Carbonate reservoirs and seismic attributes: How far can they go together?

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Summary

This paper presents the interpretation of 3D seismic attributes applied to two Venezuelan fields, where the producing interval are fractured, carbonate, platform sequences. We present practical conclusions regarding the use of similarity maps as a tool to summarize different seismic attributes responses. Considerations for interpreting the results of seismic attribute analysis for carbonates in terms of compartmentalization of the reservoirs are also given. Compartment detected by seismic attributes are validated by pressure measurements in different wells.

Introduction

Although seismic attributes have been widely used for increase the value of seismic interpretations (Rijks and Jouffed, 1991; Bahorich and Bridges, 1992), their application to mixed carbonate-siliciclastic environments has not been extensively documented (Gallager and Hoover, 1994). The practical problems due to the high heterogeneity of these kind of reservoirs, and the typical compartmentalization associated with them are studied in the two case histories presented, where a systematic data analysis was performed.

Venezuelan Cretaceous carbonate reservoirs comprise a large number of prolific oil provinces, that contribute extensively to the total national hydrocarbon production. It is noteworthy that these reservoir are generally deep (at an average 3,400 m), with intense fracture systems enhancing the production mechanisms. Stratigraphically, these reservoirs correspond to a large and extend period of sea level rising, that lasted all the period, and resulted in the sedimentation of very large carbonate platforms, occasionally mixed with siliciclastic influx from the shelf. This stratigraphic setting of highly heterogeneous carbonate and siliciclastic sediments does not allow a conventional approach to seismic stratigraphy interpretation or modeling.

Important structuring greatly affected these carbonate Cretaceous sequences. There is evidence of important normal Cretaceous faults that changed later to reverse faults (Stiteler et al., 1996) in a tectonic event related to the collision of the Caribbean plate with the Suramerican plate. Minor Cretaceous faults, generally with semi-vertical fault planes, are numerous, and tend to compartmentalize the reservoirs, due to their sealant character (Martinez et *al.,* 1996). The presence of these two sets of fault systems affects the seismic data in great proportion, difficulty the conventional seismic interpretation and leaving a large space for use of enhanced seismic interpretation techniques, such as statistical analysis of attribute mapping. We conclude that seismic attributes interpretation should be confined to reservoir compartments when dealing with carbonate rocks.

Study areas

The methodology described in this paper was applied to two important areas for Venezuela's production plans: Lake Maracaibo and Barinas (Figure 1). The Maracaibo's 250 km^2 area presents a faulted sequence that forms a bisected anticlinal. The east flank of the fault is uplifted, forming a simple structure cut by smaller faults. The west flank is deeper and structurally complex (Stiteler et *al.,* 1996). This west flank is recipient of very important reservoirs, of the order of 10^9 barrels of oil (Reijers and Bartok, 1985). The objective of this study was the Cretaceous carbonate sequence, particularly the Cog0110 Group.

Barinas' 20 km^2 area is located in the north flank of Merida Arch. It is a plane that dips gently towards the Northwest, faulted by important reverse faults (wrench?) that run N40E, and limit the reservoirs. The main objective of this study was a mixed Cretaceous dolomitic-carbonatic sequence, with an important siliciclastic component towards the south (Martinez et *al.,* 1996).

Due to some dry well drillings and the pour understanding of the entrapment mechanism, new developments were stopped in these two areas. As part of the efforts for setting new bases for a short-term re-exploration phase, a 3D seismic attributes interpretation project was carried out in each of these areas.

Data analysis

The first step in the analysis of the seismic data was aimed to determine the variance of the seismic attributes in the vicinity of wells (Figure 2). The result of these analysis was the determination of the averaging procedures to be applied later when smoothing the maps, and for the correlation methods established among seismic and well data. For the Barinas area, the smoothing was done by gridding the data in a 50 by 50 m regular grid, with a searching radius of 100 m. Besides the smoothing introduced by gridding, seismic attribute maps were additionally smoothed areally by the application of mean filters. For the

Lake Maracaibo area, the best parameters found for this procedure were gridding in a regular scheme of 40 by 40 m, and search radius of 80 m.

More than 50 attributes maps were obtained for the two areas. Almost all attributes reflect structural trends present in the study areas. In particular, the compartmentalization of the reservoirs does not necessarily follow major fault settings.

We studied also the variability of the data around various wells with respect to azimuth and radial distance. In Lake Maracaibo, where the study area had only two producing wells, the results for each of those wells vicinities were completely different (Figure 2). Conclusions related to Well A were discarded (Capello et al., 1997), due to high variability in the seismic data. This variability was attributed to the presence of a fault at the well location. Uncertainties related to well head position, and precise fault interpretation in the 3D data further difficult this analysis. Well B calibration was considered useful for area1 extrapolation of results, because the seismic data around this well did not show high variability or dispersion. Since previous studies show this reservoir is compartmentalized, we believe the large difference observed in the seismic response around the two producers are a consequence of such a compartmentalization.

Crossplots

Another statistical approach for the attribute interpretation was the conventional crossplotting technique, that relates the attributes distribution around different wells.

The seismic attribute response around two dry wells does show an overlay in the crossplots for the Lake Maracaibo's field. This overlay could be interpreted as seismic response of a non-producing area or a poor reservoir rock. The comparison between a dry and a producer well results in a clustering apart of the seismic attribute responses, as if seismic attributes could really determine rock quality. An interpretation difficulty arose when a comparison was established between the two only producing wells in the area (Figure 3). In this case, when an overlay of response was expected, a separation showed that both responses for equally good producers was different. Is important to mention that these producing wells have a very large accumulated production (9.4 MMBO for well A and 14.8 MMBO for well B, as of June 1995), so a large drainage area was deducted. Since the seismic attributes are statistically so different around each well, one should be careful when extrapolating results to the whole field when compartmentalization is suspected; such extrapolations may be meaningless,. In these cases attributes should be interpreted integrating geological data such as fault presence, structural framework, and reservoir rock presence with production data. Information regarding fractures presence can not be underutilized or neglected either.

Similarity maps

A methodology proposed to summarize seismic attribute maps and simplify their interpretation is the generation of what we called similarity maps. These maps show areas of the reservoir whose seismic attributes response is the same as the attributes measured around a known location taken as reference. The idea of the similarity maps is that similar seismic response should be related to similar rock properties. Because they are related to calibration wells, the objective is the extrapolation of the reservoir rock parameters at the well location to those in other areas with no other information but seismic data. When the calibration well is a producer well, then maximum in the similarity maps should be associated with productive areas, untapped or not. If the calibration well is a dry one, then the maximum would be areas to avoid in re-exploration or production plans.

In the two case studies presented, similarity allowed the interpretation of prospective areas and were consistently with previous multidisciplinaries studies. Similarity maps provided new and more arguments for re-initiating drilling in the areas.

In Lake Maracaibo, the most useful map was the similarity map associated with well B (Figure 4), a well that accumulated 14.8 MMBO by June 1995. In this map, reservoir compartmentalization was inferred, based also on comparison with the predictions of previous integrated studies in this area.

For the Barinas area, the similarity map of interest was related to well 1, a producer well with an accumulated production of 0,3 MMBO (by July 1996, being a well drilled in 1994). This map also show a trend for good quality reservoir rock related to well 1. The compartmentalization in the Barinas' reservoir was also proved by a 320 psi pressure difference between wells 1 and 2 (Figure 5).

Conclusions

1. In carbonate rocks, seismic response can change dramatically from one compartment to another. If compartmentalization is suspected, extrapolation of properties

around a well to the whole field may produce meaningless results.

2. Carbonate reservoirs at great depths need to be studied with integrated approaches. Extracting conclusions that do not consider the general production and geological framework is risky. The great heterogeneity exhibited by a mixed carbonatic-siliciclastic sequence was approached with statistical considerations for the interpretation of results.

3. Similarity maps have a great potential for application in areas where few well control is available. The generation of this maps is a powerful tool for the determination of prospective areas to be explored.

4. The analysis of the similarity maps resulted in the identification of possible compartments associated with oil production in both case histories presented. This compartmentalization was sustained by other studies.

5. In the two areas studied in this paper the interpreted compartments follow the structural, probably reflecting possibly the distribution of reservoir quality rock in zones where production is generally attributed to fracturing.

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Figure 1. Study areas: Lake Maracaibo and Barinas, both in western Venezuela.

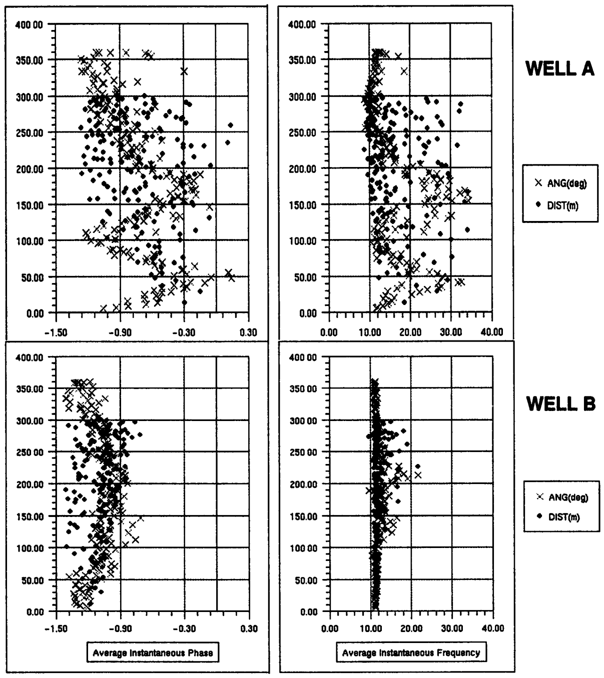

Figure 2. Comparison of variability of two seismic attributes around wells A and B at Lake Maracaibo. Note dispersion in well A.

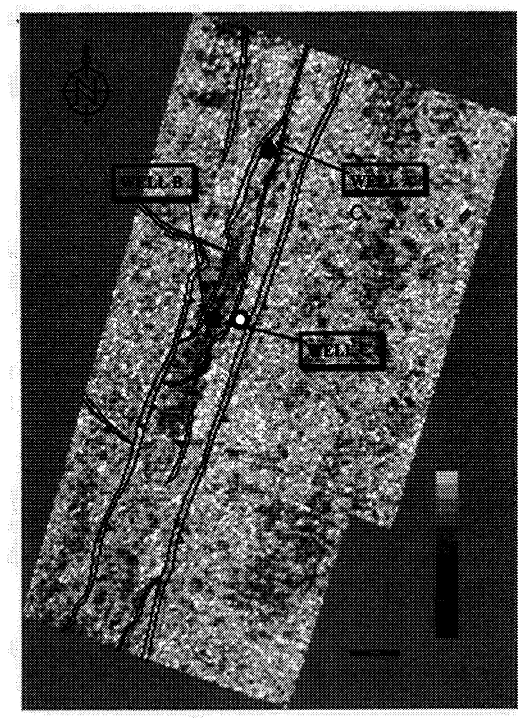

Figure 4. Similarity map for well B, Lake Maracaibo area. Dark gray areas around this well could be also prospective areas.

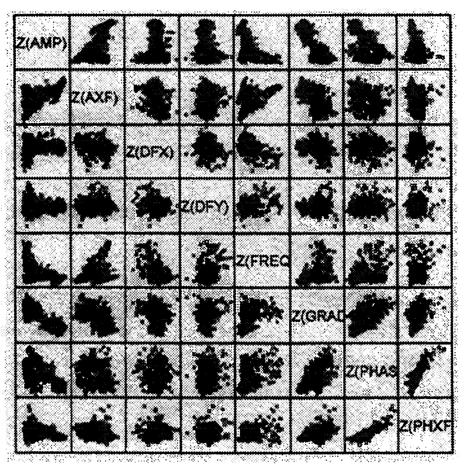

Figure 3. Separation of response in a crossplot of two producing wells, when a possible overlay was expected.

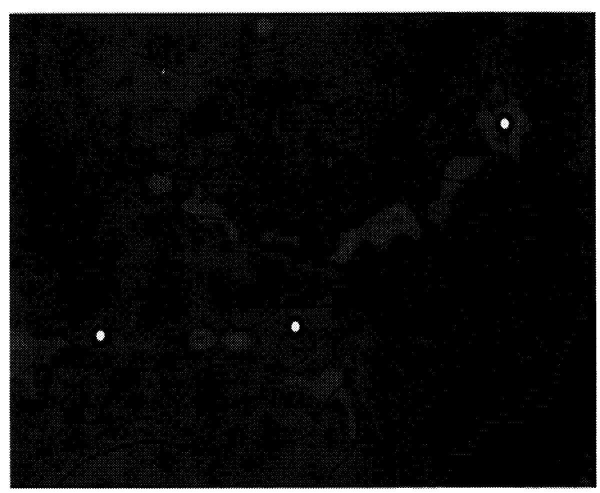

Figure 5. Similarity map for well 1, Barinas area. Well 1 is a producer, whereas wells 2 and 3 are dry. In light gray areas, seismic attributes are identical to the attributes around well 1. A re-entry from well 2 to one of these areas was proposed.