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Igneous bodies characterization by means of seismic reflection attributes and wavelet transform

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IN SUPREMÆ DIGNITATIS

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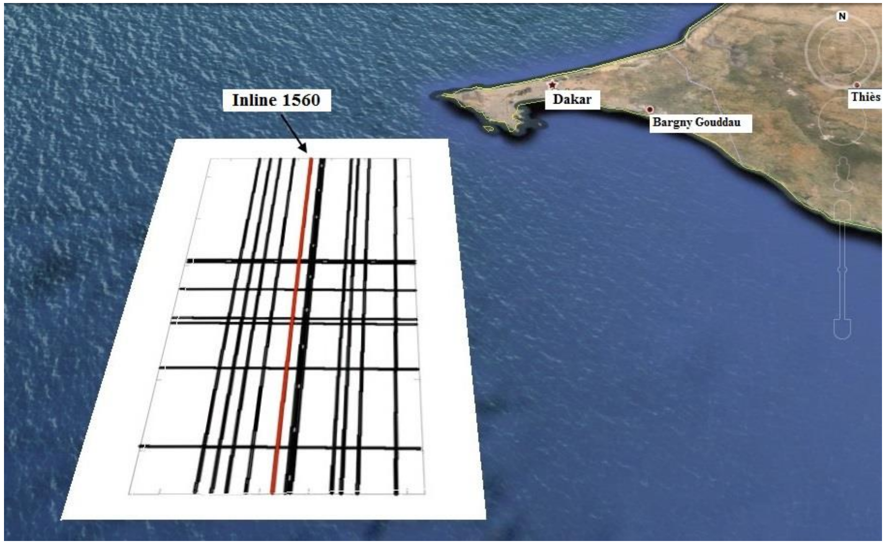
Aim of the work

- Detection and characterization of several igneous bodies observed in 2D seismic sections.



Map of the area: *offshore* Senegal (S-W of Dakar).

Type of energy source	Air Guns
Number of source	2 groups
Source depth	5.5 m (+/- 1m)
Shot point interval	25 m
Number of streamers	10
Streamer length	6000 m
Number of traces	480 / streamer
Trace interval	12.5 m
Nearest seismic offset	360 m
Streamer depth	7 m +/- 1 m
Number of channels	10x480 + 37 auxiliary channels used
Record length	8100 ms
Sample interval	2 ms

- Application of the complex seismic attributes to better characterize the igneous bodies on the basis of their physical properties.

- Application of the Continuous Wavelet Transform (CWT) to improve the visualization of the seismic dataset.

Complex Seismic Attributes

"The quantities that are measured, computed or implied from the seismic data" (Subrahmanyam et al., 2008).

- Line by line description of each amplitude anomaly.
- The seismic lines are characterized on the basis of their amplitude, phase and frequency.
- The main complex seismic attributes applied on the entire seismic dataset are:
  - **Reflection Strength** $E(t) = \sqrt{(T2(t)+H2(t))}$
  - **Instantaneous Phase** $\varphi(t) = \arctan |H(t) / T(t)|$ $[-\pi, \pi]$
  - **Instantaneous Frequency** $IF(t) = d\varphi(t) / dt$
  - **Sweetness** $S(t)=E(t) / \sqrt{IF(t)}$

Complex Seismic Attributes

"The quantities that are measured, computed or implied from the seismic data" (Subrahmanyam et al., 2008).

The Reflection Strength

- Permits to visualize the data taking into account the seismic reflectivity.
- Highlights the strong impedance contrasts related to the lithological changes.
- Allows to discriminate the limits between sequences and to localize the amplitude anomalies related to the igneous bodies.

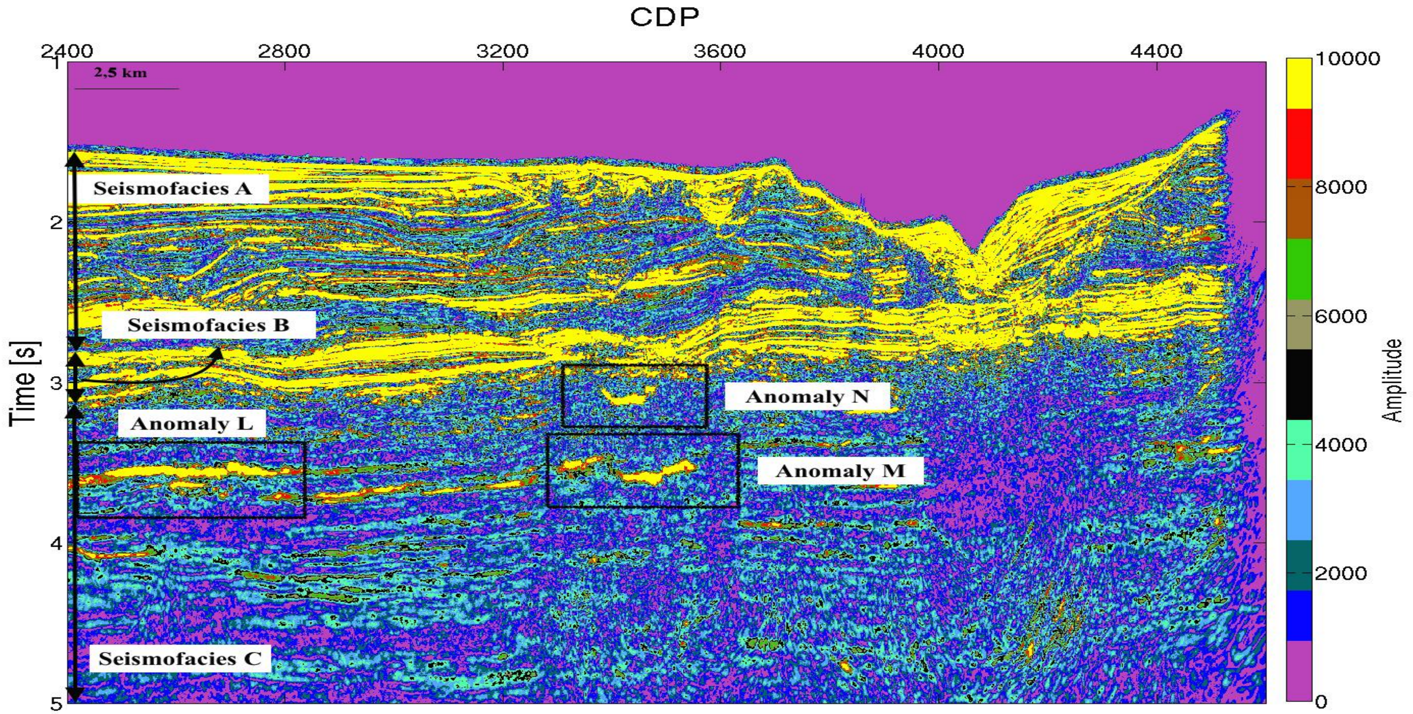
According to the amplitude response, each seismic section is divided into three different seismofacies (from the top to the bottom): seismofacies A, Seismofacies B and seismofacies C.

Furthermore, this attribute permits to isolate the high amplitude value anomalies from the low reflective seismofacies C.

Complex Seismic Attributes

"The quantities that are measured, computed or implied from the seismic data" (Subrahmanyam et al., 2008).

The Reflection Strength Data



Complex Seismic Attributes

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The Instantaneous Phase

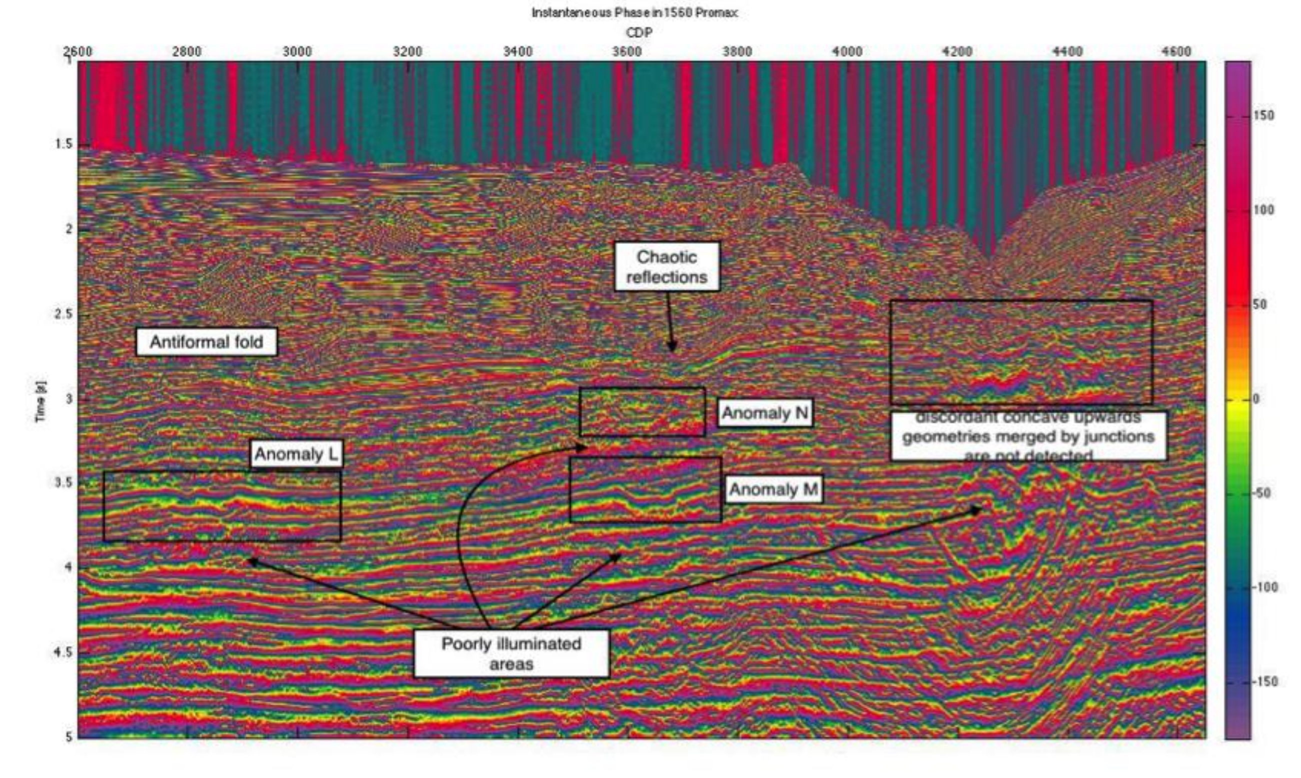
- Permits to emphasize the lateral continuity of strong and weak events.
- Allows to estimate the geometrical properties of the amplitude anomalies.
- Highlight the discontinuities, such as faults and joints.

This attribute is not necessary for the description of the seismofacies. Therefore, it consents to distinguish the seismic bodies, within the seismofacies B, characterized by different bodies merged together by antiformal or T- and F-shaped junctions and immersed in a chaotic facies.

Complex Seismic Attributes

"The quantities that are measured, computed or implied from the seismic data" (Subrahmanyam et al., 2008).

The Instantaneous Phase Data



Complex Seismic Attributes

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The Instantaneous Frequency

- Allows to discriminate the limits between sequences and to localize the anomalies related to the igneous bodies.
- Permits to discriminate the different range of frequency that characterize the data.

According to the frequency response, the three seismofacies exhibit distinct Instantaneous Frequencies behaviours. Moreover, the amplitude anomalies highlighted by the Reflection Strength attribute correspond to low Instantaneous Frequency anomalies.

Complex Seismic Attributes

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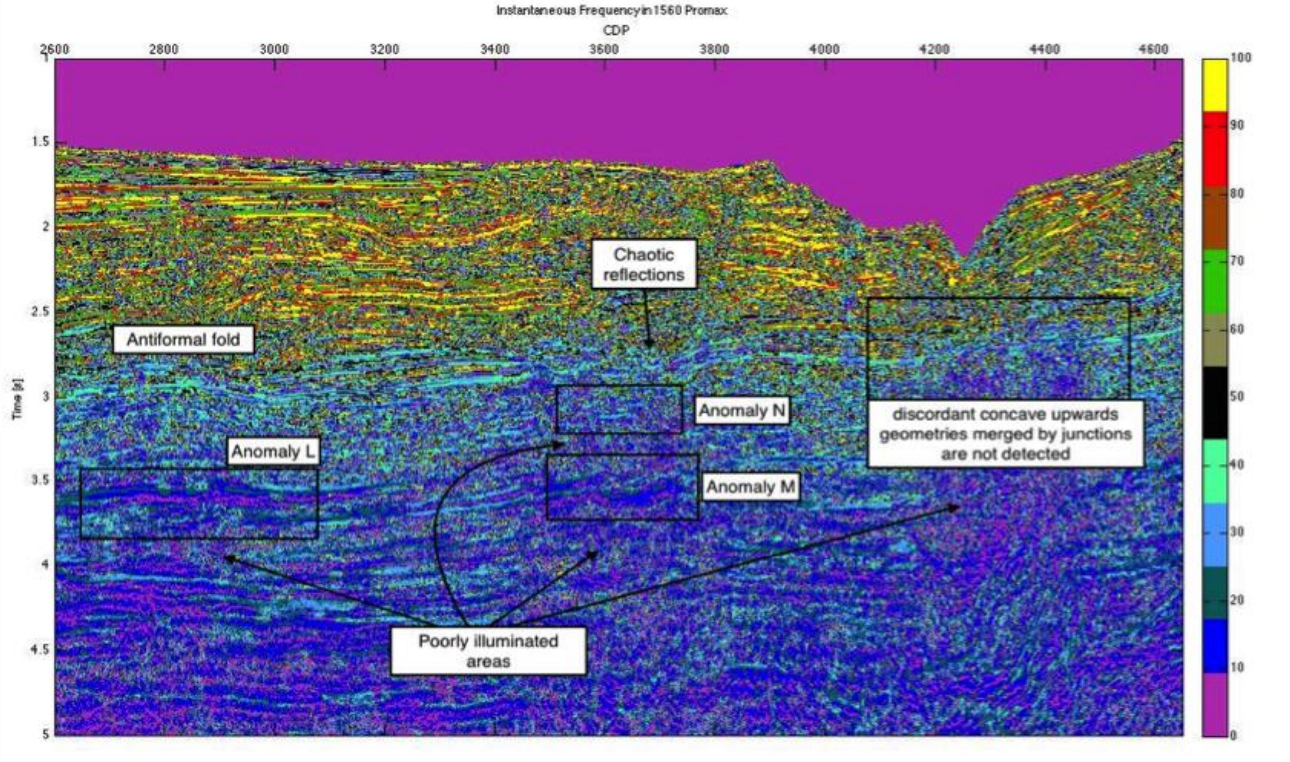
The Instantaneous Frequency Data



Complex Seismic Attributes

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The Sweetness

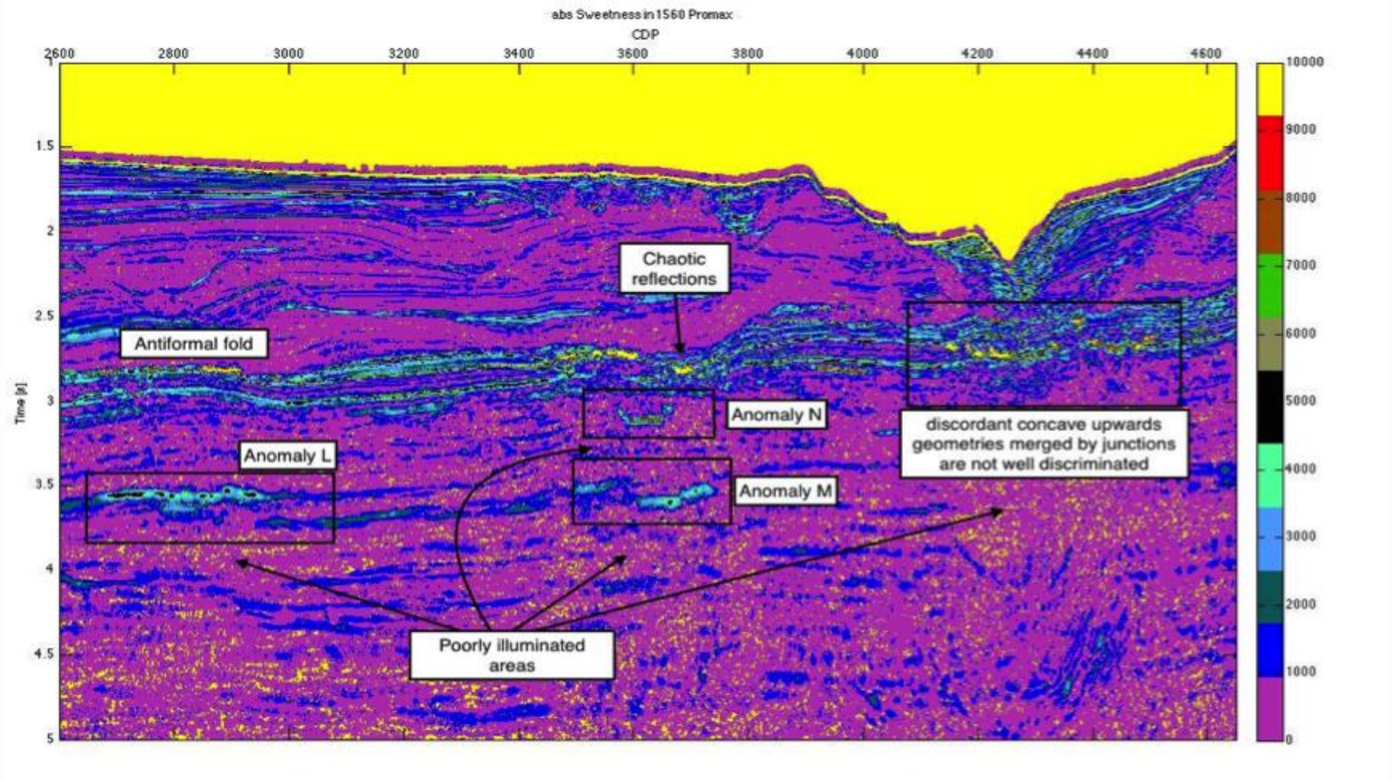
- Distinguishes the events characterized by high values of acoustic impedance.
- Allows to discriminate the limits between sequences and to localize the amplitude anomalies related to the igneous bodies.
- The parameter is not the sign of the acoustic impedance value, but the magnitude of the acoustic impedance contrast.

According to the Sweetness response, the three seismofacies exhibit distinct behaviours. Moreover, the Sweetness attribute permits to isolate the high amplitude value anomalies from the low reflective seismofacies C.

Complex Seismic Attributes

"The quantities that are measured, computed or implied from the seismic data" (Subrahmanyam et al., 2008).

The Sweetness Data



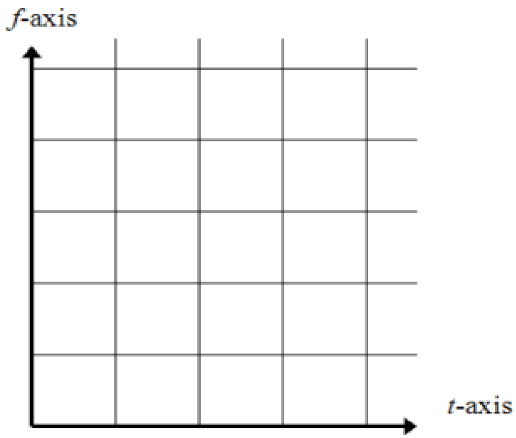
The Continuous Wavelet Transform (CWT)

- The CWT provides a fast method for displaying and analysing signals as a function of TIME and SCALE.
- The scale and the frequency are related to an inverse relationship of proportionality.
- Allows to decompose the seismic data into a time versus scale (frequency band) domain and to reconstruct them in the scales of interest.
- The analysis of the reconstructed common scale volumes permits to obtain a representation of the frequency information.
- The CWT is defined as follow (Daubechies, 1988; Zhang et al., 2006):

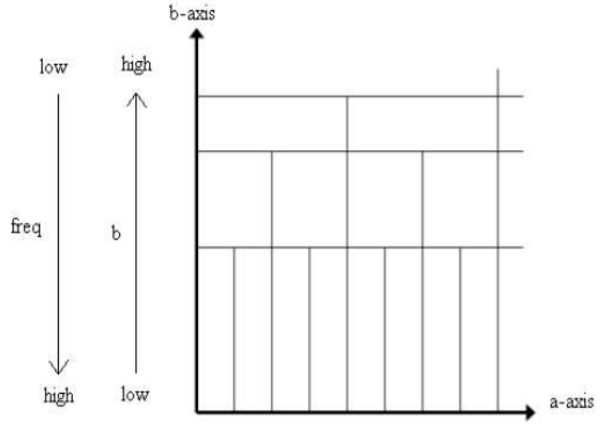
$$X_w(a,b) = \frac{1}{\sqrt{b}} \int_{-\infty}^{+\infty} x(t)\psi(t)^* \left(\frac{t-a}{b}\right) dt, \qquad \begin{cases} a \epsilon (-\infty, \infty) \\ b \epsilon [0, \infty\} \end{cases}$$

The Continuous Wavelet Transform (CWT)

- By shifting and scaling the mother wavelet *ψ(t)*, the Wavelet Transform is able to capture, at the same time, information of short duration (high frequency) and information of long duration (low frequency).
- It is more flexible than other time-frequency transform such as the Short Time Fourier Transform (STFT).

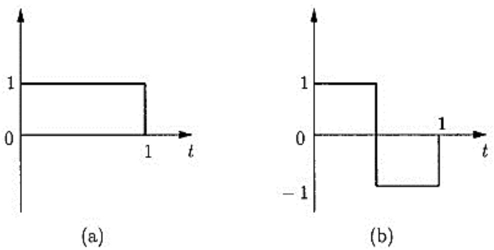


STFT vs CWT

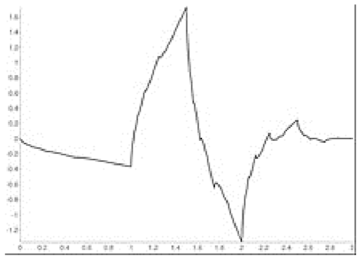


The Continuous Wavelet Transform (CWT)

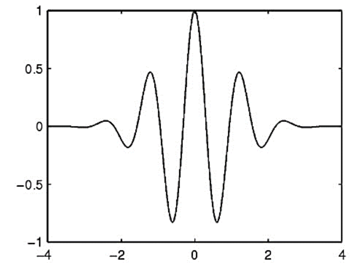
- *Line by line* description of each amplitude anomaly.
- Three different mother wavelets are used: the Haar wavelet, the order 2 Daubechies wavelet (db2) and the Morlet wavelet (morl).



Haar Wavelet



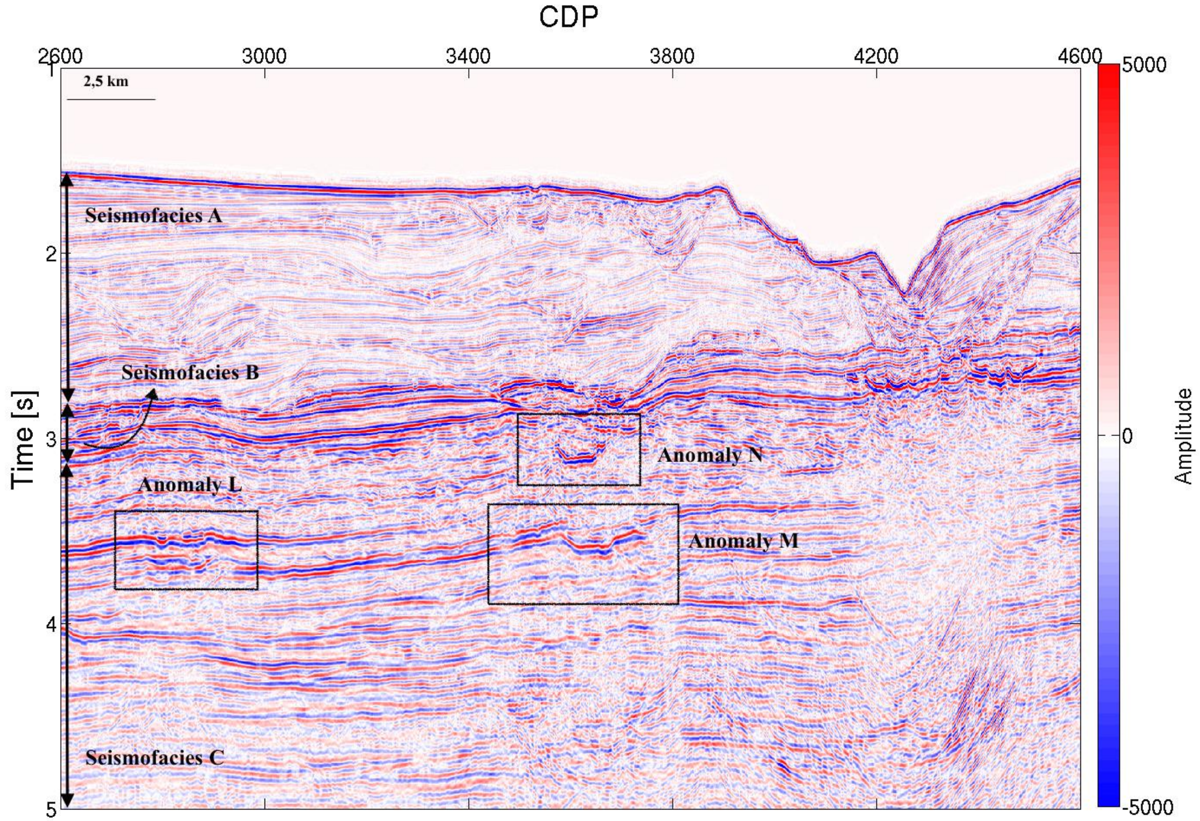
db2 Wavelet



Morl Wavelet

- The best result is achieved by the application of the db2 wavelet.
- The anomalies related to the igneous bodies can be approximated in a frequency range from 20 up to 30 Hz.

The Continuous Wavelet Transform (CWT)



Conclusions

- The Senegal Basin is characterized by the presence of discordant low frequency high amplitude reflection anomalies, that are interpreted as Miocene intrusive bodies.

- From this analysis, 19 sills are classified on the basis of their age, levels of emplacement and geometries.

- Three different levels of emplacement are found:

  1) the 1st level is at times greater than 3.5s;

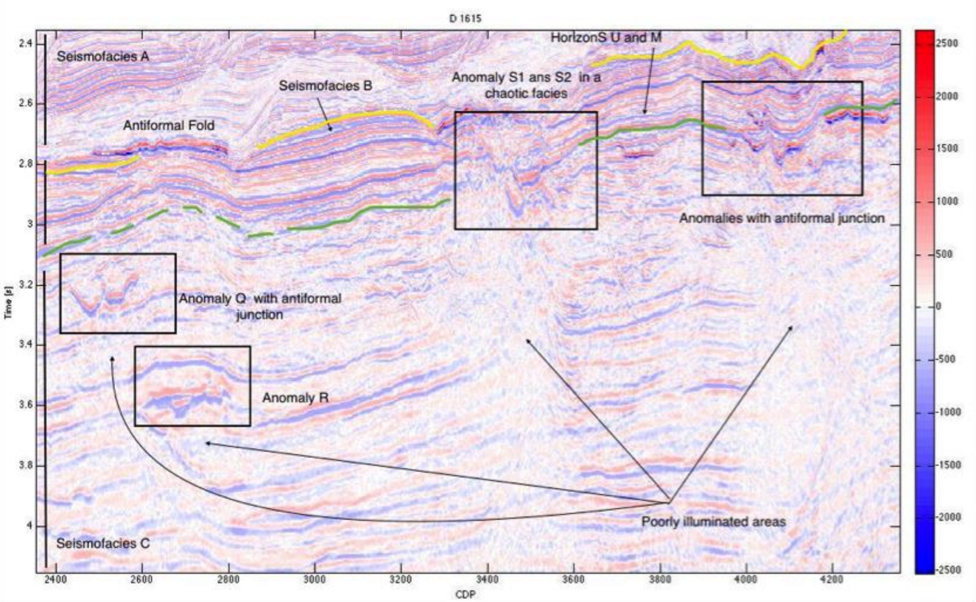
  2) the 2nd level is comprises between 2.7s and 3.5s;

  3) the 3rd level is at times lower than 2.7s.

Conclusions

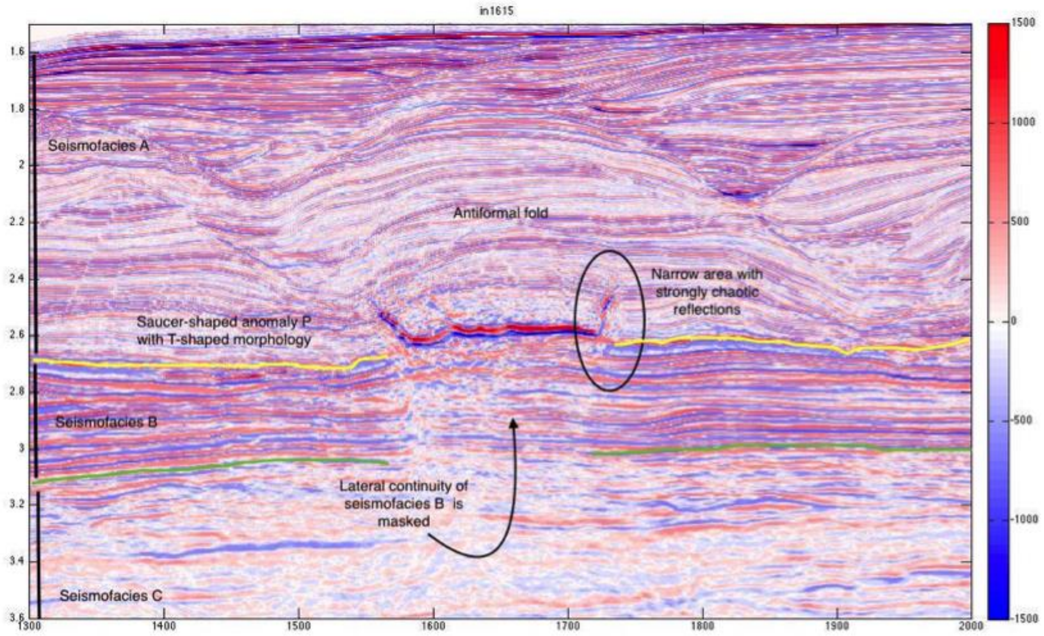
1st level: flat inner saucer geometry, often bounded by an inclined sheet that cross-cuts upwards the seismofacies C, and deform the overburden reflectors in a gently symmetrical antiformal fold.

2nd level: concave-upwards saucer-shaped morphology and are characterized by the formation of two inclined sheets, often one steeper than the other. Moreover, some of these bodies show T- and F-shaped or antiformal morphology.



Conclusions

3rd level: saucer-shaped morphology, they cross-cut the seismo-stratigraphic reflectors, obliterate the underlying seismofacies B and deform the overlying reflectors in a domal structure.



Conclusions

- By applying the seismic attributes, it is possible to better distinguish the sills on the basis of the strong Reflection Strength and Sweetness response, which allow to isolate the seismic anomalies from the low amplitude background.
- The Instantaneous Phase allows to distinguish, particularly within the seismofacies B, the seismic bodies characterized by a composite shape and masked in a chaotic facies.
- The Instantaneous Frequency is useful to differentiate the igneous bodies on the basis of the frequency values, always lower than the host-rock.
- According to the seismic attributes, the results obtained by the application of the CWT permit to classify the anomalies as bodies with a frequency range about 25-30 Hz.
- The CWT permits to characterize the bodies on the basis of their geometrical features and is fundamental to compute thickness, lateral extent, depth of emplacement, diameter-to-depth ratio and the related-fold amplitude of the sills.

Conclusions

- This work can supply new inputs that can be used to improve the knowledge of the stratigraphy, the geological setting and the evolution of the investigated area.

- The achieved characterization of the igneous bodies can be of crucial importance for the hydrocarbon exploration since the presence of igneous intrusions in a petroleum system could cause important effects on the maturation of the source rocks, on the creation of structural and stratigraphic traps and, finally, could affect the oil migration pathway.

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Thanks for the attention

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References

Daubechies, I.; 1988: *Orthonormal bases of Compactly supported wavelets*. Communication on Pure and Applied Mathematics, **41**, 909-996.

Subrahmanyam, D. and Rao, P.H.; 2008: *Seismic Attributes- A Review*. 7th International Conference & Exposition on Petroleum Geophysics; Hyderabad, India.

Zhang, L., Gao, R.X., and Lee, K.B.; 2006: *Spindle Health Diagnosis Based on Analytic Wavelet Enveloping*. IEEE Transactions On Instrumentation And Measurement, **55**, 5, 1850-1858.