Special Seismic Processing for Faults and Fractures Imaging

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Abstract

Plane-wave destruction (PWD) filters originate from a local plane-wave model for characterizing seismic data. There are a lot of works in this direction in literature, this work applies an advanced improvement from Fomel (2002) applied to Petrobras seismic data to deal with faults and fractures imaging. In Fomel's (2002) work there are many synthetic data applications showing good results with this kind of filter beyond our work scope, as well as seismic interpolation and noise attenuation. This present work shows real data results in faults and fractures detection only.

Introduction

In this work we applied a Plane-wave destruction (PWD) filters, introduced by Claerbout (1992), that characterizes seismic images by a superposition of local plane waves, improved by Fomel (2001,2002). They are constructed as finite-difference stencils for the plane-wave differential equation. In many cases, a local plane-wave model is a very convenient representation of the seismic data. In this work the application of this filter results in improving faults and fractures imaging. Beyond this application PWD filter could be applied to data interpolation, noise attenuation and alias problems solutions.

The advantages of this PWD filter compared to the traditional T-X prediction-error filters (PEFs) or F-X-PEFs applied in the industry (Spitz (1991)), are to keep the number of adjustable parameters to a minimum, and the only estimated quantity has a clear physical meaning of the local plane-wave slope. In fact, no local windows are required because the slope is estimated as a smooth continuous function of the data coordinates.

The total processing of seismic data presented in this work was done in-house development.

Method

The physical model of local plane waves is defined mathematically as a plane-wave destruction filter with the following local plane differential equation

$$\frac{\partial P}{\partial x} + \sigma \frac{\partial P}{\partial t} = 0, \qquad (1)$$

where $P(t,x)$ is the wavefield and σ is the slope, which we consider locally constant. Then in frequency domain the equation (1) writes

$$\frac{\partial \hat{P}}{\partial x} - i\omega\sigma\hat{P} = 0, \qquad (2)$$

and has the general solution

$$\hat{P}(x) = \hat{P}(0)e^{i\omega\sigma x},$$

The time-shift operator $e^{i\omega\sigma}$ has the analog plane-wave prediction filter in a finite-difference sense. A property of this propagator is that its energy is constant because the energy spectrum is equal one. In the time domain an equivalent effect is the all-pass filter and in z-transform notation the implicit finite-difference solution of equation (1) is

$$\hat{P}_{x+1}(Z_t) = \hat{P}_x(Z_t)\frac{B(Z_t)}{B(1/Z_t)}. \qquad (3)$$

The coefficients of $B(Z_t)$ are determined for instance by fitting the filter frequency response at low frequencies to the response of the phase-shift operator, by Taylor series scheme. Expanding the Taylor series around zero frequency yields the expression

$$B_3(Z_t) = \frac{(1-\sigma)(2-\sigma)}{12}Z_t^{-1} + \frac{(2+\sigma)(2-\sigma)}{6} + \frac{(1-\sigma)(2+\sigma)}{12}Z_t \qquad (5)$$

for a thee-point centered filter.

A five-point centered filter is derived by the same procedure, the response of the filter matches the low frequencies and the accuracy improves with the length of the filter, but it is needed to deal with numerical noise.

Taking both dimensions, time and space the equation (3) becomes a 2-D prediction filter that could be characterized by several plane-waves applying a cascade filter

$$A(Z_t, Z_x) = 1 - Z_x\frac{B(Z_t)}{B(1/Z_t)}. \qquad (6)$$

To avoid a polynomial division, the application was made applying the filter

$$C(Z_t, Z_x) = A(Z_t, Z_x)B(1/Z_t) = B(1/Z_t) - Z_x B(Z_t)$$

to the data with the local slope estimation σ evaluated by the convolution in the frequency domain

$$C(\sigma)d \approx 0 \qquad (7)$$

where d is the seismic data.

Solving by linear iterative optimization methods the linearization of convolution equation (7), the dominant slope can be determined without need to break the data into local windows. Of course, to improve the computer performance this process can be easily parallelizalized.

After the local slope estimation we apply nonstationary plane-wave destruction filter for the fault detection.

Examples and Results

The traditional discontinuity processing in seismic data was suggested by Claerbout (1994,1999) and further refined by Schwab et al. (1996). Schwab uses simple plane-destruction filters in a similar setting to compute coherency attributes.

In this work, we first tried to test the ability of the new processing PWD to detect faults, applying it to a selected seismic section data in which faults could be clearly identified.

The result is shown in Figure 1. It is easy to see the better definition of faults in Figure 1b compared to the original seismic section of Figure 1a. Therefore the application of the PWD filter was acceptable in the Petrobras area.

The next step was to apply PWD with the same procedure in a cube seismic data and that time we tried to identify not only faults but also some fracture features in reservoir that is already mapped in the well drilled in the area, plotted in blue line in Figure 2.

Also Figure 2 shows a horizontal and vertical slices in the seismic cube where was applied PWD filter.

Figure 3 shows detail of the horizontal slice of the seismic cube, in Figure 3a is the original data and in 3b is the results of application of the PWD filter. It is clear the better resolution of the features, due to the higher frequency of the section, and the characterization of geological features related to faults in the area encourage to identify those features as fractures in reservoir.

Next we selected two blocks in the cube seismic data (Figure 4) to better analyze those features.

The upper part is more defined by faults that are shown in Figure 5a and the reservoir window is more characterized by fracture features that can be see in Figure 5b. Applying 2D opacity and transparency filter in the seismic amplitudes we have generated both sub-cubes present in Figure 5.

Conclusions

The dominant slopes could be very well determined in this work, and the improving of the faults and fractures interpretation in Petrobras seismic data was well used in PWD filter applications. The results of the real data encourage the application of PWD filter even in pre-stack data for another purposes, as saying diffractions velocities analyses in migration processes to better focusing faults and fractures and accurate imaging. The mapping of the faults and fractures helps the structural geological modeling and this special procedure can be applied to regular processing.

Acknowledgments

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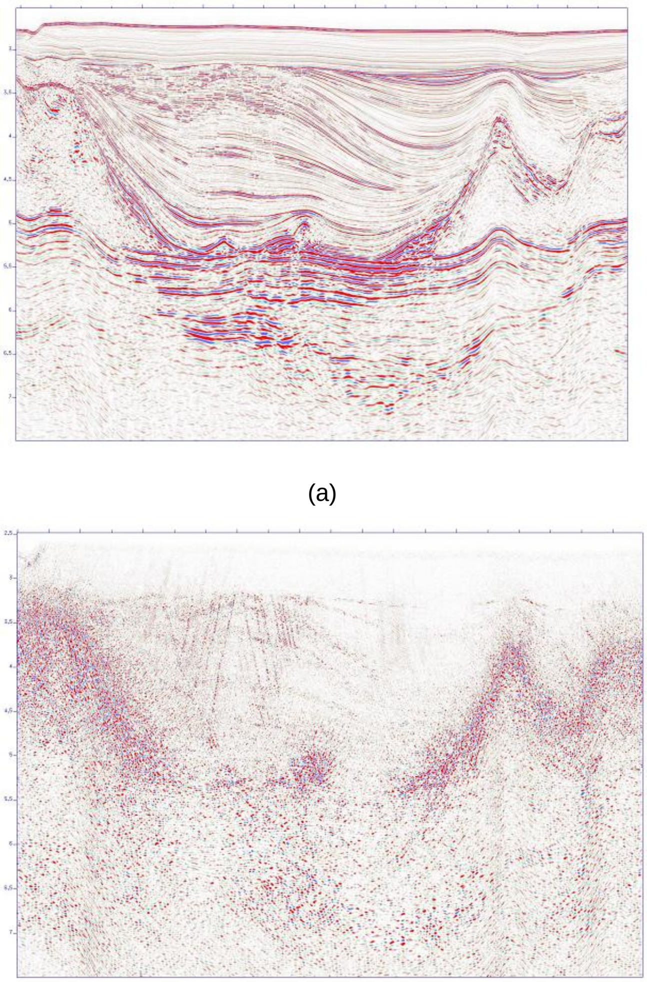


(a)

(b)

Figure 1: (a) Original Seismic section (b) PWD filter results, showing clear faults region in the upper part of the section. Note the appearance of the coherency energy at the reservoir area in (b)

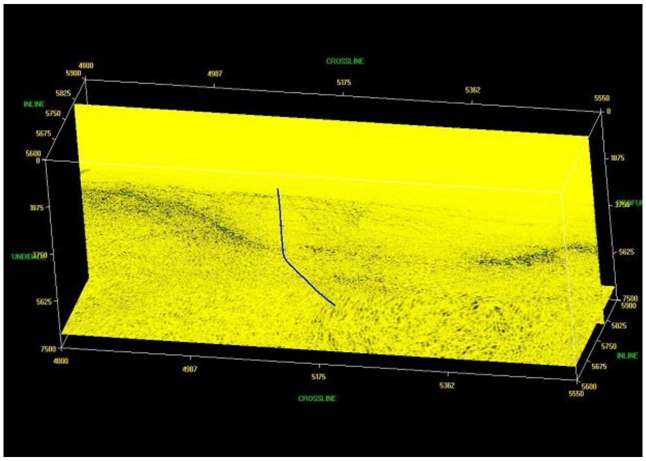
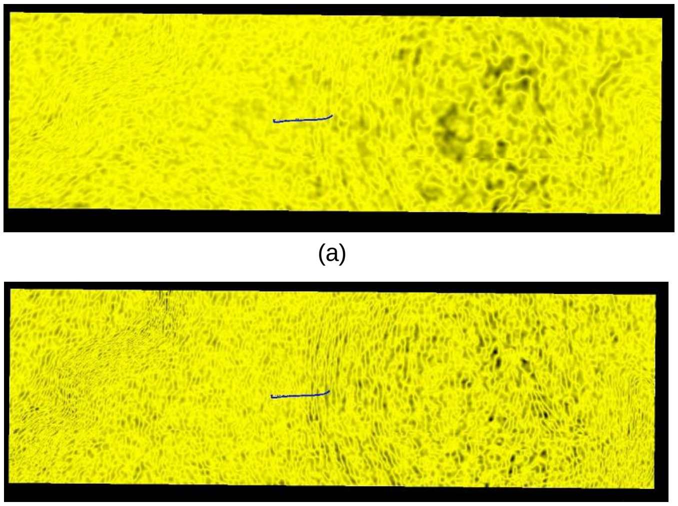


Figure 2: Seismic Cube with horizontal and vertical slices and a well drilled (blue line).



(a)

(b)

Figure 3: (a) Original horizontal section from the Seismic Cube (b) Results of the PWD filters applied to the Seismic Cube. Note the higher frequency in (b) compared to (a) and the lineations at suppose fractures associated to faults.

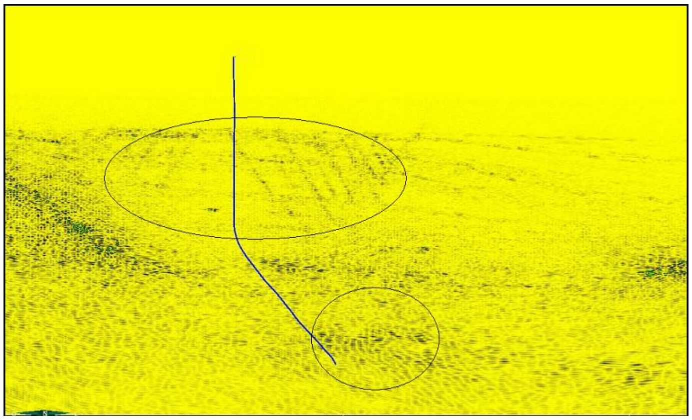
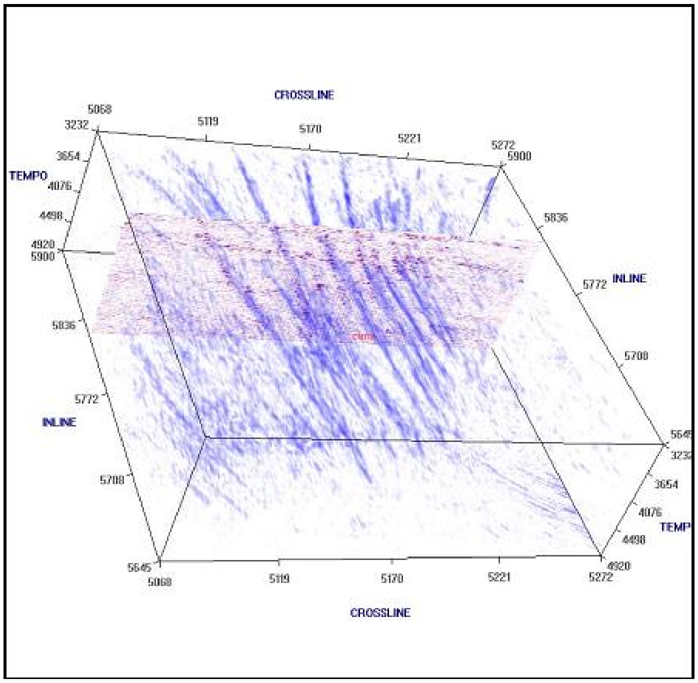
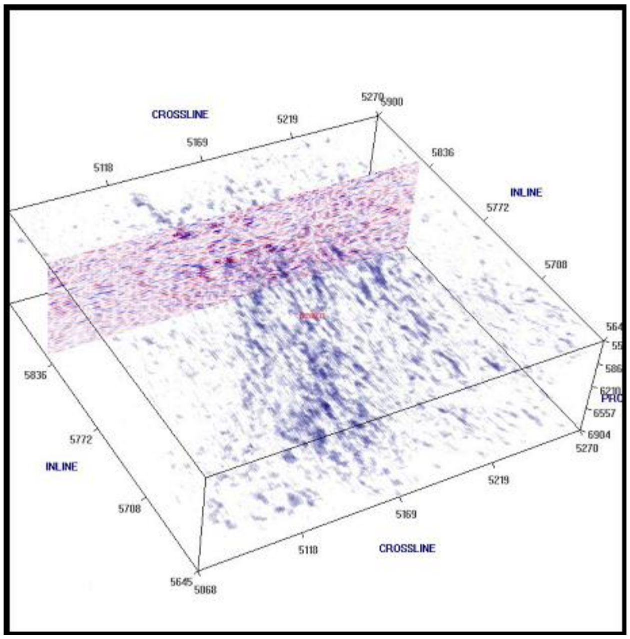


Figure 4: Location of two blocks cube seismic data: Higher Block and Lower Block for faults and fractures mapping shown in the Figure 5.



(a)



(b)

Figure 5: Opacity and transparency mapping results: (a) Faults in Higher Block (b) Fractures in Lower Block of the PWD filter in the seismic cube data.