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STACKING CHARTS: AN EFFECTIVE WAY OF HANDLING SURVEY, QUALITY CONTROL AND DATA PROCESSING INFORMATION[1]

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ABSTRACT

Surface stacking charts are used for the display of basic information related to various aspects of acquisition and processing of seismic data. At the prestack stage the proposed technique provides a fast and convenient means for displaying, error-checking and analyzing large volumes of data such as trace sequential signal and noise estimates, trace edits, traveltime picks, or static corrections. Displays in the form of surface stacking charts are ideally suited for interactive processing at graphics workstations. Contoured or 2-D median-filtered displays enable the user to identify variations in recording conditions, source strength and receiver coupling, to analyze first-break picks, and to identify erroneous information at an early processing stage.

INTRODUCTION

At various stages of reflection seismic processing, data bases are used for the storage and retrieval of information such as line geometry, stacking fold, trace editing, static corrections and stacking velocities. For stacked data, many useful interactive display systems are available for the display of seismic data, together with relevant information such as fold, stacking velocities and borehole logs. At the prestack stage, graphical display schemes are available for crooked-line geometries, binning and live fold information. However, the user may have difficulties in accessing many other useful quantities such as rms amplitudes, trace scaling factors, and source-receiver offsets. New ways are required to use the wealth of information contained in prestack seismic data.

This paper focuses on prestack quality control, automatic trace editing and crooked-line first-break analysis applications. At the data acquisition and early processing stage reflection seismic data are ordered shot-sequentially. A wide range of parameters can either be obtained from the data (e.g., signal and noise estimates, scaling factors, trace edits, first-break picks, static corrections) or assigned to the data (e.g., fold, latitude and longitude, elevation, offset). Many of these parameters are then stored in data bases together with shot and receiver locations and, at a later stage, are accessed by various sorting and stacking processes. In this paper, surface stacking charts (SSC), which are simply grids with shotpoint and geophone locations as the two axes, are used to display and analyze data-base information.

Displays in the source-receiver space such as surface stacking charts (Sheriff and Geldart, 1982) or surface diagrams (Morgan, 1970; Taner and Koehler, 1981), were originally used to define common-depth-point (CDP) and common-offset planes. These diagrams have also been used to display waveform data. Morgan (1970) described an analysis procedure whereby the seismic wavelets from a reflecting horizon were displayed in the four principal planes (CDP, common-offset, common-shot and receiver). In this paper it will be shown that surface stacking charts are ideally suited for displaying data-base information. Improved management of prestack information may then lead toward convenient displays of first-break picks and static corrections, or toward quality control, automated trace editing and true amplitude stacking schemes (Mayrand and Milkereit, 1988).

In the following sections, surface stacking chart (SSC) analyses are applied to three data sets: a Vibroseis[†] survey on Vancouver Island (Clowes et al., 1987), a Vibroseis survey across the Rocky Mountain Trench in British Columbia (Cook et al., 1987), and a marine survey across the Midcontinent Rift System and Grenville Front in the Great Lakes (Behrendt et al., 1988; Green et al., 1988). All data were collected as part of the Canadian Lithoprobe program.

QUALITY CONTROL AND AUTOMATIC TRACE EDITING

True amplitude processing of large volumes of reflection seismic data requires continuous quality control and effi-

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[†]Vibroseis is a trademark of Conoco Ltd.

cient trace editing of large volumes of data. The quality control scheme used in this paper is based on attributes (signal and noise power estimates) that are obtained from each trace of the seismic data set. Graphic displays of these trace attributes, organized by the SSC, help to identify local source and receiver coupling problems and variable noise conditions. They can also be used to edit noisy traces automatically (Mayrand and Milkereit, 1988).

Marine-data example

The trace envelope display (Taner and Sheriff, 1977; Taner et al., 1979) of 16 s of a true amplitude marine-shot gather is shown in Figure 1. A 128-litre air gun array and a 3-km-long 120-channel streamer were used for data acquisition. Amplitude information is colour coded and covers approximately 80 dB. The dB-scale is normalized with respect to the overall maximum amplitude. The near-offset traces show significantly higher noise levels than large-offset traces; such noise level variations can affect true amplitude processing of the data and should be accounted for. In addition, variations in source and receiver performances and background noise level fluctuations during the course of the survey must be taken into account during processing.

In order to use SSCs for quality control purposes, windows, representing either signal or noise, are defined in time and offset (see Figure 1). Maximum amplitudes, rms amplitudes or mean energy values are determined for each trace and window of each shot gather*. Reliable noise estimates can be determined at either very late or early recording times, and the direct wave and/or first-break window can be used as a basis for signal strength estimates. True amplitude scanning results in signal and noise estimates for each shotpoint and each receiver which are displayed in the form of SSCs. Signal and noise estimates for 60 marine shot gathers are shown in Figure 2. The mean energy of the signal analysis window is shown in Figure 2a. The SSC display is normalized with respect to the overall maximum energy. The signal scan in Figure 2a indicates (a) overall good signal propagation (energy decay within a shot gather) and (b) no major source strength variations during the course of the survey. The SSC display helps to identify a misfired shot (labelled "!") and erroneous amplitudes from one receiver group (labelled "?" in Figure 2a). The noise analysis is based on the scanning of a late 12 to 16 s time window. The mean energy of the noise analysis window for each trace is shown in Figure 2b. The noise scan is normalized with respect to the overall maximum energy. The SSC display of noise estimates confirms the observation made earlier that the inside traces have a higher noise level (representing either source-generated noise by the towed air gun array or cable noise). Three receiver groups are highlighted (labelled "?" in Figure 2b) which show continuously higher noise levels. In addition, random spikes (labelled "S") can be identified. Anomalous signal and noise estimates do not seem to be correlated. With both source strength variations addressed and noise conditions controlled, this data set is ideally suited for true amplitude processing. Examples are given by Milkereit et al. (1989a).

*This straightforward scanning technique is applicable to data sets for which a noise-rejection algorithm has taken care of time-dependent noise bursts. If noise bursts or randomly distributed spikes are a problem, multi-window amplitude scans should be applied. Examples used in this study are based on unprocessed, true amplitude data. In practice, it may be necessary to apply band-pass filtering and deconvolution to the data prior to scanning.

Vibroseis example

The size of many crustal-scale seismic reflection data sets and their large dynamic range of amplitudes are reasons for seeking an efficient quality control and trace-editing scheme. Median filters (Huang et al., 1979; Stewart, 1985) or alpha-trimmed mean filters (Bednar and Watt, 1984) can be used to identify "outlier" traces, for example, all those traces which are extremely noisy. Median filters, which are usually applied to smooth or despike data, can also be used to enhance and highlight spikes or outliers.

A portion of an unusually noisy Vibroseis survey is used to illustrate a SSC approach to automatic trace editing. The example consists of 60 shot gathers from a 120-channel acquisition system with a receiver spacing of 90 m. Vibrators were moved through a fixed spread. The true amplitude shot gathers were scanned trace-sequentially for their maximum amplitude within the first-break *P*-wave window. Results of the signal scans are displayed on a SSC for 60 shots and 120 surface stations and shown in Figure 3a. Maximum amplitudes within the *P*-wave window for all traces recorded at the same field station are shown along a vertical line on the chart, whereas those for a shot gather are shown along a horizontal line. Again, the scale is normalized with respect to the overall maximum amplitude. The scan shows a physically reasonable offset-dependent decay of amplitudes within each shot gather. The signal scan display shows some local amplitude anomalies, but no major source strength variations are observed in these data. While SSC displays of signal estimates can be used to assess the overall data quality, signal estimates are offset-dependent, and therefore it is difficult to use them in an automatic editing scheme.

The noise-energy estimates of individual traces were used to analyze variable recording conditions and to identify noise sources. In this example, noise estimates were obtained trace-sequentially at very late recording times between 14 and 16 s. The SSC of noise-energy estimates is shown in Figure 3b. Compared to the marine-data example shown in Figure 2b, the land survey exhibits a complex pattern of large fluctuations in background noise. The complexity of the noise distribution makes an automatic trace-editing scheme desirable. The amplitude information in the SSC can be considered as a 60 x 120-element digital image $I(x, y)$. A two-dimensional (2-D), 7 x 7-element running

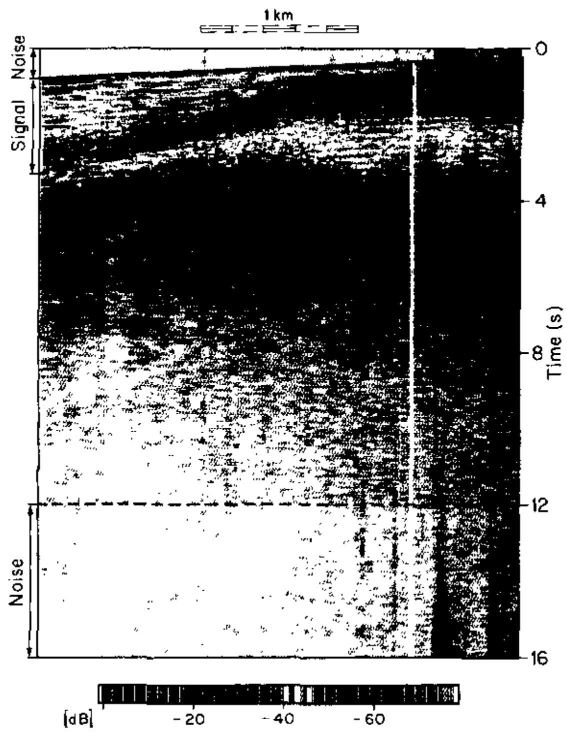

Fig. 1. Trace amplitude envelope display of a 120-channel marine shot gather. Amplitudes are colour coded and cover a range of 80 dB. User-specified windows for signal and noise analyses are indicated.

median filter was applied to $I(x, y)$ in Figure 3b to obtain a spatially smoothed filtered image $F(x, y)$. The median-filtered noise display is shown in Figure 3c. Figures 3b and 3c indicate that for shots 1 to 50, all traces recorded between stations 60 and 120 are abnormally noisy. In addition, long wavelength variation in recording conditions can easily be identified: the overall higher noise level for shots 1 to 50 correlates with daytime data acquisition. The information about local noise conditions can be used as input for an automatic trace-editing and stacking scheme. The local residual $R(x, y)$ is defined as the original image (Figure 3b) less the median-filtered image $F(x, y)$ (Figure 3c):

$$R(x, y) = I(x, y) - F(x, y).$$

Only local noise anomalies (outliers) remain in residual image $R(x, y)$. Traces with residual noise power greater than a user-specified threshold can be identified and excluded from further processing (Mayrand and Milkereit, 1988). All anomalous traces are displayed in Figure 3d. The SSC shows all those anomalous traces that were detected by the automatic noise power scanning and subsequent median filtering of the data. Such information can be used as input for stand-alone, automatic trace editing or can be used to complement conventional, manual trace editing. It is important to note that many of the outliers shown in Figure 3d are associated with certain station

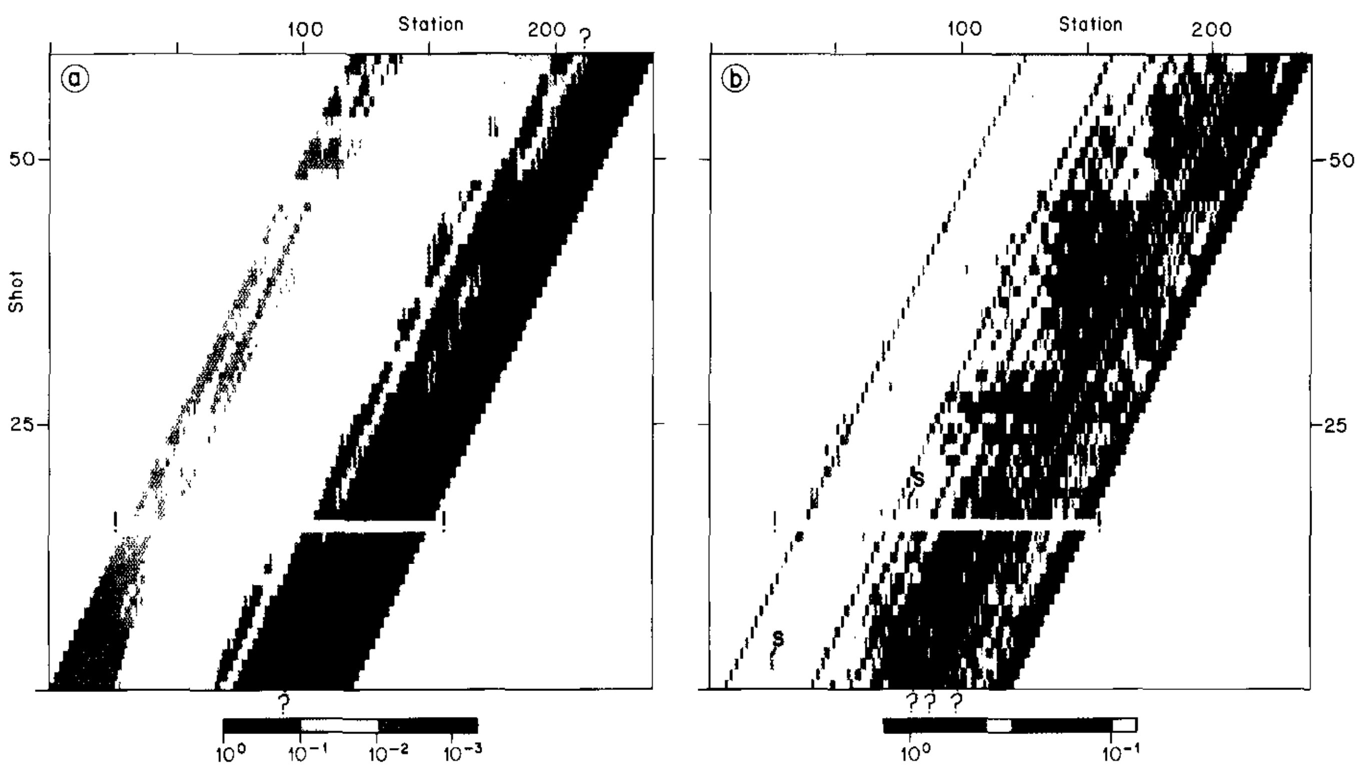

Fig. 2. (a) Surface stacking chart display of signal strength estimates. The station spacing is 25 m, the source-near-receiver offset is 225 m (a 9-station gap). The mean energy of the signal analysis window is colour coded. The display is normalized with respect to the overall maximum energy. *The scale covers a relative energy range of 10^{-3}. A misfired shot "!" and erroneous amplitudes of one receiver group "?" are* highlighted. **(b)** Surface stacking chart display of noise estimates. The mean energy of the noise analysis window is colour coded. The display is normalized with respect to the overall maximum energy. The scale covers a relative energy range of 10^{-1}. Two outliers/spikes "S" are annotated.

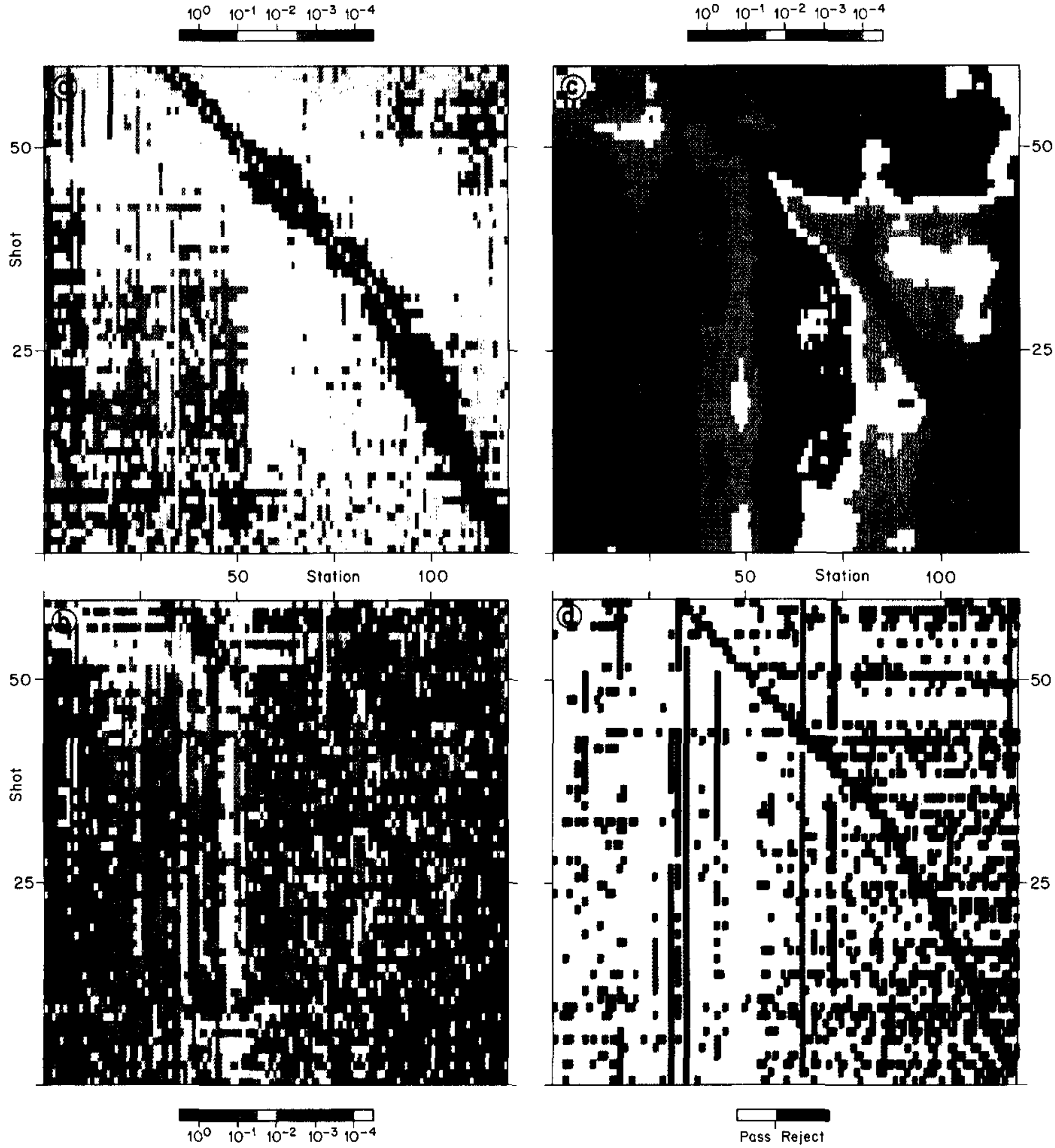

Fig. 3. **(a)** Surface stacking chart of signal estimates from Vibroseis first-break data. The maximum amplitude of the signal analysis window is colour coded. The display is normalized with respect to the overall maximum amplitude. The scale covers a relative amplitude range of 10^{-4}. The station spacing is 90 m. Vibrators are moving through a fixed 120-channel spread. **(b)** Surface stacking chart of noise estimates from Vibroseis data at late recording times. The mean energy of the noise analysis window between 14 and 16 s recording time is colour coded. The display is normalized with respect to the overall maximum energy. The scale covers a relative energy range of 10^{-4}. **(c)** Two-dimensional median-filtered surface stacking chart of noise estimates shown in Figure 3b. **(d)** Surface stacking chart display of traces to be edited. The display shows outlier traces based on the difference between the input and median-filtered data in Figures 3b and 3c.

locations (vertical correlation) and vibration point numbers (horizontal correlation).

Other Display Parameters

Another powerful application of SSC displays can be found in the analysis of first-break picks. As an example of how SSCs can be used to handle, display and interpret large volumes of prestacking information, the technique is applied to a Vibroseis data set from the Rocky Mountain Trench (RMT) area in British Columbia. A 120-channel recording system with 100-m station interval and both conventional split-spread and undershooting/wide-angle recording geometries were used for data acquisition. A total of 154 Vibroseis shot gathers were collected along an extremely crooked line. The length of the profile is approximately 20 km with more than 300 m of topography.

A split-spread Vibroseis shot gather with manually picked first breaks (where possible) and a generalized location map are shown in Figure 4a. A conventional display of traveltime picks is shown in Figure 4b with accompanying topography and location of the topographic trench with respect to the profile. It is obvious that such displays of first-break data bases with more than 10 000 entries (and split-spread recording geometry) are difficult to read. Figure 5a shows the SSC display of the first-break time data, plotted as colour-coded contours of user-specified time bands. The positions of vibrators within and outside the 120-channel spread are indicated.

The following example demonstrates the use of SSC displays for delay-time and static-correction applications. An apparent layer velocity of 4500 m/s is found to represent consolidated basement along the seismic profile. The intercept time τ is defined as:

$$\tau = t - x/v,$$

where t is the picked traveltime at offset x and v is the layer velocity. The intercept times for offsets greater than 1000 m are displayed in Figure 5b. West of the RMT the 4500 m/s layer is close to the surface. In the trench, sources and receivers are delayed by as much as 250 ms (two-way time). The SSC display immediately highlights the asymmetric and inhomogeneous subsurface structure for the geographic centre of the trench. Static corrections are obtained by splitting intercept times into source and receiver contributions. Figure 5c shows the SSC display for the long-wavelength static corrections which range from less than 15 ms up to more than 100 ms (one-way time) in the centre of the trench. Again, the horst-like structure is well pronounced. The application of the static corrections improved the seismic image beneath the geographic trench (for details see Milkereit et al., 1989b).

Besides displaying traveltime picks, intercept times and static corrections, SSC displays can be used to analyze the data in several ways that are not shown here:

1. Reciprocal time errors can be displayed to evaluate the quality of the picks.
2. Apparent and refractor velocities can be obtained from first breaks.
3. Erroneous traveltime picks (outliers) can be identified on 2-D median-filtered charts.

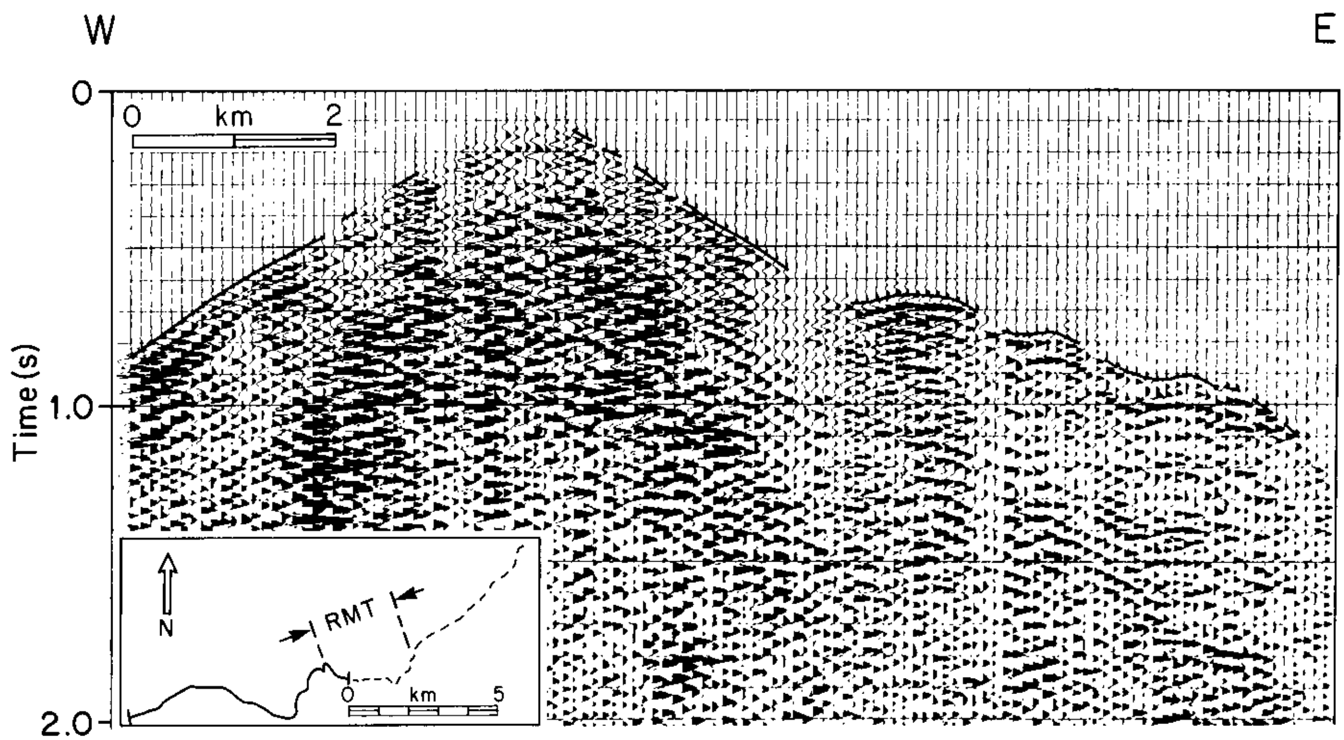

Fig. 4a. Crooked-line, 120-channel Vibroseis shot gather from the Rocky Mountain Trench (RMT) area with first-break picks. The station spacing is 100 m. Insert shows crooked-line geometry (the line is located at approximately 115°45′W, 50°10′N).

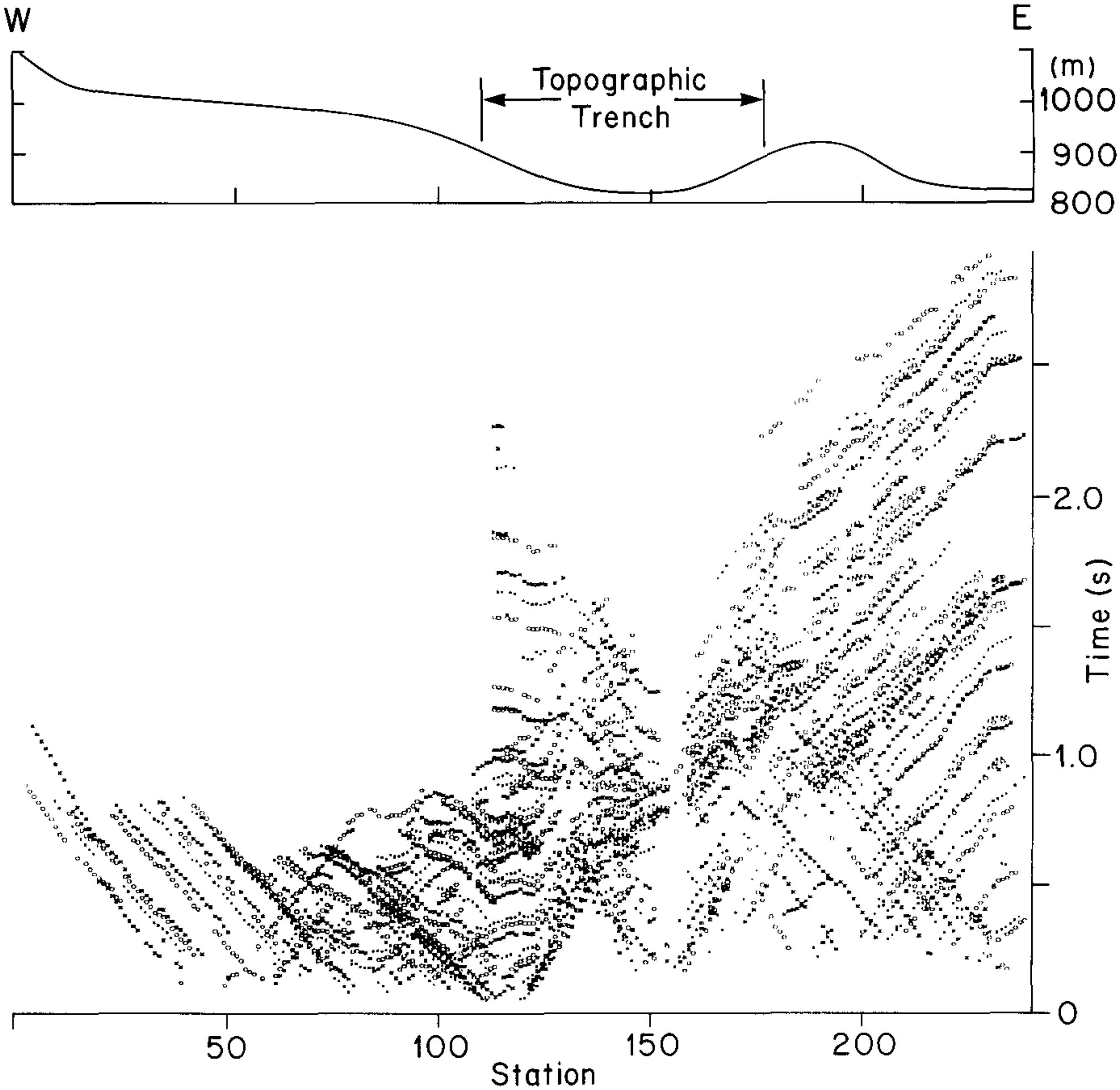

Fig. 4b. Top: Elevation along profile (m). Bottom: Conventional display of first-break time picks for 154 shot gathers in split-spread and undershoot recording geometry.

Discussion and Conclusions

Surface stacking charts provide an ideal environment for the storage, display and analysis of prestack seismic information. Alternative grids for the graphical display of prestack information can be defined by using any combination of CDP-number, geophone location, shot location, or offset. This study focused on the use of SSC displays for quality control and first-break applications. In this context, SSC displays of trace attributes, such as signal and noise estimates, traveltime picks and delay times, were used

- — to assess the overall data quality,
- — to identify anomalous performance of sources and receivers,
- — to estimate background noise-level fluctuations,
- — to provide fast and convenient displays of a large number of data-base entries, and
- — to automatically edit outliers.

Further SSC applications, outside the scope of this paper, can be found in displaying and checking seismic data-base entries concerning survey information, such as source-receiver offsets, coordinates and elevations, or concerning processing parameters, such as binning, live fold and near-surface velocities.

Trace-sequential scanning of the data, colour coding, 2-D median filtering and displaying of SSCs are computationally inexpensive processing steps that can be integrated

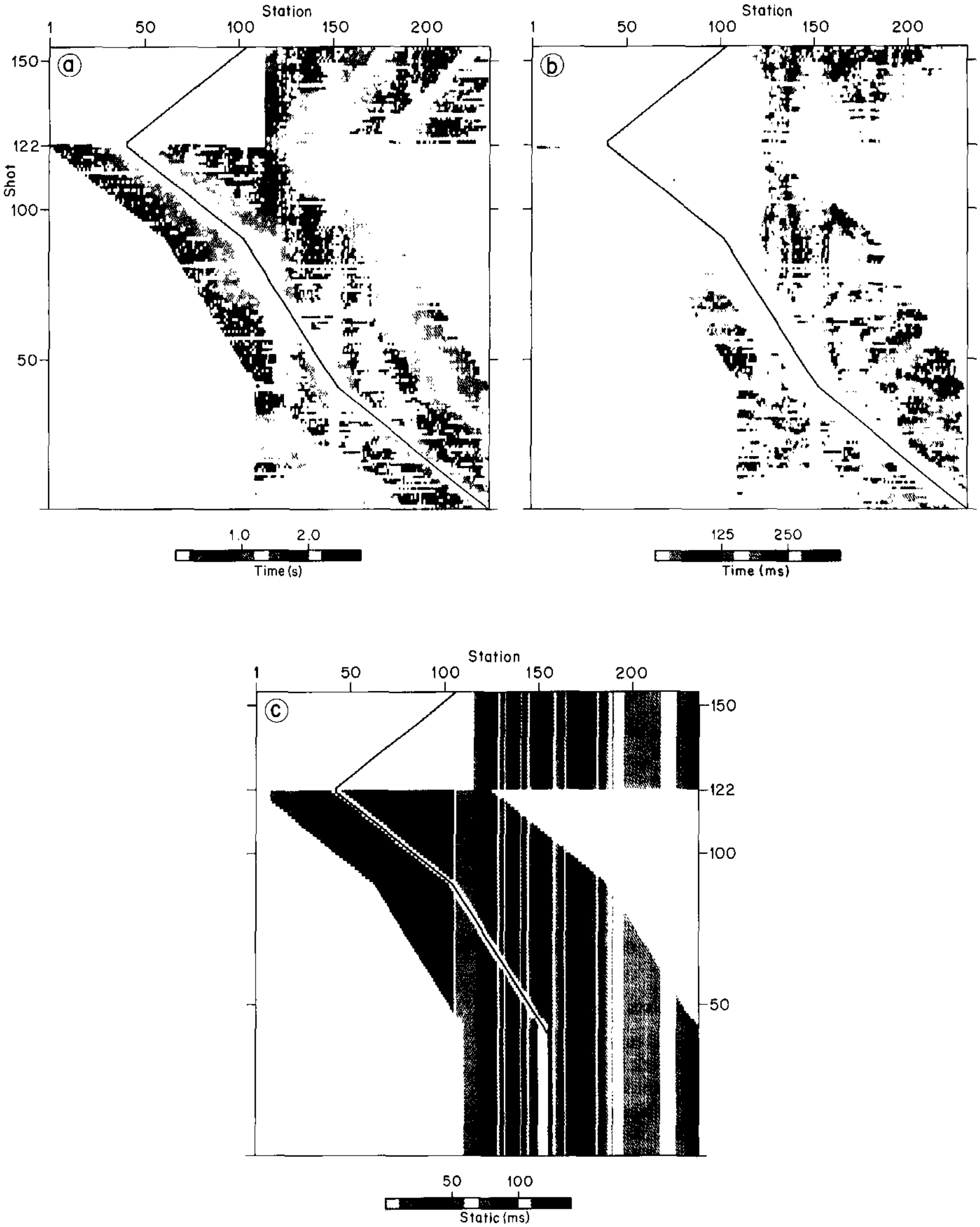

Fig. 5. (a) Surface stacking chart display of first-break data shown in Figure 4b. Shot gathers 1 to 122 were recorded in split-spread geometry; shot gathers 123 to 154 were part of an undershoot experiment. **(b)** Surface stacking chart display of intercept time (ms) for a layer represented by consolidated basement velocities. **(c)** Surface stacking chart display of long-wavelength static corrections (ms) based on delay times shown in Figure 5b.

efficiently into conventional seismic processing packages and workstation-based graphical display systems. SSCs provide a fast, interactive and convenient means of displaying and analyzing otherwise unmanageable large data volumes at an early data-processing stage.

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