attenuation as well.

Spectral Detection of Lithology

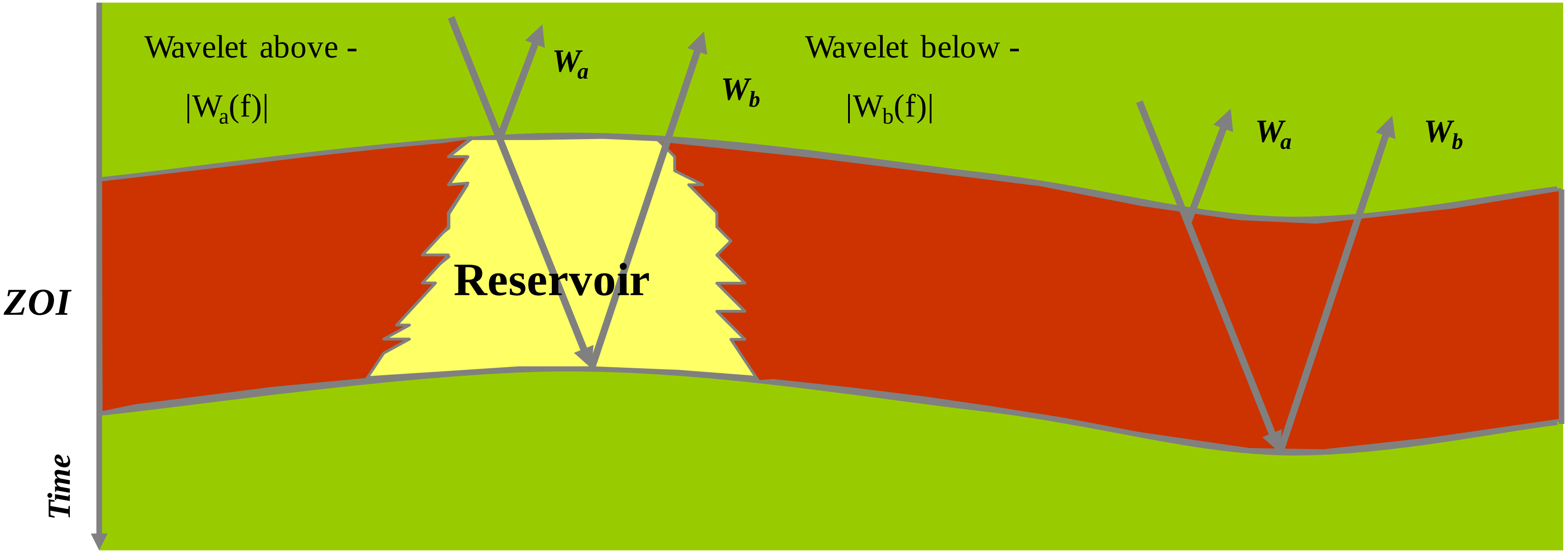


Often, spectral patterns are more distinct than waveform patterns.

Devonian Pinnacle Reef Example:



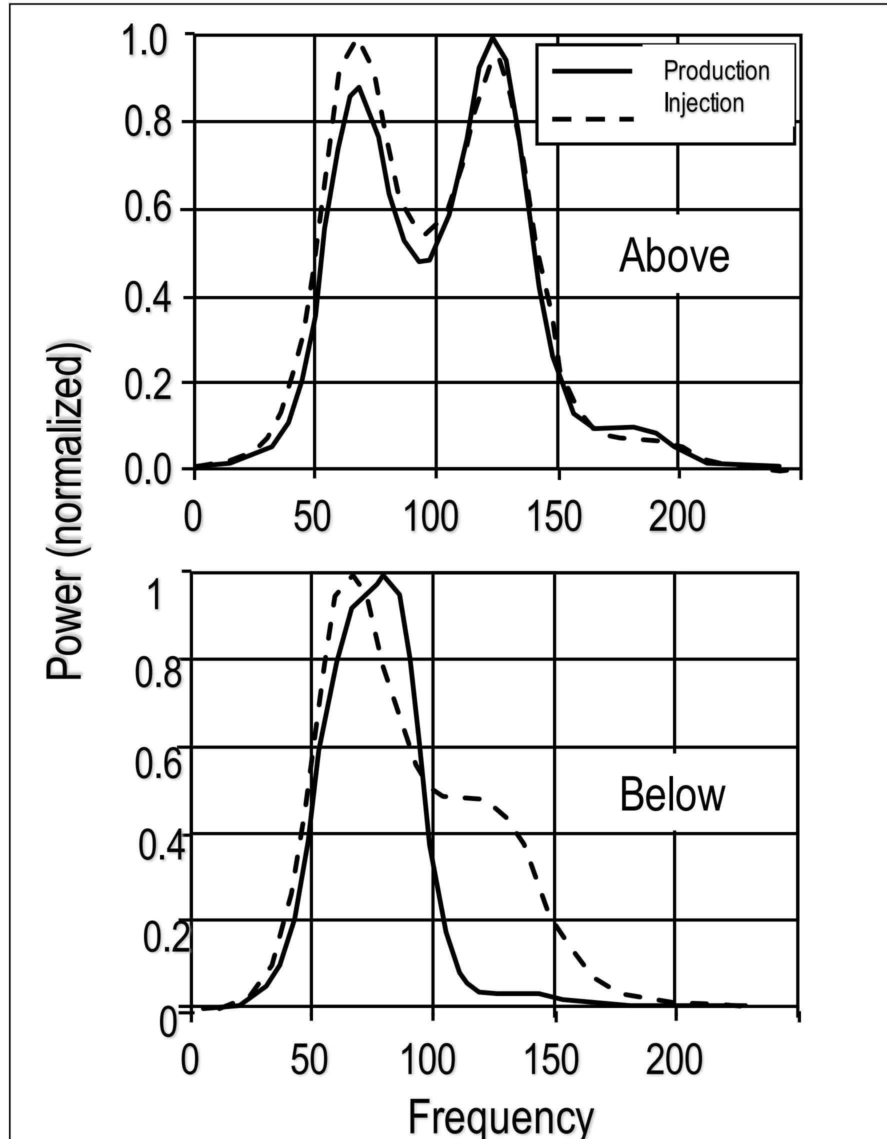
Attenuation



$$\textbf{Attenuation} = \frac{|W_b(f)|}{|W_a(f)|}$$

4D Monitoring: Cold Lake

Dilay, A J, Maklad, M S and Eastwood, J., “Spectral Analysis Applied to Seismic Monitoring of Thermal recovery,” Extended Abstracts of the 1993 SEG International Meeting, Washington, pp. 331-334.

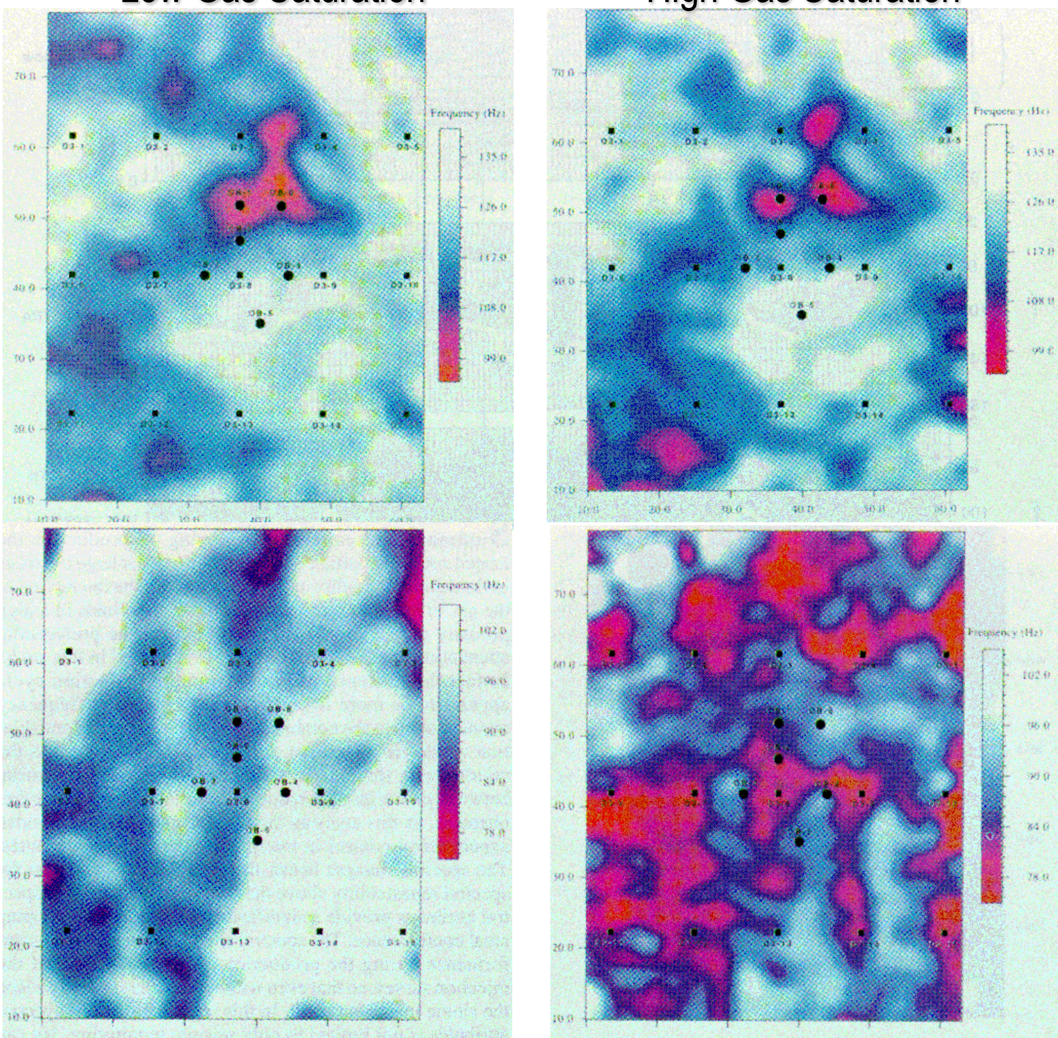


- Power Spectra above the reservoir shows good spectral repeatability between the two surveys.
- Below the reservoir higher frequency attenuation is evident in the production cycle.

4D Monitoring: Cold Lake (85% quantile frequencies)

	Injection	Production
	High Temp & Fluid Press Low Gas Saturation	Low Temp & Fluid Press High Gas Saturation

Above

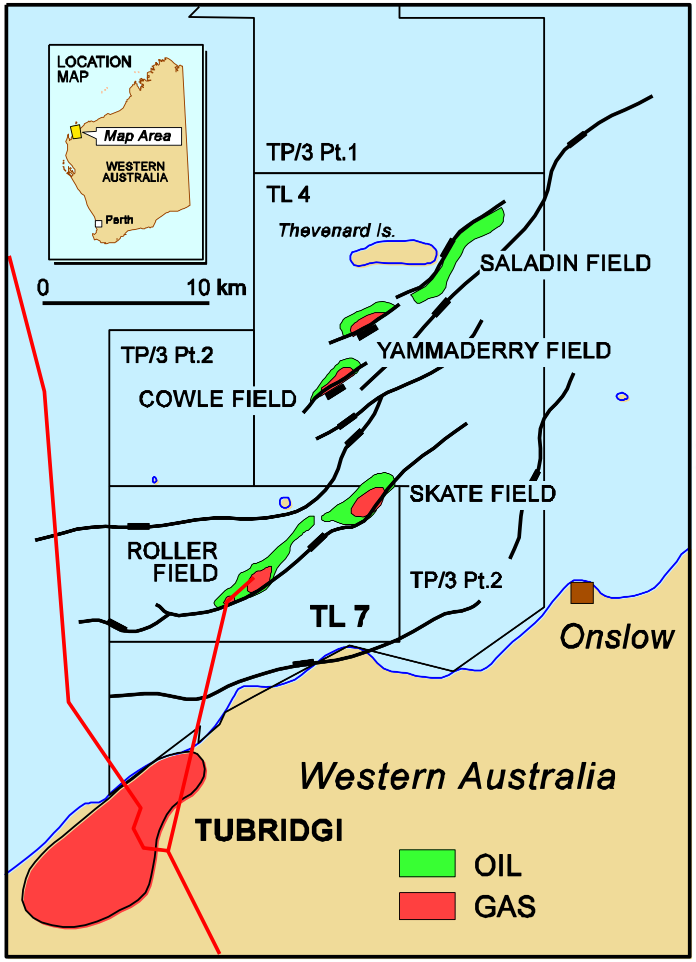


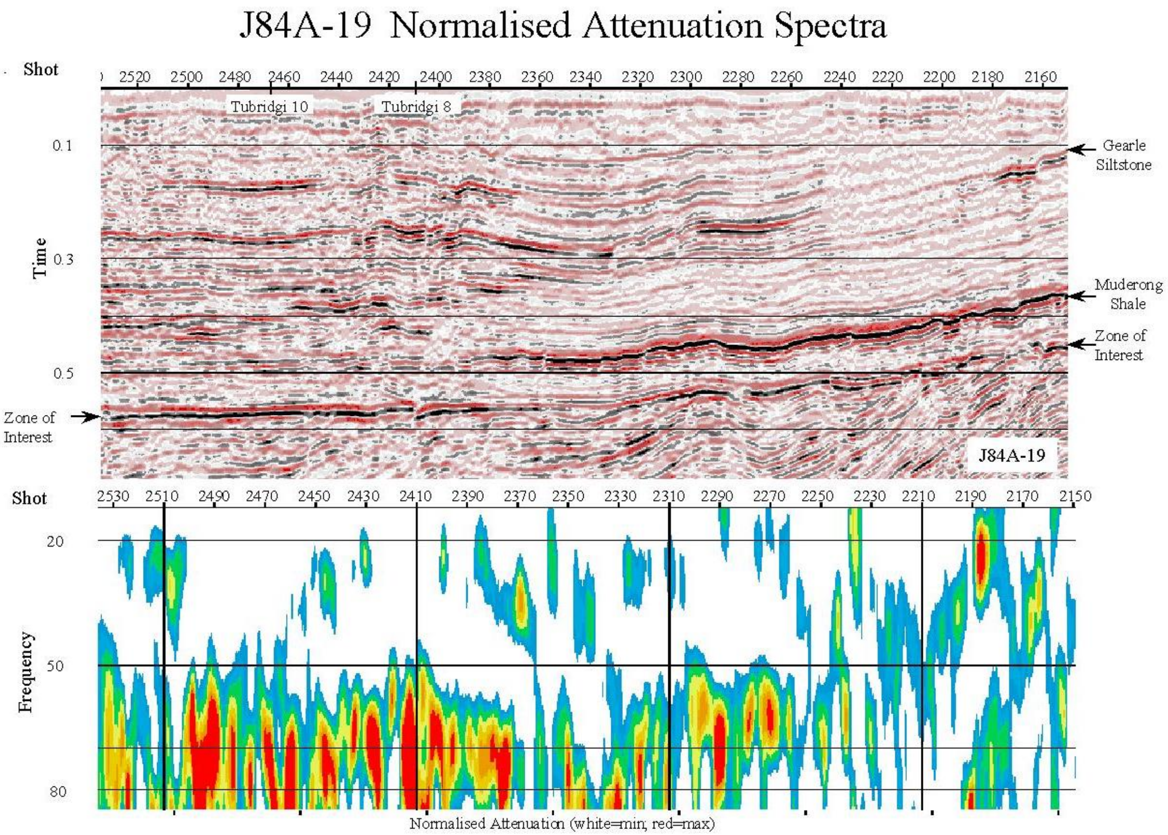
Below

- 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

Tubridgi: Conventional Gas

Spectral Signatures of the Tubridgi Field: Onshore Carnarvon Basin, Western Australia
J.K.Dirstein & M.S. Maklad PESA News: 1997 & 2007





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

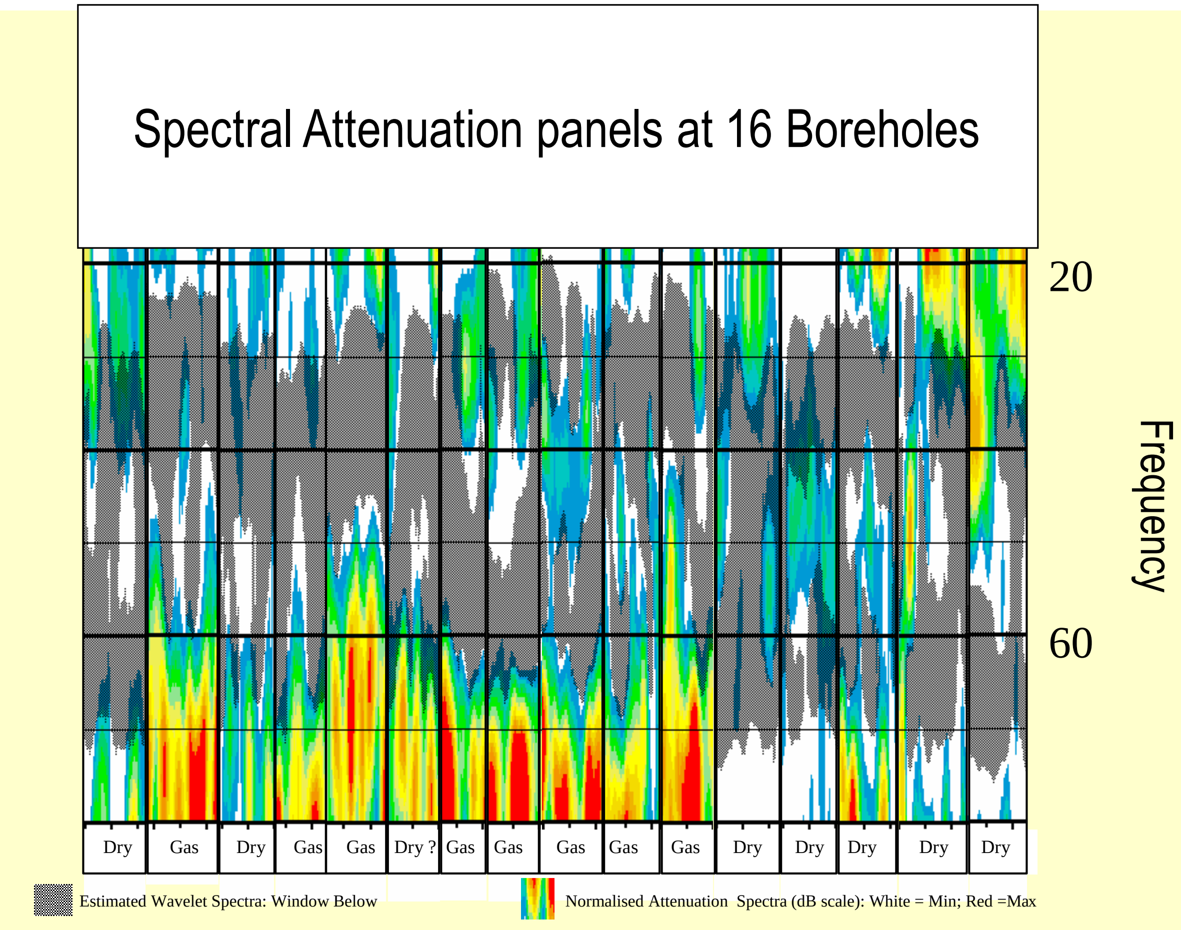
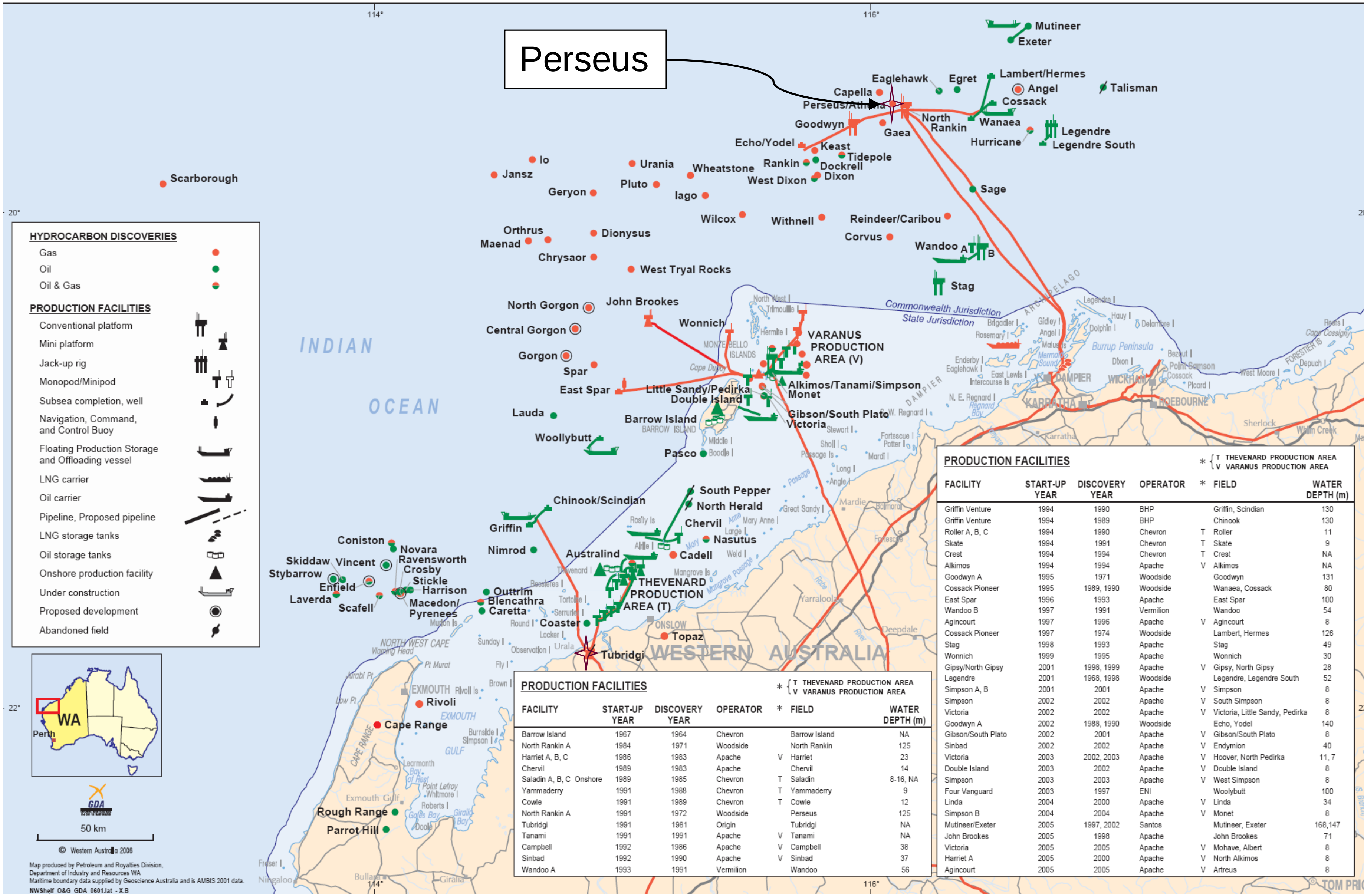


Image on the left is a composite showing panels of spectral attenuation (color) and wavelet spectra (grey), taken from seismic data ties with 16 boreholes. Note that there is a greater than 90% correlation with the presence of hydrocarbons and the higher frequency seismic attenuation. Follow-up drilling 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.

Department of Industry and Resources

NORTH WEST SHELF OIL & GAS

JANUARY 2006



PRODUCTION FACILITIES

* T THEVENARD PRODUCTION AREA
V VARANUS PRODUCTION AREA

FACILITY	START-UP YEAR	DISCOVERY YEAR	OPERATOR	*	FIELD	WATER DEPTH (m)
Barrow Island	1967	1964	Chevron		Barrow Island	NA
North Rankin A	1984	1971	Woodside		North Rankin	125
Harriet A, B, C	1986	1983	Apache	V	Harriet	23
Chervil	1989	1983	Apache		Chervil	14
Saladin A, B, C Onshore	1989	1985	Chevron	T	Saladin	8-16, NA
Yammaderry	1991	1988	Chevron	T	Yammaderry	9
Cowle	1991	1989	Chevron	T	Cowle	12
North Rankin A	1991	1972	Woodside		Perseus	125
Tubridgi	1991	1981	Origin		Tubridgi	NA
Tanami	1991	1991	Apache	V	Tanami	NA
Campbell	1992	1986	Apache	V	Campbell	38
Sinbad	1992	1990	Apache	V	Sinbad	37
Wandoo A	1993	1991	Vermilion		Wandoo	56

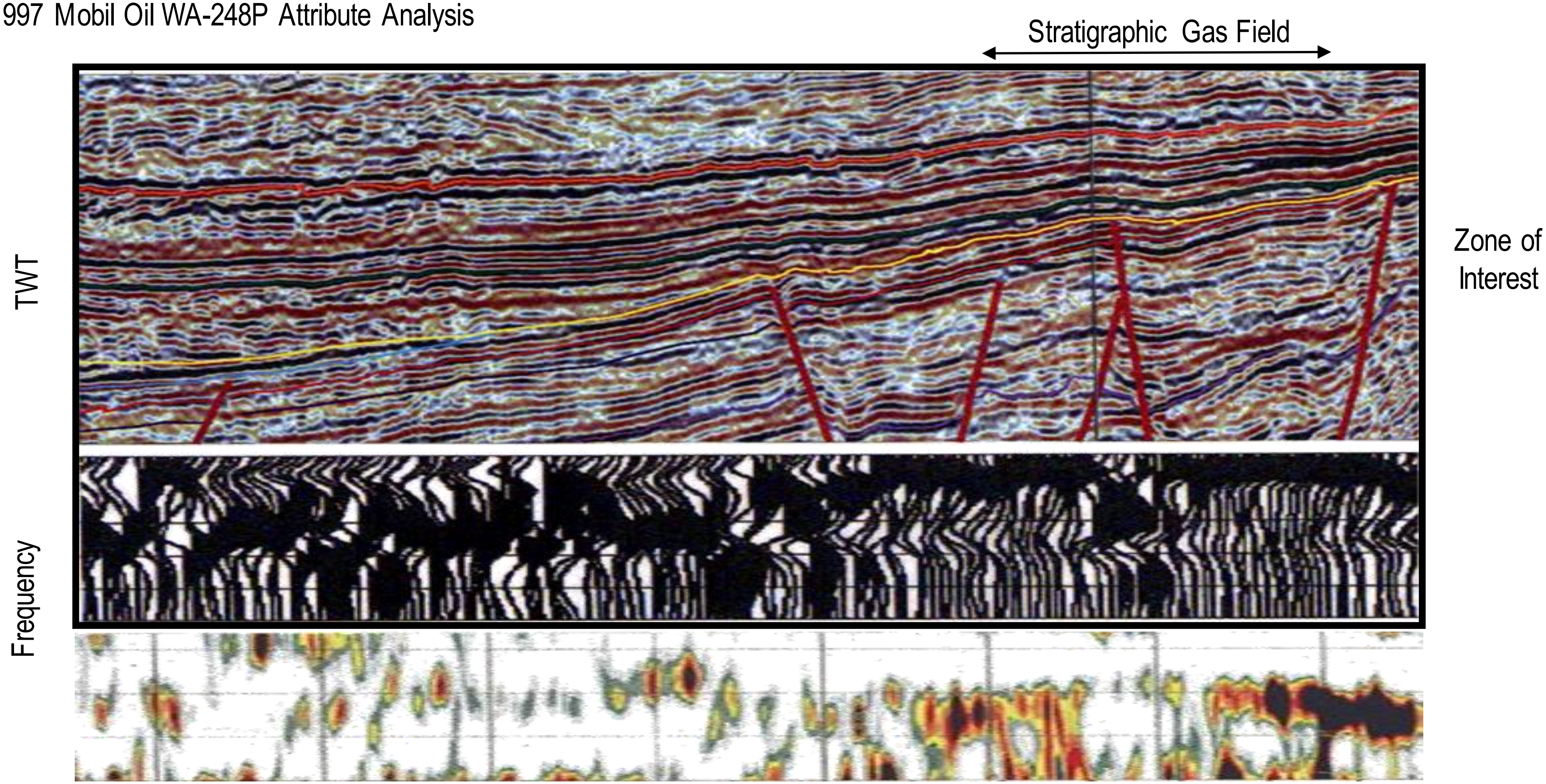
PRODUCTION FACILITIES

* T THEVENARD PRODUCTION AREA
V VARANUS PRODUCTION AREA

FACILITY	START-UP YEAR	DISCOVERY YEAR	OPERATOR	*	FIELD	WATER DEPTH (m)
Griffin Venture	1994	1990	BHP		Griffin, Scindian	130
Griffin Venture	1994	1989	BHP		Chinook	130
Roller A, B, C	1994	1990	Chevron	T	Roller	11
Skate	1994	1991	Chevron	T	Skate	9
Crest	1994	1994	Chevron	T	Crest	NA
Alkimos	1994	1994	Apache	V	Alkimos	NA
Goodwyn A	1995	1971	Woodside		Goodwyn	131
Cossack Pioneer	1995	1989, 1990	Woodside		Wanaea, Cossack	80
East Spar	1996	1993	Apache		East Spar	100
Wandoo B	1997	1991	Vermilion		Wandoo	54
Agincourt	1997	1996	Apache	V	Agincourt	8
Cossack Pioneer	1997	1974	Woodside		Lambert, Hermes	126
Stag	1998	1993	Apache		Stag	49
Wonnich	1999	1995	Apache		Wonnich	30
Gipsy/North Gipsy	2001	1998, 1999	Apache	V	Gipsy, North Gipsy	28
Legendre	2001	1968, 1998	Woodside		Legendre, Legendre South	52
Simpson A, B	2001	2001	Apache	V	Simpson	8
Simpson	2002	2002	Apache	V	South Simpson	8
Victoria	2002	2002	Apache	V	Victoria, Little Sandy, Pedirka	8
Goodwyn A	2002	1988, 1990	Woodside		Echo, Yodel	140
Gibson/South Plato	2002	2001	Apache	V	Gibson/South Plato	8
Sinbad	2002	2002	Apache	V	Endymion	40
Victoria	2003	2002, 2003	Apache	V	Hoover, North Pedirka	11, 7
Double Island	2003	2002	Apache	V	Double Island	8
Simpson	2003	2003	Apache	V	West Simpson	8
Four Vanguard	2003	1997	ENI		Woolybutt	100
Linda	2004	2000	Apache	V	Linda	34
Simpson B	2004	2004	Apache	V	Monet	8
Mutineer/Exeter	2005	1997, 2002	Santos		Mutineer, Exeter	168,147
John Brookes	2005	1998	Apache		John Brookes	71
Victoria	2005	2005	Apache	V	Mohave, Albert	8
Harriet A	2005	2000	Apache	V	North Alkimos	8
Agincourt	2005	2005	Apache	V	Artreus	8

Perseus Gas Field: Offshore NW Australia

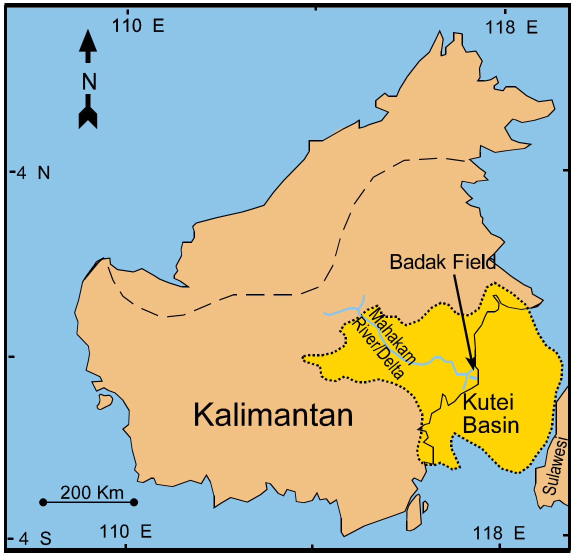
1997 Mobil Oil WA-248P Attribute Analysis

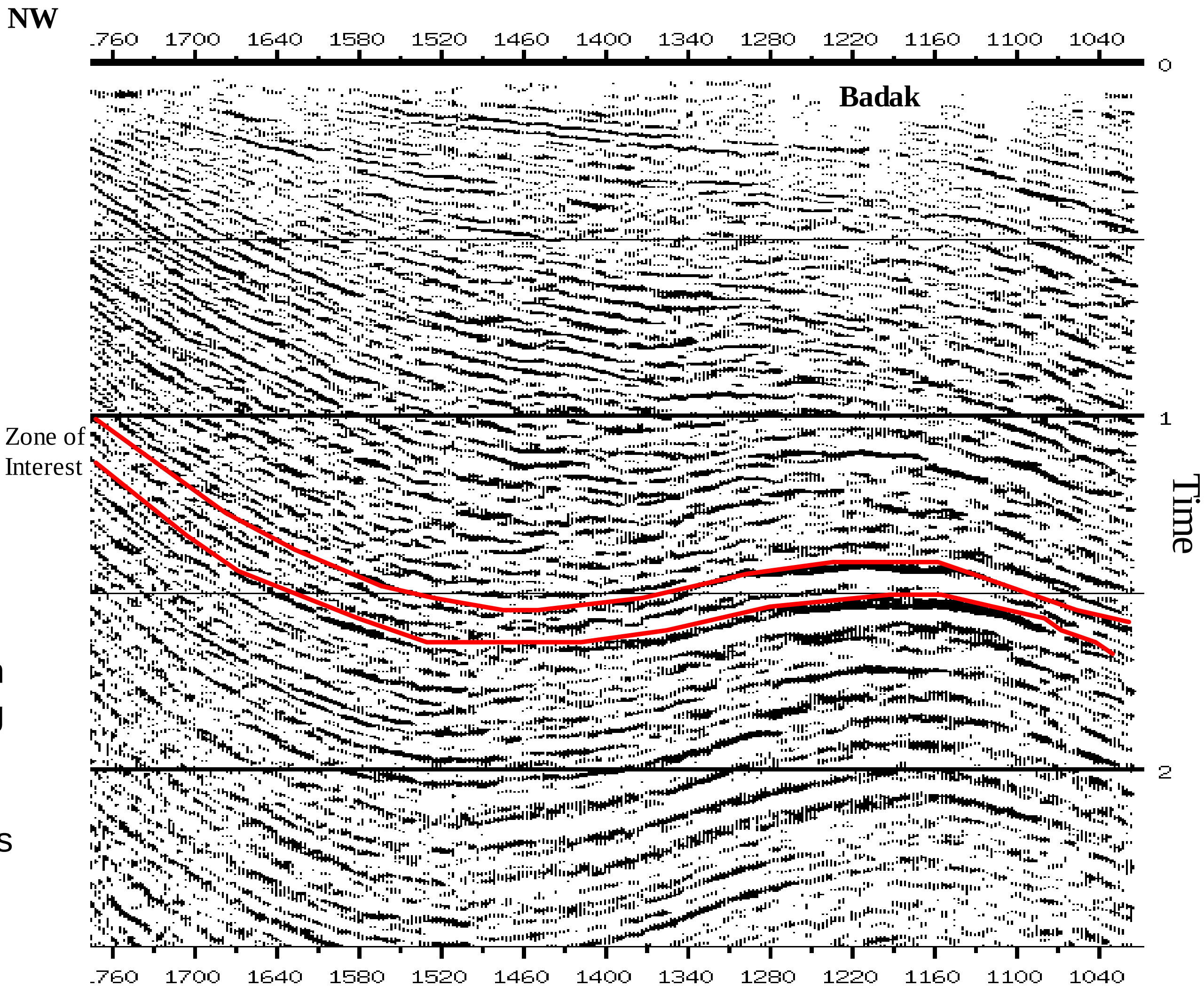


Attenuation Spectra:Black = Maximum Attenuation

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.

Badak Field: East Kalimatan



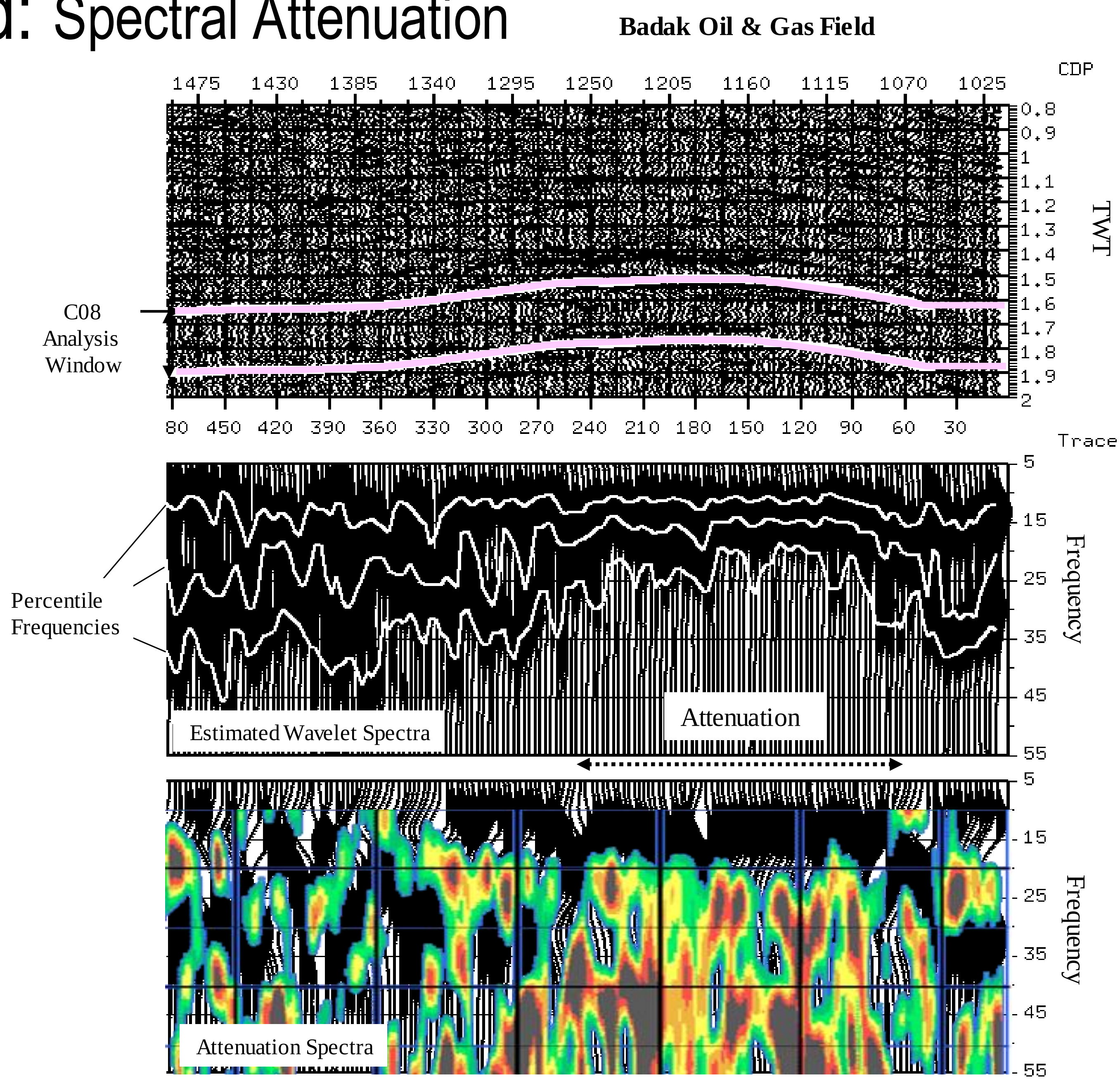


The Badak field was discovered in 1972 and a seismic line templating the field is shown. Hydrocarbons are trapped in a large anticlinal structure in stacked accumulations at depths from 1100 to 3600 metres. The spectral example shown in this study examines a zone of productive Upper Miocene sandstone reservoir around 1700 metres below the surface.

Spectral Signatures of the Badak Oil and Gas Field: Onshore Kutei Basin, Kalimantan, Indonesia: Dirstein, Maklad et. al. 1999 IPA conference.

Badak Field: Spectral Attenuation

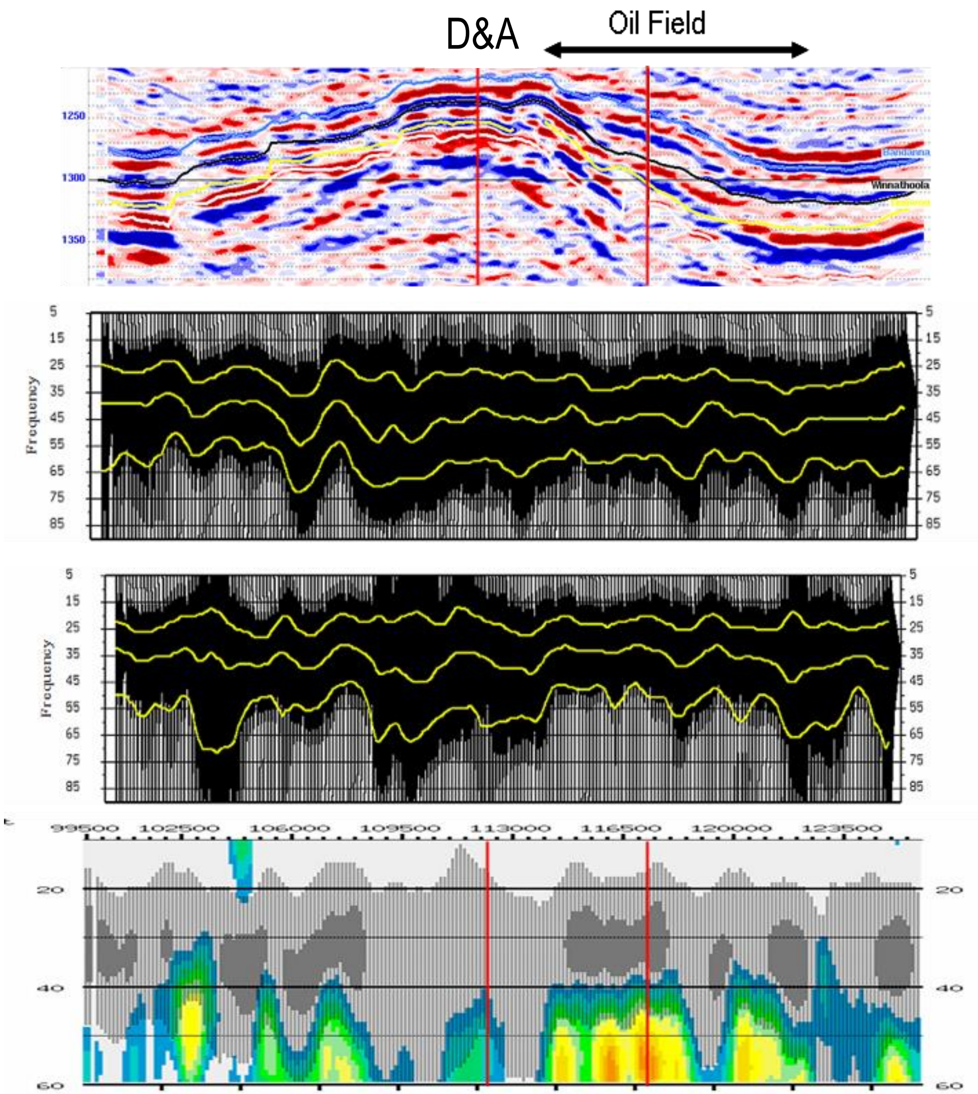
- The attenuation spectra shows an attenuation anomaly between 20-50 Hz.
- The presence of hydrocarbons in the Miocene Sandstone reservoirs at the Badak field appears to have caused measurable attenuation of higher seismic frequencies.
- The attenuation measurement was made from geophysical archived 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?

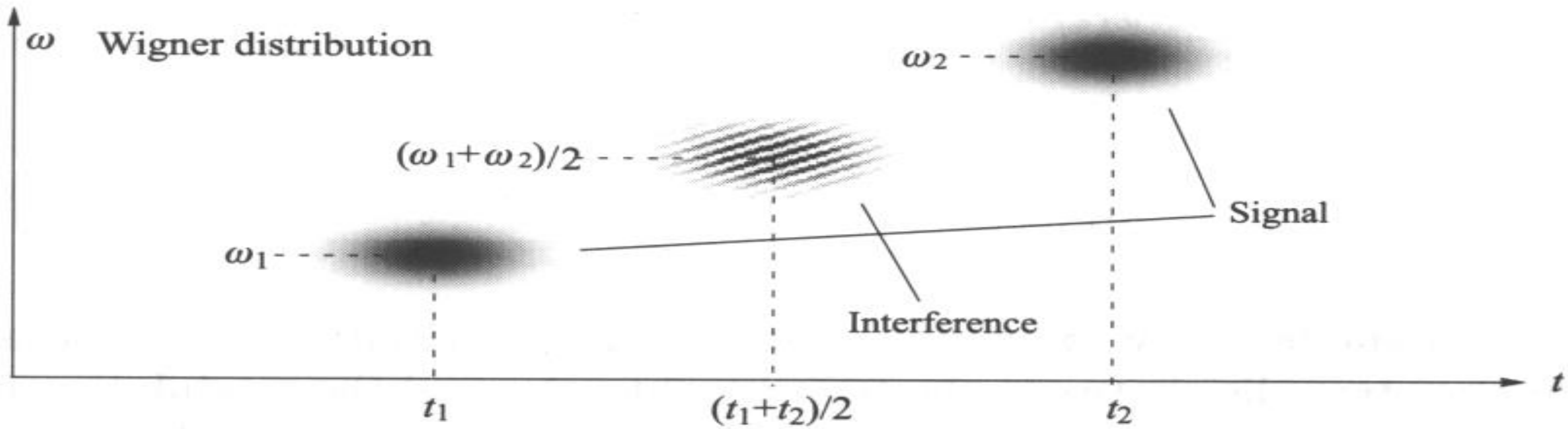
Spectral attenuation showed an anomaly on the eastern flank of the structure. Subsequent well location suggested by this anomaly was an oil well (no associated gas). The field has expected recoverable reserves of around one million barrels.

Time Frequency Analysis

- Provides better time localization of the frequency content of seismic data
- First Technique ultilized 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)



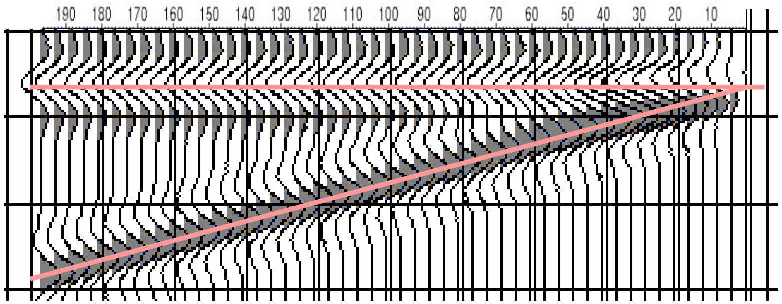
WV distribution of above signal. Notice the interference term.

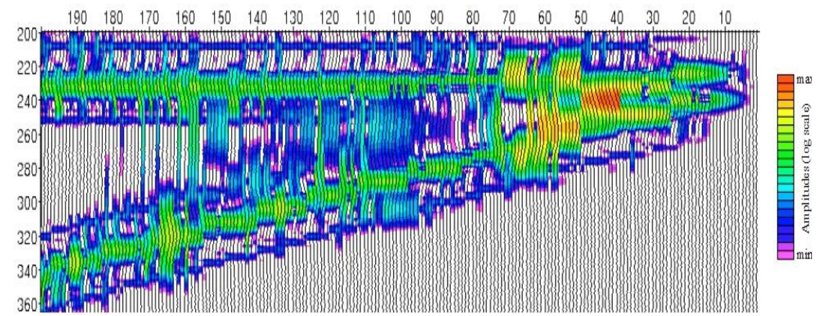
- Decomposing the signal into time-frequency wavelets addresses the cross-term problem.
- The time-frequency distribution of the signal is obtained by adding the Wigner-Ville distribution of the individual components.

Time Frequency Analysis: Applications

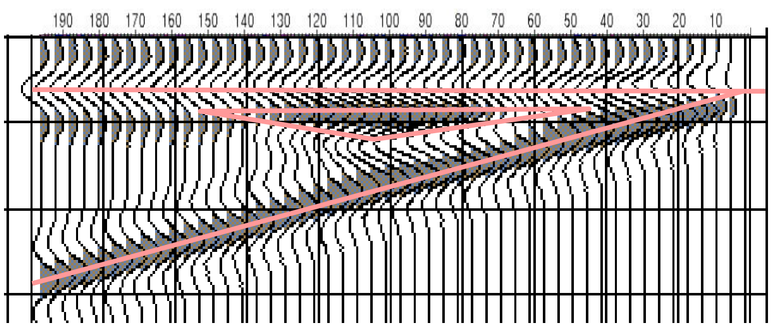
1. Detection of changes in lithology.
2. Detection of coherent noise.
3. Crude attenuation indicator.

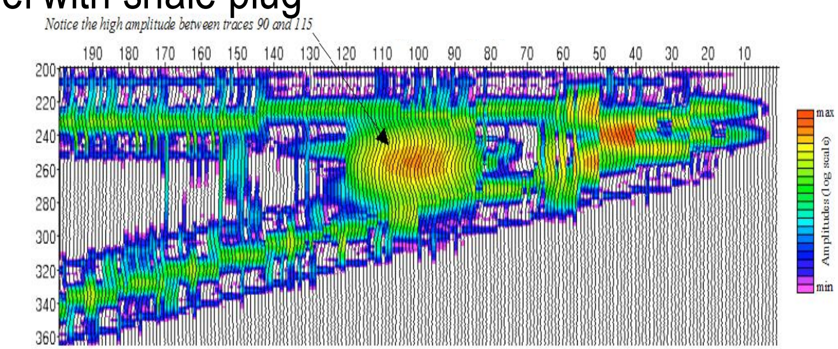
Wedge Model





Wedge Model with shale plug





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 and 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.