Seismic Attributes adding a new Dimension to Prospect Evaluation & Geomorphology Identification in the Malay and adjacent basins

Dr. Deva P Ghosh and Nor Azhar Ibrahim, PETRONAS Research Sdn Bhd, Bernato Viratno and Hamdan Mohamad, PETRONAS Carigali Sdn Bhd*

Summary

The purpose of this paper is to document the application of Seismic Attributes for prospect evaluation, delineation and geomorphology in the Malay and adjacent basin. This includes classification of Seismic Attributes and algorithms as applied to our basins. A methodology and workflow is developed and applied successfully in a series of geologic problems that includes:

1. Structural plays
2. Stratigraphic channel plays
3. Carbonate and basement plays
4. Hydrocarbon/Lithology prediction

Several pitfalls have been discussed and can be avoided by judicious choice of pertinent attributes. Attributes that are most successful applied in this region are Coherency, Dip/Azimuth, Curvature, Spectral Decomposition, Waveform Classifier and AVO attributes.

Introduction

Since the pioneering work on complex trace by late Turi Taner, seismic attributes have found recognition and wide spread application in E&P; prospect evaluation, field delineation, reservoir development, geomorphology and seismic stratigraphy. Milestones in this rapid development are:

a) Fault mapping through Coherence cube (Bahorich & Farmer, 1995)
b) Thin bed analysis and channelling (Partyka et al., 1999)
c) Structure and Stratigraphy application (Marfurt & Chopra, 2002).

Algorithm developments have been progressed steadily through our Vendors (Landmark, Paradigm and Petrel).

Malay Basin Geology

Malay basin is a pull apart extensional mature basin highly petroliferous and has seen extensive hydrocarbon exploration and production. The geology is layer cake that has seen thermal subsidence in the early Eocene Oligocene phase with rapid sedimentation and later inversion in the Early Miocene phase resulting in half graben type anticlinal features with basement supported faults. The adjacent basins in East Malaysia are Sarawak and Sabah basins. The geology is more complex and has steep dips and faulting. Also Sarawak has a spectacular carbonate build up in Luconia province which contributed 40% of our national gas reserves.

Motivation

This paper describes the application of seismic attributes in solving exploration problems but also discusses field delineation issues and further aspects of geomorphology identification and seismic stratigraphy, The Malay basin geology is "lithologically" complex in that soft shales, coals and thin beds cause considerable ambiguity and pitfalls while evaluating prospects and leads. Here is where attributes come in handy in revealing the true geology and contributed to the exploration success.

Attributes Classification as applied to the Malay basin

Based on Their Geologic Application

In this region we have used Seismic Attributes to a wide spread problem as mentioned above in prospect and reservoir evaluation. Depending on their application, we classify Seismic attributes into three (3) principal categories.

CLASS 1: Structure/Geomorphological Attributes

Mapping and identification of geologic features be it structural or stratigraphic is the main objective. Furthermore geomorphological analysis is an important aspect of our prospect mapping and evaluation strategies. Besides that, geological depositional facies of environment using seismic attributes is also useful in reservoir delineation. The seismic trace shape is classified within certain interval spatially using neural network technique to analyze the geological pattern.

Structure/Geomorphological Attributes	
Geological Application	***Algorithms***
Structural Compressional anticline, Faults	Dip/Azimuth, Semblance Hilbert transform, Cross-correlation, Coherency)
Stratigraphic Unconformity	Amplitude Coherency
Geomorphology (Toplap, Downlap, Onlap) Fracture Analysis	Curvature, Cosine of Phase & Instantaneous Attributes Dip/Azimuth, Curvature
Seismic Facies Pinch-out, unconformity, sinuosity	Sesimic waveform, Impedance Stratal slicing, sedimentology analysis, Phase attributes

CLASS 2: Spectral Attributes

These attributes play a very strong role in improving the resolution where hydrocarbon occurrence are in stacked thin beds. Spectral properties like instantaneous frequency and phase are used to improve interpretability and resolution of seismic data. Spectral attributes play a strong role in delineating internal architecture of reservoirs that require higher resolution and interpretability. Events that were not evident within the dominant frequency are illuminated.

Spectral Attributes	
E&P Application	***Algorithms***
Seismic resolution	Wavelet Transform, Cepstrum, Instantaneous Frequency & Instantaneous Phase
Thin bed tuning	Spectral Decomposition
Absorption, Saturation	Qp/Qs

CLASS 3: Fluid/Lithology atributes For HC prdiction & Reservoir Characterisation

The rocks in this younger Tertiary basin are generally soft, unconsolidated and are sensitive to fluid replacement and response as per Gassman. Hence quantitative AVO plays a significant role in HC prediction. Elastic inversion is useful in solving ambiguity problems of discriminating HC sand from shales and coal as shown in the latter examples.

Fluid/Lithology atributes	
Q.I. *Application*	***Algorithms***
Quality of reservoir	Amplitude/Impedance
HC prediction	AVO attributes : Intercept gradient, Envelope
Liihology vs Porefill	Elastic Impedance (EI), Vp/Vs, σ

Example of Seismic Attributes Application

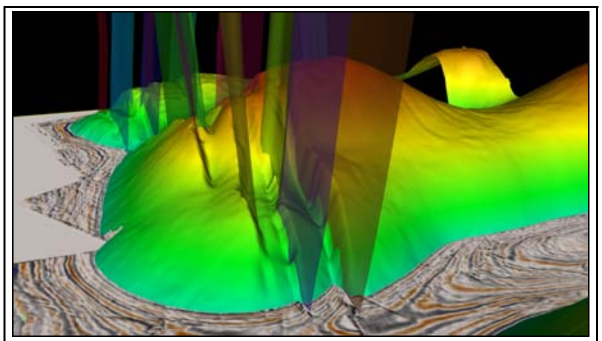

Figure 1: 3D Visualization and volume interpretation is the way forward in Prospect mapping. Tools such as transparency and opacity and multi-attributes co-rendered display aids the interpretation.

Sructural Attributes

A variety of structural styles that reflect the tectonic history in our basin are recognised. They include basement controlled normal fault with compressive inversion anticlinal structures (Figure 1).

3D Visualization techniques have been found best to analyse some spectacular carbonate buildup platforms or pinacles as shown in Figure 2 from the Luconia province in Sarawak.

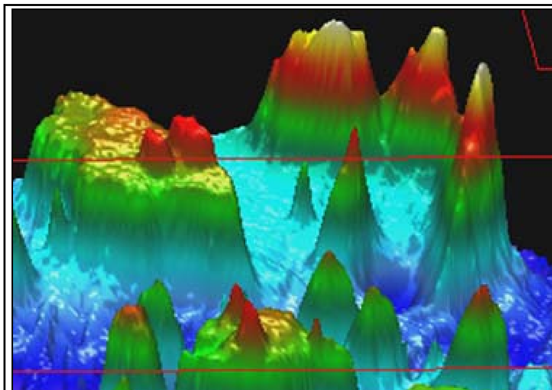

Figure 2: Seismic Visualisation for Mapping Top Carbonate in Luconia province, Sarawak.

Geomorphological Attributes

i. <u>*Stratigraphic Play*</u>

Since year 2000 the Malay basin is reasonably covered with hi-res 3D data. The resulting merged (mega) is the key input to our regional geological studies. The recorded data is best interpreted with attributes using geological analogues and models as shown in Figure 3. Spectral inversion further enhances the quality and details of these images and makes chasing stratigraphic play is viable.

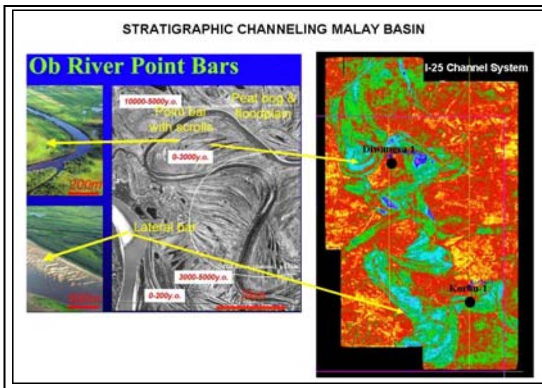

Figure 3: Stratigraphic Channel Imaging and channel morphology identification using Seismic Amplitude.

ii. Carbonate Play

Edges of the Kujung Carbonate features (Madura basin, Indonesia) are best detected by discontnuity attribute, whereas impedance like attributes can map porosity variation as a function of wind direction during the carbonate build up (Figure 4).

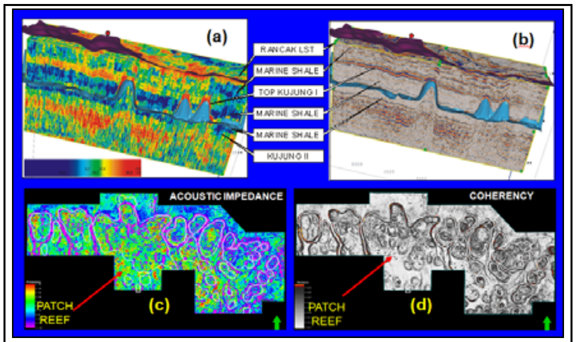

Figure 4: Carbonate bodies are best analysed through: (a) Sweetness (b) Reflectivity (c) Impedance (d) Coherency

Dip/Azimuth, curvature and anisotropy are useful in mapping fractured reservoir. Examples to be shown.

Class 2: Spectral Attributes

i. Instantaneous Attributes

Usage of three complex attribute family has been successful to delineate, analyze and understand carbonate reservoir architecture. Reflection strength (envelope) could identify sweet spot of strong acoustic contrast on top of carbonate, phase help interpreter to address reflector continuity and frequency attenuation demonstrates text-book example of lower frequency below a gas reservoir as shown in Figure 5.

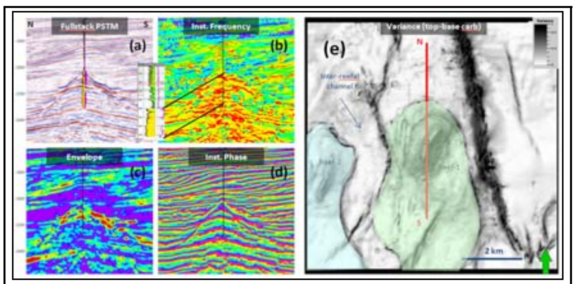

Figure 5: Application of complex trace attributes for carbonate gas field of Sarawak Basin:
(a) Amplitude (b) Instantaneous Frequency (c) Envelope (d) Instantaneous Phase (e) Variance (or coherency)

ii. Spectral Decomposition

The Malay basin stratigraphy is dominated by thin coal beds that accumulated from Group I to E under Coastal plain swampy/marshy environment. These coal are excellent source rock for high grade of oil found in the Malay basin. Coal beds are generally about 2m thick and hence can be filtered out because of their high spectral content thus revealing geology (Figure 6).

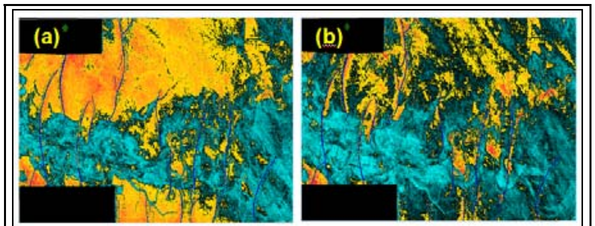

Figure 6: (a) Coal amplitude dominates response (Before). (b) After filtering coal effect, channels revealed.

Class 3: Lithology/Porefill Attributes

QI methodology has been quite successful in solving a wide range of problems including but not limited to:

a) Soft shale/HC sand discrimination
b) Coal interference between HC sand
c) High quality wet sand gives also a positive AVO response and hence a major pitfall in HC Prediction.

i. Amplitude : a Sand Quality Indicator

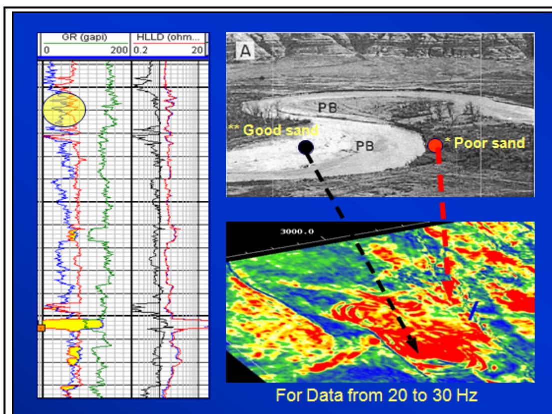

Figure 7: Poor sand quality on the overbank of a channel levee system causes scattered amplitude (: red arrow) compared centre of channel (**: black arrow). Well log confirms the poor sand development at the levee. Please note that wells drilled at both locations were discoveries.*

Amplitude analysis in the Malay basin has considerable interference from coal, soft and carbonaceous shales. Hence interpretation in the AI domain is misleading as their response is similar to that of a gas sand. On the other hand the Vp/Vs or Poisson's ratio are quite different (higher for coals/shales) and can be used as a discriminator as shown in Figure 8 from North of the Malay basin.

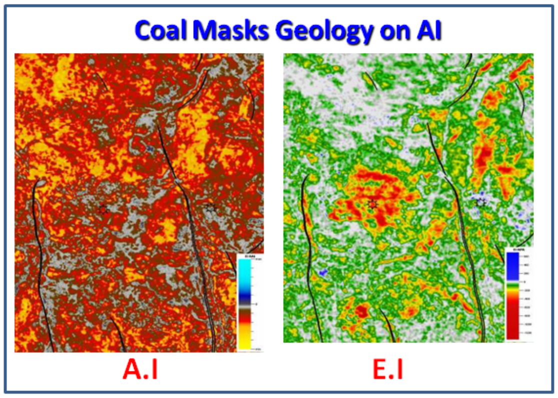

Figure 8: In EI domain, gas sand (low σ) can be separated from coal (high σ) through Elastic Inversion.

ii. *DHI Indicators*

Predicting HC from amplitude in Malay basin could be quite tricky. A good knowledge of the petroleum system in terms of basin modelling, facies identification and depositional environmental together with the understanding of structural styles, pressure regime and fault integrity lowers the dry hole risk.

In order that an amplitude anomaly is considered as a DHI, at least one of following conditions need to be satisfied:

1) Structural conformable amplitudes
2) Flat spot with correct polarity (hard kick)
3) Amplitude shut-off
4) Phase change at contact
5) Frequency drop below gas reservoirs
6) Pock marks & Gas wipe out symptoms

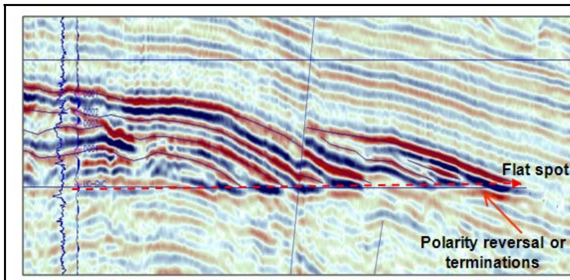

Figure 9: DHI flat spot identified through amplitude shut-off and phase reversal at fluid contact.

Conclusions

Attributes are now forming an integral part of our seismic prospect evaluation, maturation, risk, resource evaluation. Further attribute are increase use in reservoir modelling. Attribute analysis requires high quality data with good S/N ratio. Since year 2000, we in this part of the world had made a concentrated effort to acquire high resolution 3D marine data that has facilitated the use of attributes in our workflow. Further improvement in resolution is offered by the spectral attributes themselves by bringing in dormant and hitherto unravelled geological features.

Attributes are classified and categorized in three (3) principal groups depending on their geologic application. Three classes of application are identified as:

1) Structural mapping and geomorphological identification
2) Resolution of thin beds and improving Interpretability
3) Porefill and Lithology discrimination in HC prediction & reservoir characterization.

The critical attributes that satisfy these criteria are:

1) Coherency, dip/azimuth and curvature
2) Instantaneous attributes, Spectral inversion and Wavelet transforms
3) Amplitude, AVO-Inversion, Vp/Vs and Poisson's ratio

Lastly all attributes do have to be interpreted in geological context with a conceptual model to avoid artefacts and over reliance. The final interpretation has to be geologically plausible.

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