Six tests of sparse log decon

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ABSTRACT

Previously, we developed a sparseness-goaled decon method. Here we test it on six data sets. None showed the unfortunate phase-shift we always see with minimum-phase decon. None showed the polarity reversals or time shifts that perplexed our earlier work. Results on all six data sets enhance polarity visibility. We had expected to see sparseness decon limit the bandwidth in some natural way unlike prediction-error decon with its white output. Instead, in all the cases our sparseness decon boosted frequencies much the way predictive decon does. We had not expected to see an estimated shot waveform containing a lot of low-frequency sea surface waves. One such result provoked a new theoretical development not yet tested (Claerbout and Guitton, 2012).

INTRODUCTION

We have tested our basic sparse deconvolution method on six data sets. Results are generally positive, but not totally as expected. We are pleased to report none of the results here showed the kind of phase-shift issues we always see with minimum-phase decon. For the most part, the decons enhance the appearance of polarity. One of the data sets (DATA4) had a clearly defective gun array with an extremely non-minimum phase wavelet and our deconvolution worked wonders on it (see Figure 5).

One problem persisted until about six months ago: we could not be sure which of the three lobes of the Ricker wavelet would be enhanced. Then a new regularization, proposed theoretically, ensured spiking on the central Ricker lobe, meaning we shall no longer see apparent polarity reversals or time shifts.

We had expected to see that sparseness would limit the bandwidth in some natural way. Instead, in all the cases the sparseness decon boosted frequencies much the same way predictive decon does. Worse yet, one of the shot waveforms contained a lot of low-frequency sea surface waves. Serendipitously this bad result provoked Jon Claerbout to introduce theory augmentations (Claerbout and Guitton, 2012) that have not yet been coded or tested.

REGULARIZATIONS

Because predictive decon fails on the Ricker wavelet, Zhang and Claerbout (2010) devised an extension to non-minimum phase wavelets. Then Claerbout et al. (2011)

replaced the traditional unknown filter coefficients by lag coefficients u_t in the log spectrum of the deconvolution filter. Given data $D(\omega)$, the deconvolved output is

$$r_t \;=\; \mathrm{FT}^{-1} \left[D(\omega) \;\exp\left(\sum_t u_t Z^t \right) \right] \tag{1}$$

where $Z = e^{i\omega}$. The log variables u_t transform the linear least squares (ℓ_2) problem to a non-linear one that requires iteration. The gained residual $q_t = g_t r_t$ is "sparsified" by minimizing $\sum_t H(q_t)$ where

$$q_t \;=\; g_t \; r_t \tag{2}$$

$$H(q_t) \;=\; \sqrt{q_t^2 + 1} - 1 \tag{3}$$

$$\frac{dH}{dq} \;=\; H'(q) \;=\; \frac{q}{\sqrt{q^2+1}} \;=\; \mathrm{softclip}(q) \tag{4}$$

Traditional decon approaches are equivalent to choosing a white spectral output. Here we opt for a sparse output.

Earlier frustrations led to various regularizations. We minimize the following functional:

$$J(\mathbf{u}) = |\mathbf{q}|_{hyp} + \frac{\epsilon_1}{2}\|\mathbf{W}_1\mathbf{u}\|_2 + \frac{\epsilon_2}{2}\|\mathbf{W}_2\mathbf{J}\mathbf{u}\|_2 \tag{5}$$

where bold faces are for either vectors or matrices. The first regularization term tends to limit the range of filter lags (Figure 1). The second term, introduced by Claerbout et al. (2012) encourages symmetry ($u_{-\tau} = u_\tau$) around the central Ricker lobe. It does this by a matrix $\mathbf{J}$ that senses asymmetry $u_\tau - u_{-\tau}$ at small lags τ and suppressing it.

The gradient search direction becomes

$$\Delta\mathbf{u} = \sum_t (r_{t+\tau})\,(g_t H'(q_t)) + \epsilon_1 \mathbf{W}_\mathbf{1}' \mathbf{r}_{u1} + \epsilon_2 \mathbf{J}'\mathbf{W}\mathbf{r}_{u2} \tag{6}$$

It happened in all the examples in this paper (except the one with a defective airgun array) the ϵ_2 "Ricker regularization" was not needed because no polarity reversals or apparent time shifts were noted so $\epsilon_2 = 0$ in all cases. The value of ϵ_1 was selected by trial and error.

Data plots

Data panels have gained raw data on the left and the results of sparseness decon on the right. Observe how they almost invariably show the sparseness panel preserving signal polarity.

Sparse decon is applied on six different data sets referred as DATA4, DATA5, DATA6, DATA8, DATA11 and DATA12.

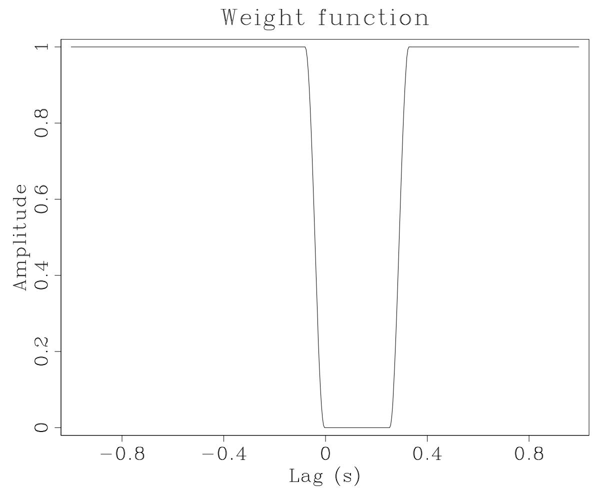

Figure 1: Weighting function used in the regularization to force long lags to be zero. The positive lags allow more non-zero coefficients to include the bubble. These limits apply in the lag-log space of u_τ and so apply only approximately to the shot waveform and the decon filter. [**ER**]

DATA4 was dug out from our SEP data server (Δt=2 ms). Its origins are unknown.

DATA5 is a common-offset section from the Gulf of Mexico (Δt=4 ms). It was Yang's "discovery" data set, in many ways still the most interesting data set, but with some problems noted.

DATA6 is a common-channel section from a 2-D line shot in Baja California (Lizzaralde et al., 2002) during the PESCADOR experiment (Δt=4 ms). It was downloaded from the academic seismic portal at the University of Texas, Austin (http://www.ig.utexas.edu/sdc/)

DATA8, 11 and 12 are unprocessed, raw common-channel sections coming from 2-D lines shot offshore Washington state as part of the COAST project (Δt=2 ms).

Spectral plots

The spectrum calculation in all the cases (except for DATA4) is based on gaining the output by t^{tpow}. The value of *tpow* was chosen to balance amplitudes throughout the section. With the sparse decon, that gain is done after filtering. We have since decided a more appropriate gain function is $t^2/t_0(x)$ where $t_0(x)$ is water depth, but our software to do it requires completion and more testing.

Unexpectedly, we found that sparse decon yields nearly white output for all six datasets. Its whiteness is comparable to that of the Burg decon. We had hoped it would drop off naturally at high and low frequencies as those frequencies should contribute little to sparseness. This observation was another prod to Jon Claerbout to revise the current sparseness theory to an augmented theory found elsewhere in this report. This augmented theory provides those "bad frequencies" another place to go besides the decon output.

Shot waveforms

The shot waveforms turned out to be Ricker like in all cases except DATA4 which clearly has misfiring guns.

ACKNOWLEDGMENTS

We thank workers here at SEP that worked earlier in this area. Yang Zhang's classic result charged up our initial enthusiasm. Yi Shen and Qiang Fu coded up the logarithmic parametrization and found it generally superior to the earlier product parametrization. Qiang Fu's last work (unpublished) eventually led Jon to the long needed "Ricker regularization".

We thank Bob Clapp for extracting for us 2-D constant-line data sets from a 3-D data set here at SEP. Unfortunately that data turned out to be uninteresting.

We gratefully acknowledge Steve Holbrook for sending us DATA8, 11 and 12. We feel more confidence than usual that his data was unprocessed before we received it. We also gratefully thank Stew Levin for importing Holbrook's SEG-D data into the SEP system. We thank him also for reading and struggling to convert other data offered freely on the internet but which contained many glitches and ultimately turned out to be too noisy to be of interest.

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Lizzaralde, D., G. Axen, G. Kent, J. Fletcher, A. Gonzalez, A. Harding, S. Holbrook, and P. Umhoefer, 2002, PESCADOR seismic experiment. funding agency: NSF. data set accessed 20 july 2012 at http://www.ig.utexas.edu/sdc/.

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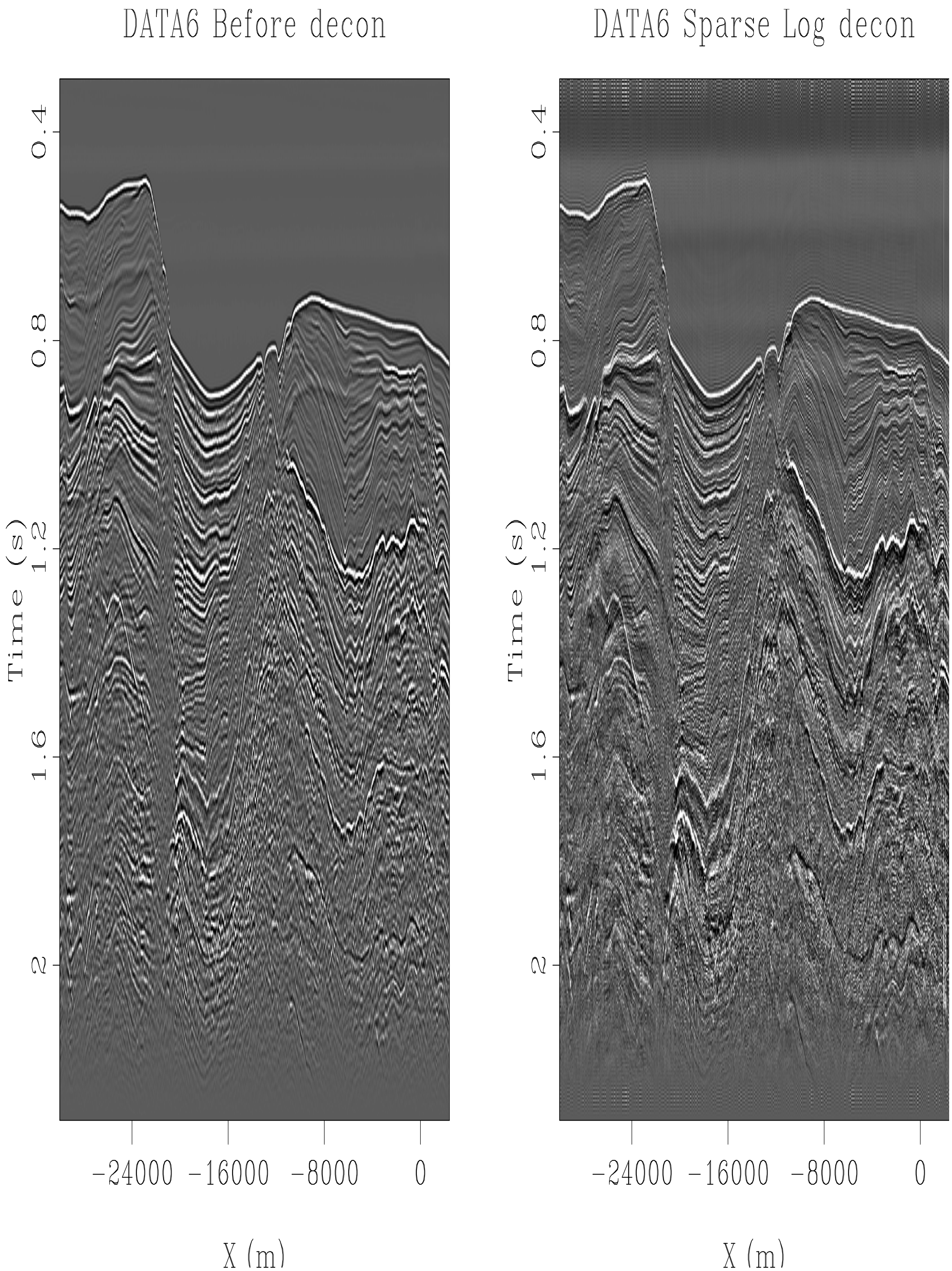


Figure 2: Data set from Baja California. The decon is bringing up some low frequencies after strong events in the water, but not after the water bottom. We observed that the Burg predictive decon does the same (not shown here). We feel this is wrong, most likely a result of this data having an unknown preprocessing history, likely a low-cut filtering of the sea swell. [**ER**]

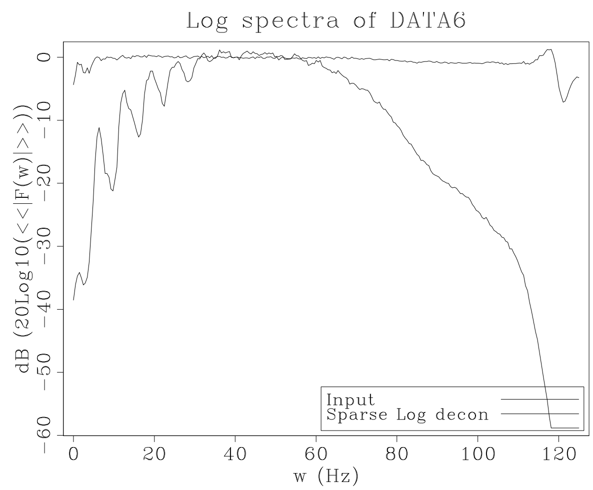


Figure 3: The data spectrum shows we have 4ms sampling. Sparse decon is almost as white as an industry PEF. [**ER**]

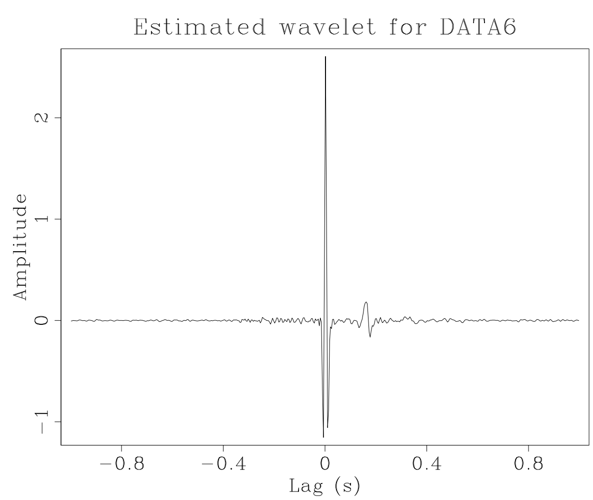


Figure 4: A shot waveform beautifully consistent with our preconceived ideas about causality, Ricker wavelets, and bubbles. [**ER**]

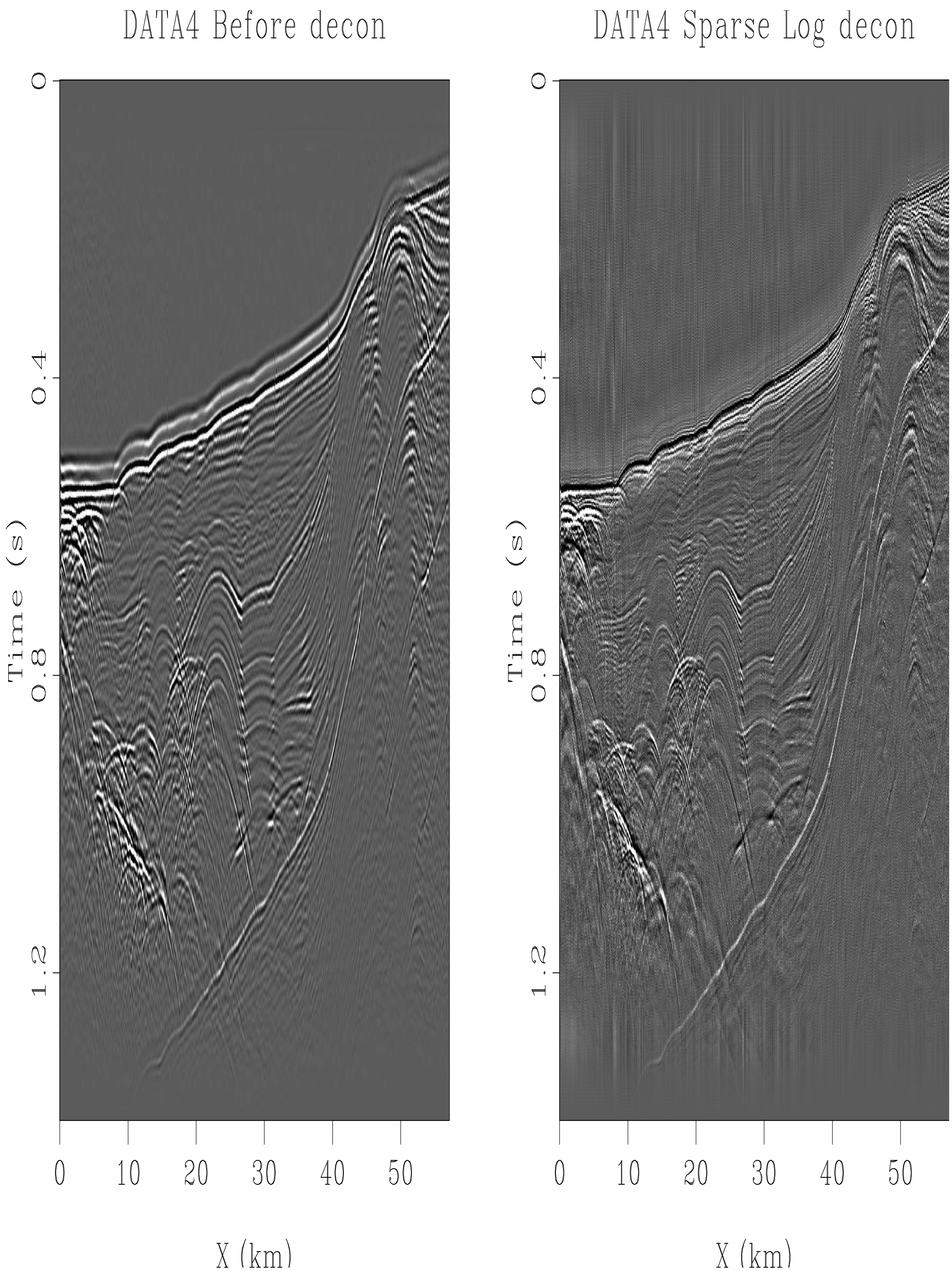


Figure 5: This data was very badly recorded (precursor to main pop) and would have been tossed out except that it very nicely demonstrates sparse decon's ability to handle a drastically non-minimum phase source. [**ER**]

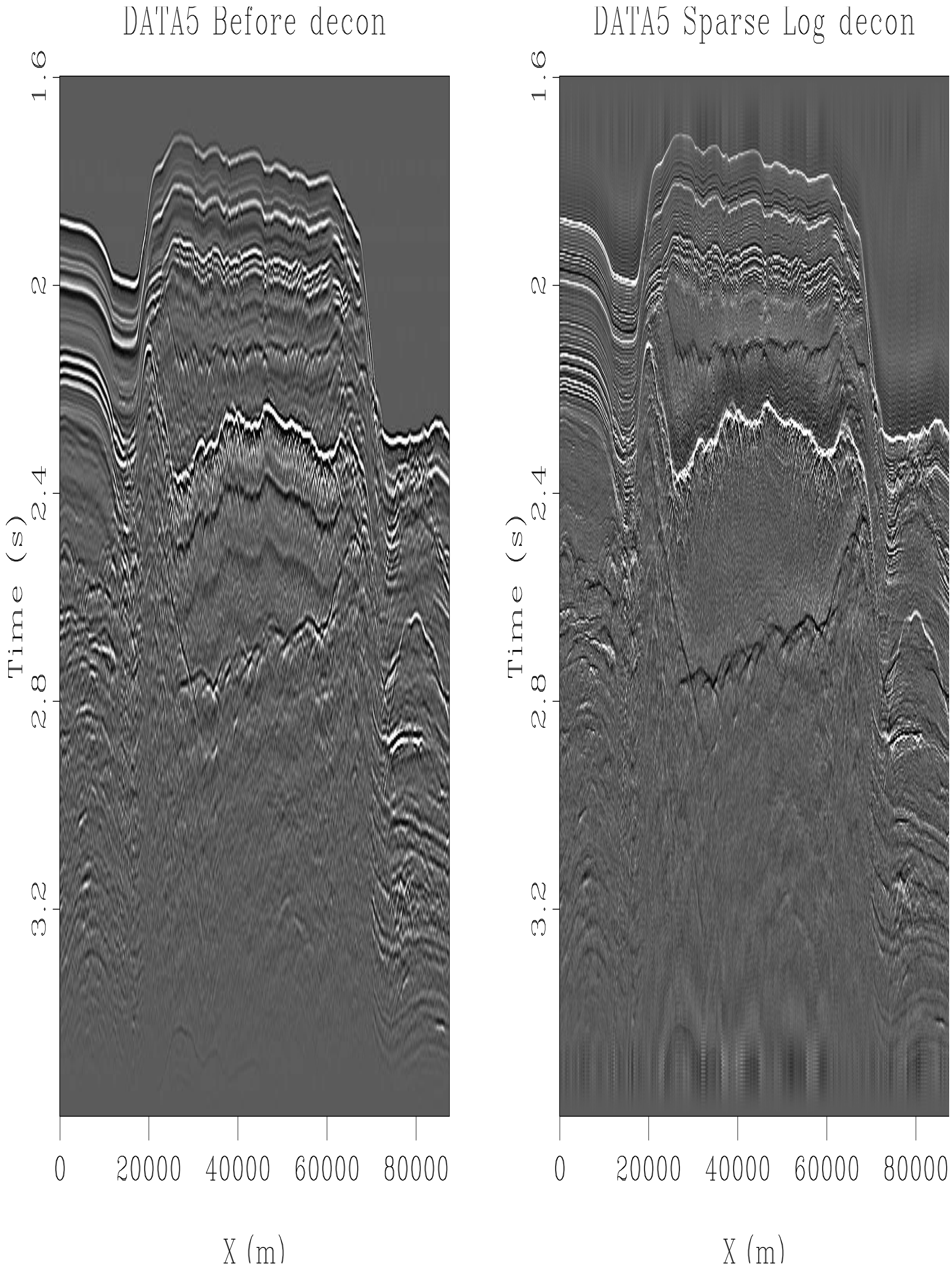


Figure 6: Yang's discovery data set from the Gulf of Mexico. We love this one because it shows so clearly the opposite wave polarity (black) on the bottom of the salt (2.7 sec). It also shows another delightful soft layer (black), a rugose layer above the top of salt (2.1 sec). [**ER**]

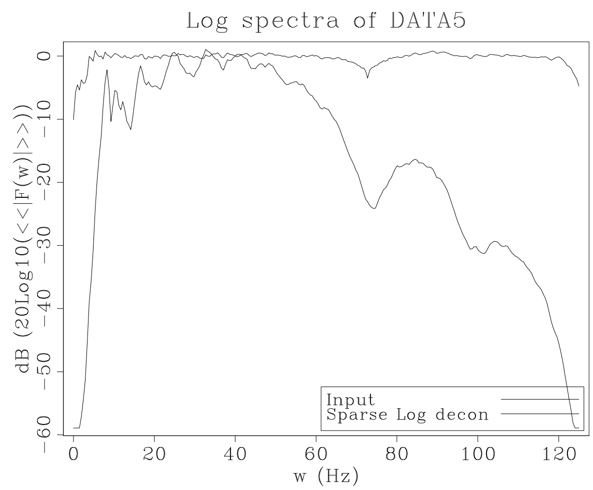


Figure 7: The data spectrum shows we have 4ms sampling. Sparse decon output is almost as white as an industry PEF decon (not shown). Again it's annoying that the sparse decon so strongly boosts very high and very low frequencies. [**ER**]

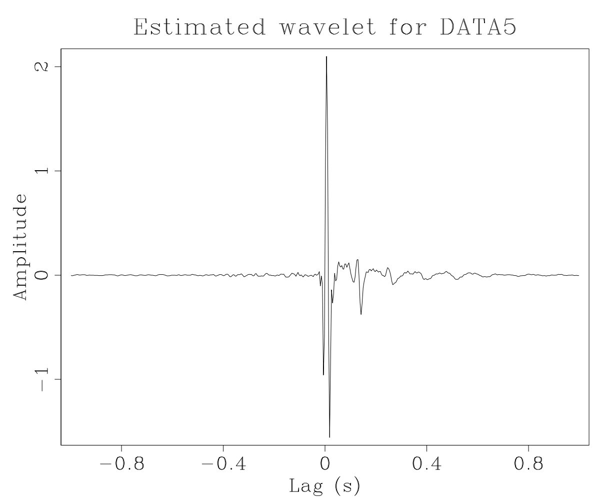


Figure 8: A shot waveform with good causality and bubble, but would be improved if we were to use some of the "Rickerness" regularization. [**ER**]

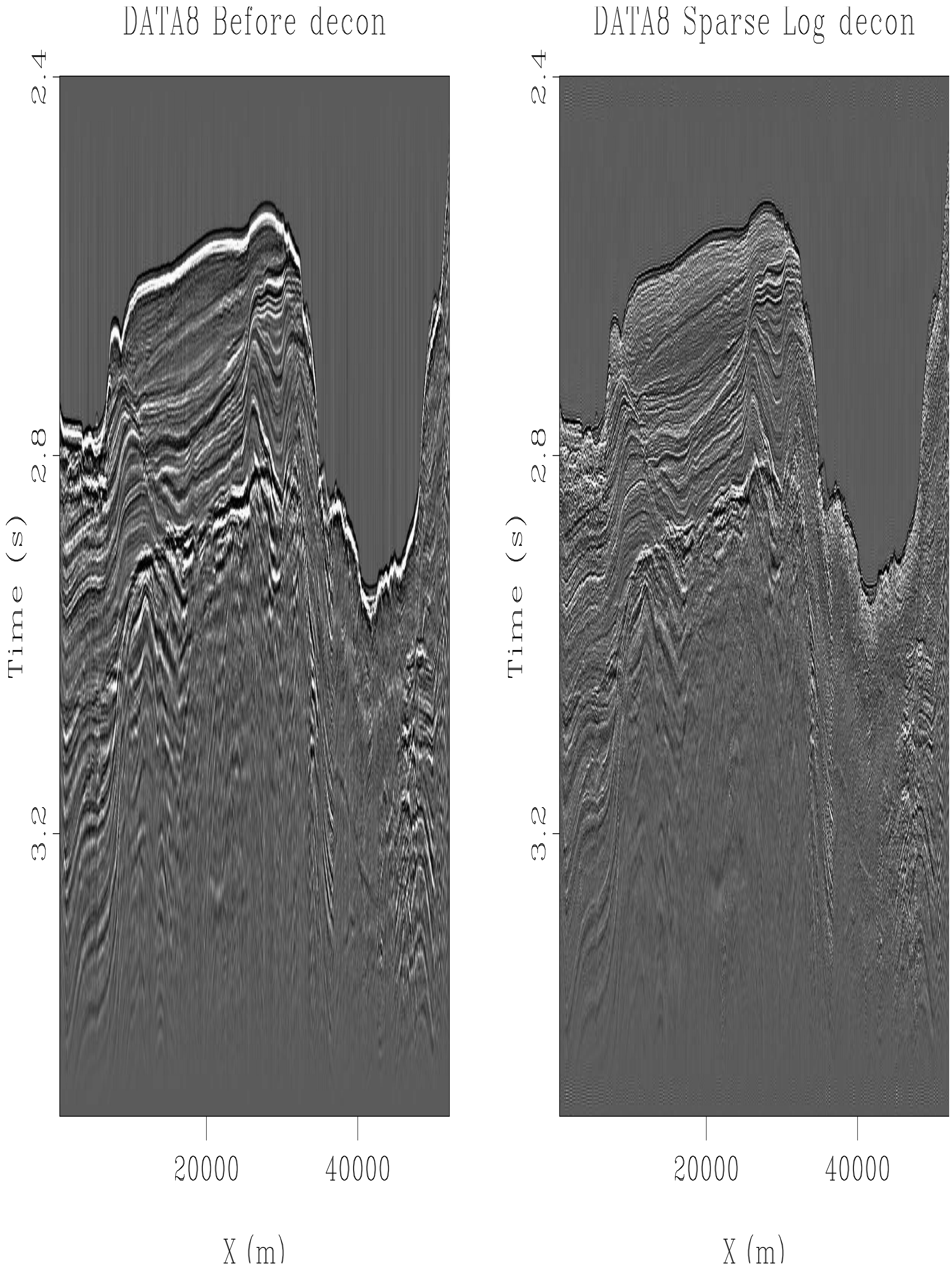


Figure 9: The data set from offshore Washington. This data set misbehaves. The water bottom does not look as Ricker-like as we usually see and the sparseness decon happens to have spiked the first lobe instead of the middle lobe. So this is a case for which we might like to introduce some "Ricker regularization". [**ER**]

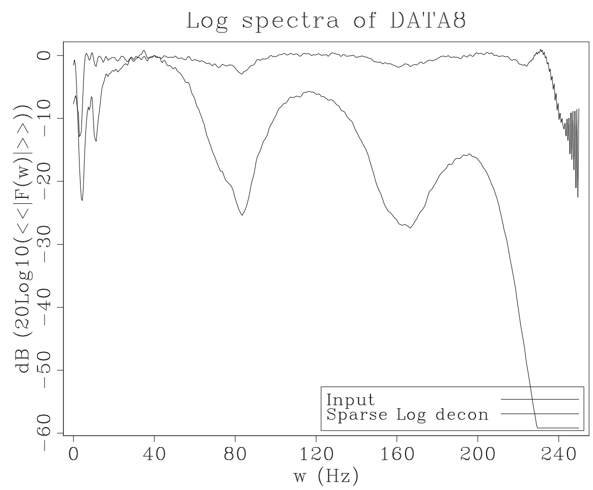


Figure 10: The spectrum shows sparse decon pulling up frequencies all the way to 240Hz. This is very suspicious! Essentially, the same result (not shown) was seen with DATA11 and DATA12. This result is unexpected to us. We suspect it means we will find such a result with almost any 2ms data set. [**ER**]

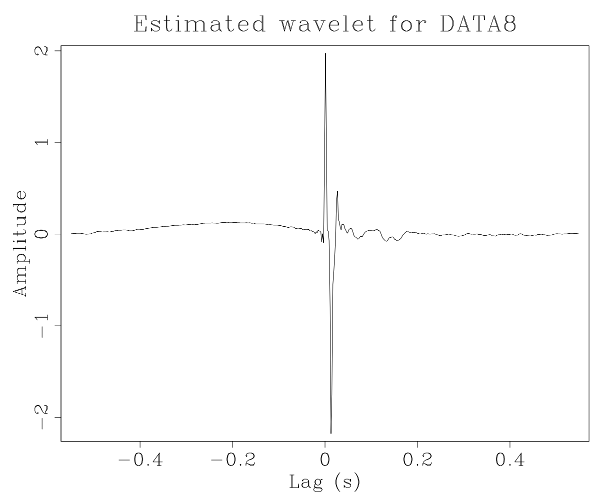


Figure 11: This shot waveform is obviously wrong. Understanding why was a great boon to Jon Claerbout who has an augmented theory paper in this report. The shot waveform here appears to have a low frequency that has soaked up a lot of the ocean surface-wave frequency, a fraction of a Hertz. [**ER**]

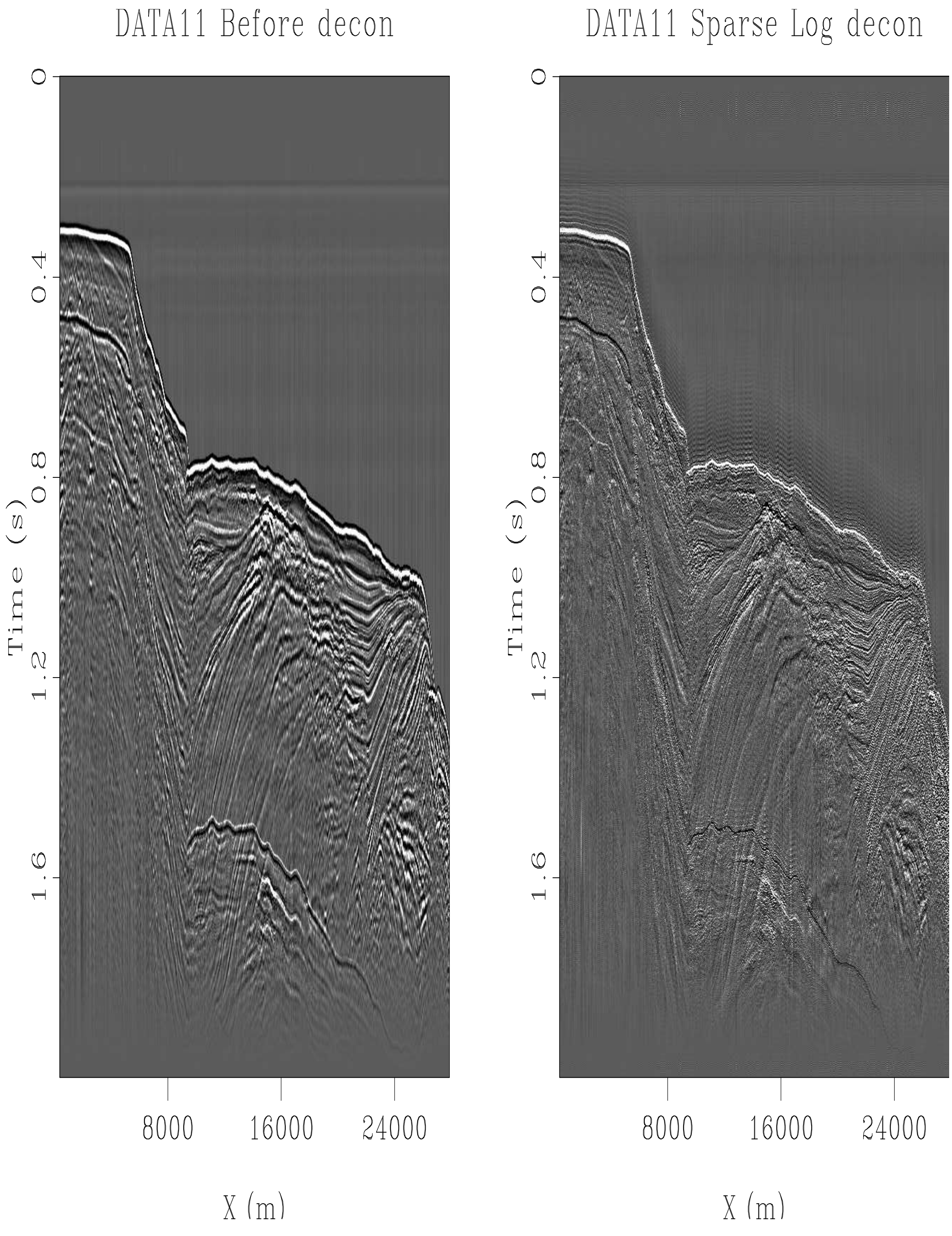


Figure 12: Data set from offshore Washington. On multiples where we obviously expect to be able to recognize polarities we find them nicely enhanced by the deconvolution. Unfortunately, we don't pick up such sharp events in the sedimentary section. The sparseness decon is very high frequency, as any decon. Again, we feel the "bad frequencies" are coming through much more strongly than the sparseness goals suggests. [**ER**]

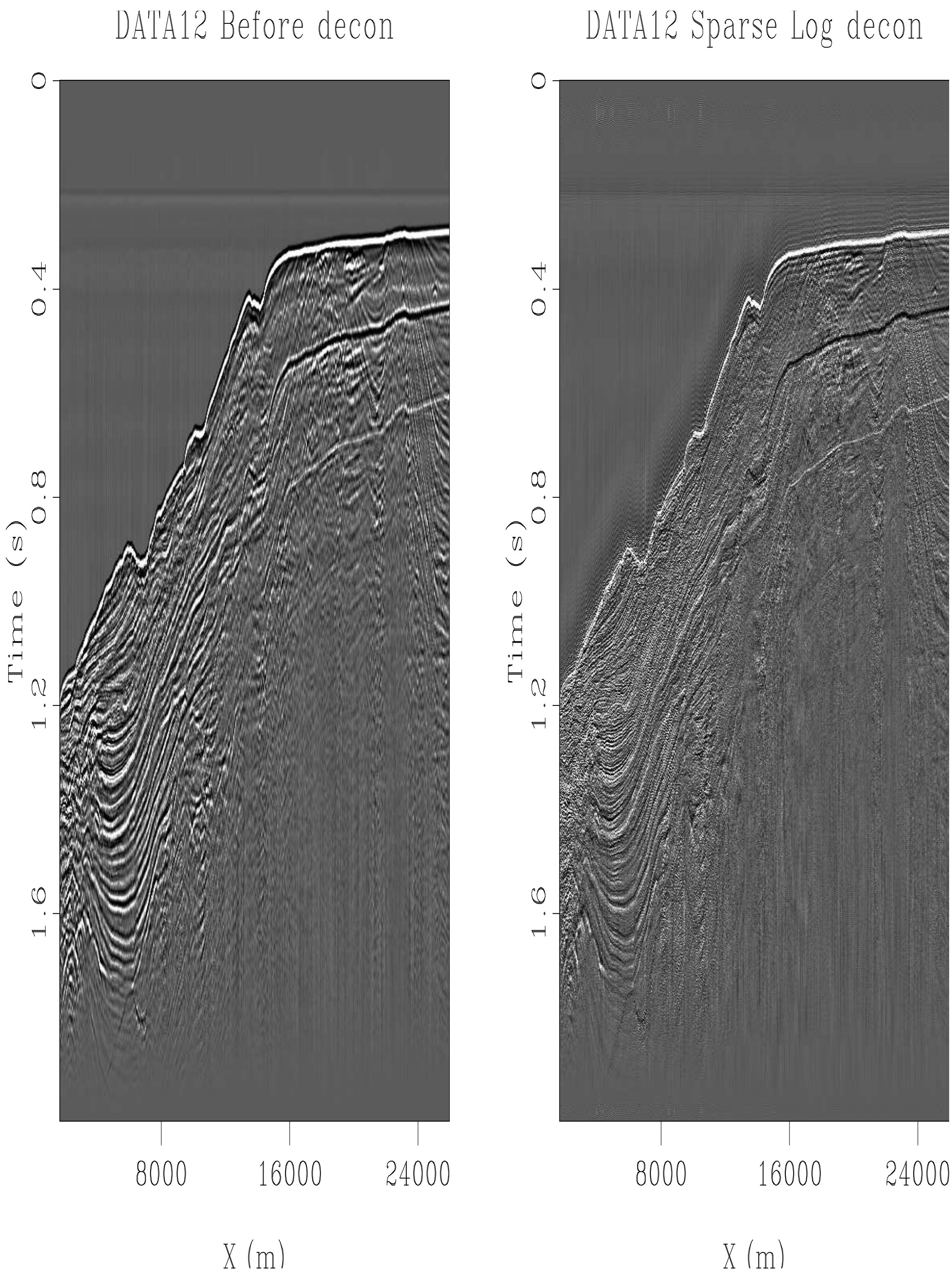
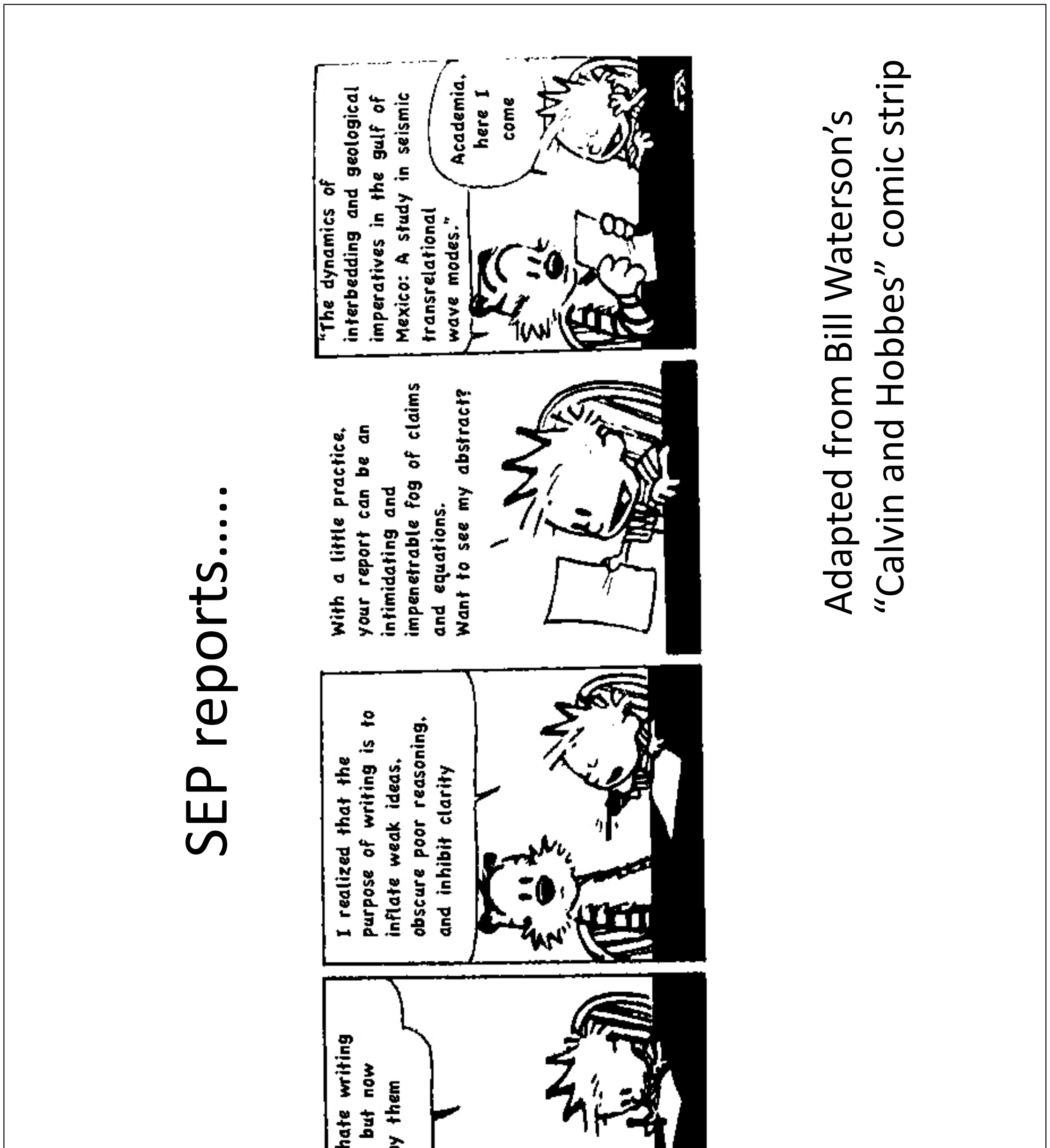


Figure 13: Another data set from offshore Washington. Conclusions similar to DATA11. [**ER**]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