Chapter 1

Missing data or too much data?

On one hand, spatial aliasing is a missing data problem: we need more data to adequately sample the seismic wavefield. On the other hand, it seems that we have too much data: there are many traces in every common-midpoint gather, and we reduce the data size in the stacking process. The goal of this thesis is to use the apparently redundant data to overcome the missing data problem.

§ 1.1 Sampling and aliasing in reflection seismology

To explore the earth's interior, reflection seismologists use a wavefield which they sample on the surface of the earth. They extrapolate that wavefield into the subsurface, and this requires that the wavefield is adequately sampled.

Adequate sampling, according to Fourier analysis, is at least two sampling points per the smallest wavelength. If this sampling condition is violated, events may appear as (alias) other events: high frequencies alias as low frequencies (Figure 1.1.1); steep dips may alias as flat events (Figure 1.1.2).

The seismic wavefield is sampled in time and space. Sampling in time is seldom a problem: temporal sampling can be improved by using faster analog-to-digital converters which are available and cheap. Spatial sampling can be improved by using more recording and source stations, but this may be technically impossible, especially in 3-D surveys.

When the stacked section is spatially aliased, resolution deteriorates, and dipping events are lost — they alias as flat events or as noise. A stacked section and its migration are shown in Figures 1.1.3 and 1.1.4. These are well-sampled sections with a trace interval of 12.5 m. When spatial aliasing is introduced by taking a quarter of the data (50 m midpoint interval), the dipping events (at 1.5 and 3.8 km at 1 sec) can still be recognized on the stacked section (Figure 1.1.5), but they are lost in migration (Figure 1.1.6). When spatial aliasing is severe (100 m midpoint interval), the dipping events are completely lost on both the stacked and the migrated sections (Figures 1.1.7 and

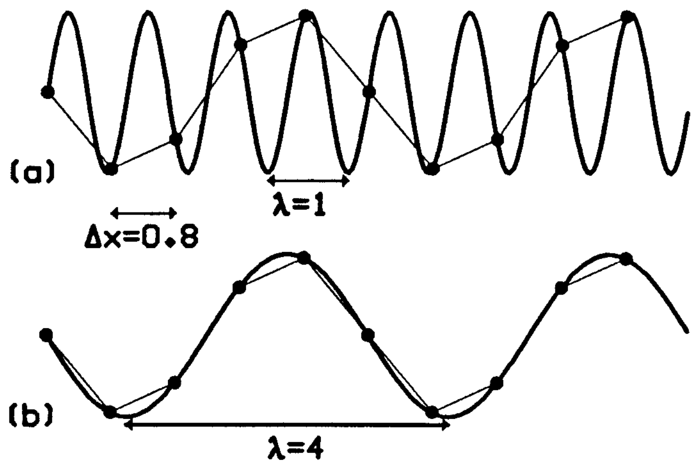


FIG. 1.1.1. Aliasing in one dimension. Samples from a high-frequency signal (a) cannot be distinguished from samples from a low-frequency signal (b). The high frequency (λ_a =1) aliases as low frequency (λ_b =4) because the sampling interval (Δx =0.8) is bigger than half the wavelength (λ_a /2=0.5).

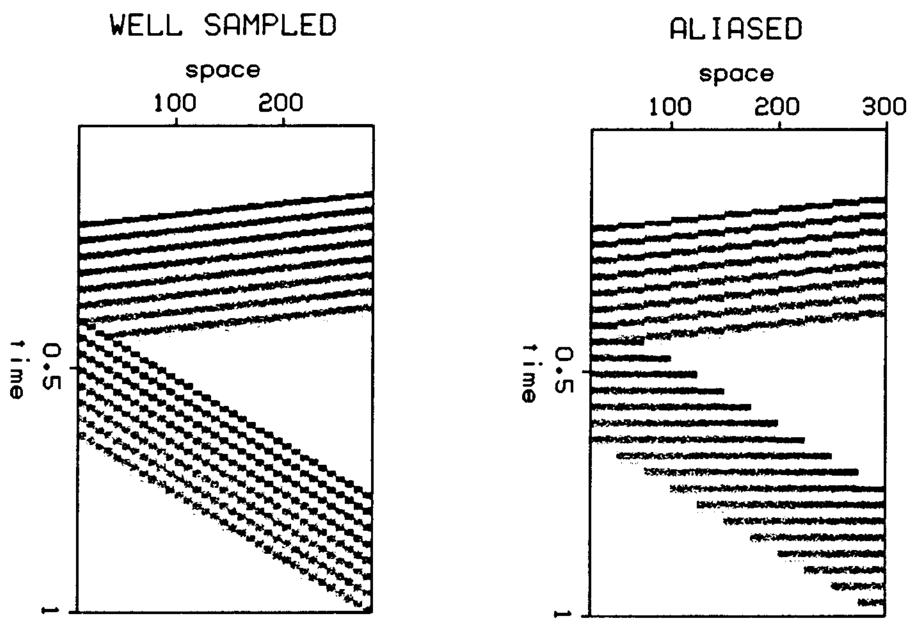


FIG. 1.1.2. Spatial aliasing on synthetic a zero-offset section. The dominant frequency is 30 Hz, the velocity is 1500 m/s. Left: adequate sampling (Δx =8.3 m). Right: spatial aliasing (Δx =25 m): the reflection from a 90 ° dipping event aliases as flat events.

1.1.8).

Suppose the data have frequencies up to 50 Hz, and the (half) velocity is 1000 m per second. The minimum wavelength is then 20 m, and the adequate sampling interval is 10 m. Small sampling intervals like this can be achieved in two-dimensional surveys (mostly marine), but in three-dimensional surveys it is difficult to find a reasonable compromise between recording cost and spatial aliasing. In 3-D surveys the sampling is generaly not uniform, and midpoint intervals may reach 100 to 200 m. Interpolation methods are used to fill in the missing data between sampling points.

§ 1.2 Multichannel data in reflection seismology

In early reflection surveys a technique called *isolated correlation* was used: isolated shot points, hundreds of meters apart, and a small number of geophones near each shot. The interpreter had to deal with a severe missing data problem: he had to correlate the isolated shots.

The technological developments in recording and shooting since the days of isolated correlation, allowed the use of more receivers per shot and more shots per mile, closing the gaps between the shots and making 100% coverage possible. Then, with overlapping coverage and the multichannel data of the common-reflection-point method (Mayne, 1956), more data are collected than are needed to describe the image of the subsurface.

Multichannel data are of great value for velocity analysis and signal-to-noise enhancement. A section called the *stack* is extracted by summing (stacking) partially processed data.

Prestack processing is designed so that the stacked section is approximately the zero-offset section. Poststack migration uses the stack to produce an image of the earth's reflectivity. All the information on the geometrical properties of the subsurface — where the reflectors are, and some measure of how strong they are — is contained in the zero-offset section (or in any other common-offset section). In principle, the various common-offset sections do not carry any additional information on the reflectivity. Indeed, when the signal-to-noise ratio is high it seems better to use the near-offset section than the stack. The near-offsets section of Figure 1.2.1 contains no less information than the 6000% stacked section of Figure 1.1.3, although it was prepared using less than 2% of the data!

The various common-offset sections in the data are not independent; they all correspond to the same earth; there is a great deal of redundancy in the data. This

FIG. 1.1.3. A stacked section (Chevron, the Gulf of Mexico). Processing: gain for spherical spreading (tpow), filter, NMO, DMO, 6000% stacking. The stack is adequately sampled with a trace interval of 12.5 m.

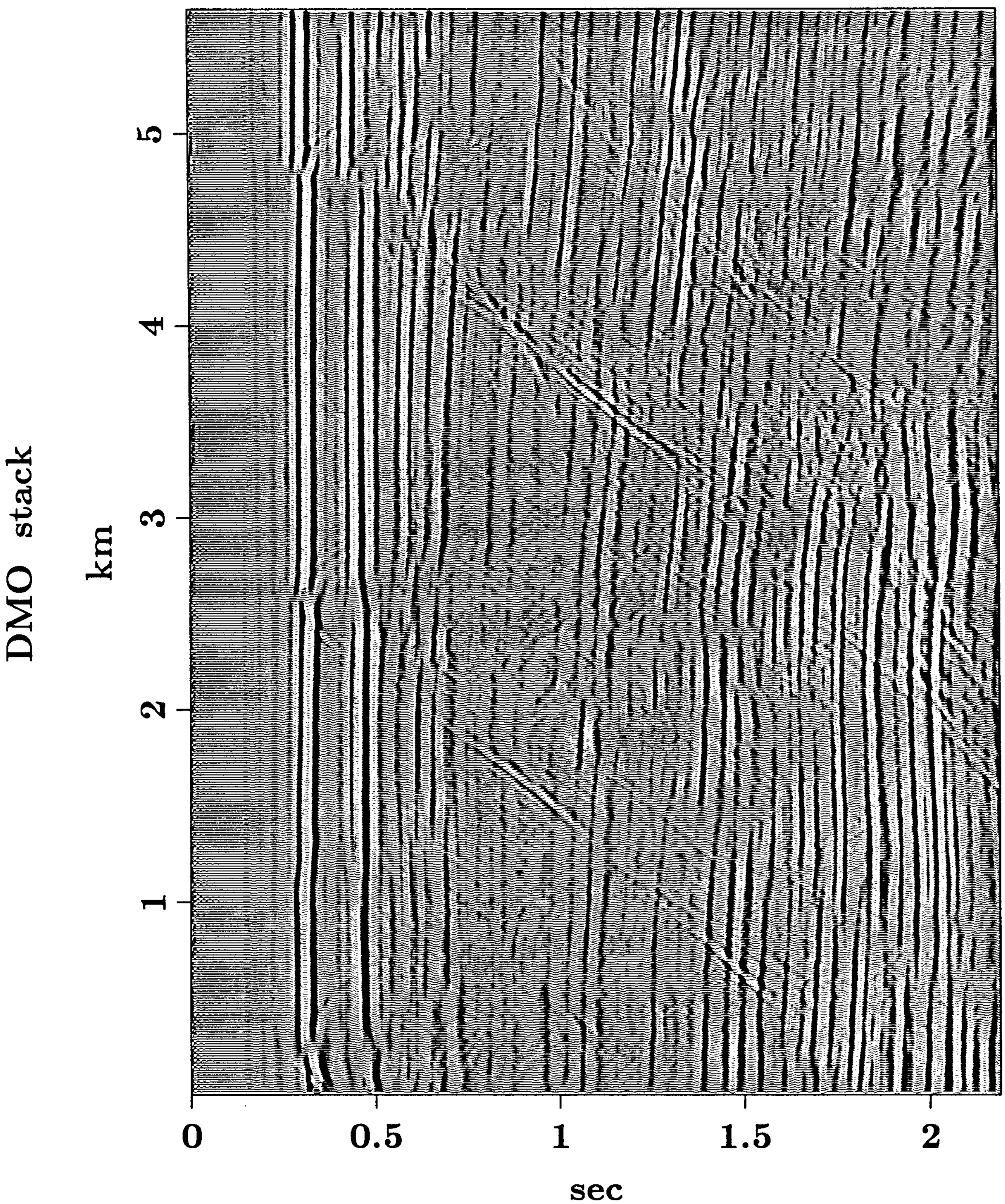


FIG. 1.1.4. Migration of the stack in Figure 1.1.3.

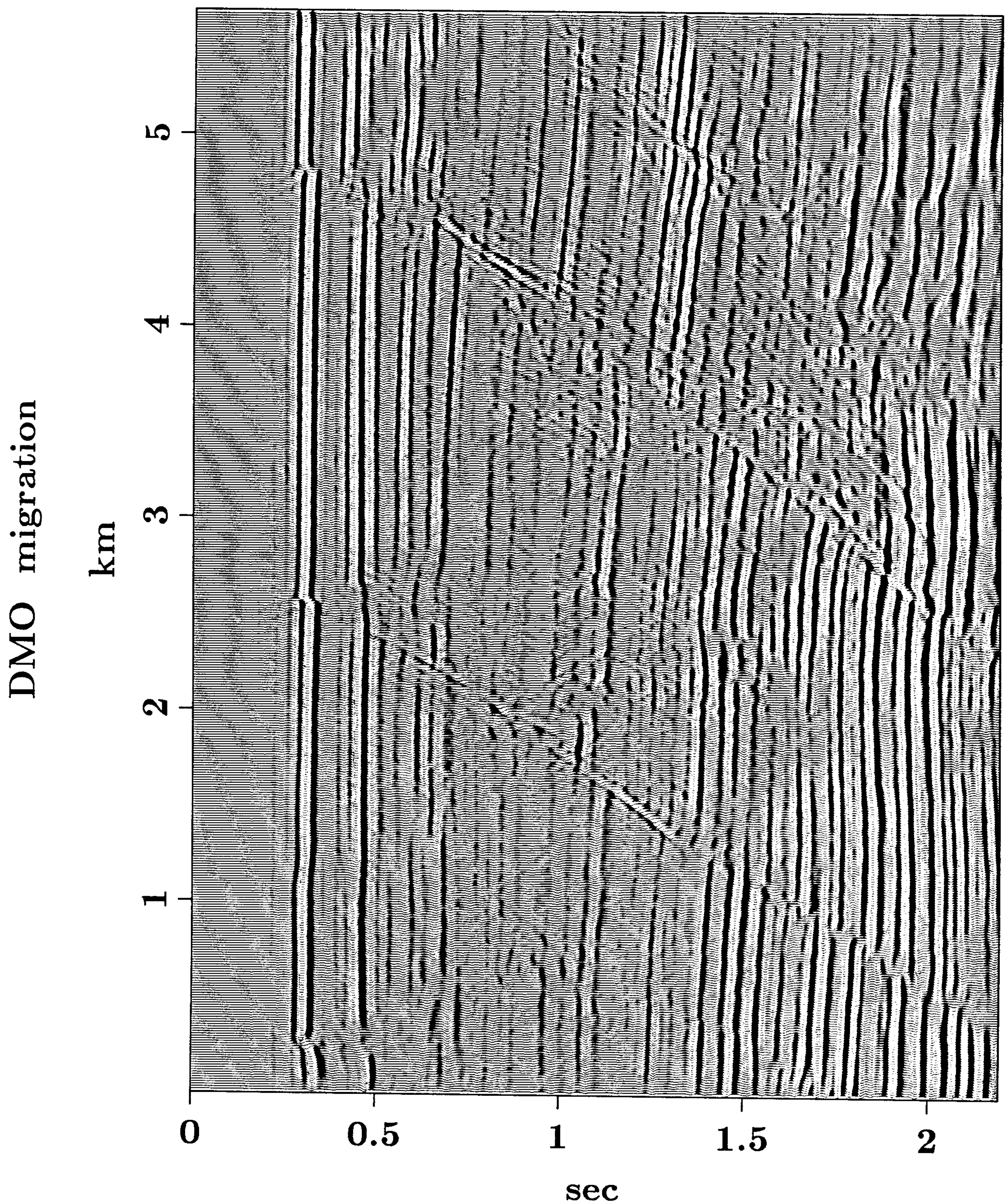


FIG. 1.1.5. Subsampled stack with a trace interval of 50 m. Processing: gain, filter, NMO, DMO, 6000% stacking, window (elimination of three traces out of each four). The dipping events are aliased but can be traced by the eye and be restored by poststack interpolation.

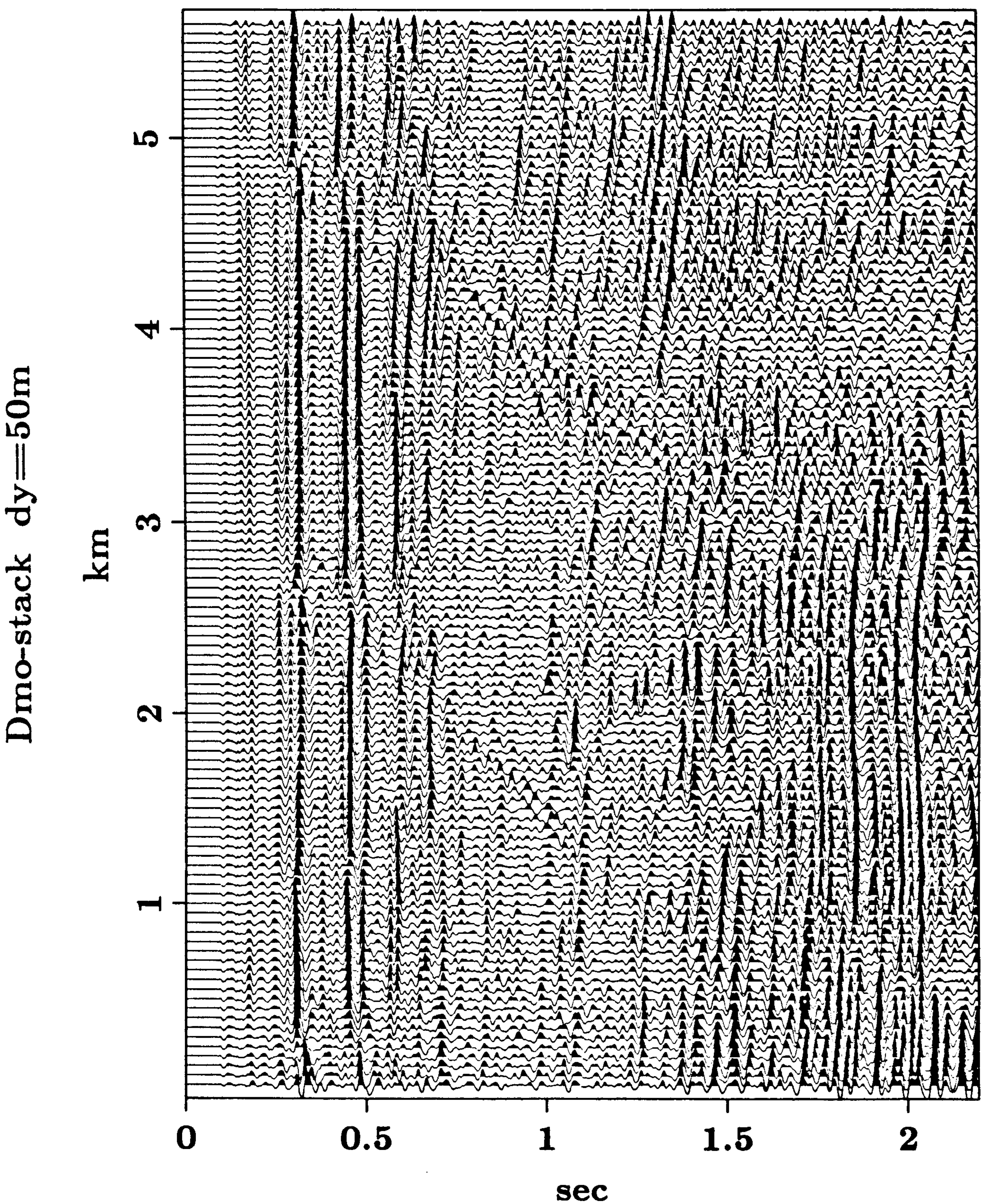


FIG. 1.1.6. Migration of the stack in Figure 1.1.5. The dipping events are lost.

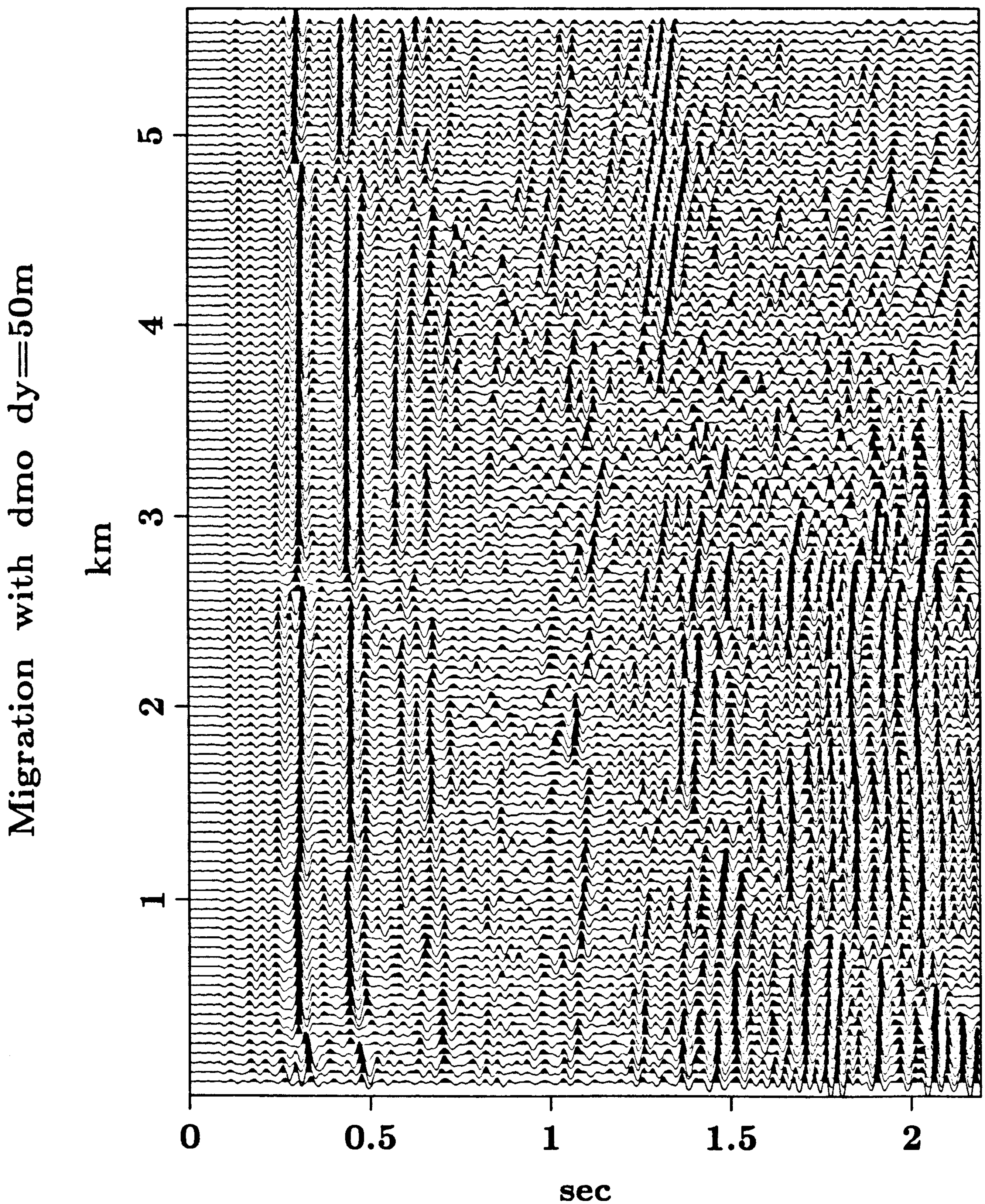


FIG. 1.1.7. Severe spatial aliasing with a trace interval of 100 m. Processing: gain, filter, NMO, DMO, 6000% stacking, window (elimination of seven traces out of each eight). The dipping events cannot be traced by the eye.

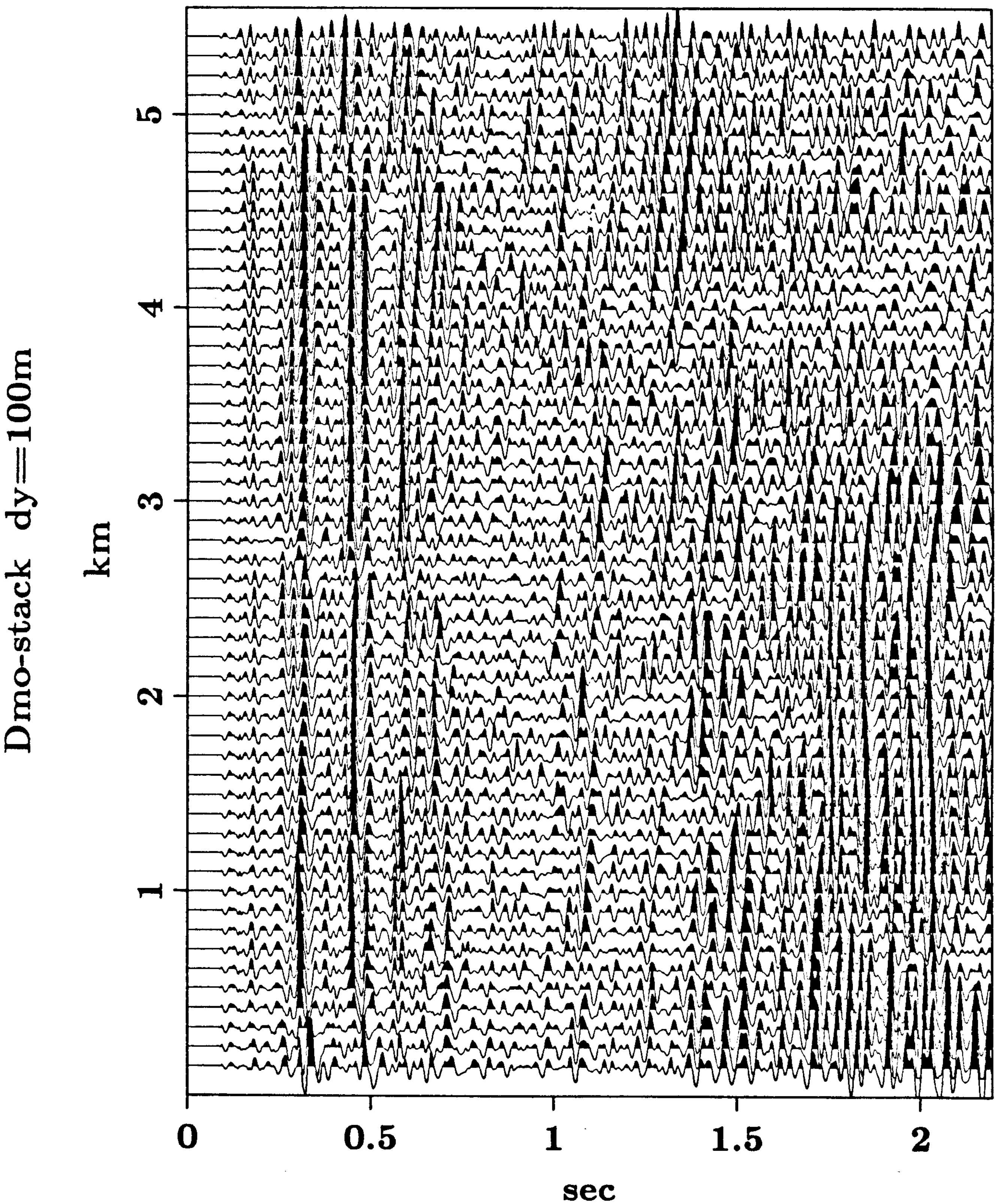


FIG. 1.1.8. Migration of the stack in Figure 1.1.7 does not seem to have any effect because all the reflectors on the stack are either flat or alias as flat.

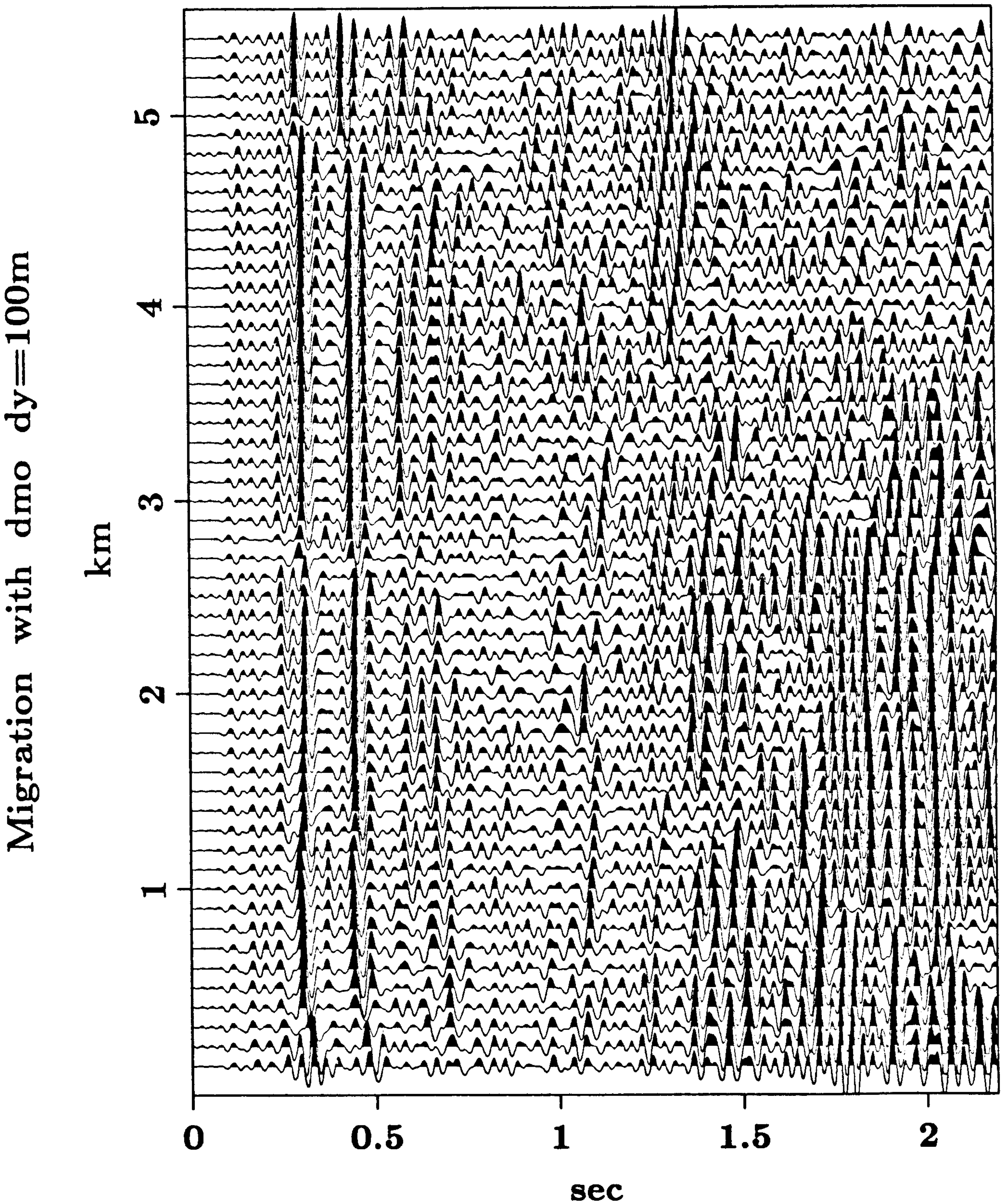
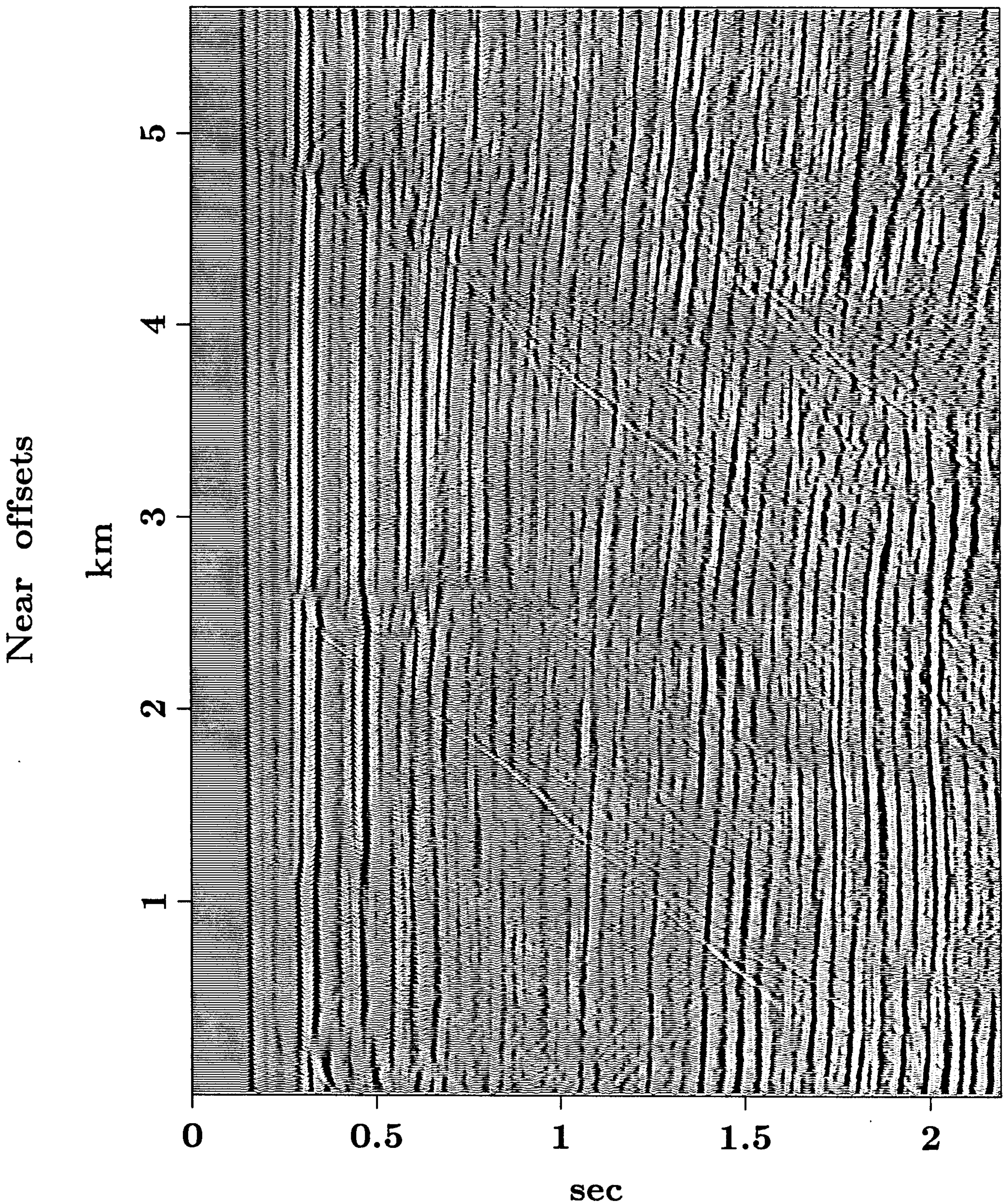


FIG. 1.2.1. Near-offset section. Processing: gain, filter, NMO, window (elimination of all the data except the two near offsets).



redundancy is useful for signal-to-noise enhancement, velocity estimation, and for finding the physical properties of the earth; but to find the geometrical properties of the subsurface we collect many common-offset sections while we need only one.

§ 1.3 Thesis overview

Overcoming aliasing of multichannel data is an active research subject in information theory (Shannon, 1949; Linden, 1959; Papoulis, 1977; Brown, 1981). Shannon wrote about reconstructing a function from its samples:

> *One can further show that the value of the function and its derivative at every other sample point are sufficient. The value and first and second derivatives at every third sample point give a still different set of parameters which uniquely determine the function. Generally speaking, any set of* $2TW^{\dagger}$ *independent numbers associated with the function can be used to describe it.*

If a function is filtered by independent filters in parallel, as shown in Figure 1.3.1, a certain amount of aliasing is allowed, and we can still recover the original signal.

The same principle applies to seismic data, as Bolondi et al (1982) noted, and as schematically shown in Figure 1.3.2. The earth's image is the signal that is filtered by a number of channels filters before subsampling. The data in each channel may be aliased, but the combination of all can give a high-resolution image.

† $2TW$ is the number of samples needed to describe a function that has a band-limit spectrum of W, over a finite interval T.

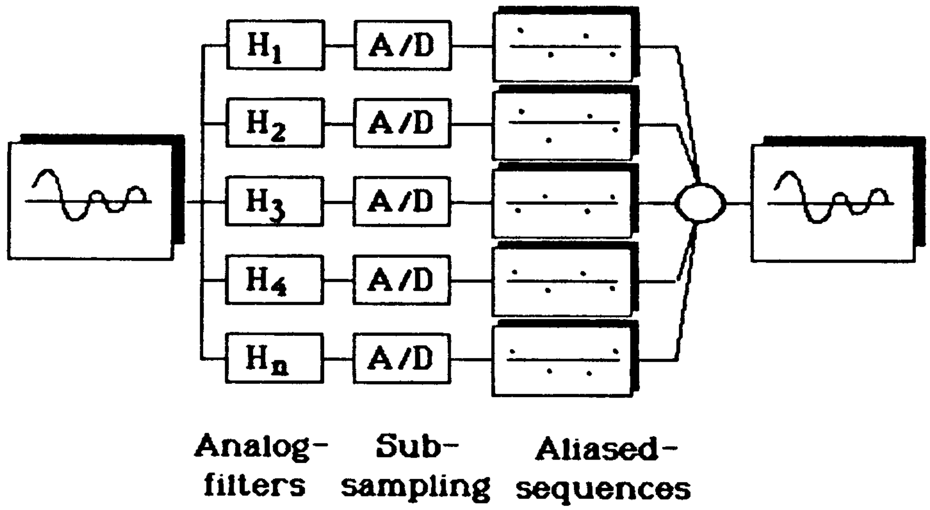


FIG. 1.3.1. Overcoming aliasing for a one dimensional signal.

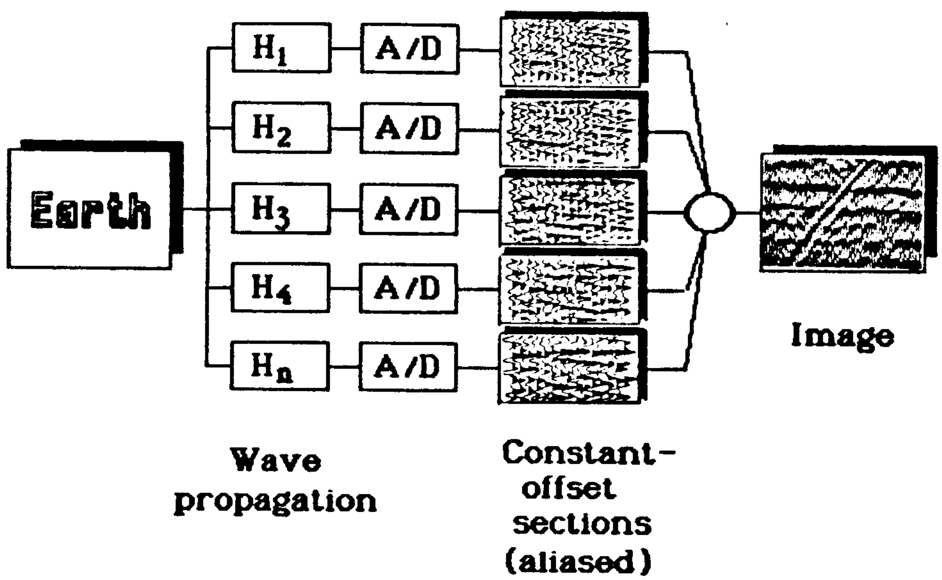


FIG. 1.3.2. Overcoming aliasing in reflection seismology.