Analysis of a two-component data set

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INTRODUCTION

In this paper I discuss a two-component data set that was given to me by a sponsor who wishes to remain anonymous. My hope was to find converted-wave data; instead, I may have found evidence of anisotropy.

THE DATA SET

Figures 1 and 2 show the data set after normal moveout and stacking. Figure 1 was recorded with vertical geophones, and Figure 2 was recorded with horizontal (radial) geophones. Individual geophones were recorded; there was no array. Coverage was 48-fold, and the common-depth points were 50 feet apart. An explosive source was used.

Prestack processing

First I windowed the data to 5 seconds, and subsampled it to change the sampling rate from .002 milliseconds to .004 milliseconds per sample (a high-cut filter was used during the subsampling). To reduce ground-roll noise I applied a low-cut filter with a cutoff of 8 Hz. I applied time-dependent gain of t^2 to the traces, and then used a trace-balancing program written by Shuki Ronen. This program uses a simple algorithm that Shuki invented (or rediscovered): first, the 97th percentile is found for a particular trace (that is, the value is found that is greater than 97 percent of the sample values in the trace, and less than the remaining 3 percent). Every sample value in the trace is then divided by the value of the 97th percentile. This seems to be a fast and easy way of removing various sorts of noise. If this balancing had not been applied in the processing of the radial-geophone data, Figure 3 would have been the result. Compare it with Figure 2, where balancing was used. After trace balancing the data were ready for further

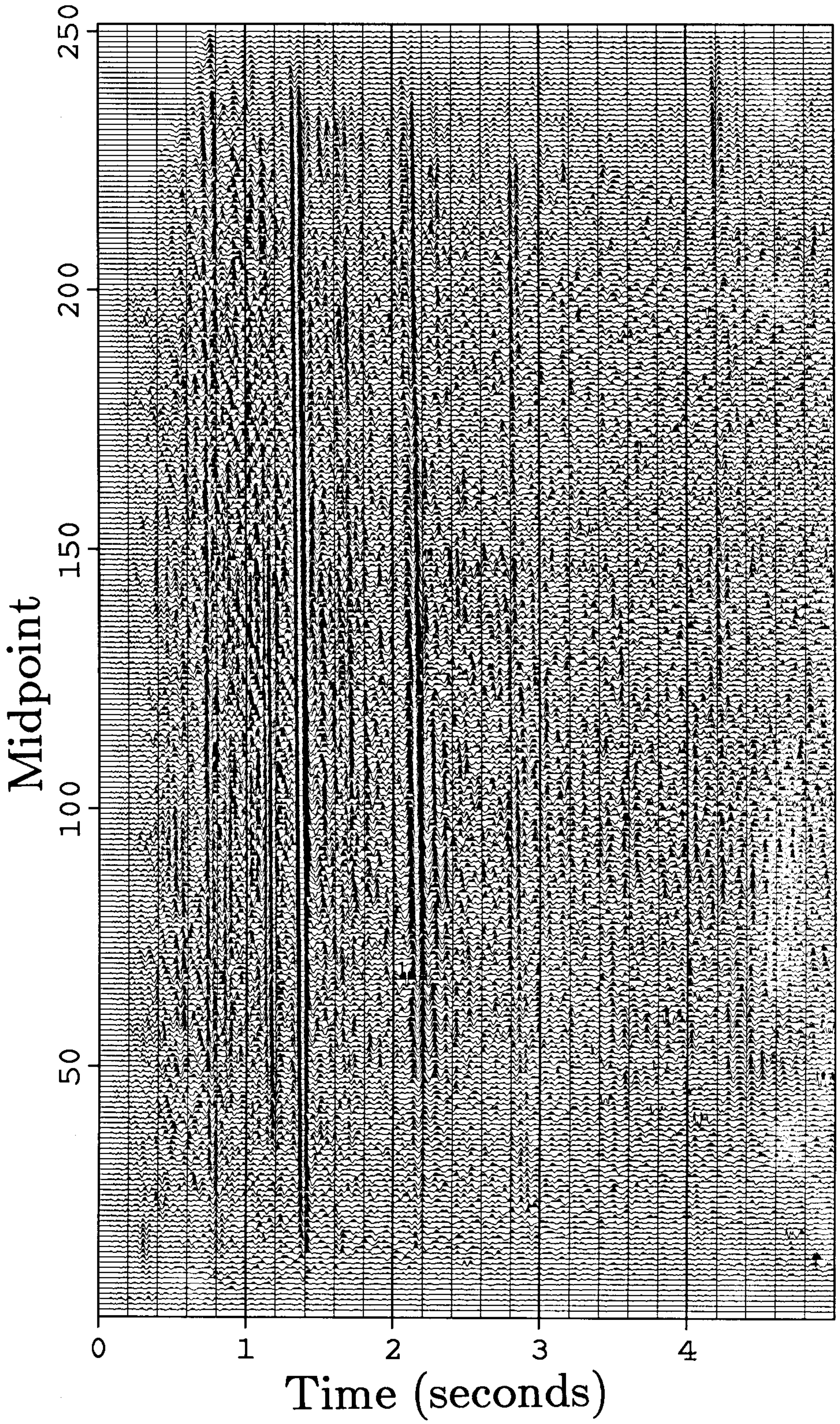

FIG. 1. Vertical-geophone data after spherical-divergence correction, trace balancing, NMO, and stack.

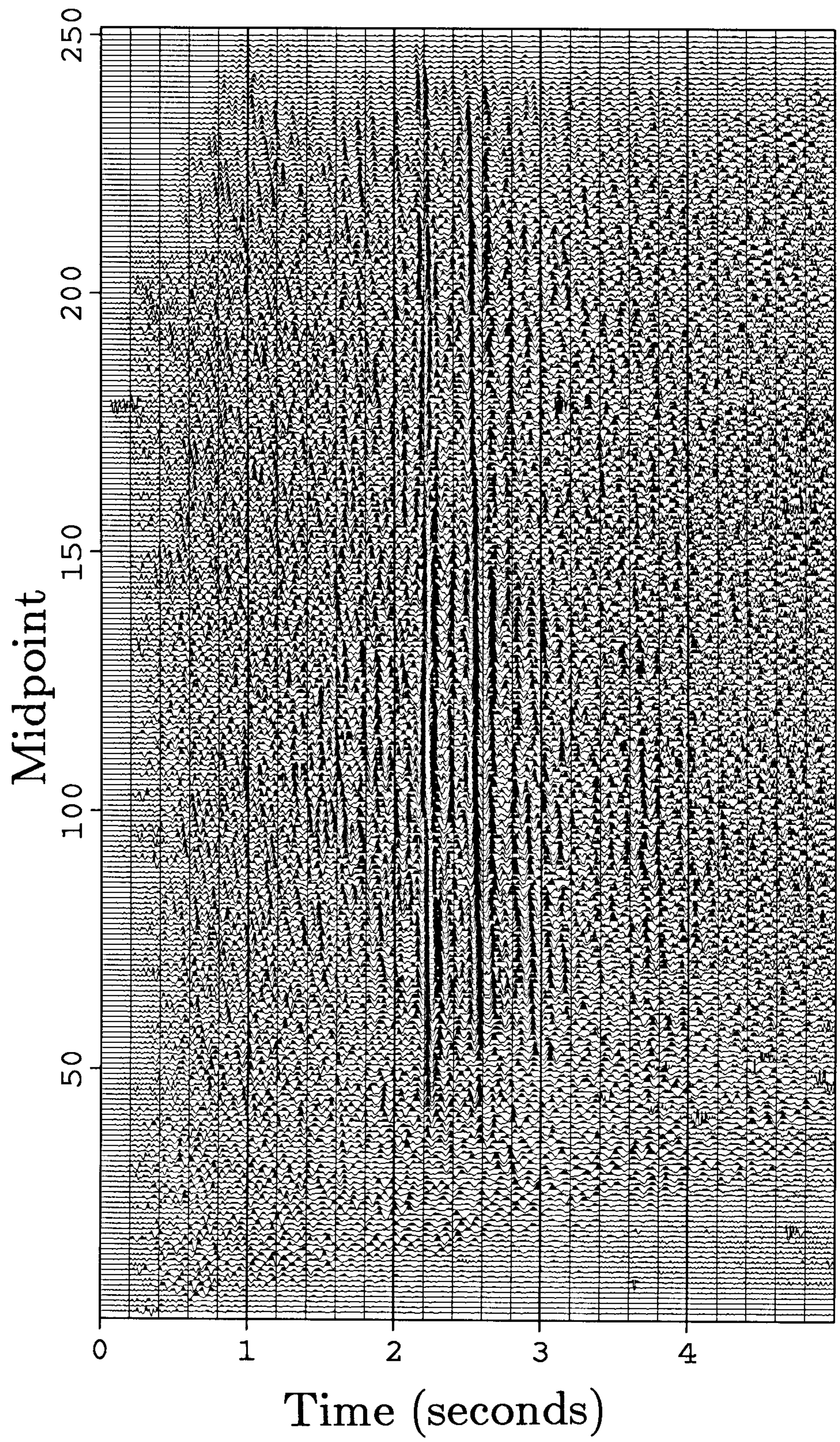

FIG. 2. Horizontal(radial)-geophone data after spherical-divergence correction, trace balancing, NMO, and stack.

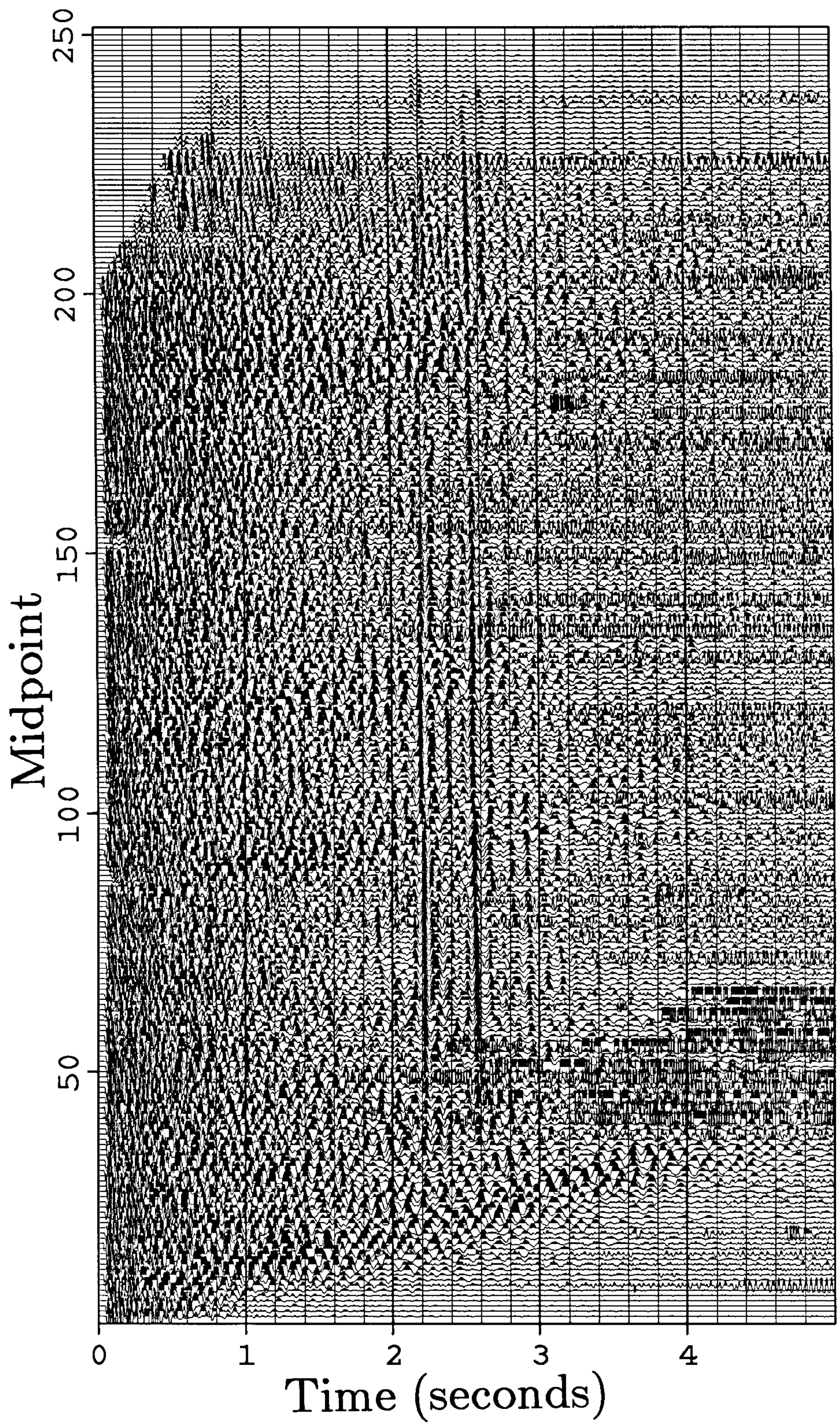

FIG. 3. Same data as in Figure 2, but without trace balancing.

processing, to be described below.

Interpretation

After staring at the data for a while, I decided that the events at 1.2 and 1.4 seconds in Figure 1 correspond to the events at 2.2 and 2.6 seconds in Figure 2. One unresolved question is why the event at 2.2 seconds in Figure 1 doesn't seem to correspond to anything in Figure 2. Francis Muir (personal communication) has pointed out that the reflectors that show up best in P-wave sections do not necessarily show up the best in S-wave sections. (Taken to extremes, this would suggest that it is dangerous to make any correlations at all between P-wave and S-wave sections.) One question to be discussed below is what type of S-waves are seen in Figure 2: are they SS waves, or converted (PS) waves?

VELOCITY ANALYSES

Flat beds do not make a very interesting test case. They do have advantages, though. One is that it is possible, before stacking over offset, to stack over nearby midpoints, thus enhancing the signal-to-noise ratio and allowing better velocity analyses. On the vertical section I stacked over midpoints 93-106, and on the radial section, I stacked over midpoints 101-116, producing the composite common-midpoint sections shown in Figures 4 (vertical geophones) and 5 (radial geophones). (The data had already been processed in accordance with the section above on pre-stack processing.) I ran these sections through a standard velocity-analysis program to produce the semblance stacks shown in Figures 6 (vertical) and 7 (radial). Then I picked velocities (shown as X's on the semblance stacks), and applied these velocities to the composite common-midpoint sections, with results shown in Figures 8 (vertical) and 9 (radial). I applied NMO-and-stack to the entire dataset to produce Figures 1 and 2.

SS OR PS?

Now that the data has been analyzed and stacked, it should be possible to determine what types of waves are seen on the vertical and radial sections. As I stated above, I decided to correlate the events at 1.2 and 1.4 seconds on the vertical section with the events at 2.2 and 2.6 seconds on the radial section. Velocities can be picked from Figures 6 and 7. The velocity and travel-time information are summarized in Table 1.

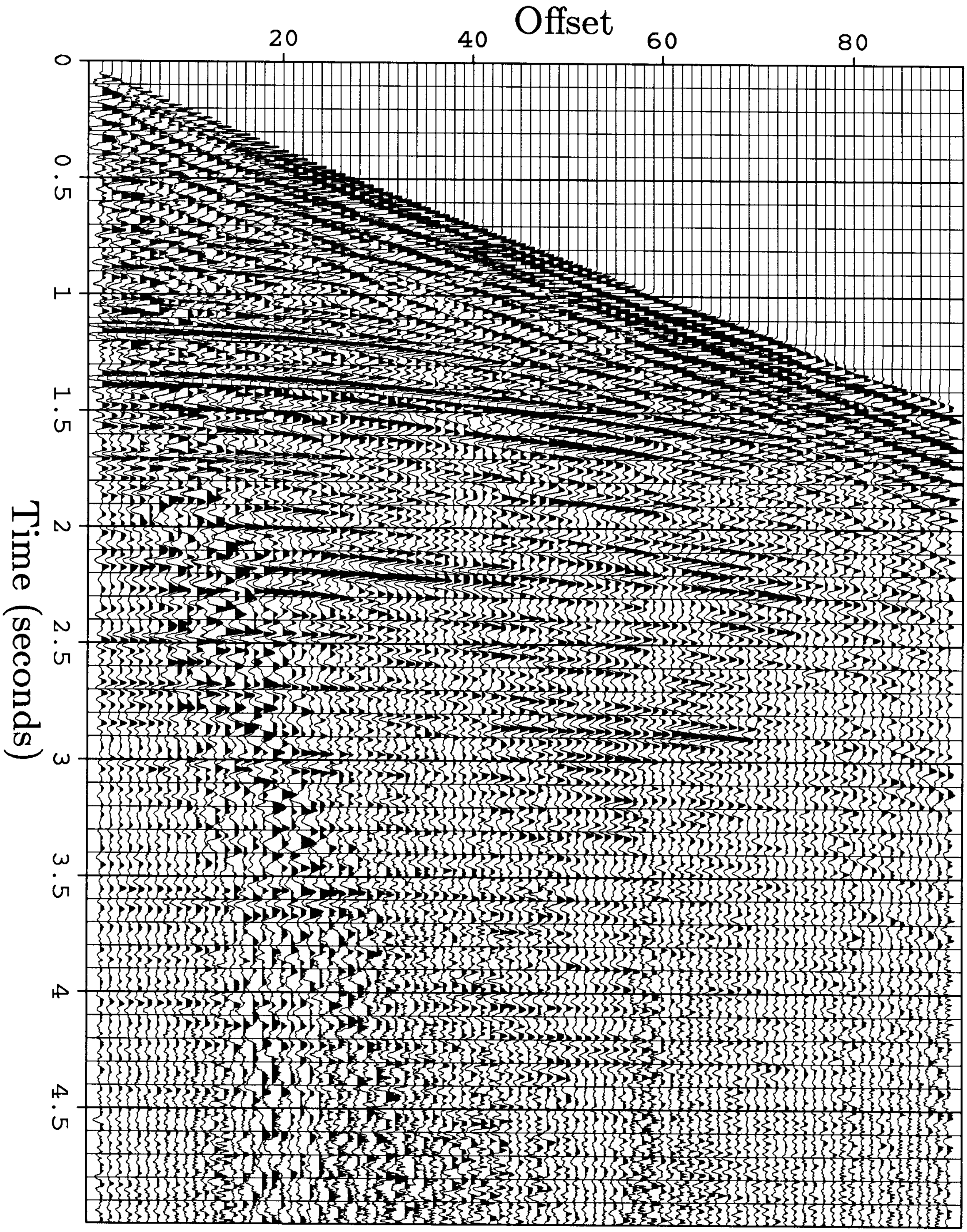

FIG. 4. Composite vertical-geophone CDP gather. Traces from midpoints 93-106 were stacked to produce this gather. A spherical-divergence correction and trace balancing have been applied.

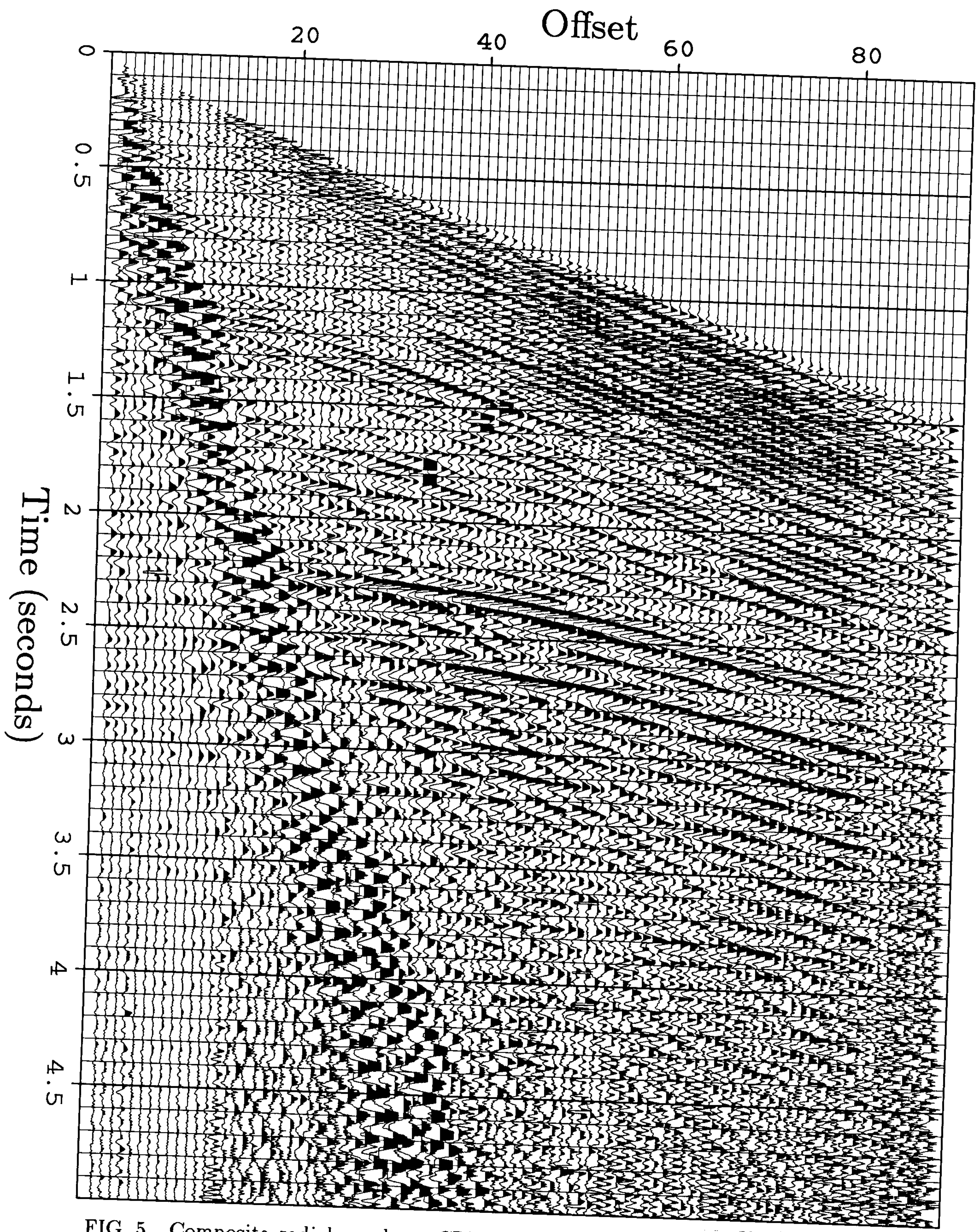

FIG. 5. Composite radial-geophone CDP gather. Traces from midpoints 101-116 were stacked to produce this gather. A spherical-divergence correction and trace balancing have been applied.

t_r	t_v	t_r/t_v	v_v	v_r	v_v/v_r
2.2 sec	1.15 sec	1.91	7750 ft/sec	5250 ft/sec	1.48
2.55	1.35	1.89	8250	5500	1.50

TABLE 1. Summary of travel-time and NMO-velocity measurements for two reflectors.

It is reasonable to average the results and suppose that $t_r/t_v = 1.9$ and $v_v/v_r = 1.5$. How can these numbers be interpreted? First, let us define some more variables: t_{ss} is the vertical two-way travel time of an SS wave to a given reflector, while t_{ps} and t_{pp} are the vertical two-way travel times of a PS (converted) and a PP wave, respectively, to that same reflector. Correspondingly, let v_{pp}, v_{ps}, and v_{ss} represent the measured NMO velocities of the waves reflected from that reflector.

Now let us assume that we have an isotropic medium, and that the ratio γ between P-wave velocity and S-wave velocity does not vary with depth. Then we can define

$$\gamma \equiv t_{ss}/t_{pp} = v_{pp}/v_{ss}, \tag{1}$$

and it is not difficult to show that

$$\gamma = 2t_{ps}/t_{pp} - 1. \tag{2}$$

From some of my previous work (Sword, 1984) it is possible to show that

$$v_{pp}/v_{ps} = \sqrt{\gamma}. \tag{3}$$

Now we can construct two hypotheses, and see which one better matches the data.

Converted-wave hypothesis. By substituting into Equation (2) we find that $\gamma = 2\times1.9 - 1 = 2.80$. This gives us a value of γ based on measured travel times. By substituting into Equation (3), on the other hand, we find that $\gamma = (1.5)^2 = 2.25$, which represents a value of γ based on NMO velocity measurements. Neither value of γ seems particularly realistic.

SS-wave hypothesis. We can read directly from Table 1 that $\gamma = 1.9$ based on measured travel times, and that $\gamma = 1.5$ based on velocity measurements. The value of $\gamma = 1.9$ is close to the expected value (Muir, personal communication) of $\gamma = 2$, but it is not consistent with the γ value based on velocity.

It seems likely, though, that Figure 2 shows SS waves rather than PS waves, since the differences between the two values of γ can be explained by resorting to anisotropy. In fact, for typical anisotropic shales one would expect that (for near offsets) γ values determined from velocity measurements should be lower that those determined from

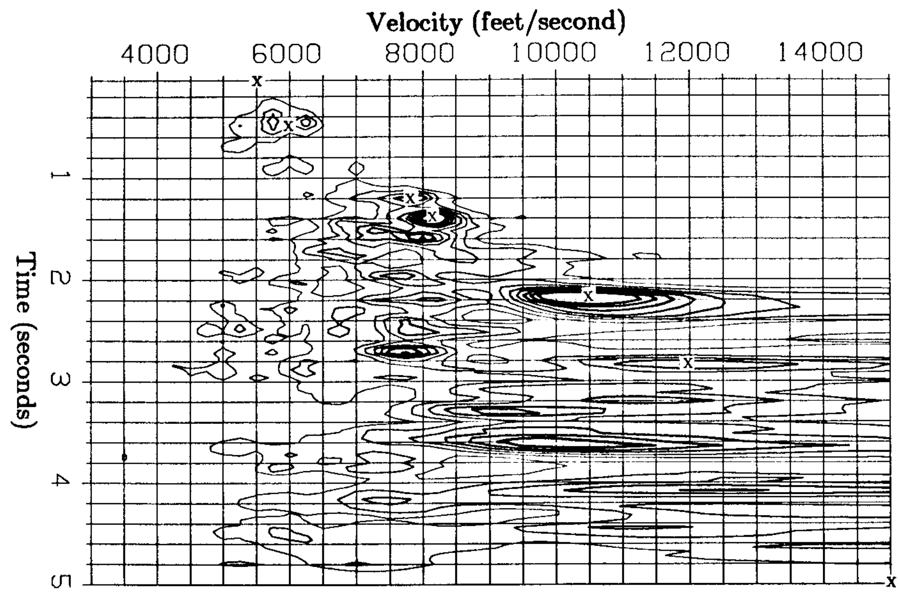

FIG. 6. Velocity analysis (semblance stack) of the vertical-geophone data in Figure 4. X's denote velocity picks.

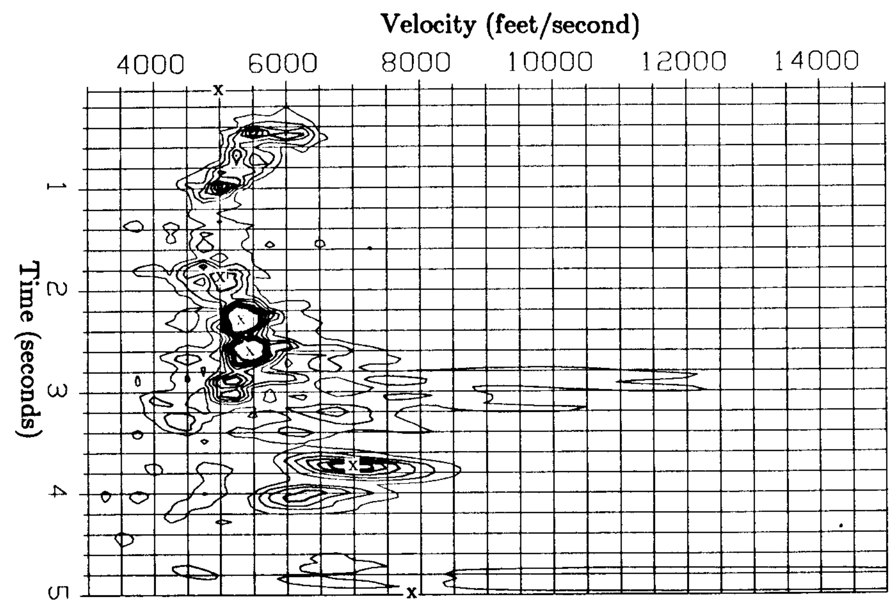

FIG. 7. Velocity analysis (semblance stack) of the horizontal-geophone data in Figure 5. X's denote velocity picks.

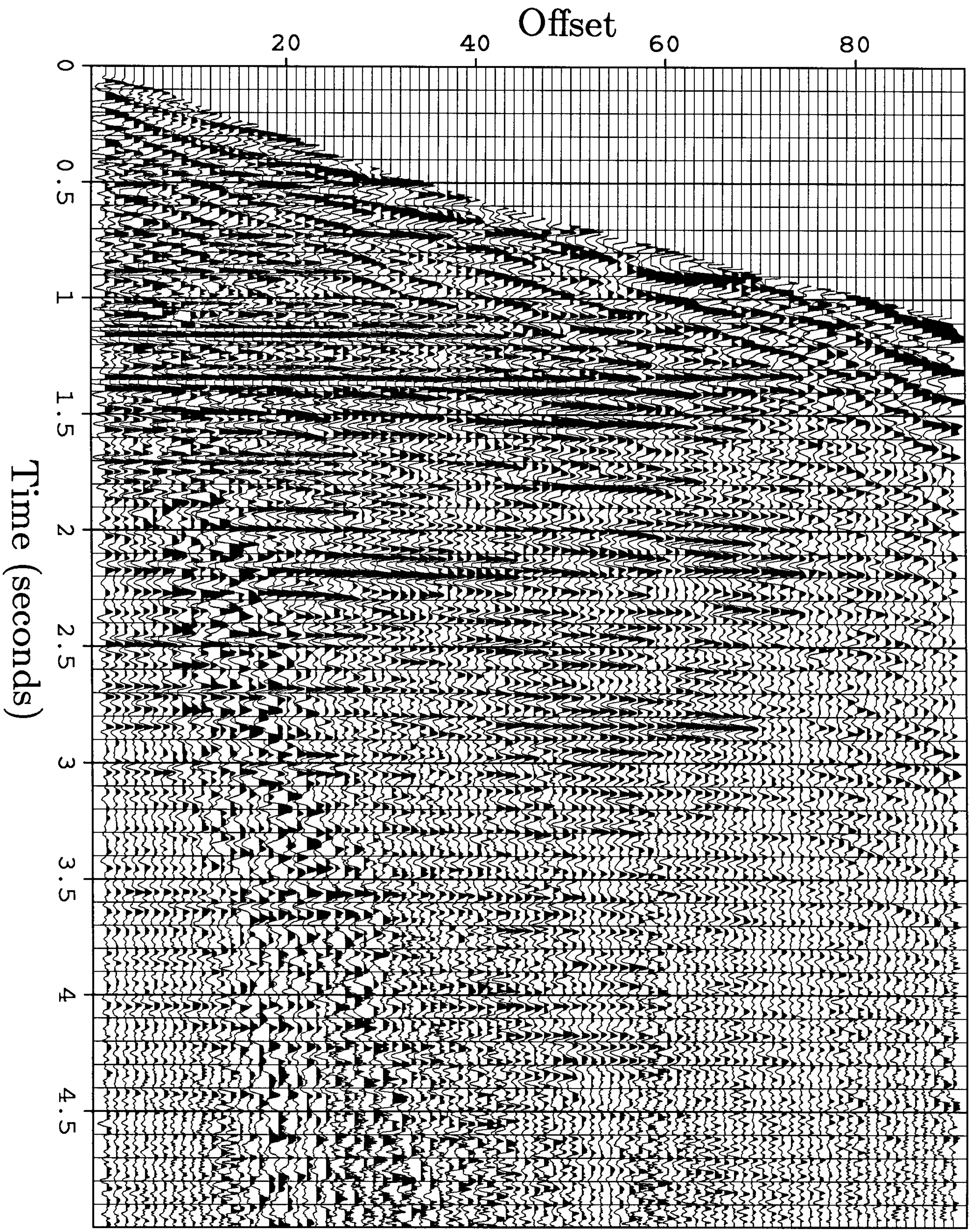

FIG. 8. Composite vertical-geophone gather after NMO correction. The velocity picks from Figure 6 were applied to the data in Figure 4.

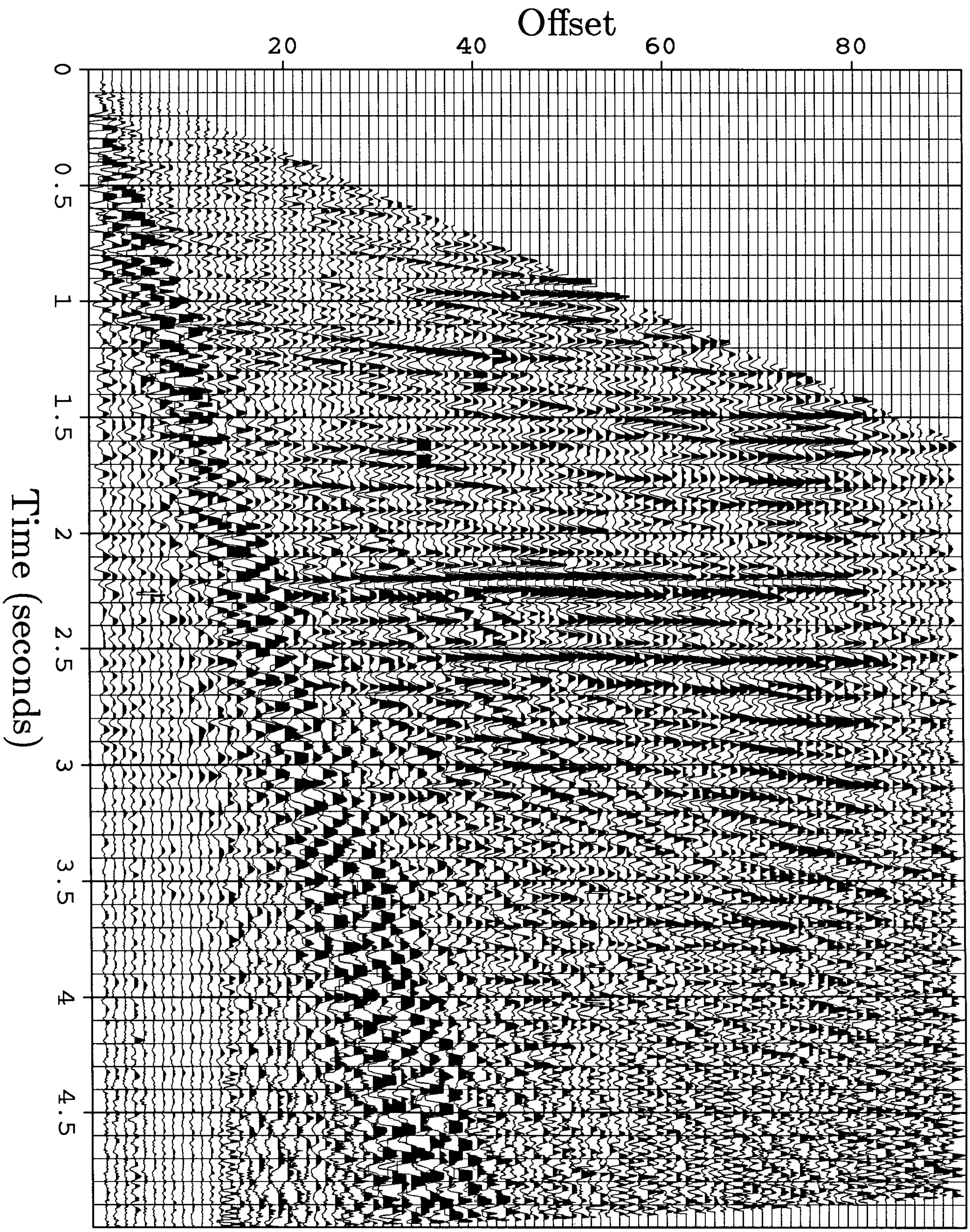

FIG. 9. Composite horizontal-geophone gather after NMO correction. The velocity picks from Figure 7 were applied to the data in Figure 5.

travel-time measurements (Dellinger, 1985). I haven't attempted to quantify this anisotropy.

CONCLUSIONS

I looked at a two-component data set and found evidence of SS waves and anisotropy. I did not find any converted waves. The weakest link in my paper is the correlation of events; all subsequent reasoning depends on this correlation, and it is difficult to find evidence for supporting one particular correlation over another. I am surprised by the apparent lack of converted waves, since I was expecting that PS waves would show up much more clearly on the radial section than SS waves. The discovery of anisotropy will undoubtedly be of interest to Joe Dellinger, who is studying that subject in exhaustive detail.

ACKNOWLEDGEMENTS

I most sincerely thank the anonymous sponsor who was kind enough to provide me with this data set. It is, perhaps, the cleanest set of land data I have seen, with a relatively small amount of noise and almost no statics problems. I also thank the other sponsors who have offered me data; I will be using it in my contuing search for converted waves. But I am still interested in hearing of other data sets that contain (or potentially contain) converted-wave events. I thank Joe Dellinger for telling me about some of his preliminary results in the study of anisotropy, and I thank Francis Muir and Jon Claerbout for helpful advice.

REFERENCES

Dellinger, J., and Muir, F., 1985, Axisymmetric anisotropy I: kinematics: SEP-42 (this volume).

Sword, C., 1984, Approximating the kinematics of converted waves: SEP-41, 347-368.