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ANCESTRAL STRUCTURE OF THE NEUQUEN BASIN, EVIDENCED BY A DEEP SEISMIC STUDY

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ABSTRACT

A singular mathematical reprocessing of old seismic lines recorded by the industry, let to illuminate the crustal structure down to about 33 km depth. An iterative depth-migration methodology guaranteed the consistency of a final model of the Crust. Important inversion events were recognized by seismic stratigraphic analysis of the basin, and dated as Pliensbachian - Toarcian, and Bathonian - Callovian. Deep seismic reflectors were interpreted as the top of the lower Crust, and two important faults which controlled the rift basin geometry during its evolution. Rift basin geometry would be driven by deep ancestral discontinuities, associated with the late Triassic - early Jurassic opening of the Neuquén Basin. In such sense, a first-order crustal-reflection attribute (about 20-33 km depth, and with east polarity) was located beneath Las Cárceles region (western foothills of Sierra de Los Chihuidos). It could be the evidence of a thermal-mechanical (extensional) collapse of an early orogen located on the Proto-Pacific continental margin of Gondwana.
Keywords: Deep seismic reprocessing-crustal-reflection attributes-Neuquén Basin

RESUMEN

Un original reprocesamiento matemático de viejas líneas sísmicas registradas por la industria, permitió iluminar la estructura cortical hasta una profundidad aproximada de 33 km. Un método iterativo de migración en profundidad garantizó la consistencia del modelo definitivo de la corteza. Importantes eventos tectónicos de inversión fueron reconocidos mediante el análisis sísmico-estratigráfico de de la cuenca, siendo datados como Plensbachiano - Toarciano y Bathoniano - Calloviano. Reflectores sísmicos profundos fueron interpretados como el techo de la Corteza inferior, y dos importantes fallas que controlaron la geometría de la cuenca de rift durante su evolución. Un orógeno ancestral, manifestado actualmente por discontinuidades profundas, habría dado origen al ulterior sistema extensivo asociado con la apertura Triásica - Jurásica temprana de al Cuenca Neuquina. En tal sentido un atributo de reflexión de primer orden (detectado entre 30-33 km de profundidad, y con polaridad este) fue localizado debajo de la región de Las Cárceles (en el piedemonte oeste de la Sierra de Los Chihuidos). El mencionado rasgo sería la evidencia de un colapso extensional térmico-mecánico de un orógeno temprano emplazado en el margen continental Proto-Pacífico de Gondwana.
Palabras Claves: Reprocesamiento sísmico profundo-atributos reflectores corticales-Cuenca Neuquina

INTRODUCTION

About 220 million years ago, part of the Proto-Pacific margin of Gondwana suffered a strong process of continental extension (Mpodozi and Ramos, 1989; Franzese and Spalletti, 2001). This tectonic event was induced by the thermal-mechanical collapse of a Late Paleozoic orogenic belt, giving place to a marginal active basin (Neuquén basin)

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during the whole Mesozoic, between the current 30° - 40° S. The Neuquén Basin is an ensialic extensional basin modified by subsequent growth of the Andean magmatic arc. Its complex post-rift stage comprise multiple episodes of Mesozoic and Cenozoic inversion, and the development of the Andean fold and thrust belt and Late Tertiary foreland basin (Vergani *et al.*, 1995).

Sin-extensional processes led to the creation and evolution of several isolated troughs with NNW-SSE and ENE-WSW orientations (Vergani *et al.*, 1995; Legarreta and Uliana, 1996; Franzese and Spalletti, 2001). The sin-rift infill (Pre-Cuyo Group) consists of coarse-grained continental sediments, volcanics, and volcaniclastic materials. The transition to an initial post-rift stage (Cuyo Group) is marked by the widespread development of marine paleoenvironments during the Lower Jurassic (Vergani *et al.*, 1995). However, the distribution and thickness of the early sequences of the Cuyo Group locally match up with the Pre-Cuyo depocentres, signifying that extensional faulting was an important control of sedimentation during the Early Jurassic at least in some areas of the basin (Vergani *et al.*, 1995).

During the post-rift, the existence of localized tectonic-inversion episodes controlled the evolution of the basin (Vergani *et al.*, 1995). Restructuration events are very evident in the Huincul dorsal area (Fig. 1), where they contributed to the generation of significant hydrocarbon fields. Early interpretations imply that the Huincul arch would have been the product of post-Jurassic strike-slip movements along a transcurrent Fault system (Ploszkiewicz *et al.*, 1984), although more recent interpretations agree that they was generated trough inversion of the initial halfgrabens in a NNW - SSE compressive stress field during the Middle Jurassic (Vergani *et al.*, 1995; Veiga *et al.*, 1997). Evidence of older local inversions involving some areas of the Huincul Arch during the early Jurassic was addressed by Pángaro *et al.* (2002), and specifically during the Toarcian by Vergani (2003). Other events of tectonic re-structuration were observed by Pángaro and Bruveris (1999), who described normal fault systems produced by transtensive deformation, and controlling the contem-poraneous sedimentation in central-sectors of the basin during the late Jurassic-early Cretaceous.

The inversion produced by the Andean tectonic shortening is to much complex. Evidence of backarc tectonics such as thrusts belts and foreland basins could have been so old as Late Cretaceous (Diraison *et al.*, 2000). During the Tertiary (and strongly in the Pliocene) compressive tectonics gave place to a fold and thrust belt that reconfigured the whole occidental sector of the basin. Even during this tectonic phase, the influence of old structural alignments of the initial basin is

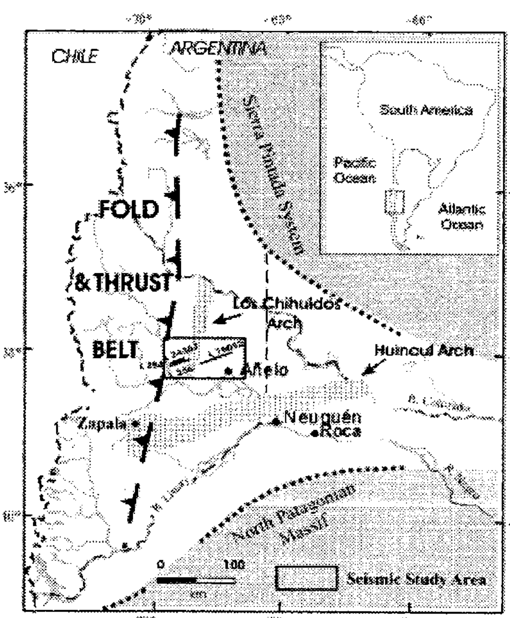

Figure 1. Tectonic sketch of the Neuquén Basin. Seismic lines are enclosed by a rectangle which identifies the study area at the central place of the Basin.

present in the deformation style (Zapata *et al.*, 1999).

While the geometry and evolution of tectonic inversion is considerably known in the oil productive areas of the Huincul arch, studies along Los Chihuidos Arch (the other inverted arch of the basin) are less abundant. This structure is a N-S structure (Fig. 1), described as a tertiary large wavelength fold super-imposed over a pre-cretaceous structural high (Ramos, 1978). Deep-seismic mathematical reprocessing across Los Chihuidos Arch allowed us to describe evidence of the main deep structure of the Neuquén basin for the first time as well as to give much insight on the inversion structures that controlled the basic stratigraphic pattern of this huge depocenter.

SEISMIC PROCESSING AND RESULTS

Deep seismic sections were obtained by mathematical reprocessing of conventional vibroseis data recorded in the central sector of the Neuquen Basin. The lines involved linear upsweeps with frequency band of 12-65 Hz and time-length of 8 sec. The field records were characterized by time-lengths of 13 sec and a sampling period of 4 msec .

The Self-Truncating Extended Correlation algorithm (Okaya and Jarchow, 1989) was used to compute cross-correlation between the sweep and the records. The original frequency-band of 12-65 Hz was preserved for the first 5 sec of trace. However, this band was affected by an upper-frequency decreasing from 5 sec on, at a predicted linear-rate of 6.625 Hz/sec. Hence, correlated deep-records with a time-length of 11 sec and a final trace-band of 12-25 Hz were calculated.

Ω-X Depth-Migration was implemented on the extended traces (Yilmaz, 2001). Consequently, progressive models of Crust velocity were iteratively matched with their resulting migrated sections. The iterative process was considered concluded when it was observed acceptable coincidence between the model and its resultant depth-migrated profile.

The basin stratigraphy in the area consists of a continental sequence of initial synrift (Precuyano) deposited on halfgrabens, followed by strong cycles of marine and continental postrift units (Cuyo, Lotena, and Mendoza groups). In addition, continental sedimentites are present covering the before sequences (Rayoso and Neuquén groups).

The initial structuration is considered of Superior Triassic-Liasic age. While, the postrif phase would have extended until Early Cretaceous.

The analysis in the area of Las Cárceles (Fig. 2) reveals the following: (1) The lower-crust top is placed at about 23-24 km; (2) An oblique reflector horizon between 16 and 18 km depth, is considered as a master shear that controlled the extensional system; (3) A submaster fault, between 8.5 and 12 km depth, is partially recognized in seismic sections; (4) The top of the rift basemen is characterized by irregular depths that, from W to E, fluctuates in a series of steps from 9 to 5 km; (5) Evident features of tectonic inversion, including synrift as well as part of postrift sequences (i.e. Cuyo and maybe Lotena groups) are observed to the W of Los Chihuidos arch (this inversion episode was possibly initiated in the Bathonian-Callovian).

In Bajada de Añelo (Line 19052 in Fig. 1), the study demonstrated that: (1) The top of the pre-liasic basemen is located at about 5 km depth, showing a smooth topographic relief; (2) In the central-western sector are detected features of bipolar inversion (this inversion episode dated Pliensbachian-Toarcian is previous to the Bathonian-Callovian inversion, and is not reported in previous papers); (3) The middle level of the Cuyo group is characterized by oblique reflections related with a strong sedimentary progradation toward the west.

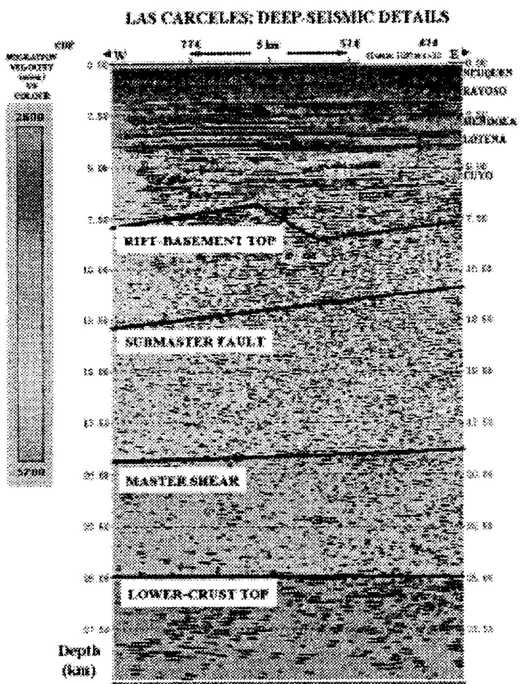

Figure 2. Depth-migrated window of Seismic Line 254, evidencing seismic-stratigraphic sequences of the Basin and local details of the Crust.

INTEGRATED DISCUSSION AND CONCLUSIONS

Seismic-tracings comprising both the eastern and western sectors of Sierra de los Chihuidos, showed the deep structure of the Neuquén basin. Deep reprocessing of historical industrial seismic-lines supplied interpretive information down to approx. 30 km. Thus, seismic data reprocessed with "self-truncating extended correlation" (Okaya and Jarchow, 1989) confirmed an economic way of acquiring deep-seismic information where Vibroseis records are available. In addition, the FMED algorithm (Sacchi *et al.*, 1996) was an appreciated mathematical tool for recognizing the different synrift and sag sequences.

Promissory results synthesized in Figure 3 reveal that: (1) An acoustic contrast at about 24 km depth, must be the top of the lower Crust; (2) An oblique reflector between 16 and 18 km depth, must be assumed as the local image of the master shear that controlled the extension system during the Late Triassic-Early Jurassic period; (3) A sub-master fault dipping about 8° W, surely have been controlling the evolution of 'Las Cárceles' area; (4) An important inversion event initiated during the Bathonian-Callovian, sensibly affected the western sector of the 'dorso de los Chihuidos'; (5) Pliensbachian-Toarcian inversion developed during the transition to the Cuyo Group (related with attractive small-traps in a marine environment), has not been evidenced in the area by other studies, although Pángaro *et al.* (2002) and Vergani (2003) reported it in the Huincul Arch region; (6) In the western sector, a middle Jurassic postrift episode is characterized by a deltaic depositional system prograding to the west with accentuate high energy; (7) Deep discontinuity emphasized in Figure 3 must be closely related with an ancestral orogen, previous to the rift basin; (8) Bulk extension of an ancestral thickened crust can be only justified if a relative free boundary is adjacent to the orogenic domain (Rey *et al.*, 2001; Schellart and Lister, 2004), in such case the idea of rollback of the western subducting slab, would emerge as the most credible hypothesis.

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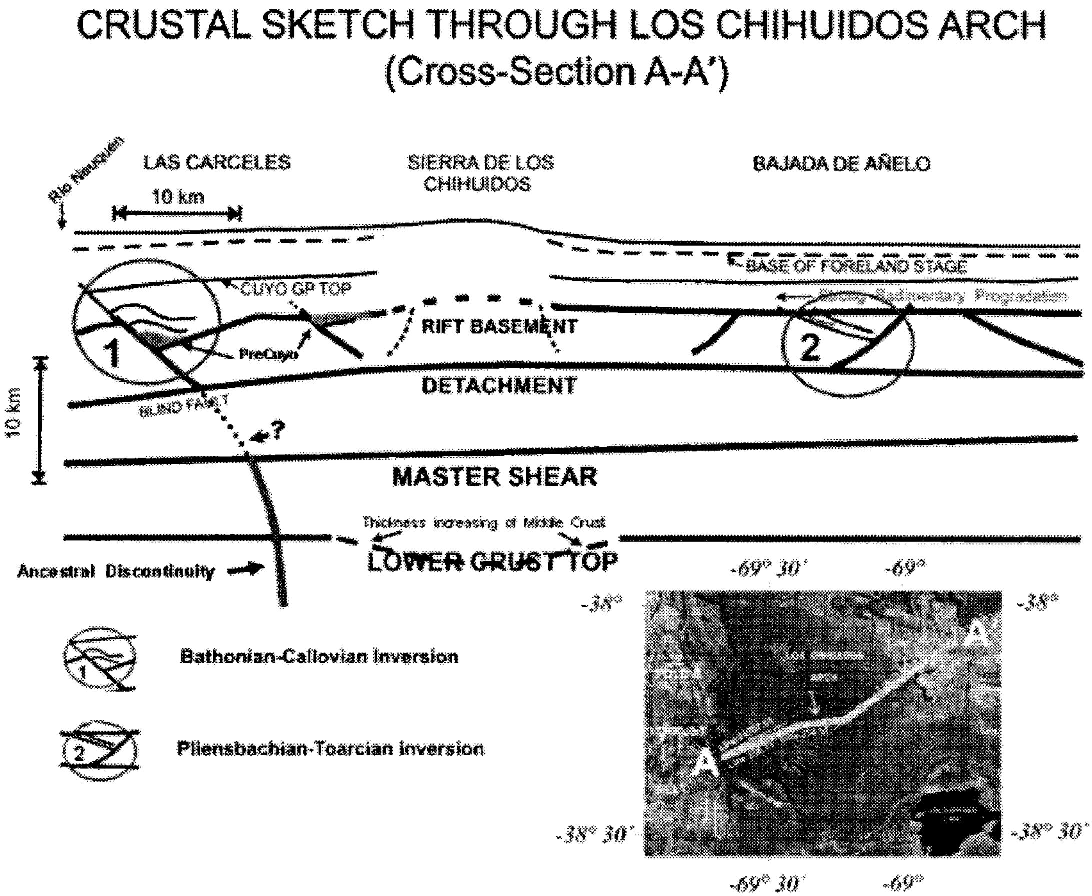

Figure 3. Depth-Migrated Seismic Profiles corresponding to the lines placed in Figure 1 were integrated along the Transect A-A'. The Crustal Sketch emphasizes important tectonic events recognized in this step of the project.

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