A seismic characterization of a non conventional reservoir using geometric and geomechanical attributes

Joaquín Cardoso*, Eduardo Trinchero* and Luis Vernengo*, Pan American Energy LLC

Summary

In the event that geoscientists are challenged to seismically characterize some reservoirs, in which their uniformity makes it difficult to identify the seismic facies and, especially, when conventional seismic attributes clearly do not solve the problem, geometric attributes provide a new perspective from a different viewpoint.

This often gives greater geological sense to the seismostratigraphic interpretation of these reservoirs since new features can be identified in relation to both the structural architecture and the stratigraphic aspects of the characterization.

Classic attributes provide a satisfactory solution, especially in the seismic characterization of conventional reservoirs such as sandstones, but this is not so evident in shales, tight sands or in presence of more compact and uniform reservoirs, which, however, are currently incorporating an amount of reserves that was unthinkable a few decades ago and whose development seemed almost impossible.

This paper describes the application of geometric and geomechanical attributes and its interrelation, in an area covered with 3D seismic and characterized by the existence of important geological sequences traditionally classified as source rock. The steps followed included the proper condition of seismic data and a coherent and systematic working methodology that contributed to the seismic-geometric characterization of the potential reservoirs and displayed a more encouraging outlook for the discovery of commercially exploitable hydrocarbons and for the development of these unconventional reservoirs.

Introduction

For seismic interpreters, coherence has been a tool that offers a robust support to identify and link the structural elements present in the 3D seismic data, especially when there are complex arrangements of faults that overlap and interact.

In the seismic response of these events, even using complex algorithms available today when processing data, such as pre stack depth migration, which allows increased confidence in the interpretation of seismic data, uncertainties persist in many cases and can produce important errors at the moment of defining the static model of the reservoir under study.

Not only are the architectural seismic elements of the structural behavior the ones linked to a reliable static model, but also the variations of the intrinsic geometry of the data of the full extent of the analyzed reservoir, which can be understood as a continuous succession of geometric elements linked to each other and which can be associated in families or groups that follow a similar pattern. The seismic character of the structural and stratigraphic discontinuities almost always involves lateral variations in the waveform, dip, edge and amplitude.

In the study area, the persistence of these patterns, detected by various processes and calculations of geometric attributes, and then the selection and identification of those which most strongly characterized the studied region, allowed the assembly of areas that may have been rationally subject to varying degrees of tectonic stress.

On the other hand the seismic response to the geomechanical properties of these reservoirs also shows the distribution of events that we can associate with depositional facies families. With the Elastic Inversion we can get the P and S waves impedance cubes and density, as well as the geomechanical seismic attributes, such as the Lame Constants (Lambda and Mu, usually used as Lambda*Rho and Mu*Rho), the Poisson Coefficient (Sigma), the Young Modulus (E) and the Transverse Elasticity Modulus (G) cubes.

Some of the geometric attributes have proved themselves to be powerful organizers of structural groups of seismic facies. The relationship between them and the geomechanical seismic attributes offers the possibility to visualize, interpret and in many cases magnify features that are very often subtle in isolation but seismically meaningful when interrelated wisely. In this context the generation of cross plots and co-visualizations are the key to reveal the seismic characterization of these reservoirs and the clue to have reliable indicators for sweet spot identification.

These features have required the development of a methodology for systematic and orderly work that eventually led to recognize items associated with seismic morphologies that are not often evident in the classic analysis of the amplitudes.

Not only do these features contribute to the construction of a static model of the reservoir, but can also contribute to the identification of the options to be considered in the design of future wells and, for example, in the design of hydraulic fractures necessary in this type of unconventional reservoirs.

Methodology

In the study area, we performed the basic interpretation firstly, through the processing and correlation with synthetic seismograms and seismic data, and the subsequent identification of the horizons of interest related to data from the wells, which then formed the basis that became the support and initiation of a sequence of work that had the cadence of identification, propagation, resolution, and correlation.

The analysis of the seismic data, its geological plausibility and the harmonious relationship between the robust seismic data and the geological information, provided the necessary framework in the first stage of the analysis.

Once the reflectors of interest were identified and interpreted, the sequences involved were tuned in detail and once their seismic time expression was known, as many sub-volumes as the analysis window allowed were generated, each of them containing at least one sample per trace in the resulting micro-cube.

In this way, we had the possibility to analyze the seismic response behavior in the generated sub-volumes in greater focus. This methodology was repeated in three sequences of interest known in the study as top, middle and basal sequence.

At this point, the criterion of the interpreter and its interaction with the multidisciplinary team, becomes important to carry out the dismantling of the integrated data set and then putting them together after recognizing the answers to the processes the information has been submitted. The consistency of the recognized events in successive seismic horizons and adjacent windows increases the likelihood of their plausibility. In order to show the intrinsic characteristics of the available seismic data, we calculated a series of geometric seismic attributes, especially the cubes of curvature, among which the maximum, minimum, most positive, most negative, mean and Gaussian curvature (Fig. 1).

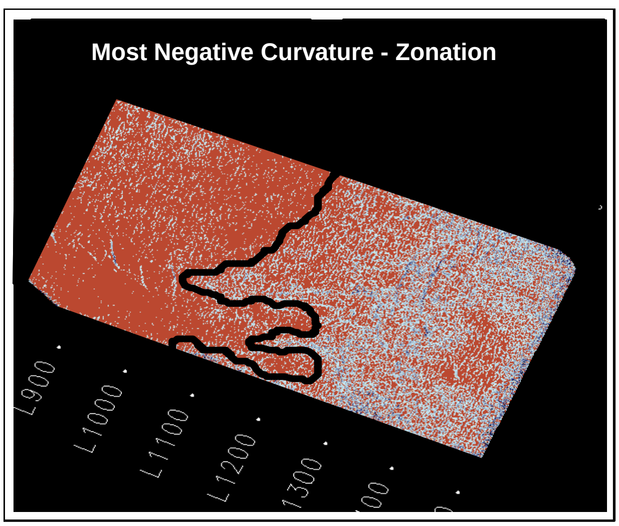


Figure 1 - Most Negative Curvature - Zonation

Among these attributes, the most negative and the mean curvature were finally selected as the best approach to the problem of this unconventional reservoir. Then horizontal slices were generated in the windows that had divided the sequences of study and were extracted from the calculated cubes, obtaining the horizontal slices of each type of curvature.

Previously, available seismic data from a pre stack time migrated cube was filtered in order to prepare the data before performing the calculation of the mentioned attributes. This step was very important because the curvature, which can be thought of as the second derivative of any surface, is very susceptible to noise anomalies on analyzed surface.

The filters that can be used are of varying design and should always be constructed to achieve a compromise somewhere among removing noise effectively without reducing the resolution, masking the details or changing the seismic character.

In the case of the data used in this study, eight different filters were designed. The ones which best preserved the signal / noise ratio were a triangular filter trace mix of 7 traces, with more weight in the central trace and a dip scan stack filter, with a horizontal window of 7 traces; the latter made in the direction of the inlines and rescaling the information to 8-bit integer, to avoid the generation of unwanted seismic artifacts.

It should be mentioned that in order to prove that, as it is the case with amplitudes, in the geometric attributes of curvature, the seismic resolution and the capacity to identify bigger or smaller details are also affected basically by the frequency contents of the seismic data, a short-wavelength cube (high frequency content) and a long wavelength one (low frequency content) from the 3D data set were generated.

An Ormsby filter 35/40-75/90 Hz was designed and applied to the data to generate the short-wavelength cube and another one 8/10-40/45 Hz to generate the long-wave one.

The result of the calculations of the geometric attributes of curvature on the horizon slices extracted from the cubes showed a similar variation and response to the ones of the amplitudes.

In addition to conventional instant attributes, as mentioned above, the geometric attributes, mean and most negative curvature were calculated, in each of the windows of the sub-volumes that were divided in each sequence of interest and in the cubes filtered with the above features. In particular for the intermediate sequence, some of the classic attributes showed zoning that persisted in the section observed in the results of the Reflection Strength, Perigram, Quadrature and Perigram by cosine of the phase.

Through the interpretation of seismic data, together with the coherence cube, it was easy to recognize a sector heavily affected by faults, many of them of importance, but also we were able to recognize that they had settled in well-defined regions of the study area. It was noted that much of it was not affected, from the standpoint of coherence, or from the same amplitudes, by the events described. In this situation it was easy to recognize zoning or clustering in families, basically two, in the classic attributes, which seemed to fit the data on horizontal slices.

When analyzing the results of the extraction of the horizontal slices from the cube, calculated attributes and especially geometric attributes (most negative and mean curvature), it was remarkable and it became immediately evident that this zoning persisted and even more, to given levels of the sub-volumes, this expression was remarkable.

By analyzing in detail these expressions, especially those related to the curvature most negative, the definition of two patterns, of two groups in different families was found, in the upper sequence and more clearly in the intermediate sequence.

The geological analysis of the context led us to link these two characters to areas with different degrees of tectonic attitude, one in which natural fractures appeared and another that also showed the effect of faulting overprint and a manifestation of stress that impacted areas along the fault trend.

At this point, we have the availability of a tool that did not only accompany the results of the views provided by the classical attributes, but clearly framed sub regions whose characteristics facilitated decisions when planning a drilling or designing a specific well.

If we compare the results obtained from the extraction of the horizontal slices of the coherence cube with the extracted cube most negative curvature attribute, for example, it is easy to visualize the strength in the identification of faults of different orders the geometric attribute of curvature shows, and so there are two important aspects here: a real interest in supporting the association of events of similar seismic response and associated areas and a robust support when associating and linking schemes of complex faulting or detecting subtle faults. These features do not only contribute to seismic reservoir characterization aspects and configuration of the static model, but also, and more specifically, in the case of unconventional reservoir, to the design and determination of the fracture parameters for the reservoir stimulation and production of the well.

In addition, it is essential to analyze the geomechanical seismic attributes, their response to these specific reservoirs and to visualize them together with the geometric attributes in order to understand the zonation obtained from the different responses. When analyzing different attributes and their relationship, we can identify and enhance the heterogeneous nature of these reservoirs. The geomechanical seismic attributes can identify sweet spots in shale and tight reservoirs, highlighting brittle and ductile zones. Mapping the brittle zones is a very important task for the seismic reservoir characterization.

The Elastic Inversion is the pathway to calculate the geomechanical seismic attributes. Lamé Constants (Lambda and Mu), Poisson Coefficients (Sigma), Young´s Modulus (E) and Transverse Elasticity Modulus (G), have been processed from P and S Impedances. In order to represent higher brittle zones, the co-visualization of the geometric attribute curvature and the geomechanical seismic attributes become a powerful brittleness indicator in shale and tight reservoirs (Fig. 2).

Furthermore, the generation of cross plots that relate the geometric and geomechanical seismic attributes allows us to focus and solve the problem, reinforcing our working hypothesis through the consistency analysis of the different attribute responses. The extraction of geobodies from these attributes can be incorporated into the static modeling of the reservoir. Also most important, the zones identified as brittle and ductile are crucial for decision making at the hydraulic fracturing and stimulation stages.

In the analysis of the studied sequences in the area we have mentioned the characteristics of the so called intermediate sequence. In the case of the basal sequence, a similar methodological approach to the one above was made, also defining the seismic time development of the sequence under study and dividing it into equal windows, which gave rise to sub volumes associated with them.

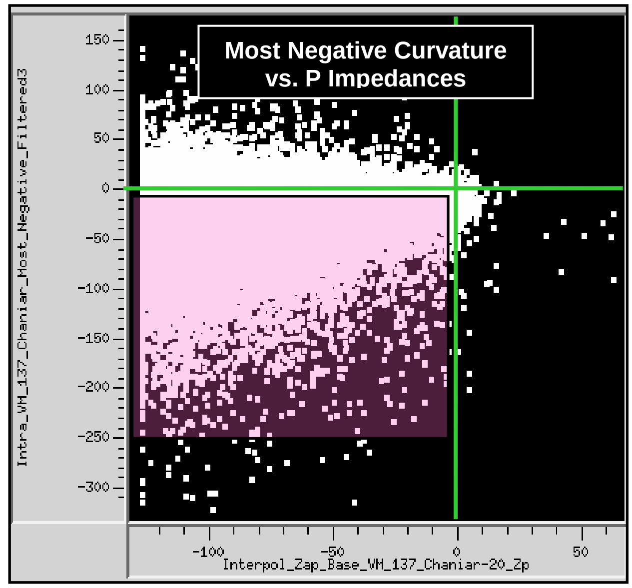


Figure 2 - Cross plot Most Negative Curvature vs. P Impedances. Most negative values interrelated with low P Impedances, optimal association in this type of reservoirs.

Horizontal slices of conventional geometric attributes were extracted from the volumes of this basal sequence. The configuration and arrangement presented in the results in horizontal slices of the attributes of curvature, showed the persistence of the zoning observed for the intermediate and higher sequence, though not with the same intensity and seismic character. But the aspect of the guidelines of the faults of a different order did show clearly and became more relevant when identifying and defining the structural scheme than the information provided by the coherence cube.

Observation and analysis of cross plots in the range of interest, the values of coherence and geometric attributes (mainly most negative curvature), supported the orientation of the studies and highlighting shaded boxes identify the relationship between clusters groups.

This region agrees, from the point of view of most negative curvature attribute values, with the largest cluster events, which indicates for example, that where coherence can not provide help in the identification of unique events, the geometric curvature attribute can, and this situation has been clearly substantiated, particularly in the central zone of the study area. Processing adequate cross plots is a powerful tool to analyze and support the main results of this job.

At this point, moreover, by observing the horizontal slice of the bottom base of this sequence, the section of certain consistent morphologies in both their longitudinal development and repetition becomes evident.

These shapes have a defined direction, which can not be associated to events related to possible acquisition footprints, since this problem should have a different orientation if we took into account the azimuth of the seismic line. In addition, they are not processing artifacts and are only identifiable by the attribute of curvature. This same observation was repeated in the horizontal slices 4 and 8 milliseconds above the base of the basal sequence, as well as 4, 8 and 12 milliseconds on the basis of the formation under study, but within the formation underlying it.

This morphology detected with the result of curvature attribute (most negative) was observed in the last terms of the basal sequence and the first terms of the underlying formation we had been studying.

Considering the characteristics of the sedimentary appearance of the upper terms of this underlying formation through the neighboring wells and geological studies of the area, we are in the presence of eolic events, which may associate these morphologies with dunes (?) (Fig. 3).

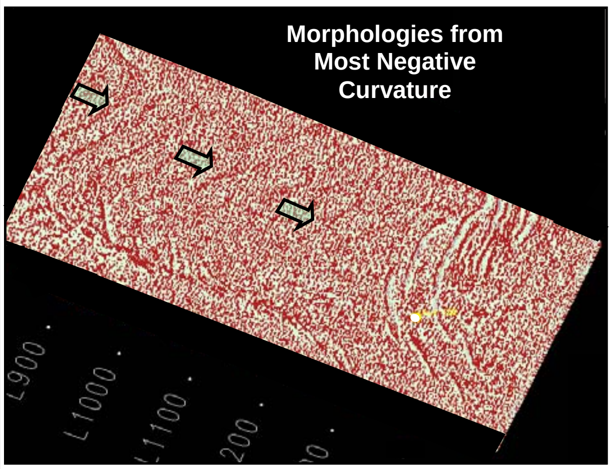


Figure 3 - Particular morphologies shapes in the response of most negative curvature.

However, the effect that these morphologies have had on the last terms of the overlying formation characteristics of unconventional reservoirs may have been partly to control the formation sedimentation, which might have copied in part these forms and followed the available surface morphology. This could explain the presence of these events in the first terms of the lower or basal sequence.

It should be noted that in the horizontal slices taken from the cube of seismic amplitudes, these morphologies are not observed. They do not have a visible impact on the amplitudes, conspicuously evident only in the horizontal slices of the cube drawn using geometric most negative curvature attribute. With this consideration and given the result and the persistence of these features, this is an additional element to those mentioned above for the middle and upper sequence and for the location of future surveys, it could add interest in searching the areas between the morphologically viewed lines where a greater thickness of the basal sequence of interest (bottom) might have been deposited (Fig. 4 and 5).

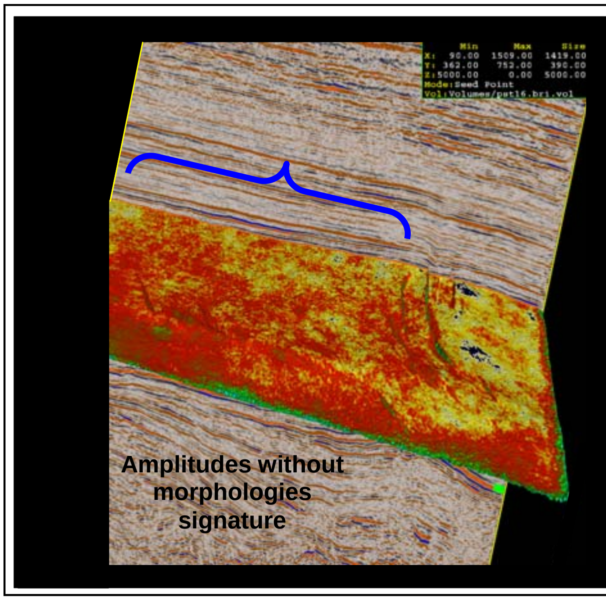
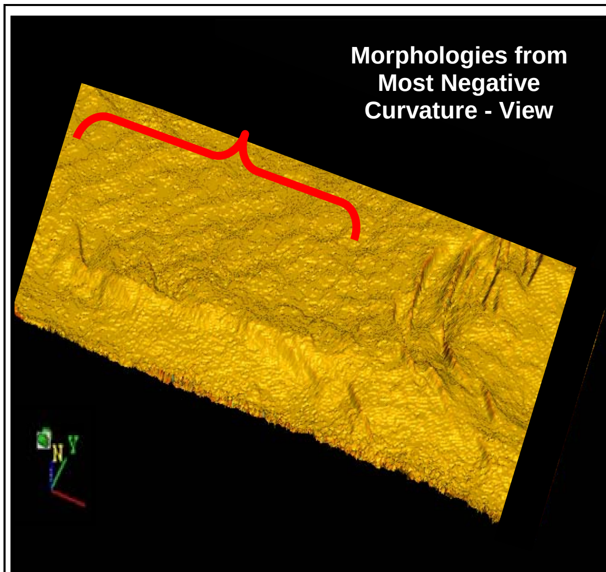


Figure 4 - 3D visualization of amplitudes cube and horizon slice. No evidences of particular morphologies.



Figures 5 - 3D view from most negative curvature shows more geometric detailed shapes.

Conclusions

We have presented the detailed analysis for seismic characterization of an unconventional reservoir through the process and the detailed observation of the geometric attributes of curvature and geomechanical attributes.

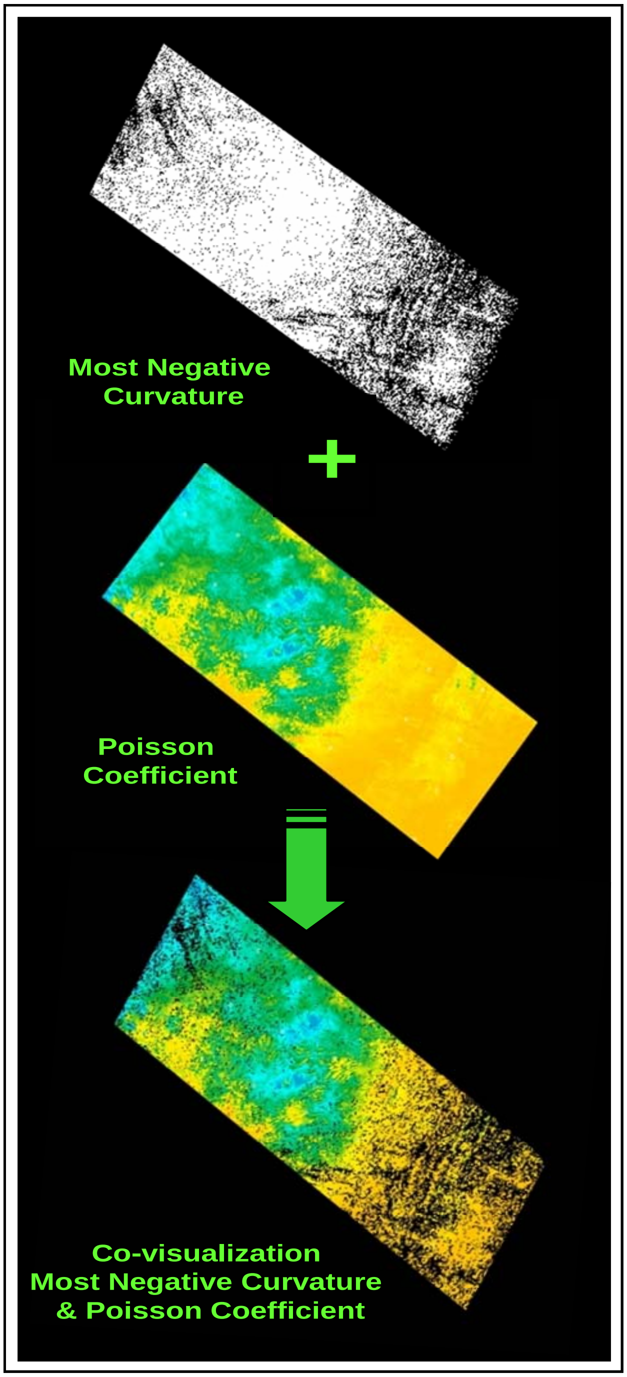


Figure 6 - Co-visualization of geometric and geomechanical attributes is a powerfull tool to identify sweet spots zones in non conventional reservoirs.

This seismic-geometric and seismic-geomechanical characterization has shown the benefits of considering the above attributes versus the classic attributes that although guiding the interpretation, did not give either the necessary detail to define the grouping areas of similar response or the definition of structural scheme of detail. This can be a robust complement to coherence data.

In addition, as was said before, the recognition of brittleness and ductile zones co-visualized with the most negative curvature, solidify the analysis and the identification of seismic geobodies for incorporate into the reservoir static modeling (Fig. 6).

The identification of the appropriate windows and associated sub-volumes, using the calculation of the above attributes and their subsequent interpretation, made it possible to draw a sequence of analysis that was effective and comfortable at the time of the final performances. Identification of morphologies, also clearly visible in one of the sequences analyzed (lower sequence), was able to open up a fuller picture at the time of developing these unconventional reservoirs, which will help when deciding future locations of wells and will also give a context for designing hydraulic fracturing treatments.

The exploration and development of oil (conventional) in low permeability reservoirs (unconventional) is a big challenge and often leads at each stage of decisions to the implementation of new technologies, designing new and specific methods of analysis and observing the different processes involved through the concepts of lateral thinking.

This approach has certainly increased the probability of success and encourages the development of applications in multidisciplinary teams.

Acknowledgments

We would like to thank to Pan American Energy LLC for the permission to show the examples in this presentation. Special thanks to Mrs. Esther Maseda, Mr. Roberto Werner and Mr. Carlos Seguí.

References

Al-Dossary, S., and K.J. Marfurt, 2006, Multispectral estimates of reflector curvature and rotation. Geophysics: 71, pp.41-51.

Al-Dossary, S., and K.J. Marfurt, 2007, Lineament preserving filtering. Geophysics: 72, N° 1, pp.1-8.

Alireza, S., Tatham, R., Stoffa, P. and Kyle, T., 2009. Comprehensive petro-elastic modeling aimed at quantitative seismic reservoir characterization and monitoring, Jackson School of Geosciences, the University of Texas at Austin, pp.1-4

Bergbauer, S. T. Mukerji, and P. Hennings, 2003, Improving curvature analyses of deformed horizons using scale-dependent filtering techniques, AAPG Bulletin, 87, pp.1255-1272.

Chopra, S., 2009, Interpreting fractures through 3D seismic discontinuity attributes and their visualization: CSEG Recorder, October 2009, pp.5-14.

Chopra S., and Marfurt K.J., 2006, Curvature attribute applications to 3D surface seismic data, CSEG Recorder, September 2006, pp.44-56.

Chopra S., and Marfurt K.J., 2007, Volumetric Curvature-attribute applications for detection of fracture lineaments and their calibration, Denver Geophysical Society, The Record, June 2007, pp.23-28.

Chopra S., and Marfurt K.J., 2007b, Volumetric curvature attributes adding value to 3D seismic data interpretation, The Leading Edge, 26, pp.856-867.

Chopra S., and Marfurt K.J., 2008, Emerging and future trends in seismic attributes, The Leading Edge, March 2008, pp.298-318.

Chopra S., and Marfurt K.J., 2008, Gleaning meaningful information from seismic attributes, First Break, September 2008, pp.43-53.

Chopra S., and Marfurt K.J., 2009, Curvature attributes aid interpretation, The American Oil & Gas Reporter, July 2009, pp.138-145.

Chopra S., and Marfurt K.J., 2011, Curvature computations enhance exploration, The Geophysical Corner, AAPG Explorer, November 2011.

Chopra S., and Marfurt K.J., 2011, Euler curvature can be a calculated success, The Geophysical Corner, AAPG Explorer, December 2011.

Chopra S., and Marfurt K.J., 2011, Getting more from frequency-enhanced datas, The Geophysical Corner, AAPG Explorer, March 2011.

Chopra S., and Marfurt K.J., 2011, Interesting pursuits in seismic curvature attribute analysis, CSEG Recorder, April 2011, 40-50.

Goodway, W., 2001, AVO and lame constants for rocks Parameterization and Fluid Detection, Recorder, 39-60.

Klein, P., Richard, L., and James, H., 2008, 3D curvature attributes: a new approach for seismic interpretation, First Break, 26, April 2008, pp.105-111.

Rijks, E.J.H., and Jauffred, J.E.E.M., 1991, Attribute extraction: An important application in any 3D seismic interpretation: The Leading Edge, 10, N° 9, pp.11-19.

Roberts, A., 2001, Curvature attributes and their application to 3D interpreted horizons, First Break, 19, pp.85-99.

Tonn, R., and Pusic, D., 2004, Case Study: Seismic Reservoir Characterization of a Deep Water Prospect Offshore Newfoundland, EnCana Corporation, CSEG National Convention, Calgary, pp.1-3.