Recursive estimation of reflectivity by minimum-delay seismic trace decomposition

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- By estimating a minimum-delay wavelet for each time-sample position of the seismic trace,
- Gives a decomposition of the seismic trace as a sum of minimum-delay wavelets.
- The data vector is equal to a wavelet matrix, which is lower triangular with elements 1 on the diagonal, multiplied by the seismic reflectivity vector.
- Recursive solution of this equation provides an estimate of reflectivity.

SEISMIC TRACE DECOMPOSITION

We consider a seismic trace $d(t), t = 0, 1, \ldots, L$, and choose a data window $d(k+j), j = 0, 1, \ldots L_d$. The local auto-correlation function is

$$R_k(\tau) = \sum_j d(k+j)d(k+j+\tau)\,, \quad \tau = 0, 1, \ldots, L_d$$

From this we use the Levinson (1947) algorithm to compute a damped spiking filter (Robinson, 1967)

$$[R_k(\tau) + \lambda^2\delta_\tau] * g_k(\tau) = \sigma^2\delta_\tau$$

The inverse of the spiking filter is a minimum-delay wavelet computed directly from

$$g_k(t) * w_k(t) = \delta_t \qquad\qquad w_k(t) = \begin{cases} 1 & t = 0 \\ 0 & t > L_w \end{cases}$$

This can be written in vector-matrix notation as

$$\begin{pmatrix} d(0) \\ \vdots \\ \vdots \\ \vdots \\ d(L) \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ w_0(1) & 1 & 0 & 0 & 0 \\ \vdots & \ddots & \ddots & 0 & 0 \\ w_0(L_w) & \ddots & \ddots & 1 & 0 \\ 0 & \ddots & \ddots & w_{L-1}(1) & 1 \end{pmatrix} \begin{pmatrix} r_0 \\ \vdots \\ \vdots \\ \vdots \\ r_L \end{pmatrix}$$

$$\mathbf{d} = \mathbf{W}\mathbf{r} \qquad\qquad (1)$$

TIME-VARYING DECONVOLUTION

In time-varying deconvolution we compute and apply a different filter for each time sample.

$$\hat{r}_k = \sum_{\tau} d(t-k-\tau) g_k(\tau)$$

This can be written

$$\begin{pmatrix} \hat{r}(0) \\ \vdots \\ \vdots \\ \vdots \\ \hat{r}(L) \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 \\ g_1(1) & 1 & 0 & 0 & 0 \\ \vdots & \ddots & \ddots & 0 & 0 \\ \ddots & \ddots & \ddots & 1 & 0 \\ 0 & g_L(L_f) & \ddots & g_L(1) & 1 \end{pmatrix} \begin{pmatrix} d_0 \\ \vdots \\ \vdots \\ \vdots \\ d_L \end{pmatrix}$$

$$\widehat{\mathbf{r}} = \mathbf{G}\mathbf{d} \qquad (2)$$

COMPARISON

Combining eq. (1) and (2) we obtain

$$\widehat{\mathbf{r}} = \mathbf{G}\mathbf{W}\,\mathbf{r} \qquad (3)$$

The matrix F = GW is also lower triangular with elements 1 on the diagonal. It is, however, different from the identity matrix, so that the two estimates of reflectivity are different.

From equation (1) we have

$$\mathbf{r} = \mathbf{W}^{-1}\mathbf{d}$$

The lines of inverse matrix can now be considered as time-varying filter impulse responses. They are, however, not necessarily minimum delay.

The new process is a decomposition of the seismic trace in minimum delay wavelets.

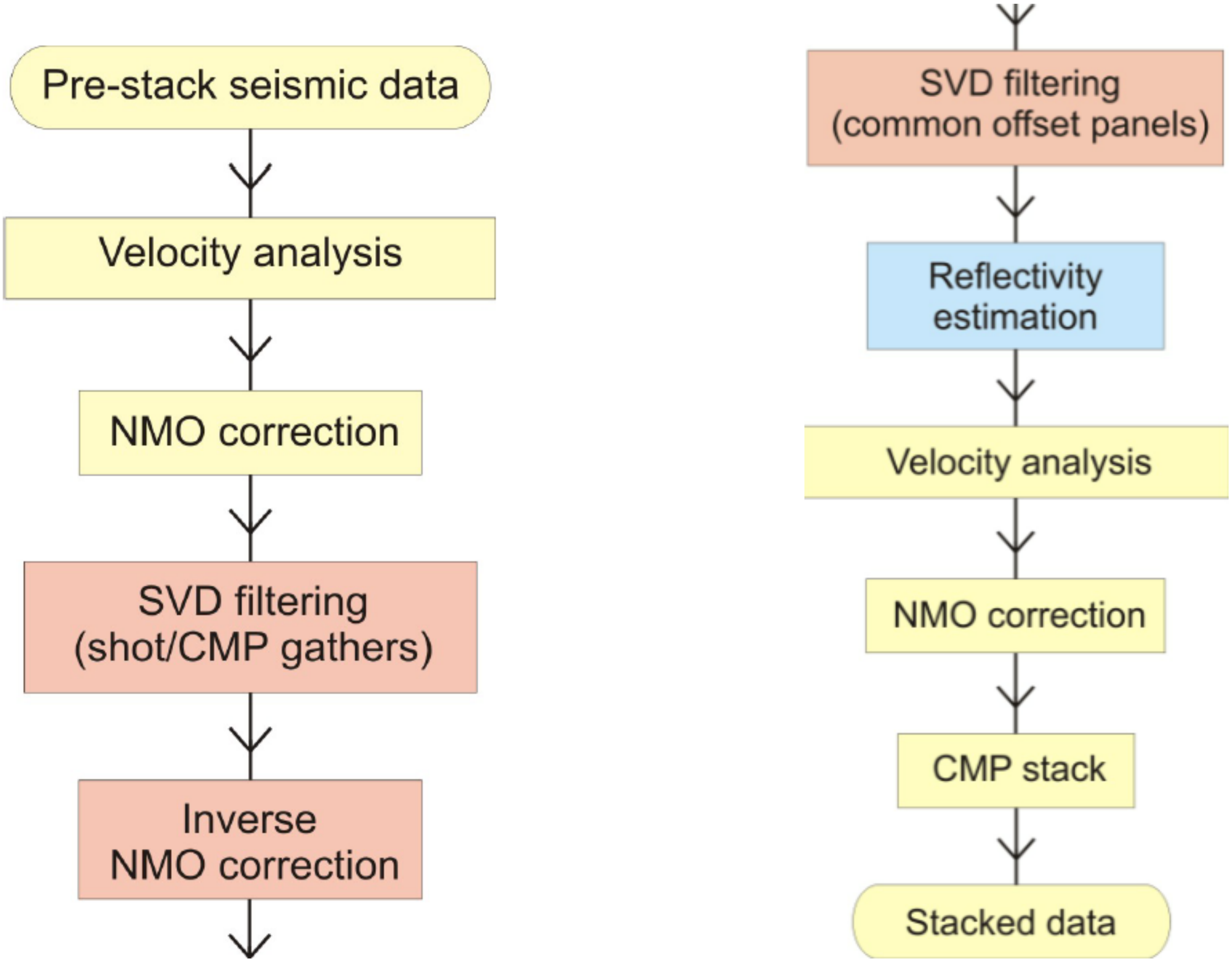
The recursive estimate of the reflectivity may also be considered to be the output of a mixed-delay time-varying filtering procedure.

LAND DATA PROCESSING EXAMPLE

Land seismic line from the Tacutu basin,
located in the North-east of Brazil

- 179 shots recorded at 4 ms sampling interval
- 96 channels per shot
- split-spread geometry with offsets from -2.500 m to -150 m and 150 m to 2.500 m and 200 m
- The distance between the shots is 200 m, giving a low CMP coverage of 12 fold

Flowchart of the seismic data processing:



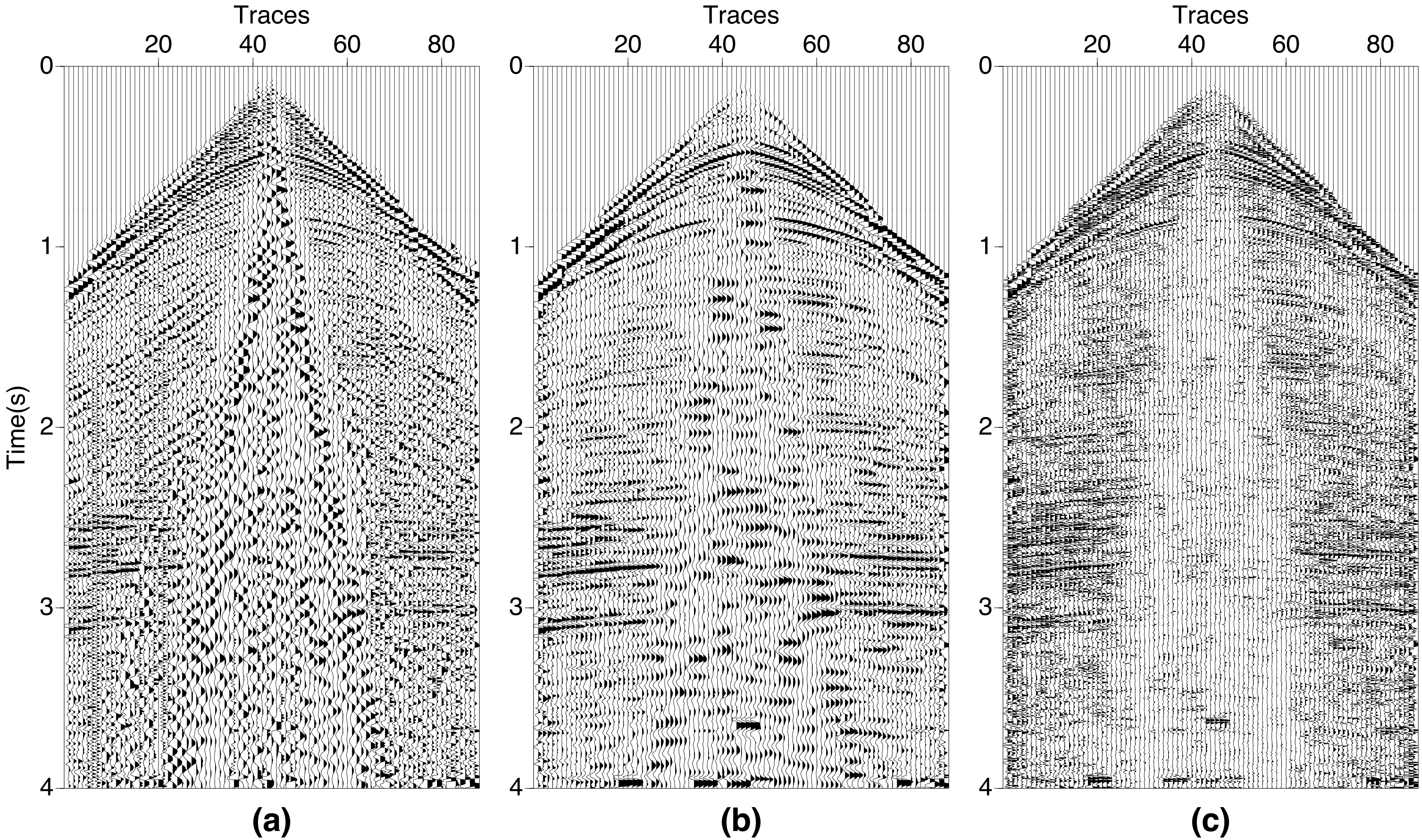
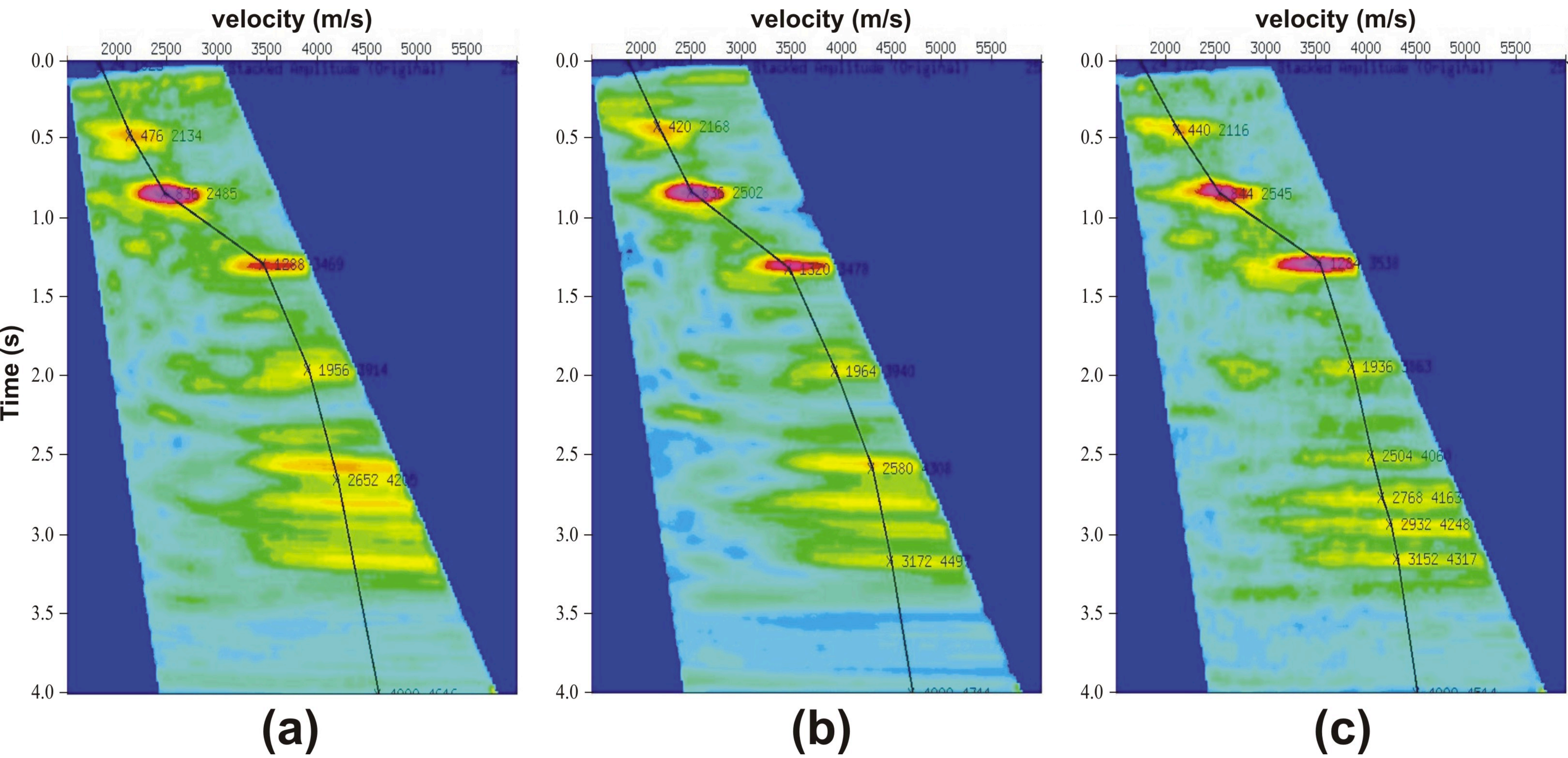
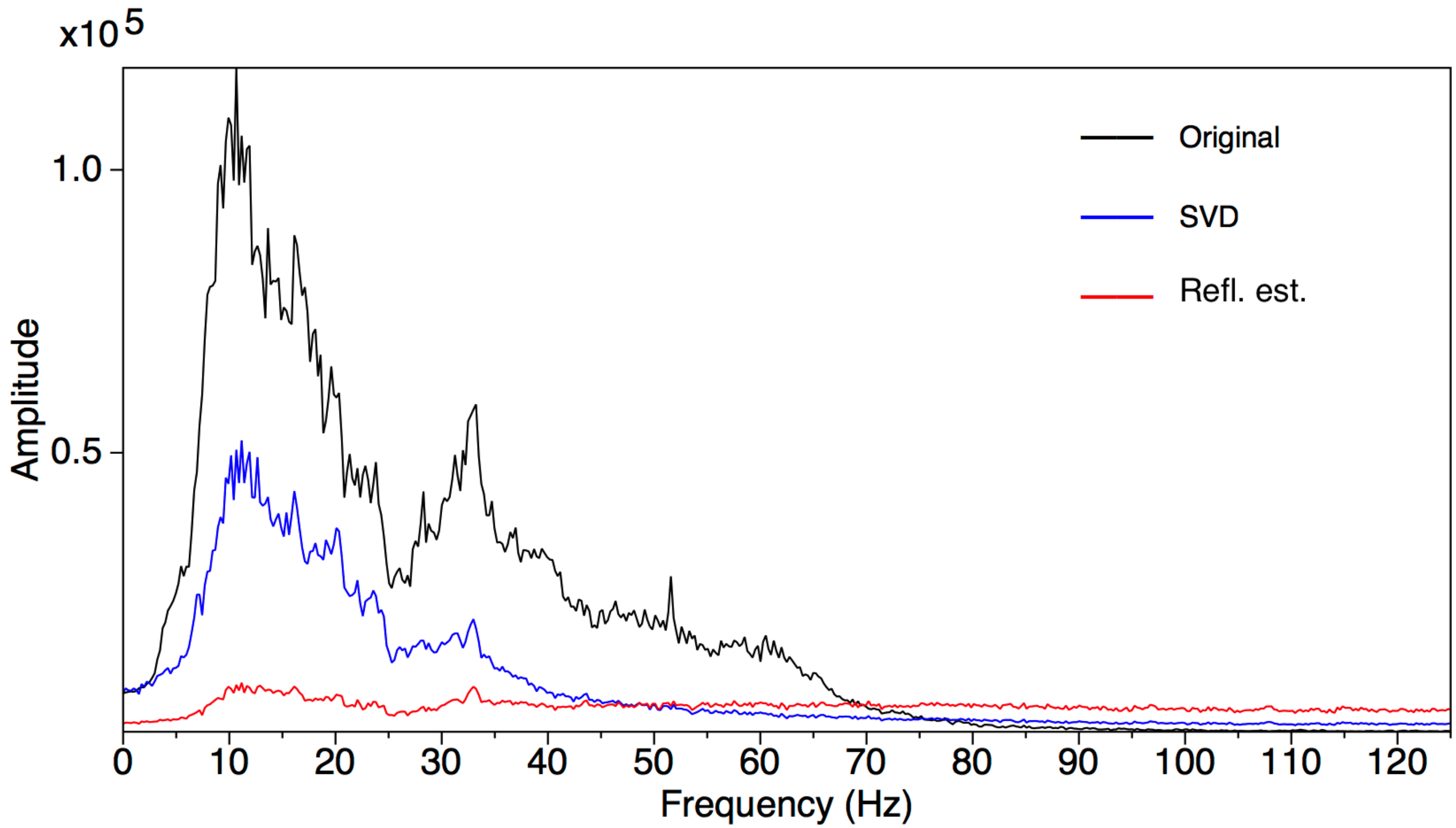


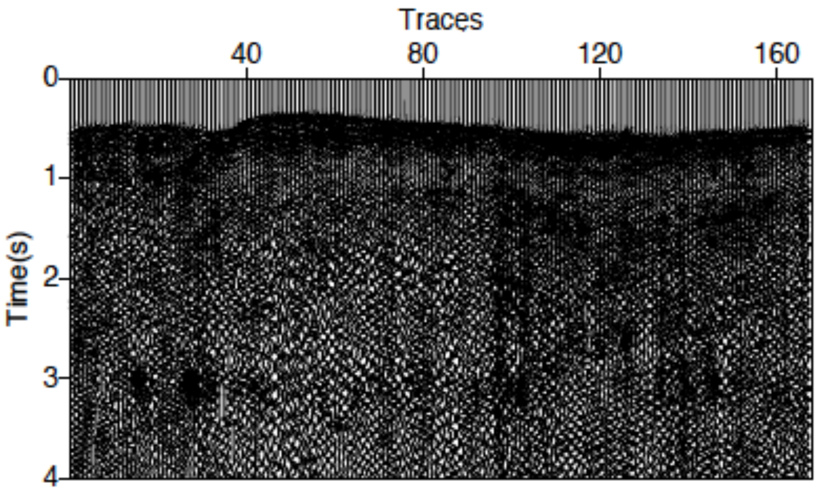
Figure 2: Comparison of SVD and reflectivity estimation filtering of a shot gather. Input data in (a), after SVD filtering (b) and after SVD filtering followed by recursive reflectivity estimation (c).



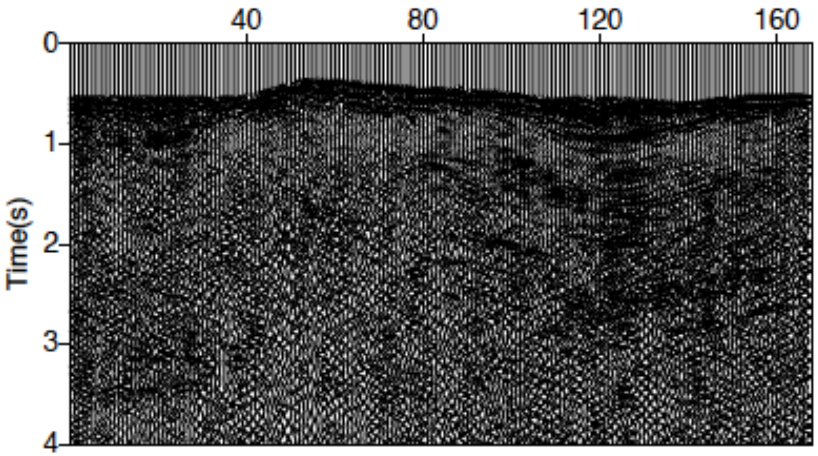
Velocity analysis plots corresponding to the three gathers in Fig. 2 with matching (a), (b), and (c).



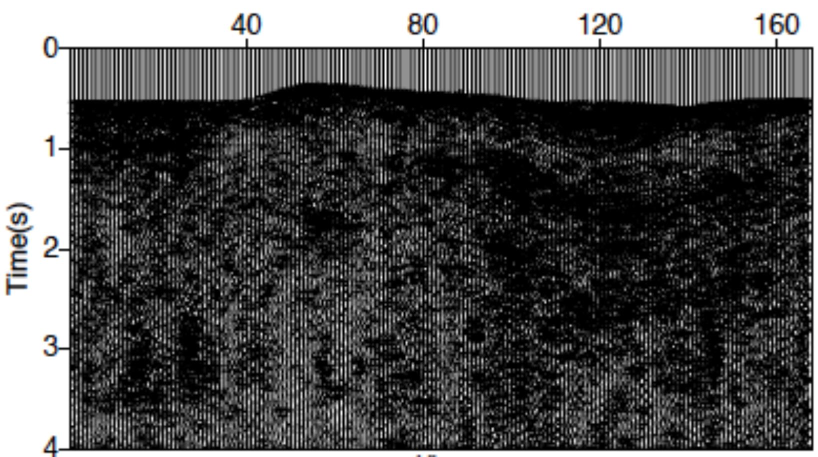
Average amplitude spectrum of the shot gathers in Fig. 2.



A common-offset panel at 2050m

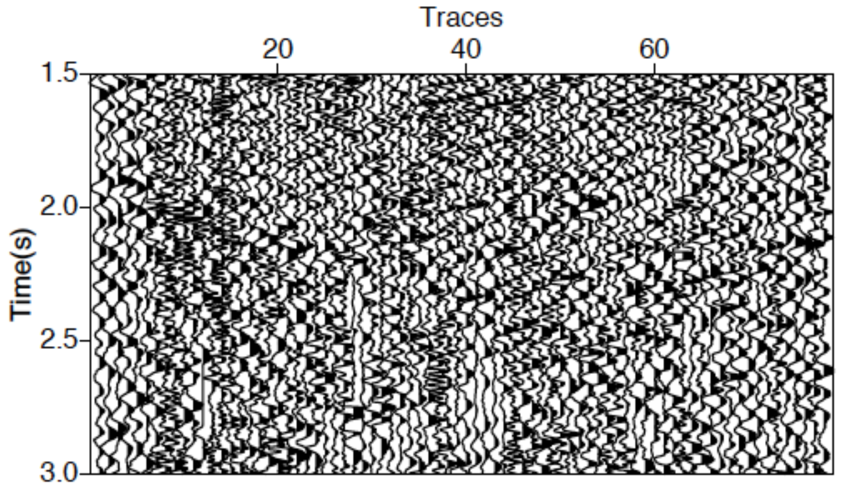


After SVD filtering

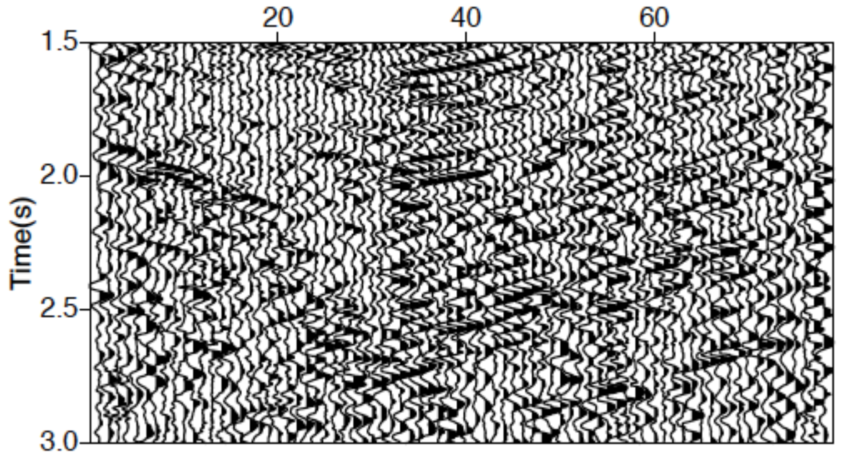


After SVD filtering followed by reflectivity estimation

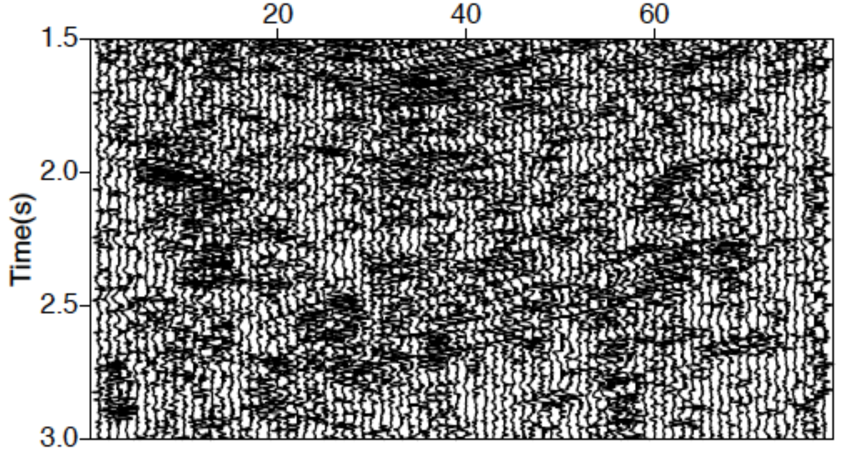
Detail of a common-offset panel



A common-offset panel at 2050m

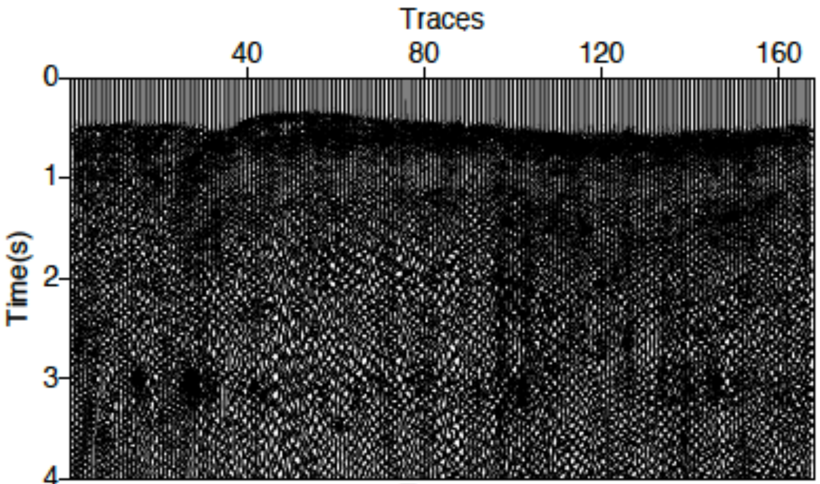


After SVD filtering

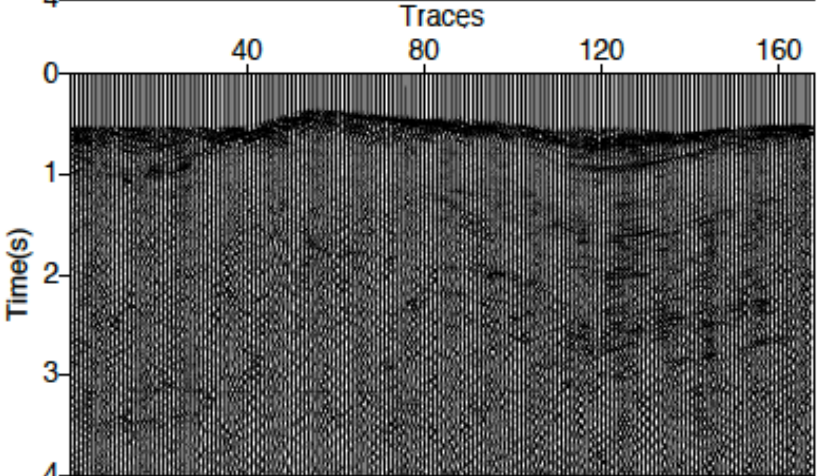


After SVD filtering followed by reflectivity estimation

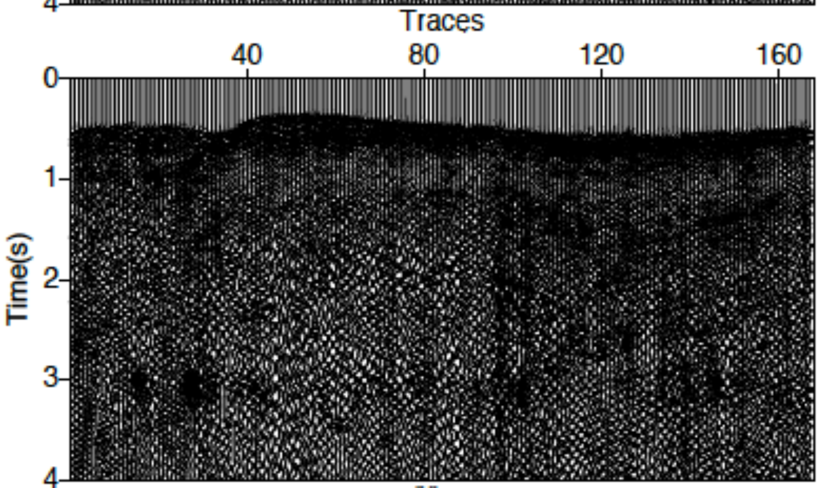
Removed noise in common offset panels



After SVD filtering

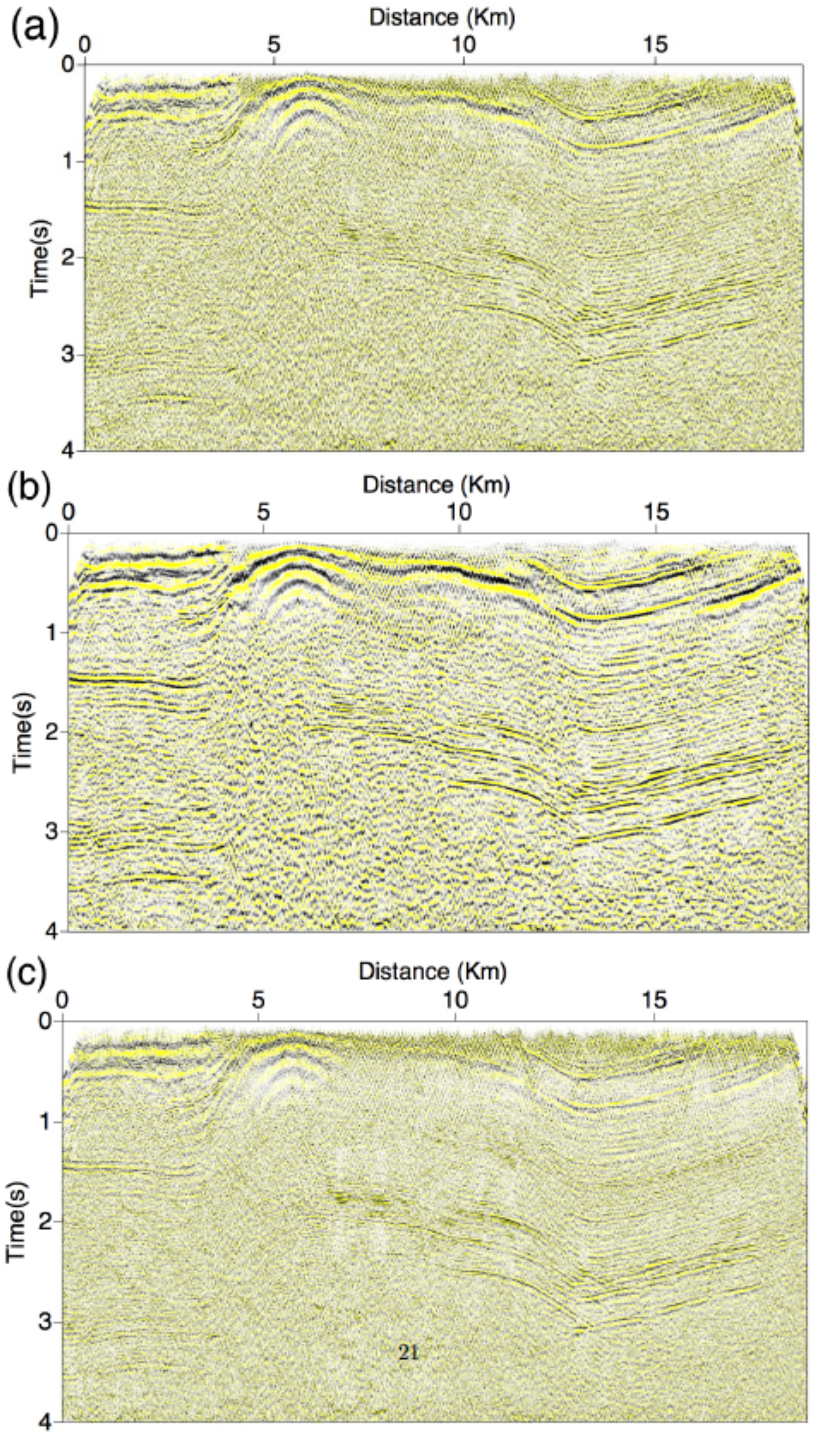


Additional noise removed by reflectivity estimation



Total removed noise after SVD filtering followed by reflectivity estimation

Stacked sections

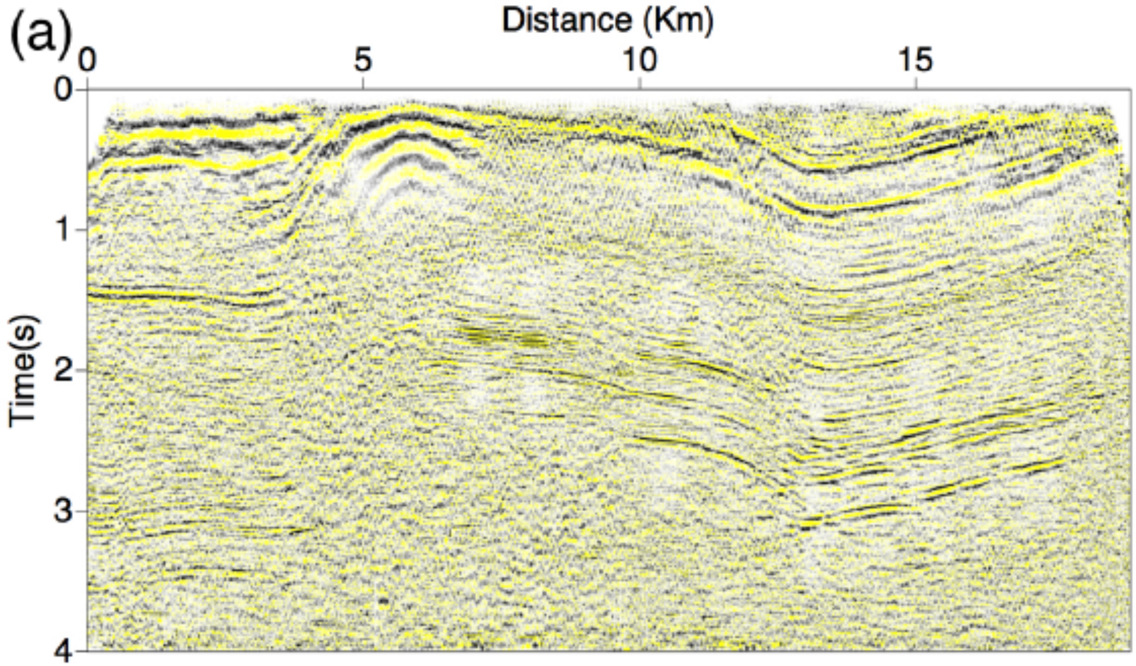


Original data

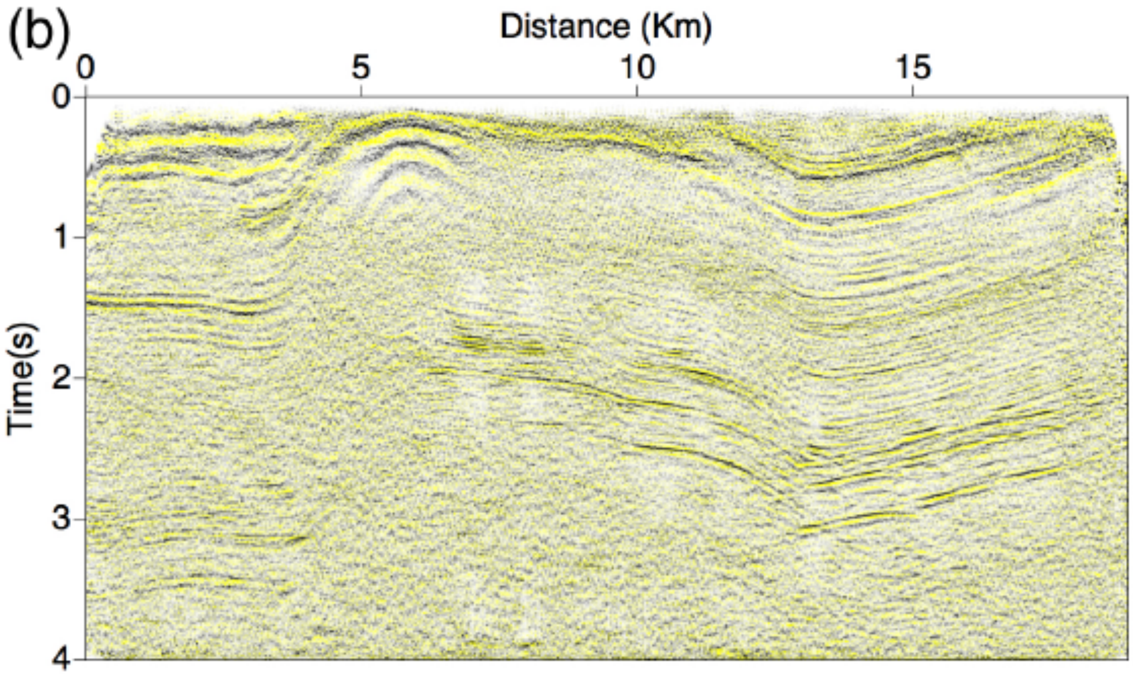
After adaptive SVD filtering

After recursive reflectivity estimation

Stacked sections

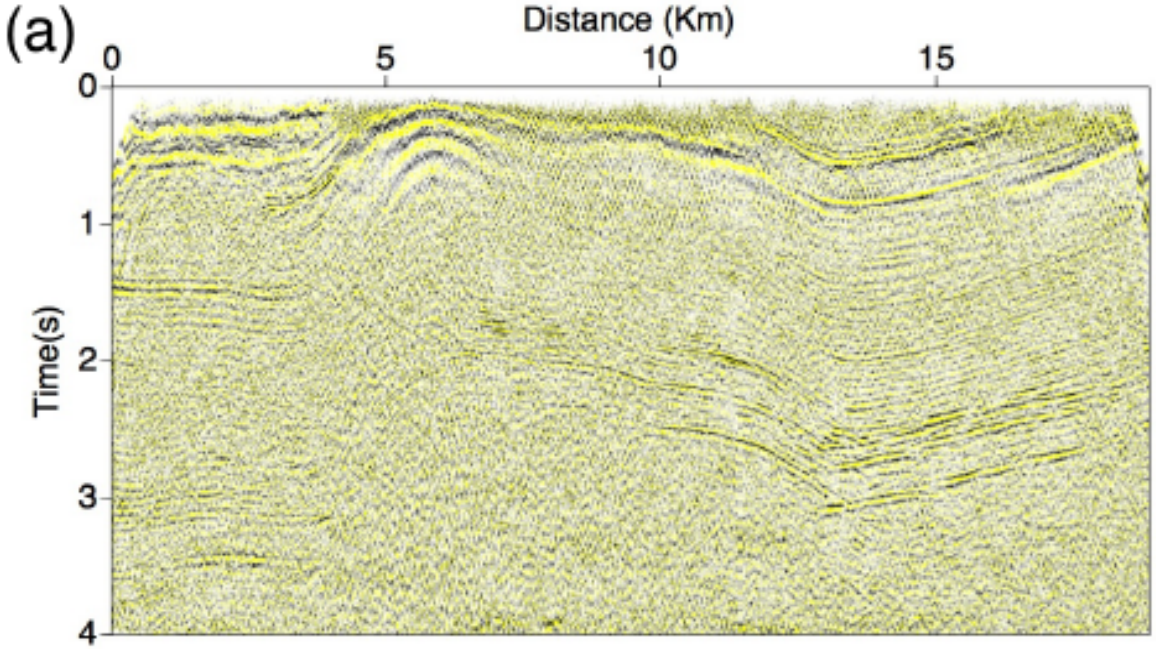


After recursive reflectivity estimation followed by adaptive SVD filtering

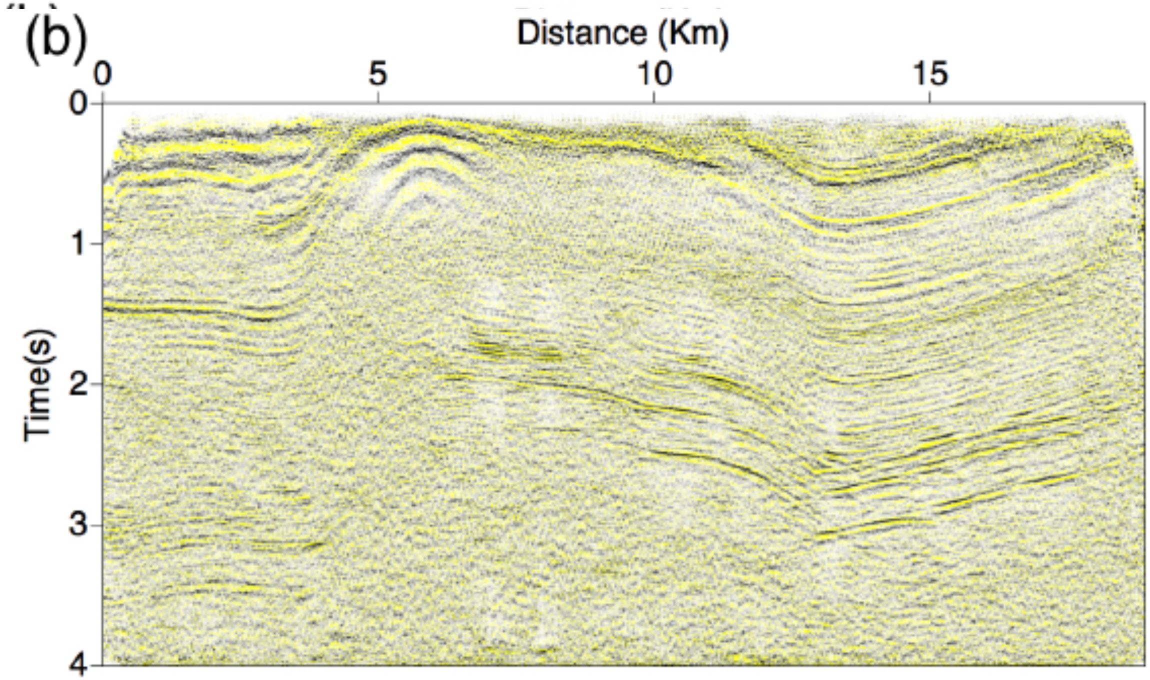


After adaptive SVD filtering followed by recursive reflectivity estimation

Stacked sections



Original data



After adaptive SVD filtering followed by recursive reflectivity estimation

CONCLUSION

- A new method for estimating seismic reflectivity by decomposition of a seismic trace in minimum-delay wavelets.
- The method improves vertical resolution for a source wavelet which is close to minimum delay.
- For a mixed-delay source wavelet one may apply an all-pass phase filter before or after the reflectivity estimation.
- We have also developed a data processing strategy for noise removal and signal enhancement by combining adaptive SVD filtering with reflectivity estimation.
- The SVD filtering removes noise and improves lateral continuity while the reflectivity estimation increases the high-frequency content in the data and improves vertical resolution.

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