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Similarity analysis: A new tool to summarize seismic attributes information

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Seismic attribute analysis is generally performed by correlating various attributes with reservoir properties. Even though experienced interpreters may have developed a good intuition about which attributes usually exhibit good correlation with particular reservoir properties, correlations between attributes and reservoir properties cannot be extrapolated from one reservoir to another. The analysis becomes more difficult as the number of attributes becomes larger, since the interpreter has to rely less on his/her experience and more on the actual correlations found in the data. Although some of the attributes seem to provide different information about lateral changes in the study area, they also contain redundant information that makes the analysis even more awkward.

We present in this paper a method to ease the interpreter's task of analyzing tens of seismic attributes by summarizing all the information into just one map. This map, the similarity map, shows the resemblance of the seismic response of each region of the whole study area with respect to a selected location in the field. If changes in the reservoir are assumed to be gradual, similarity maps can be used to map areas of the reservoir whose properties are similar to the properties around a control point, a producing or dry well, for instance. As we show in the examples, similarity maps can be a powerful tool to support exploratory work by highlighting prospective areas.

The field examples in this paper did not have statistically significant well control. This discouraged generation of attribute-based reservoir-property maps, because the correlation between petrophysical and production parameters with attributes may be misleading in areas where scarce well control is available (see "Potential risks when using seismic attributes as predictors of reservoir properties," *TLE*, March 1997).

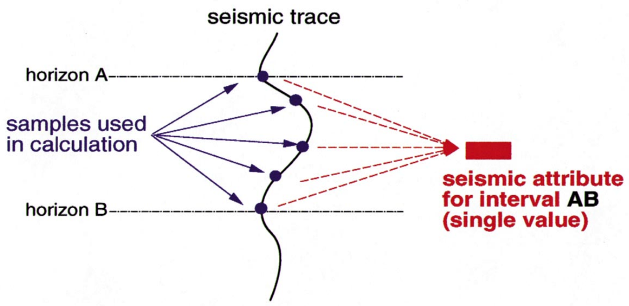

Figure 1. Computation of interval seismic attributes. All trace samples within two horizons are used to obtain a single attribute value.

Similarity maps. To correlate seismic attributes to interval reservoir properties and to avoid problems related to variations in layer thickness, we calculated interval attribute maps (Figure 1). Lateral changes in these average attributes indicate relative variations within the interval of interest.

The inputs of the similarity analysis are a set of uncorrelated seismic attribute maps, the coordinates of the control point, and the radius around the control point that circles an area (the reference zone) of nearly constant attribute response. Seismic attribute maps used for the similarity analysis should be independent to avoid introducing redundant information that could influence the results with some preferential trend. To generate a set of independent attributes, we use the method of Gram-Schmidt orthogonalization. By using this method on the conventional, correlated, zero-mean seismic attributes, we generate a new set of attribute maps that, by construction, are independent. Attributes with the smallest standard deviations are not considered further. To define the limits of the area around the well that will be considered as the reference zone, we analyze the distribution of the attribute values around the well as a function of distance from the well and azimuth. The distance from the well where attribute response remains nearly constant is considered as the radius of the reference zone in further calculations. Principal components analysis can also be used to generate a set of orthogonal attributes from the original, correlated attributes. However, since principal components analysis also computes other vectors that are not needed for this purpose, it is much more costly than Gram-Schmidt orthogonalization.

The process of generating the similarity maps can be divided into three steps: computation of reference values, classification, and sum (Figure 2). To calculate the reference values, the first step, we compute the mean and standard deviation of the attributes in the reference zone around the calibration point "p" (Figure 2a). In the second step, each point of each attribute map is classified depending on whether its mean falls within a window centered in the mean plus-minus the standard deviation of the attribute at the reference zone. For instance, to classify point "a" in Figure 2b, we compute the mean value of one attribute around such point in an area equal to the area of the reference zone. If the mean around point "a" is close to the mean of the reference zone (within the standard deviation), a high value, typically 1, is assigned to that point. If not, a low value, typically 0, is assigned. The procedure is repeated for all points and all attributes, and the result is a set of N binary maps, each related to one attribute map. The last step is simply to add up all the binary maps; the result is the similarity map. Obviously, values in the similarity map range from 0 to the number of independent attributes used in the process (N).

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Similar reservoir areas should have high seismic similarity when related to producing wells.

There are many other ways to characterize the matrix of attribute values around the calibration point, besides their mean and standard deviation, that may be more robust in the presence of noise. For instance, we could use the median of the matrix elements, or its singular values or singular vectors, or we could fit a quadratic surface around the reference point and compare any of these properties with the same ones calculated around all points in the map. However, if we have tens of uncorrelated attribute maps, the mean and the standard deviation should be enough to characterize the seismic response around the calibration point. Moreover, mean and standard deviation are by far the fastest to compute.

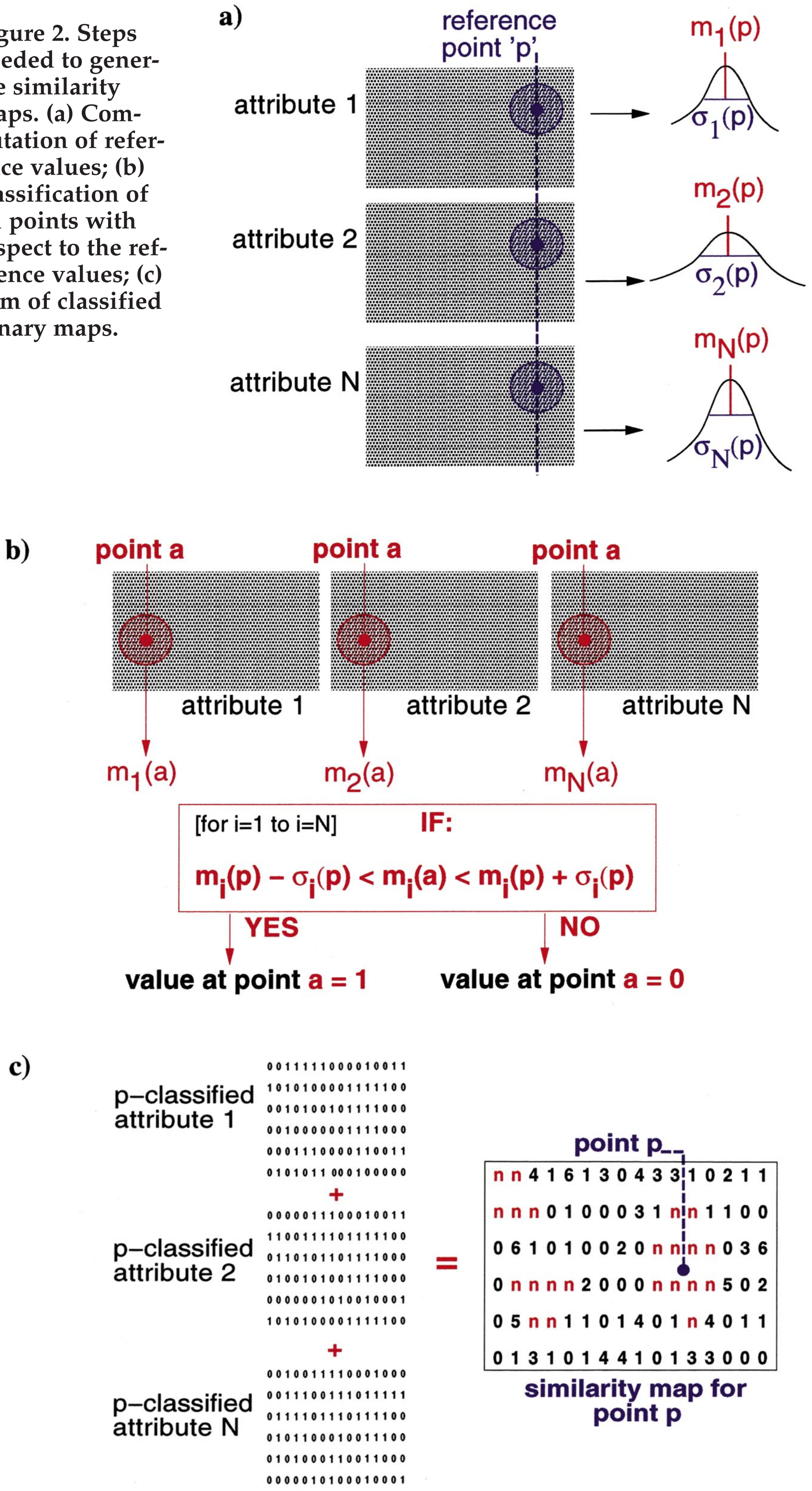

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Figure 2. Steps needed to generate similarity maps. (a) Computation of reference values; (b) classification of all points with respect to the reference values; (c) sum of classified binary maps.

Similar rocks or similar reservoir conditions produce similar seismic responses that independent attributes should capture. Although the opposite may not always be true for areas far from the calibration point, we expect areas close to the calibration point with similar seismic response to have similar rock properties, if we assume that changes in the reservoir are gradual. If the calibration point is a producing well, the similarity map associated with it will be a map of possible prospective areas in its vicinity. If the calibration point is a dry well, the similarity map associated with it highlights the zones with lower priority in exploratory or infill drilling programs.

Case histories. Similarity maps were calculated for two western Venezuela areas, Maracaibo and Barinas, in order to integrate the results of seismic attributes for productive Cretaceous limestones. Hydrocarbon production from Cretaceous, carbonate reservoirs accounts for 30% of total Venezuelan production. However, a complete understanding of the mechanisms that control this production has not been established for most of these reservoirs. Fracturing processes, diagenesis, compartmentalization, difficulties in seismic imaging, great depths, and structural complexities are all factors that have made difficult the development of fields whose production potential per well is up to 4000 bd.

Lake Maracaibo. In western Venezuela, a large Cretaceous reservoir located in central Lake Maracaibo was studied by means of similarity analysis applied to 12 seismic attribute maps. Figure 3 shows three of the attribute maps computed for the Albian-Aptian interval of the early Cretaceous limestones in the field. Each map shows different trends that are difficult to interpret in a way that is consistent with all other maps. Petrophysical evaluation and production information from only four wells were available for this study. Wells A and B are both excellent producers with cumulative productions

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of 9.4 and 14.8 million barrels, respectively, since June 1995. Wells C and D are dry. Due to the scarce well control, seismic calibration with petrophysical or production parameters would be unreliable.

We started the study by analyzing the attribute values in the neighborhood of the two producers. We plotted each seismic attribute as a function of the distance from the wells and azimuth. Figure 4 shows the behavior of the instantaneous frequency around each producing well. Values around well B are almost constant whereas values around well A show high dispersion around the mean. All other attributes show the same behavior around each well.

The similarity maps helped to confirm results of previous studies that showed compartmentalization of the reservoir and the extent of the prospective areas. The similarity map related to well B (Figure 5) shows the extension of what was interpreted as a compartment. The response of the seismic around well B is clearly different from that of well A, which is consistent with the hypothesis of reservoir compartmentalization proposed by previous integrated studies performed in the field. The company that operates the field felt that these results opened a path for establishing new exploratory strategies for the area.

We also computed the similarity map for well A (Figure 6), the other good producer in the area. Due to the high variability of the seismic attributes around this well (Figure 4), the process of classification was less accurate, and the similarity map obtained was considered not reliable.

Barinas area. In this area, we computed a similarity map referred to the only producing well in the field, well 1. This map summarizes the response of 10 attribute maps. Well 1 has produced 400 000 barrels in two years. The similarity map shows a southwest-northeast trend that was interpreted as a carbonate rim (Figure 7). After analyzing the spatial variation of the similarity value near the producer well, a reentry from well 2 was proposed. This reentry was designed as a deviated hole into the high-similarity valued zone where the rock properties are probably similar to those near well 1 (red arrow in Figure 7).

Figure 8 shows the similarity map that results when the calibration point is one of the dry wells. Areas to

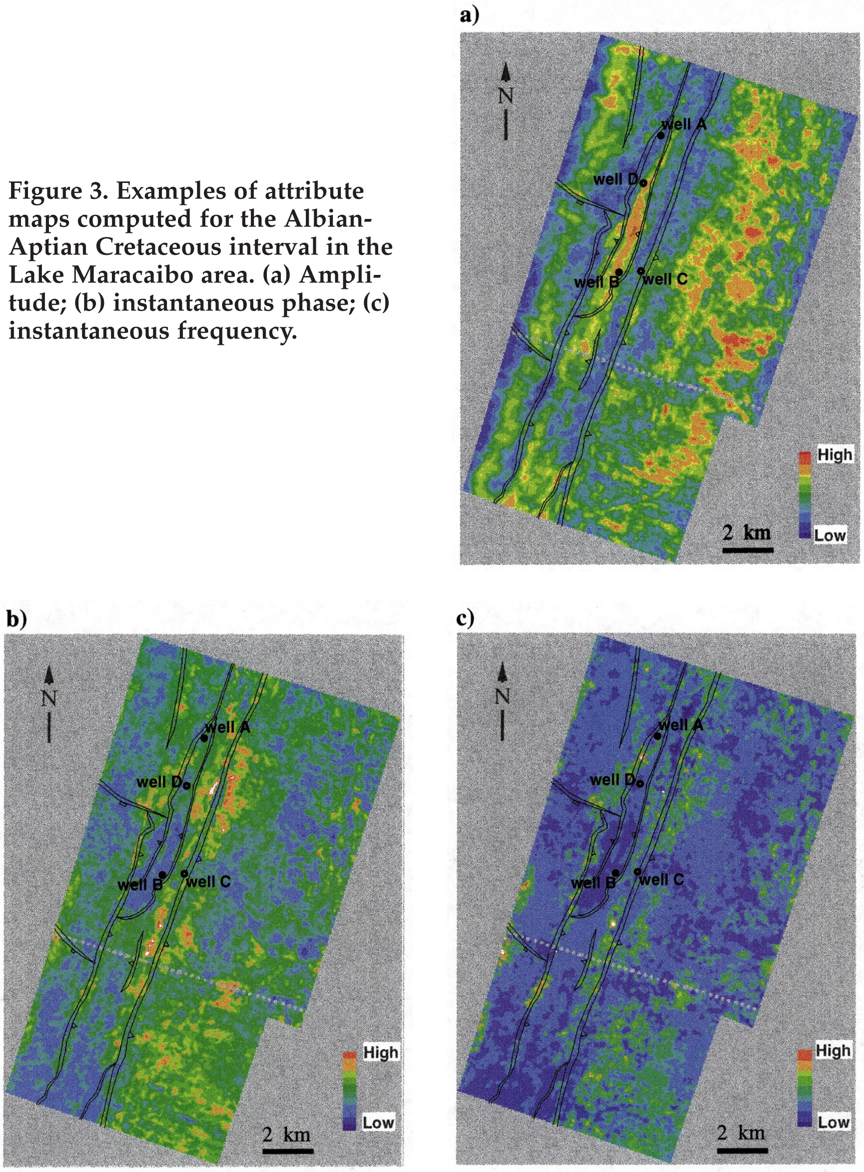

Figure 3. Examples of attribute maps computed for the Albian-Aptian Cretaceous interval in the Lake Maracaibo area. (a) Amplitude; (b) instantaneous phase; (c) instantaneous frequency.

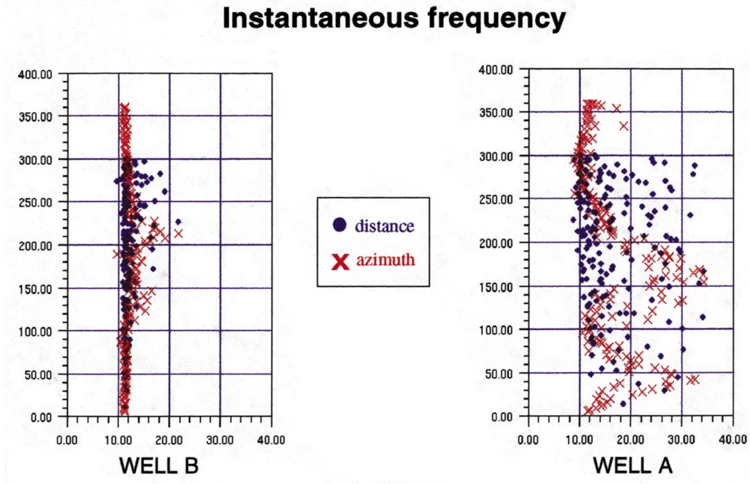

Figure 4. Behavior of the instantaneous frequency around each producer in the Lake Maracaibo area. The vertical axes indicate variations in both distance from the well and azimuth. Values around well B are almost constant unlike values around well A. All other attributes show the same behavior. X = azimuth and circle = distance.

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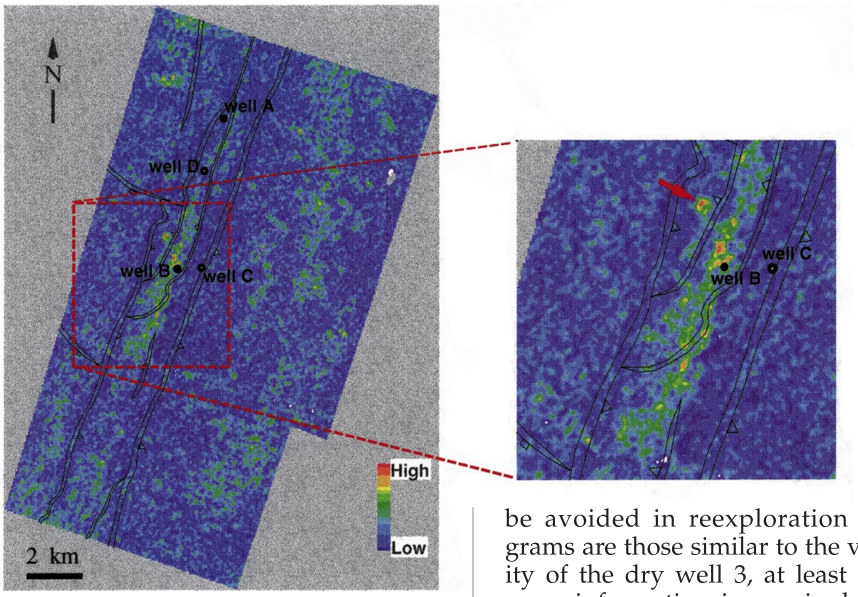

Figure 5. Similarity map for well B (producer, Lake Maracaibo area). High similarity values indicate the extension of a compartment. The red arrow indicates a prospective area that was also proposed by independent studies.

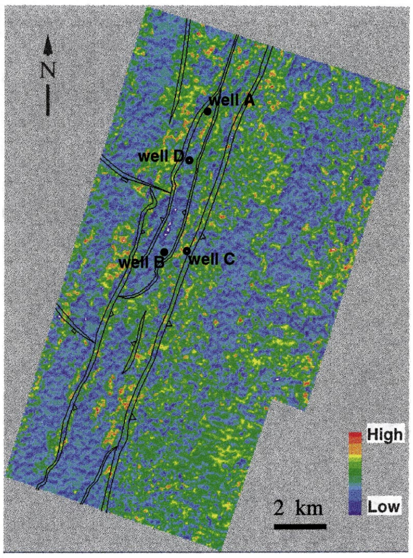

Figure 6. Similarity map for well A (producer, Lake Maracaibo area). Attributes are so variable they cannot be used to discriminate the area around well A from the rest of the field.

be avoided in reexploration programs are those similar to the vicinity of the dry well 3, at least until more information is acquired, and the reservoir rock is better characterized.

Conclusions. We presented a practical method to simplify the analysis of seismic attribute maps in exploratory areas, with examples of application to two Venezuelan fields. The procedure generates what we call similarity maps, which we believe are a powerful tool to support exploration and development plans, simplifying the interpreter's communication issue when evaluating and presenting the prospects. Similarity analyses optimize the use of seismic attributes by summarizing the information contained in many attribute maps. Similarity maps were used in this study in exploratory areas with scarce well control. More work needs to be done to understand the use of this technique in areas with more petrophysical and production information. In addition, in the future it is anticipated that 3-D visualization of similarity volumes will greatly enhance the understanding of our reservoirs.

Suggestions for further reading. "Carbonate platform seismic sequence attributes, Maracaibo Basin, Venezuela," by T. C. Stiteler et al. (in *Carbonate Seismology*, SEG, 1996). **E**

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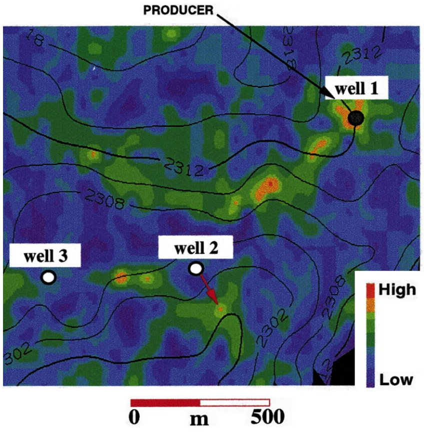

Figure 7. Similarity map for well 1 (producer, Barinas area). High similarity trend was interpreted as a carbonate rim. This result helped to justify a reentry from well 2 to the area indicated by the arrow.

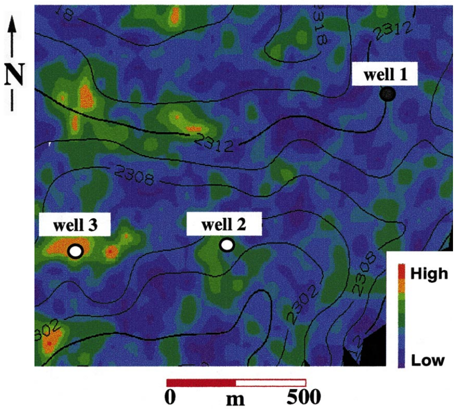

Figure 8. Similarity map for well 3 (dry, Barinas area). Areas with high similarity values should have lower priority in development programs.