Unsupervised Seismic Reservoir Characterization Using Wavelet Transform and Self Organizing Maps of a Deep-water Field, Campos Basin, Offshore Brazil

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Summary

This work presents a new alternative to extract seismic pattern attributes and a new methodology to build seismic facies maps. We propose using Wavelet Transform to identify singularities in each geological oriented segment of the temporal seismic trace and then using Self Organizing Maps (SOM) in a two-level approach. To illustrate this technique we applied it to real data from a deep-water field in the Campos Basin, Brazil.

Introduction

Seismic facies analysis is neither a deterministic nor a simple task. Usually, facies analysis is performed through the following steps (Johann et al, 2001):

1. Geological oriented spatial and temporal segmentation of seismic traces (input space);
2. Seismic attributes selection (variable space);
3. Choosing the optimal number of classes (facies) and algorithm iterations;
4. Training and classification of the selected attributes using some statistical or neural networks methods (pattern space);
5. Building and interpreting facies map.

Normally, the geological oriented spatial and temporal segmentation should be carefully done, because any horizon interpretation error could lead to wrong or very noisy facies results. The attributes selection is another complex task, because it should be physically consistent and statistically independent. It is common to use the whole seismic trace amplitudes around the region of interest (Taner et al, 2001).

Nowadays, Self Organizing Maps (SOM), or Kohonen Maps (Kohonen, 2001), have become one of the most popular tools to build seismic facies maps (Morice et al, 1996). But, it is still empirical how to choose the number of classes and the best seismic attributes to discriminate geological features from seismic data.

We propose to use a Wavelet Transform to identify singularities in each geological oriented segment of the temporal seismic trace and then using SOM in a two-level approach (Vesanto and Alhoniemi, 2000). To illustrate this technique the method was applied to real data from a deep-water field in the Campos Basin, Brazil.

Self Organizing Maps (SOM) and Seismic Facies Analysis

SOM, besides producing a similarity graph of input data, it is an effective tool for the visualization and clustering of high-dimensional data. Basically, it converts the nonlinear statistical relationships between high-dimensional data into simple geometric relationships of their image points on a lower-dimensional display, usually as a regular two-dimensional grid of nodes. Thus, the SOM can be interpreted as a topology preserving map from input space onto the two-dimensional grid of map units. The obtained grid can be used as a powerful qualitative visualization tool for showing different features of the data, such as their cluster structure. A useful tool to evaluate the cluster structure is the Unified Distance Matrix - U-matrix, which gives the distances between prototype vectors of neighboring map units. Typically, a red color indicates long distances and a blue color indicates short distances, when using a RGB colormap. This gives an impression of “mountains”, which divide the map into “fields” such as dense parts or clusters. Each cluster represents a different class.

In an unsupervised classification, one way to identify and to separate different seismic classes of a multidimensional attributes is by clustering of the SOM results rather than clustering the attributes directly (Vesanto and Alhoniemi, 2000). For seismic facies analysis, it consists of:

1- Geological oriented spatial and temporal segmentation of seismic traces (input space);

2- Seismic attributes selection (variable space);

3- Visualize the Self-Organizing Map (SOM) formed using the chosen seismic attributes input space

4- Cluster the SOM using K-means, or other clustering algorithms, with as many clusters as shown on the SOM map or use some empirical metrics as the Davies-Bouldin index. (Vesanto and Alhoniemi, 2000)

5- Construct and interpret the facies map.

Figure 1 illustrates the proposed methodology applied to 32 samples in each trace around the base of reservoir horizon (26 above and 5 below it). In order to do this you may need to use samples outside the two horizons. K-means algorithm was used to cluster the SOM map and the minimum Davies-Bouldin index was used to identify the number of clusters of the instantaneous amplitude attribute.

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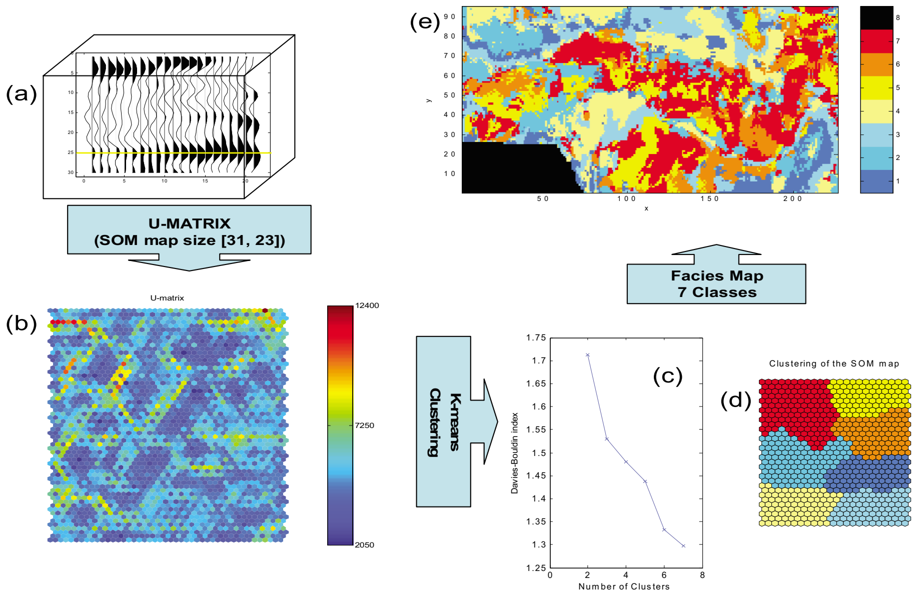

Figure 1: **Facies analysis methodology**. This example uses 32 seismic amplitudes around the reservoir bottom as an input attribute. (a) seismic amplitudes; (b) The U-matrix of a 31x23 SOM map; (c) Davies-Bouldin index with a 7 class minimum; (d) clustering of SOM map and (e) facies map.

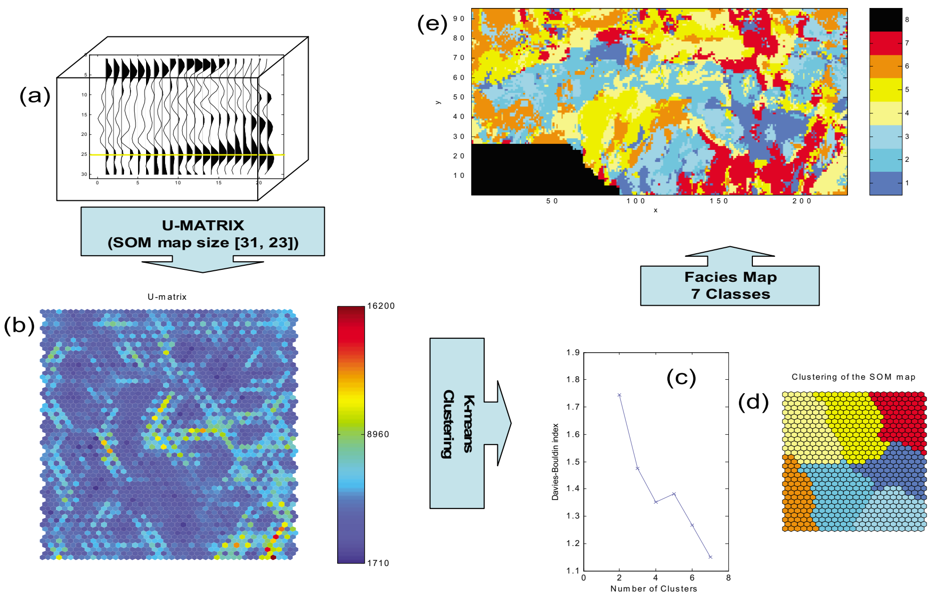

Figure 2: **Facies analysis methodology**. This example uses 29 interpolated amplitudes between the top and the bottom of the reservoir as an input attribute. (a) seismic amplitudes; (b) The U-matrix of a 31x23 SOM map; (c) Davies-Bouldin index with a 7 class minimum; (d) clustering of SOM map and (e) facies map.

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When geobodies of interest have been deposited in a non-parallel bedding environment, getting parallel seismic amplitudes could not be a very good idea, especially in a complex geology system as the turbidites data used in this work.

An alternative way is to interpolate samples in the traces so that a constant length window is maintained with the information between the horizons. Figure 2 illustrates the same methodology with a maximum 29 interpolated samples between the top and the base of the reservoir, which at first, best characterize the waveform shapes between two horizons.

In resume, it is not an easy task to segment the seismic data to get good facies analysis, and also the chosen seismic attributes should be statistically independent between each other (Johann et al, 2001). One way to get statistically independent attributes is to decompose the signal in orthogonal bases.

Seismic Trace Singularity Detection with Wavelet Transform

Signal transitions can be described using its local degree of regularity, which can be derived from a multi-scale evaluation of the wavelet coefficients that result from the transitions. Mallat and Hwang (1992) showed that the amplitude evaluation along the modulus maxima line formed by the undecimated wavelet transform, also called Wavelet à Trous, can be used to characterize signal singularities, as follows:

1. Decompose the signal using wavelet à trous;
2. Find the Wavelet Transform Modulus Maxima Line (WTMML), checking if all its points are in the cone of influence;
3. Evaluate the amplitudes along the modulus maxima line (WTMMLA).

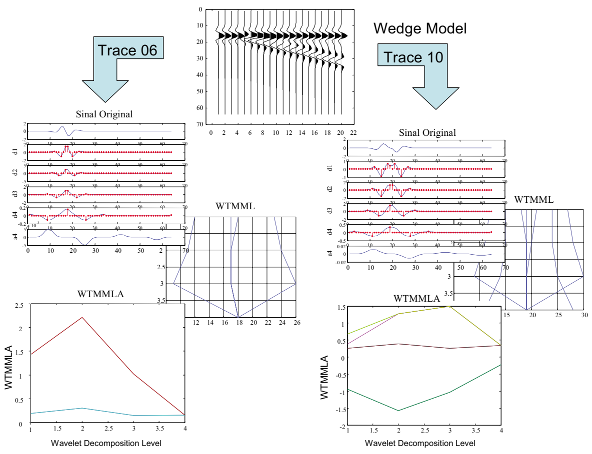

Figure 3: Synthetic signals; its wavelet à trous decomposition; WTMML and WTMMLA.

Mallat and Hwang (1992) also showed that it is possible to reconstruct a close approximation of the original signal trace from the WTMMLA's. Thus, the WTMMLA are a single time-frequency representation of the original trace and they can be used as input attributes to the seismic facies analysis methodology proposed here.

The WTMMLA could also be used to obtain the Hölder exponent as another seismic attribute (Hoekstra, 1996), but, in this work, we preferred to use the whole WTMMLA curve as singularities patterns.

Figure 3 illustrates the procedure applied to two different synthetic traces. Traces 06 and 10, were obtained from a synthetic wedge model and the resulting WTMMLA confirms that they can be used as different patterns for a classification system. WTMMLA can also be viewed, in a very simple form, as the ridges of the Continuous Wavelet Transform.

Wavelet transform (WTMMLA) and Kohonen Map (SOM)

The method proposed here brings together the wavelet à trous seismic trace expansion with the clustering characteristics of the SOM and K-means, to obtain an interesting new way to cluster seismic facies. This can be done as follows:

1. Segment each seismic trace around a geological oriented region.
2. Find the Wavelet Transform Modulus Maxima Line Amplitudes (WTMMLA) using the desired number of levels.
3. Visualize the self-organizing map (SOM) formed using WTMMLA as the seismic attributes input space.
4. Cluster the SOM using K-means, or other clustering algorithms, with as many clusters as shown on the SOM map or use some empirical metrics as the Davies-Bouldin index.
5. Construct and interpret the facies map.

As an example, the method proposed was applied to a 3D seismic data from a deep-water field in the Campos Basin, offshore Brazil and the result using only the two highest energy WTMMLA's (illustrated in Figure 3) seems consistent, showing a very good cluster definition in the SOM map, which is consistent with the petrophysical data analysis (Johann, 1997).

The whole algorithm, from SEGY files and horizon reading to seismic maps visualization, was implemented using Matlab from Mathworks and the SOM Toolbox from Helsinki University of Technology.

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Conclusions

Usually, the number of seismic facies choices is an empirical task. This work proposes a new way to start the choosing process

Detailed attribute analyses requires high quality signal-consistent interpretation. Using WTMMLA's as input attributes alleviates this condition because the detection of singularities in the time window is independent of the reference horizon position. Then, by using the metodology proposed here, it seems that the changes in the size of the analyzing window as little infuence in the facies analysis process.

The results have shown that the new proposed method for seismic facies analysis can be an alternative way to 3D or 4D seismic reservoir characterization. Particularly, we propose a new approach to extract reliable seismic attribute as input data for self-organizing map visualization and clustering of an entire volume of seismic data of a deep-water field in the Campos Basin, offshore Brazil.

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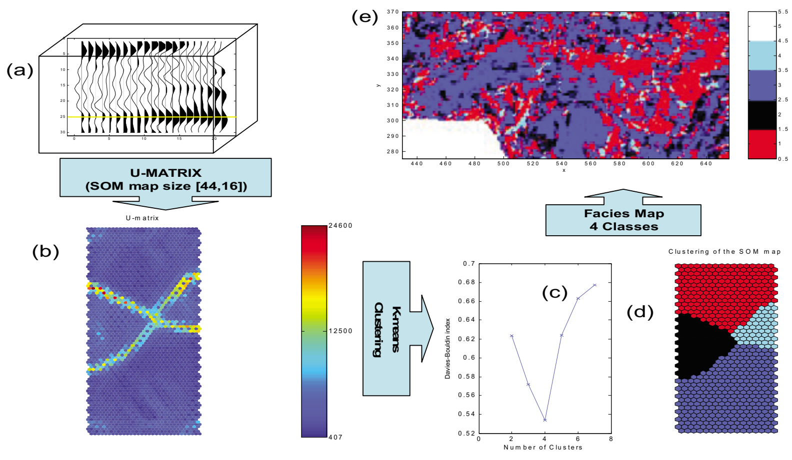

Figure 4: **Facies analysis methodology**. This example uses the two highest energy WTMMLA's between the top and the bottom of the reservoir as an input attribute. (a) seismic amplitudes; (b) The U-matrix of a 31x23 SOM map; (c) Davies-Bouldin index with a 6 class minimum; (d) clustering of SOM map and (e) facies map