Downward continuation analysis of passive seismic data

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ABSTRACT

One of the guiding principles in the design of the SEP passive experiment was to create a 3-D array with a fine enough spatial sampling to allow us to use wave-equation methods to extrapolate the recorded wavefield in depth. I hoped that we would see energy that had diffracted off near-surface structure, and that downward continuation would focus this energy and resolve the structure. There is coherent energy in the data that exhibits some moveout. A problem is that the array is so small that our ability to see this energy focus as we downward continue is very limited.

INTRODUCTION

In a previous paper (Cole, 1988) I used wave-equation techniques to analyze a passive seismic dataset. Theorizing that we could see ambient seismic energy as it diffracted off near-surface structure, I proposed to apply downward continuation, hoping to see such energy focus as the depth of the scatterer that gave rise to the diffracted energy was reached. The method was partly successful. I did see some energy that exhibited roughly hyperbolic moveout, which focused as the data was downward continued. But the picture was not very clear or consistent. One major drawback was that I was looking at 2-D data. I couldn't attribute focused energy to a scatterer buried in the earth; it could just as easily have been due to a surface noise source located some distance off the line. Data from a 3-D survey would be needed to eliminate this ambiguity.

In 1988, we at SEP planned and conducted our own passive seismic experiment, described by Claerbout et al., (1988). We set out a 2-D array of receivers in a 13 by 13 grid to record 3-D passive data. I hoped to apply downward continuation in 3-D, and to try to image near-surface scatterers acting as secondary sources. The

3-D data allow us to know for certain whether any such sources are truly buried scatterers.

DATA PROCESSING

The SEP passive data has high-amplitude spikes due to errors in the process of transcribing the field tapes, strong 60 Hz energy due to nearby power lines, and large variations in trace to trace amplitudes due to poor geophone to earth coupling. Nichols et al. (1989) describe preprocessing techniques used to eliminate these contaminating effects. I have applied the same pre-processing here.

3-D dip filtering

Nichols et al. show that there is a considerable amount of steeply emergent energy present in the data, and a great deal of energy arriving at slow apparent velocities that is probably surface-travelling energy generated by cultural noise sources such as a nearby freeway. I would like to search the steeply emergent energy for hyperbolic moveout that would indicate diffractions off subsurface structures, and downward continue the data to see this energy focus at the location of the diffracting structure. For this application, then, the surface-travelling energy may only contaminate the picture. I will try using a three-dimensional dip filter to pass only the steeply emergent energy and see if that improves the results. The three-dimensional dip filter is a two-pass application of the two-dimensional dip filters discussed by Claerbout (1985). Figure 1 shows a portion of one record before and after dip filtering. One can see that there is clearly some steeply emergent energy present, even before dip filtering.

Downward continuation

In SEP–59 I showed how we could analyze passive data using downward continuation. We couldn't use the imaging principle of exploding reflectors because there was no "time zero" at which our reflectors had exploded. But we could downward continue and either examine the downward continued data as a function of time, or sum the power in the downward-continued panels over time to get something resembling a depth section.

In this paper I will perform downward continuation in 3-D using a 45 degree finite difference scheme with data-dependent absorbing boundaries. As I extrapolate the 3-D data volume down in depth, I obtain a new 3-D data volume *at each depth level.* Thus the result of downward continuation is a four-dimensional dataset, difficult to display using our seismic movie program, let alone on paper. To reduce the data volume, I will select one vertical slice from the 3-D volume at each depth and display it. Then I will also perform the summation of power over time to generate a depth image. As in SEP–59, there will be two criteria for success. First, we want to see evidence of hyperbolic moveout and focusing on the downward continued panels.

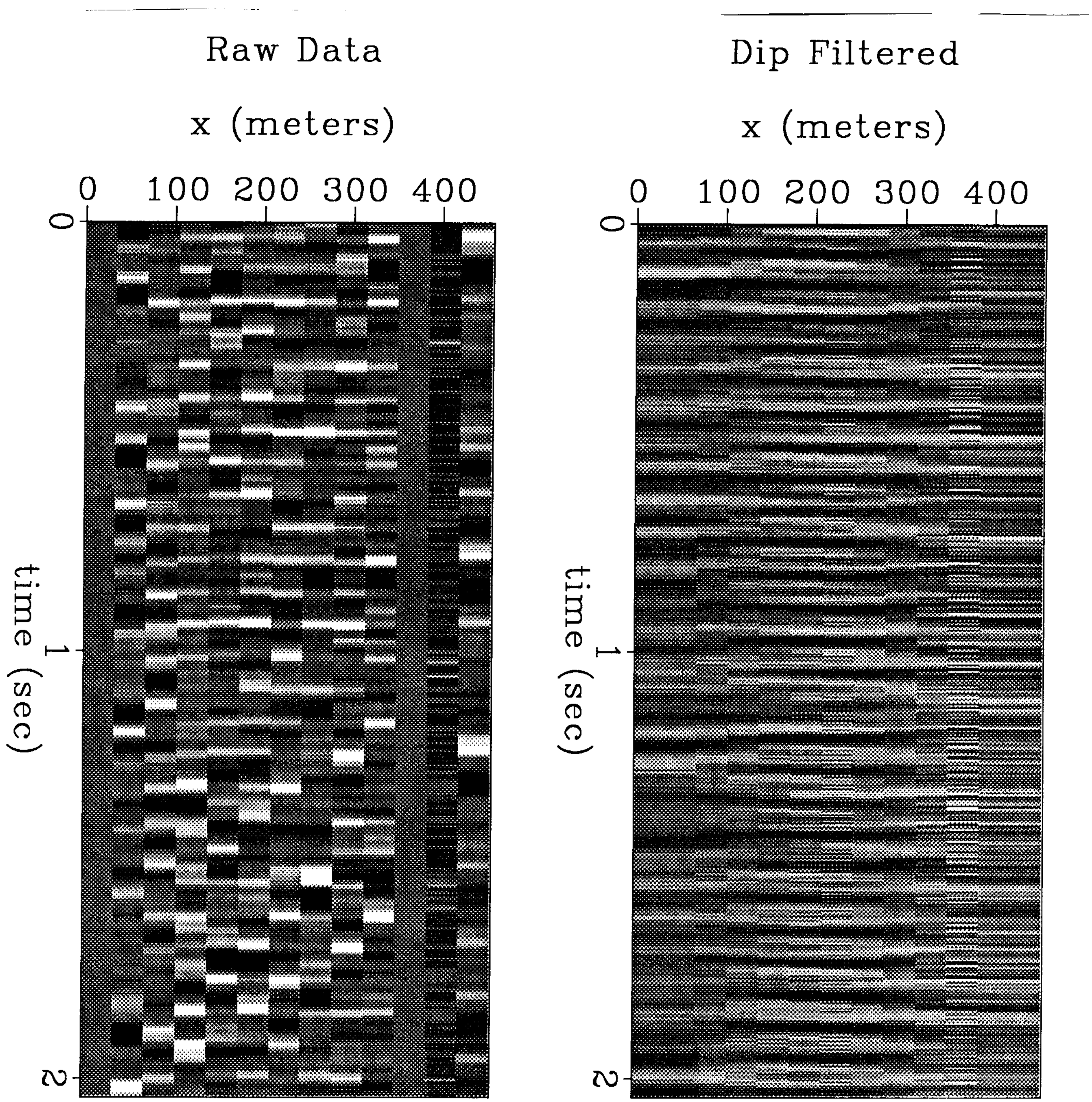

FIG. 1. A portion of a passive seismic record before (left) and after (right) three-dimensional dip filtering to pass only steeply emergent energy. Some steeply emergent energy is visible even before dip filtering.

Second, we want to see a somewhat consistent depth image when we process data recorded at different times. A consistent picture would indicate that perhaps we are seeing subsurface structure.

RESULTS

Figure 2 shows a vertical slice from a 3-D record, downward continued to several depths. The vertical slice has been taken along the x-direction. The y-coordinate is constant, and in fact the slice comes from the middle of the survey. While I have included absorbing boundaries in the finite-difference extrapolator, in this figure I have also padded the data in x and y to make the action of the program more apparent. One can see that there is some energy exhibiting moveout, with its apex near the center of the grid. But with only thirteen points on a side in the grid, it is difficult to see much of an event. As the data are downward continued, can we see this energy focus? Figure 3 shows the same data, only 3-D dip filtering has been applied before downward continuing.

We can sum the power in these downward-continued images along the time direction to create a three-dimensional map of subsurface scatterer strength. Each frame then is a map of subsurface scatterer strength at some depth. In Figure 4 I show constant-z slices through this image for the data shown in Figure 2, the data with no dip filter applied. The padding region has been removed in these plots. In Figure 5, the same result as in Figure 4 is shown for the data from Figure 3, where dip filtering was applied before downward continuation. Note that certain regions have high power at shallow depths, and that these features persist with depth. I think the power summation method is more sensitive to amplitude variations in the pre-processing than amplitude events caused by focusing of diffracted energy.

One measure of the success of the method is consistency. If we take data recorded at another time and process it in the same way, the downward continued data may look different, but if our hypothesis is correct, the subsurface scatterer strength map will be similar. Figure 6 shows a portion of a second record from our passive experiment. This record was recorded during the night, while the previous one was recorded during the day. In Figures 7 and 8, depth slices from the subsurface image formed by summing power over time are shown. Again we can see in the dip-filtered results that high power values from shallow depths persist as we downward continue. This fact, along with the fact that the pictures from the two recording intervals aren't similar, seems to suggest that I was right in deciding that the power summation method is sensitive to amplitude variations in the preprocessing. I don't know why dip filtering introduced such variations, but clearly it did so because the data had just been trace balanced.

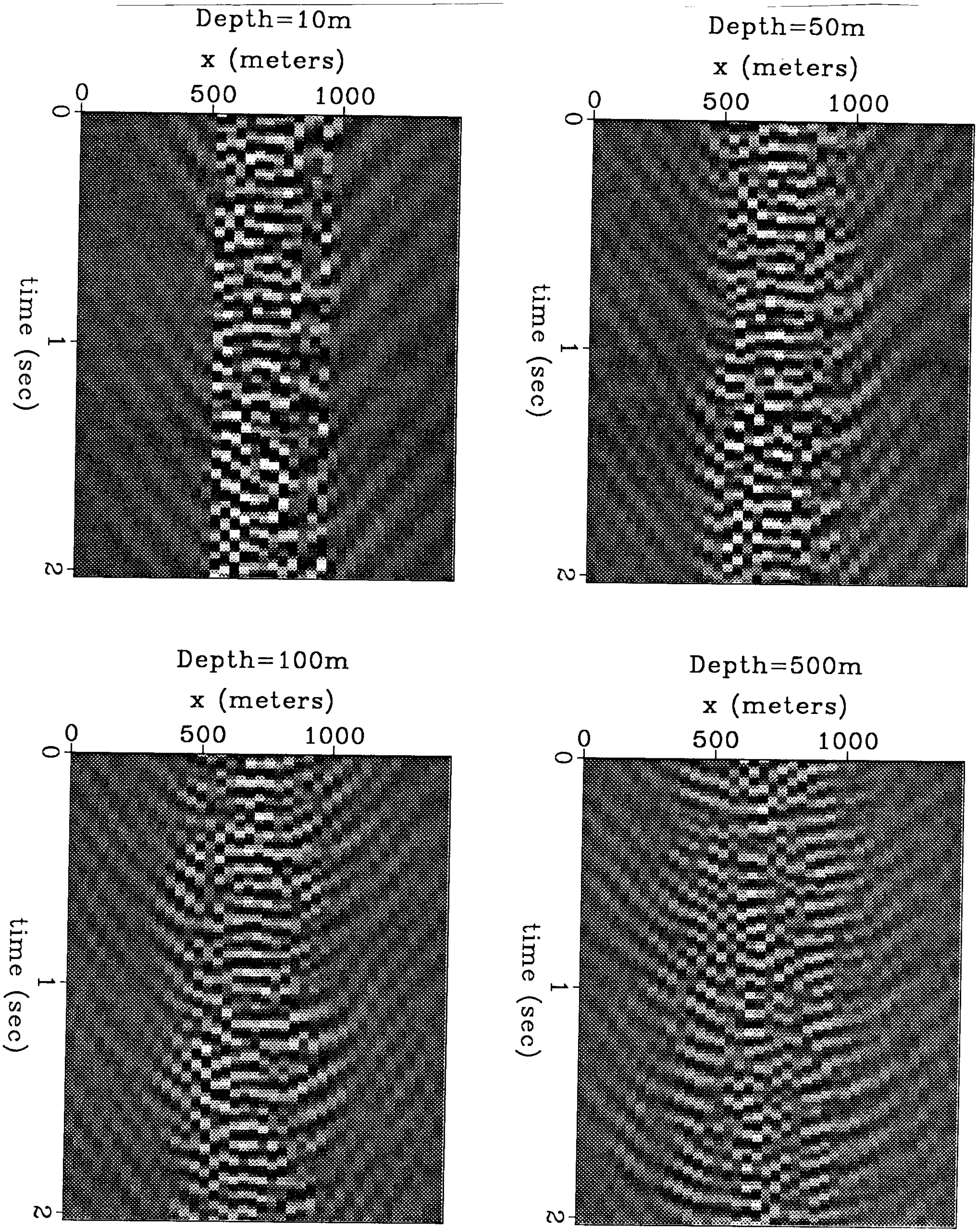

FIG. 2. Vertical slices taken at various depths from a downward-continued 3-D data volume. The slices are taken at the center of the survey, in the x direction. It is easy to see energy being over-migrated, but more difficult to see focusing.

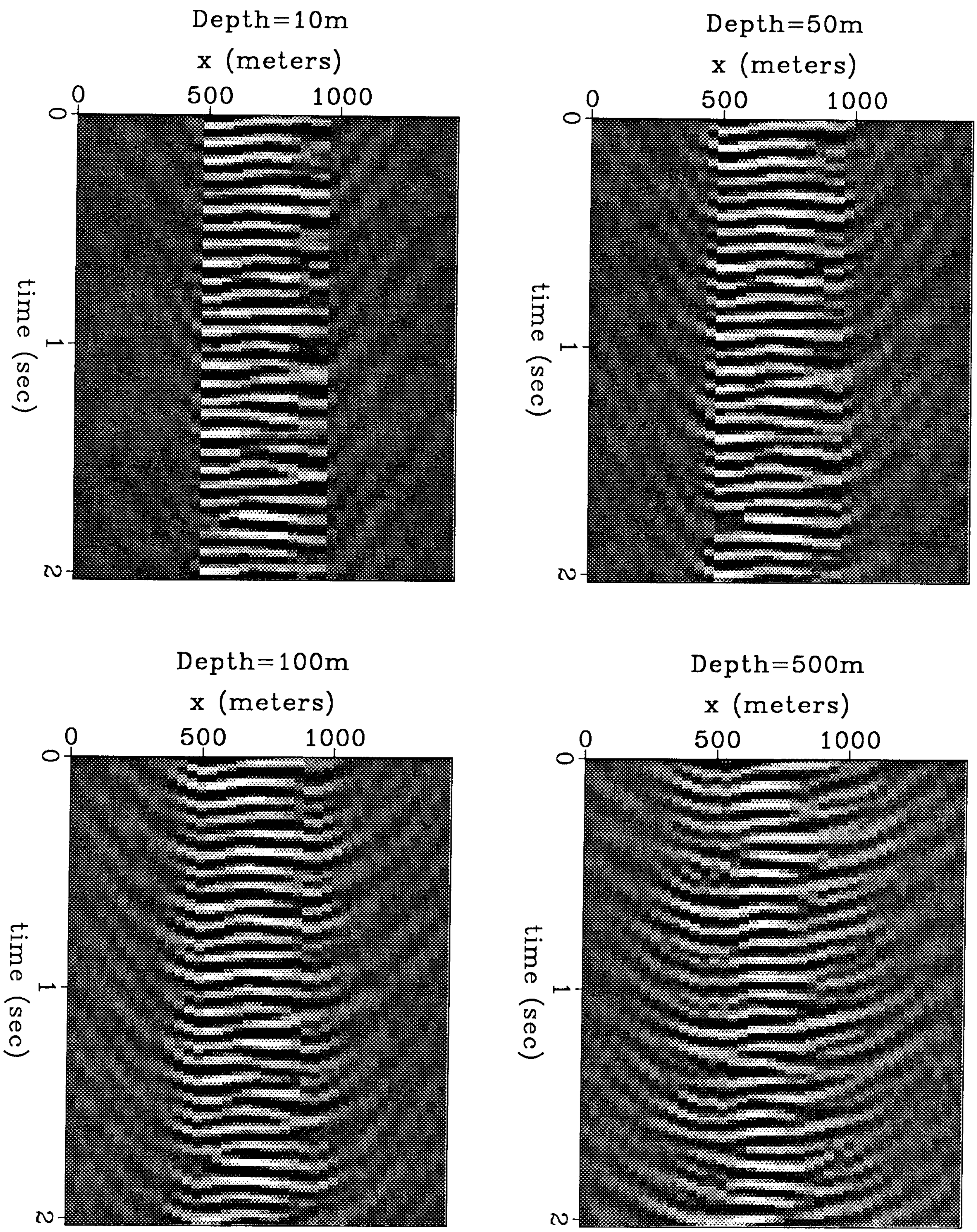

FIG. 3. Same as Figure 2 only the data have been dip filtered in 3-D prior to downward continuation.

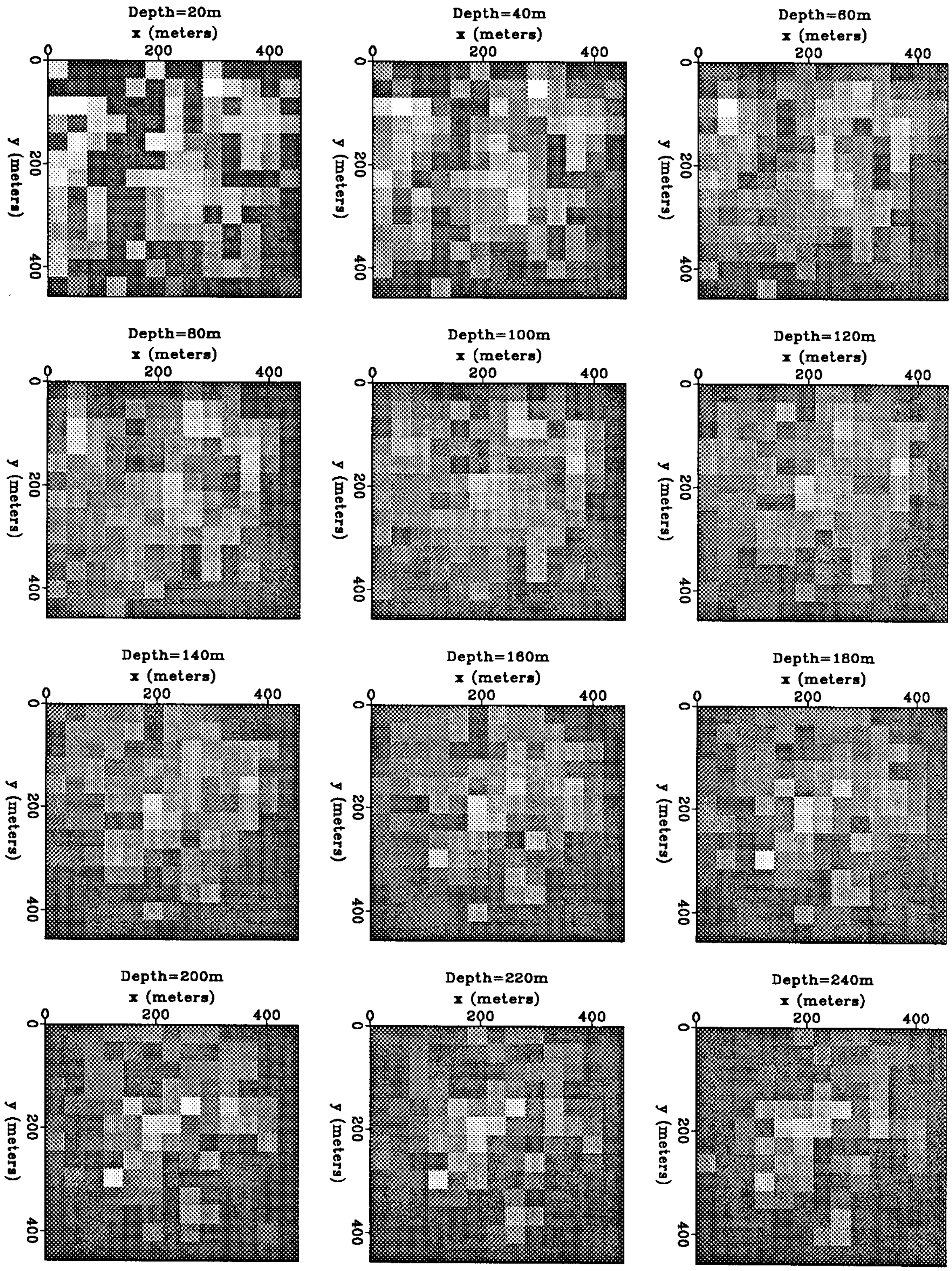

FIG. 4. Constant-depth slices through the 3-D image formed by downward continuing one passive record using a constant velocity of 2000 meters/second, then summing power over the time axis.

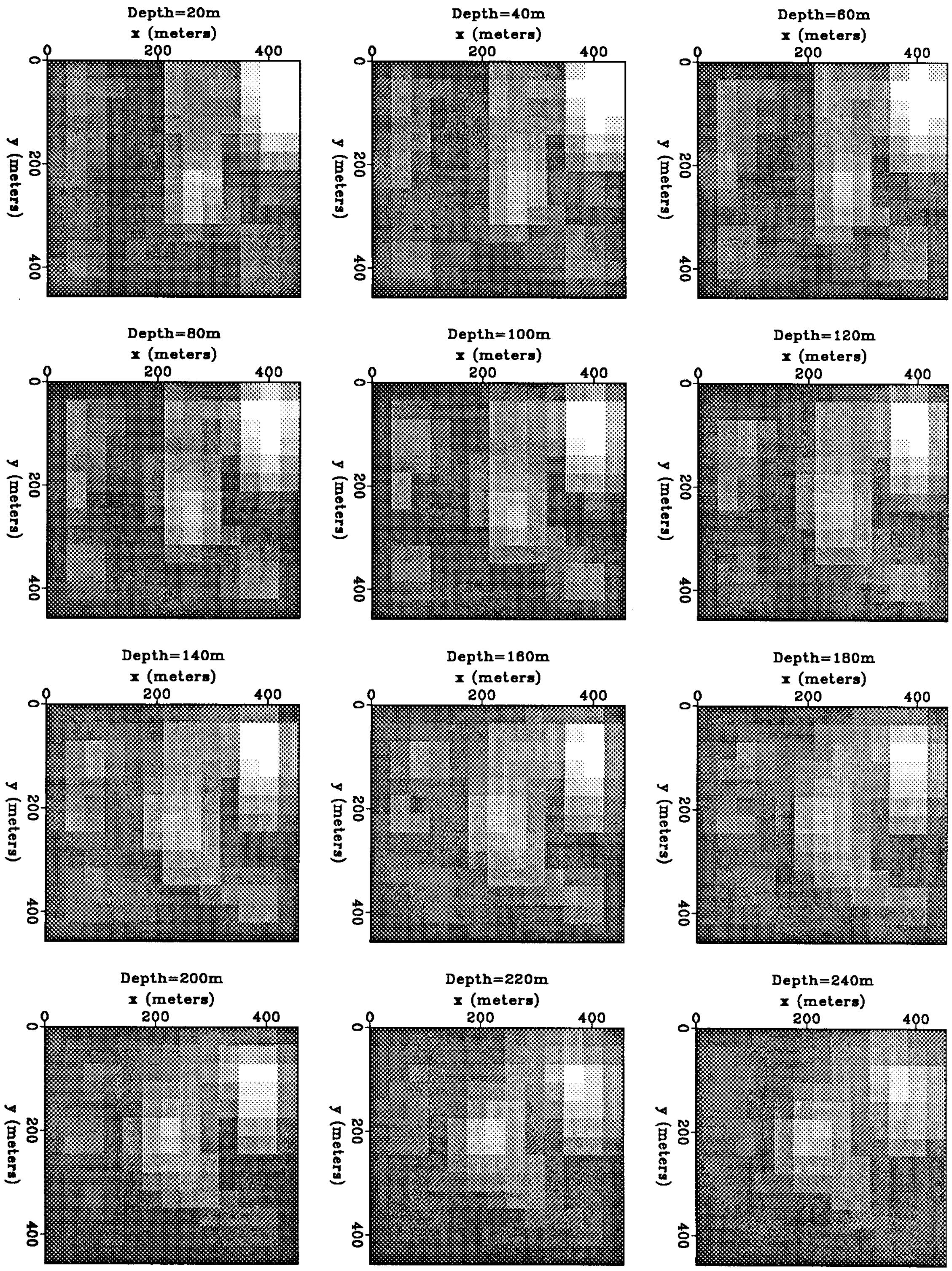

FIG. 5. Same as Figure 4 but the data were dip filtered prior to downward continuation.

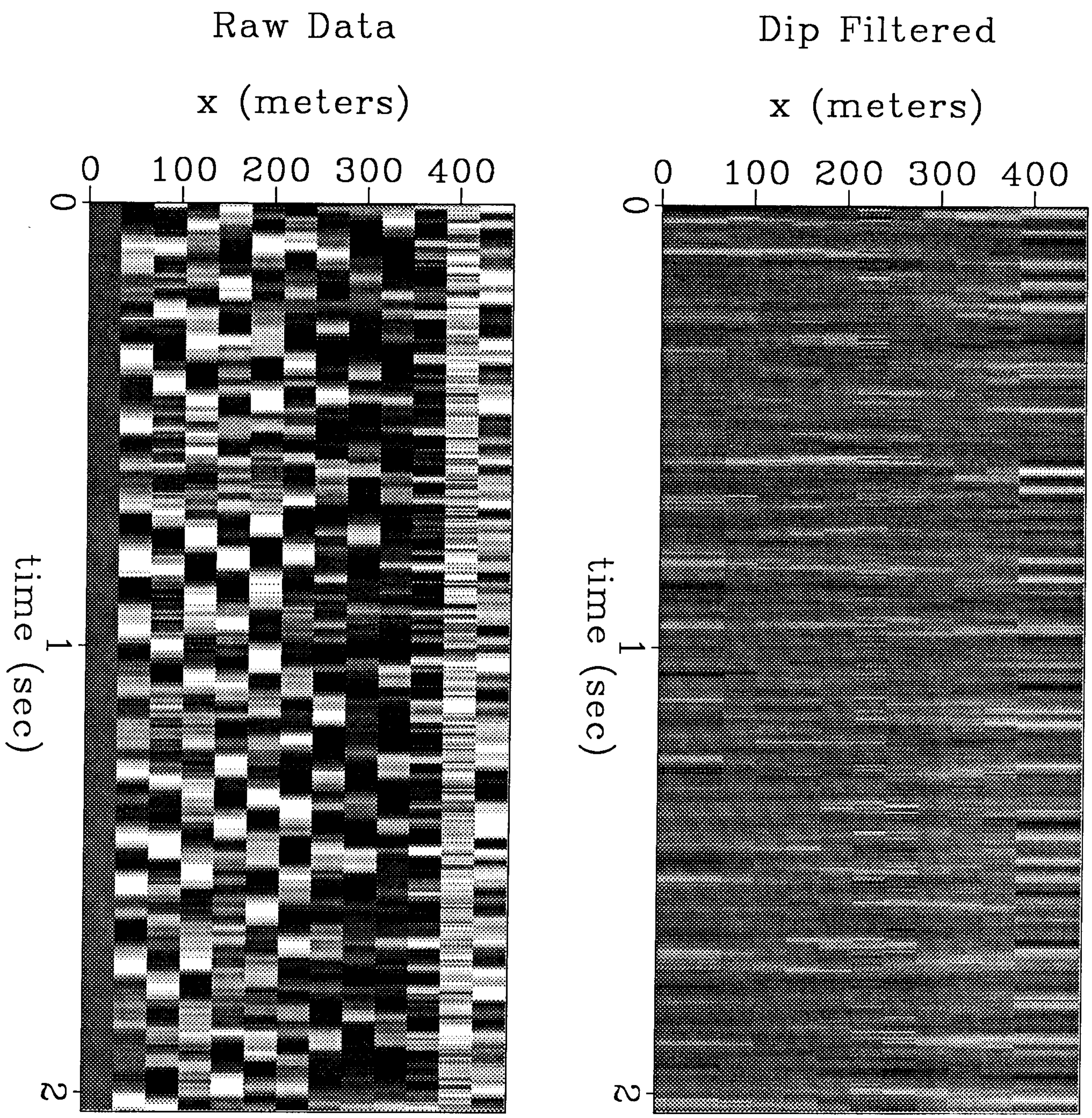

FIG. 6. A portion of a second passive seismic record before (left) and after (right) three-dimensional dip filtering to pass only steeply emergent energy. These data were recorded during the night.

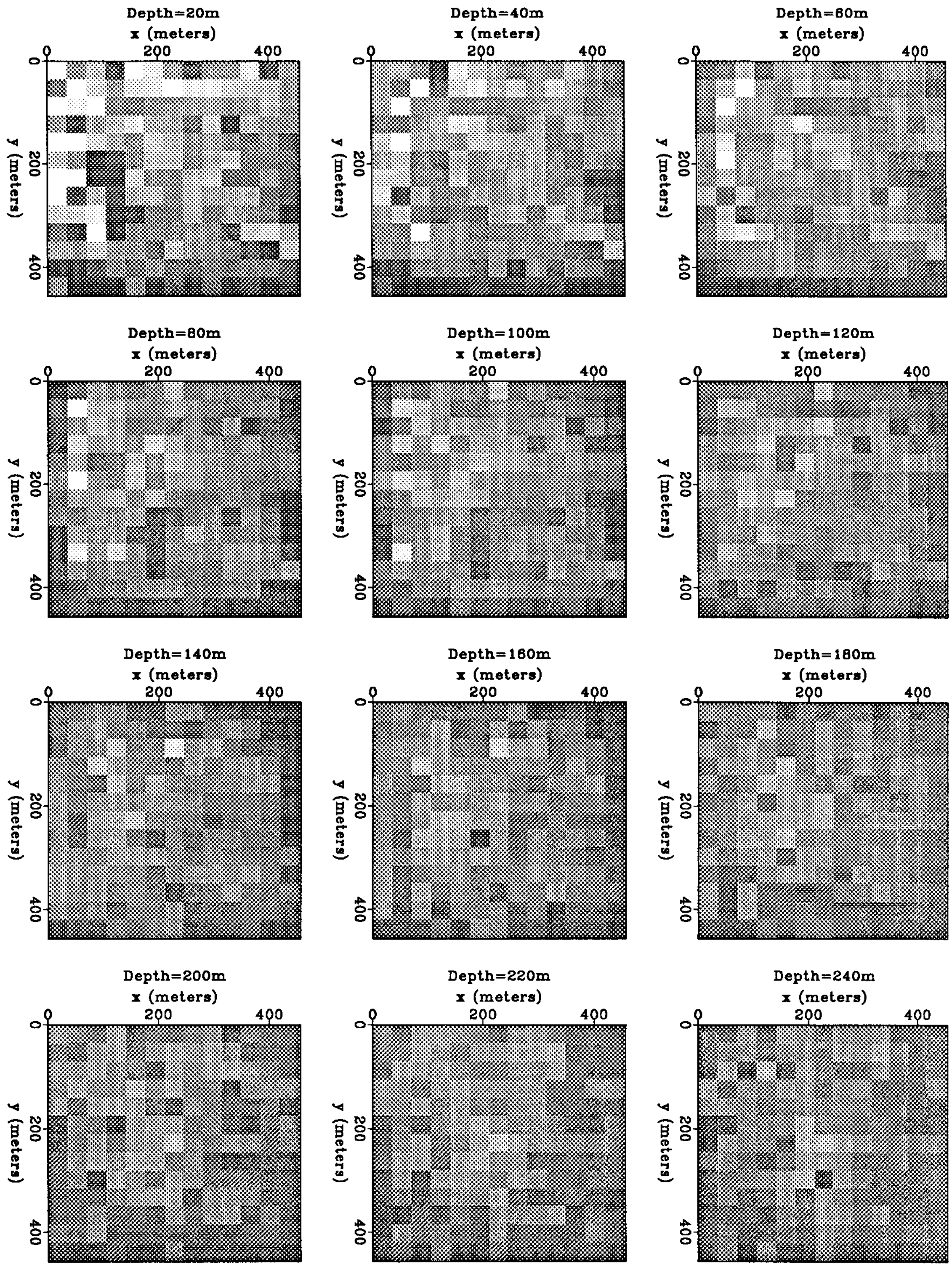

FIG. 7. Constant-depth slices from a 3-D data volume formed by summing the power in the downward-continued panels over time.

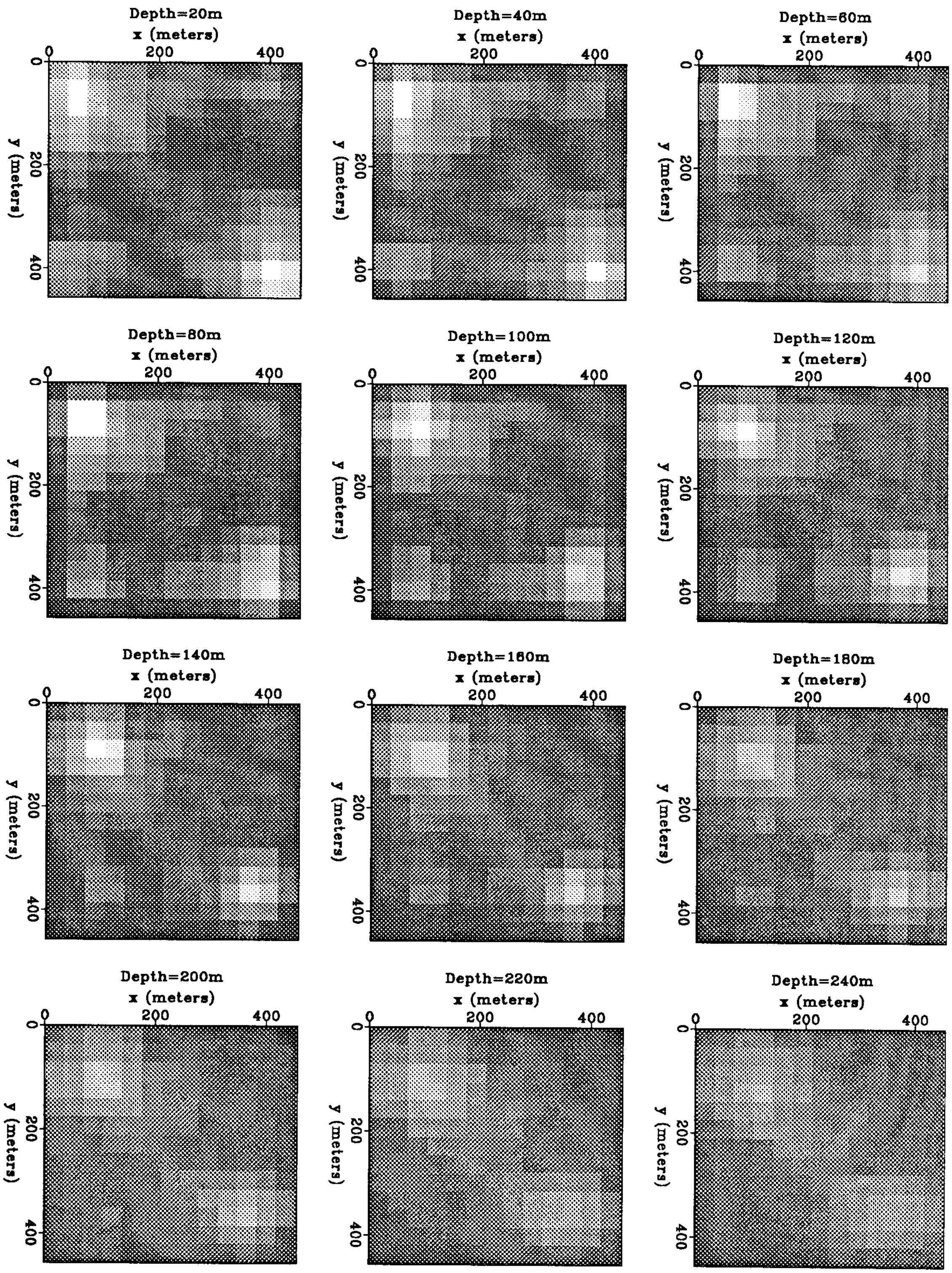

FIG. 8. Same as Figure 7 except that dip filtering was applied prior to downward continuation.

CONCLUSIONS

Some energy with roughly hyperbolic moveout is present in the data, and in principle we can use wave-equation techniques to focus it. In practice there are two problems. First, the computation grid is so small in each direction that it is difficult to see such events clearly. Second, the method of summing power of the downward-continued wavefields over time to form an image is very sensitive to amplitude variations introduced by other processing steps such as the dip filter that I used to suppress surface noise.

REFERENCES

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