Seismic Imaging of the Crust in the Aconquija and Adjacent Regions; Catamarca, Tucuman and Santiago del Estero, Argentina.

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ABSTRACT

Deep Seismic Study, in eastern and western foothills of Sierra de Aconquija, northwestern Sierras Pampeanas, Argentina, shows the deep structure of the range and the deep geometry of the Andean foreland basin. "Self-truncating" extended correlation algorithm was applied to compute cross-correlation between the sweep and the records of Vibroseis lines. Special procedures, such as finite difference migration, FX deconvolution, FMED processing and complex demodulation, were applied in order to improve the interpretation.

On the eastern side of Sierra de Aconquija, the structure is characterized by reverse faulting with eastward vergence, with the Guasayán and El Rosario faults exhibiting the most deformation. To the south, the Guasayán fault produces the uplift of the Guasayán basement range over tertiary deposits, and can be identified in the seismic reflection record down to 40 km depth.

On the western side of Sierra de Aconquija, the deep structure of Campo del Arenal is characterized by westward vergent structures controlled by the anisotropy of the Sierra de Aconquija basement. Further to the west, the deformation style changes to eastward vergence.

Conspicuous sub-horizontal acoustic-reflectors at about 18, 30, 40 and 50 km depth, are interpreted as present or past brittle-ductile transitions.

INTRODUCTION

Seismic data acquired by Yacimientos Petrolíferos Fiscales (YPF S.A.) between 1989 and 1991 were reprocessed. A total of approximately 350 km of seismic lines were analyzed (see location in figure 1). Vibrators were used as a unique source in the central sector (Southern Tucuman), while the records in Santiago del Estero involved explosives, and in Campo del Arenal (Catamarca) experiments included both vibrators (line 2545) and explosives (lines 1591 and 1553). In general field parameters changed from one sector to another, for both Vibroseis and explosive data.

The YPF wells 'Isca Yacu x-1' and 'El Rincon x-1', were used as a control to support the interpretation of shallow acoustic horizons. However, geologic information from several old deep water-drillings beside the lines contributed to the partial understanding of the seismic data.

FIELD WORK AND PROCESSING CHARACTERISTICS OF VIBROSEIS DATA

Field parameters and correlated records

The lines where vibrators were used, involved linear upsweeps with dissimilar time-length (e.g. 8, 12, or 16 sec), but a unique frequency-band (that is 12-65 Hz). While, the field record were characterized by different time-length (e.g. 13, 14, or 17 sec) and a sample rate 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 seismic section (6 sec in the particular case of line 2481). However, this band was affected by a upper frequency decreasing from 5 sec, at a predicted linear-rate. Hence correlated records of 11-14 sec were calculated, depending on the particular set of field parameters characterizing the seismic line.

Before- stacking skills

Significant steps in Vibroseis before-stacking processing were:
(1) A CDP Gather Equalization, that is a scaling process designed to correct amplitude anomalies of source records. Such anomalies could be produced by variations in the source array , charge amount and depth, etc. In performing the scaling with this process we tried to maintain the relative amplitude of the data, both spatially and in time.
(2) A Balance Process used to equalize seismic trace amplitudes. With this procedure, areas exhibiting weaker acoustic-amplitudes could be strengthened relative to areas of stronger amplitudes. Therefore, after the application of the balance operation the variations between shallow and deep areas appeared less severe. However we tried to conserve the relative amplitude within the boundaries of definite areas (for example: the sedimentary basin, the middle crust, the lower crust, etc.).
(3) A careful monitoring work intended to remove noisy zones in each trace of the field gathers. Anyway, some difficulties became visible when we try to perceive acoustic horizons in the deeper parts of the crust because of the low signal-to-noise ratio characterizing this particular trace-sector. So we accomplished the manual trace-mute with the use of a 'Generalized Automatic Trace Editing'. A previous statistical analysis let to establish appropriate thresholds for the automatic editing (for example based on dominant frequency or on peak to reference amplitude). As result of combining manual and statistical editing we could image reliable crust details down to 14 sec (42-45 km deep, approximately).
(4) The use of a temporary Floating Datum before normal moveout correction. Application of large static shifts prior to velocity analysis and normal moveout corrections distorts the hyperbolic character of reflected events . This complication is more evident at shallow travel-times where the distortion significantly affects velocity measurements. To minimize this distortion, datum statics were typically decomposed into two time-components, one that corrected the data to a floating datum (short wavelength static corrections), and another, involving much larger components, that corrected the data to a final datum (long wavelength static corrections). The former static was regularly used prior to velocity analysis and normal moveout corrections, while the later was applied after normal moveout corrections.
The floating datum was established by performing a smoothing operation over a physical datum or surface (for instance, surface elevation or shot-depth surface). Travel-time differences were subsequently computed between the floating datum and the fixed reference datum. Alternatively, the floating datum was indirectly calculated by averaging static corrections from all the traces belonging to a single common-depth-point gather or group of subsequent gathers. Floating datum statics (short wavelength corrections) were finally computed by simple subtraction of the mean CDP-static value from the total trace static (computed from a fixed datum).
In particular, the application of this concept let us to recognize the basement-outcrop on both sides of the Aconquija range, when seismic sections as well as interval velocity profiles were studied.
(5) Prior to channel stacking, a deconvolution operation with unmodified phase (zero phase deconvolution) was applied, which resulted in flattening of the amplitude spectrum along a 16-50 Hz frequency band. With this operation, precise seismic velocity analysis was ensured up to 8-9 sec of trace length (in turn, a good acoustic response from the crust was found to occur in this sector, e.g. lines 2545, 2529, 2481 and 2477) . Likewise, since phase characteristics of the diffracted signals were kept unmodified, they could be properly focussed by migration process (Trorey, 1979).

AFTER-STACKING SKILLS

In adition to the above points, important aspects in Vibroseis after-stacking processing were:
(1) Calculation and application of residual statics. This procedure included determination of new stacking velocities, new stacking, and a second step of calculation and application of residual statics.
(2) Migration of the section using Claerbout_(1976) finite difference algorithm.
(3) Seismic sections enhance by using FX deconvolution. This process apply a fast Fourier transform to convert a time window for an specified number of traces (that is a t-x domain) in a f-x domain. For each frequency of the new domain the complex signal is then enhanced by a predictive filter. An inverse "Fast Fourier Transform" restores the signal to the original t-x section producing the attenuation of details which are not predictable from one trace to the next. Time windows of 1000 milliseconds, as well as spatial windows of 200 traces were used in order to enhanced the continuity of acoustic reflectors. In same cases, the operation was accomplished by the use of a coherency operation. That is an process designed for signal enhancement by dip scan and semblance scaling.
(4) The use of complex demodulation techniques (Claerbout, 1976), as a help to the fault analysis.
(5) Once final migrated and enhanced seismic sections were calculated, the FMED (minimum entropy algorithm with frequency-domain constrains) developed by Sacchi et al. (1996) was used in some sectors, in order to improve signal resolution as well as to match continuous acoustic reflectors with geological-well information. In particular, FMED was a robust tool to support the seismic-stratigraphic interpretation of the Cenozoic basin .

EXPLOSIVE SOURCE DATA

Sources of explosive origin complemented the regional study, specifically in the western sector (lines 1459A, 1459B, 1459C, and 1459D), and in Campo del Arenal (Catamarca Province) where lines 1553 and 1591 considerably reinforced the seismic stratigraphic study of the area. Before and after stacking process-steps were analogous to those adopted for lines where vibrators were used. For example, zero-phase deconvolution was applied prior to stacking and this resulted in a flattening of the amplitude spectrum along a 16-46 Hz frequency band.

SEISMIC MODEL AND CONCLUDING REMARKS

Deep reprocessing of industrial seismic lines at both the eastern and western foothills of Sierra de Aconquija (figure 1), northwestern Sierras Pampeanas of Argentina, shows the deep structure of the range and the deep geometry of the Andean foreland basin (figure 2a).
Figure 2b represents the structure restitution just previously to the Sierra de Aconquija uplift during the development of the basal sequences of the foreland basin. The figure shows the early geometry of the foreland basin and the location of the peripheric promontory.
The progressive deformation to the western sector during the Pliocene, after the uplift of the Altohuasi and Hualfin ranges, produces the activation of a backthrust series controlled by the anisotropy of the Sierra de Aconquija basin. These backthrusts were observed by Fauqué and Strecker (1987) on the Aconquija western front, but the present seismic reprocessing let the deep detection of them below the oriental slope of this range.
The subsequent faults activity along the western sector, is responsible of the Neotectonic evidences which characterize the Region of the Rio Hondo reservoir. These scarps would be the shallow expression of the Guasayan-del Rosario fault system. Thus, the activity would represent an reactivation of the ocloyic-movements front.
Conspicuous sub-horizontal acoustic-reflectors are present at about 18 and 30 km depth (line 2419 and 2481, in figure 1), like at about 25, 40, and 53 km depth (line 2529, 2525 and 1519, in figure 1). The deep detachment level sketched in figure 2a is agree with the deepest seismic level obtained in this work, and is consistent with the statistic of seismic-hypocenters recorded in the region (data base of the National Earthquake Information Center, U.S. Geological Survey).
On the western side of Sierra de Aconquija, the deep structure of Campo del Arenal is characterized by westward vergent structures controlled by the anisotropy of the Sierra de Aconquija basement. Further to the west, the deformation style changes to eastward vergence. The cross-cutting relationships between the west and east vergent fault systems, as well as the geometry of the synorogenic deposits permits establishment of the uplift history of Sierra del Aconquija. The uplift started during the Late Miocene, after the Paranense sea transgression, and still continues, as demonstrated by neotectonic activity. The deep seismic data show that the west vergent thrusts developed later than, and below, the east vergent thrusts.

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