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CRS SEISMIC PROCESSING OF A GEOLOGICAL COMPLEX AREA

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ABSTRACT

We applied the NMO and CRS (Common Reflector Surface) approaches to a complex geological area in order to compare their performances for obtaining enhanced images. Unlike NMO, CRS does not depend on a previous time velocity model and uses a hyperbolic equation to estimate 2D travel times through three parameters (Normal ray emergence angle, NIP and N wavefront curvatures). To obtain the image a solution provided by coherence analysis algorithm was used.

A low quality Colombian seismic line acquired in Middle Magdalena basin was used, where a foothill geological area is characterized by a thrusting fault. The CRS provided an enhanced image which allowed a new geological interpretation that is best constrained with other regional observations.

***Key words*:** Common Reflection Surface (CRS) stack, Zero-offset (ZO), Normal Moveout Correction (NMO), Common Mid Point (CMP)

RESUMEN

El propósito de esta investigación es comparar las técnicas de Superficie Común de Reflexión (CRS) y Normal Move Out (NMO) en su desempeño en zonas geológicamente complejas, procurando imágenes sísmicas de mejor calidad. A diferencia del NMO, el CRS no depende de un modelo previo de velocidad y usa una ecuación hiperbólica de tiempos de viaje 2D dependiente de tres parámetros (ángulo de emergencia del rayo normal, curvatura de la onda de punto de incidencia normal y curvatura de la onda normal). Para obtener la imagen se usó una solución provista por un algoritmo de análisis de coherencia.

Se usó una línea sísmica de baja calidad adquirida en la cuenca del Valle Medio del Magdalena - Colombia, en una zona de pie de monte caracterizada por una falla de cabalgamiento. El CRS suministró una imagen mejorada que permitió una nueva interpretación geológica que se ajusta mejora con otras observaciones regionales.

Palabras clave: superficie común de reflexión CRS, Zero-offset (ZO), corrección por sobre tiempo normal (NMO), punto medio (CMP)

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Introduction

The CRS method has been considered an attractive stacking method to provide improved zero offset sections (Trappe et al., 2001; Hertweck *et al*., 2007).

In Colombian a known example with the CRS applied to complex areas does not exist, although there is a reported paper with CRS applied to a mild topography and quiet tectonically zone with relevant results (Cárdenas and Montes, 2006). In complex tectonically areas seismic tests are hampered by several factors that often lead to low quality seismic images with ravel reflectors, due to poor signal/noise ratio or weak seismic signal focusing.

In order to compare NMO and CRS performances in complex zones, a low quality seismic line of the Middle Magdalena basin was used. The area includes a thrust fault in the foothill zone. Instead of stack velocities CRS used parameters picked automatically by a coherence analysis algorithm (Birgin *et al*., 1999).

As result, an enhanced CRS image allowed a new geological interpretation.

CRS method

The *CRS* stack is a theoretically well established method (Jager *et al.*, 2001; Mann *et al*., 1999; Tygel *et al*., 1997). It considers layers separated by curved reflectors whose reflection comes from a reflecting segment. A second order approximation of transmitted and reflected travelime rays in seismic system was developed (Bortfeld, 1989). A multicovering seismic data set is acquired over a set of homogeneous and isotropic layers, with arbitrary velocities separated by smooth interfaces.

The seismic system is defined by a zero offset ray, called Central ray, which incidences normally on the reflector.

In a second order approximation around central point (x_0) the travel time of the *SRG* ray is approximated by the hyperbolic function:

$$t^2(x,h)=\left[t_0+\frac{2\sin\beta}{v_0}(x-x_0)\right]^2+ \\ +\frac{2t_0\cos^2\beta}{v_0}[K_N(x-x_0)^2+K_{NIP}h^2] \quad (1)$$

According Figure 1, $x = (G + S)/2$ is the common midpoint, $h = (G – S)/2)$ is half offset, v_0 is the near surface velocity and β and t_0 are angle of emergence and travel time of the Central ray. K_{NIP} is the wavefront curvature of a hypothetical wave with the source located at point NIP K_N is the wavefront curvatures of an exploding reflector segment around point NIP.

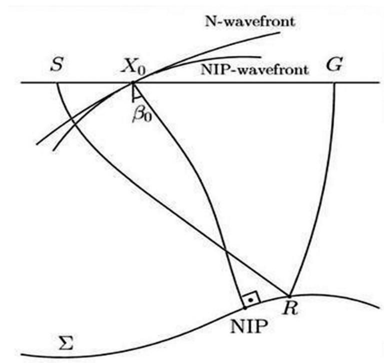

Figure 1. The Central ray is perpendicular to the reflector Σ and emerges at x_0 with an β angle. The NIP and N waves reach the surface at point x_0.

A more deep and complete theoretical development about CRS can be revised in others references (Bortfeld, 1989; Tygel *et al.*, 1997)

Procedure

The NMO stacked section was obtained by a current seismic processing sequence in ProMAX®. Due to CRS does not require a previous known velocity model the velocity analysis and stacking steps were replaced by searching and optimizing local and global CRS parameters through coherence analysis solution until obtain an optimized stacked section. This equivalent step was done using MPT® (a Numerica´s software trade mark). After stacking, the NMO and CRS images were filtered and enhanced applying the same ProMAX sequences. A flow diagram of both sequences is shown in Figure 2.

Search of CRS parameters

This non conventional procedure replaces the NMO analysis and stacking currently used in seismic processing sequences. The whole procedure is explained in the following sequence of steps with a visual description in the flow chart of Figure 3, as was defined by Muller (Muller, 1999)

The first step is to estimate V_{NMO} from *CMP* gathers at point $x=x_0$, this reduces equation 1 to:

$$t^2_{CMP}(h)=t_0^2+\frac{4h^2}{v^2_{NMO}} \quad (2)$$

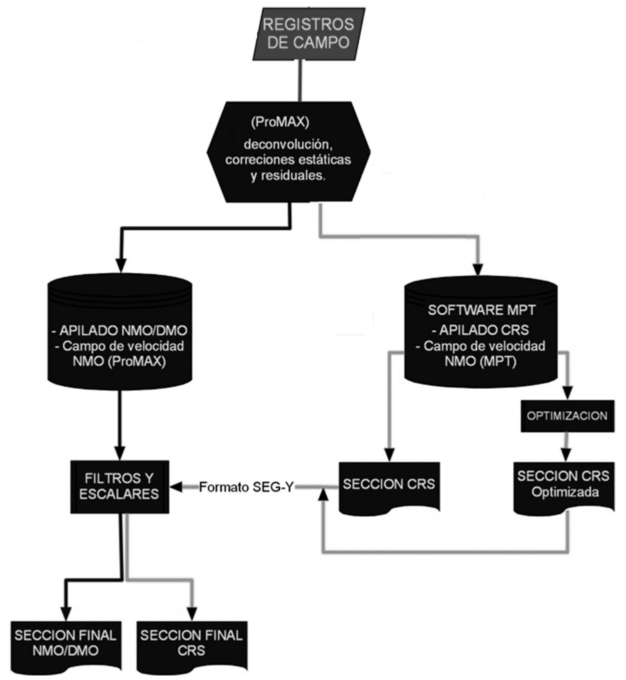

Figure 2. The CRS sequence differs from NMO sequence in velocity analysis and stacking steps where instead, searching and optimization of CRS parameters are used.

This step is an NMO velocity analysis and stacking which provides an initial simulated ZO section (zero-offset).

In the second step β is searched. For that, the reflectors in anterior ZO section are considered locally flat, i.e. case of small apertures ($K_N = 0$), that simplifies equation 1:

$$t(x, h=0) \approx t_0 + \frac{2 \sin \beta}{v_0}(x - x_0) \qquad (3)$$

In the third step β is known and with the equation in zero offset configuration, K_N value is estimated from ZO section.

Finally the K_{NIP} is calculated using the β parameter and the expression

$$K_{NIP} = \frac{2 v_0}{t_0 v_{NMO} \cos^2 \beta} \qquad (4)$$

Geological setting

Geologically the area has been deformed by thrusting associated to compressive tectonic events. In the area a monocline dips to the East and the basement outcrops at West. The cretaceous rocks are below a gently dip Eastward Tertiary sequence, as seen in Figure 4. Different structural styles are observed: a first thrust with East vergence, a second one with West vergence and a lineation and NE-SW strike slip fault system.

A low to high dip thrust fault emerges in surface with a high inclination. This fault causes the repetition of the cretaceous sequence which was observed in the well sited at West. A second fault inferred from seismic section, allows the elevation of basement over the footwall block below the fault. A tertiary detachment fault interpreted in the seismic section was observed in the cartographic recognition of the area.

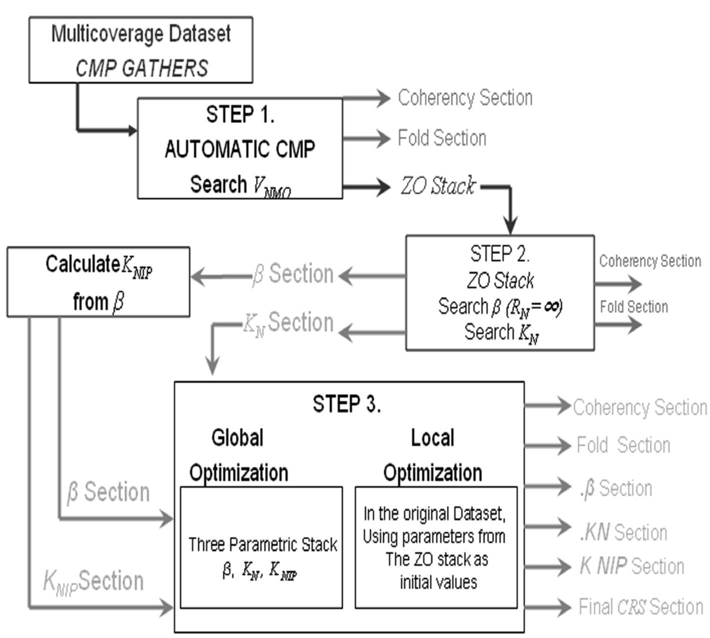

Figure 3. Flow charts with step sequence to obtain final CRS stack section.

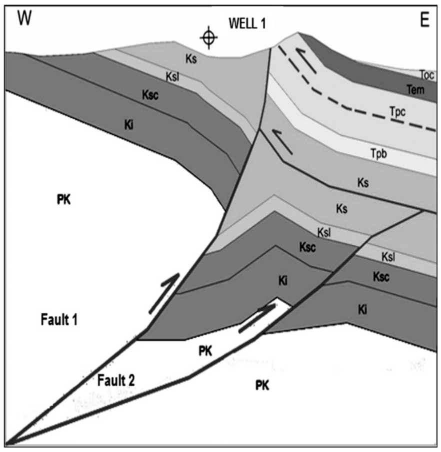

Figure 4. Geological section of the zone with several structural styles observed and a well at West, from an interpreted stacked section (internal report).

Discussion and results

An E-W acquired seismic line was selected to be processed by the two methods in order to compare their performances in producing the seismic images. At East side of the thrust fault a well allowed to identify the stratigraphic units in the seismic section.

This seismic line was previously processed using a conventional flow of processing to obtain a PSTM section, shown in Figure 5.

In that figure is observed two different behaviors at left and right of the thrust fault. A set of clear and continuous reflector with gentle dips can be seen from 2200 ms to 400 ms at right of the fault, whereas al right is almost impossible to identify a reflector.

The seismic line was properly processed applying a conventional sequence flow with a careful selection of parameters, as result a new stacked section was obtained, providing also a more reliable NMO velocity model to be used as starting model in CRS method.

The stacked section is displayed in the figure 6, where is evident the enhancement of the image compared with that other in figure 5.

After the CRS processing a better image is showed the stacked section included in Figure 7. In figure 6 the reflectors appear weaker, strong and less coherent can be seen with a better continuity, with low noise and besides that the image owns more seismic events in the shallow part.

Compared with NMO stack section the CRS is a more enhanced and allow to constraints the monoclonal structure descripted in the geological setting section.

To compare the quality of the images a S/N content evaluation was made. First the noise was isolated from the signal in the image through band pass filters and then respective spectral analysis´s were done. The results are depicted in Figure 9, at top for NMO image and at bottom CRS image. Comparing the figures 9a and 9b the random noise level is reduced from 27.8% in NMO image to 17.9 % in CRS image. It represents a significant improvement in signal to noise ratio and in consequence a rising in the seismic resolution.

A post-stack CRS migrated section was interpreted using the software Geographix (Landmark Graphics Co®). The change in the quality of the image permitted a new geological interpretation matching the seismic section with the

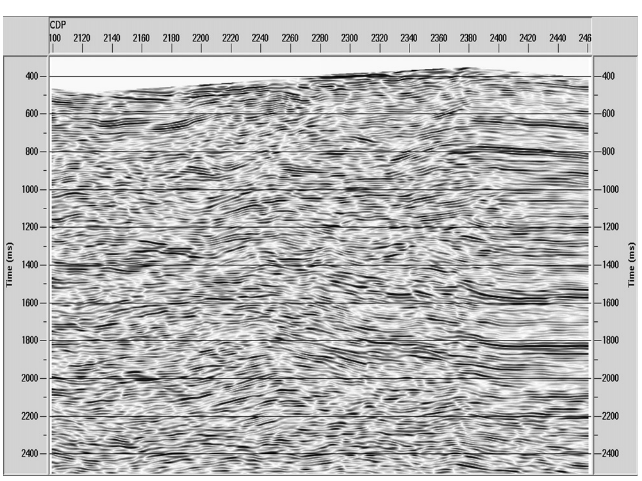

Figure 5. In the previous PSTM section CDPs 2100-2460, clear reflectors are observed from CDP 2380 to the right but blurred at left.

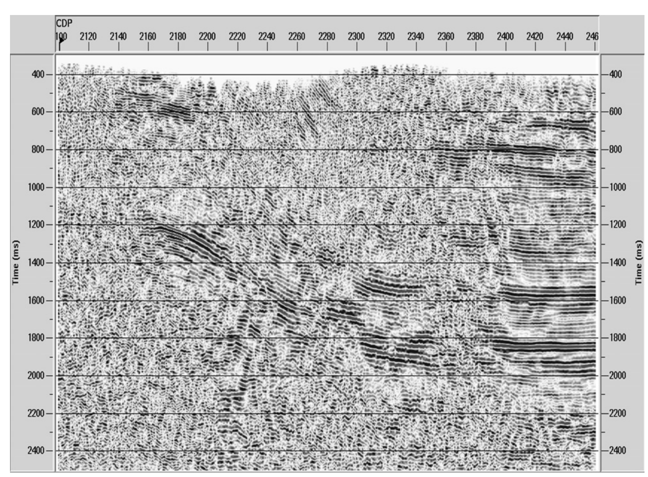

Figure 6. In the new NMO Stack section CDPs 2100-2460 the reflectors are observed along the whole section, including at left of CDP 2380.

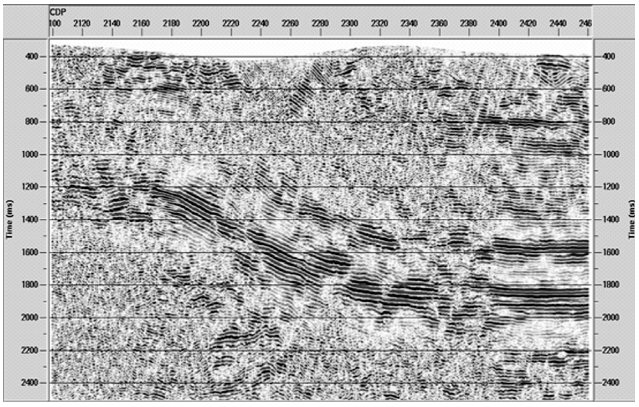

Figure 7. The CRS stack section CDPs 2100-2460 displays an enhanced image with better continued and more clear reflectors along the section.

lithological units identified in the stratigraphic column and the borehole logs (Figure 8).

A schematic geological section was extracted from the interpretation and depicted in the Figure 10.

The difference among the geological interpretation gotten in Figure 3 and the interpreted in Figure 10 is evident.

This new interpretation is due to the enhanced quality of the new obtained CRS image.

Conclusions

A low quality Colombian seismic line acquired in Middle Magdalena basin was processed using the NMO and the CRS techniques looking for an enhanced of the image on a thrusting fault. The CRS provided an improved image which allowed a new geological interpretation that is best constrained with other regional observations. Our observations suggest that the *CRS* technique improves the imaging of complex areas and constitutes an alternative in seismic

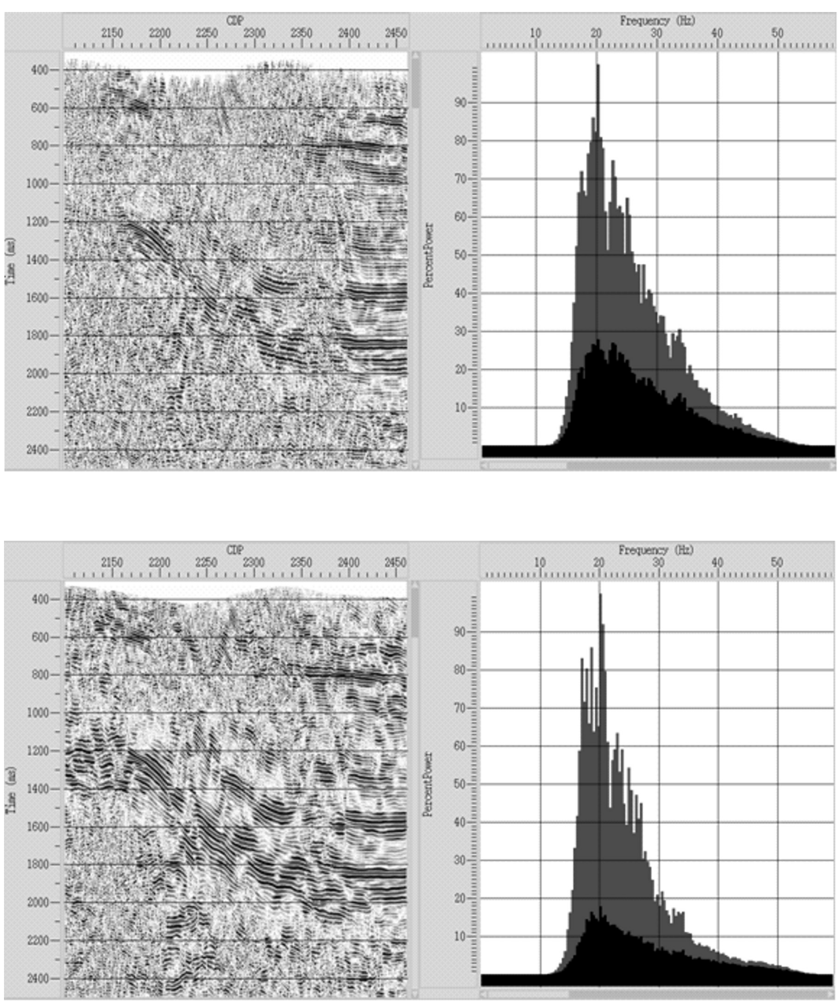

Figure 8. NMO at top and CRS at bottom images with respective spectral analysis show reduction in the level of random noise.

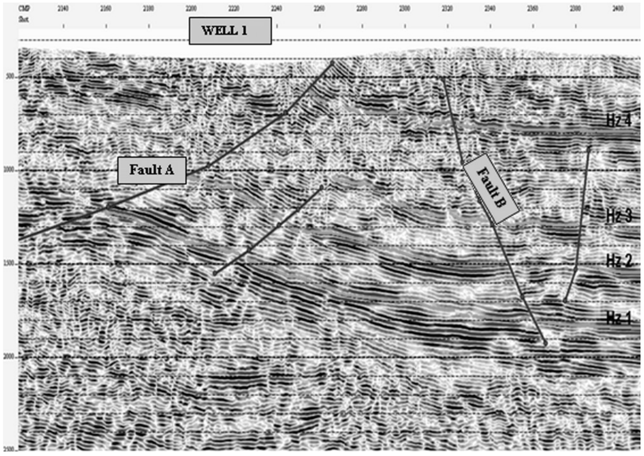

Figure 9. A new seismic interpretation resulted from the CRS image.

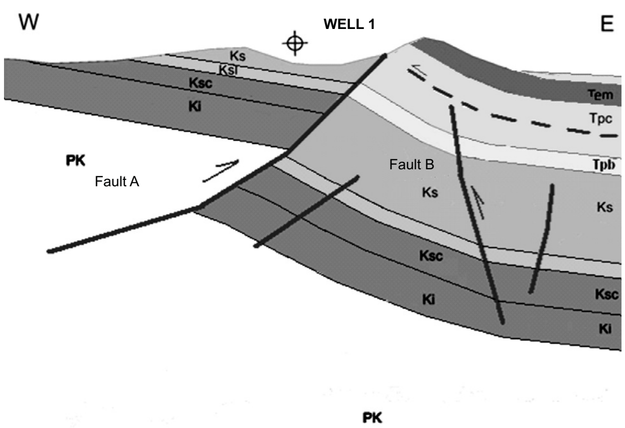

Figure 10. A new schematic geological section provided by the interpretation of the CRS image.

processing. *CRS-2D* method generated seismic sections of good quality without knowledge of subsurface velocity model, essential in expensive process like pre-stack migrations.

Performance of *CRS* methods in thrusting zone, allowed a new interpretation and geologic model. Futures works should emphasize the *CRS* technology in *3-D* data and use the information given by *CRS*, attributes in tomography inversion, *AVO*, migration and coherent cube analysis.

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