Seismic characterization of delta front sand bodies in Lower Magdalena Valley basin and their potentiality as reservoirs in Cienaga de Oro Formation, Colombia.

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Introduction

The Lower Magdalena Basin is located in the northwest of Colombia where oblique subduction along the Romeral fault system has produced transpressional and transtensional deformation since late Cretaceous to present day. The Lower Magdalena Basin is limited to the northeast by the Bucaramanga - Santa Marta fault system; to the south by the Central Cordillera and to the west by the Romeral fault system. This basin is subdivided by three structural elements that have controlled sedimentation since Eocene to late Miocene. These structural elements are: The Plato sub-basin to the north, the Cicuco Arch in the central part, and the San Jorge sub-basin to the south. Within the sequence, Cienaga de Oro Formation is subdivided in Upper and Lower, where the Upper corresponds to transitional delta facies and the lower to delta front sandstone deposits, the objective of this study. Delta front deposits are from transitional environment deposits and are formed by high volumes of sediments that have been transported from their original location due to hyperpycnal flow. Although the bulk of the material in delta front deposits are sand and silt blocks that could represent potential reservoir, having good reservoir quality and being surrounded by shale material of distal delta facies. The objective of this study is to highlight these sandstone blocks within the Lower Cienaga de Oro formation using seismic attributes and estimate the amount of hydrocarbon present in one of those blocks.

Geological Background

The Lower Magdalena Basin is limited to the northeast by the Bucaramanga - Santa Marta fault system; to the south by the Central Cordillera and to the west by the Romeral fault system. This basin is subdivided by three structural elements that have controlled sedimentation since Eocene to late Miocene. These structural elements are: The Plato sub-basin to the north, the Cicuco Arch in the central part, and the San Jorge sub-basin to the south (**Figure 1 and 2**).

Problem to Solve.

The sand deposits are not properly imaged in conventional seismic displays and color scales. For this reason is not very clear to locate and map the possible reservoir bodies, thus the application of seismic attributes in an option for getting a better imaging and improve the seismic resolution of the delta front sandstone bodies.

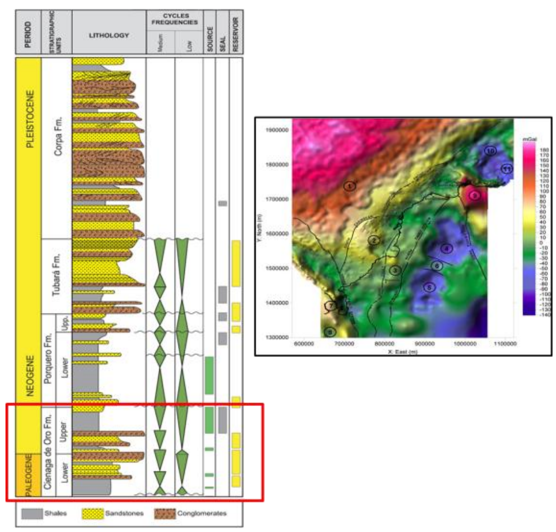

Figure 1. General stratigraphic column of the Lower Magdalena Valley Basin, Colombia. The Tertiary reservoir sequences in the basin are the Cienaga de Oro formation and the Porquero Formation. Red rectangle indicates Cienaga de Oro formation, objective of this study. Some wells have tested accumulation in delta front facies. Image at the right corresponds to the Bouger Anomaly gravimetric map. The Lower Magdalena Valley basin is divided in San Jorge basin (5), and Plato sub basin (4) divided by the Cicuco high (6). Source, ANH, 2007.

DOI http://dx.doi.org/10.1190/segam2012-1493.1

Data Quality

In general the quality of the data is good, with good signal to noise ratio that allows the basement to be recognized. The interpretation of top and bottom of Cienaga de Oro Formation is limited due to the bed tuning. Although acquisition footprints are not clear, some remaining is present in the survey volumes. The orientations of the footprints are N-S and E-W. Lateral continuity of seismic horizons is limited due to the depositional delta front system (**Figure 4**).

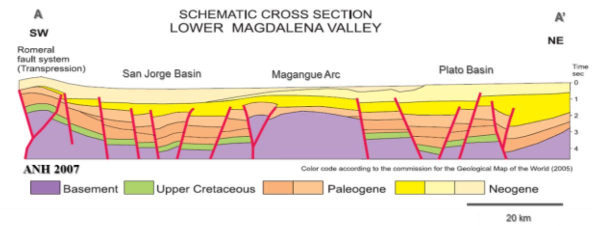

Figure 2. Schematic structural section illustrating the tectonic deformation of the Lower Magdalena Valley basin. Normal faulting is affecting the tertiary formations that are proved reservoirs in the Basin (ANH, 2007).

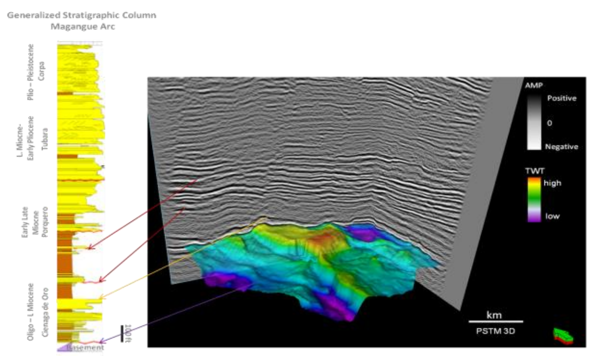

Figure 3. Stratigraphic column of the Magangue arc, which is a basement paleo high. The column formation is schematically tied with the seismic amplitude inline horizons.

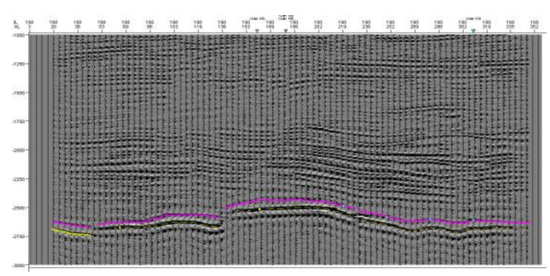

Figure 4. Stratigraphic interpretation in an inline direction of the lower Cienaga de Oro formation.

Note on **Figure 4**, that the continuity of the seismic horizons is not evident. The most continuous reflector has been identified as crystalline basement.

The interpretation of the magenta horizon, the Lower Cienaga de Oro Formation, was made based on the peak response guided by the wiggle display.

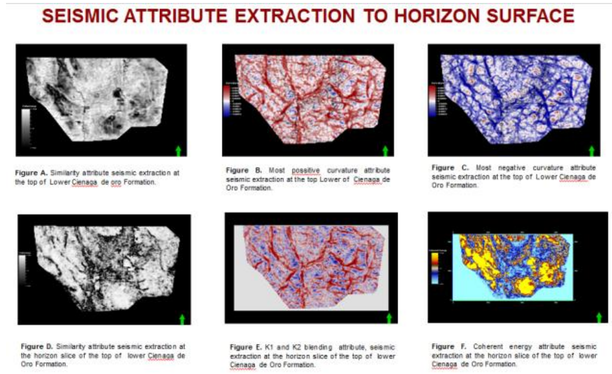

Figure 5. Multiple seismic attribute extraction to the horizon surface of Cienaga de oro Formation top.

Seismic Attribute Characterization of Sandstone Blocks In Delta Front Deposits.

Identification of sandstone blocks within the Delta front Deposit. Sandstone blocks within the deltaic system are characterized by high coherence, high RMS Amplitude and their orientation are toward Northwest.

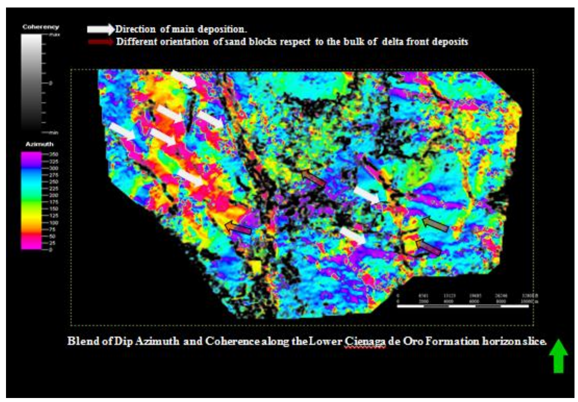

Figure 6. Dip azimuth and Coherence blend of the Lower Cienaga de Oro formation horizon slice. White narrows indicate the NW-SE direction of depositation of the delta front sandstone facies.

In addition to dip magnitude, we computed the dip azimuth (**Figure 6**), which is perpendicular to the strike of a dipping reflector. In this case we see that the reflectors on the eastern edge are dipping to the NW (colored magenta) while those on the western side are dipping SE (colored green). The strike-slip faults seen in the previous slide have a southernly apparent dip (colored blue).

DOI http://dx.doi.org/10.1190/segam2012-1493.1

The RMS Amplitude and spectral decomposition extracted along the flattened top of Lower Cienaga de Oro formation and horizon slices above and below, allowed to identify the sandstone deposits that may correspond to potential reservoirs (**Figure 7 and 10**). The vertical variation in terms of shape and thickness in the sand blocks can be observed by applying the spectral decomposition and RMS amplitude. The sandstone bodies are extended from the bottom part of the Lower Cienaga de Oro formation towards the top. The seismic attribute response of sandstone blocks within the delta front deposits are: High Coherent, High RMS Amplitude and frequency are some of the seismic characteristics of these sandstone bodies (**Figure 8 and 9**).

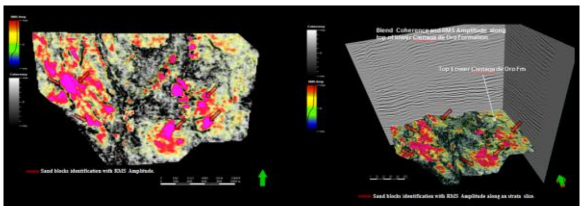

Figure 7. Sand blocks identification with RMS Amplitude, highlighted on magenta color and with red narrows.

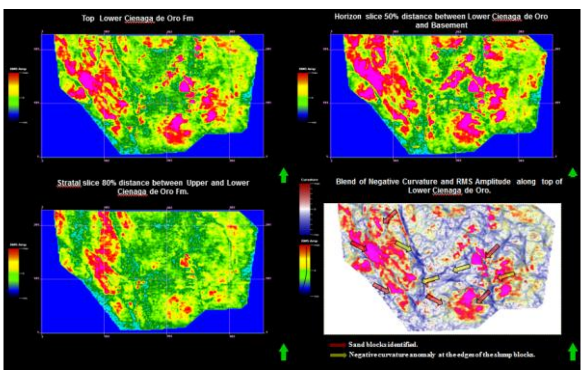

Figure 8. RMS amplitude and most negative curvature blending for Lowe and upper Cienaga de Oro Formation.

Spectral decomposition and the convolutional model.

Typically, we assume that the multiple-free reflectivity spectrum has very little structure (is very common to display a white spectrum). Next, we calculated the Fourier spectrum of the entire (unwindowed) trace. Finally, we explicitly flatten its spectrum, which, under the assumption of white additive noise, will flatten the spectrum of the source wavelet. Similar assumptions are made in the deconvolution algorithms routinely used in seismic processing (After Partyka et al., 1999). Short-window spectral decomposition and the convolutional model was applied, Although was necessary to assume that the reflectivity has a more or less white spectrum, any short-windowed realization of this white distribution had only a few discrete reflection spikes and thus invariably will have a colored spectrum. The data was processed with OU AASPI software to provide a band-limited white source spectrum and assume we have white noise, the colored spectrum of the windowed seismic data will be a band-limited representation of the colored spectrum of the reflectivity within the window (After Partyka et al.,1999). These results are in **Figure 9 and Figure 10.**

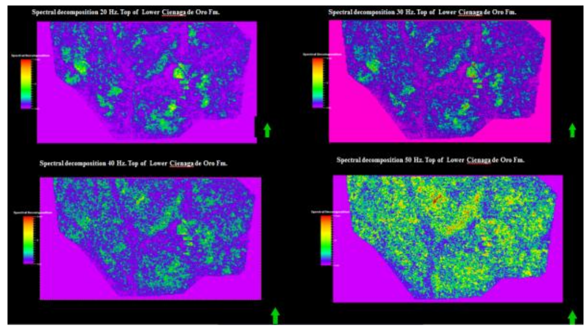

Figure 9. Spectral decomposition at (a) 20Hz (Upper left image); (b) 30 Hz (upper right image); (c) 40 Hz (lower left image); (d) 50 Hz (lower right image).

Three spectral components, increasing in frequency from 20 Hz to 50 Hz with the highest spectral amplitude plotted in light green. Each spectral component responds uniquely to variations in reservoir thickness. The thickest part of the channel is seen in Figure 9 b(a to d), thicker parts of the delta front sandstone bodies appear in the faulted areas. The spectral components, increasing in frequency from (a) to (d), with the highest spectral amplitude plotted in yellow. Each spectral component responds uniquely to variations in reservoir thickness. The thickest part of the channel is seen in (a), thinner parts of the channel appear in (b), and the thinnest parts, including the flanks of the channel, appear in (c and d) (**Figure 9**).

The spectral components look ‘better’ than time-thickness maps and amplitude slices, part of the reason for the better quality images is geological, is possible that little differential compaction took place. But the other part of the better quality image is statistical. We are simply using many more data points in the volumetric attributes than the two samples used in the formation thickness calculation. Steeply dipping backscattered ground roll will ‘stack out’ over the analysis window. We also need to reason that part of the reason for the improved

DOI http://dx.doi.org/10.1190/segam2012-1493.1

images with spectral decomposition is interpretational. We scanned through dozens of constant frequency images and chosen those images that liked best. The choice of the good images often has to do with details of velocity and thickness, parameters that are unknown before the interpretation begins.

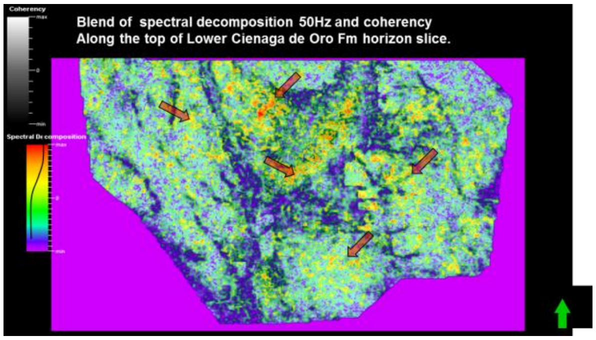

Figure 10. Blend of spectral decomposition 50Hz and coherency Along the top of Lower Cienaga de Oro Formation horizon slice. Sandstone bodies highlighted with red narrows.

Conclusions

The Deltaic deposits involve sandstone, shale and siltstone strata that are arranged depending upon proximal or distal facies. The data set provided for this study involves a delta front deposit, the Cienaga de Oro formation, Lower member. This formation is a proved gas reservoir in the Lower Magdalena Valley basin, Colombia. The importance of this assessment, is that the sand rich deposits located down dip in a transitional depositional environment setting can be recognized, although the apparently distribution of material and the directions of deposition can be inferred. The sandstone bodies within delta front deposits are potential reservoirs that can compromise important resources. By using the seismic attributes it is possible to delineate and locate those sandstone blocks and also a specific seismic expression can be recognized; high RMS Amplitude and spectral decomposition of high frequencies, high coherent and positive curvature anomalies are some of the responses obtained. Curvature anomalies are produced by the differential compaction between the sandstone blocks and the surrounding shale and siltstone deposits, producing a negative curvature at the edges of the blocks and a positive on top of those. The structural settings of this area of the basin was recognized by applying most positive, most negative curvature and coherency attributes; these structural settings are normal basement influenced faulting.

Acknowledgments

The authors would like to express special thanks to Dr Roger Slatt, Oswaldo Davogustto and Andrea Cadena for their technical support. To Ecopetrol S.A. for the data set. To Schlumberger company for the software license.

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DOI http://dx.doi.org/10.1190/segam2012-1493.1

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DOI http://dx.doi.org/10.1190/segam2012-1493.1