# A statistical approach to residual statics removal

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## ABSTRACT

Images created from seismic data acquired on land are often significantly degraded by the influence of the weathered and non-uniform materials at or near the surface of the earth. Because of the relatively small-scale variations in these materials, seismic wavefronts arriving at the surface are distorted in space and time as they reach the detectors. In many cases, the bulk of the effect can be removed by the application of a discrete time shift to each trace recorded by a detector at the surface, applying a correction termed a "static shift". This is only an approximation, however, to the correction that should actually be applied, which is more properly represented as a distribution of shifts, unique to each trace.

This work explores an approach for removal of near-surface effects from seismic data in which the distribution of statics embedded in each trace is estimated, then removed by the application of an appropriate operator. This approach should automatically correct for such effects as multi-path arrivals on seismic traces; and it should be extensible to the non-stationary case where "statics" may vary with travel time due to local variations in rock velocity at depth. We demonstrate the general validity of the "statistical statics" approach by estimating and removing static distributions from the shot gathers of a set of field data; and we identify the main areas for further research.

## INTRODUCTION

One of the perennial problems encountered by geophysicists acquiring, processing, and interpreting reflection seismic data is that of applying appropriate corrections to remove the effects of the near-surface "weathered layer" on reflections from deeper interfaces and layers in the earth. Because of the large variability in composition and uniformity of the near-surface, its effects can vary from negligible to profound, sometimes along the same seismic profile. These effects can be so great at times that they render otherwise good quality seismic reflection data totally unusable for imaging.

Many investigators have explored different approaches for estimating and removing near-surface effects, for example, Taner et al. (1974), Wiggins et al. (1976), Rothman (1986), Zanzi and Carlin (1991), and Wilson et al. (1994). Most approaches are classified as "statics" methods because of their essential reduction of the problem to one of finding and applying a single "static" time shift to each trace of a data set. The underlying assumption for such methods is that most of the near-surface effect on seismic energy traversing the near-surface environment can be approximated by a simple time shift of each trace representing the seismic energy traversing the near-surface at a single surface location. Given this assumption, most investigators have explored various techniques for detecting relative time shifts, or "picks" on raw seismic traces that can then be used as redundant but noisy input data for some technique to compute a set of "statics" for the input traces. These, when applied, in some optimum sense reduce the variance of the input relative time shifts. Various constraints, such as "surface consistency" can be

imposed to improve or guide the solution, but the quality of the resulting seismic image still depends on the validity of the initial assumption that near-surface effects can be removed by time shifts alone. Fortunately, for a large proportion of land seismic data, this assumption is adequate for obtaining seismic images of sufficient fidelity. The assertion that near-surface effects on a seismic trace can be compensated by a single time shift is based on these fundamental assumptions:

1. The average velocity of the surface weathered layer is much lower than that of the underlying materials, implying near-vertical raypaths through the surface layer, regardless of the incident or emergent angles of raypaths from deeper interfaces.

2. A source or receiver is considered to be a discrete point, even if it is actually an array, so that only a single wavefront arrival can be emitted or detected.

3. Only one raypath from source to receiver is assumed; multi-path transmission is not acknowledged.

4. The seismic data are noise-free, so that the static shifts can be exactly determined.

These assumptions are summarised in Figure 1, where raypaths corresponding to two single seismic traces are depicted. One important aspect to note of this simple statics model is the fact that since raypath segments through the weathered layer are near vertical, they are assumed to be common to all the raypaths having a common source (or common receiver). This simplification is what allows the invocation of "surface consistency" in the mathematical solution for either "source statics" or "receiver statics".

Figure 2 shows some of the ways in which the intrinsic assumptions for statics might be violated:

1. When the weathered layer has a relatively high velocity, raypath segments through it are no longer vertical, nor are they common for all raypaths terminating at a given surface point.

2. Receivers, in particular, are rarely discrete points; wavefronts arriving at different geophones at a single receiver station can be significantly shifted relative to one another. The same event arrival may thus occur at several slightly different times on the same trace.

3. For certain near-surface environments, there may exist more than one possible path along which seismic energy can travel, leading to more than one possible arrival time for a single wavefront (multi-path transmission).

4. Even if the geometric assumptions for a single static shift per trace are honored, noise contaminating the seismic traces means that the shift can only be obtained with limited certainty.

For data where one or more of these possible violations apply, a single time shift applied to each seismic trace is no longer sufficient to compensate for all of them, since each of the above violations implies that more than one shift pertains to the energy on any trace: a "distribution" of shifts, in other words. The notion of a probability density function associated with static shifts was described by Rothman in an early SEP report (Rothman, 1984a) which formed some of the background for the later introduction of "simulated annealing" statics solutions (Rothman, 1984b, 1986). In Rothman's work, however, the goal remained the derivation of a single optimum shift per trace, determined by analysis of the probability density function associated with the static. It was the intractability of the problem of solving simultaneously for a set of optimum statics from the set of density functions for an entire seismic line that led Rothman to the use of simulated annealing for testing all probable combinations of solutions.

The idea presented here, however, is to represent the near-surface and multi-path effects on each seismic trace as a series of static shifts, each scaled by an associated probability. This series, or *density distribution,* is considered to be convolved with the unaffected seismic trace to produce the observed near-surface effects. To remove the effects of this distribution function from its associated trace, deconvolution techniques such as match filtering or inverse filtering can be used. This "static distribution" model has the advantage of accommodating all of the described deviations from the "single static" model. The static correction procedure for the static distribution model consists of two parts: finding the static density function for each trace, and removing the effects of the function from the trace.

## STATIC CORRECTION BY DECONVOLUTION

### The "superposition" view

Ordinarily, treating static correction as a deconvolution operation is unnecessarily complicated when applying a single static to each trace, since any known static shift, even one involving a fraction of a sample interval, can be applied by interpolation. If there is more than a single static associated with a seismic trace, however, as we assert in the "statistical statics" model, deconvolution methods are an obvious approach for removing them. A shifted seismic trace can be considered to be the original unshifted trace convolved with a unit spike displaced from zero by the amount of the static. The shift can be removed by convolving with a second unit spike displaced from zero by the negative of the first static. This operation can be considered to be either correlation with a match filter or convolution with the inverse filter, the two operations being indistinguishable in this infinite bandwidth case.

The statistical statics model proposes that near-surface effects, instead of being represented (only approximately) by a single time-shifted unit spike, should more properly be represented as a "superposition" of fractional amplitude positive spikes positioned at the various static shifts associated with inter-array effects and/or any multi-path phenomena which affect the trace. This superposition leads naturally to the idea of a "density distribution function", which is just the normalized sum of the superposed time shift spikes. In this "superposition" view, the amplitude of each sample of the density distribution function can be thought of as the fractional portion of the seismic energy on the trace which arrives with the time delay associated with the sample.

## The "uncertainty" view

An alternative view of the distribution or density function is that each function sample represents the probability that the particular sample time is the actual (single) static shift intrinsic to the seismic trace. The density function thus serves to describe the probable picking error associated with a static shift. This view, adopted by Rothman (1984a, 1984b, 1986), is closer to the conventional statics approach, in that it can motivate a choice of a single statistic (like the expected value, most probable value, median value, etc.) and its associated time position as the (single) static for the trace. This approach has difficulties, however, whenever the density function is legitimately multimodal (has more than one peak), since a single statistic will never adequately capture the geophysical information implied by a multimodal function. An important instance in which a multimodal statics density function might arise (in addition to noisy input traces) is the case of multi-pathing, where seismic energy follows more than one path between source and receiver, and the paths differ significantly in transit time. In this context, an interbed multiple or reverberation could also be considered to be a multi-path transmission.

Regardless of which interpretation is associated with the statics density function (both views may apply simultaneously), its effects can be removed from a seismic trace in exactly the same way as the single static shift described above. That is, it can be removed by match filtering, or by deriving an inverse filter for the density function and convolving the seismic trace with the inverse filter.

We illustrate the static deconvolution concept in Figure 3. Figure 3a shows a hypothetical seismic event in its unshifted, desired position. In Figure 3b, a hypothetical static density function is shown, containing five static shift spikes of various amplitudes centered on 50 ms. in Figure 3c, the seismic trace in Figure 3a has been shifted by application of the density function in Figure 3b. Figure 3d shows a bandlimited version of the static density function (Figure 3b) as it might appear after being imperfectly estimated from data, while Figure 3e shows a single unshifted, bandlimited unit spike. The match filter between the bandlimited density function (Figure 3d) and the bandlimited spike (Figure 3e) is displayed in Figure 3f, while the deconvolved seismic trace, obtained by convolving Figure 3c and Figure 3f, appears in Figure 3g, with the original input seismic trace displayed in Figure 3h for comparison. It is obvious from this demonstration that even an imperfect estimate of a static density function can be used successfully to remove the embedded static density function from the seismic trace. It should also be obvious that the trace in Figure 3c could not be made to look like the trace in Figure 3a by simply applying a single static shift.

## STATIC DISTRIBUTION FUNCTIONS

The more difficult aspect of the proposed statistical statics method is estimating static density functions from the input data, particularly when noise is present. Much of the following is devoted to testing an ad hoc scheme for estimating static distribution functions. In conventional single static methods, seismic traces are "picked" by comparing them either to neighboring traces or to specially constructed "pilot" traces and choosing the "most probable" shift, often the shift corresponding to the maximum of a cross-correlation function. Although the statistical statics method specifically avoids explicit time picks, one technique used to determine static density functions assumes the

same starting point—cross-correlation functions of subject traces with neighboring traces or pilot traces. The problem with using neighboring traces is that cross-correlations between single raw traces are both noisy and bandlimited, and the noise is often correlated between adjacent traces. The main difficulty in using pilot traces, on the other hand, is in constructing usable pilot traces in the first place. Since a pilot trace usually consists of a stack of raw traces, its bandwidth is affected not only by the bandwidth of the various input traces, but by the variance of their relative shifts, as well. Hence, for data sets consisting of low-noise broadband data with small static variance, good pilot traces are readily constructed; but for noisier data with larger statics, pilot trace construction can be very difficult.

Conventional statics methods use logical rules of various sorts to extract a single time shift value for each cross-correlation function (often the time shift associated with a maximum correlation value); and various constraints (like surface-consistency) and smoothing techniques are applied to the set of noisy, redundant time picks to compute a set of static shifts to apply, one to each of the input traces. The part of this procedure most susceptible to error is the extraction of a single time shift value or "pick" from each cross-correlation function, since the shape of these functions is dependent upon not only the bandwidth of the embedded signal waveform, but upon the nature and spectrum of contaminating noise. Rothman (1986) demonstrated a technique for converting a correlation function to a distribution function whose "spikiness" was controlled by a scale parameter. The distribution function was then used to identify the single shift value most likely to be the "true" shift. If the signal waveforms legitimately occurs at more than a single time on an input trace (as, for instance, in cases of multi-pathing), there is usually no logically consistent way to determine a single time shift from the resulting cross-correlation function, however.

Where the statistical statics method departs from conventional statics is in its use of the cross-correlation functions and the associated distribution functions generated during the picking phase of the technique. In our proposed statistical method, following Rothman (1984a, 1984b, 1986), an assumption is made that the cross-correlation function can be used to construct an estimate of the static density function representative of each of the input traces. The cross-correlation function itself is not suitable, since it has both positive and negative values, which is inconsistent with the definition of a probability density distribution. Its bandwidth is also generally much lower than the bandwidth of the distribution function of static shift spikes that it is assumed to contain. We therefore attempt to "condition" a correlation function in various ways so that its characteristics more nearly correspond to a probability density function of finite length (the integral of the function over a finite interval must be unity, and the function should taper to zero at the interval limits). In the results section of this report, we describe a purely ad hoc operation which we apply to correlation functions to condition them and show the resulting "density functions" for the source gathers on a set of field data. Some of the issues to be considered when conditioning the correlation function are as follows:

- How should negative correlation values be treated; could they indicate legitimate correlation with a signal waveform of opposite polarity?

- How can the bandwidth of the correlation function be broadened to more nearly reflect the bandwidth of the true distribution?

- When imposing constraints such as surface-consistency, should the summation over common surface points involve the cross-correlation functions or the estimated static distribution functions?

## EXPERIMENTAL RESULTS

### Results using pilot traces

The statistical statics approach is still in its early stages; no comprehensive algorithm exists yet to apply to a set of seismic data. We have, however, tested significant portions of the idea and present various test results below, including an estimation and removal of shot statics from a real field data set. The data set chosen for experimentation is from the Hansen Harbor area of the MacKenzie Delta. It is a 2-D vibroseis line, recorded into 3-C receivers. We use the vertical component of these data only. There are only 50 receiver stations on the line, and the survey was acquired by incrementally moving the source from large positive source-receiver offset distances, through the geophone spread, then to large negative offset distances. A significant feature of these data is that for the first half of the line, the source is on floating ice, thus creating a high level of source-generated noise. The treatment of this noise, mostly the guided modes known as the "ice flexural wave", is covered in a separate chapter of this report (Henley, 2004). For the purposes of this investigation, however, the significance of the noise is that half of the resulting line is poor in quality, while the other half is good quality. Most of our testing has focused on the good quality portion of the line. Figure 4 shows a "brute" stack of this part of the line, with no statics applied to either shots or receivers. Receiver statics appear to be minimal for this line, based on examination of some of the better shot gathers. The shots, however, are distributed along a much longer line than the receivers, and significant corrections are necessary to remove shot "statics". This demonstration only deals with these shot corrections.

We illustrate first the technique of creating static density functions from cross-correlations of raw shot gather traces with "pilot" traces. A simple method of creating pilot traces is simply to use the traces from the brute stack. With data as noisy as the Hansen Harbour data, the stack traces show considerable variation in waveform from trace to trace, so they were smoothed laterally to make the waveforms more uniform. Simple trace mixing can be used, but we elected to use wavefront healing (Henley, 2000), which has less effect on underlying structure than simple mixing. Lateral smoothing, unfortunately, has the undesired effect of laterally smearing embedded static distribution functions.

To cross-correlate raw traces with pilot traces, we matched each shot gather trace with the pilot trace of the same CDP. Although correlation window length is one of the parameters to investigate further, we chose a relatively long window for this test. Ultimately, our goal is to correlate in several overlapping windows in order to implement non-stationary static deconvolution on the same framework as Gabor deconvolution (Margrave and Lamoureux, 2001); but for these tests we used only a single window. The cross-correlation functions, once computed, were summed for common shots to create a

single cross-correlation function for each shot, hopefully containing the desired static density function information. We experimented with various operations to convert cross-correlations to credible "density functions", including the one given by Rothman (1986). One non-linear procedure that appeared to work relatively well was to convert the cross-correlations to absolute values, thus making them non-negative, then to exponentiate the samples to a relatively high power, thus making the peaks more "spiky", and to normalize each function to unity. A set of static density functions derived from the cross-correlations with the shots is shown in Figure 6 for the entire Hansen Harbour line, while Figure 7 shows a more detailed view of some of the functions, revealing their "distribution-like" appearance, and also that several of them are significantly bimodal. The functions shown in Figure 6 show no particularly large bulk shifts, but do indicate some peak-to-peak shifts on the order of 15 ms. This appears to be in agreement with the magnitude of short-wavelength statics derived by conventional means for these data.

The bimodal functions in Figure 7 could indicate possible multi-path transmission, or even short-period multiples. Since two shifts cannot be accommodated simultaneously in the conventional static sense, the statics implied by these distribution functions can only be removed by deconvolution techniques. The simplest and most robust method for applying the functions in Figure 6 to correct the underlying "statics" is to cross-correlate each density function with all the traces in the shot gather to which it corresponds. The cross-correlation comprises a bandlimited match filter, in which the target output wavelet is the autocorrelation of the distribution function. Figure 8 shows a stack of the Hansen Harbour data after the traces of each shot gather have been cross-correlated with the corresponding static distribution function. Comparing with Figure 4, improved event flatness and continuity can be seen, particularly within the outlined region. Another match filter technique is to explicitly derive a match filter for each distribution function which will convert that function into a bandlimited spike, where the bandwidth of the spike can be chosen by the processor. Each match filter is then applied by convolution to the traces of its corresponding shot gather. The stack in Figure 9 corresponds to shot gathers corrected by this technique. There appears to be some slight improvement in event amplitude and continuity compared with Figure 8.

Deriving an inverse filter for each static distribution function is very similar numerically to deriving a match filter between the function and a spike whose bandwidth is limited only by the magnitude of a chosen stability factor. Indeed, the results of deriving an inverse filter for each of the shot static distribution functions, then applying it to each of the traces in the corresponding shot gather, and stacking the gathers, as shown in Figure 10, can hardly be distinguished from the match filter results in Figure 9. The choice of technique largely reduces to choosing which match filter computation method or which inverse filter computation method appears to give the most stable results for a particular data set.

## Results using adjacent traces

Obtaining believable pilot traces for a seismic line is more an art than a science, and statics resulting from the use of pilot traces are often smaller in magnitude than the actual statics, due to the lateral smearing in the pilot traces. One alternative to using pilot traces for obtaining the cross-correlation functions needed for statics solutions is the use of

cross-correlations between "adjacent traces", i.e. traces recorded at the same station from adjacent shots. This method is reminiscent of the old "hand picking" techniques in which a reflection event would be "picked" on each trace of the paper display of the gather. These picks would then be used to guide the picking of the same event on corresponding traces of the next paper shot gather, and so forth, down the line. As implemented for our tests, adjacent trace picking consists of cross-correlating the windowed traces of one shot gather with the windowed traces of the adjacent shot gather, matched by receiver stations. The correlation functions are then summed over common shot before being "conditioned" into static distribution functions.

Strictly speaking, adjacent-trace statics are "differential" statics that must be integrated over the seismic line from beginning to end in order to derive the "absolute" statics to be applied to the traces in the gathers, since each shot static measures the relative shift from one shot to the next, not the shift relative to a common datum. For our method, that would mean that the first "differential" distribution function would be applied to the second shot to match it to the first, then the first and second functions would be applied in succession to match the third shot to the first two, and so on. This quickly becomes cumbersome, and after only two or three such applications, the cumulative corrections tend toward zero. This means that the most significant part of the static correction is applied by the last one or two of the "differential" distribution functions. As a test, we decided to apply only a single "differential" distribution function to each shot to match it to the preceding shot, with the realization that the embedded statics are likely not correct in magnitude, but generally agree in sign with "correct" statics. Figure 11 shows the differential distribution functions extracted for the entire Hansen Harbour line. Comparing with the "absolute" distribution functions (Figure 6) obtained using the pilot trace approach, we note that "significant" statics (functions whose peaks deviate significantly from zero shift) correspond in surface locations between the two figures. The differential distribution function set seems to show fewer occurrences of multi-modal distributions, however, and it appears to reflect data quality of the raw shot gathers in a more fundamental way (the functions from the "poor" end of the line show much more scatter than the functions from the "good" end). The latter effect is not unexpected, since noisy raw traces are being correlated with each other rather than with cleaner "pilot" trace.

The result of applying differential distribution functions to the shot gathers before stacking is shown in Figure 12, for the "good" end of the line. Comparing this result with Figure 9, we see that the reflection event continuity, amplitude, and flatness are at least as good for these results as for the earlier pilot trace results. Though not shown, the results are not as good in the poor data zone. Nevertheless, the adjacent trace technique appears to be worth pursuing and refining, relative to the pilot trace method, for finding and applying residual statics.

**Larger statics**

Since most of the statics detected and applied via distribution functions were small, we decided to test the method further by applying the total statics derived during the conventional processing of Hansen Harbour, then seeing whether these statics could be detected and applied by deconvolution. Hence, Figure 13 shows the line with total statics

applied, as retrieved from the Hansen Harbour database. These statics include elevation statics, refraction statics, and residual statics. The strength and continuity of the reflections on Figure 13 attest to the success of these conventional statics. Figure 14 shows the shot static distribution functions derived for the raw shot gathers, using a smoothed version of the section in Figure 13 as pilot traces. Clearly, both long and short wavelength statics are successfully detected and represented in these distribution functions, even shifts as large as 100 ms. Comparing with Figure 6, we see that the short wavelength statics are generally larger in magnitude in Figure 14, but similar in their pattern. In addition, there are fewer multi-modal distribution functions in Figure 14 than in Figure 6.

Applying these distribution functions to the raw shot gathers using match filters results in the stack in Figure 15. While somewhat better than the brute stack in Figure 4, these results are inferior to those in Figure 13. When we look at the other half of the line, however, in the poor data zone, we see that the stack incorporating the conventionally applied statics (Figure 16) is inferior to the stack (Figure 17) incorporating the deconvolved distribution functions from Figure 14. We currently have no explanation for why the distribution functions would appear to work better in the poor data zone than in the good data zone.

## FURTHER WORK

We have shown that formulating the static correction problem in terms of a deconvolution operation allows extension of the term "static correction" to a more general operation whose intent is to correct seismic traces for several phenomena related to near-surface weathering and the use of shot/receiver arrays, as well as for multi-path transmission, by allowing a single static shift to be replaced by a distribution of shifts. We have shown that such a distribution of shifts can be successfully removed from a seismic trace; and we have shown one way of extracting usable distribution functions from cross-correlation functions of raw traces with neighbor traces or pilot traces. Finally, we have shown that application of these prototype methods results in significant improvement of stacks of the raw data traces. This work is still in a preliminary stage, and a number of issues remain to be investigated. In addition to the crucial task of constructing meaningful static distribution functions from the data, further work is needed on the technique for constructing pilot traces and on a method for applying differential static distribution functions to get absolute statics. Iteration of statics passes should also be investigated, since this almost always proves worthwhile in conventional statics.

While we have demonstrated the basics of statistical statics using a real data example, modeling would help verify the concepts as well as identify new approaches.

Although we have thus far considered the statistical representation of statics for the stationary case, where "statics" effects do not vary with transit time, there is no reason why the statistical statics model cannot be extended to the non-stationary case. Instead of deriving and applying one distribution function for an entire seismic trace, functions could be derived for a set of overlapping windows, to form a 2-D array of distribution

functions. The existing Gabor deconvolution algorithm could be readily adapted to derive and apply non-stationary statics match filters to test the concept.

## CONCLUSIONS

Static correction has always been an approximation to the true wavelet correction needed to remove near surface and array effects from seismic traces. We have shown that it is possible to remove these effects using a combination of statistical concepts and deconvolution techniques. For many exploration areas, these methods are unnecessarily complex and would likely not yield better results than conventional static correction; but for those areas where the near surface conditions likely violate static correction assumptions, where array effects are large, or where multi-path transmission can occur, seismic correction methods based on statistical statics may prove beneficial.

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## ACKNOWLEDGEMENTS

## FIGURES

## Conventional statics assumptions
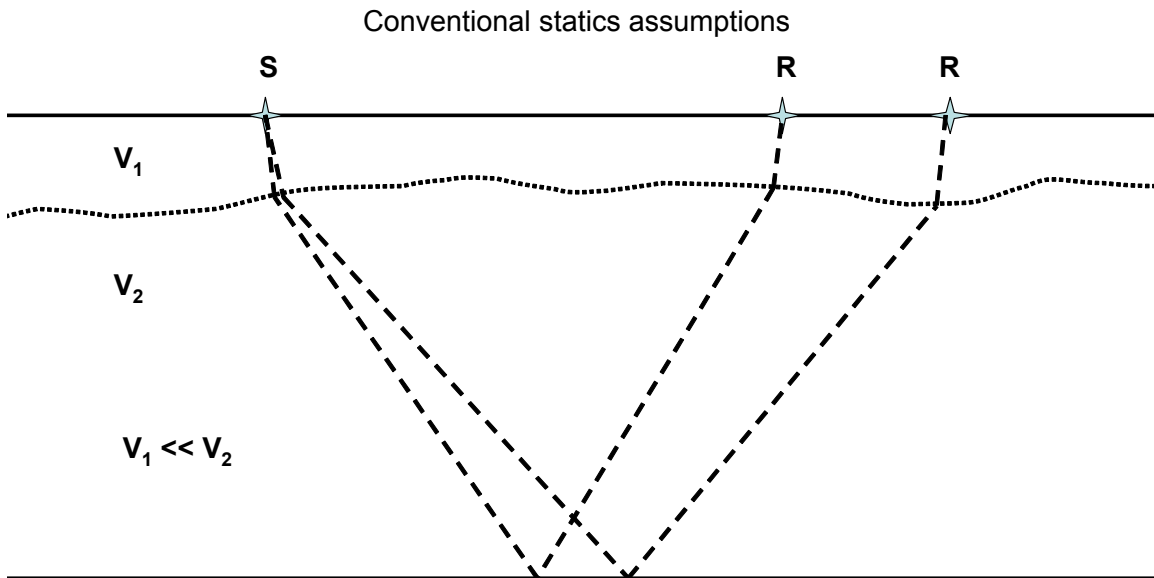


**Raypath segments beneath each surface point nearly vertical; static constant at each surface point. Sources and receivers assumed to be single points. Single raypath between each source and each receiver.**

FIG. 1. Assumptions made about seismic geometry and geology in order to simplify near-surface correction to a single "static" time shift of each seismic trace.

## Conventional statics assumptions *violations*
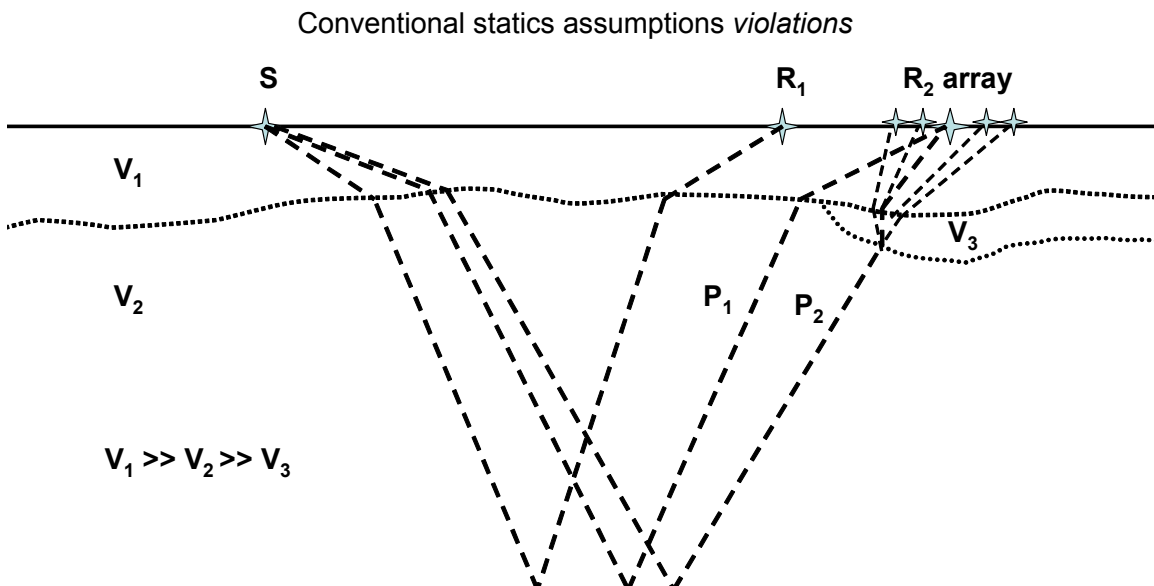


**Raypath segments beneath surface points not vertical; no common static at each surface point Sources and receivers can be arrays, with different statics for each surface point in the array. Multiple raypaths possible between each source and receiver location (P$_1$ and P$_2$), due to buried velocity anomalies (V$_3$)**

FIG. 2. Various ways in which the simplifying assumptions used to justify static corrections may be violated in practice. The effect of each of these violations is to smear seismic event energy over a distribution of arrival times, which is approximated only crudely by a single time shift.
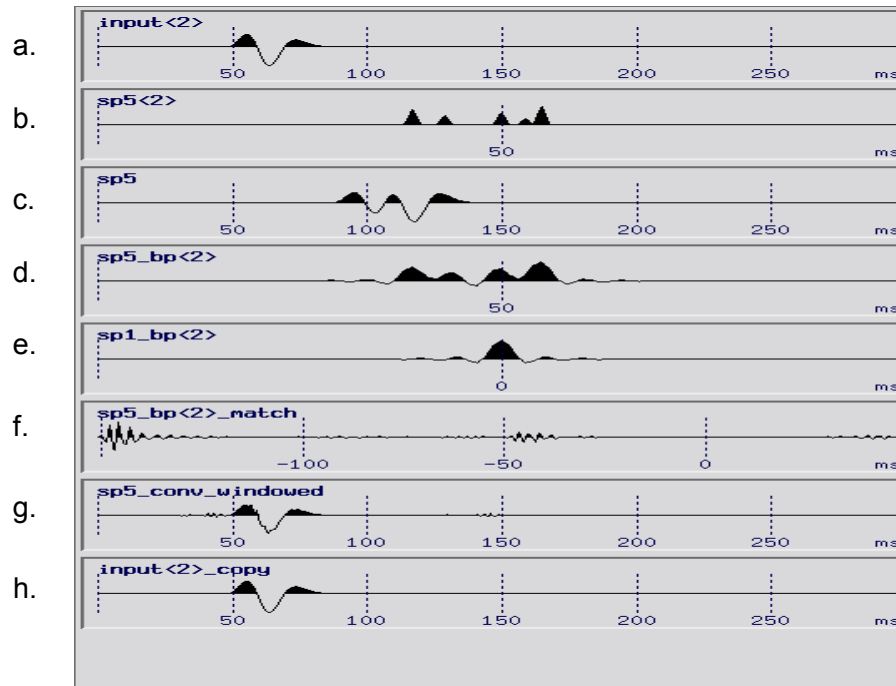
The static deconvolution principle

FIG. 3. A model demonstration showing that a distribution of "statics" can be removed from a seismic trace by deconvolution methods. (a)—An ideal seismic trace with one event. (b)—A distribution of 5 static shifts of various strength and time shift (the sum of their amplitudes is unity). (c)—The seismic trace of (a) as affected by the "statics" distribution in (b). The event undergoes a bulk shift as well as smearing in time. (d)—A bandlimited version of the distribution function, as might be obtained by operating on a cross-correlation function between the trace (c) and some "pilot" trace. (e)—A bandlimited spike at the zero shift position. (f)—The match filter between (d) and (e). (g)—The smeared, shifted seismic trace in (c) after application of the match filter (f). (h)—The original seismic trace for comparison.
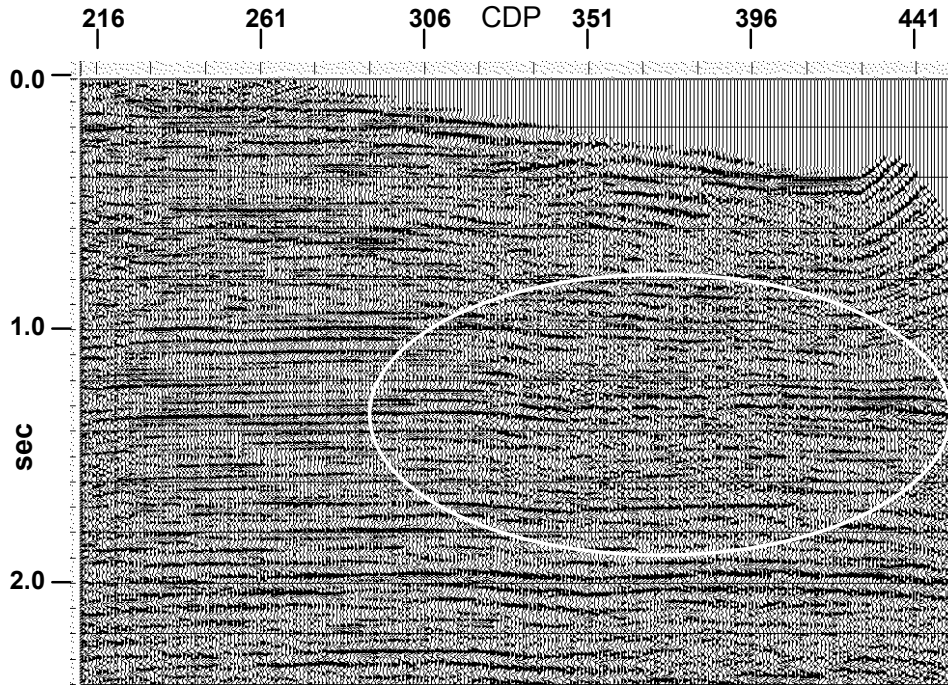
Hansen Harbour brute stack—no statics applied

FIG. 4. A portion of the Hansen Harbour vertical component vibroseis line with no statics applied to the shots or receivers.
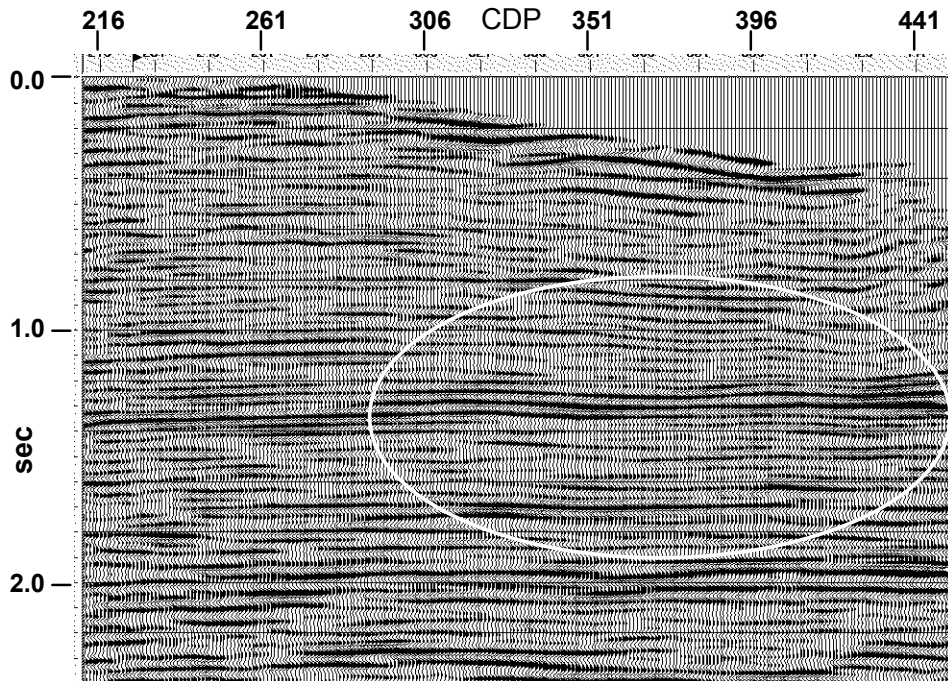


Hansen Harbour pilot trace stack—smoothed using wavefront

FIG. 5. The brute stack of Hansen Harbour vertical component data was smoothed laterally using wavefront healing in order to provide coherent "pilot" traces with which to correlate raw shot gathers for creation of statics distribution functions.

Shot static distribution functions between brute stack pilot traces and raw input shot gathers
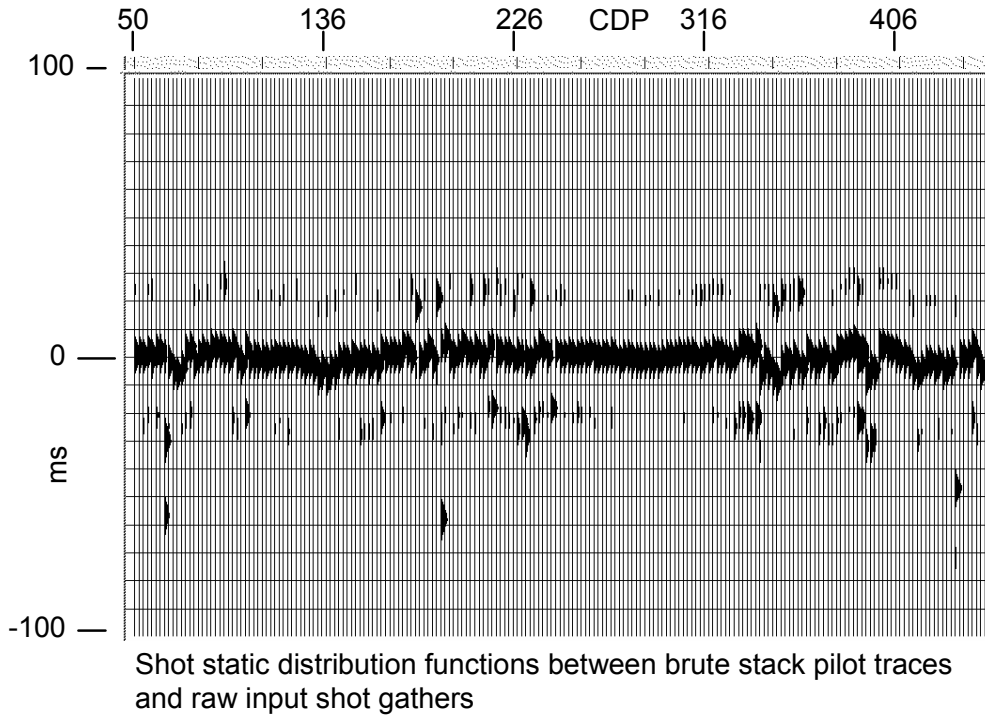
FIG. 6. Shot static distribution functions constructed by cross-correlating raw traces with corresponding brute pilot traces, stacking the cross-correlations over common shot, and "conditioning" the functions to make them non-negative and sharply peaked.



Static distribution functions showing some bimodal distributions—evidence for multi-path?
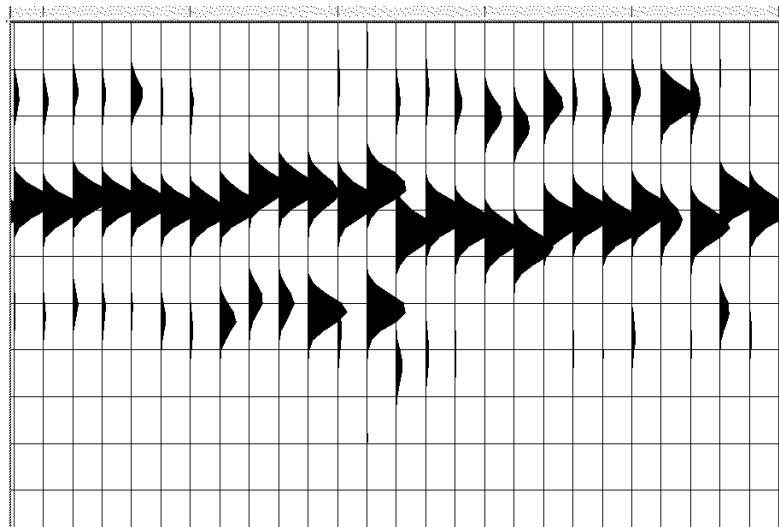
FIG. 7. Detail of static distributions showing some functions with more than one significant peak, implying that a single static shift cannot satisfactorily correct the data for its disparity with the pilot image. This could be evidence of multi-path transmission, or of multiple reflection.
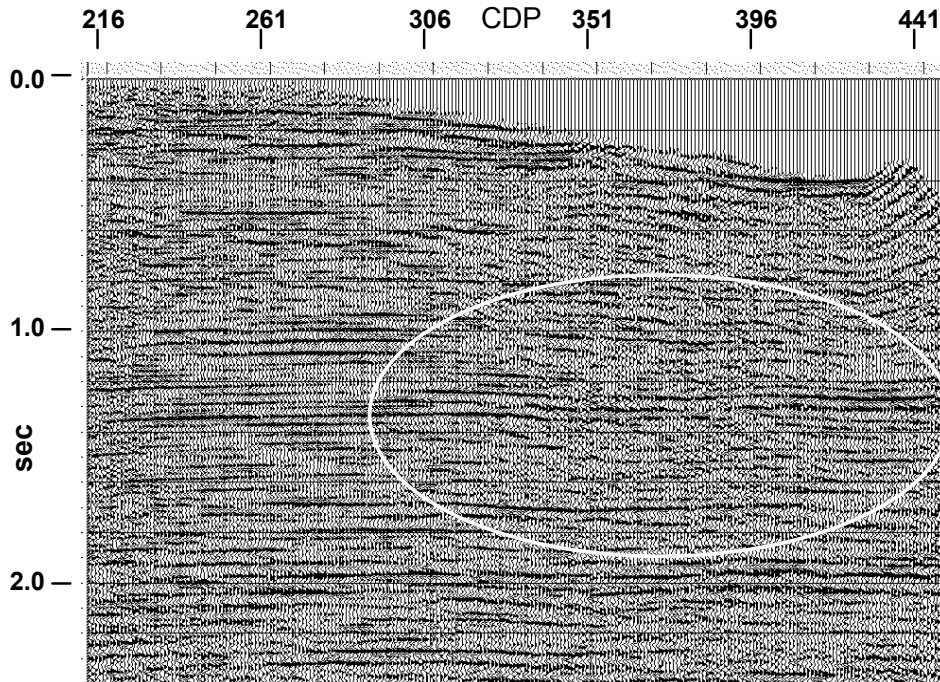
Hansen Harbour stack—pilot trace statics applied by correlation
with distribution function

FIG. 8. Portion of Hansen Harbour line comparable to Figure 5, but with static distribution functions applied by cross-correlation with shot gather traces.
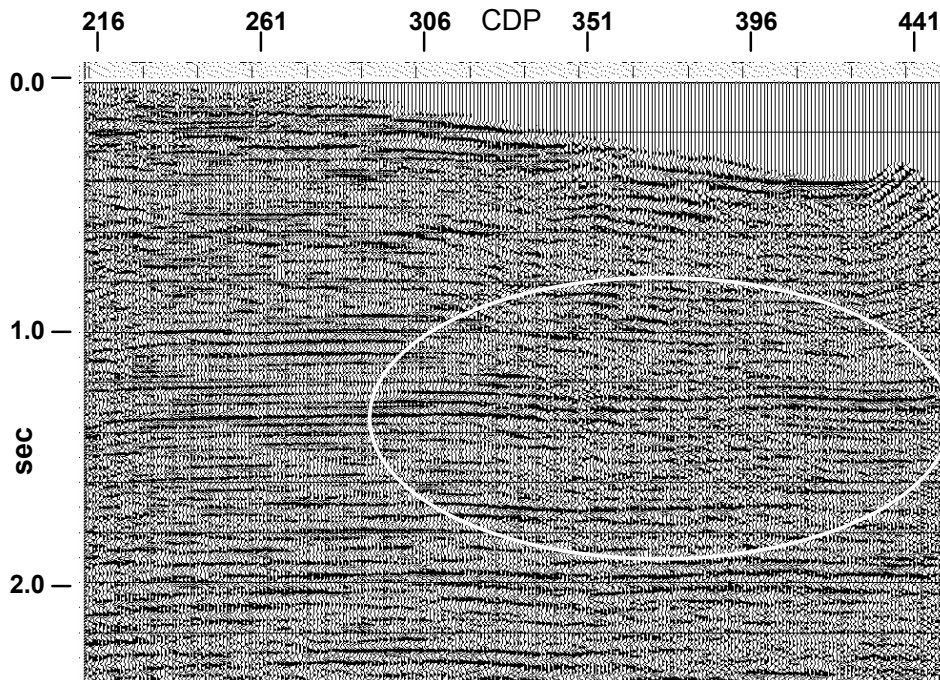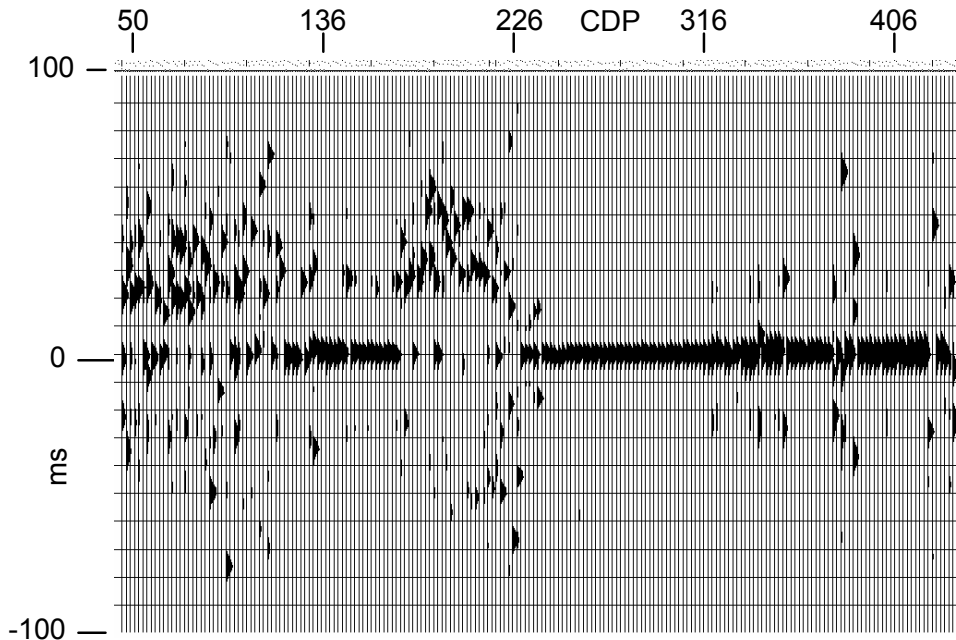


Hansen Harbour stack—pilot trace statics applied by match filter
between distribution function and single spike

FIG. 9. Hansen Harbour line with static distribution functions applied by deriving match filters and convolving with shot gather traces.
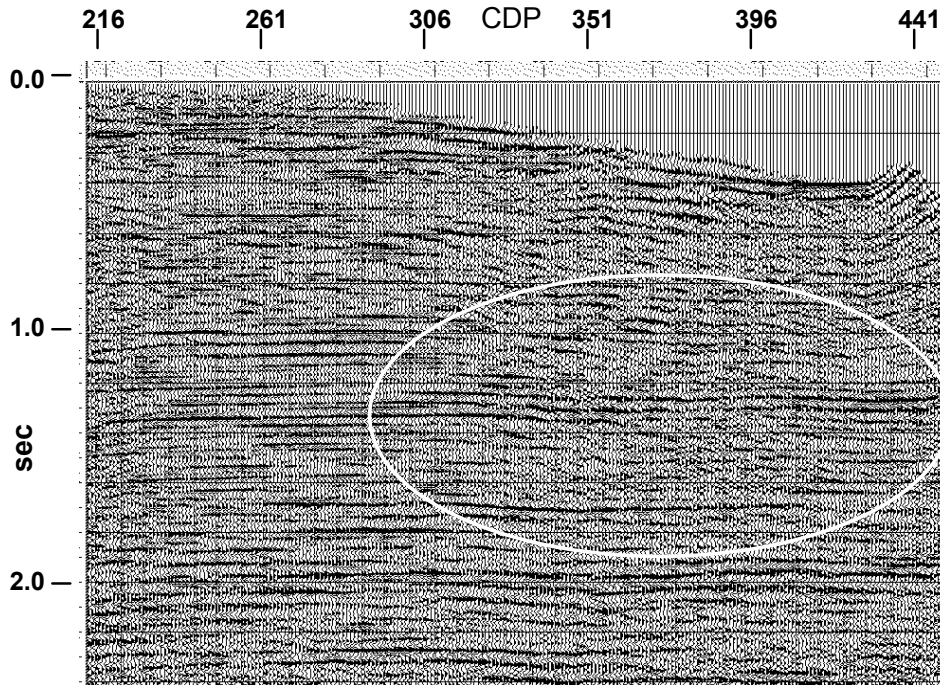
Hansen Harbour stack—pilot trace statics applied by inverse filter
of distribution function

FIG. 10. Hansen Harbour line with static distribution functions applied by convolution of shot
gather traces with inverse filters of distribution functions.



Shot differential static distribution functions between
corresponding traces of adjacent raw input shot gathers

FIG. 11. Static distribution functions constructed from cross-correlations between traces of
adjacent shot gathers…these are differential statics, not total statics.
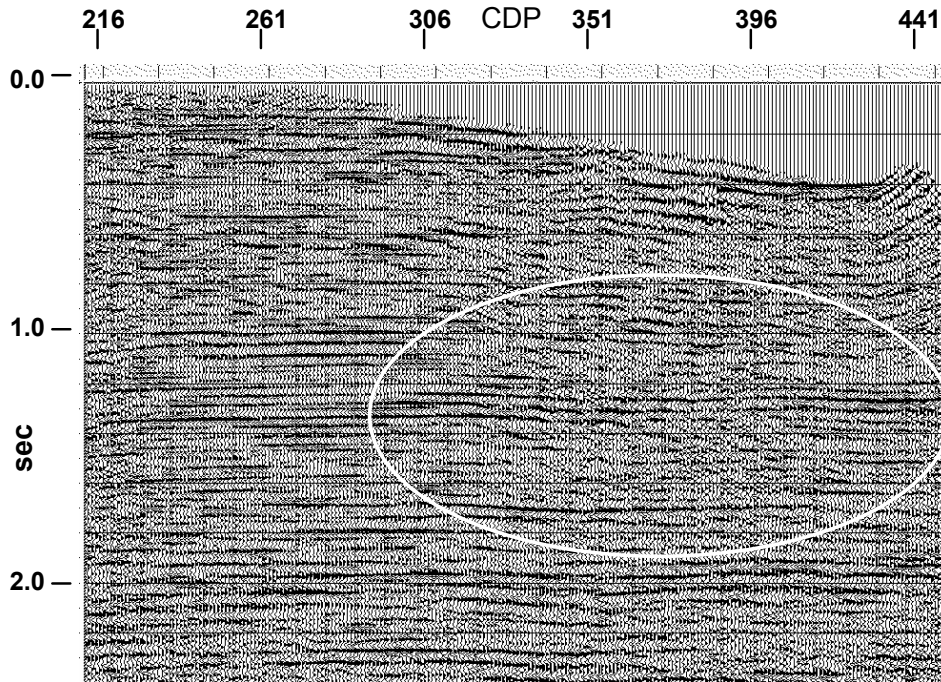
Hansen Harbour stack—differential statics applied by match filter
between distribution function and single spike

FIG. 12. Hansen Harbour line with differential statics distributions applied by convolving shot
gather traces with match filters derived from distribution functions.
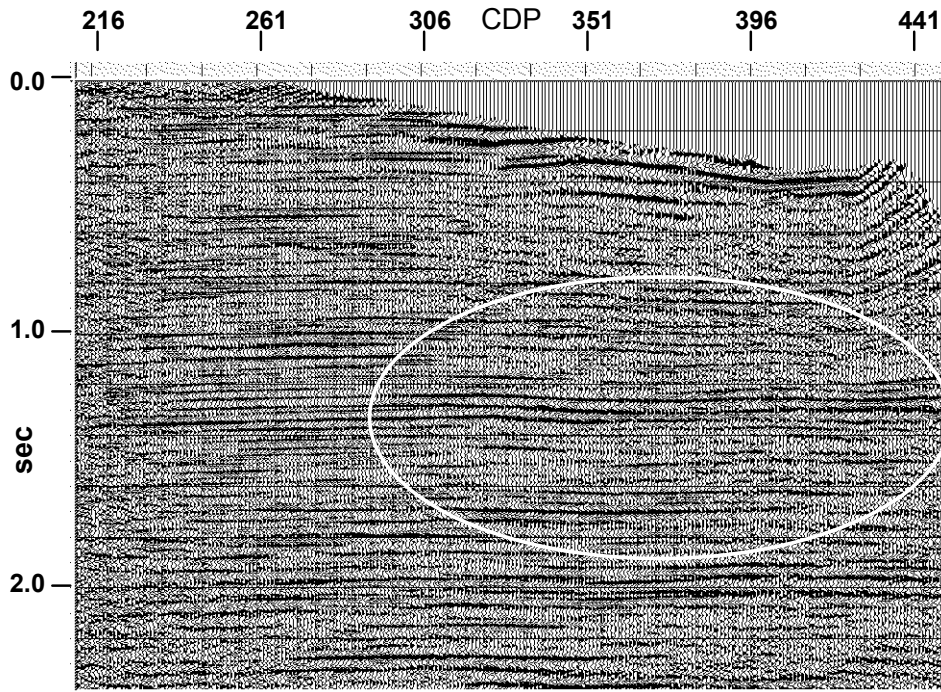


Hansen Harbour stack—total statics from database applied

FIG. 13. Hansen Harbour line with archival total statics from database applied.
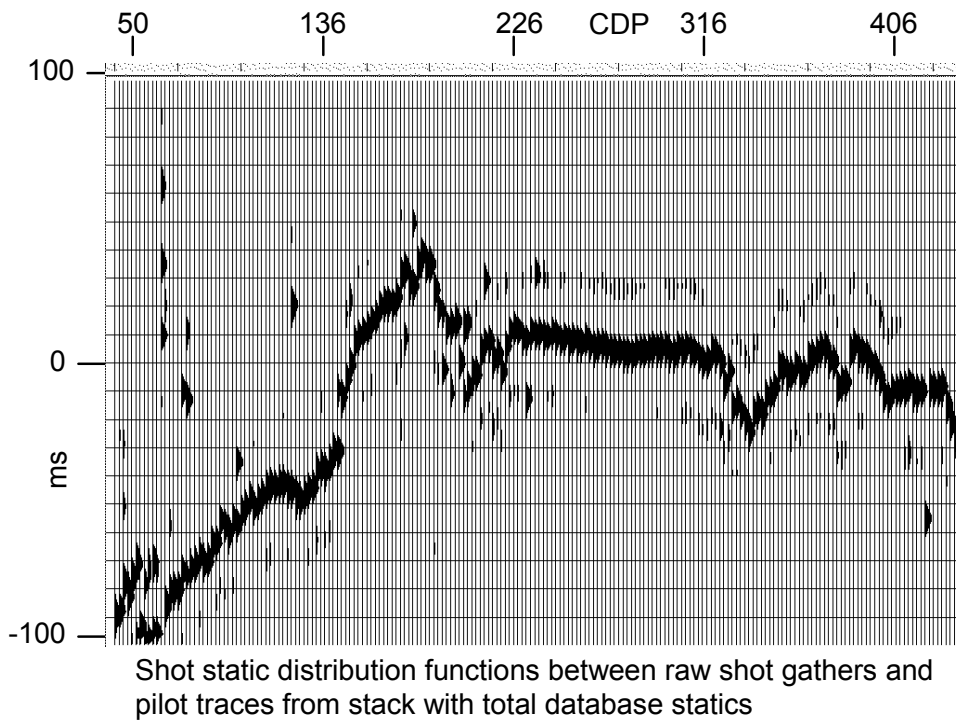
Shot static distribution functions between raw shot gathers and pilot traces from stack with total database statics

FIG. 14. Static distributions derived from cross-correlating uncorrected raw shot gather traces with pilot traces from stack in Figure 13 with database statics applied.
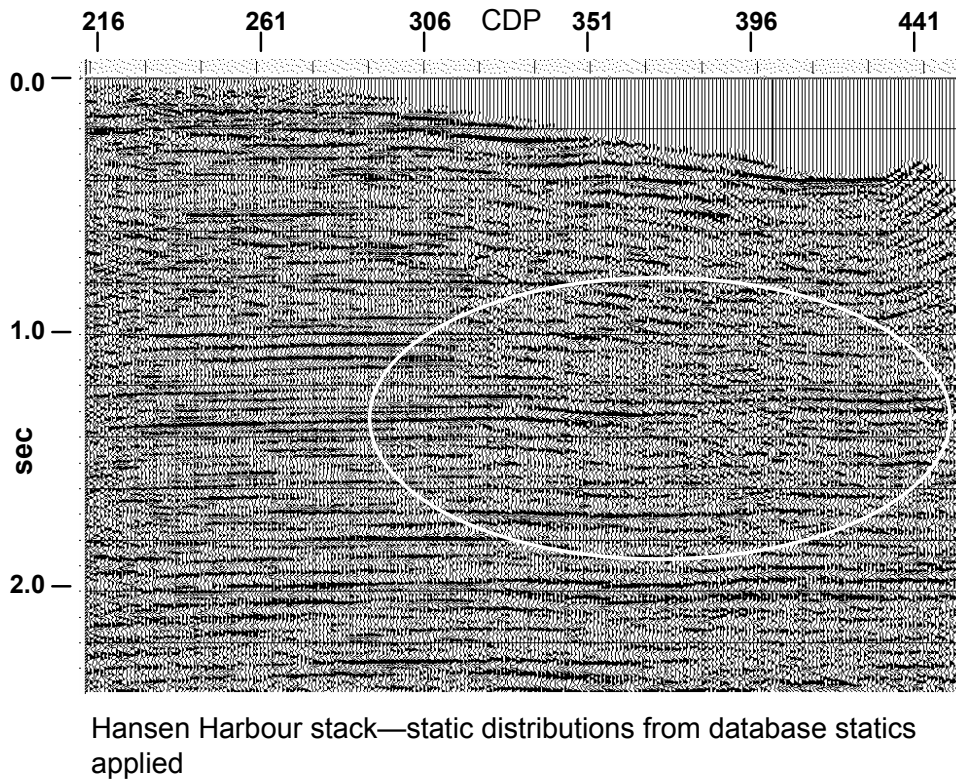


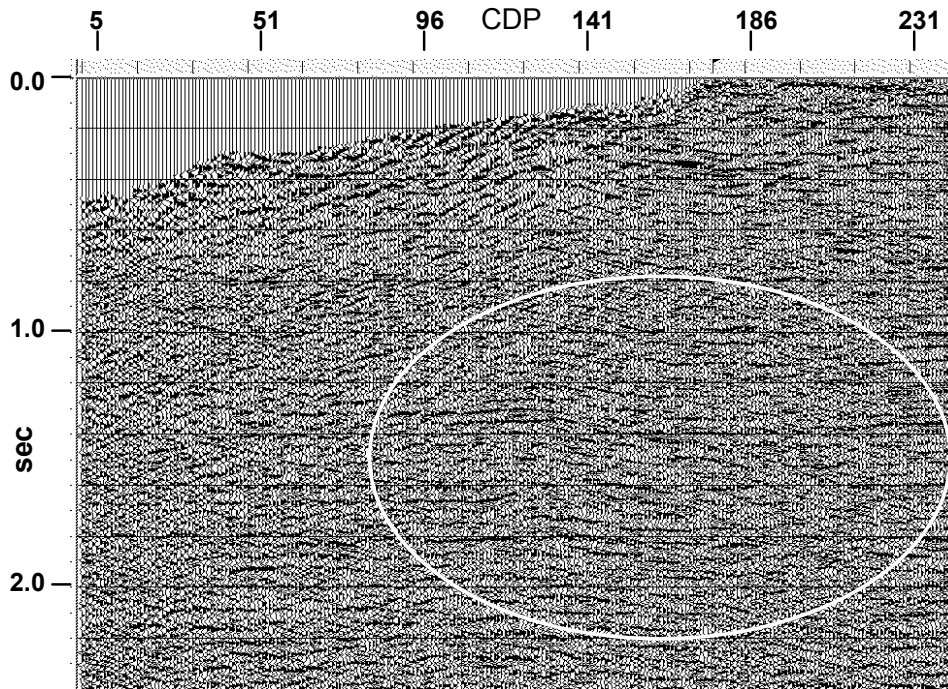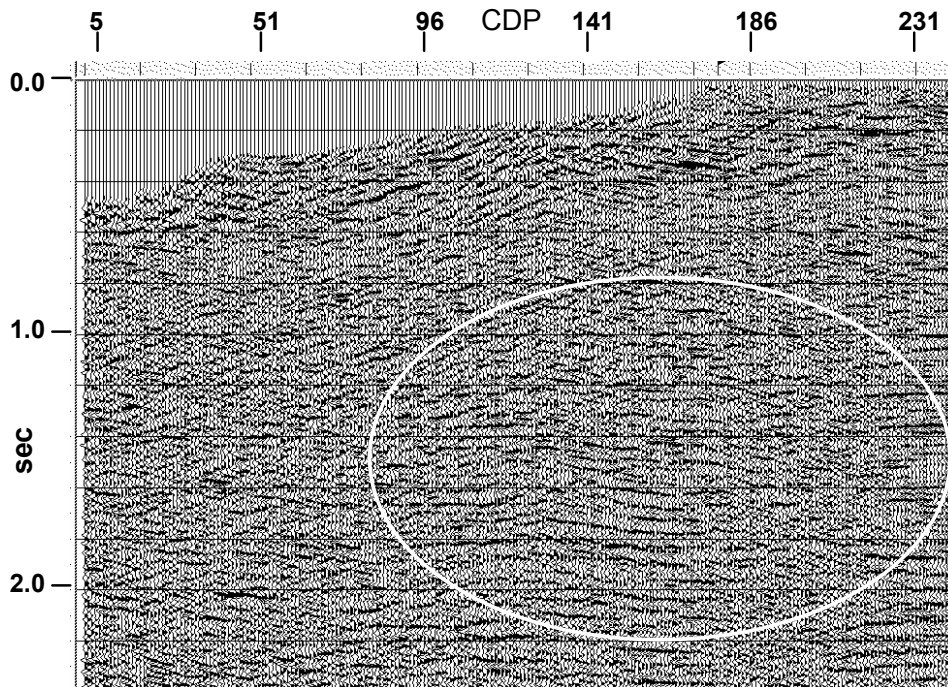Hansen Harbour stack—static distributions from database statics applied

FIG. 15. Hansen Harbour line with distribution functions of Figure 14 applied to shot gather traces by convolution with match filters derived from distribution functions.

Hansen Harbour stack—total statics from database applied

FIG. 16. A different portion of the Hansen Harbour line with database total statics applied before stack.



Hansen Harbour stack—static distributions derived from database statics stack applied

FIG. 17. Comparable portion of Hansen Harbour line with static distribution functions applied to shot gather traces before stack.