OTC 8276

Use of seismic attributes at Lake Maracaibo to reduce exploratory risk

Mariangela Capello, Reinaldo Michelena, and Ezequiel González, INTEVEP S.A, Adrián Peinado, Universidad Simón Bolívar; Miguel Araujo, and Fernando Tizón, MARAVEN, S.A.,

Abstract

Although there is not a unique approach to understand the meaning of seismic attributes, they are becoming a widespread tool in reservoir characterization. In areas where very little petrophysical and production information is available, seismic attributes can play an important role in identifying new prospects and reducing exploratory risks. We present a simple methodology to do such an assessment and examples of its application to a Cretaceous carbonate sequence at Lake Maracaibo, Venezuela, one of the oldest and most prolific oil provinces in the world.

The main idea behind the proposed methodology is that independent seismic attributes should be related to different, but not necessarily independent, properties of the reservoir. By sampling the space of seismic attributes as completely as possible, computing as many attributes as possible from the seismic data , we try to increase the probability of deriving a set of seismic parameters that correlates with the parameters that control production. Reservoir quality is derived from comparison of independent seismic attributes related to rock properties.

The described methodology was applied in a Cretaceous carbonate sequence at Lake Maracaibo, Venezuela. After a careful examination of the attribute responses and their correlation with production and petrophysical data available, we were able to identify new prospective areas, identify possible producing intervals, and confirm the reservoir engineers ideas about compartmentalization of the field.

The proposed methodology was proved useful in decision making processes to reduce exploratory risk in areas with scarce well control but with 3D seismic data.

Introduction

An area in the Maracaibo Lake had been producing from Eocene sands very successfully. The discoveries of light oil in the deeper Cretaceous carbonate rocks, at an average depth of 12,000 feet, in the Lake led to exploratory programs searching for oil in these strata. The study area of this paper was no exception, and from 1968, several Cretaceous exploratory wells were drilled. After several successful wells drilled in structural highs (one accumulated 14.8 MMBO), the dry wells and poor producers that were drilled afterwards, showed that the production mechanism was not clearly understood. The exploratory program was stopped until a coherent production scheme was proposed.

The task of reaching an understanding of the processes that accumulated good reservoirs in this area, to better define the prospective areas, was assigned to a multidisciplinary team. As part of these efforts, a 250 km^2 3D seismic survey was acquired in 1990. This paper presents the results of the study of the seismic attributes and how they were used to match petrophysical characteristics with seismic response in order to determine possible prospective areas in a zone with scarce well control.

Recently, the use of seismic attributes has proved its value in defining details at reservoir level, extending the information that is in the seismic trace farther than just for structural and stratigraphic purposes. Examples of this use are the so-called Hilbert attributes, or "instantaneous attributes": amplitude, phase and frequency, where "instantaneous" refers to the fact that they are calculated for each seismic time sample. Several papers deal with the use of these attributes in reservoir characterization. (Lendzionowski *et al.*, 1990[1]; Rijks and Jouffed, 1991[2]; Bahorich and Bridges, 1992[3], Malcotti *et al.*, 1994[4]).

The complex trace attributes or instantaneous attributes are calculated from the seismic trace under signal processing assumptions, and there is no direct theoretical derivation that could relate them with reservoir properties. Therefore, the analysis of seismic attributes is a more qualitative than quantitative one. The calibration with well data is then a key factor.

Previous works (Taner *et al.*, 1979[5]) show how in some cases, instantaneous amplitude variations can be associated with porosity variations, fluid saturations or lithology changes. Instantaneous frequency can be associated with vertical lithology changes (like sand/shale alternation). Instantaneous phase is generally related to lateral continuity of events, and for this, to lateral lithologic variations.

Study Area

Location and structure. The study area is located in Lake Maracaibo, Venezuela (Fig. 1). Particularly, the area covered by a 1990 3D seismic survey, processed in 1992 that totals 250 km^2 (Chacartegui *et al.*, 1995[6]). Information from the eight wells that reached the Cretaceous interval was used for seismic interpretation and calibration. Previous works provided the stratigraphic and structural framework used in this study.

The Cretaceous interval in this area is a carbonate sequence that in some localized areas thickens up to 450 meters. This sequence is folded forming a bisected anticlinal, divided in two by the Icotea Fault. The east flank of the fault is uplifted (2700 to 3400 m), forming a simple structure cut by smaller faults. The west flank is deeper (3600 to 4600 m) and structurally complex (Stiteler *et al.*, 1996[7]). This west flank is recipient of very important reservoirs, of the order of 10^9 barrels of oil (Reijers and Bartok, 1985[8]).

Seismic data characteristics. The data was acquired in 1990, with a 4 ms sampling interval, 40 m line separation, 20 m CDP separation. The processing was completed by 1992, following a conventional sequence that included one pass migration. The vertical resolution for the Cretaceous interval is approximately 45 m.

The interpretation was provided by the operating company, Maraven, S.A, a PDVSA affiliate. Four main seismic events were interpreted: Socuy Member, Maraca Formation, La Luna Formation, Lisure Formation, Apón Formation, and Río Negro Formation (top of pre-K unconformity).

Methodology

The methodology followed for the attributes processing was:

* Zero phase conversion of seismic data
* Attributes calculation
* Statistics
* Correlation of attributes and well data
* Similarity maps calculation
* Interpretation of attribute maps
* Prospective areas determination

After ensure a zero phase of the seismic data through performing rotation analysis, calculation of the attributes was performed, averaging the several time samples that covered the time interval between two interpreted reflectors (Fig.2). In this case, four intervals were considered, based on the five tops provided.

At the depths considered, 4,000 meters o more, with a resolution of the Fresnel zone of about 300 m, it was necessary to examine the data on a gross-interval basis, knowing that only an average of the petrophysical properties was recorded in the seismic data. This calculation was considered in this case a better representation of the studied intervals than a conventional pick calculation.

Statistical Approach

A statistical analysis of the attributes was performed, on the seismic attributes themselves (areal distribution and linear dependency), and the attributes related with petrophysical parameters.

Attributes distribution. The calculated attributes were analyzed regarding distance and azimuth from the two producing wells of the area, A (9.4 MMBO) and B (14.8 MMBO).

The instantaneous phase, instantaneous amplitude and instantaneous frequency attributes show a high variability, almost showing a random behavior around well A (Fig. 3). This observation tell us that seismic data around this well is highly disturbed, probably for one of two reasons: the presence of a big fault nearby or problems in acquisition and processing the data due to surface facilities or mud layer presence at the bottom of the Lake. Instead, the same attributes around well B do show consistency, especially from zero to 100 degrees and in distances lesser than 300 m (Fig. 4).

These observations had an important impact on the results, because it was concluded that seismic data around well A did not have good lateral continuity or resolution, affecting the attribute calculations and resulting in an uncertainty in the calibration with petrophysical parameters. One of the most important results of these plots was the estimation of the area for averaging the similarity calculation. This area was 300 m.

Attribute maps. In the four intervals studied, following the averaging procedure shown in figure 2, 40 maps were produced, some of which are shown in figures 5 and 6.

The instantaneous frequency did not provide a reliable tool in this study, not only for the scarce petrophysical correlation, but also for its areal random distribution. The response of this attribute was flat for all intervals, giving no clues for a correlation with well data or structural features (Fig. 5). The cross-plots that were constructed relating instantaneous frequency with petrophysical parameters showed no correlation at all, so the instantaneous frequency maps were discarded for all the intervals in the interpretation.

The instantaneous phase and instantaneous amplitude (Fig. 6) did show a good variability, that was related apparently to the main structural features present in the area. The interpretation of the observed trends in the instantaneous amplitude maps provided a good visual correlation with the main structural features, easily relating the two sets of data. The reservoir compartments limited by faults and identified in previous studies (Chacartegui *et al.*[6]), do show as separate attributes maximun zones. Instantaneous amplitude and instantaneous phase constituted the most contributive effect in the construction of the similarity maps.

Linear dependency. The attributes calculated were submitted to statistical analysis aimed to determine their linear dependency. Eight attributes were calculated: Instantaneous frequency, instantaneous phase, instantaneous amplitude, Instantaneous phase times instantaneous frequency, Instantaneous amplitude times instantaneous frequency, Instantaneous phase gradient, Instantaneous phase derivative in the east-west direction, Instantaneous phase in the north-south direction. The analysis of the several linear functions applied to the eight attributes resulted in proving that the instantaneous amplitude was deterministic, in the sense that it was able to discriminate between different data quality. Six of the attributes were independent (Fig. 7).

Petrophysical correlation. When comparing the attributes with petrophysical quality parameters such as porosity, net sand, cumulative production and water saturation, only the instantaneous amplitude hinted a reliable correlation, that was not studied in detail due to the lack of hard data. A series of cross plots relating the independent attributes in the vicinity of the available wells were produced.

Comparison of the attribute response of the seismic data in the vicinity of the producing well B with the non-producing well C, showed what seems to be the solution of the problem, that seismic attributes could determine a difference between a producer and a non-producer zone: the attribute values cluster apart in the crossplots (Fig. 8). An uncertainty arose when the comparison of the attribute responses of the only two producing wells available in the area, A and B, also resulted in a separation, as if the attributes were completely different. For two equally producing zones, a different seismic response: a discrepancy (Fig. 9), because no separation was expected.

As a consequence, discerning producers from non-producer wells using only the seismic attributes away from the structural and geologic context was not possible in this case.

We interpreted this result as related to the high variability of the data. It is important to mention that although results from well B matched the assumptions of the correlations established with the petrophysical properties, results from Well A do not show any match at all. This confirmed the previous statistical result, that seismic data around well A could be anomalous, of very low quality, leaving the validation of this assumption to further studies.

Similarity Maps

Besides the basic calculation of the attributes, a measure of the quality of the reservoir rock was estimated through maps that compare all the six attributes calculated (Fig. 10). These maps aim to show how accurately a certain area of the map reflects the same properties than the area around a certain known calibration point (a well). Directly, these maps provide a tool to look for areas which attribute response is similar to that of a producing well. Identical seismic responses should be related with similar reservoir characteristics. Through this work, we were able to develop and implement the calculation of the "similarity" maps, in an effort to extract the maximum from the scarce hard data (well data) available: two producer wells and six non-producers.

The six independent attributes found in the statistical analysis, were used to elaborate the similarity maps, where values ranged from zero to six. Six was the maximum value of similarity, in the vicinity of the wells considered and other places. These other zones of high similarity values were considered interesting, because they showed the same seismic response than the area near wells. If the well to compare is a producing one, as wells A and B, the high values areas would be prospective; if the well of the similarity map is a dry one, then the high values are associated with poor zones.

The similarity map generated for the Apón-Lisure interval related to well B, a well with cumulative production of 14.8 MMBO production shows several important features (Fig. 11). Areas with high similarity look attractive to reinitiate exploration.

Conclusions

1. Similarity maps have a great potential of application in areas where few well data control is available or poor seismic quality is present. The generation of this kind of maps resulted in a powerful tool for the determination of prospective areas to be explored.
2. The analysis of the similarity maps resulted in the identification of compartments associated with oil production in the area.
3. The interpreted compartments follow the structural trends present in the study area, reflecting perhaps the distribution of reservoir quality rock, in a zone where production is generally attributed to fracturing.
4. The instantaneous frequency attribute maps are preponderantly uniform, showing a flat response that could not be associated with any petrophysical parameter. The crossplots regarding instantaneous frequency and the reservoir characteristics had a big dispersion, no correlation was found.
5. The maps of instantaneous amplitude and instantaneous phase do show a good variability, and are independent variables when statistically analyzed. Nevertheless, none of these two could be related to the production parameters with a fair degree of confidence.

Acknowledgments

The authors express their gratitude to INTEVEP S. A. and MARAVEN S. A. for permission to present this paper at the Offshore Technology Conference.

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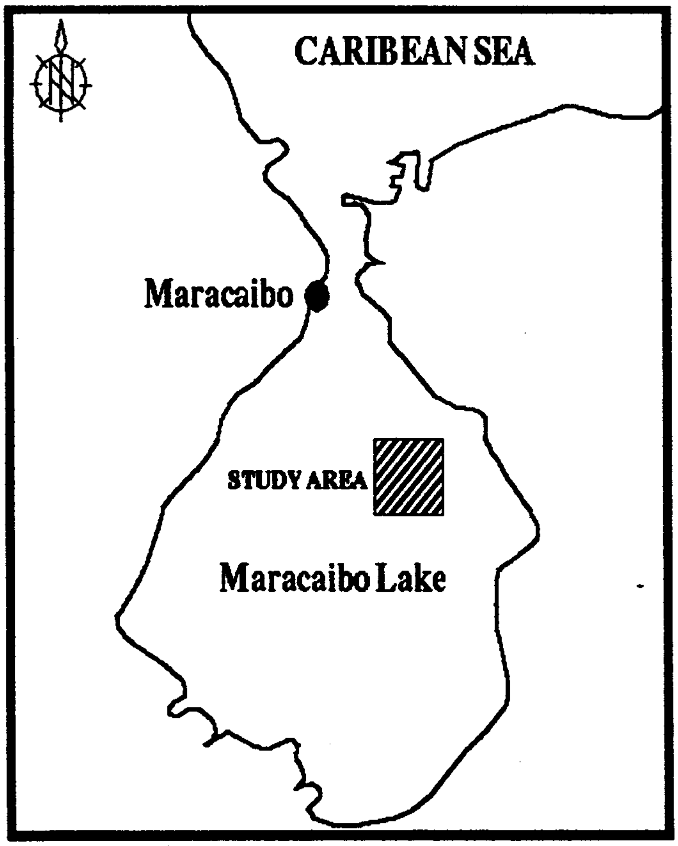

Figure 1 Study area, Lake Maracaibo, Venezuela

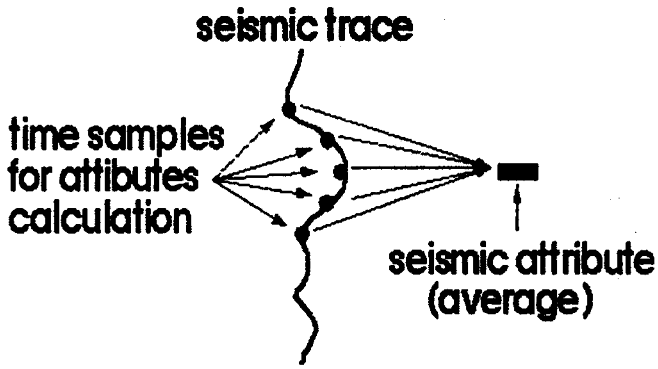

Figure 2 Calculation of seismic attributes. Note the averaging

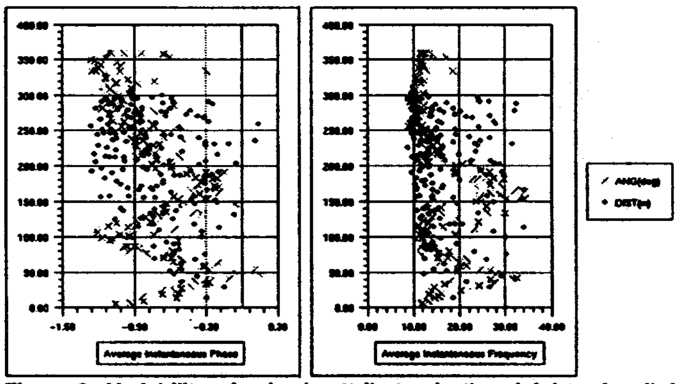

Figure 3 Variability of seismic attributes in the vicinity of well A. Scale refers to azimuth and distance

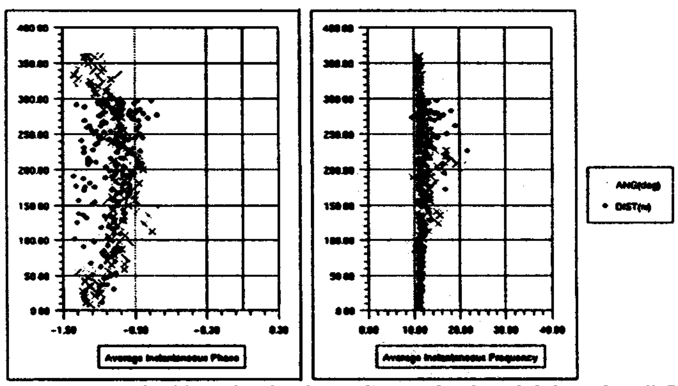

Figure 4 Variability of seismic attributes in the vicinity of well B. Scale refers to azimuth and distance

Figure 5 Instantaneous frequency, interval Apón-Lisure. Note the flat response

Figure 6 Instantaneous amplitude, Apón-Lisure interval. General trends follow structural features

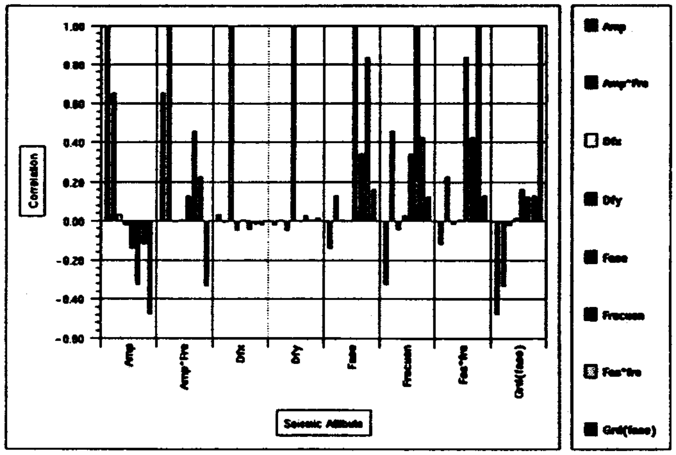

Figure 7 Linear dependency of attributes. Instantaneous amplitude times instantaneous frequency, and instantaneous phase times instantaneous frequency are the two calculated attributes that show a high degree of correlation with other attributes (greater than 0.6). They were not used in the similarity maps. The other six attributes are linearly independent

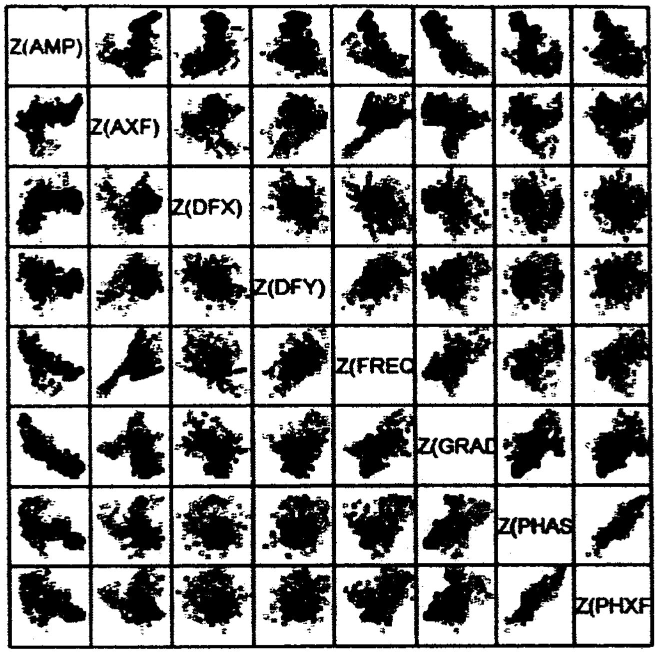

Figure 8 Crossplots of attributes in the vicinity of wells B (producer) and C (dry). Note the separated response especially in instantaneous amplitude.

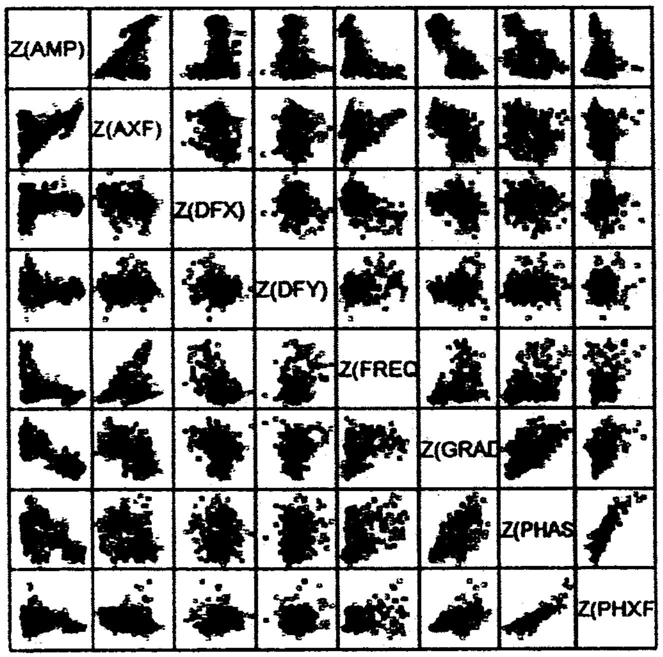

Figure 9 Crossplots of attributes in the vicinity of wells A and B. Both wells are excellent producers, but note the separated response especially in instantaneous amplitude.

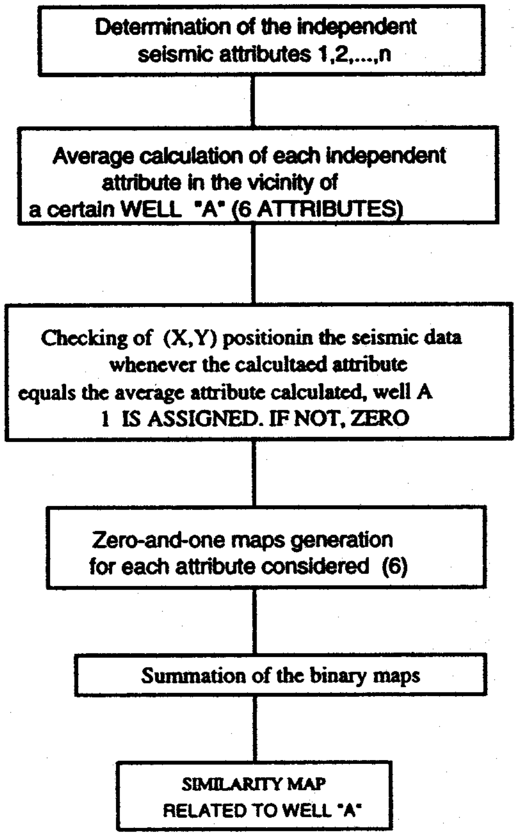

Figure 10 Flowchart for similarity maps generation.

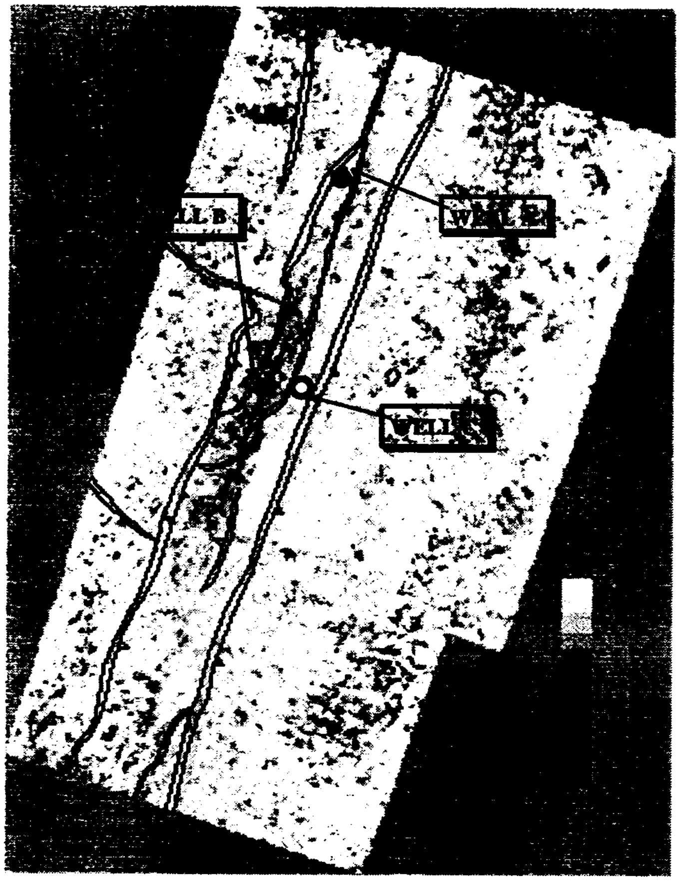

Figure 11. Similarity map for Well B (producer with 14.8 MMBO to date), Apón-Lisure interval. Note that maxima similar to Well B location are prospective.