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USING THE KARHUNEN-LOÈVE TRANSFORM TO SUPPRESS GROUND ROLL IN SEISMIC DATA

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RESUMEN

En este estudio se implementó y modificó el Algoritmo de Sacchi (2002), basado en la Transformada Karhunen-Loève (K-L), como una técnica para la supresión de Ground Roll, mostrando que aunque la amplitud del Ground Roll es mayor que la amplitud de la señal al usar la Transformada K-L se tiene éxito en suprimirlo sin causar distorsión en las señales de reflexión, obteniendo mejores resultados frente a técnicas convencionales de remoción: *f-k,* Paso Alto y Pasa Banda. La Transformada K-L ha sido utilizada en el campo de la detección y procesamiento de imágenes (Levy and Linderbaurn, 2000), en el reconocimiento de caras, iris y huellas dactilares como factores biométricos de identidad. Una sección sísmica es una imagen del subsuelo por tanto esta transformada puede ser usada en el procesamiento sísmico, porque remueve partes correlacionadas espacialmente y proveyendo una imagen clara y coherente.
El algoritmo se aplicó a registros generados con Martillo, Thumper y fuentes explosivas. Se hizo un procesamiento convencional hasta el apilado, remplazando los filtros por le uso de la transformada K-L. Los resultados muestran que la Transformada K-L hace una mejor recuperación de la amplitud de los reflectores, eliminando refracciones que causan eventos someros irreales e incrementando la coherencia lateral de los eventos sísmicos, facilitando la interpretación geológica.

Palabras clave: Amplitud, coherencia, filtro, Onda de Tierra, ruido.

ABSTRACT

The Sacchi's algorithm (2002) based on the Karhunen-Loève (K-L) Transform was modified and implemented to suppress Ground Roll without distortion of the reflection signals, it provided better results than conventional techniques for noise removal like *f-k,* High-Pass and Band Pass Filters. The K-L Transform is well known in other fields as image processing (Levy and Linderbaurn, 2000), face, iris and fingerprint identification. A seismic section is an image of subsurface where the K-L can be useful in seismic processing because spatially uncorrelated signals can be removed providing a clear and coherent image. The algorithm was applied to seismic data generated with hammer, thumper and explosive sources. Conventional processing flows were used, but one replaced filters with K-L Transform, providing stacked sections. The

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K-L Transform recovers better the reflector amplitudes when compared with others filters, also it removes refractions that cause unreal shallow events and increases the lateral coherence of seismic events showing a more interpretable geology.

Key words: Amplitude, coherent, filter, Ground Roll, noise.

INTRODUCTION

The Ground Roll is (Scales and Snider, 1998) generated in shallow layers and is a typical Rayleigh wave. It is characterized by low velocity and frequency and high amplitude, being considered a coherent noise in seismic exploration (D'Agosto et al., 2002). The KL algorithm transforms the seismic data in a reasonable number of independent eigen functions that represents the most important signal characteristics. It has been considered a very advisable tool in the processing and analysis of reflection data (Al-Yahya, 1991).

The conventional filtering techniques: *f-k*, High-Pass and BandPass are applied in the frequency domain but in the case of Ground Roll amplitude stronger than reflection signals, *f-k* filters cause serious distortion of the signal (Karsh and Bayrak, 2004). High Pass filter is based on the low frequency of the Ground Roll, with the disadvantage that also eliminates the low-frequency content of reflection signals. Band pass filter depends on the amount of overlaps between the noise and the signal, therefore when the frequency bands concentrated the energy in each band without overlap, the signal/noise ratio will not change (Yilmaz, 1987).

The K-L Transform separates the Ground roll from the reflector signal, permitting to subtract it from seismic data. Its application to real data showed that the Ground Roll suppression increased lateral coherence of seismic events in a stacked section.

THEORETICAL BACKGROUND

The surface waves in the raw register in figure 1 travel with velocities ranging from 100 to 1000 m/s and with frequencies around 10 Hertz and lower than those of reflections and refractions. Note how the near surface effects distort travel time curve at the right flank of reflection "A".

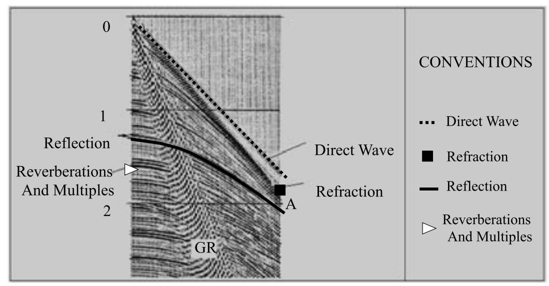

Figure1. Different waves in a raw shot gather.

The Karhunen-Loève Transform

It makes a principal component analysis that is a mathematical way of determining that linear transformation of a sample of points in L-dimensional space which exhibits the properties of the sample most clearly along the coordinate axes. Along the new axes, the sample variance are extremes and uncorrelated, see figure 2. Using a cutoff on the spread along each axis, a sample may be reduced in its dimensionality. This way it can be used to transform independent coordinates into significant and independent ones.

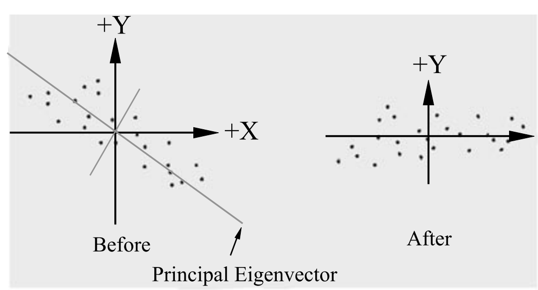

Figure 2. K-L Transformation Principal Eigenvector

K-L Transform Implementation

The seismic traces $x_i(t)$ correspond to the rows of the named data matrix x_{n*m} , n is the number of traces in the gather and m the number of gathers. The zero-lag covariance matrix Γ_{n*n} is (Jones and Levy, 1987):

$$\Gamma_{n*n} \quad X_{n*m} X^t_{m*n} \tag{1}$$

This expression can be decomposed as

$$\Gamma_{n*n} \quad V_{n*p} A_{n*n} V^t_{p*n} \,. \tag{2}$$

In equation 2 the columns of the matrix V_{n*p} are the eigenvectors Γ_{n*n} and A_{n*n} is a diagonal matrix with the eigen values on the diagonal. These eigen values are ordered in descending sequence along the principal diagonal of the matrix A_{n*n} , V^t_{n*p} is the corresponding transpose matrix. The principal component of the data can be written by:

$$M_{p*m} \quad V^t_{p*n} X_{n*m} \tag{3}$$

If we form the matrix M'_{p*m} by selecting the upper m rows of the matrix M_{p*m}, m is related with the order of the filter or principal row number, placing zeros in the remaining n-m rows, n is related with the Cut of the Filter, the Ground roll is assumed to be represented by the matrix product between the eigenvectors matrix V_{n*p} and the matrix M'_{p*m}, that include the principal components in agreement with the following expression:

$$X'_{n*m} \quad V_{n*p} M'_{p*m} \tag{4}$$

Finally, the Ground roll X'_{n*m} is subtracted from the data matrix X_{n*m}, obtaining the gather without Ground roll

$$X0_{n*m} \quad X_{n*m} \quad X'_{n*m} \tag{5}$$

Xo is a $n*m$ matrix that represents the filtered seismic gather.
As mentioned before x_{n*m} is the input data matrix and X'_{n*m} is a matrix that represents the Ground roll extracted from the input data.

RESULTS

The capacity of KL Algorithm to suppress Ground Roll at gather level is evaluated using shot gathers with dispersive waves of high amplitude, obtained from shallow and dip seismic surveys using 3 types of source were used: hammer, dynamite and thumper.

Hammer

The 102.data seismic gather (figure 3) is a record corresponding to the UN-01 Seismic Line. Note in the red square like the Ground Roll diminishes before (left) and after (right) KL Algorithm application; the gather is much less noisy in the first 100 ms, with Order of the Filter: 2 and Cut of the Filter: 1.
Figure 4 shows the interactive spectral analysis for Seismic Record No 12 of UN-01, before on top and after on bottom the application of the K-L Transform. The K-L Filtering gives good results because it compresses more the amplitude spectrum. Additionally, the maximum amplitude of the raw power spectrum with the K-L is lower into the red circle (10000) compared with one of the same gather without this filter in the black circle (4,5 e + 07), indicating high amplitude concentrations in the spectrum; corresponding to the Ground Roll suppressed with K-L. The record with K-L displays seismic events with coherence and continuity.

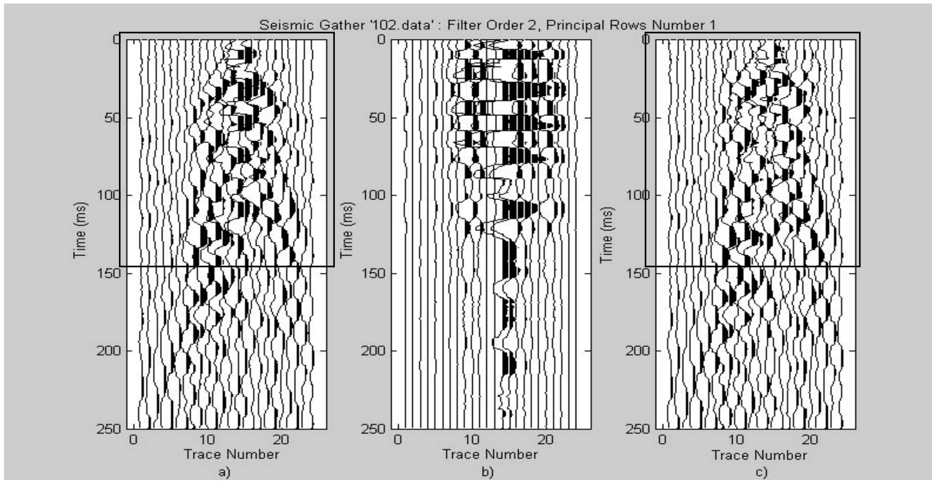

Figure 3. a) Seismic Gather '102.data' with content of Ground Roll of high amplitude, acquired with a symmetric spread. b) The Ground Roll extracted using the KL Algorithm, with Order of the Filter: 2 and Cut of the Filter: 1. c) The gather after the subtraction of the Ground Roll.

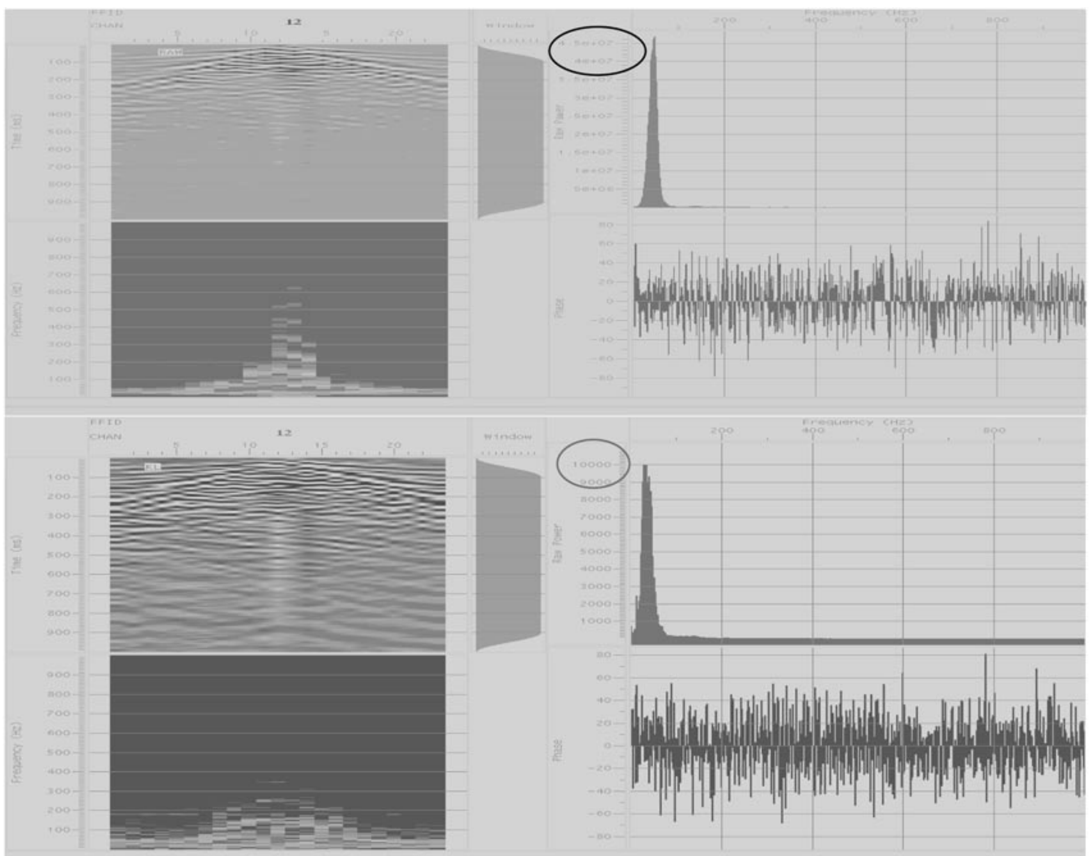

Figure 4. Interactive spectral analysis of seismic data acquired in the UN-01 Seismic Line before (top) and after (bottom) the application of the new KL Filter.

Explosive Source

The shot gather in Figure 5, was generated using dynamite, it displays hyperbolic moveout, coherent noise masking the reflection signals. The analyses with *f-k,* High-Pass and the KL Filters gave the better results for the last one.

The Band-Pass filter is used where the seismic trace contains low-frequency noise, such as Ground Roll and high-frequency ambient noise. The seismic reflection energy usually is confined to a bandwidth between 10 to 70 Hertz, with dominant frequency of 15 Hz.

Comparison between Band-Pass [15-30-55-70] (Figure 6), and KL Filter gave a better result for the KL, the Ground Roll cone has been suppressed and the lateral coherence of deeper seismic events increased.

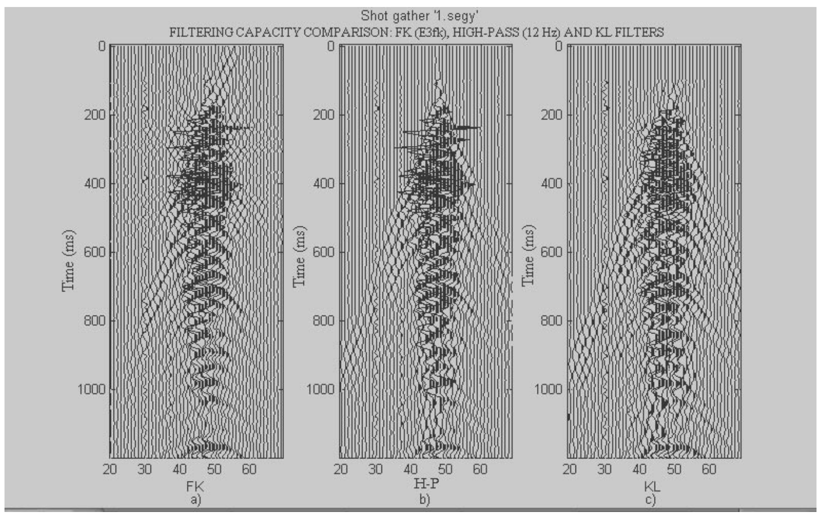

Figure 5. Common Shot gather '1.segy'. Comparison between a) f-k Filter with the E3 test, b) High-Pass Filter with 30 Hz and c) KL Filter. Note distortion in the reflection signals and noise presence with the f-k filtering; noise content with High-Pass filtering; in contrast, better resolution and increasing the lateral coherence until of deeper seismic events applying the K-L Transform.

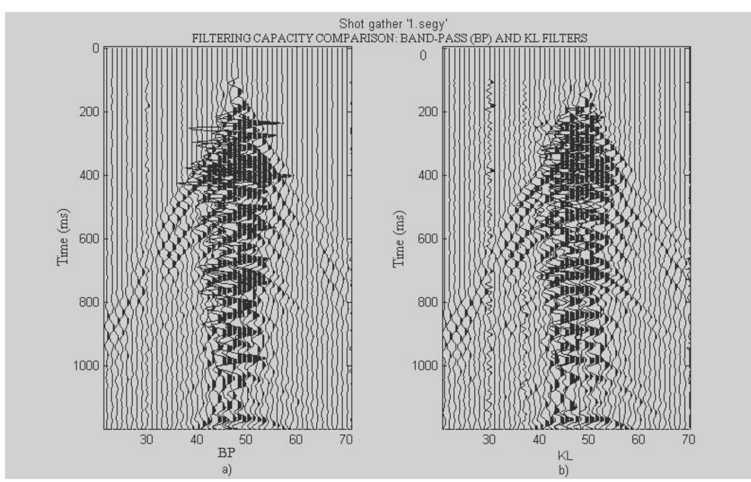

Figure 6. Common Shot gather '2.segy'. Comparison with filtering capacity between a) Band-Pass [15 – 30 – 55 - 70] Filter and b) KL Filter. Note presence of remain Ground Roll with high amplitude once has been applied the Band-Pass Filter, in contrast to the lower content of noise and increasing the seismic events lateral coherence applying the K-L Transform. "A" corresponds to the Ground Roll cone.

Thumper

Figure 7 shows an example, of the shot gather 481 with high content of Ground Roll. The Seismic Line RM-01, was acquired using a thumper source. A substantial increasing in the lateral coherence of the seismic events below the 200 ms is remarked.

Figure 8 shows the amplitude spectrum of the shot gather 481 before and after the KL filter application, a significant reduction of the high amplitude corresponding to Ground Roll is seen.

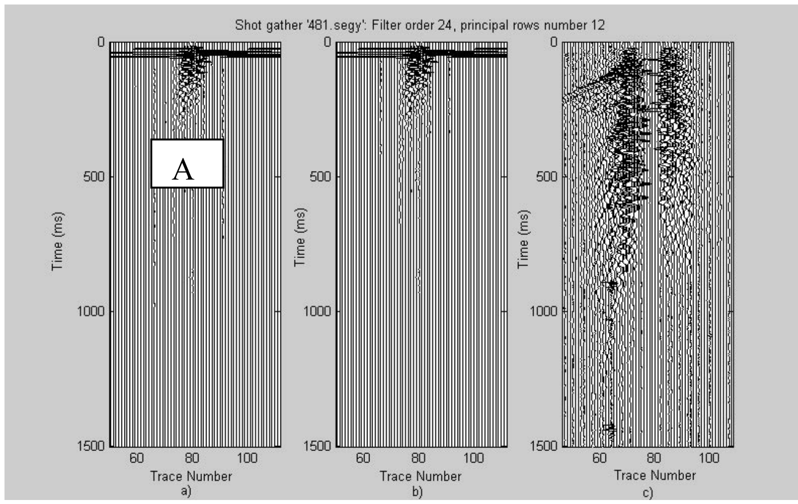

Figure 7. a) Shot gather '481.segy' containing high amplitude Ground Roll acquired with split-spread geometry. b) The Ground Roll extracted using the K-L Transform, with a filter order 24 and principal rows 12. c) Gather after the subtraction of the Ground Roll. "A" is the Ground Roll cone.

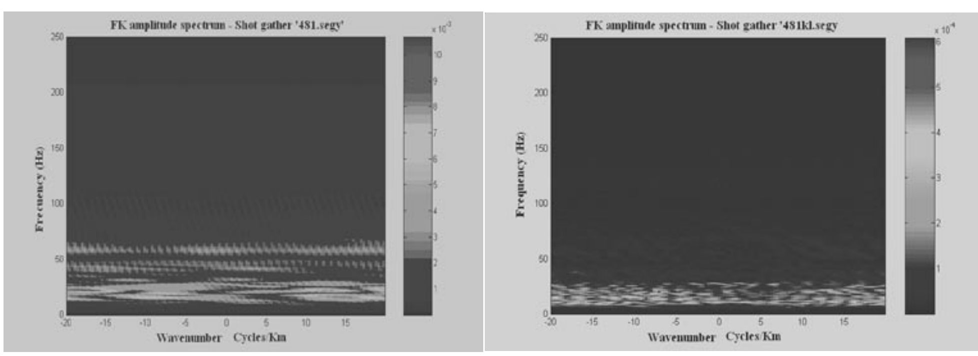

Figure 8. Shot gather '481.segy' amplitude spectrum before (left) and after (right) the application of the new KL Filter. Note in the red circle the existence of high amplitude and lower dips in the spectrum due to the great content of Ground Roll Waves, which diminish with the K-L Transform.

Shallow Survey

The 2D seismic data was acquired in October-2004 with a split spread configuration in the campus of the National University of Colombia, with a Geode seismic recorder with 24 channels for high resolution acquisition, the source consist in a hammer (8 kg) and geophones with vertical component.

The processing of the UN-01 Seismic Line provided stacked sections shown in Figure 9, on top conventional and on bottom with K-L. The section on bottom presents better results, increases lateral coherence and gives a clearer image. On the other hand, the KL suppresses unreal shallow events (indicated by the arrow), due to refractions that are observed with the conventional processing.

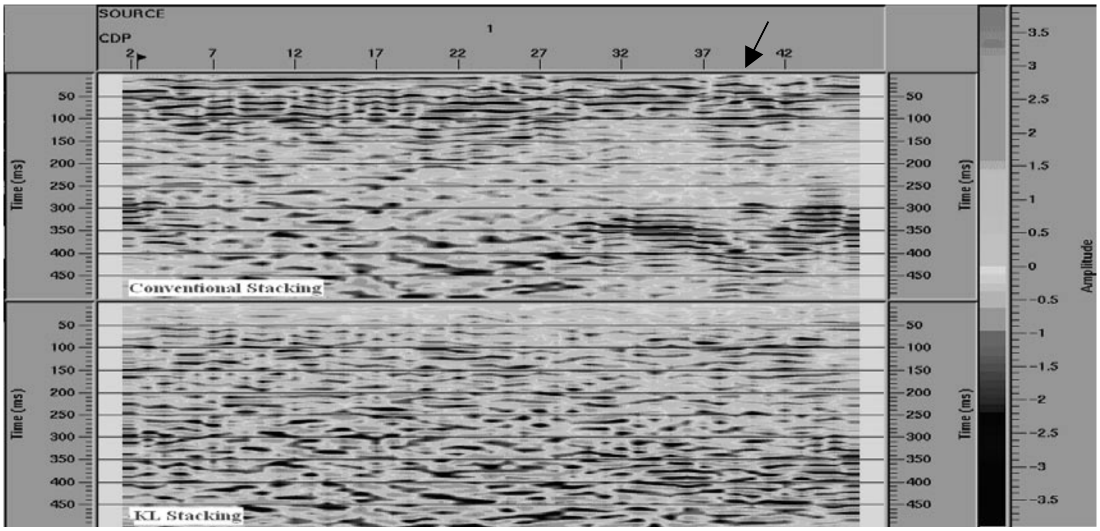

Figure 9. UN-01 Seismic Line with conventional processing until the stacking before (top) and after (bottom) the application of the new KL Filter. Although a substantial amount of coherent noise has been filtered out, the general waveform character has been maintained. Note that the section with the K-L displays one more a clearer and coherent image.

Deep Survey

This 2D data was acquired using a thumper in split spread configuration at Southern of the Middle Magdalena Valley, involving tertiary sediments from the Gualanday Group.

The stacked section in RM-01 in Figure 10 was obtained with conventional processing on bottom and with application of the K-L Transform on top. The top image presents a great rank of amplitude (-3 to 3) compared with the conventional stacked on bottom (-2 to 2) as observed into the red circles; indicating a better amplitude recovering in reflectors with K-L use, although the processing sequence did not include *fx Decon*. Besides the KL shows coherence and it does not present the whitening effect due to the conventional processing flow (Figure 10. Red square, bottom).

By the other hand, high dips (black arrow), are observed in conventional process image which are not true because the direction of seismic line was N-S, parallels to the beds strikes of the tertiary sediments with very smooth dips; in consequence they must be horizontals in the seismic section, as it is observed in the K-L image in agreement with the subsurface geology.

CONCLUSIONS

The Algorithm Karhunen-Loève is computationally economic and efficient to filter seismic data, providing coherent information of subsurface image.

The interactive spectral analysis showed more concentrations of high amplitude due to the Ground Roll, and it verifies that K-L Algorithm suppresses the Ground Roll waves. Also it is verified than the amplitude of the Ground Roll is stronger than the reflection signals. By using K-L Algorithm to extract the Ground Roll it suggests a form to suppress Ground Roll, without distorting the reflection signals.

Additionally, using K-L filter increases the lateral coherence of seismic events, in comparison with the three conventional methods of suppression: Filters *f - k*, High-Pass and Band- Pass. The algorithm was tested with raw gather containing Ground Roll (high amplitude) obtained from shallow and depth seismic land surveys with different source (hammer, dynamite and thumper. A lateral coherence increase is observed in stacked sections. The K-L use recovers the amplitude of the deep reflectors furnishing a resultant section more approximated to real geology.

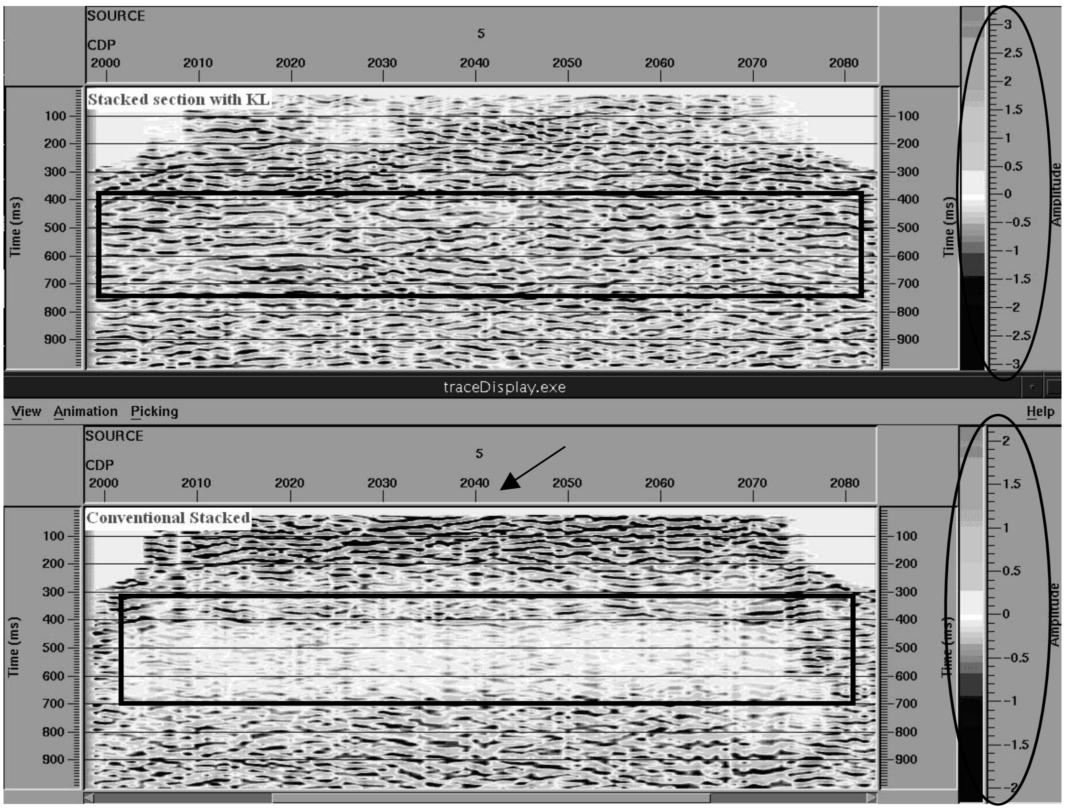

Figure 10. RM-01 Seismic Line with conventional processing until the stacking before (bottom) and after (top) the application of the new KL Filter. Although a substantial amount of coherent noise has been filtered out, the general waveform character has be
conventional stacked that are suppressed by the KL. Into the red square on the top the image enhancement of the seismic events with the KL is appraised.

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