Seismic Imaging Over Foothills - Challenges and Solutions

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Introduction

Subsurface imaging in over thrust terrains poses a major challenge to exploration operations today. The abrupt topographic and velocity variations impact the seismic data quality, resulting in poor subsurface imaging, making the structural and stratigraphic interpretation a major challenge for the interpreters. It is also well known that abrupt topographic changes, near surface anomalies, velocity variations and complex ray paths due to tectonic complexity are key factors that affect the quality of seismic data. Reliable delineation of structural geometry may be difficult (Hector Alfonso MSc thesis 2000 University of Houston).

The scope of this paper is to present examples and results of seismic imaging obtained in the foothills of Colombia during the latest years using new technologies, and share Ecopetrol´s efforts to improve the subsurface image in complex foothills terrains, and the results obtained so far with the latest technologies applied.

Improvements have been achieved using noise attenuation techniques, new seismic survey designs and innovative imaging methodologies thus reducing the geological risk and contributing to Ecopetrol´s exploration portfolio growth.

The Problem

What is the typical problem over the foothills?

The image in figure 1 was obtained along the foothills of the Colombian Eastern cordillera, where abrupt terrain conditions exist. It is evident that any interpretation in this type of data quality will be model driven rather than on actual signals identified from the image.

In figure 2, this interpretation depicts a combination of structural modelling and surface geology to try to recognize the potential prospectivity over a complex structural area. The challenge is to apply an appropriate technology in order to improve this kind of complex images.

The geology of these areas is represented by outcropping Lower Cretaceous rocks juxtaposed against a fault and outcropping Paleozoic rocks in the western part of the geological province. To the east, the geology transitions to an area of linear extensive, southward plunging anticlines and synclines with exposed Cretaceous rocks to the north and Oligocene-Miocene rocks to the south. Still further east, Miocene rocks outcrop in an area where some of the largest producing fields in the Piedemonte are found.

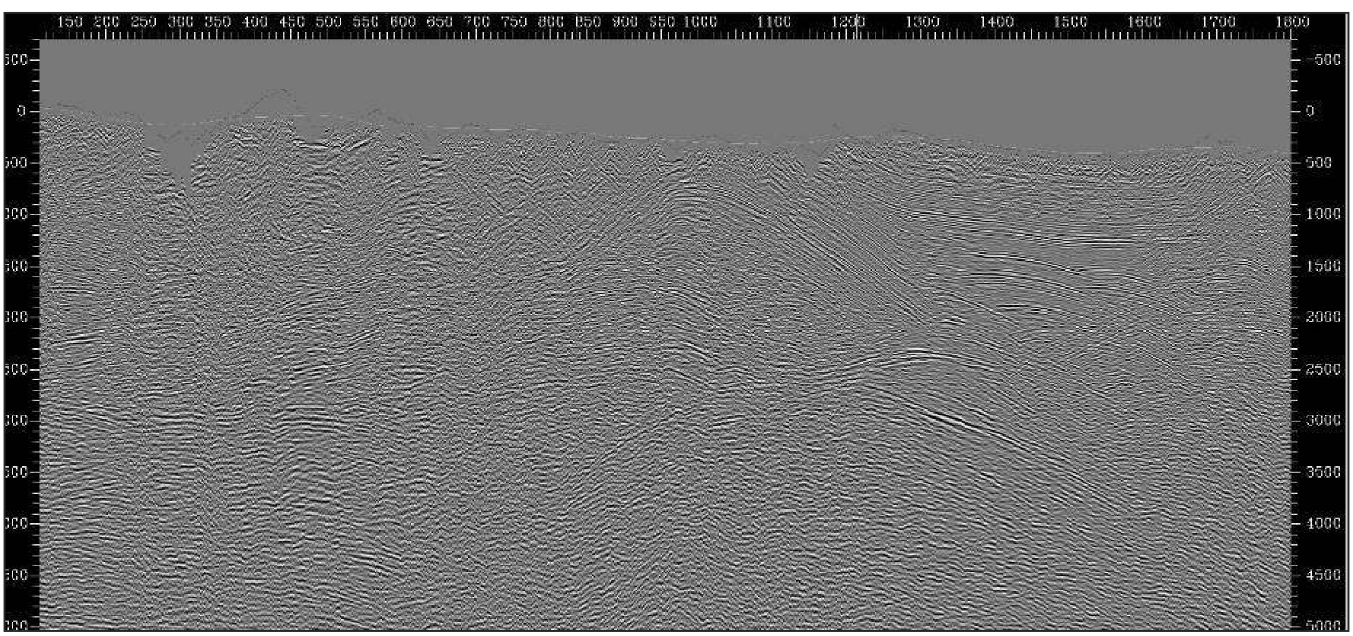


Fig. 1: Seismic line over the foothills of Colombia

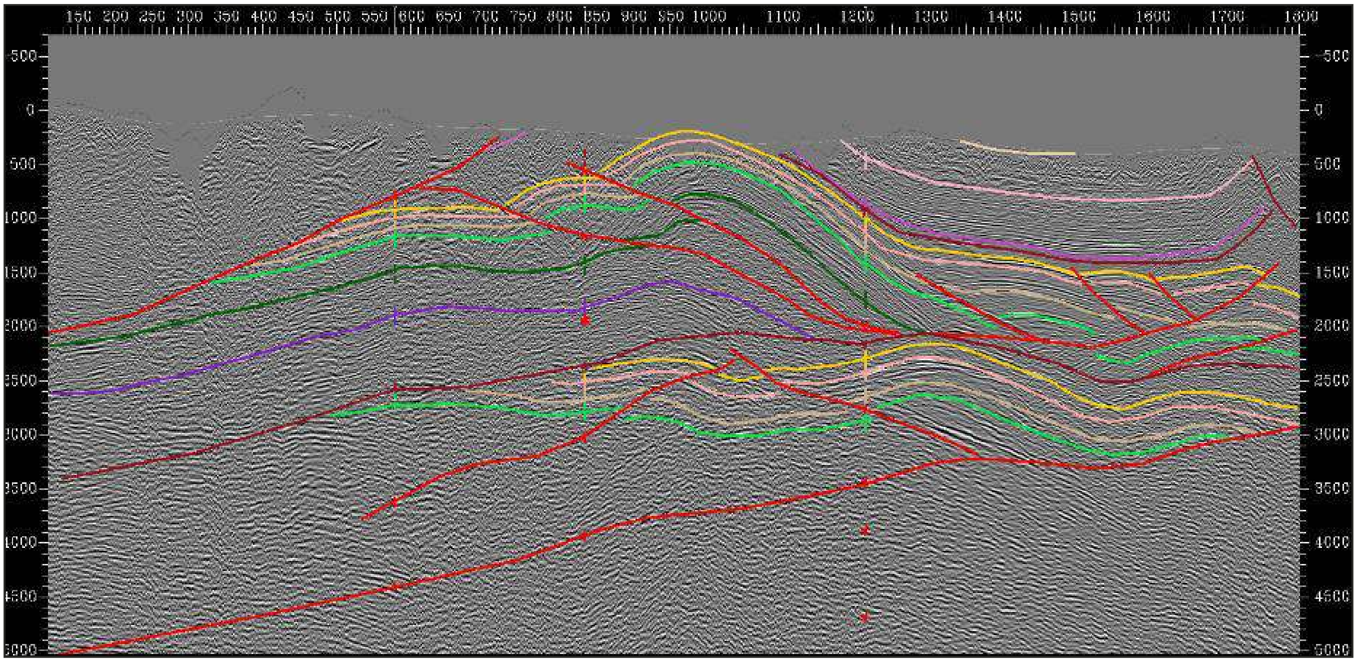


Fig. 2: Interpreted seismic line from foothills Colombia (from M. Cortez)

The section with the highest exploration prospectivity comes from stacked structures beneath the syncline and is limited by the Yopal and Cusiana Faults. Finally, the depths of the easternmost prospect are between 10,000 to 19,000 feet.

Imaging Techniques

CRS processing

One of the options that can currently be applied is CRS. The validity of this approach was tested in some of the complex lines. For reference on the details of this method, please see the following paper presented recently in Colombia: (http://www.hectoralfonso.com/papers/crs%20paper.pdf). The results were quite promising and the lateral continuity of reflections improve in great way.

The Common Reflection Surface method, in short CRS method, is a macro model independent imaging method in the time domain. Refining similar approaches by de Bazelaire and Gelchinski, it was developed by Peter Hubral and his group at the University of Karlsruhe.

An initial stack can be produced from automatic measurements of certain wave-field attributes. Manual picking of stacking velocities is on principle not required. Besides this workflow advantage, however, the CRS method incorporates as well a distinct quality increase with respect to the conventional Common-Midpoint (CMP) stacking technique. The CMP stacking hyperbolas assume reflections from an idealized subsurface with plane horizontal horizons. The CRS stacking surfaces, on the contrary, take into account arbitrary dips and curvatures of the subsurface horizons, and thus represent a much better approximation to the travel-time planes of the reflected wavefield. This implies both a better imaging of complicated subsurface structures, and an increased signal-to noise ratio of the stacked signal.

In figure 3 you can see the advantages in applying these techniques on complex lines.

Time Processing and Noise attenuation

Regarding the time processing the typical sequence is to focus on the statics solution, near surface issues, and on noise attenuation. Specifically, on noise attenuation another technology based on 4d sampling is used, with quite compelling results. See figure 4.

Velocity Model Building

One of the key aspects over the whole procedure is the velocity model building. In general time imaging methods do not depend on accurately modeling wave propagation but rather on approximately describing the travel time of seismic events. In that way we built a robust velocity model constrained by geological features doing a reality check every single time a PSDM or PSTM is produced.

One of the pitfalls in the process is to let the tomography drive the generation of the model without the natural constraints of geology.

With this approach, intervals velocities result is shown in figure 5.

From figure 5 cases a), b) and c) have the same order of magnitude regarding boundaries and actual values for interval velocities. Image from d) is clearly relying on tomography and not the structural model or even the outcropping rocks over the area.

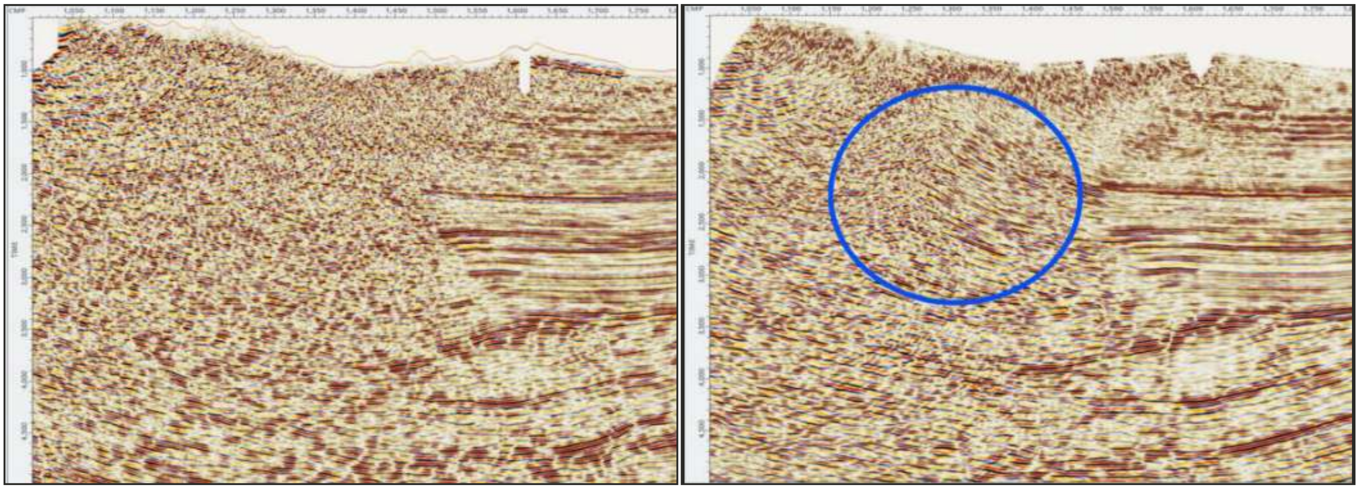


Fig. 3: Left legacy PSTM. Right PSTM after CRS processing

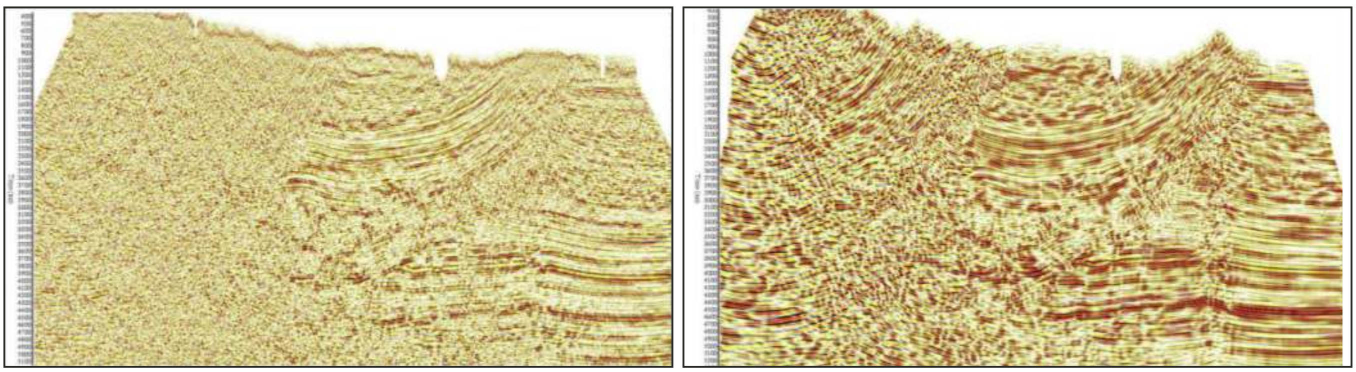


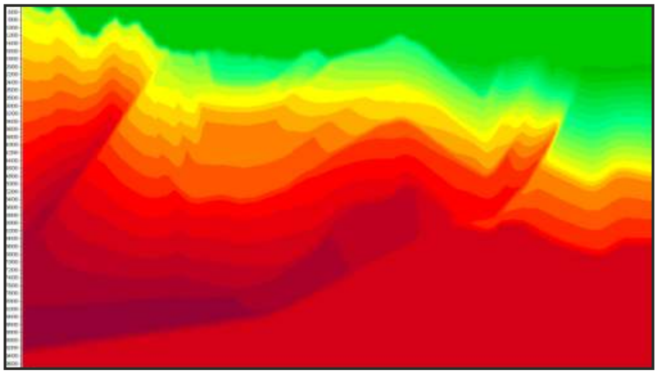
Fig. 4: Left legacy data PSTM - Right new time processing PSTM

The processing sequence is shown below:

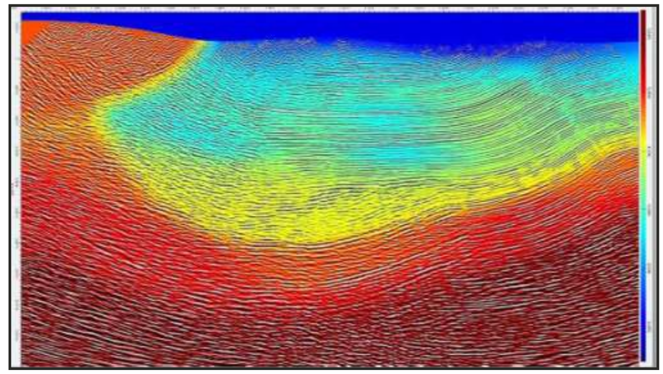
1. Reformat
2. Geometry
3. Gain recovery : 1.7 Time Power
4. Surface consistent scaling pass # 1 – shot and receiver, WINDOW: 330-5200 ms at 0 m offset, 2300-5500 at 5400 m offset
5. Coherent noise attenuation pass # 1 - WINDOW: 50-7000 ms at 0 m offset, 4500-7000 ms at 5400 m offset, FREQUENCY: 0-14 Hz. APPARENTVELOCITY: 630-1630 m/s, ITERATIONS:

. Surface consistent spiking deconvolution – 5 COMPONENT
• window: 330 – 5000 msec at 0 m offset and 2300–5400 msec at 5400 m offset
• Frequency domain (Hilbert Transform) , 4Hz. Smoothing = 128 msec time domain equivalent operator

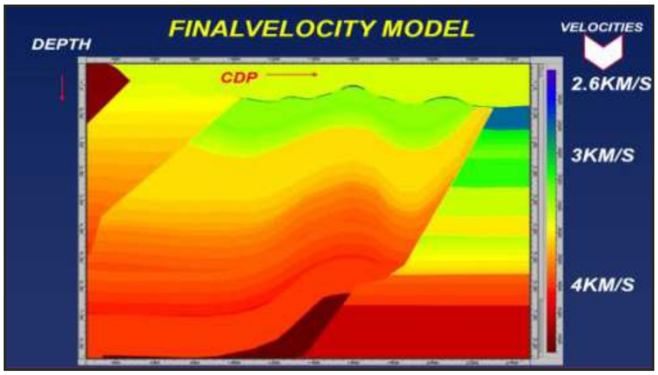
7. Surface consistent scaling pass # 2 – shot and receiver, WINDOW: 330-5200 ms at 0 m offset, 2300-5500 at 5400 m offset
8. Anomalous amplitude attenuation
10. Refraction statics computation – TOMO Solution, datum = 2000 m, VREP = 3000 m/s
11. Velocity analysis pass # 1- location at every 500 m, SEMBLANCE , GATHERS, STACKS
12. NMO, mute, stack
13. S.C. Residual Statics – first pass
14. Velocity analysis pass # 2- location at every 500 m, SEMBLANCE , GATHERS, STACKS
15. S.C. Residual Statics – second pass
16. NMO, mute, stack
17. Random Noise Attenuation – FX4D
18. S.C. Residual Statics – third pass
19. PSTM Velocity analysis – 2 passes
20. PSTM : Kirchhoff and W.E.
21. Signal enhancement
22. Filter / Scale



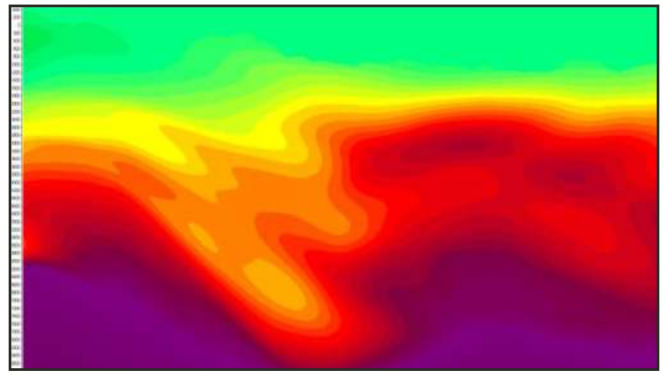
a)



b)



c)



d)

Fig 5: Pitfalls in building the velocity model. a) and b) 2 different approaches from different contractors 2018 c) Result from H alfonso MSc thesis 2000 d) another contractor 2018

Conclusions

By using different approaches regarding imaging technologies; noise attenuation and taking advantage of the CRS processing the improvements in the signal to noise ratio and over the quality of the seismic sections; will help in the interpretation and of course the identification of new prospects in the area.

Acknowledgements

I want to thank Ecopetrol for allowing to publish these results and sharing with the geophysical community. I want to thank also to all the processing companies involved; adding value to the seismic data all over these years.