Migration velocity analysis: preliminary data tests

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INTRODUCTION

In recent months I have been processing a large field data set to test some of my ideas on migration and velocity analysis. This testing is far from complete, so this paper presents only a preliminary discussion of my progress.

My first general goal is to evaluate the performance of the multiple velocity stacking, dip-moveout, and migration scheme first presented in SEP-38 (Fowler, 1984) on a field data set that included complex structure and significant lateral velocity variation. Specifically, I want to verify that high quality DMO-corrected and migrated images are obtained, and I want to compare the resulting stacking, DMO, and migration velocity fields. I also wish to study for the problems introduced by lateral velocity changes.

My second major goal is to implement and test optimization schemes for velocity analysis. I want to see if Toldi's 1-D algorithm (Toldi, 1985) for automatic picking of RMS velocities with simultaneous inversion for interval velocities can be extended to work with DMO and migration velocities as well as stacking velocities, and if it can be used on a whole data set, not just on isolated gathers. Beyond this, I also want to try out the scheme for inverting migration velocities for laterally varying interval velocities that I proposed in SEP-44 and SEP-48 (Fowler, 1985, 1986).

Currently, I have largely achieved the first goal, but not the second. I have, however, acquired a better understanding of the importance of the second goal, and how to approach it.

DESCRIPTION OF THE DATA

I was seeking a field data set that had complex structure and moderately large lateral velocity variation. I wanted to obtain a reasonable image with stacking, improve it with prestack time migration, and then improve it further with depth migration. The data also had to be of high enough quality so that aliasing or excessive noise would not cause problems.

The data set that I am testing was made available to me by British Petroleum Alaska Exploration. The data were shot off the coast of California, using water gun sources and 1.23 km cable. The frequency spectrum is broad, with significant energy as high as 100 to 120 hz. The midpoint coverage is 36 fold, with a midpoint spacing of 8.33 m. Figure 1 shows a near offset section from this data set. For display, a fast AGC has been applied to this section, and all other sections in this paper. The regular pattern of missing traces was caused by an instrument malfunction during tape reeel changes.

The sea floor dips from about 0.3 second on the right side to 1.0 second on the left. A strong reflector (partly obscured by diffractions in the unmigrated data) dips in the opposite direction from about 1.6 second at midpoint 1 to about 2.3 seconds at midpoint 900, beyond which it is less distinct. Above this reflector there is evidence of complex folding or faulting, overlain by less disturbed sedimentary layers. Near midpoints 900 to 1000 the sediments are apparently interrupted by steep faults. Beyond midpoint 1000 the layers dip opposite to the sea floor.

My principal questions about this data set are: What is the geometry of the prominent dipping reflector and of the contorted layers above it? Is there anything to be seen below this reflector besides multiples? What is going on around midpoints 900 to 1000? How well can time migration resolve the structure here? Can I derive a good enough velocity function from these data to do a good migration? How much will the lateral velocity variation arising from structure and from the wedge of overlying water affect the image? Can I derive an interval velocity model good enough to improve the image with depth migration? How much of the diffracted energy in the section is in the plane of the survey and how much will be mishandled by my algorithms because it is sideswipe?

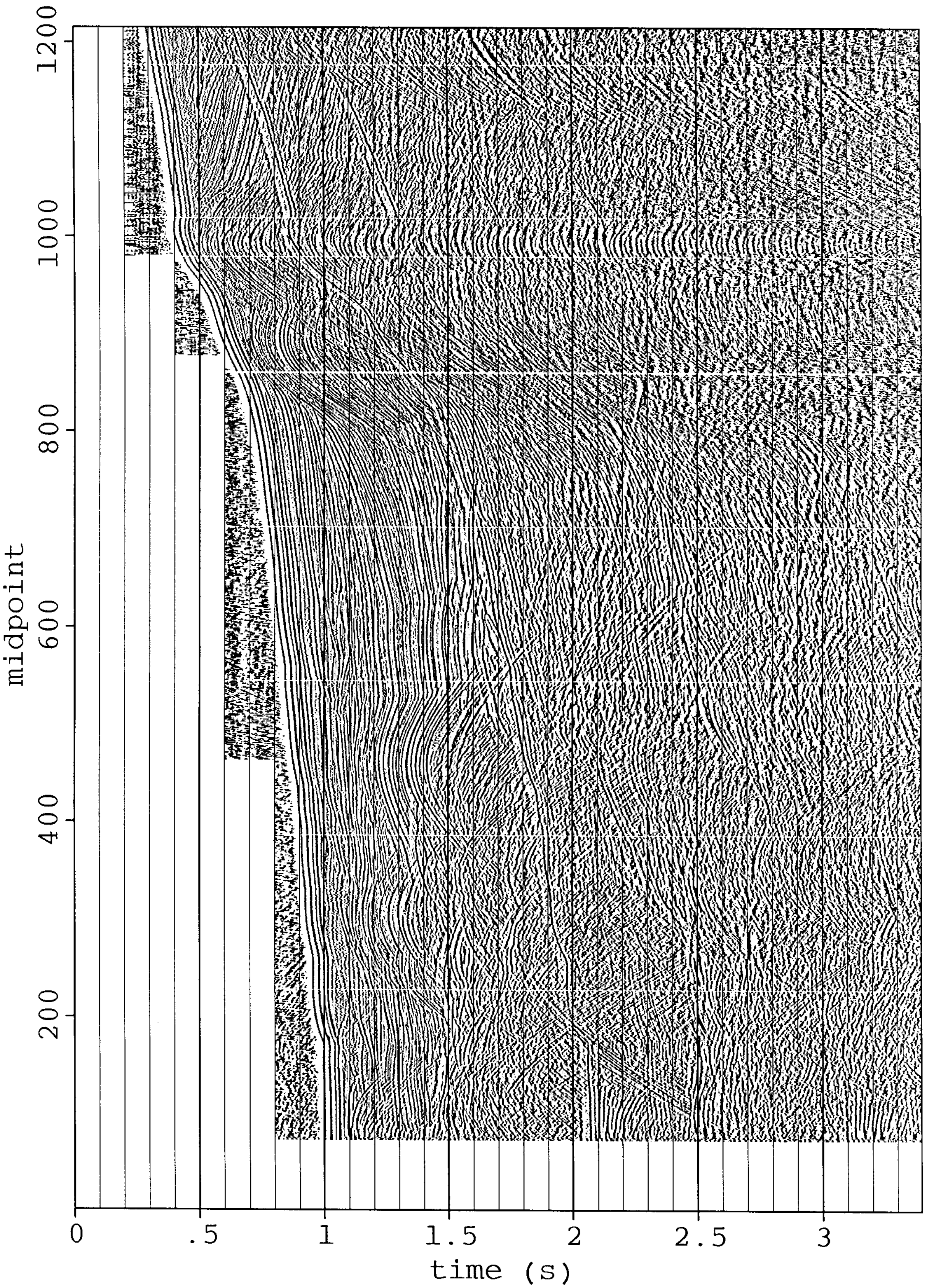

FIG. 1. Near offset section.

DESCRIPTION OF PROCESSING

After demultiplexing, editing, and sorting the data, I generated 61 constant velocity stacks, sampled evenly in slowness squared from 0.0 s^2/km^2 (infinite velocity) to 0.48 s^2/km^2 (equivalent to a velocity of 1.44 km/s). I did not do any deconvolution because the water gun source wavelet was already adequately spiky. I made no effort to suppress the multiples beyond that done by the stacking, since they are discordant enough compared to the geologic structure to be readily identifiable. I then applied the algorithm described in SEP-38 (Fowler, 1984) to do DMO and then migration on these stacks to convert them into prestack time migrated images. I used the DMO operator to resample the velocity axis; the output was 81 images evenly sampled in slowness from 0.29 s/km to 0.69 s/km (equivalent to a velocity range of 1.45 km/s to 3.45 km/s).

For the purposes of velocity analysis, these data cubes were not wholly satisfactory, because they were dominated by a few reflectors that were much stronger than the rest. This was not a major problem when examining the sections on a display screen, but it caused difficulties when comparing amplitudes or energies of events for different velocities. A common solution to this problem in stacking velocity analysis is to use semblance, a coherence measure which automatically normalizes weak and strong events. That solution cannot be carried over here directly, but applying a fast automatic gain control before stack achieves much the same goal. As I implemented it, the AGC consisted of just weighting each sample by the reciprocal of the energy in a time gate around it.

Data that is AGC weighted before stack will no longer really honor the wave equation. However, it can still be run through DMO and migration with little problem. My experience has been that the resulting images will be slightly inferior to those resulting from processing the ungained data, and of course the true amplitude information is lost, but the velocity analysis is substantially improved. Here I processed the data twice, once with AGC before stack and once without; I used the first for velocity analysis, and the second for extracting variable velocity images, only applying AGC for display at the end.

For preliminary velocity analysis I selected every 25th midpoint and calculated the energy in short running windows along the time axis of the stacks and the migrated stacks. These results are contoured to resemble conventional semblance plots. Figure 2 shows stacking energy with and without prestack AGC for midpoint 550. Figure 3 shows similar plots of the prestack migration energy for the same midpoint. As can be seen, with AGC more events are visible. Generally, both kinds of velocity analyses were straightforward to pick down to about 2 seconds, and became ambiguous after that.

Near midpoint 1000 both deteriorated substantially.

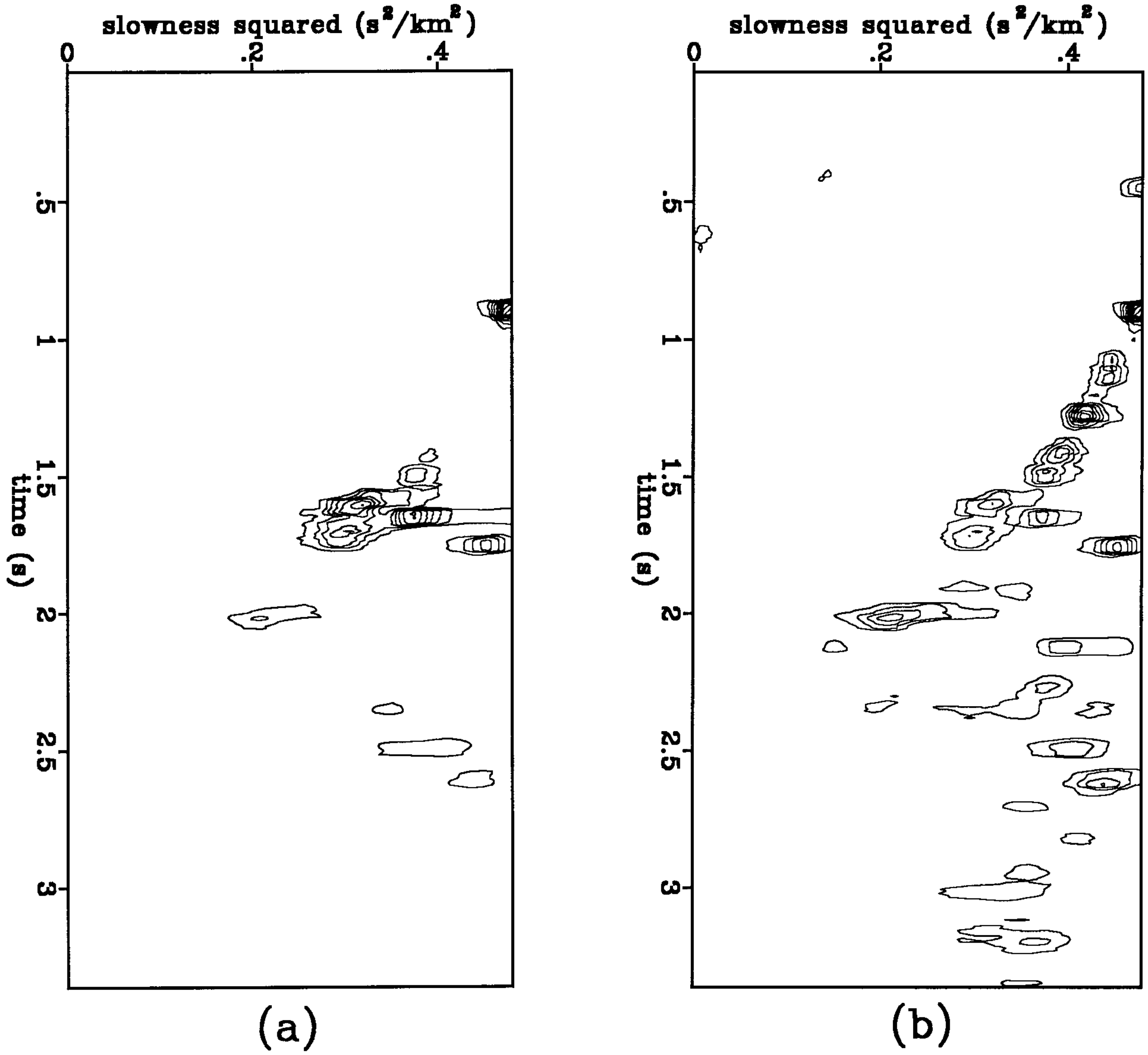

FIG. 2. (a) Stacking velocity analysis for data from midpoint 550. The energy, averaged over a short time window, is contoured. The only gain applied to the data is to multiply it by t^2. Only a few of the strongest reflectors are visible. (b) This is the same plot as in part (a), but based on data that had a fast AGC applied before stack. Many more reflectors are now visible to contribute to the velocity analysis.

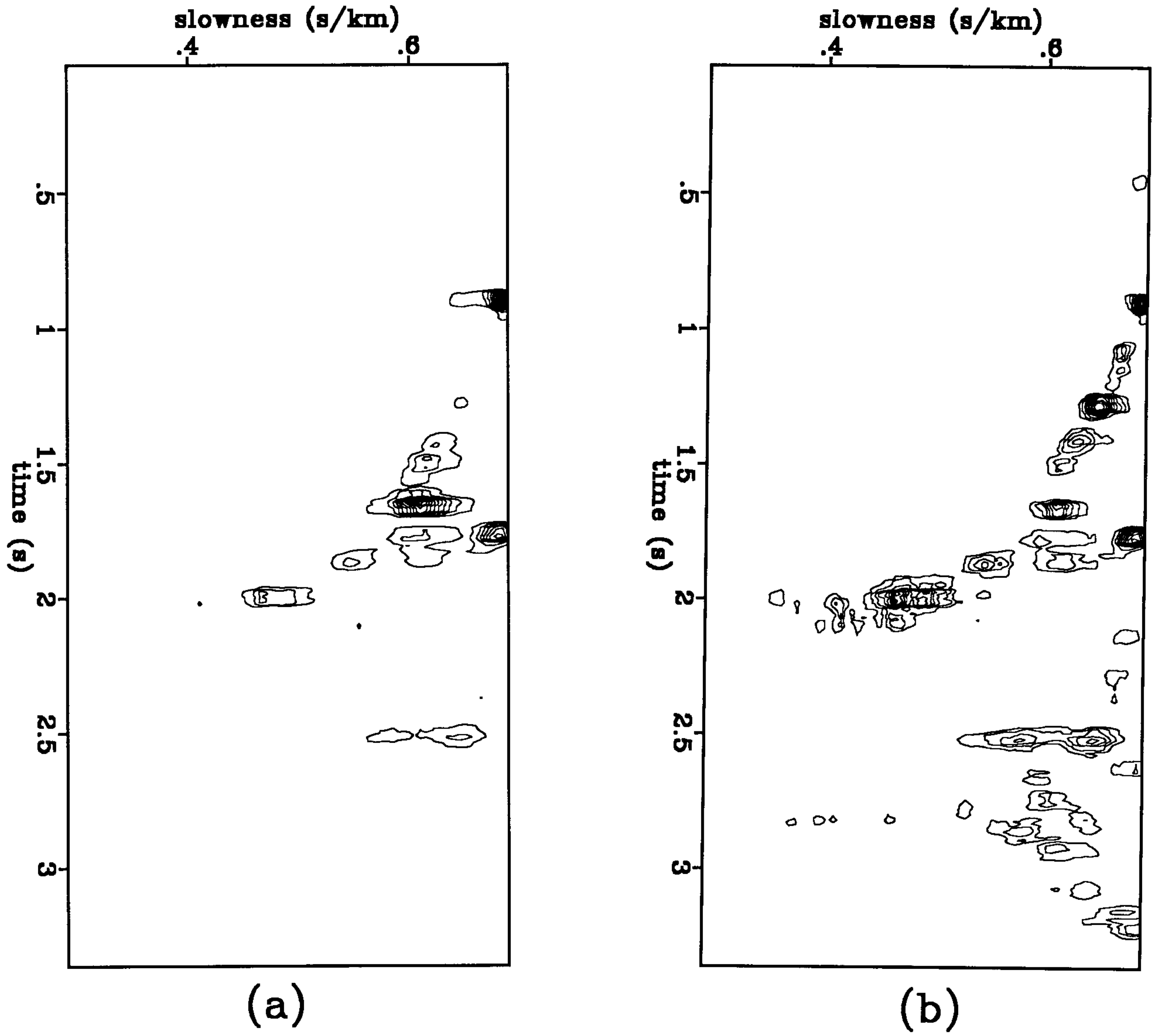

FIG. 3. (a) Migration velocity analysis for data from midpoint 550. This plot is computed by the same method as figure 2(a). (b) This is the same plot as in part (a), but based on data that had a fast AGC applied before stack.

I then picked peaks on each plot and interpolated a smoothed velocity field from these picks. Figures 4 and 5 show the resulting velocity fields, and figures 6 and 7 show the corresponding stacked and migrated sections, respectively.

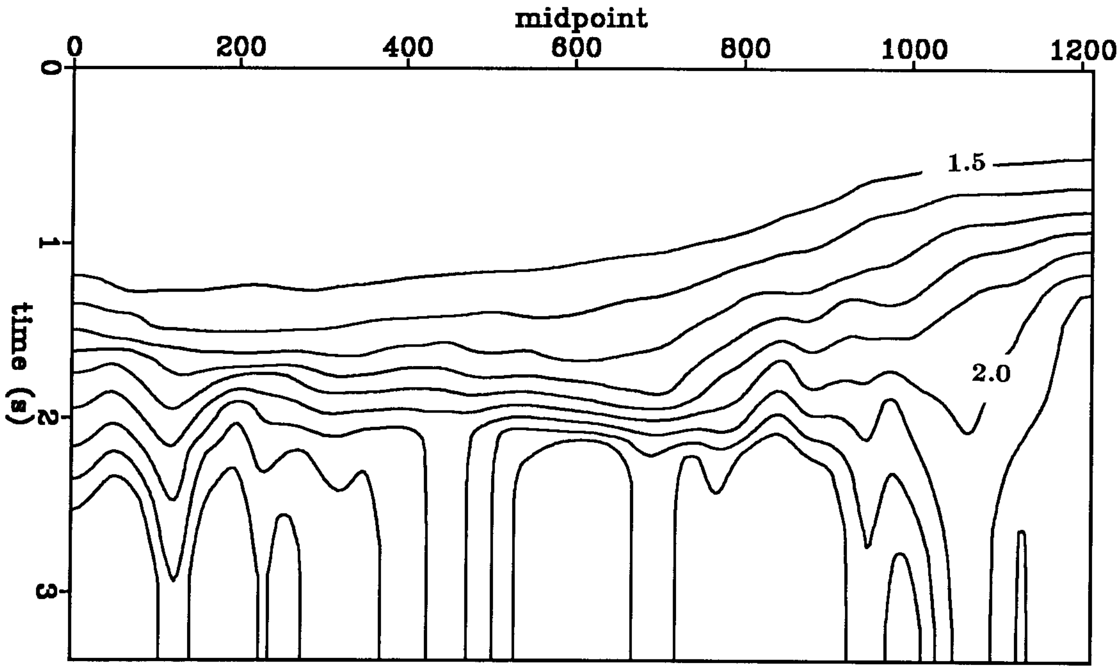

FIG. 4. Stacking velocity field. Velocities were picked every 25th midpoint, then interpolated and smoothed. This is the velocity function used to generate figure 6. The contour interval is 0.1 km/s.

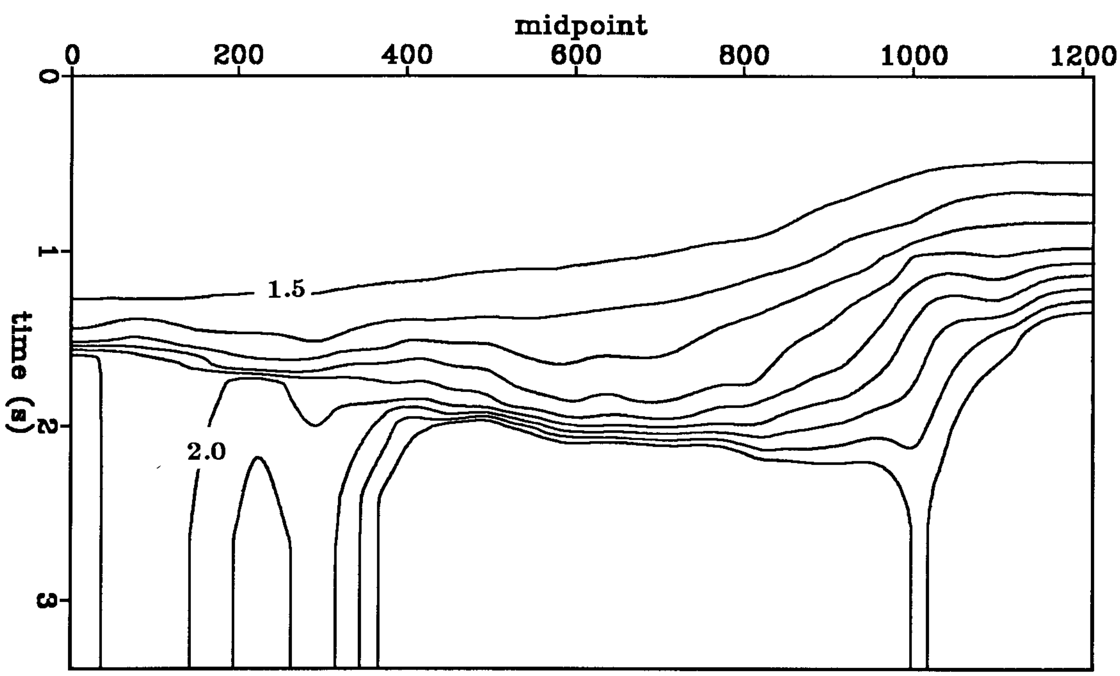

FIG. 5. Prestack migration velocity field. Velocities were picked every 25th midpoint, then interpolated and smoothed. This is the velocity function used to generate figure 7. The contour interval is 0.1 km/s.

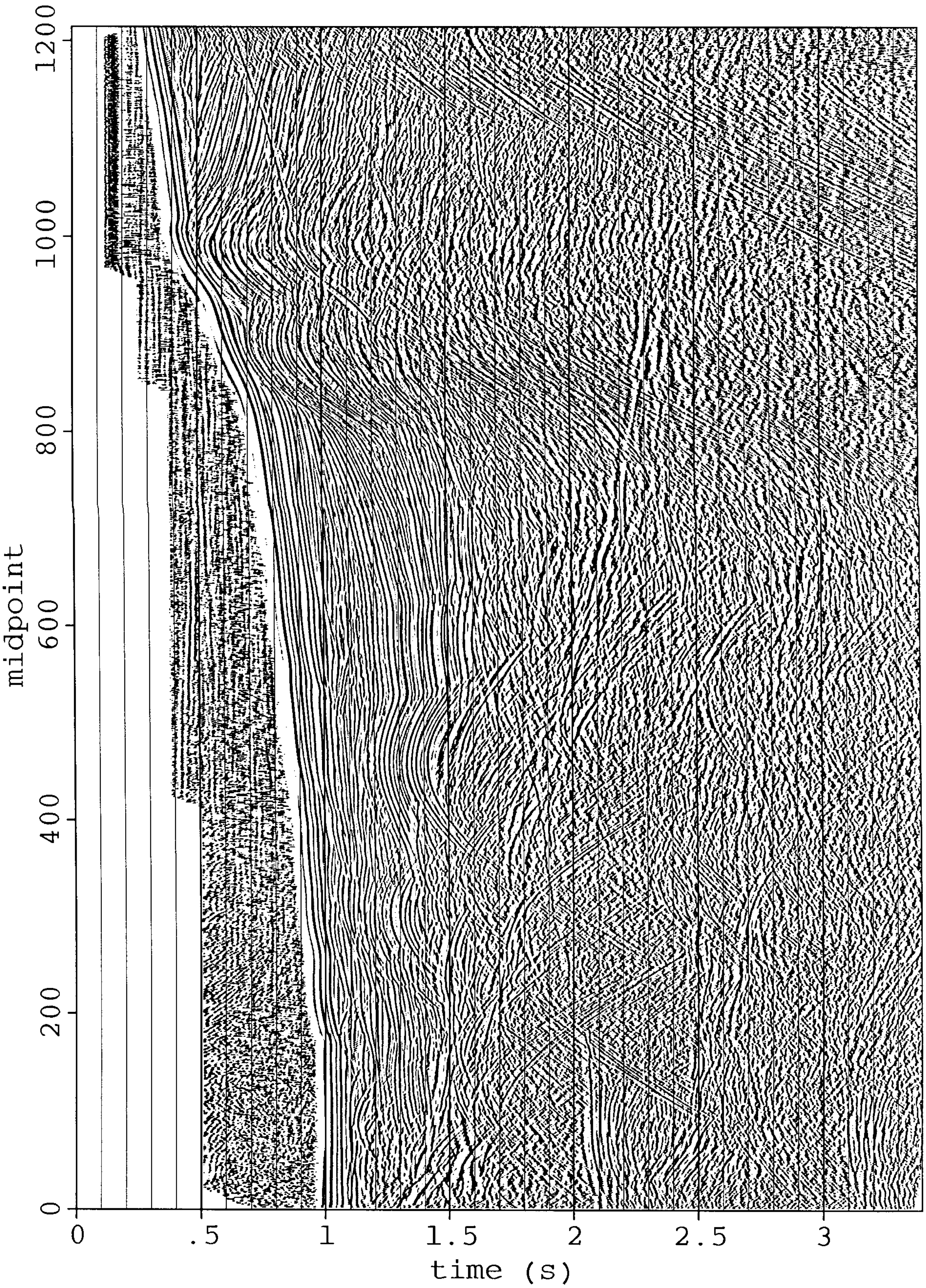

FIG. 6. Stacked section. This section has been created by interpolation between constant velocity sections using the velocity function shown in figure 4.

FIG. 7. Prestack migrated section. This section has been created by interpolation between constant velocity prestack migrated sections using the velocity function shown in figure 5.

PROBLEMS OF VELOCITY ANALYSIS

Figure 6 shows that the velocity field in figure 4 is adequate to produce an acceptable stack. The migrated image in figure 7 has resolved many of the major features in the data, but is not as good as one can get here. This is best seen by scanning through a movie of the constant velocity migrations; by isolating and magnifying small areas of the image, one can precisely pick optimal migration velocities by directly judging how good the focusing is. Looking at the movies shows that migration velocity analysis can be much more sensitive than stacking velocity analysis to small velocity perturbations because images move around so much with migration, and the human eye is adept at picking out motion or shifts in patterns. Movies are definitely superior to paper plots here. Unfortunately, we don't have software at SEP yet to let us pick velocities this way or to update a velocity field interactively, so I have not attempted to fine tune the migration velocity field this way.

The major problems with the migration velocity field in figure 5 stem from the way the velocities were picked and smoothed. There can be substantial error in the picks a person makes, and what events one picks out depends highly on the plotting and display parameters used, and on one's expectations of how a good velocity field should behave. Smoothing of the picked velocity field is necessary to eliminate the random errors and to damp out the effects of gross mis-picks, but it also can falsify the accurate picks. Interpolating between picks introduces additional errors. The effects of these small errors matter more for migration velocity analysis than for stacking velocity analysis, because migration velocity errors misposition events whereas stacking velocity errors usually just weaken an event's amplitude.

One would like to be able to use all the velocity information present in the data, not just that from a few selected midpoints while hoping for the best elsewhere. However, the data volume can become unmanageably large. One would also like to monitor continually the plausibility of the interval velocity model implied by one's migration velocity picks. An alternative (or complement) to interactive velocity analysis that might satisfy both these goals is to teach a computer how to do the work for us. This requires formulating the problem as an optimization scheme.

I am currently adapting John Toldi's 1-D algorithm to act on all midpoints simultaneously. For now I retain the assumption that migration velocities are RMS averages of the interval velocities, but the damping now acts not just on a single gather but between midpoints to constrain the rate at which velocity can vary laterally and to force neighboring traces to yield consistent velocity information. I am testing this scheme both on the data set discussed here and on synthetics.

Toldi found that smoothing over slowness helped accelerate convergence of the early iterations of his algorithm. Because he used a space of computed semblance values, he was also implicitly smoothing over a fixed window in time. Here I have yet a third direction, midpoint, over which I may wish to smooth the data as well. By calculating the energy separately at every point in the data space, I can vary the size of the smoothing window in any of these directions as I iterate. The price I pay is having to retain the entire (very large) data set on disk.

The strong rightward dipping reflector in figure 7 is not everywhere well imaged; nor is the presumed fault zone near midpoint 1000 (although I suspect sideswipe contributes to the latter problem). Both of these appear to involve large velocity gradients. To invert correctly for interval velocities in these areas, if it is possible at all, may require a more sophisticated theory relating the migration velocities to the interval velocities than the simple RMS assumption. When I get the RMS based algorithm working, I hope to substitute into it for testing the more complicated relation I derived in SEP-44 and SEP-48. The final test will be to use the derived interval velocity functions for depth migration.

As a last point, I note that I still don't know if their are any coherent primary reflections to be imaged beneath the strong right-dipping reflector. The apparent velocity jump at this reflector, and the complicated structure above it, suggest ray bending occurs to such a degree that neither hyperbolic stacking nor prestack time migration have much chance of successfully imaging beneath it. If an accurate enough velocity function can be derived above this layer, it might prove revealing to downward continue the prestack data to this surface to minimize the ray bending. Stacking or migration velocity analysis might then have a better chance if used in such a layer-stripping mode.

ACKNOWLEDGMENTS

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