The linear stacking slowness method for a field dataset.

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Abstract

In this paper, I present the application of the linear stacking slowness method (Rocca and Toldi,1982; Toldi, 1983) to a field dataset. The basic procedure is to determine stacking slownesses for as many reflectors as possible, then perform the inversion for interval slowness. For the dataset I present here there are only a few reflectors which cross the entire section. I discuss the implications of this restriction to a few datapoints, both theoretically and through the interpretation of my inversion results. Finally, I discuss alternate formulations of the linear stacking slowness method, which would allow one to use a larger portion of the dataset for the inversion.

Data processing

Stacking slownesses are determined by computing semblance along hyperbolic trajectories in offset versus time space. This can be viewed as a transformation from coordinates of (midpoint, offset, time) to (midpoint, stacking slowness, time). The dataset required for the use of the linear stacking slowness method is a set of stacking slowness curves as a function of midpoint, with one such curve for each reflector of interest. Thus, the velocity analysis required is a so-called horizon velocity analysis. For the flat reflectors present in the dataset that I am examining, one need calculate semblance only for specific time planes. I therefore make my picks from velocity versus midpoint planes, as opposed to the standard velocity versus time planes (see figure 1).

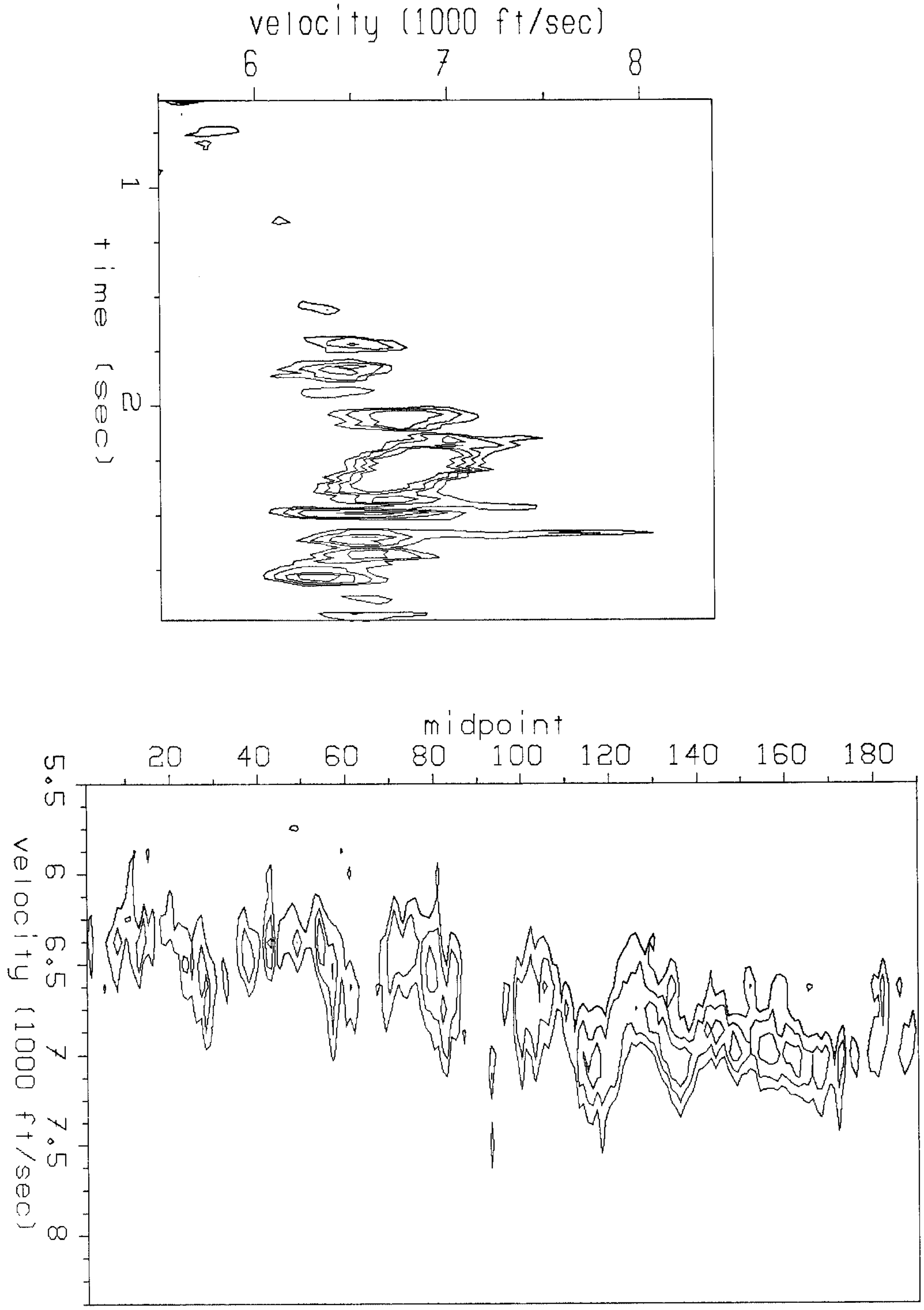

FIG. 1. Two ways of viewing semblance plots. a) Contour plot of semblance for the velocity versus time plane at midpoint 100. b) Contour plot of semblance for the velocity versus midpoint plane at 2.1 seconds.

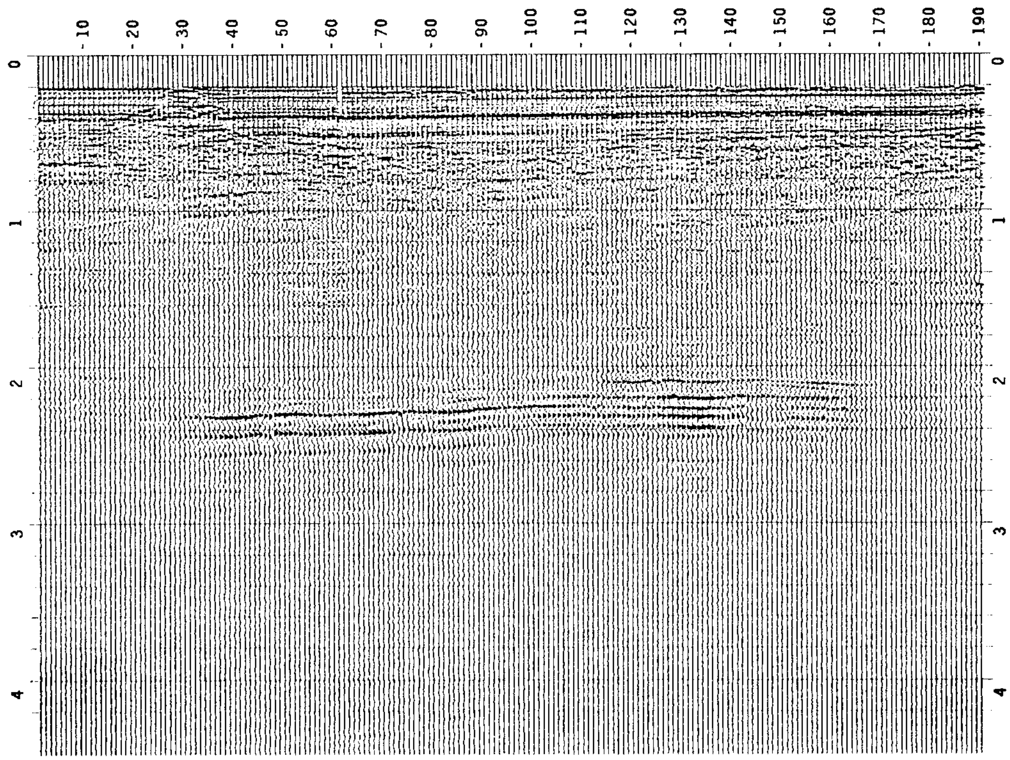

FIG. 2. Stacked section of Gulf Coast dataset.

Restrictions on usable data

Figure 2 is a CMP stack of the field dataset. Examining this dataset in terms of the basic assumptions of the linear stacking slowness method is instructive. The most important assumption is that the background distribution be laterally invariant. Because the reflectors shown in figure 2 are reasonably flat, this assumption would seem to be well satisfied by the dataset. The assumption of lateral invariance also means that the reflectors must be continuous across the entire section.

This restriction to fully continuous reflectors has important consequences for the inversion. An obvious consequence is that the dataset is left with few allowable datapoints, thereby making the system much less overdetermined. Perhaps more important than the number of datapoints is their distribution in depth.

A specific spatial frequency of anomalous interval slowness at depth (z_{an}), is filtered according to its relationship to the effective cable length. In particular, the zeroes of the transfer function between interval slowness and stacking slowness occur at wavelengths equal to some specific fraction of the effective cable length (Rocca and Toldi, 1982). Furthermore, the effective cable length at z_{an}, depends on the depth of the reflector (see figure 3). Thus, the stacking slowness responses for two reflectors, one at depth z_{r1}, the other at depth z_{r2} will be zero for different wavelengths of interval slowness at depth z_{an}.

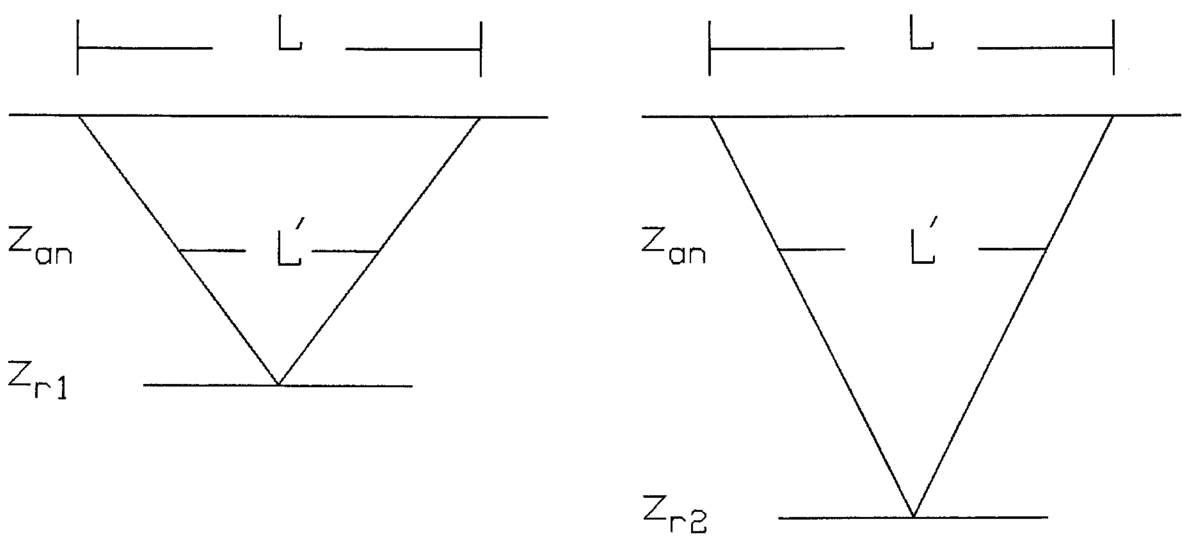

FIG. 3. Effective cable length L', for a specific depth of anomaly z_{an}, depends on the depth of the reflector. 3a) reflector at depth z_{r1}. 3b) reflector at depth z_{r2}.

On the field dataset, the only fully continuous reflectors are the strong ones between 2 and 2.5 seconds. There are several reflectors at that depth, but all will have the same effective cable length, and thereby the same filtering action.

One possible way to extract more information from one reflector would be to handle the near and far offsets independently in the velocity determination. The appropriate operators are derived in an accompanying paper in this report, where it is shown that operators for the near and the far offsets from the same reflector have their zeroes at different spatial wavelengths. Although the basic idea is appealing, the role of the noise introduced by incorrect picking would need to be carefully examined.

A more basic question is how to use the information from reflectors that are continuous across only part of the section. Note that such a question would also arise in any dataset with flat layers broken by faults, certainly a common enough case to warrant consideration.

An obvious answer is to abandon the spatial frequency domain formulation, and reformulate the theory strictly in the spatial domain. I intend to examine this possibility in future research. The most dramatic change from this formulation would come in the actual solution of the problem. Without the decoupling into several small problems (one for each wavenumber) allowed by the Fourier transform, the system becomes too big to invert directly. Some sort of iterative algorithm would be required, with all of the attendant considerations of convergence.

A less drastic solution, and one that I will pursue in this paper, is to try to combine the information from partial reflectors into one continuous pseudo-reflector. Clearly one must be careful in such an operation, particularly in light of the role of the effective cable length. That is, reflectors to be stacked together must come from depths close enough together that the difference in their effective cable length will seriously affect only wavelengths beyond the range of interest. Note that there is no simple way to filter the stacking slowness at one depth in order to simulate the slowness from some other radically different depth. The operation producing the stacking slowness depends on the interaction of the effective cable length at all depths down to the reflector of interest. Thus, the only way to do the simulation is to effectively invert for interval slowness, then re-integrate down to the new depth.

A simple way to achieve the construction of the pseudo-reflector is to allow a fairly long time window for the semblance, and then to consider all semblance peaks that fall in this window to belong to the same reflector. With such an operation, I was able to determine two stacking slowness curves from the field dataset, one from 1.6 and one from 2.15 seconds. (see figure 4)

Inversion results

Figure 5 shows the result of performing the inversion for the stacking slowness of the reflection at 2.1 seconds. As would be expected for an inversion from only one reflector, there is a limited ability to locate the anomalies in depth. The Fourier transform over midpoint of this single stacking slowness curve constitutes our input data, and thus, in the frequency domain, our data consists of one point. Clearly there is no null space in the data space, so the generalized inverse just smears the data in depth along the determinable component of the model space. It is interesting to note that the smearing is not strictly vertical, as would have been predicted from a conventional velocity analysis.

Figure 6 shows the interval slownesses derived by the inversion of the stacking slowness from 1.6 and 2.1 seconds. The location of the shallower reflector is clearly visible. Figure 4 reveals that the main difference between figures 4a and 4b is a linear trend, grading from positive to negative slowness as the midpoints go from small to large. Thus, in the portion of the data most sensitive to the difference between the slowness curves (i.e., between the two reflectors), the resulting linear trend is evident. Note that not all

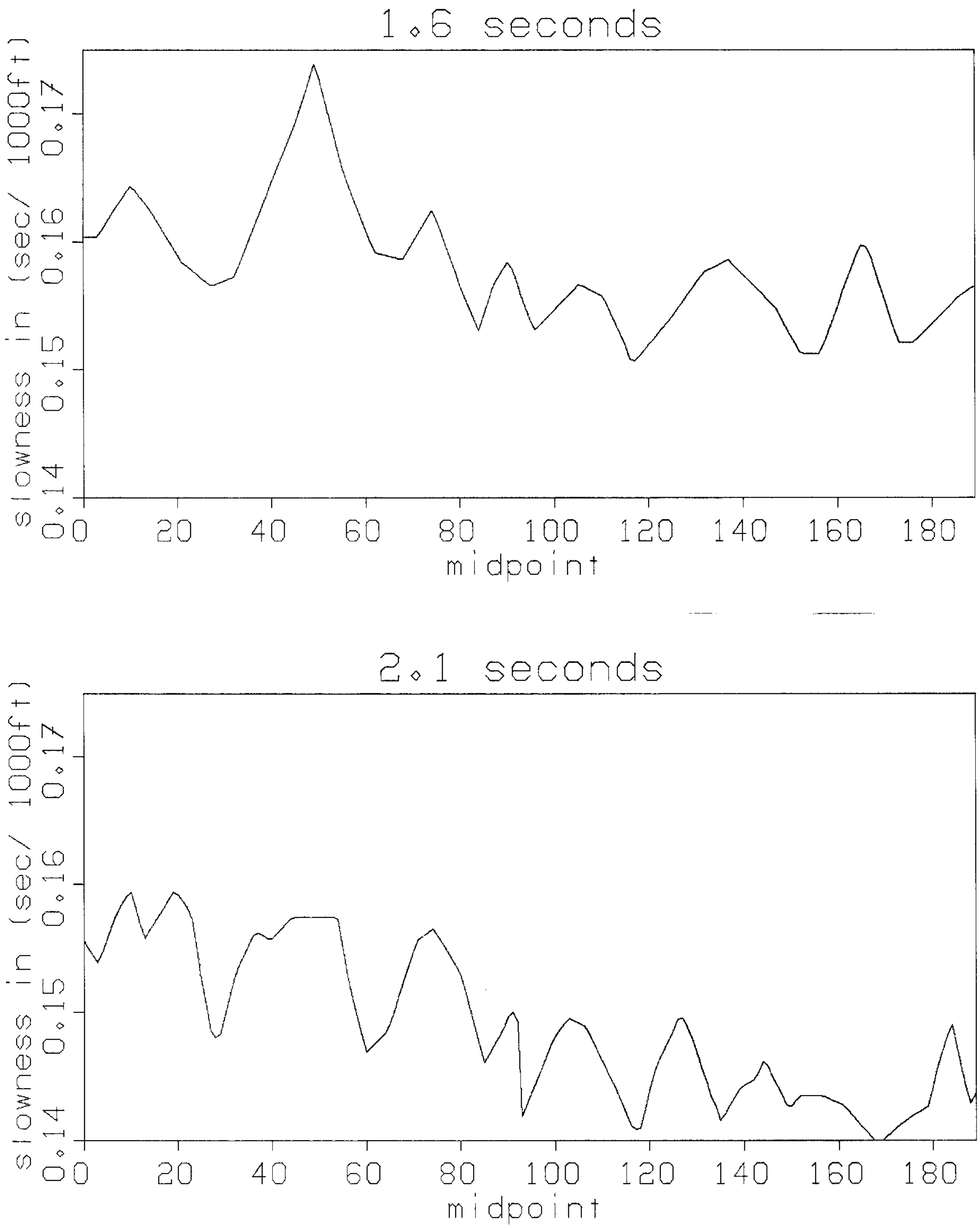

FIG. 4. Stacking slowness plotted as function of midpoint for two different reflectors. 4a) from 1.6 seconds, 4b) from 2.1 seconds.

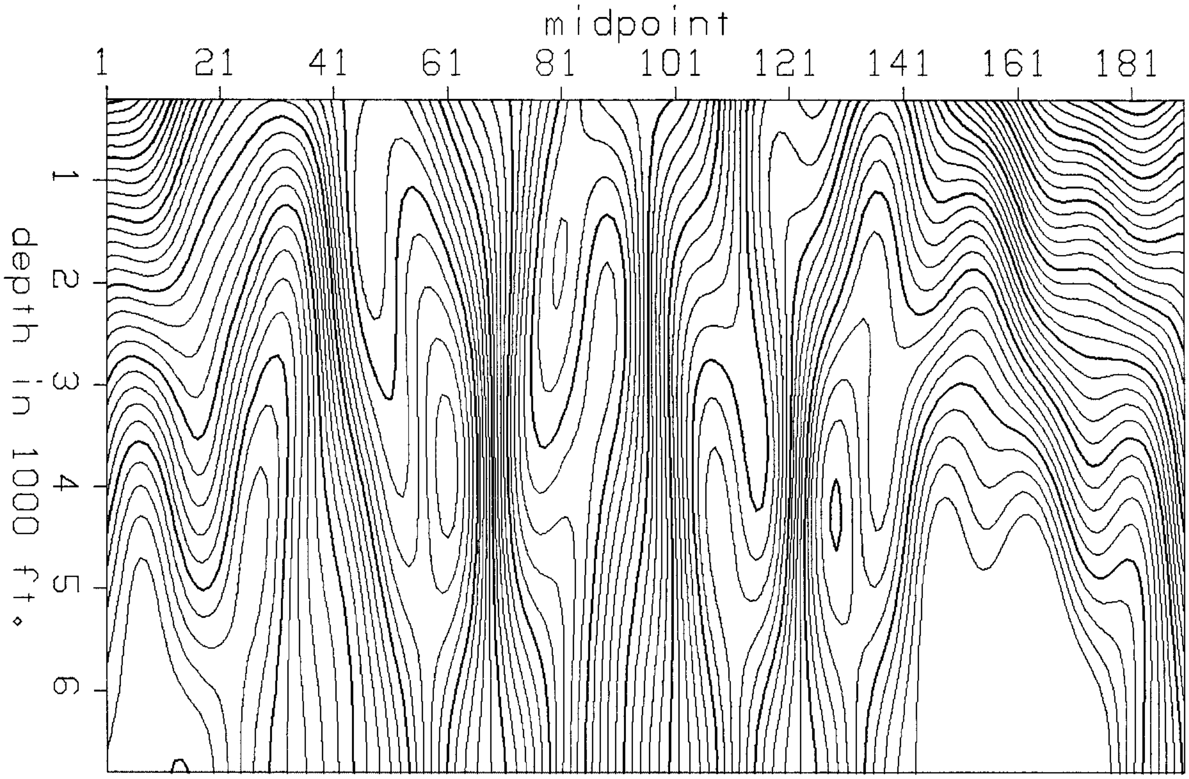

FIG. 5. Contour plot of interval slowness as a function of midpoint and depth. Calculated from the stacking slowness of the reflection at 2.1 seconds.

differences between stacking slowness curves from different depths will result in an interval slowness anomaly between the two reflectors. As shown in earlier discussion some of the differences between stacking slowness curves from different reflectors are due to their differing filter responses.

In the shallow portion of the data, the second reflector makes the most dramatic contribution. Here, a certain amount of overdetermination is possible, since we now have two different views of the same depth region--one from each reflector. Naturally, the inclusion of more reflectors would give an even clearer picture. Certain portions of the anomalous interval slowness can be given an interpretation.

Particularly interesting is the ridge of slowness at midpoint 30 and depth of about 100 feet. Note how the position of this anomaly corresponds quite closely to that of a strong diffraction on the constant offset section shown in figure 7. A further such correlation is possible between the series of anomalies between midpoints 120 and 160 and depths of about 1500 feet, and the diffractions at about .8 seconds. A similar correlation was made for this dataset by Kjartansson (1979), in his work with traveltimes.

Another interesting, and somewhat problematical portion of the interval slowness distribution, is the series of anomalies immediately above the shallower reflector, i.e. at depth 4500 feet. The distribution here is almost a replication of the stacking slowness curve for the shallow reflector (see figure 8). Clearly the inversion allows for such a solution. The effective cable length for this zone as determined for the shallow reflector is very small, with the result being that an interval slowness anomaly here would be reflected directly in the stacking slowness.

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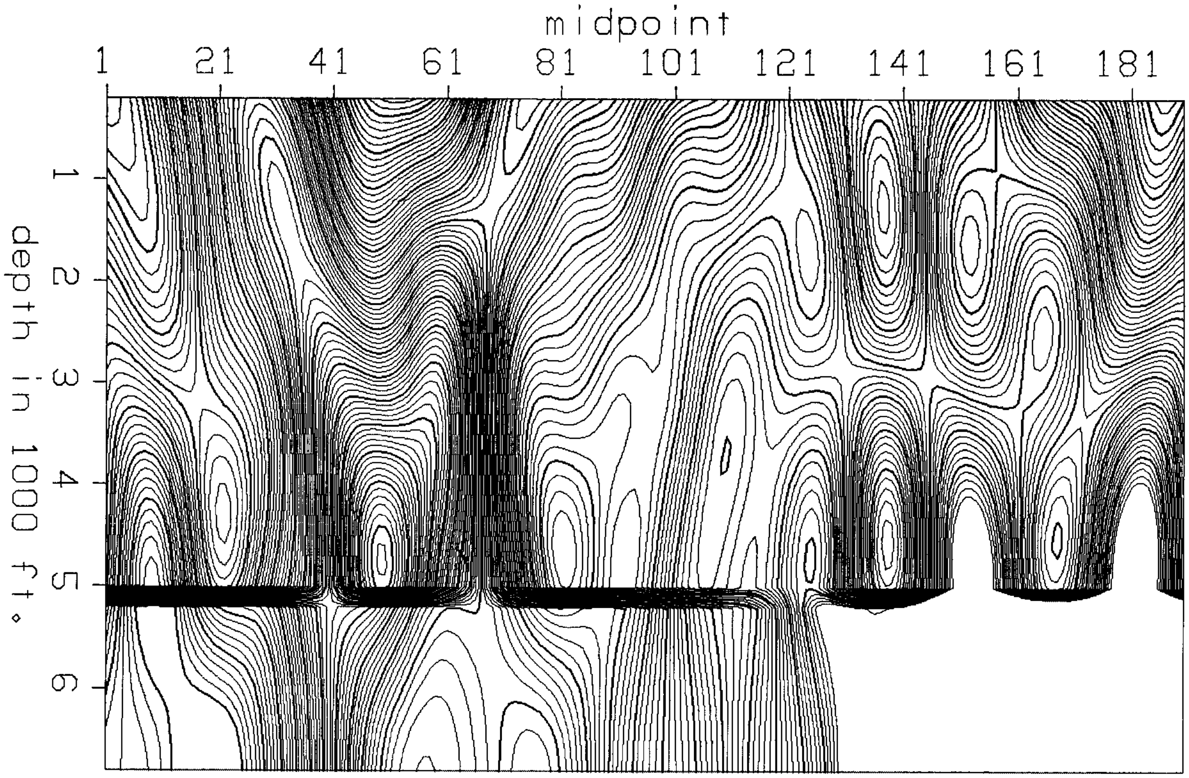

FIG. 6. Contour plot of interval slowness as a function of midpoint and depth. Calculated from the stacking slownesses of the reflections at 1.6 and 2.1 seconds.

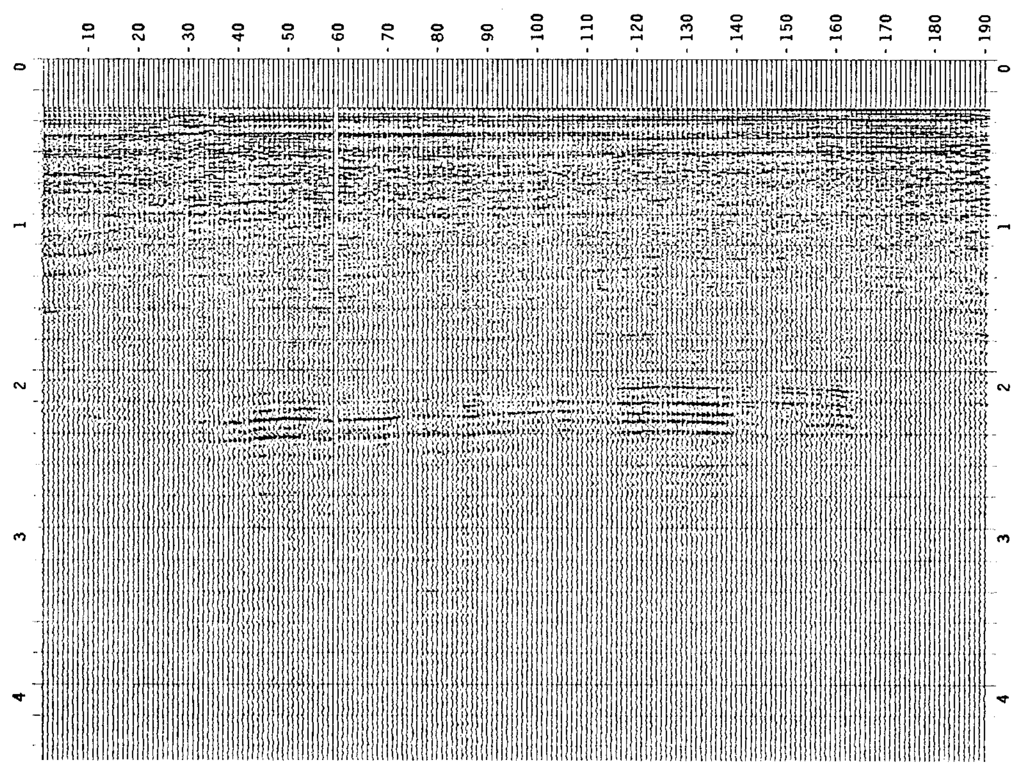

FIG. 7. Constant offset section. (offset = 1200 feet)

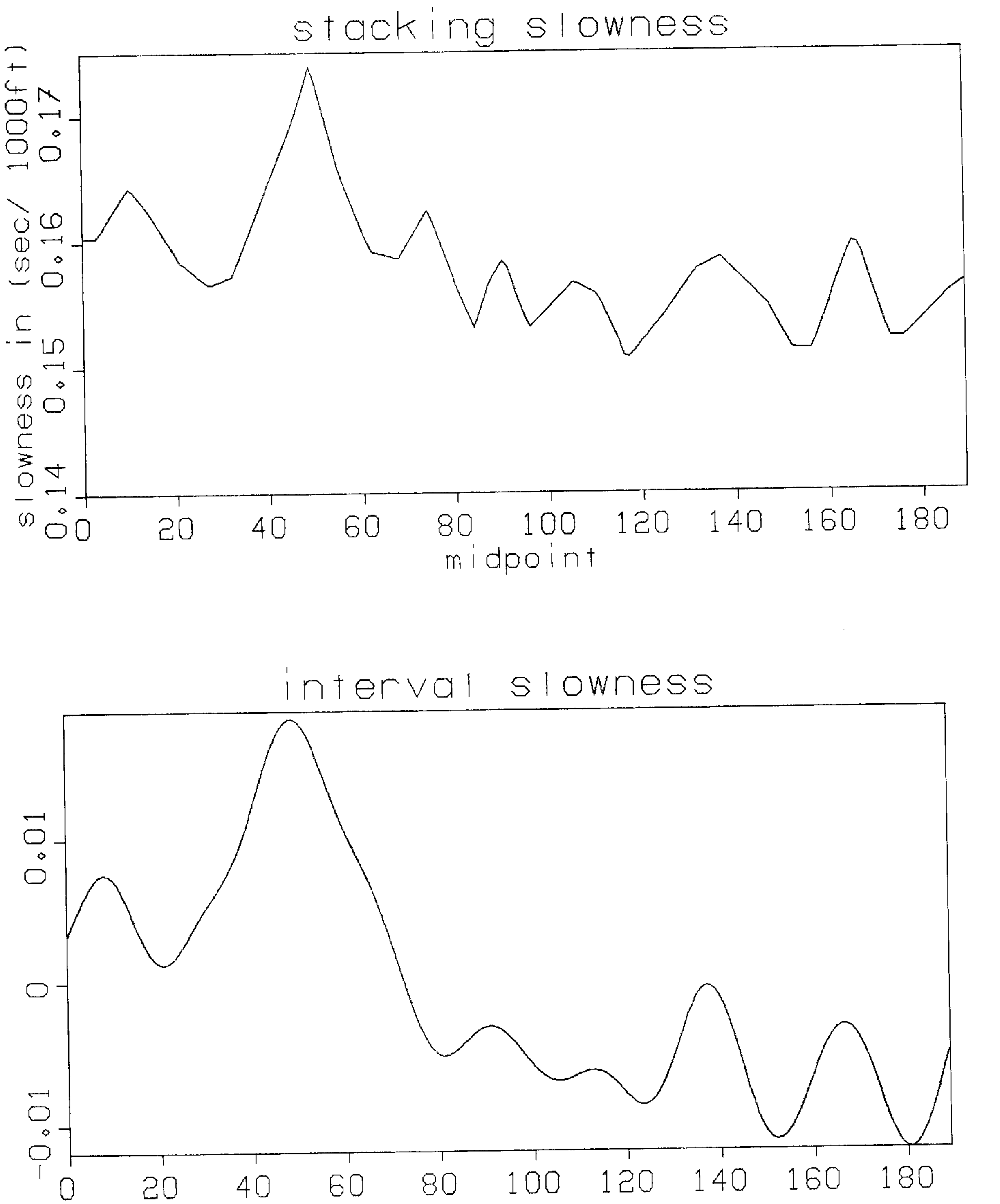

FIG. 8. Slowness plotted as function of midpoint. a) stacking slowness for reflector at 1.6 seconds. b) interval slowness for depth of 4500 feet.