# Basinal variation of seismic attribute response in deepwater architectural element recognition

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**Abstract**

The advancement of seismic attributes and visualization techniques has allowed the study of seismic geomorphology from 3D reflection data. The study of deepwater deposits denes and characterizes architectural elements depending on their genesis, morphology, and position along the slope and basin floor. However, every individual basin's geological configuration determines the dimensions, morphology, and lithological composition of its architectural elements. To understand how seismic attributes help characterize geological settings, we employ multiple datasets with variable qualities since few studies elaborate on compiling and discussing the differences between basins. We explore and compare the use of seismic attributes to highlight deepwater architectural elements in three different basins around the world: The Ceará Basin in Equatorial Brazil, The Taranaki Basin in New Zealand, and The North Carnarvon Basin in Australia, focusing on the deepwater sedimentary section in each case. Although the first two datasets are examples of siliciclastic environments and the North Carnarvon, a mixed carbonate-siliciclastic exponent, the architectural elements identified in all the datasets are similar, as well as their attribute response. The results show that the most robust attributes to characterize deepwater elements such as incised channels, channel-levee systems, and lobes are a combination of geometric, amplitude derived, frequency, and textural attributes. These seismic attributes indicate morphological, lithological, bed stacking, and help to define the stratigraphic architecture. Moreover, we found that the co-rendering of RMS (lithology-proxy), coherence (morphology indicator), and curvature attributes help to define the internal configuration for most of the deepwater architectural elements. While each basin is unique, our results and comparisons serve as a guide for seismic interpreters to use in deepwater seismic geomorphology characterization.

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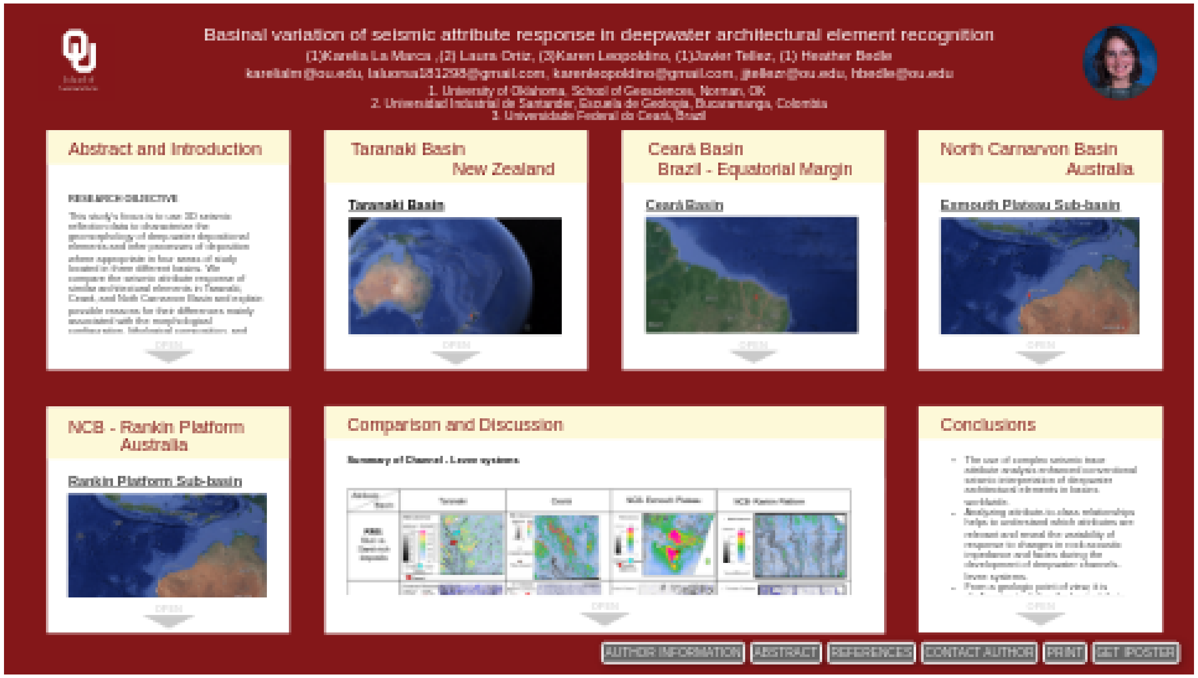
# Basinal variation of seismic attribute response in deepwater architectural element recognition

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AGU FALL MEETING
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# ABSTRACT AND INTRODUCTION

**RESEARCH OBJECTIVE**

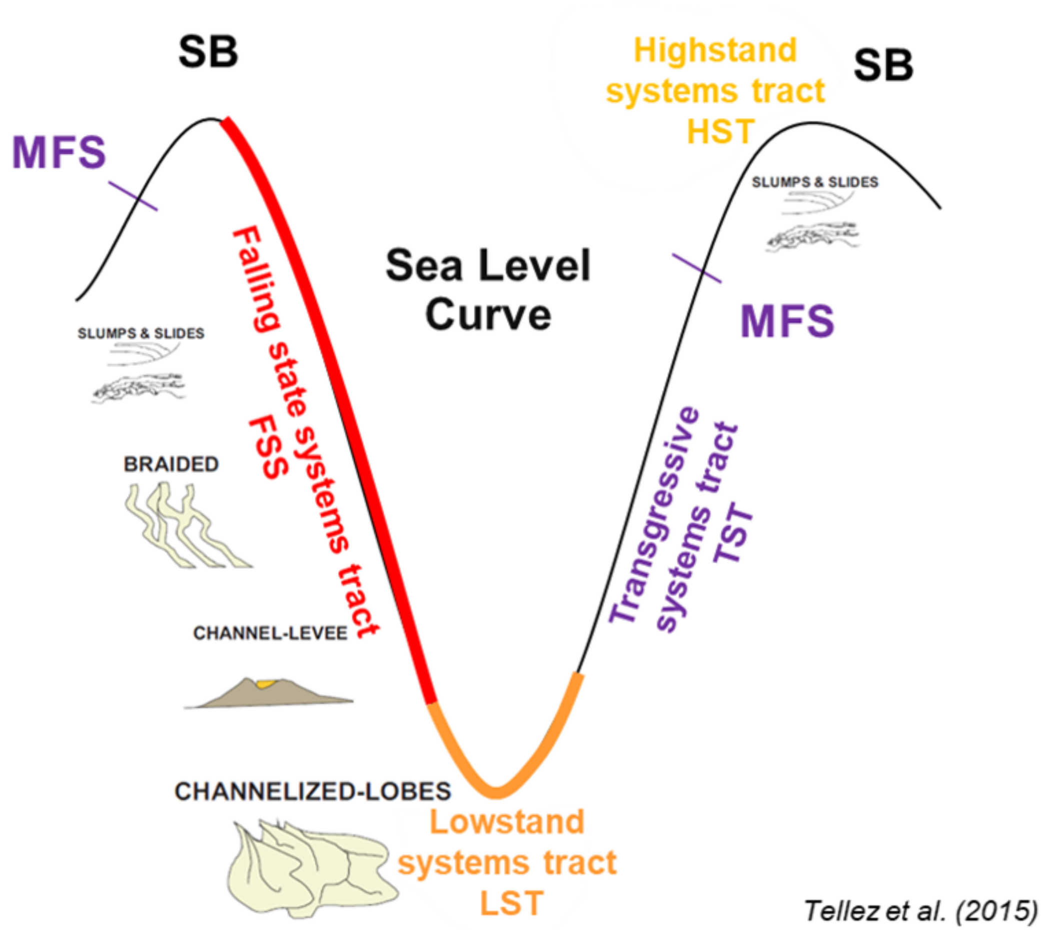
To use and analyze 3D seismic reflection data to characterize the geomorphology of deep-water depositional elements and infer deposition processes where appropriate in four areas of study.

To compare the seismic attribute response of similar architectural elements in Taranaki, Ceará, and Noth Carnarvon Basin and associate their differences to morphological configuration, lithological composition, and sediment supply.

**SUMMARY**

The advancement of seismic attributes and visualization techniques has allowed the study of seismic geomorphology from 3D reflection data. The study of deepwater deposits denes and characterizes architectural elements depending on their genesis, morphology, and position along the slope and basin floor. However, every individual basin's geological configuration determines the dimensions, morphology, and lithological composition of its architectural elements. To understand how seismic attributes help characterize geological settings, we employ multiple datasets with variable qualities since few studies elaborate on compiling and discussing the differences between basins. We explore and compare the use of seismic attributes to highlight deepwater architectural elements in three different basins around the world: The Ceará Basin in Equatorial Brazil, The Taranaki Basin in New Zealand, and The North Carnarvon Basin in Australia, focusing on the deepwater sedimentary section in each case. Although the first two datasets are examples of siliciclastic environments and the North Carnarvon, a mixed carbonate-siliciclastic exponent, the architectural elements identified in all the datasets are similar, as well as their attribute response. The results show that the most robust attributes to characterize deepwater elements such as incised channels, channel-levee systems, and lobes are a combination of geometric, amplitude derived, frequency, and textural attributes. These seismic attributes indicate morphological, lithological bed stacking and help to define the stratigraphic architecture. Moreover, we found that the co-rendering of RMS (lithology-proxy), coherence (morphology indicator), and curvature attributes help to define the internal configuration for most of the deepwater architectural elements. While each basin is unique, our results and comparisons serve as a guide for seismic interpreters to use in deepwater seismic geomorphology characterization.

**Sea Level and Architectural Elements in Deepwater settings**




Deepwater architectural elements are related and connected to the sequence stratigraphic framework and relative sea-level changes within the basins.

**The Falling Stage Systems tract**

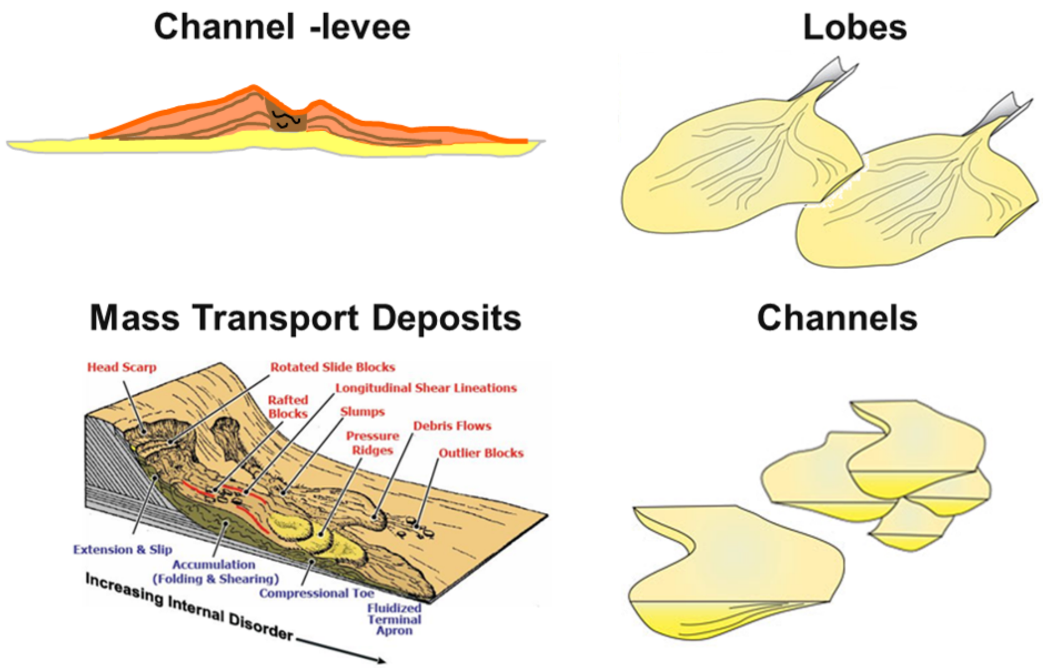
FSS marks the beginning of the deposition of deepwater elements.

First, Mass Transport Complexes (MTC's) are deposited as a result of the change of the water column that results in the destabilization of the slope and slumps.

Second, channels' formation results from the erosion in the platform carrying out material to the slope and distributing it to the lower slope and basin floor by straight channels and channel-levee elements.

Lastly, during the **Low Stand System Tracts LST,** the sediment is delivered to the basin floor or the lower slope, where it is reworked, forming lobes and distributary channels with levees.

**Characteristics of Architectural Elements**



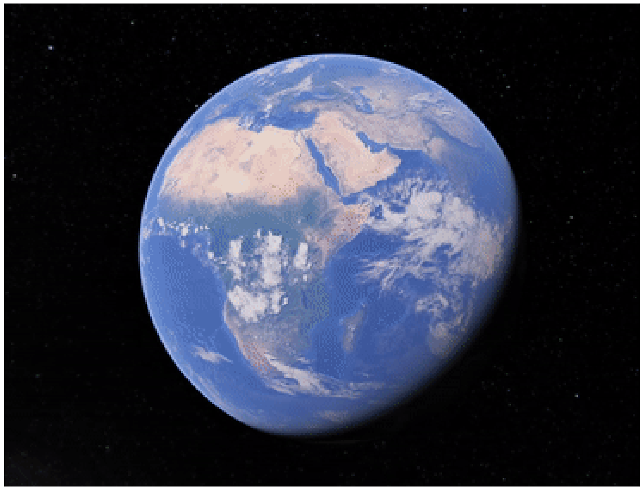

Turbidites are sediments deposited in water depths considered to be “deep,” i.e., those under gravity-flow processes and located somewhere in the upper to middle slope region to the floor of a basin beneath a storm wave base. (Slatt and Weimer, 2004).

The grouping of similar geomorphic features is referred to as architectural elements. Architectural elements were defined by Mutti and Normark (1991) and Pickering et al. (1998) as "the basic mappable components of both modern and ancient turbidite systems, distinguished based on its geometry, scale, and facies". Architectural elements type and geometry vary depending on their position on the slope.

Four major architectural elements can be recognized: Channel, Levees, Fans (sheet sands), and Mass Transport Deposits (MTD).

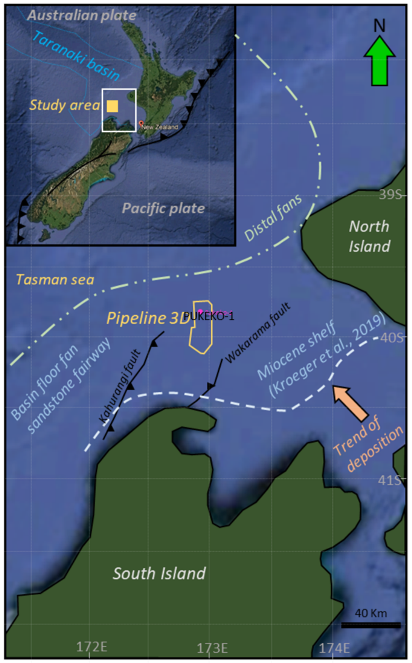
# TARANAKI BASIN
# NEW ZEALAND

**Taranaki Basin**



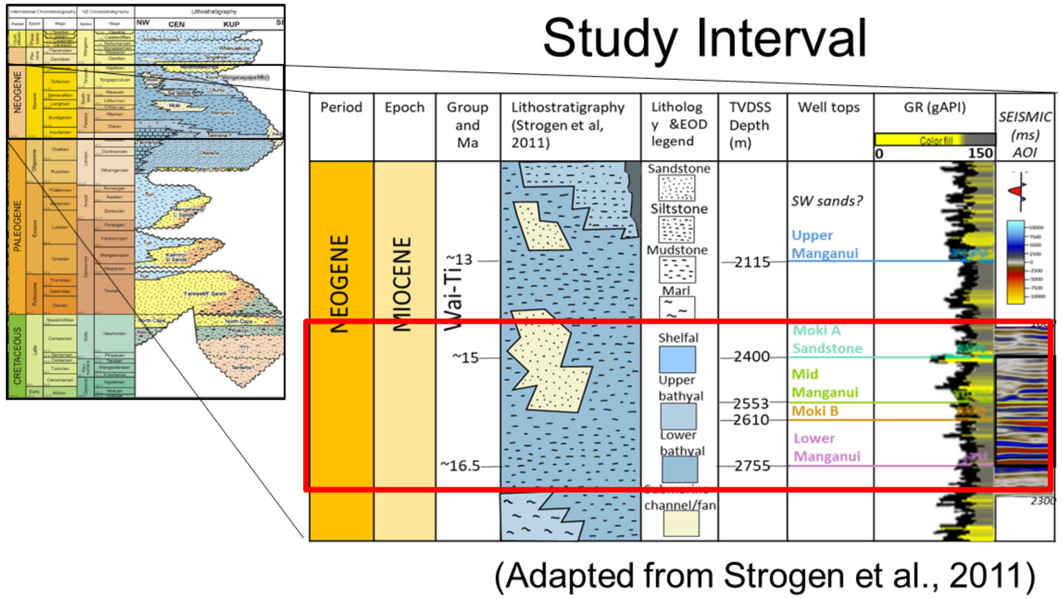
•Taranaki Basin: Rift Basin Cretaceous filled with up to 10km of sedimentary succession.

•Paleoflow direction: SE-NW



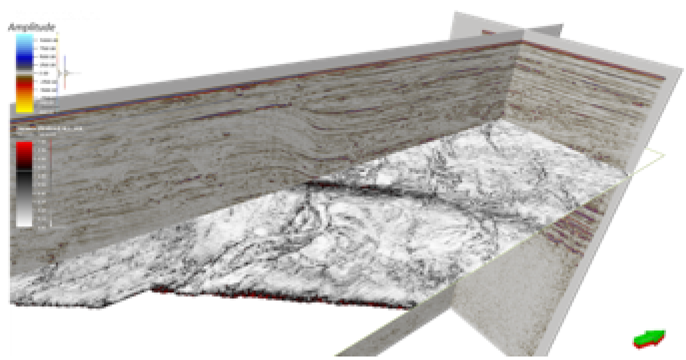

**Target Formation to analyze**

- Moki and Manganui Formations
- Deepwater deposits
- Miocene (~12- 15 Ma)
- Sandstones (Moki Fm) encased within mudstones (Manganui Fm).
- Location: West- offshore New Zealand, Southern Taranaki Basin
- Area: 330,000 km2




Study interval and sedimentary column (La Marca, 2020)

**Dataset description**



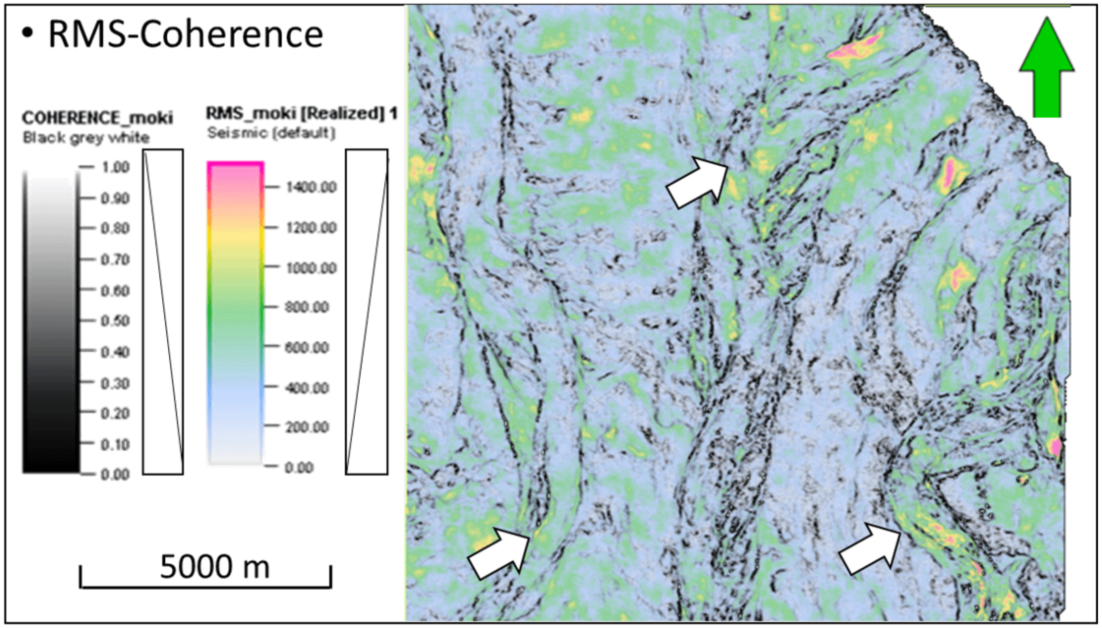
- Seismic volume (Post-Stack Time Migrated)
- 515 Km2
- Acquired in 2013 by Todd Exploration

- Data is zero-phase and SEG Negative polarity
- Sample rate 4ms, Record length: 6s
- Bin size 25x12.5m
- Datum: NZGD 2000

**Seismic attributes for architectural elements**

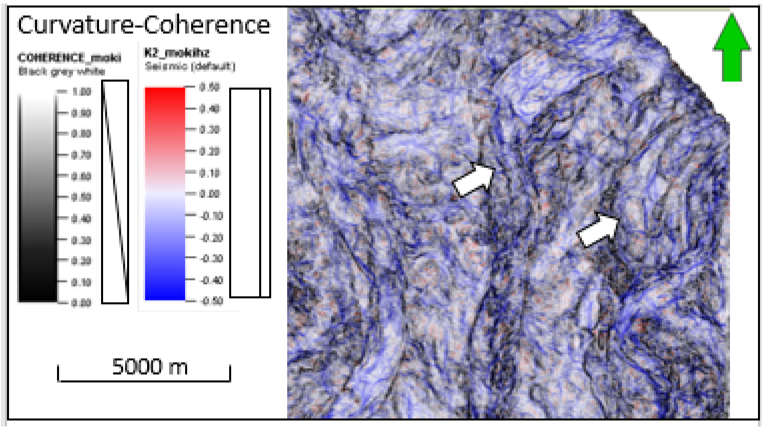
***CHANNELS***

**RMS + Coherence attributes**



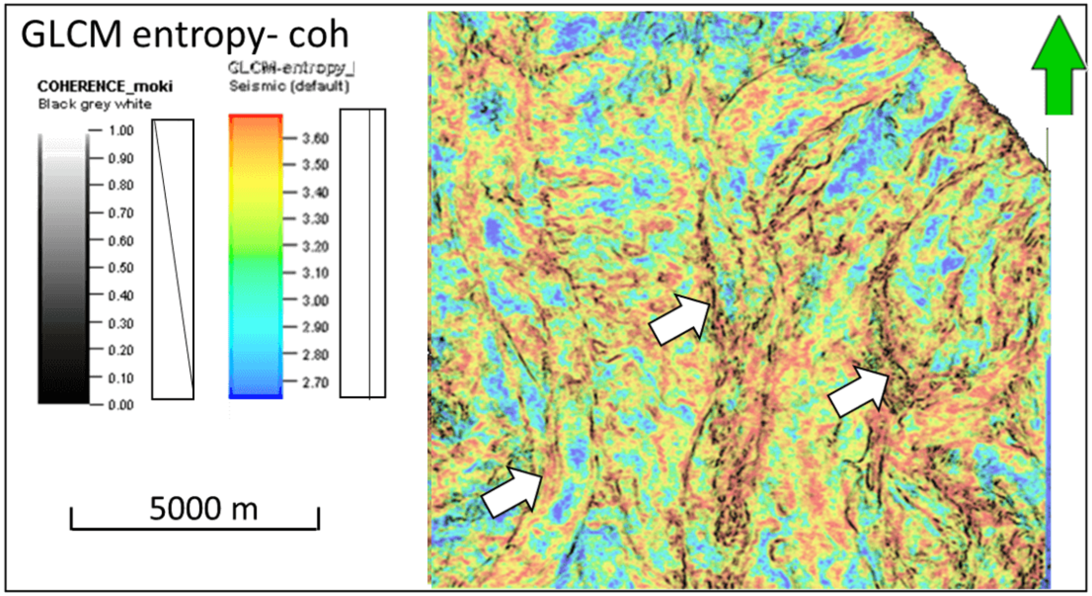

Basin floor channels of the Moki formation in the Taranaki Basin have widths from 200m to above 2Km in channel complexes (Baur, 2012 and Silver et al., 2019). The coherence attribute allows defining the geomorphology of these channels, which, combined with the Root mean square attribute (RMS), provides hints of possible good quality sandstone reservoirs indicated by high RMS values. The predominance of RMS's low values, defined by blueish colors, indicates that the system is mud prone.

**Curvature + Coherence**




Curvature attribute co-rendered with coherence is a powerful seismic interpretation tool. Negative curvature illuminates syncline-like or concave-up features, like mud-filled channels, which is the case shown in the Horizon. Note how blue colors represent negative curvature values, whereas red reflects possible sand-filled or mounded areas (typical of levees) in red color.

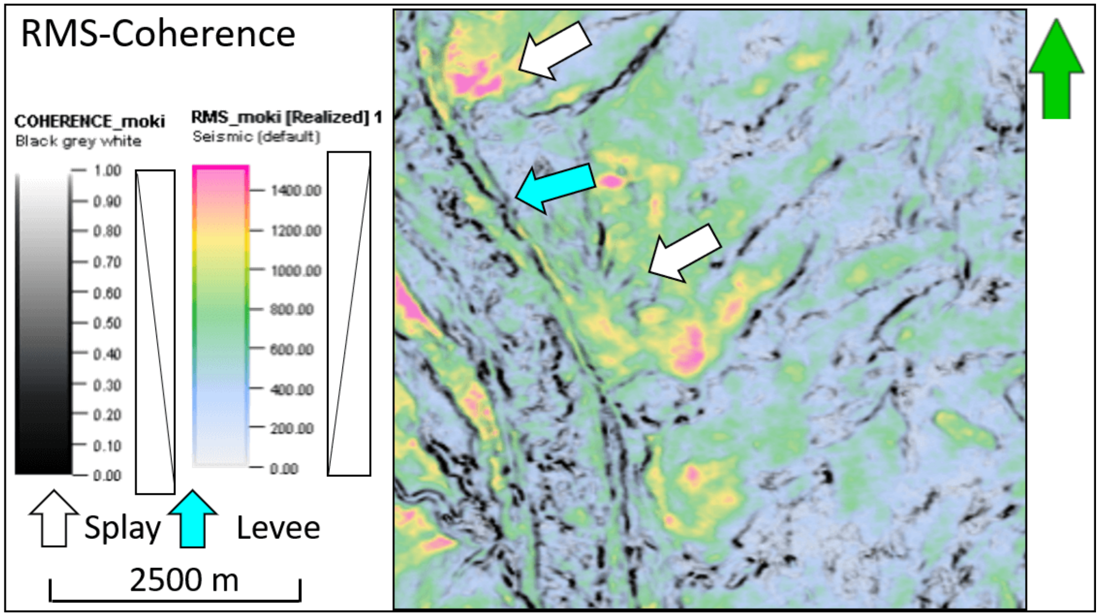
**GLCM Entropy + Coherence**




GLCM entropy is a textural attribute that quantifies the lateral variation in seismic amplitude, emphasizing how smoothly varying the voxel values or seismic amplitudes are within a window (Haralick et al., 1973). GLCM entropy co-rendered with coherence attribute in the horizon shown allows recognizing differences in facies by its textural response. We observe how the channel composition varies laterally. More turbiditic channels and scroll bars reflect higher GLCM entropy values, which is expected due to its chaotic nature.

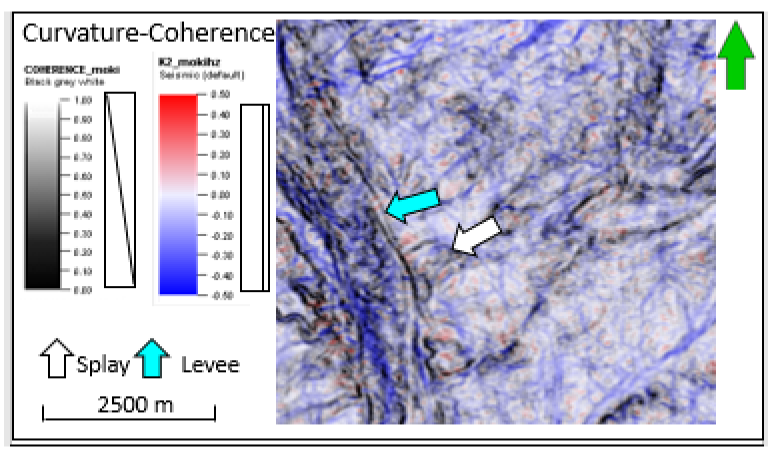
***LEVEES and FAN like Sandstones***

**RMS + Coherence attributes**



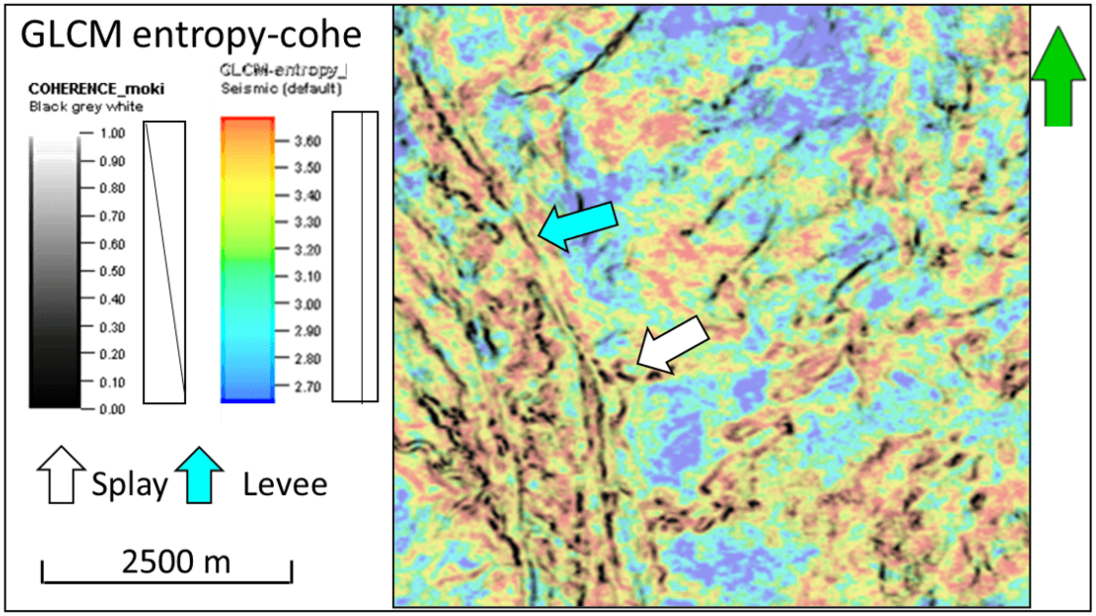

RMS is a measure of reflectivity within a time window. It computes the square root of the sum of squared amplitudes divided by the number of samples within the window used (Meek, 2013). Sand bodies often depict a high RMS value. RMS's use with coherence superimposed allows interpreting coarser-grained levees and splays compared to the background shales and mud-filled channels in the horizon interpretation.

**Curvature + Coherence**



In this case, levees are interpreted in areas of positive curvature, identified by red color. Note how minor channels and splays have red shades as well.

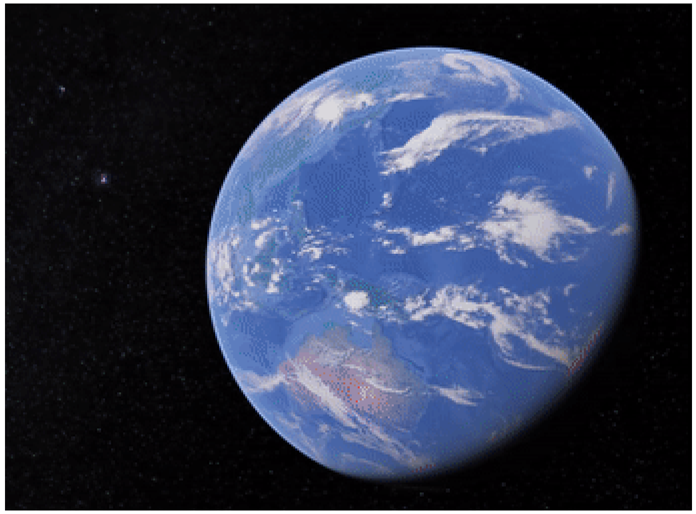
**GLCM Entropy + Coherence**



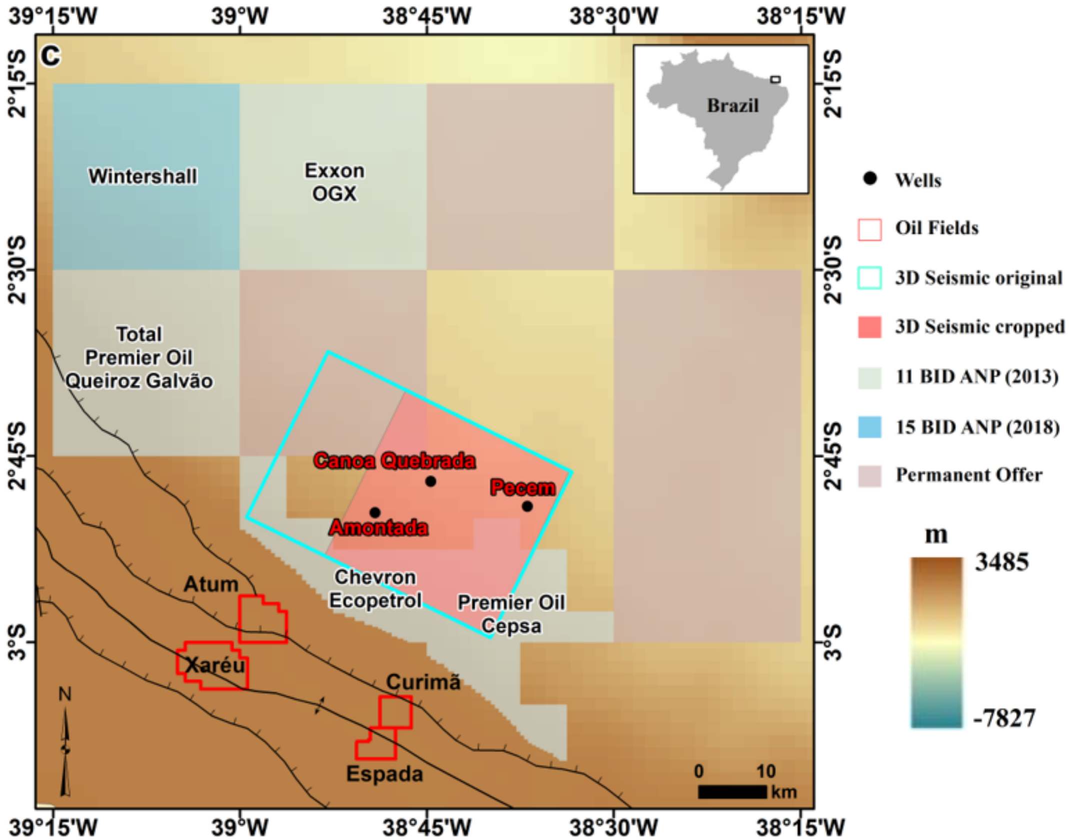

GLCM entropy co-rendered with coherence attribute in the horizon shown, allowing recognizing differences in facies by its textural response. More chaotic facies like turbiditic channels/flows show a high GLCM entropy value in red color.

# CEARÁ BASIN
# BRAZIL - EQUATORIAL MARGIN

## Ceará Basin

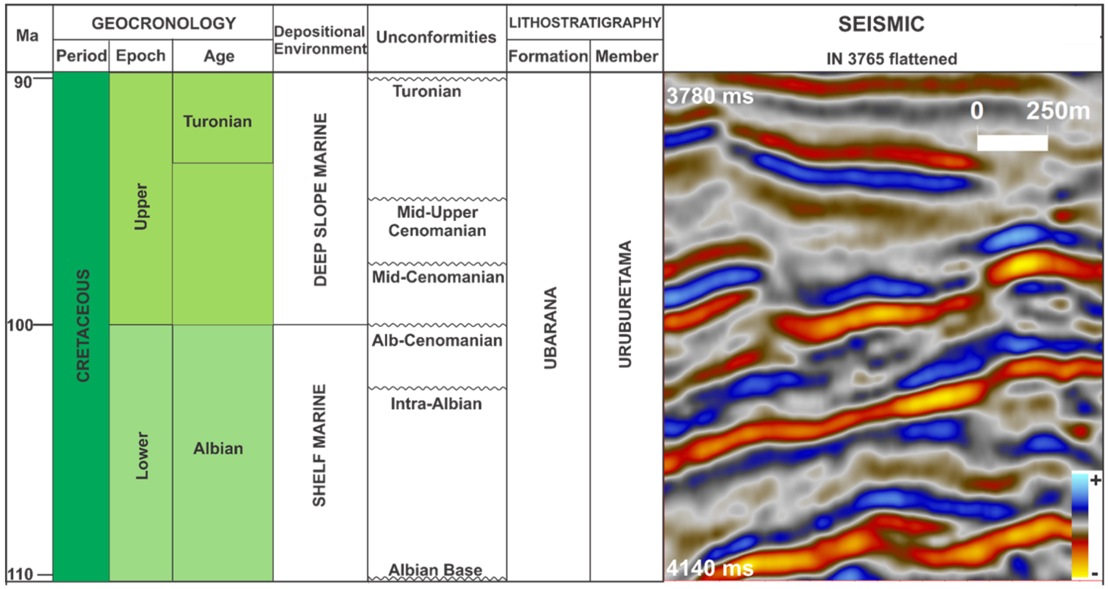


- Part of the deepwater Brazilian Equatorial Margin (BEM)
- High potential for light oil discoveries in upper Cretaceous formations
- Result of several continental rift events through a complex evolution with the tectonic regime varying from normal (distension) to strike-slip (trans-tension and transpression) regime.



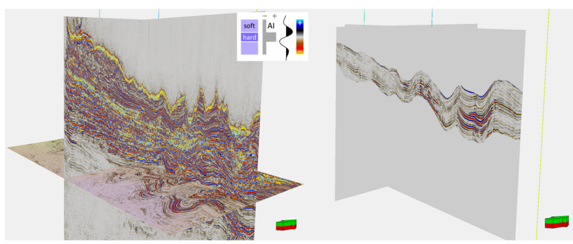

**Target Formation to analyze**

- Turbidite sandstone reservoirs of the Albian to Turonian.
- Prospective in stratigraphic traps.
- The early Cretaceous formations within the Ceará Basin indicate a working petroleum system and potential hydrocarbon reservoirs.




(Adapted from Condé et al., 2007)

## Dataset Description



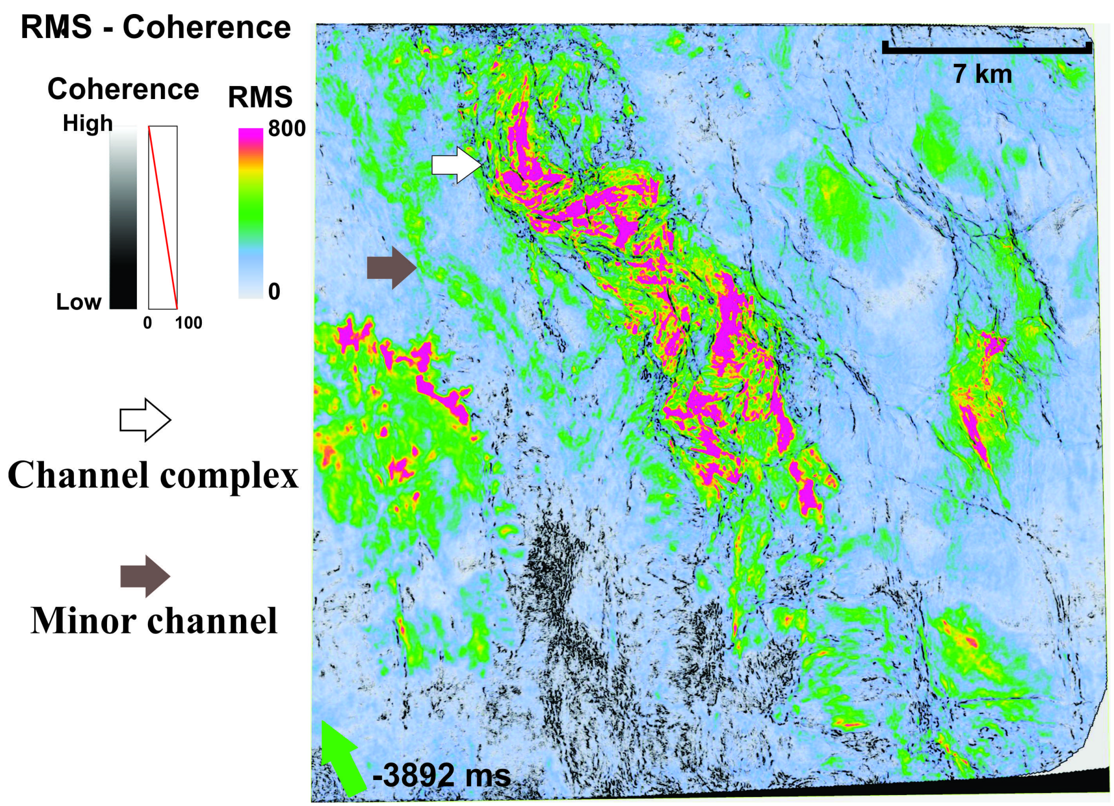
- Coverage Area ~ 1,107 km²
- Processed by CGG in 2003
- Zero phase and positive polarity
- Sample rate 4ms
- Bin size: 12,5 x 12,5 m

## **Seismic attributes for architectural elements**

***CHANNELS***

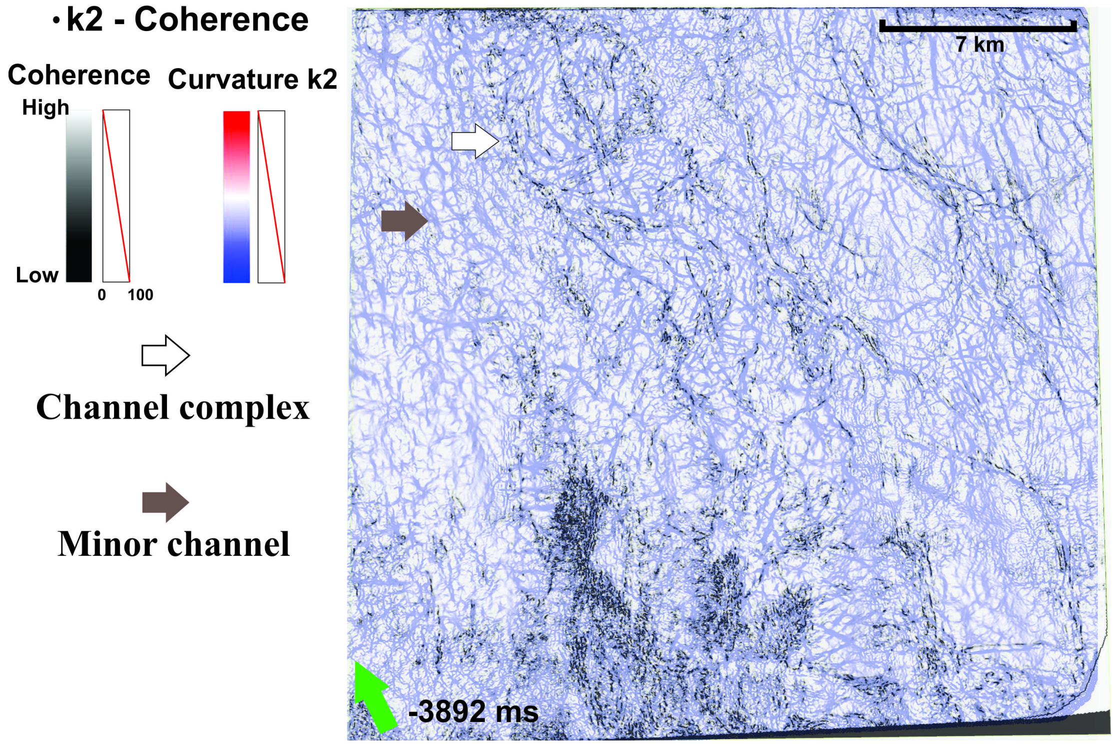
The following channel complex example was identified in the Uruburetama Formation.

**RMS + Coherence attributes**



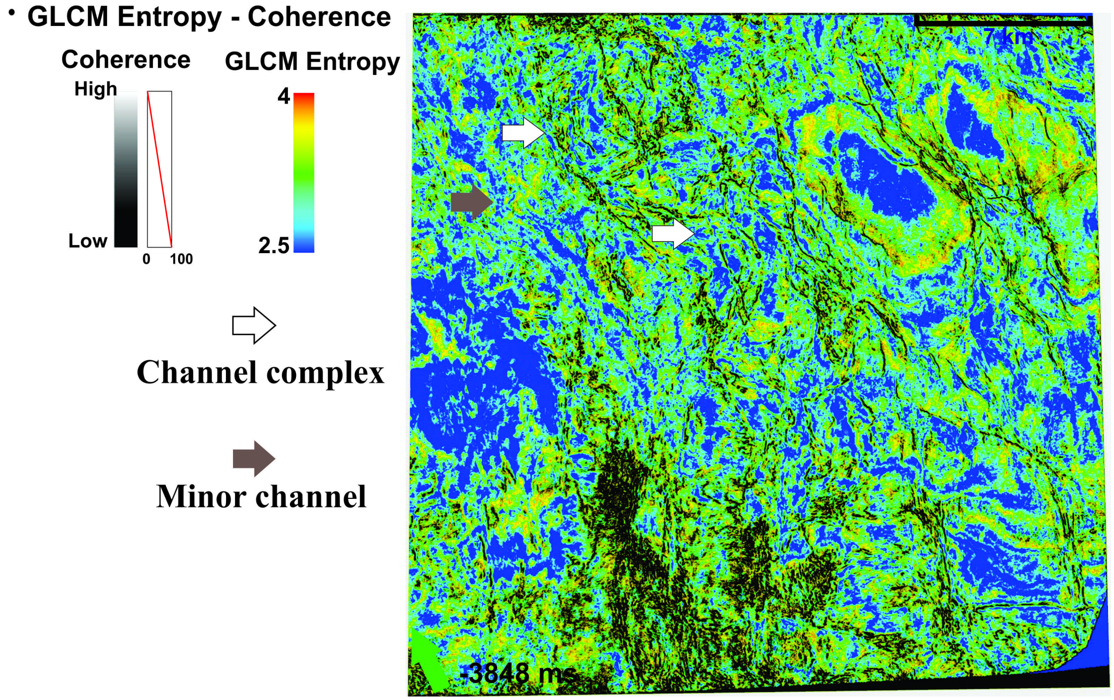

The RMS attribute displays the contrasting composition of the channel complex varying from sand-rich (pink colors) to muddy-lithology in the channel fills. The minor channel is well-imaged and is mostly composed of mud sediments (green colors).

**Curvature + Coherence**




The minor channel example is not well-imaged in the Curvature attribute, possibly due to the muddy channel composition. The channel complex is slightly well-imaged.

**GLCM Entropy + Coherence**

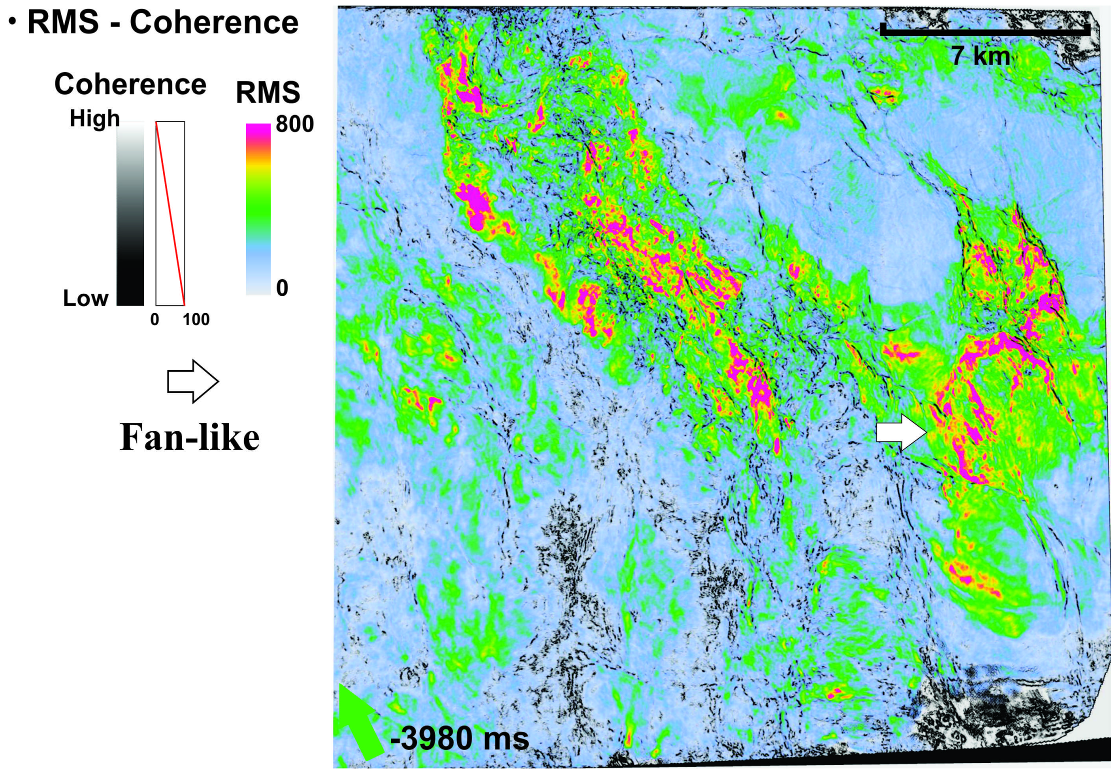



This correndering shows that the minor channels are homogenous (blue colors) while the channel complex fill is chaotic (blue to yellow).

***FAN-like deposits***

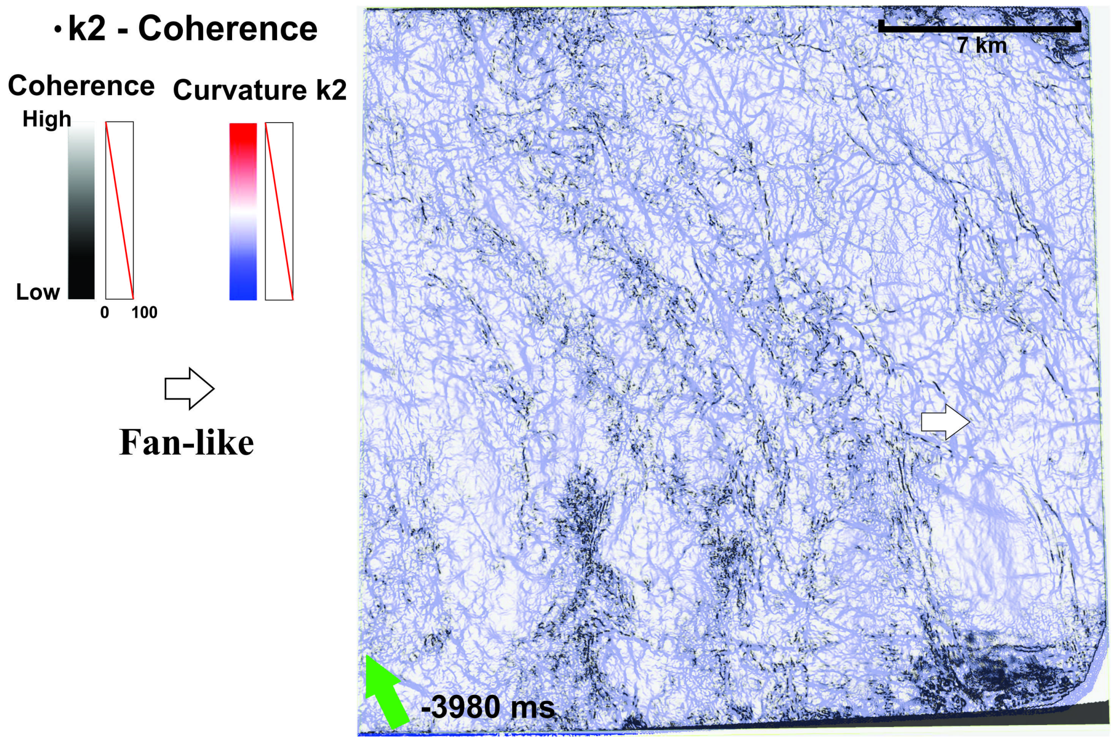
This submarine fan example was identified in the Uruburetama Formation, near the Albian base.

**RMS + Coherence attributes**




The homogenous sand-rich composition of this fan example was proven by the high values in the RMS attribute with a noticeable decrease in the mud to sand ratio from proximal to distal areas (green to pink).

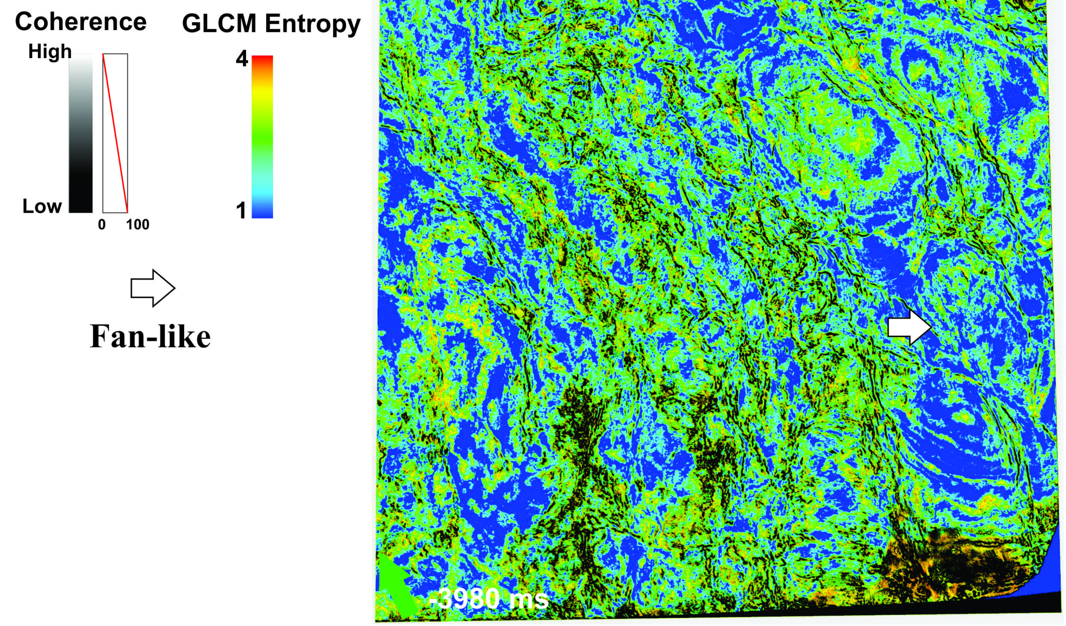
**Curvature + Coherence**




This fan example is not well-imaged in this correndering, possibly due to the faults and structures near the Albian base age.

**GLCM Entropy + Coherence**

- **GLCM Entropy - Coherence**

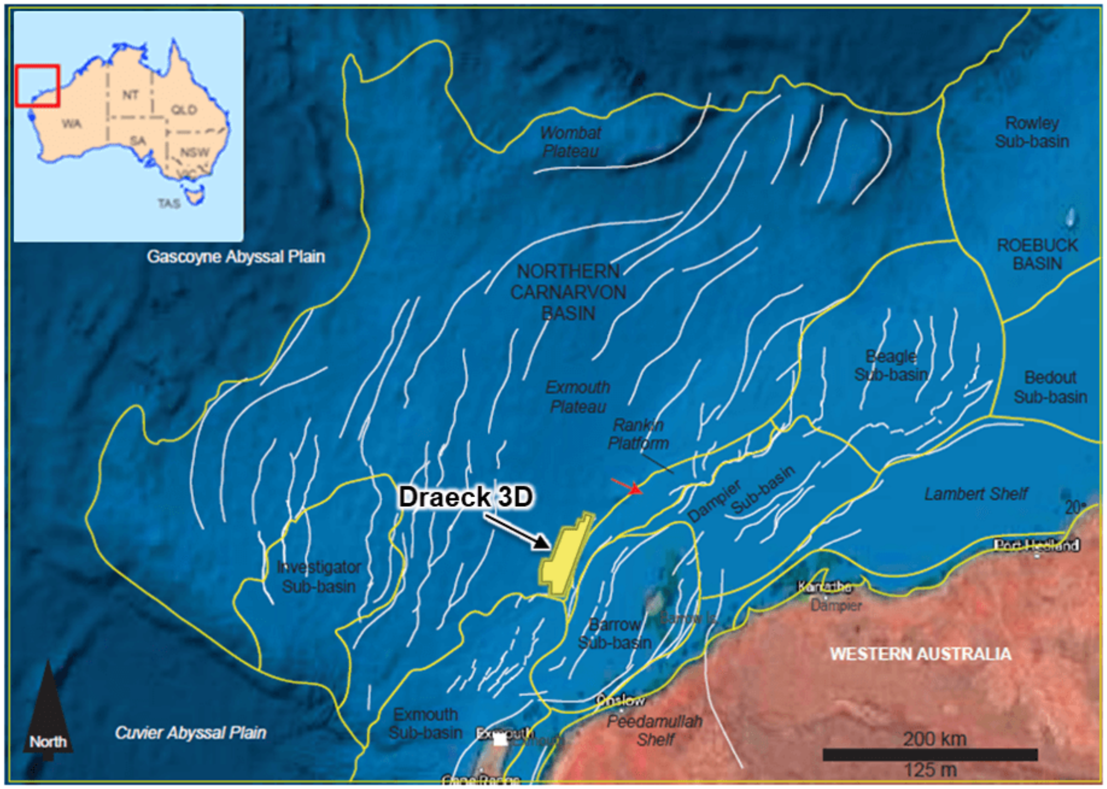



Overall, exhibits low GLCM Entropy response (blue), although towards the edges of the deposit tends to be more chaotic (greenish).

# NORTH CARNARVON BASIN AUSTRALIA

## **Exmouth Plateau Sub-basin**

- The tectonic evolution involves several stages of rifting from the Late Triassic up to the Late Cretaceous.
- Extension during the Cenozoic with deposition was controlled by relative sea-level changes (Yang & Elders,2016).

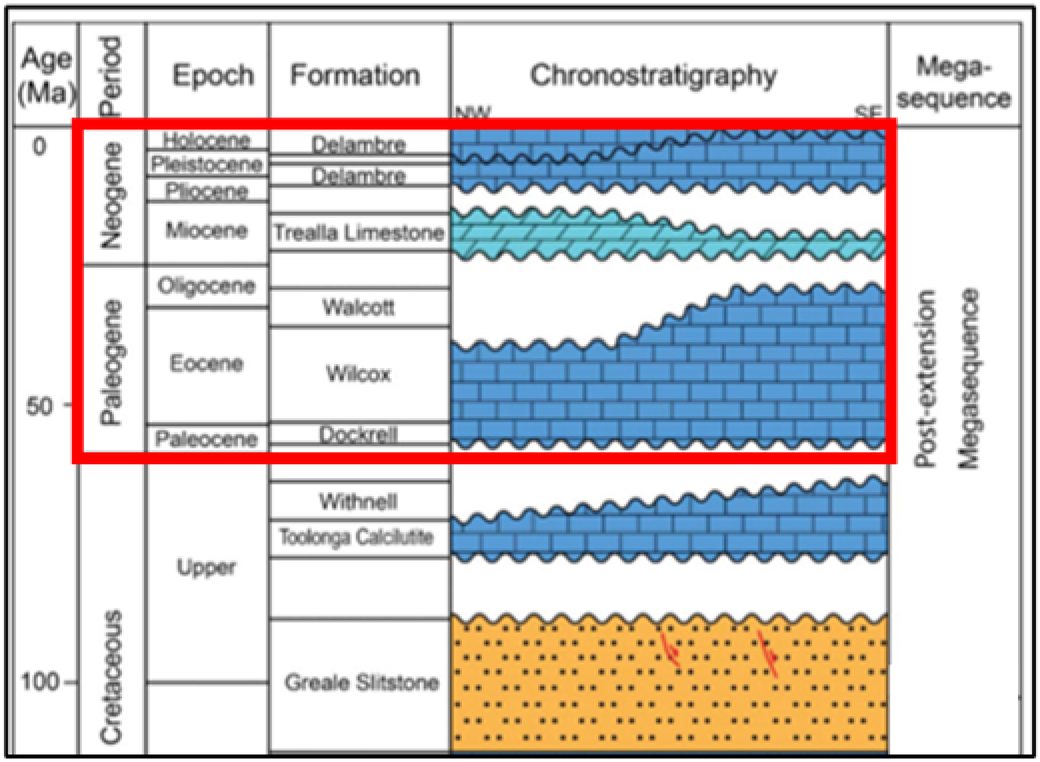



*Modified from Tellez (2020)*

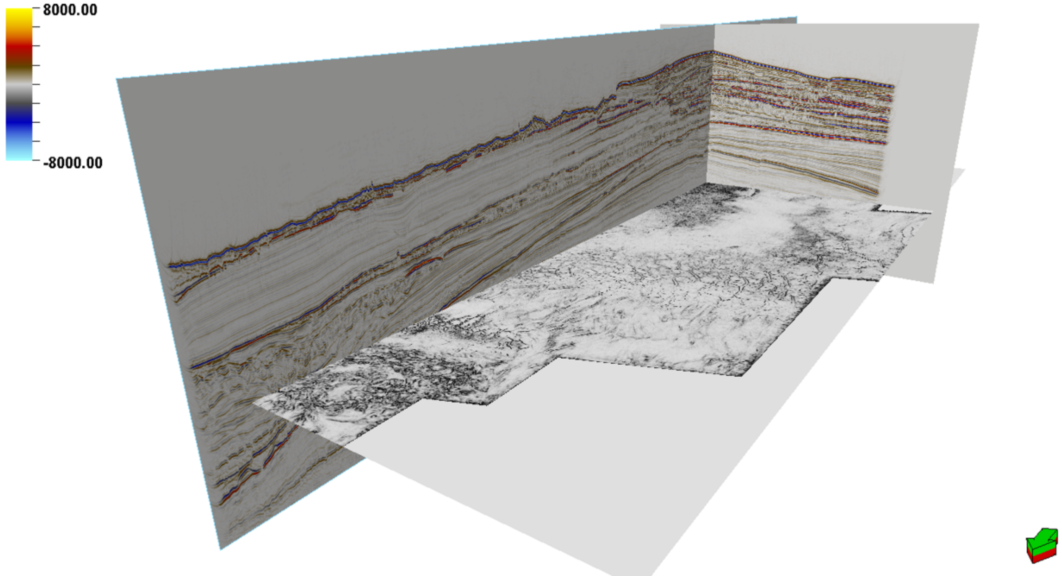
**Target Formations to analyze**

- Mixed siliciclastic-carbonate lithologies characterize Cenozoic strata.
- Five formations. From base to top: the Dockrell, Wilcox, Walcott, Trealla Limestone, and Delambre formations

## Stratigraphic chart




**Dataset description**



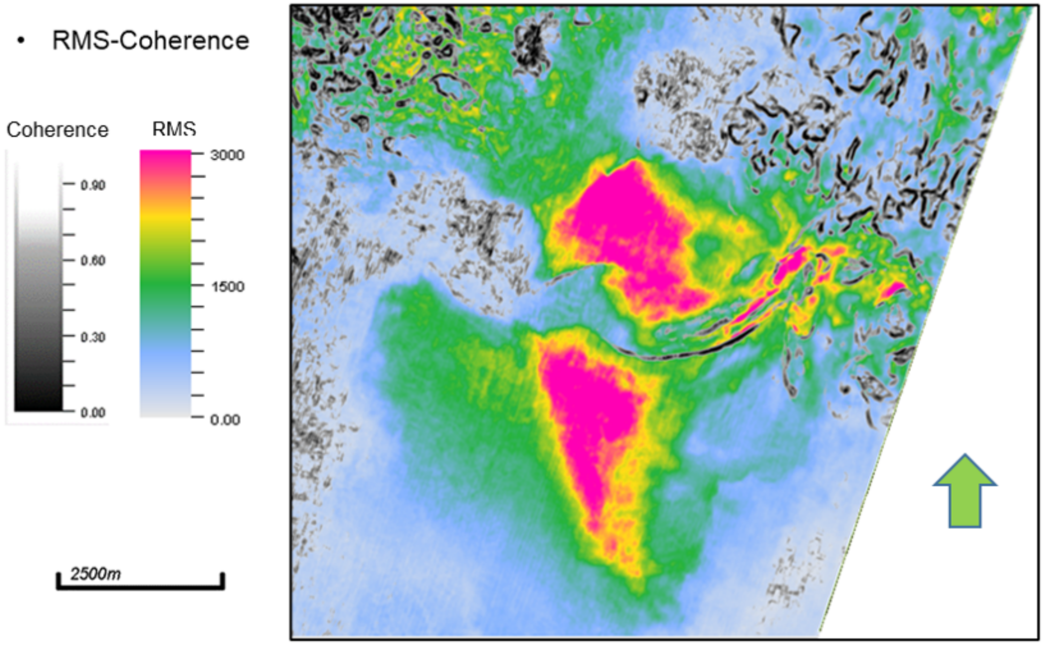

- Seismic data: Draeck 3D
- Located in the Exmouth Plateau, northwest offshore Australia.
- Acquired and processed by Chevron in 2007
- Covers 2444 km2 (29.2 x 83.6km)
- The volume contains 1560 inlines and 3346 crosslines with bin size 18.75 m x 25 m
- Time migrated & reverse polarity (SEG convention)
- Public data available in WAPIMS

## Seismic attributes for architectural elements

***CHANNEL-LEVEE***

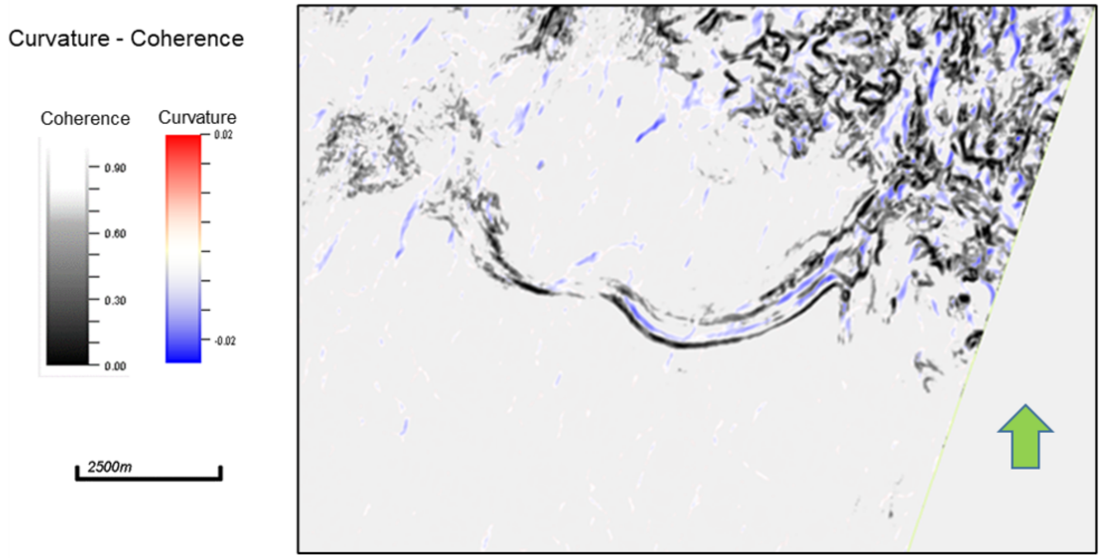
This channel-levee example was identified in the Walcott Formation, characterized by its symmetrical “gull-wing” geometry in the cross-sections.

**RMS + Coherence attributes**



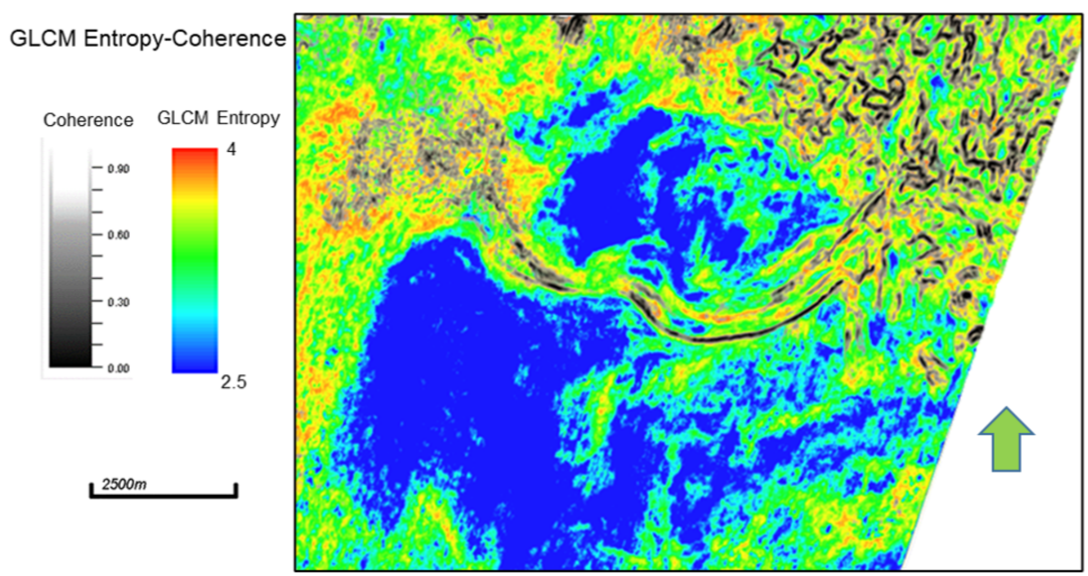

RMS attribute shows the levees' coarse-grained composition (pink colors) contrasting with the muddy-lithology in the channel fills.

**Curvature + Coherence attributes**




This channel example is not well-imaged in the curvature attribute, possibly due to differential compaction caused by the muddy channel composition and superficial depth.

**GLCM Entropy + Coherence attributes**

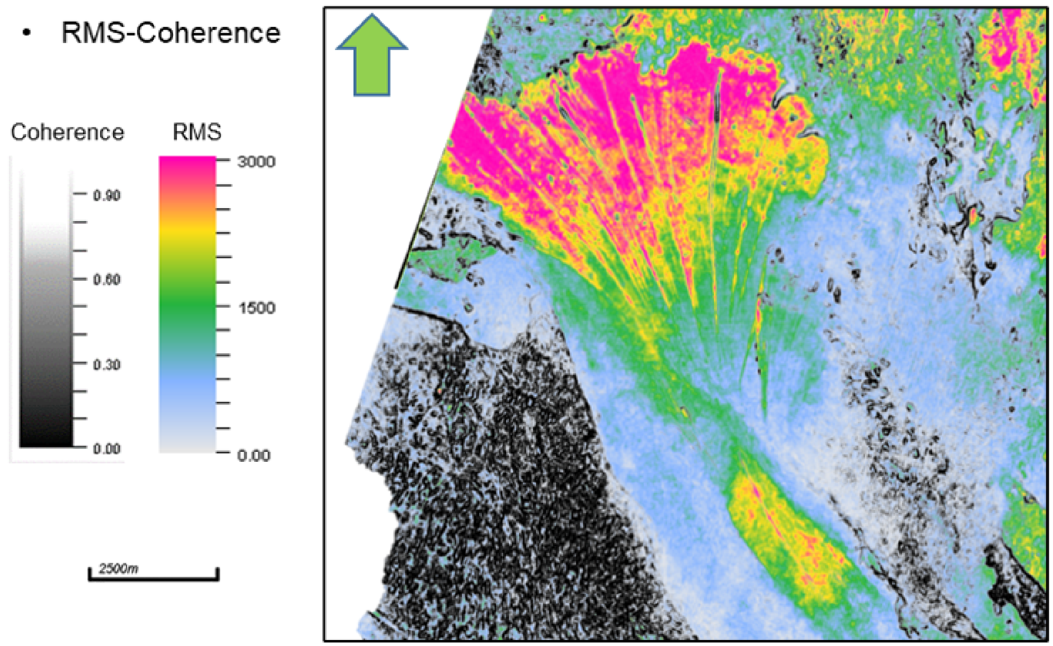


The display of co-rendering of GLCM and coherence shows overbank deposits as homogenous (blue colors) elements. In contrast, channel fills display a slightly chaotic response reflecting heterogeneity within the channel deposits (green to yellow).

***SHEET SANDS (Fan-like)***

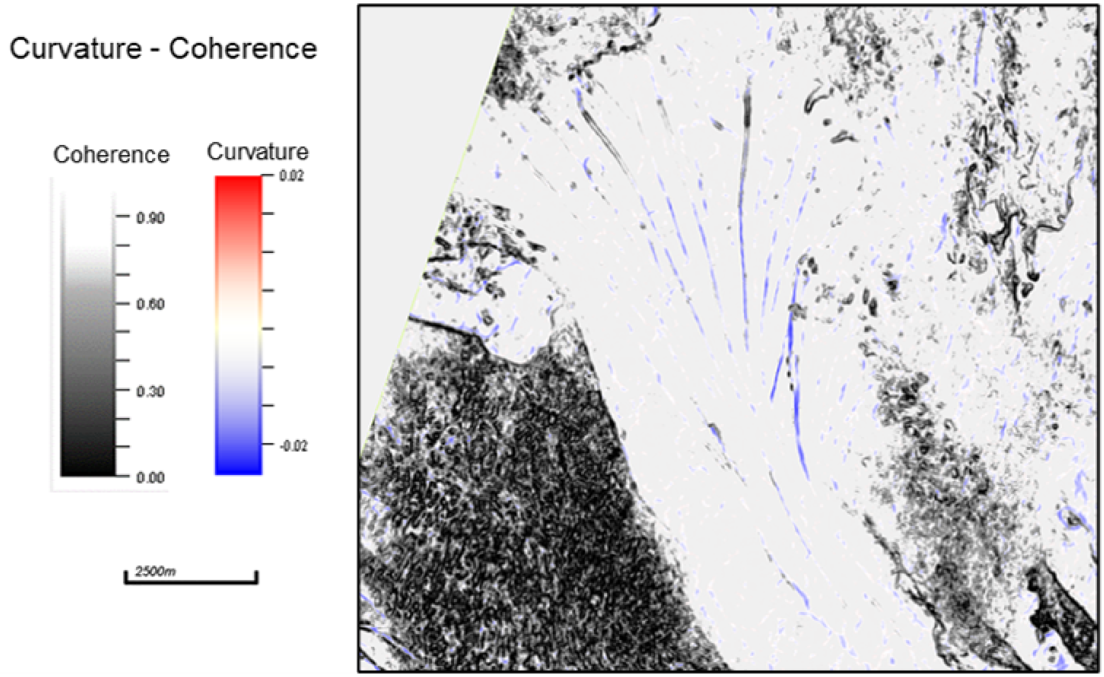
A Submarine fan example identified in the Delambre Formation. This element exhibits a high contrast characterized by continuous, sub-horizontal, high-amplitude reflectors that extend homogeneously over a mass transport deposit.

**RMS + Coherence attributes**



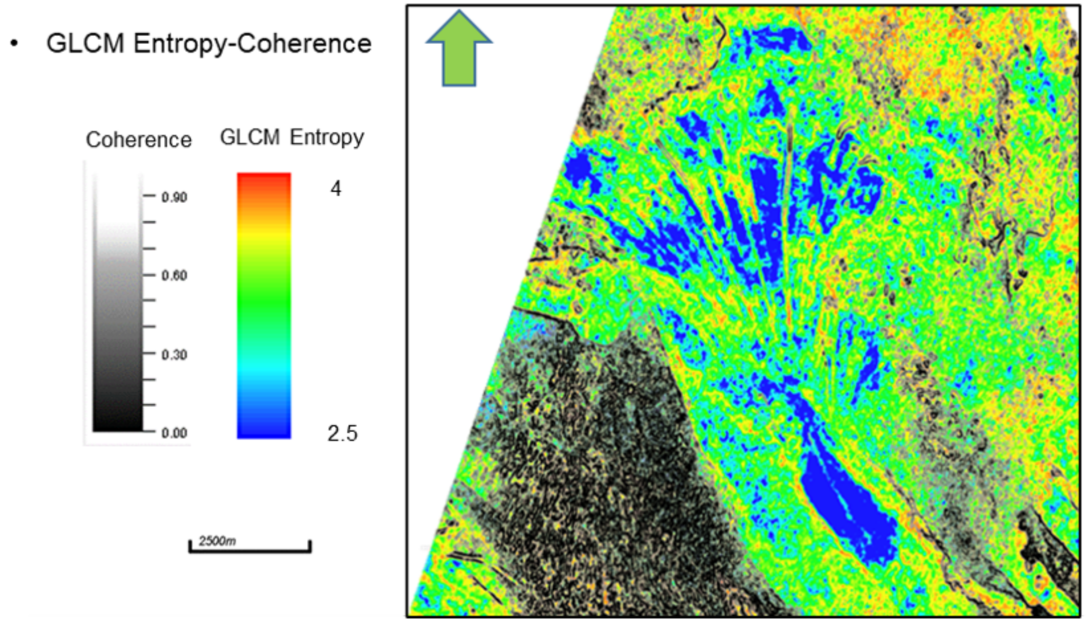

This fan's homogenous sand-rich composition is inferred by the high values in RMS attribute with a gradual decrease in the mud to sand ratio from proximal to distal areas (green to pink).

**Curvature + Coherence attributes**




This correndering highlights the fan-shaped morphology with internal thin depressions across the fan. We associated this response to feeder channels. These distributary channels are observed in amplitude cross-sections as U-shaped features.

**GLCM Entropy + Coherence**

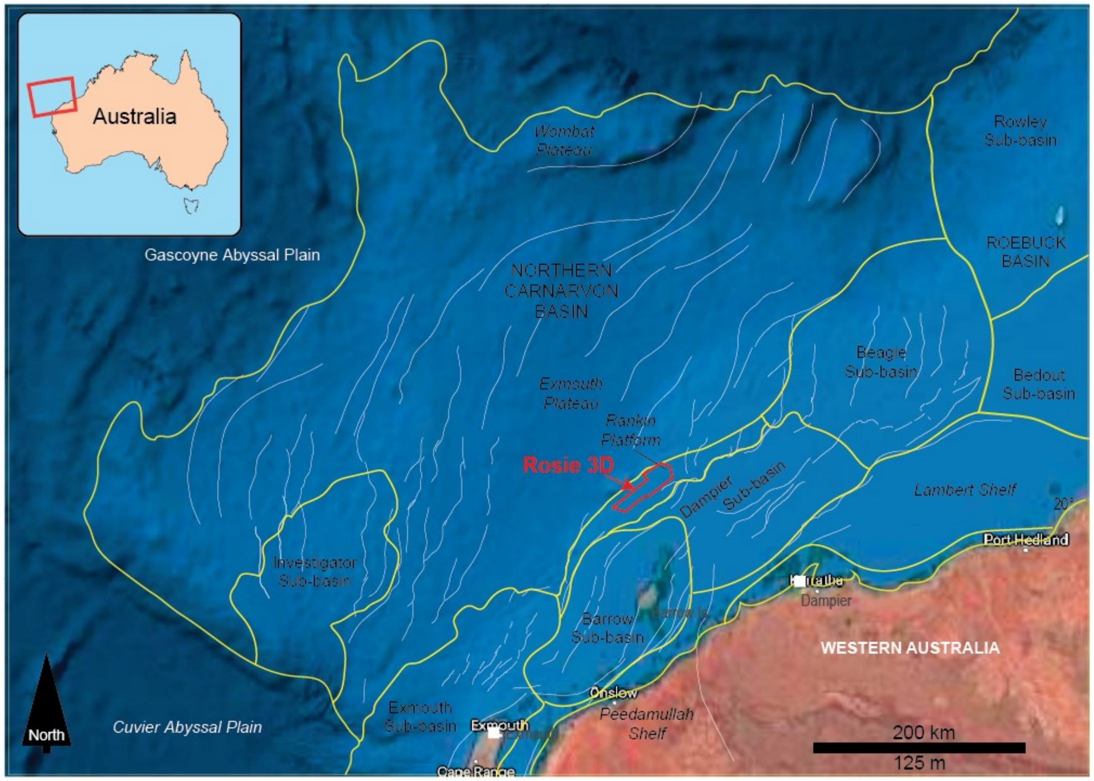



Overall, fan elements are homogeneous and show low and exhibit low GLCM Entropy response (blue). However, towards the edges and in the distributary channels' interior, it tends to be more chaotic (greenish).

# NCB - RANKIN PLATFORM AUSTRALIA

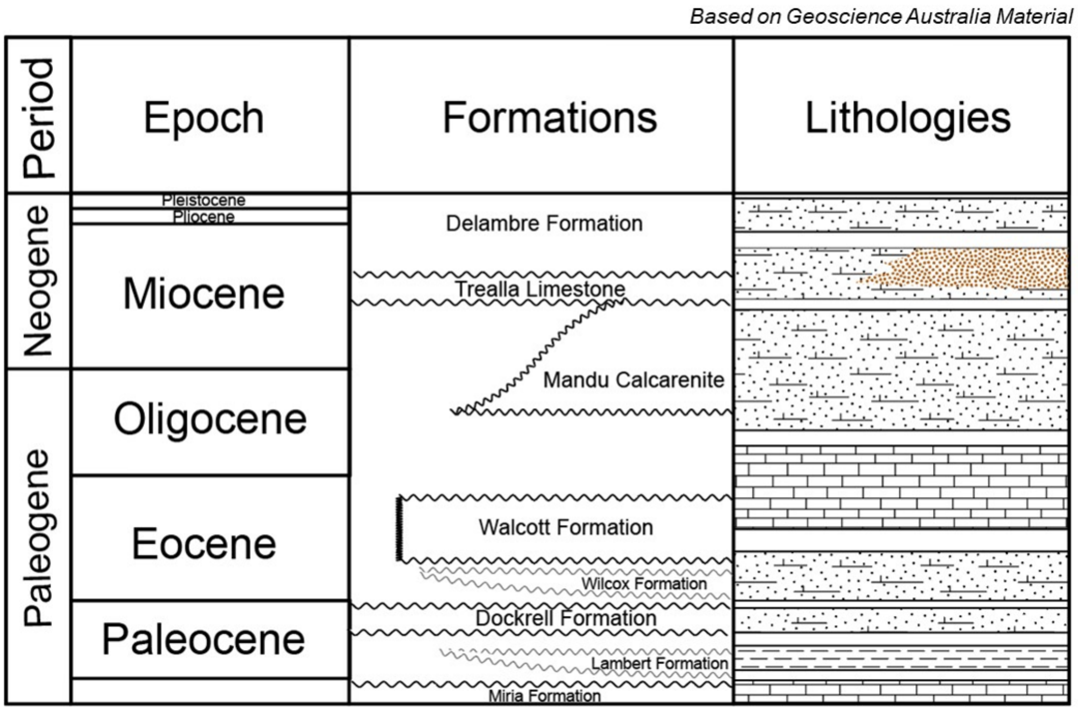
## Rankin Platform Sub-basin

- The Rankin Platform is a northeast-trending structural high separated from the Dampier and Barrow sub-basins by a major fault system.
- The sub-basin is composed of a series of en echelon fault blocks bounded by north-east and north-south faults.
- The structural configuration results from several tectonic events, including three major rifting events and a minor structural inversion.

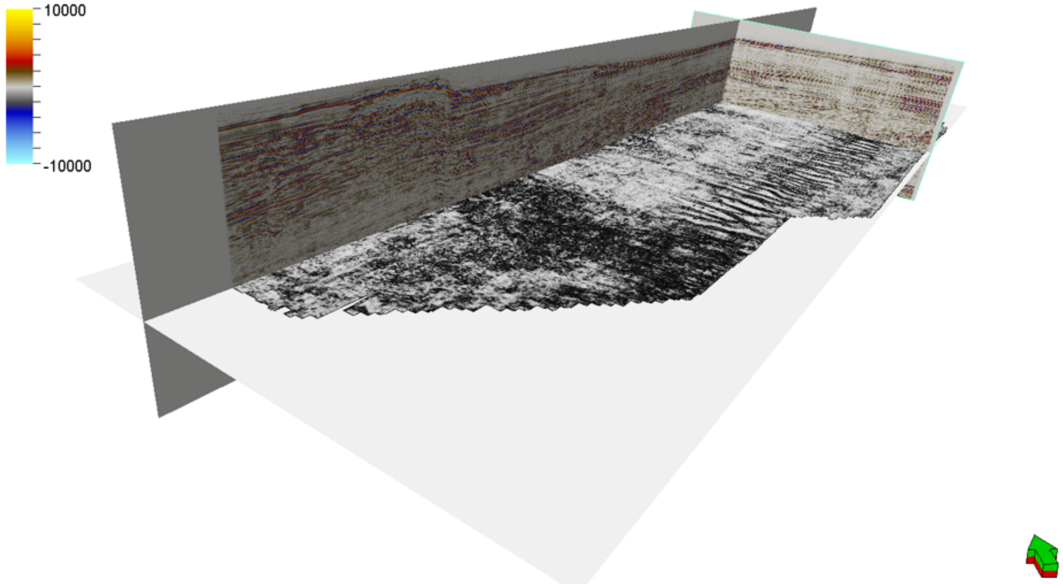



**Target Formations to Analyze**

- We studied the Cenozoic strata. The section is composed of mixed siliciclastic-carbonate lithologies.
- Five formations were studied. From base to top: the Dockrell, Wilcox, Walcott, Trealla Limestone, and Delambre formations
- We identified three groups of architectural elements: (1) erosive channel-fills, (2) channel-levee complexes, and (3) sand fan lobes and sheets.




**Dataset Description**

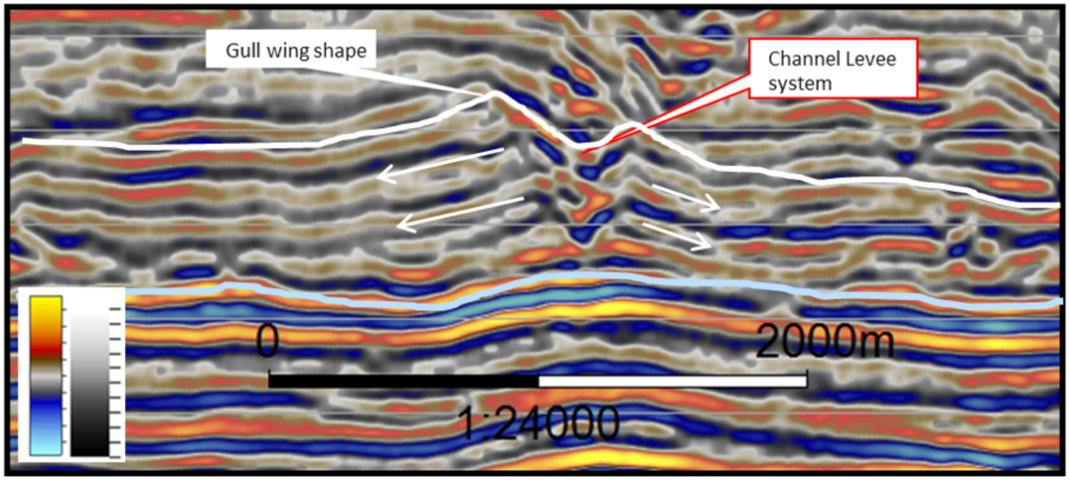



- Rosie 3D volume
- The volume covers an area of 1190 $km^2$.
- It was acquired in November 1996 by Geco Praka and processed between December 1996 and July 1997 by Western Geophysics.
- Dominant frequencies of seismic data in the studied interval are 45-55 Hz.
- Public data available in WAPIMS

## **Seismic attributes for architectural elements**

***CHANNEL-LEVEE systems***

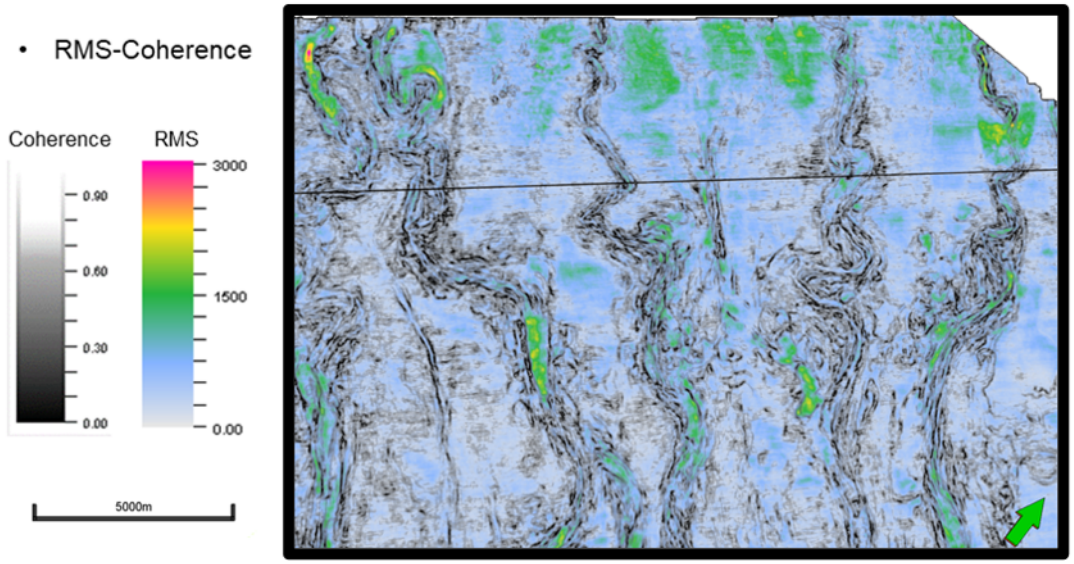
# Channel-Levee Systems




**Amplitude + Cosine of phase**

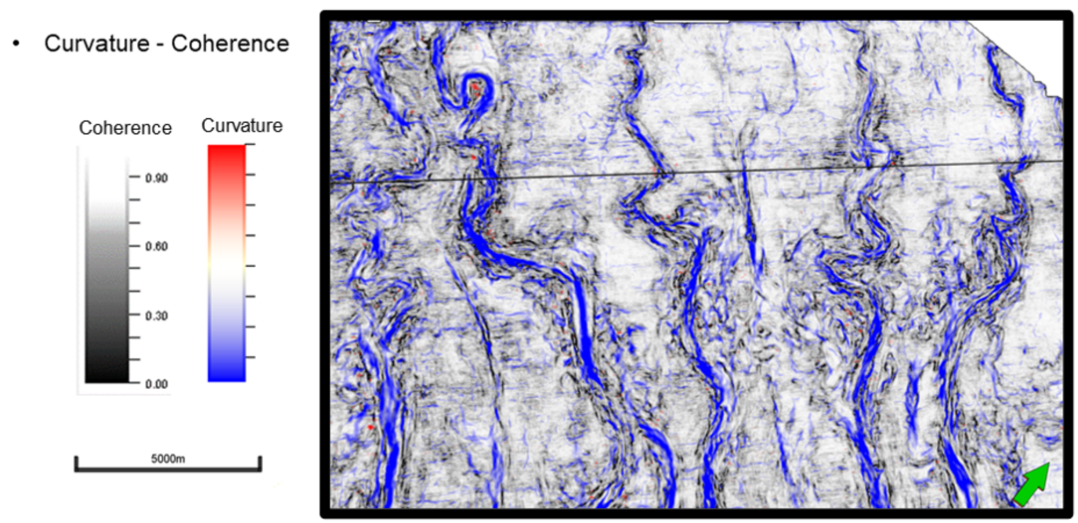
Channel elements display “Gull-wing” geometry responses in the channel levee complex in vertical sections.

**RMS + Coherence attributes**



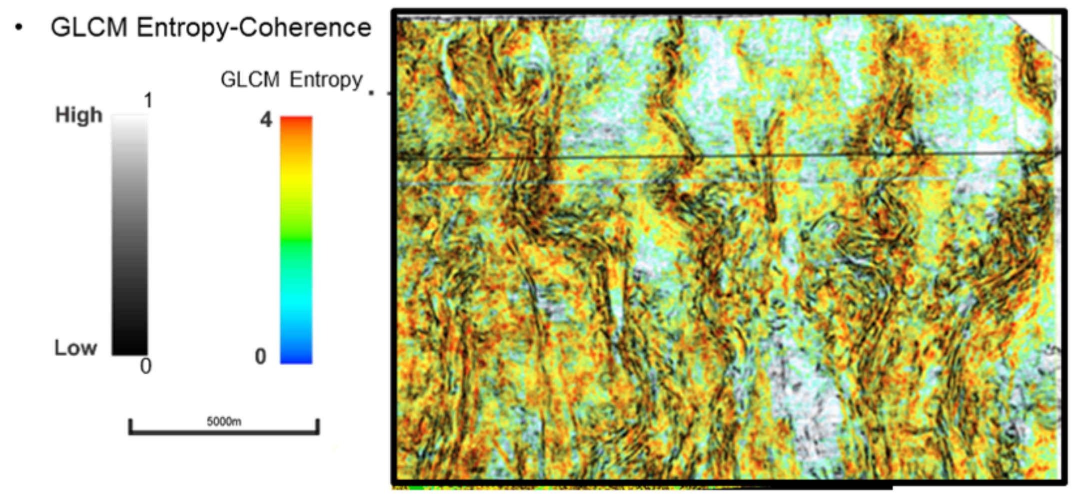

RMS attribute highlights the contrast in lithologies within the channel system. These architectural elements display high RMS values in areas of high sinuosity. Higher RMS values are interpreted as the response of coarse-grained lithologies (Very-fine sandstones or siltstones). We interpret the deposition of coarser-grained lithologies due to a decrease in the slope gradient closer to the basing floor or lower slope, further reflected by increased channel system sinuosity.

**Curvature + Coherence attributes**



To map channel systems, we used the negative curvature attribute. The co-rendering of coherence and negative curvature displays an excellent image to identify and map these elements. The horizon slide displays how channels change sinuosity from straight channels in the upper slope (base of the image) to more sinuous channels towards the basin floor (top of the image); We interpreted the channels morphology variations are due to a change in the slope gradient.

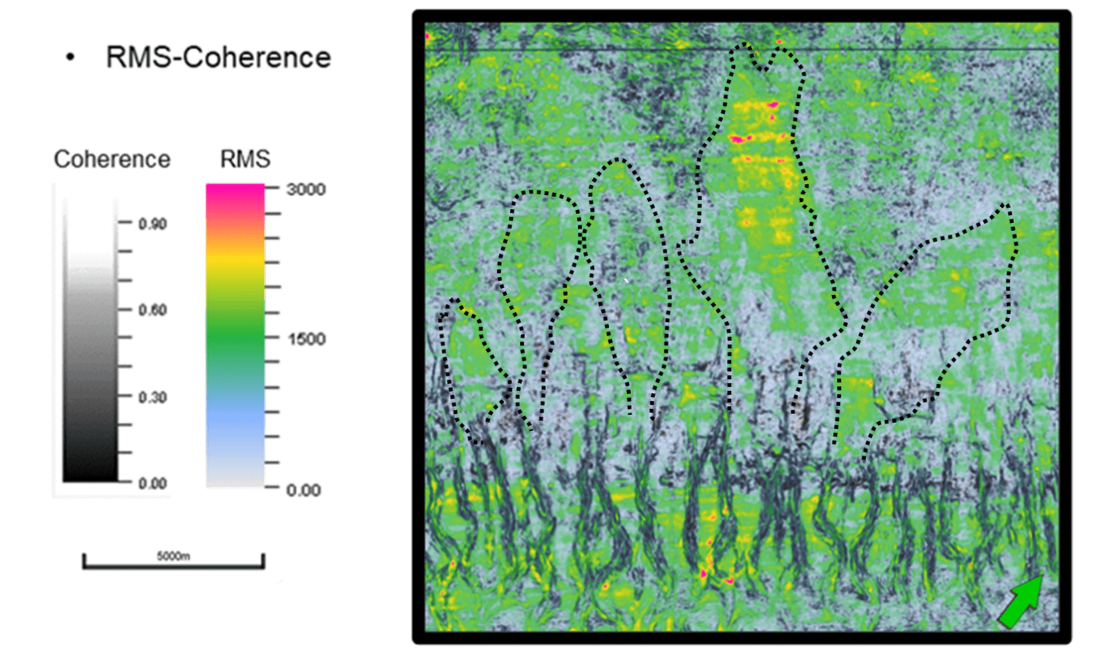
**GLCM Entropy + Coherence**




The GLCM attribute shows the rate of disturbance within the reflectors related to seismic facies. We observed high entropy values that coincide with high values of coherence where channelized deposits were mapped. In contrast, the interchannel zones were easily differentiated with lower entropy values represented by greenish colors associated with overbank deposits.

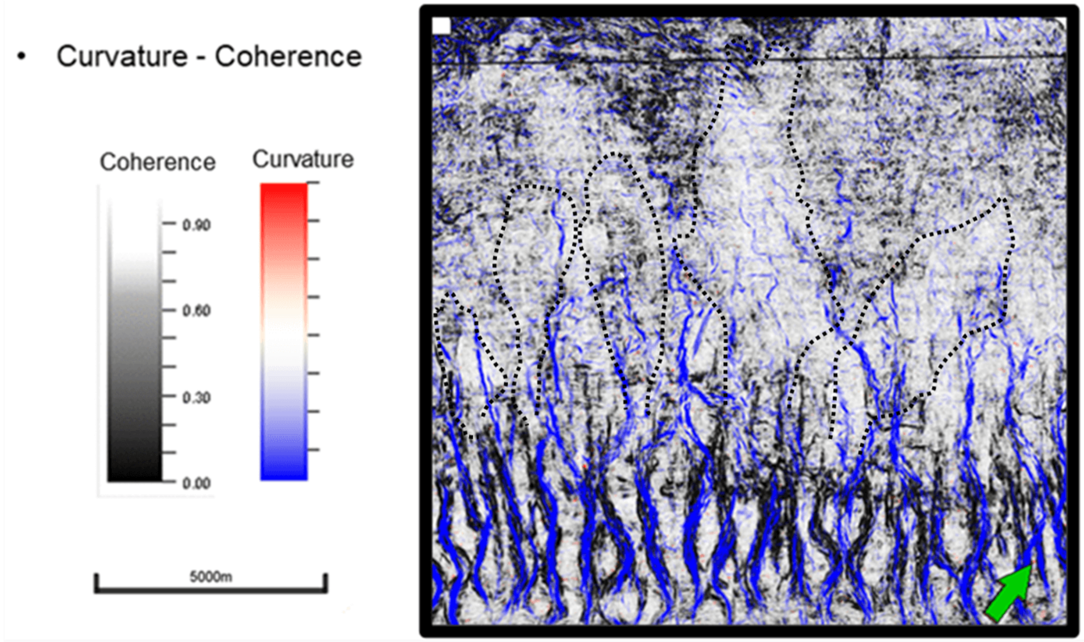
***FAN or LOBE Sandstones***

**RMS + Coherence**



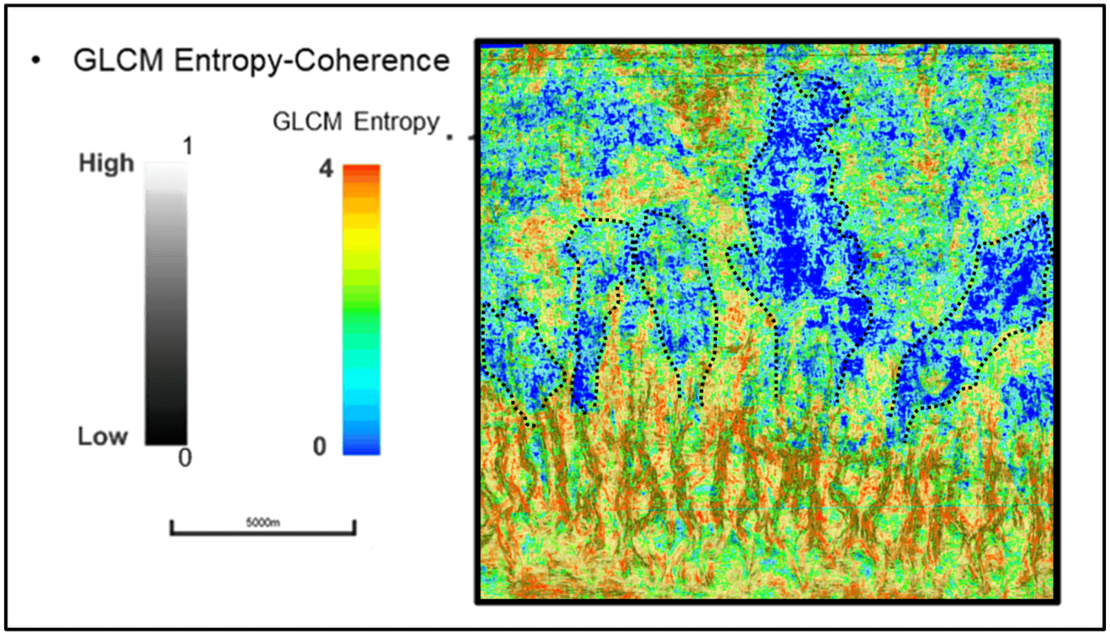

The horizon slices used to characterize fan sandstones and lobe elements in NCB show a high RMS value that indicates coarser-grained lithologies. These coarser-grained lithology areas show feeder channels that delivered sediments that formed fan and lobe-shaped and elongated geometry deposits. We interpreted these elements within the lower slope and basin floor within the deepwater system.

**Curvature + Coherence**




The co-rendering of the negative curvature attribute and coherence highlights in blue the distributary channels close to the lower and middle slope (base of the Image). However, fan-shaped deposits and lobes do not show a strong curvature response due to a subtle relief and widespread distribution of the deposits across the basin floor.

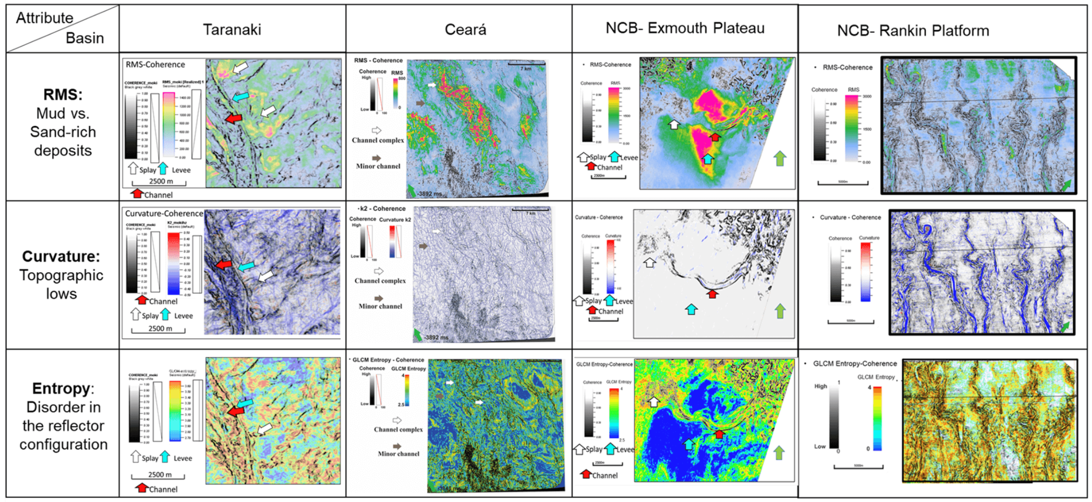
**GLCM Entropy + Coherence**



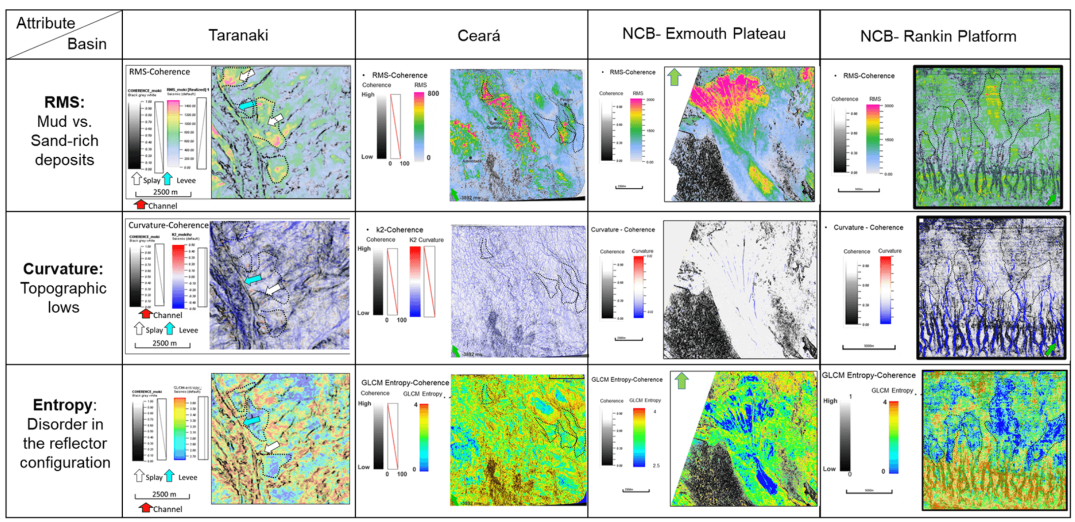

The entropy attribute' response for the fan-shaped deposits shows low entropy values that characterize a smooth horizontal distribution and widespread extension of these laterally continuous and amalgamated architectural elements.

# COMPARISON AND DISCUSSION

**Summary of Channel - Levee systems**




**Summary of Fan-shaped or lobes elements**



These charts present a compilation of the channel-levee systems' seismic attribute expression and their associated fan-shaped or lobe elements. Various seismic attributes allow us to infer crucial properties such as mud vs. sand dominance, topographic lows, and reflection configuration disorder. Most of the previous publications in seismic interpretation focus solely on coherence + RMS. RMS attributes helped identify the sheet sands or sandy lobes, sand-rich channel fills, and levee deposits presented in the Taranaki, Ceara, and NCB basins, respectively. Note that not all frontal-splays are necessarily sand-rich as it depends on the source's characteristics (Shanmugan & Moiola, 1988; Payros et al., 2008) and similarly for the channel-fills.

The curvature attribute was useful for highlighting channel fills, although the attribute delineation depends on the channel (depth, lithology, and compaction). In the Taranaki Basin, the main channel is deep and continuous enough to be well-imaged by negative curvature, while in the Ceara and NCB-Exmouth Plateau, channels are shallower. The GLCM entropy attribute provides an idea of the chaotic areas vs. the uniform ones. Channel-fills show the highest GLCM entropy values, where sedimentation is more chaotic than the adjacent overbank, splay, and fan deposits.

The attributes response of deepwater architectural elements in different basins allowed us to characterize key geomorphology aspects for local architectural elements. We compared and contrasted a set of attributes that included amplitude accentuating (RMS), geometric (Coherence and Curvature), and textural attributes(GLCM Entropy) as they help to infer lithology, morphology, and uniformity characteristics.

RMS attribute was unanimous in identifying levee deposits and sandy lobes in all the seismic surveys. The Curvature was useful to highlight channel fills in the Taranaki basin and NCB-Rankin Platform, while in the Ceará and NCB-Exmouth Plateau, the channels were poorly-imaged. This difference is probably caused by depth and lithology (compaction). The proximity to an oceanic fracture zone in the Ceará Basin could influence the sedimentation in the basin. The GLCM entropy attribute helped identify channel-fills in all the seismic surveys since the highest entropy values correspond to channel zones' internal deposits, where lithologies are more heterogeneous.

The results of our comparison suggest that each basin (and sub-basin) has a different setting as depositional controls (sediment supply, composition, and tectonics) that causes multiple effects on the geometry, lithological composition, and heterogeneity of developed deepwater architectural elements. The Taranaki Basin deposits are rich in volcanic sediments, while the Ceará and NCB contain a siliciclastic and mixed carbonate-siliciclastic, respectively. The composition of the sediments impacts the size and, therefore, the seismic response of the AE. Deepwater mixed siliciclastic-carbonate systems depend upon carbonate availability for the depositional processes and tend to form smaller systems (Payros et al., 2008). Additionally, the basins' tectonics and structural configuration affect the response of geometrical attributes, as shown in the Curvature+Coherence correndering of the Ceará Basin, where fracturing hampers the channel image.

We suggest that areas of study within the same basin require detailed analysis as the composition varies. For example, the two areas of study in the NCB show different responses in the curvature attribute. The Rankin Platform channel system was identified within the Bare Formation (A siliciclastic unit). Simultaneously, the channel-levee in the Exmouth Plateau was developed in mixed fine-grained sediments (Walcott Fm). The Bare Formation represents an interruption of the carbonate dominance and introduction of dolomitic siliciclastic sands deposited under a transitional deltaic system (Sanchez et al., 2012; Cathro et al., 2003), and it is absent towards the south of the basin (Exmouth Plateau).

# CONCLUSIONS

- The use of co-rendered attribute analysis enhanced conventional seismic interpretation of deepwater architectural elements in basins worldwide.
- Analyzing attribute-to-architectural element relationships helps to understand which attributes are relevant and reveal the variability of response to changes in rock seismic response and facies.
- Many geological aspects such as structural configuration, lithological composition, and other post-depositional characteristics should be considered to define suitable attribute options to characterize deepwater systems.
- Understanding seismic attributes response is crucial to map different architectural elements and facies indistinctly of the basin.
- The RMS attribute was consistent in identifying channels-levee deposits and sandy lobes in all the seismic surveys.
- The curvature attribute was useful to highlight channel fills in the Taranaki Basin, while in the Ceará and NCB-Exmouth Plateau, the channels were poorly-imaged. This difference is probably caused by depth and lithology (compaction).
- This study improved the understanding of seismic attribute options to recognize deepwater architectural elements and seismic facies in multiple seismic surveys and passive basins.

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# ABSTRACT

The advancement of seismic attributes and visualization techniques has allowed the study of seismic geomorphology from 3D reflection data. The study of deepwater deposits denes and characterizes architectural elements depending on their genesis, morphology, and position along the slope and basin floor. However, every individual basin's geological configuration determines the dimensions, morphology, and lithological composition of its architectural elements. To understand how seismic attributes help characterize geological settings, we employ multiple datasets with variable qualities since few studies elaborate on compiling and discussing the differences between basins. We explore and compare the use of seismic attributes to highlight deepwater architectural elements in three different basins around the world: The Ceará Basin in Equatorial Brazil, The Taranaki Basin in New Zealand, and The North Carnarvon Basin in Australia, focusing on the deepwater sedimentary section in each case. Although the first two datasets are examples of siliciclastic environments and the North Carnarvon, a mixed carbonate-siliciclastic exponent, the architectural elements identified in all the datasets are similar, as well as their attribute response. The results show that the most robust attributes to characterize deepwater elements such as incised channels, channel-levee systems, and lobes are a combination of geometric, amplitude derived, frequency, and textural attributes. These seismic attributes indicate morphological, lithological, bed stacking, and help to define the stratigraphic architecture. Moreover, we found that the co-rendering of RMS (lithology-proxy), coherence (morphology indicator), and curvature attributes help to define the internal configuration for most of the deepwater architectural elements. While each basin is unique, our results and comparisons serve as a guide for seismic interpreters to use in deepwater seismic geomorphology characterization.

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