PRAKLA-SEISMOS INFORMATION No.18

3-D Seismic Processing

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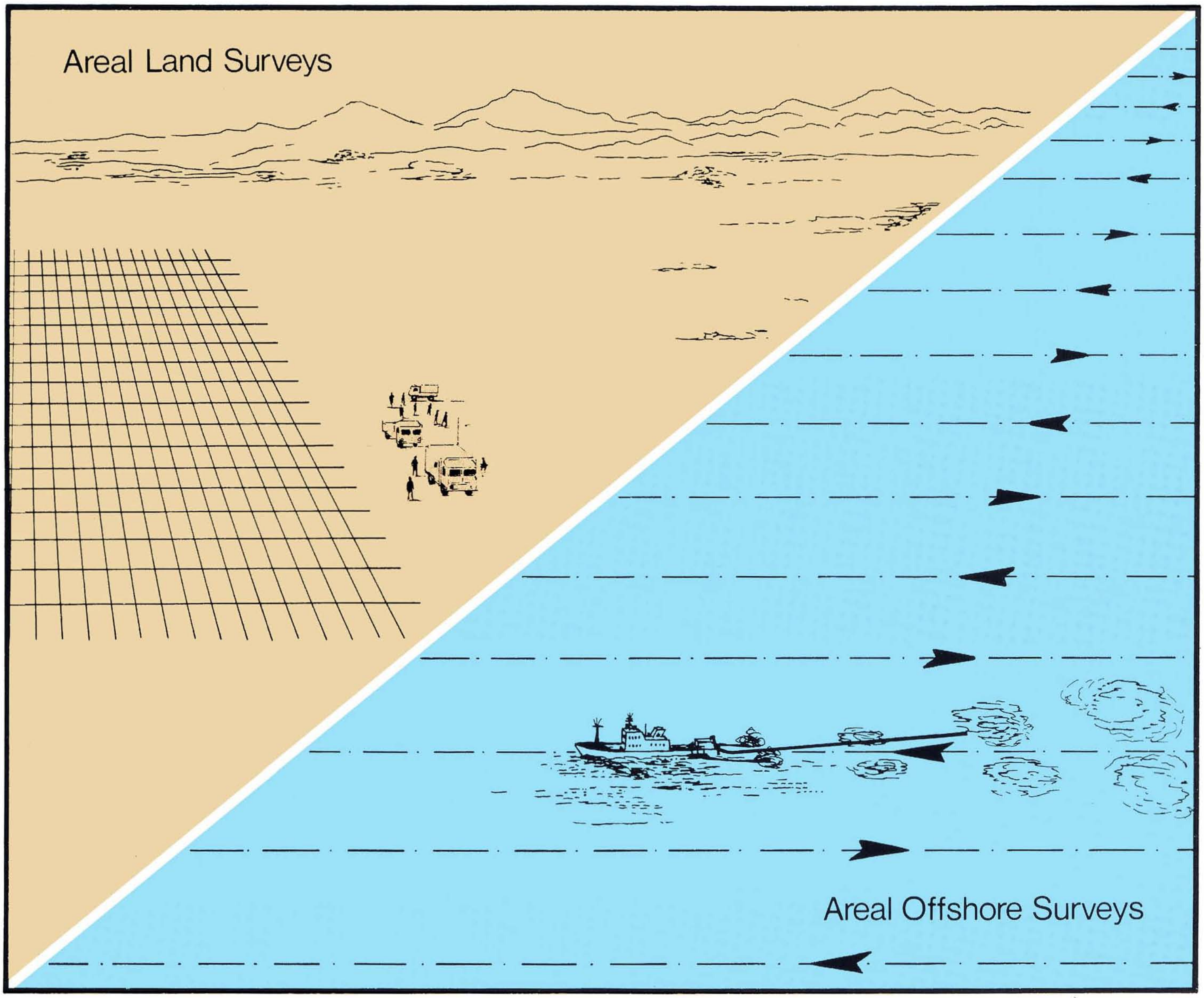


Contents

This brochure describes the main steps of PRAKLA-SEISMOS' comprehensive processing system for seismic data from 3-D surveys.

The program sequence is outlined in a block diagram on the back cover. As it shows, field data from two types of source-receiver geometries can be handled by the system. The distribution of reflection points (midpoints between sources and receivers at the surface) may be uniform or random over the survey area, depending on the local field conditions. A very irregular scattering of seismic data points, being obvious in the Meander Line Technique, has been successfully handled for several years. That kind of 3-D seismic systems was described in PRAKLA-SEISMOS' Information No. 11.

In the meantime seismic methods using 3-D techniques have become an effective tool in geophysical prospecting. The extreme density of seismic information permits the production of a series of parallel lines in intervals of the in-line trace distance. The orientation of these lines may also be arbitrarily defined over the survey area.

The process of 3-D migration enables us to produce true vertical sections without remainders of diffractions and without interference of signals that were reflected from outside the line to be processed.

By a system of four reflecting planes realized in a well designed synthetic 3-D model (Fig. 1) it will be demonstrated that pure time sections sometimes may show confusing pictures. The four reflectors are characterized by special two-dimensional structures of different strike directions.

Line A should be considered for the construction of a vertical section through this model. Fig. 2a shows the zero-offset section along line A. In fig. 2b and fig. 2c the results of 2-D migration and 3-D migration can be compared. Because of lateral events, which cannot be considered in the two-dimensional procedure, only the 3-D migration process delivers the true vertical section, well interpretable. This is the case in any other direction too, such as, for example, line B perpendicular to line A.

As well as the abundance of data to be handled in 3-D processing it is well known that many problems must be tackled to produce a reliable result for the interpretation of complex geological structures.

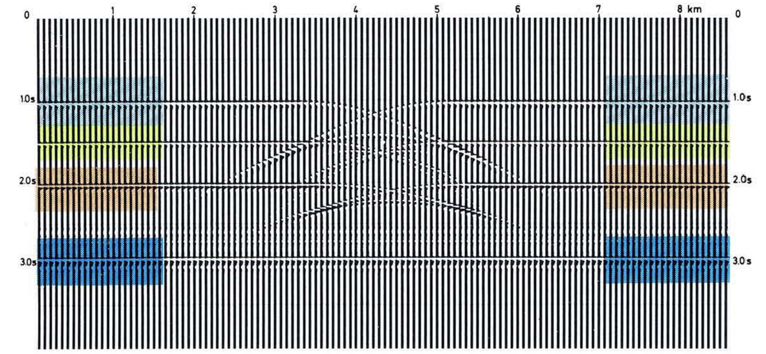


Fig. 2a: Zero-offset Section along line A

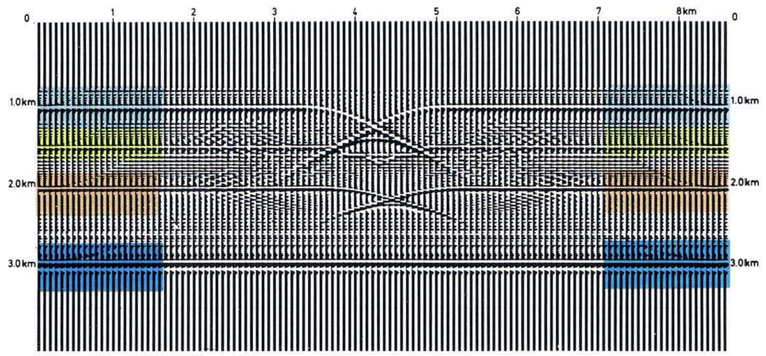


Fig. 2b: 2-D Migration

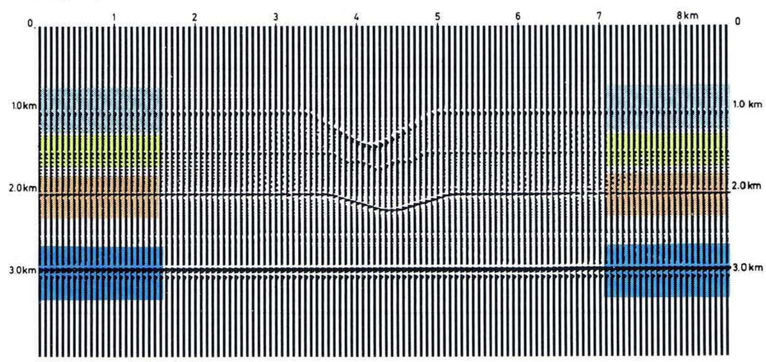


Fig. 2c: 3-D Migration

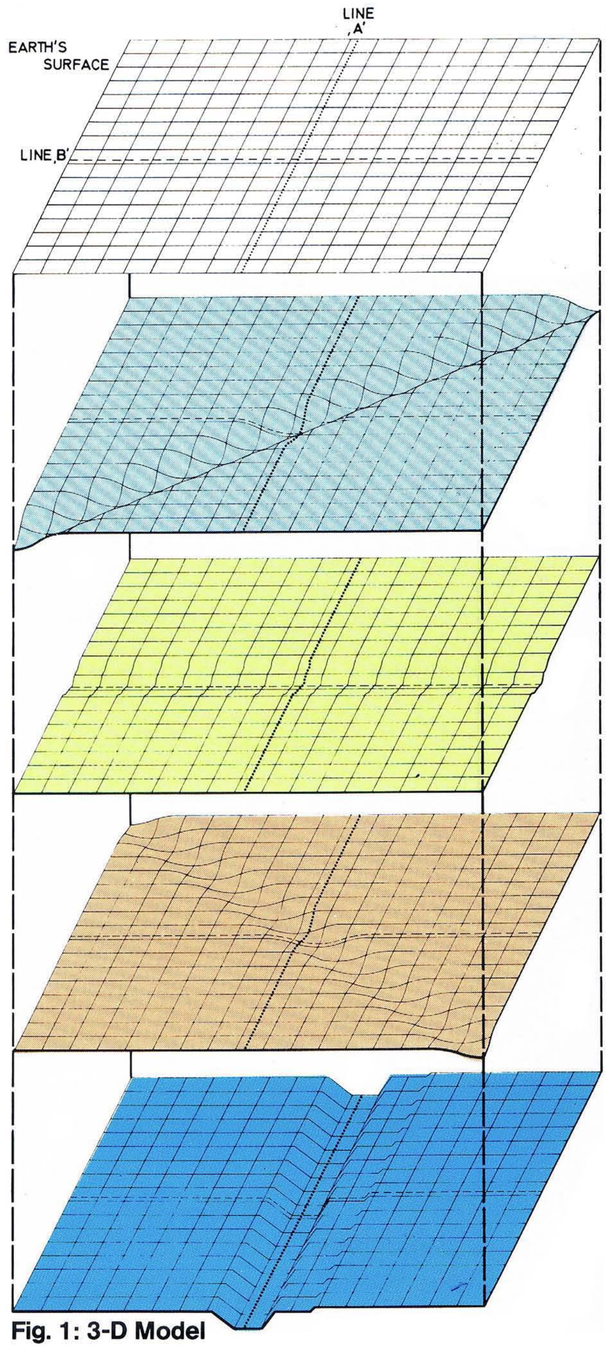


Fig. 1: 3-D Model

The most important step in the preprocessing phase is the determination of coordinates for all midpoints between sources and receivers. The basic rectangular system may be arbitrarily defined and is maintained throughout the whole processing sequence. The distribution of midpoints over the survey area is shown by a scattergram, which can be displayed in any scale on various types of plotters.

Fig. 3 illustrates an example from areal survey, containing midpoints, shots and geophones, which of course can also be plotted separately. Midpoints are marked by one or more dashes, the number of them indicating the degree of coverage. Shots and geophones are presented as asterisks and circles respectively.

The scattergram is a help in finding the best arrangement of reference lines for a special 3-D processing.

Theoretically numerous kinds of field configurations are imaginable in areal surveys, delivering a distribution of seismic data which is more or less uniform or random. Whenever field conditions are appropriate the best uniformity of areal subsurface coverage is achieved by arranging many parallel, closely spaced survey lines. The midpoint scattergram shown in Fig. 3 is an example for this type of regular grid data, which, of course, is also the easiest to handle in processing.

Particularly offshore surveys produce an uncontrollable variance of subsurface coverage caused by variations of current strenght and direction. Thus high accuracy in positioning the source- and receiver locations is required.

This accuracy can be obtained by recording the streamer feathering angle to the ship-axis using a phase-difference method, and by interpolating each receiver group center along the streamer taking 3 to 4 observed compass values along the streamer into consideration. The main error then depends only on the accuracy of the ship's gyro-compass system.

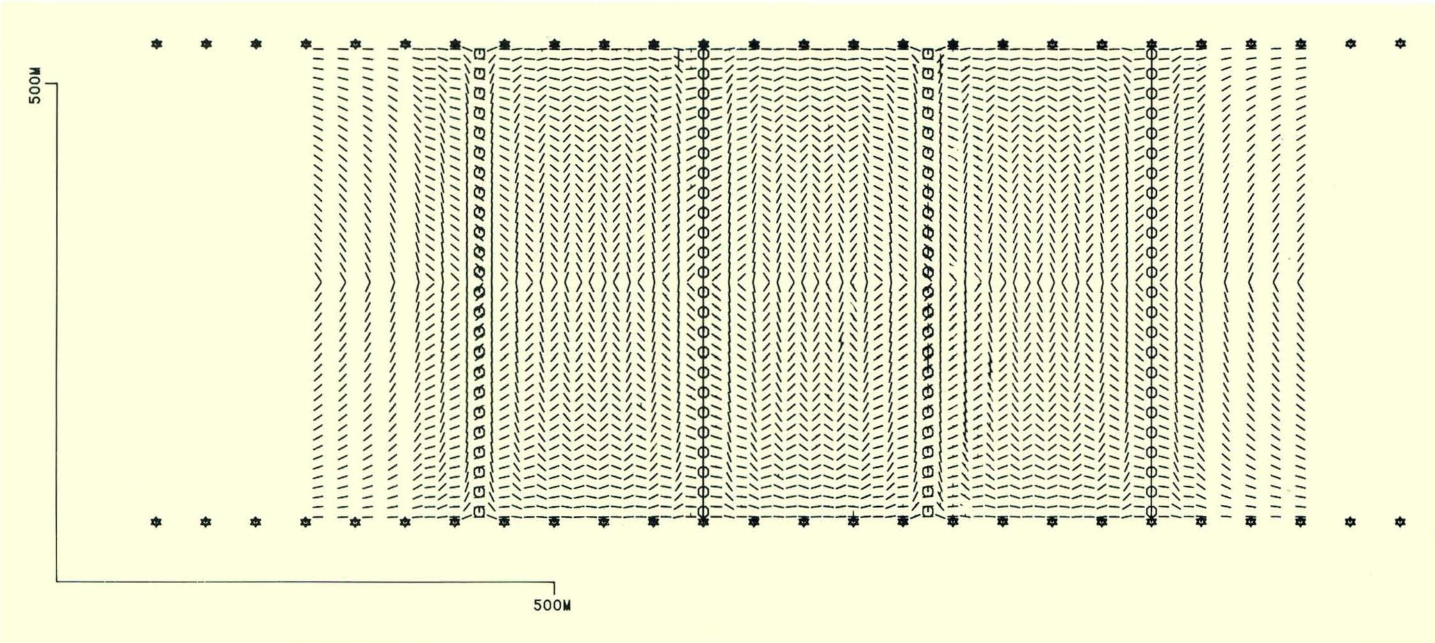


Fig. 3: Scattergram

Whichever field geometry will be used, if proper positioning information is available, a special sorting program in the processing system provides for a regular data organization over the survey area.

This is carried out by definition of equally spaced stripes perpendicular to the reference lines. The width and length of the stripes are arbitrary and must not necessarily be identical with the processing spacing. The distribution of traces within the stripes is performed using arbitrary criteria such as shot-geophone distance or simply coordinate sequence.

The data organization according to that stripe philosophy may be controlled by a display of a position map in the same scale as the scattergram.

The velocity analyses can be performed in the conventional manner. As the original coordinates are maintained throughout the processing sequence, the velocity analyses can be executed according to the real shot-geophone-distances. For special velocity studies or other parameter estimation procedures it is possible to select traces belonging to a particular range of shot-geophone-distances or in specified directions. Another position map shows the distribution of such selected points.

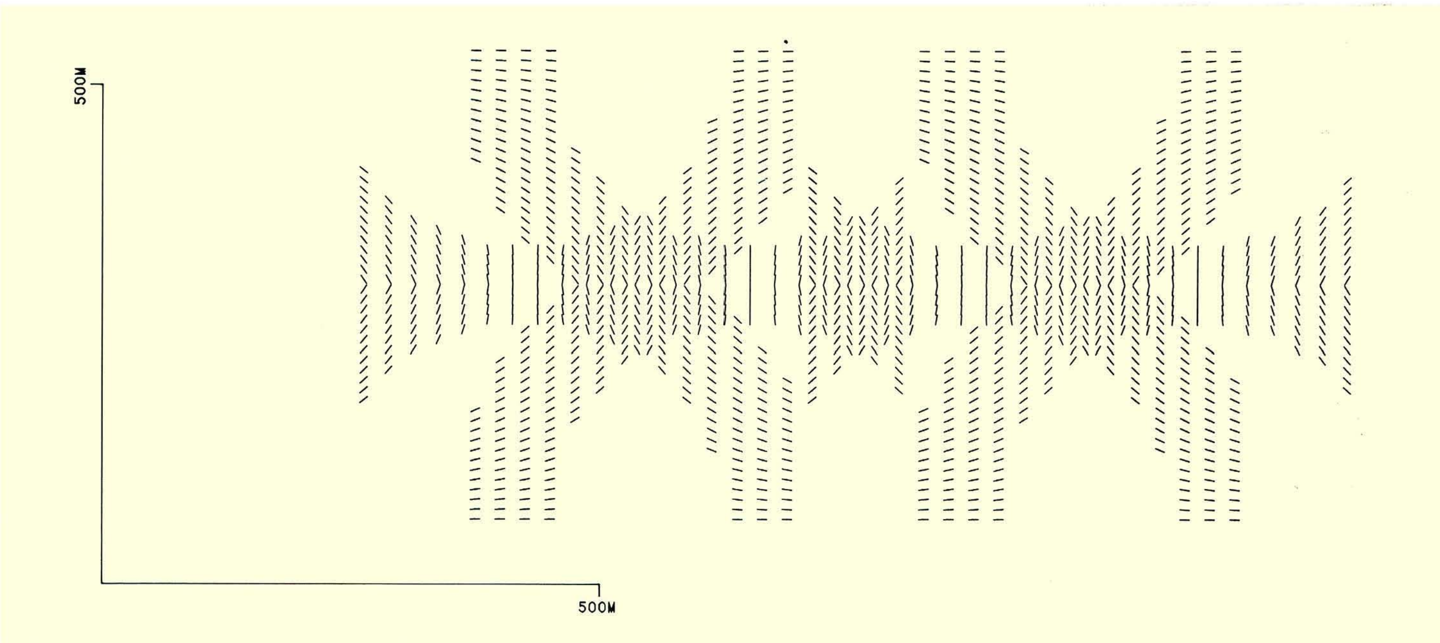


Fig. 4a: Selective Scattergram considering specified shot-geophone distances

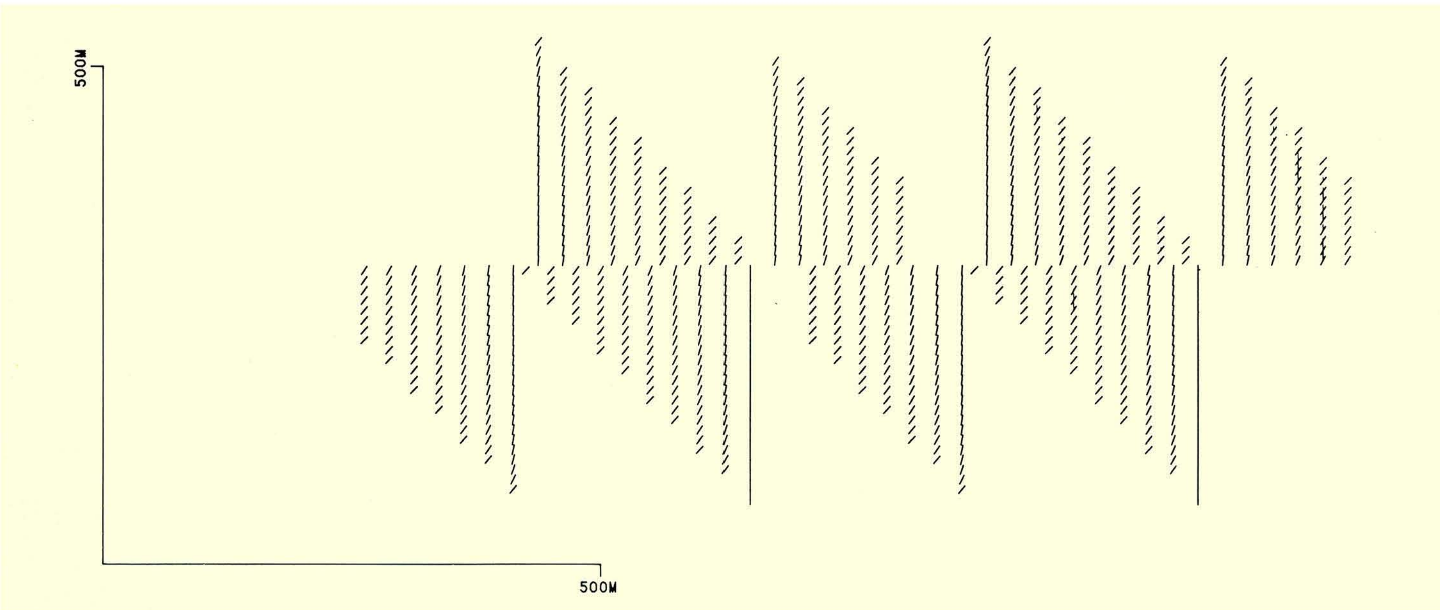


Fig. 4b: Selective Scattergram considering a specified azimuth range

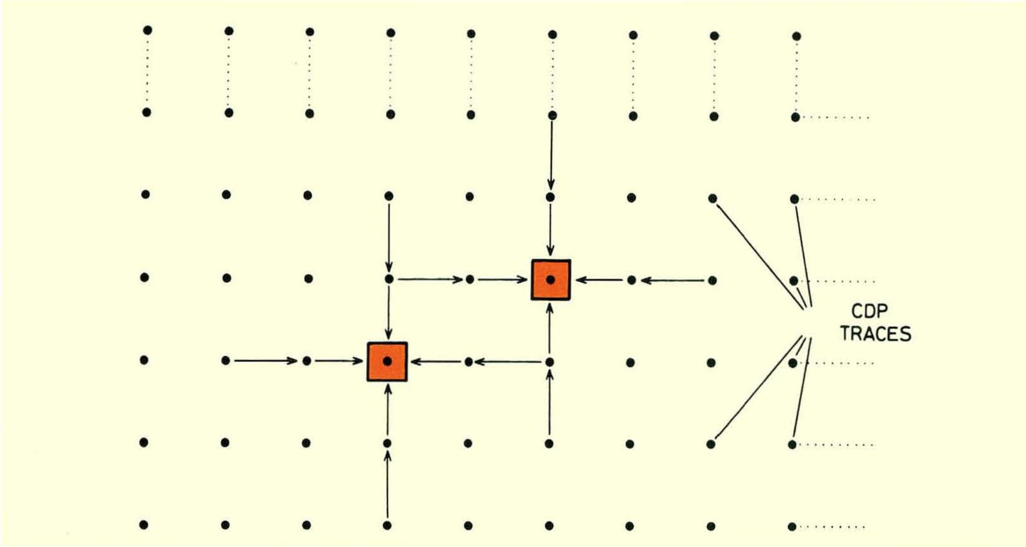
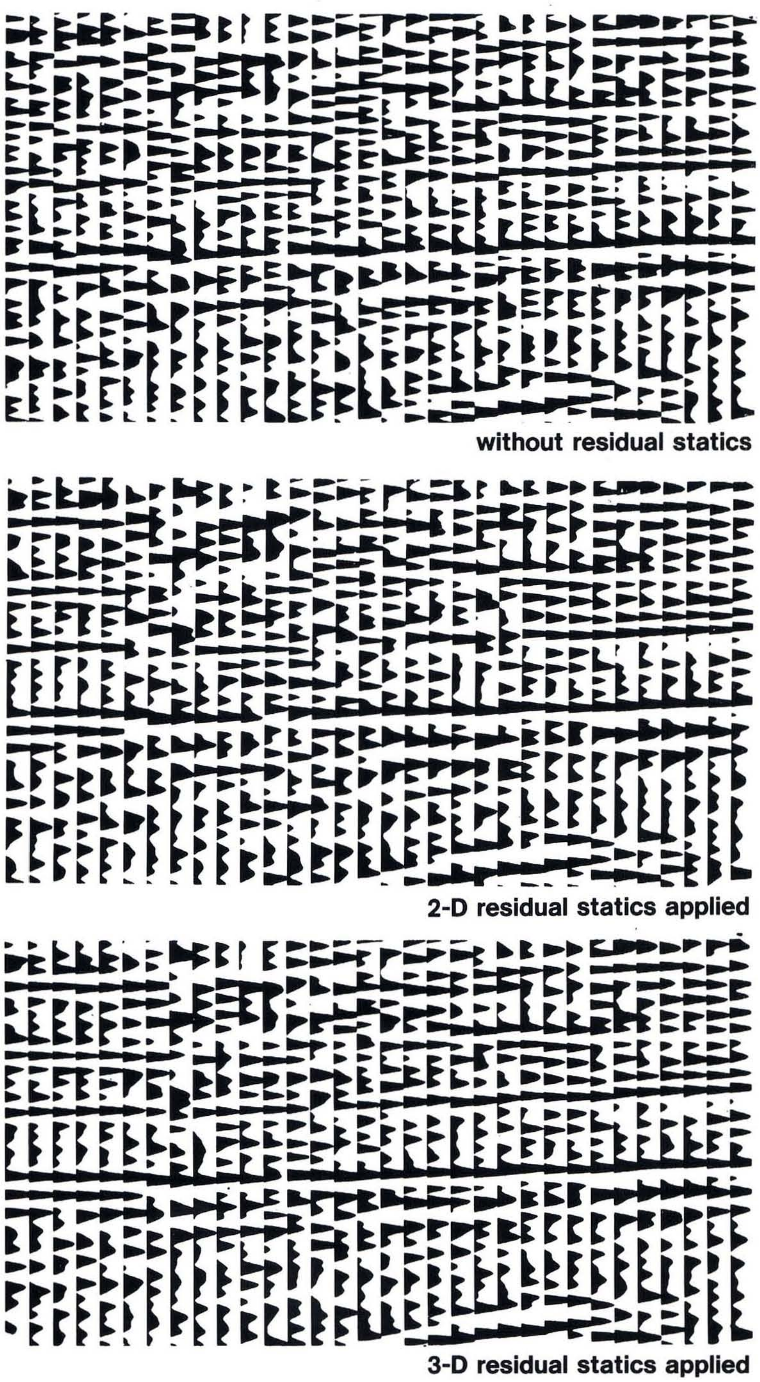


Fig. 5: Determination of the Reference Plane

Fig. 6: Enlarged Part of a Section from 3-D data



An areal equalization of surface consistent statics is an essential condition for the production of optimal stacked sections in any direction over the survey area.

The residual statics problem for areal data has been solved by an iterative procedure. Two main points have been tackled: the calculation of traveltime shifts and the splitting of the time-difference into shot- and geophone correction. The processing sequence can be derived from the 2-D procedure (see also PRAKLA-SEISMOS Information No. 9).

For each CDP the time-differences are determined between its component field traces and a reference trace.

The reference trace is of great importance for the estimation of residual statics:

1. The reference trace allows the splitting of Δt into a shot component, a receiver component and a noise term.

2. The high signal/noise ratio of the reference traces guarantees a reliable estimation of Δt.

For calculation of 3-D residual statics a reference plane covering the whole area is used. The reference plane is calculated by applying 3-D multichannel filters to the raw stacked data. From fig. 5 it is obvious that every point of the reference plane is influenced by its adjacent points in x- and y-direction.

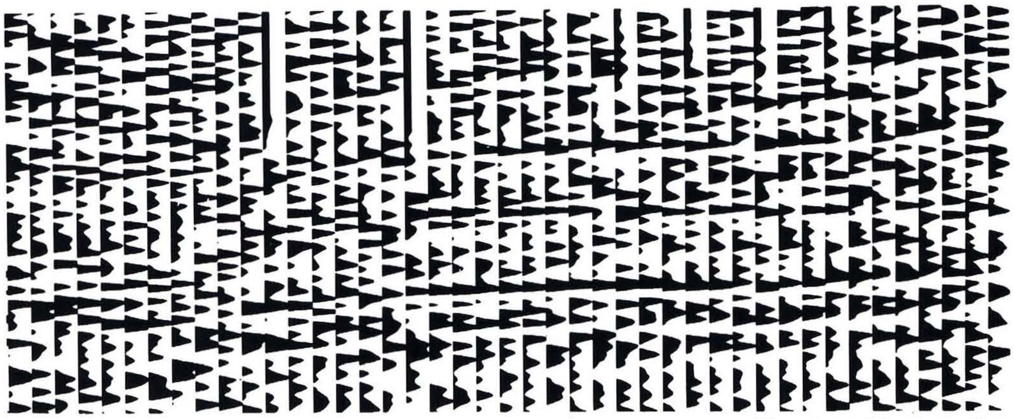
After splitting the time differences into shot- and receiver-components and application to the field traces improved stacked data are produced. An iterative procedure delivers an optimum stack after two or three runs.

To demonstrate the effect of 3-D residual statics an enlarged view of a section from an areal survey is shown. For comparison the data are presented without, after 2-D and after 3-D residual statics process (Fig. 6).

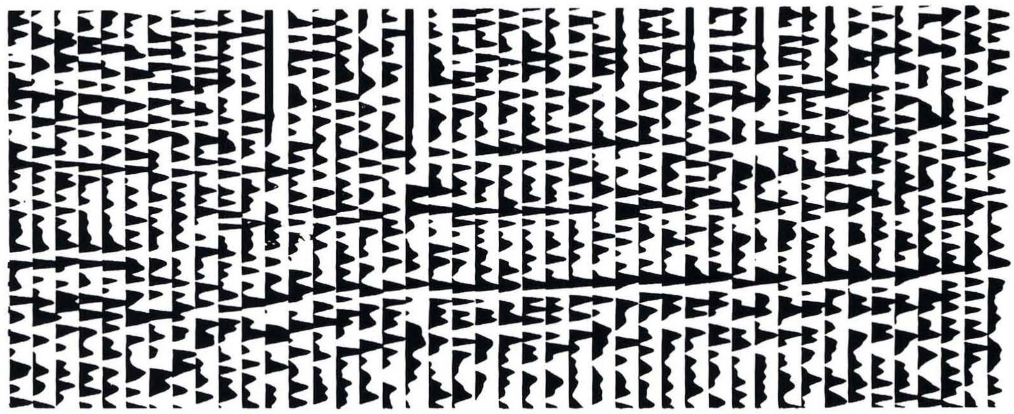
For control of the real areal equalization effect of the procedure one cross-line is displayed, running perpendicular to the section in fig. 6. The enhanced quality can be realized by checking the same enlarged view of this section presented for comparison without statics, after the 2-D process and after the 3-D procedure.

This section has been obtained only by displaying the data in the other direction; it has not been re-stacked and the static corrections have not been re-computed.

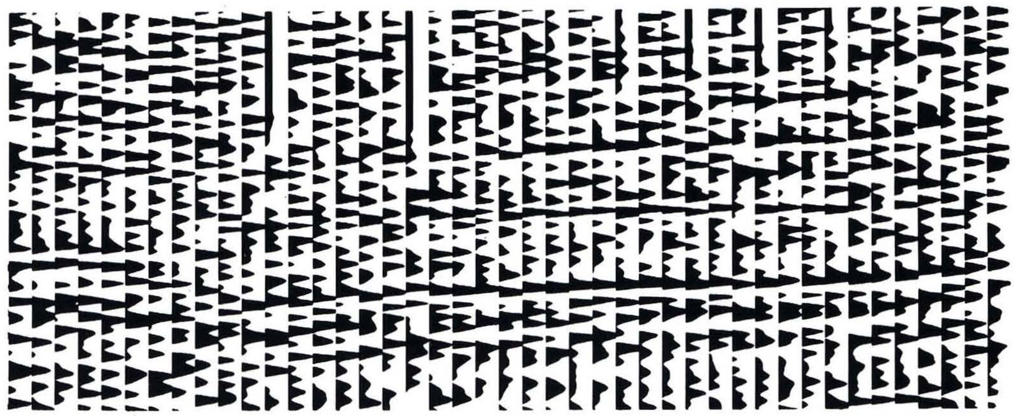
Fig. 7: Enlarged Part of a Cross-line



without residual statics



2-D residual statics applied



3-D residual statics applied

Fig. 8 shows another example demonstrating the improvement using 3-D processing. It is mainly due to the 3-D residual statics procedure, that these data show high resolution character with frequencies up to 180 Hz.

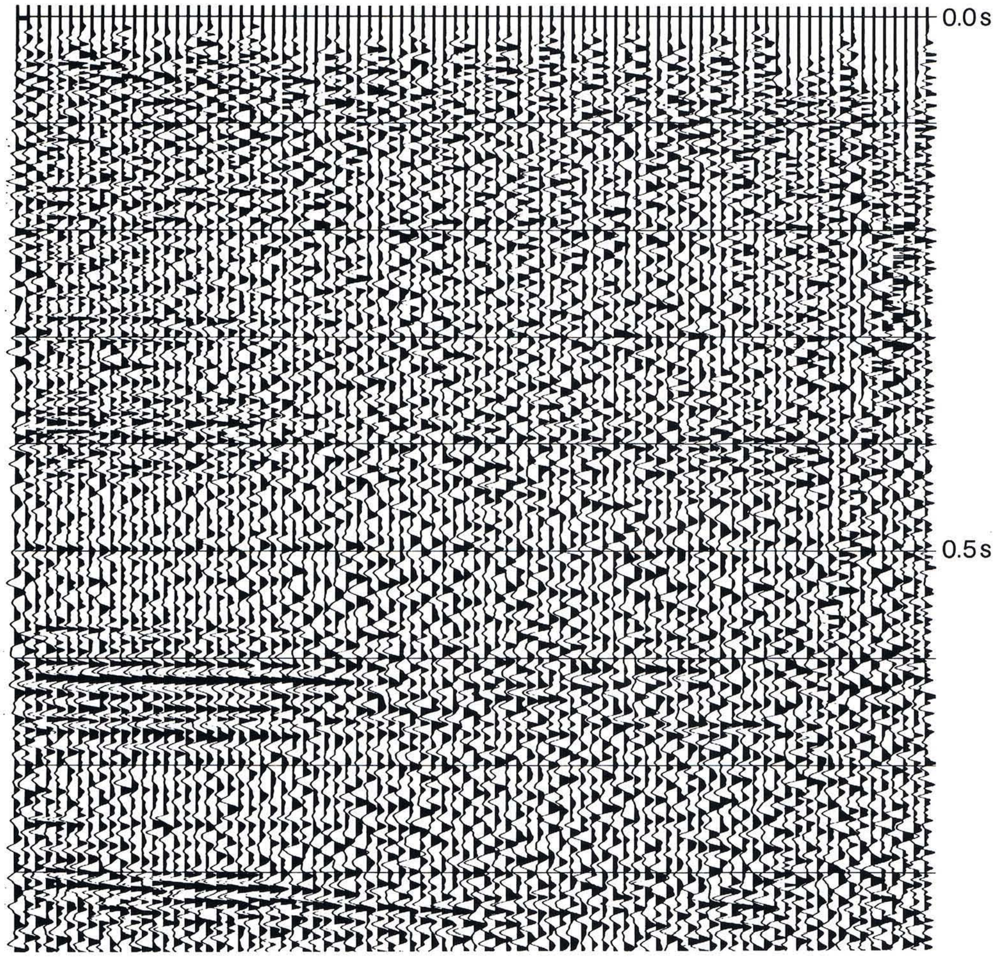
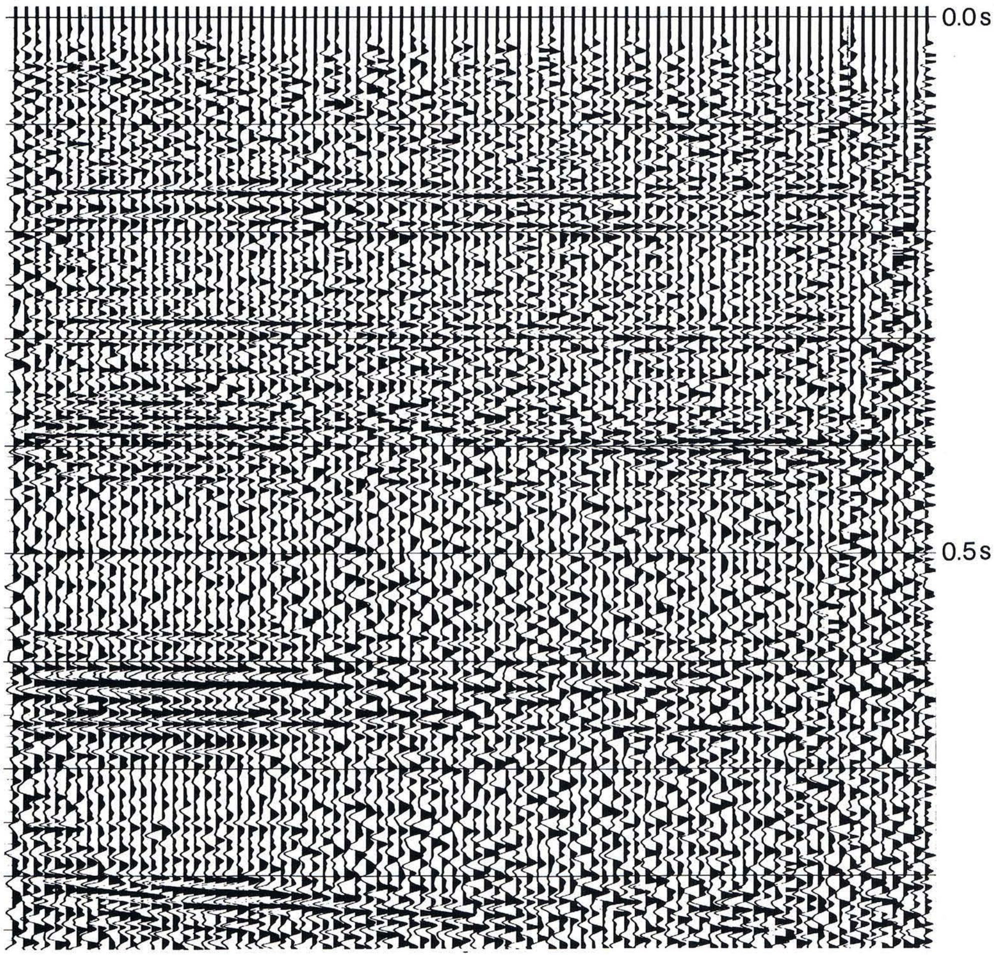


Fig. 8: Section from a High Resolution 3-D survey

without residual statics



3-D residual statics applied

For the optimal arrangement of special 3-D processing a partial conventional processing is to be recommended in most cases. This delivers preliminary information about signal quality, frequency content, geological conditions concerning dip and fault situations and other factors. From these, essential parameters such as trace distance, direction of processing line according to strike and dip directions, analyses parameters and others can be optimally chosen.

As in conventional processing the stacked section is also the first goal in the display of 3-D processed data. The orientation of these sections may be arbitrary over the survey area.

A series of parallel processing lines is usually selected. Along these lines trace spacings are defined, which must neither conform with distances in the field recording nor with those of the sorting program.

The main problem in 3-D stacking is the optimal gathering of traces from an areal distribution to a specified display position, i.e. the appropriate selection of all integration areas. As shown in fig. 9 these may be rectangular, rhombic or circular in form.

The linear stack of traces within these areas may deliver useful results in the case of good signal/noise ratio and gently dipping reflectors. In the presence of dips a gathering of data should only be performed in strike direction. If the directions of integration areas and geological strike deviate too much from one another, the orientation of the integration areas can be re-definded.

Very often the quality of stacked data can be improved by application of special weighting functions to the single traces. Different criteria may be considered such as distance, coherency etc.

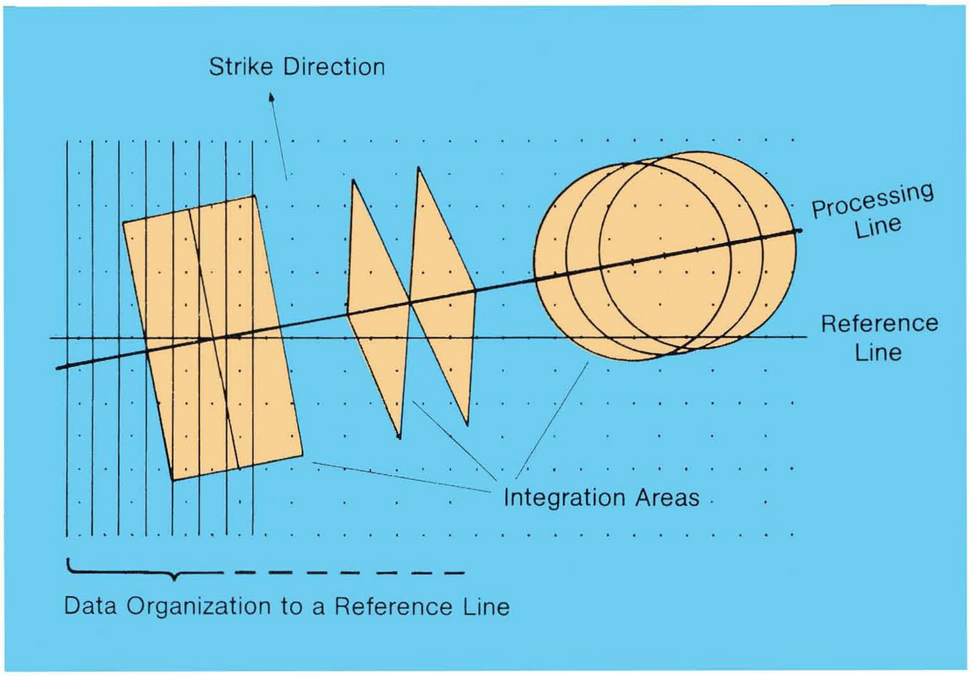
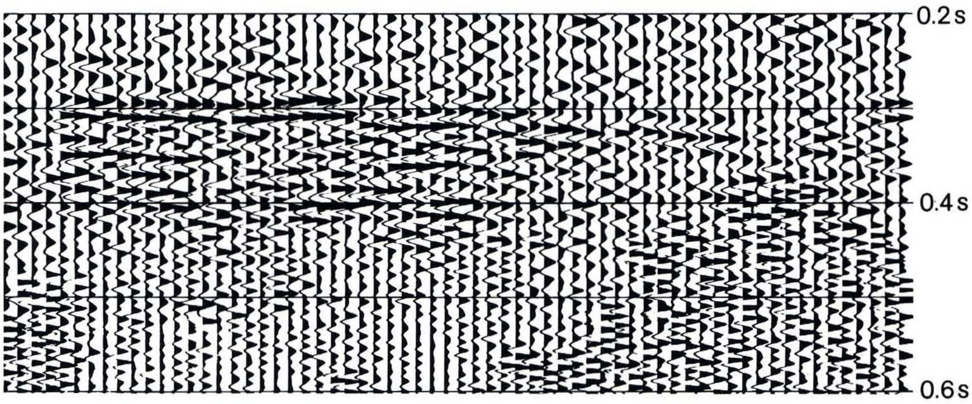


Fig. 9: Principle

Fig. 10a: Stacking result of a 3-D survey (trace spacing 15 m) considering field traces within squares of 15 x 15 m (average degree of coverage 300%)



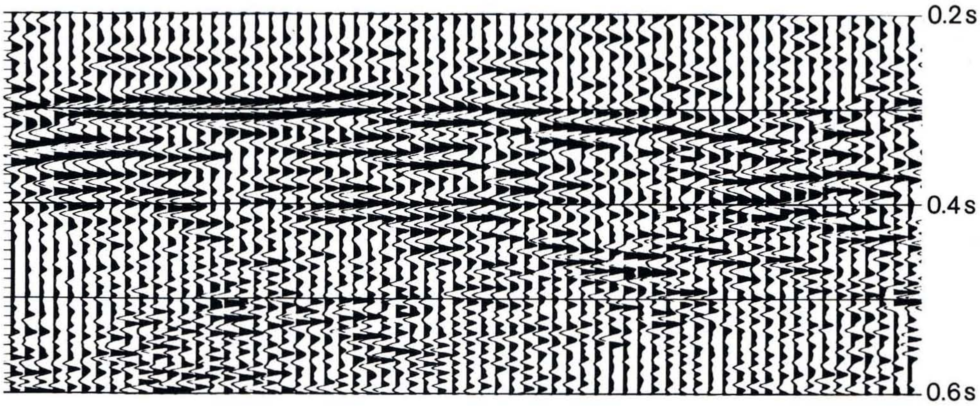


Fig. 10b: Stacking result (trace spacing 15 m) considering field traces within circles of 20 m radius (average degree of coverage 1200%)

It is well known that in contrast to the 3-D migration the 2-D migration procedure only delivers reliable results if the survey line is perpendicular to the geological strike direction. In this case the origins of all events are located in the same vertical plane through the seismic line.

Very often these idealized geometrical situations cannot be fulfilled, when field conditions are prohibitive or geological information about the subsurface is not available. But also in areas of complex geology (e.g. if strike and dip vary with depth) the failure of 2-D migration becomes obvious when trying to tie-in the migration result of two sections perpendicular to one another at their intersection point.

The synthetic data of fig. 1 represent some of these complex situations and show the superiority of 3-D migration.

The three-dimensional migration can be derived from the two-dimensional procedures. Two methods are commonly applied in 3-D seismic processing: the 3-D Kirchhoff migration and the 3-D Finite Difference migration.

Both procedures start from the basic principle that the wave field recorded at the earth's surface is a superposition of elementary waves, the origin of which can be considered as the migration result.

The physical background of both procedures is the acoustic wave equation which enables us to determine the wavefield at any depth in the subsurface starting from the wave field measured at the surface. To determine the wave field just at the point of reflection is the goal of the migration process. This technique is known as the so called downward continuation of a wave field. For practical reasons one is restricted to approximations in solving the 3-D wave equation.

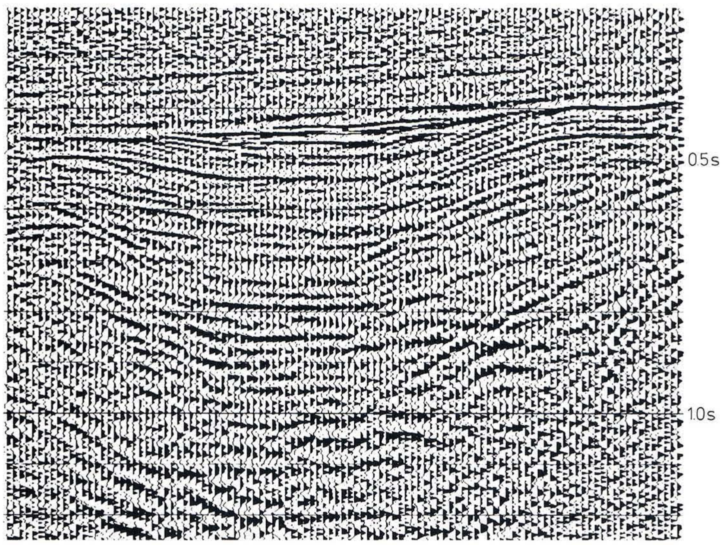


Fig. 11a: Stacked Section

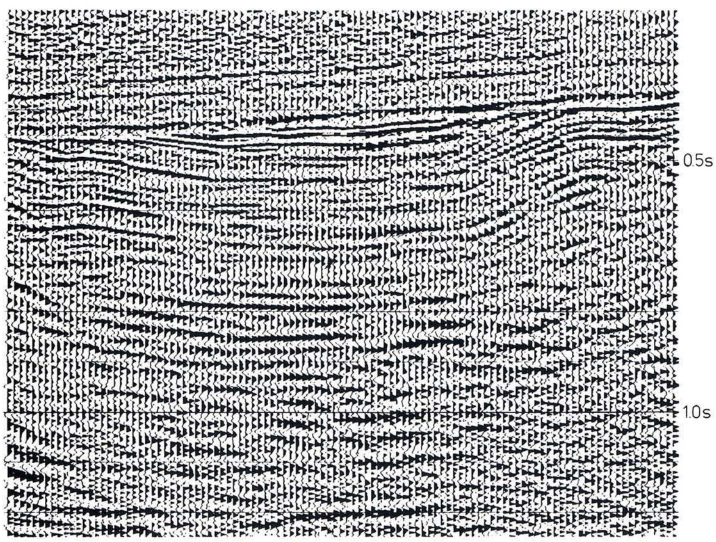


Fig. 11b: 2-D Finite Difference Migration

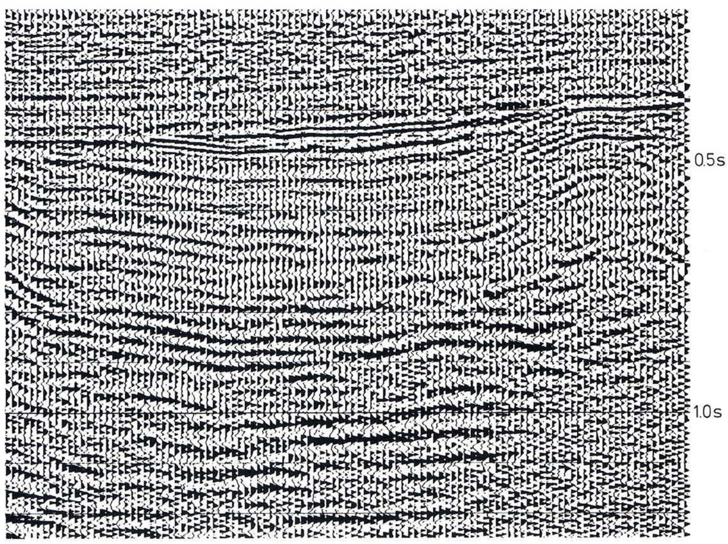


Fig. 11c: 3-D Finite Difference Migration

From the theoretical point of view both methods, the Kirchhoff and the Finite Difference migration, should deliver results of similar quality. But both procedures act differently on the character of data as to trace spacings, dips, frequency content and signal/noise ratio.

As in the 2-D procedures it can generally be stated that the Finite Difference migration tends to preserve the signal characteristics of the input data. The Kirchhoff migration sometimes shows more migration noise, visible as phantom horizons which represent organized noise.

Figures 11a to 11e demonstrate the similarity of the general reflection character of the sections. The data have been taken from an areal survey arranged for coal exploration. The CDP traces are located on a regular square grid of 12,5 m.

The section follows the general direction of dip, so one would not expect 3-D migration to produce a result widely different from 2-D migration. On the contrary regarding the huge amount of data being handled in the 3-D process the similarity of 2-D and 3-D migration might be amazing. Distinct differences can be realized within certain travel-time zones. To criticize the 2-D result it is necessary to take the CDP section into consideration, because 2-D migration acts only within this single vertical plane. The result of the 3-D Kirchhoff migration shows more continuity of events between 0.2 and 0.4 sec. This is explained by the effectiveness of the muting parameter. Also between 0.4 and 0.6 sec the Kirchhoff result exhibits a better resolution in the up-dip region. The method is also known to master steep dips.
In the lower part of the section where the Kirchhoff migration tends to produce "smiling" events, the finite difference procedure clearly separates signal from noise energy thus giving a better possibility of recognizing faults.
As is known from the 2-D finite difference technique the solution of the wave equation can be approximated by a socalled 15°-operator and 45°-operator. Both are limited with respect to a maximum dip value. In fig. 11d the 3-D 15°-operator clearly shows its failure in the presence of steeper dips.

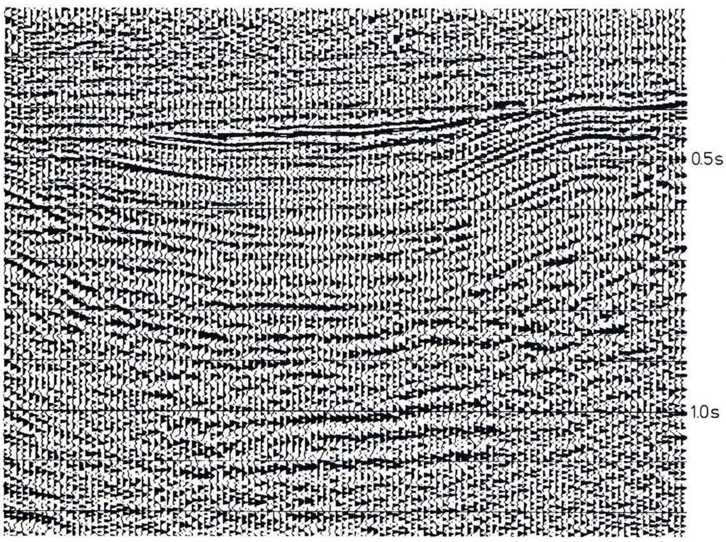


Fig. 11d: 3-D Finite Difference Migration (15°-operator)

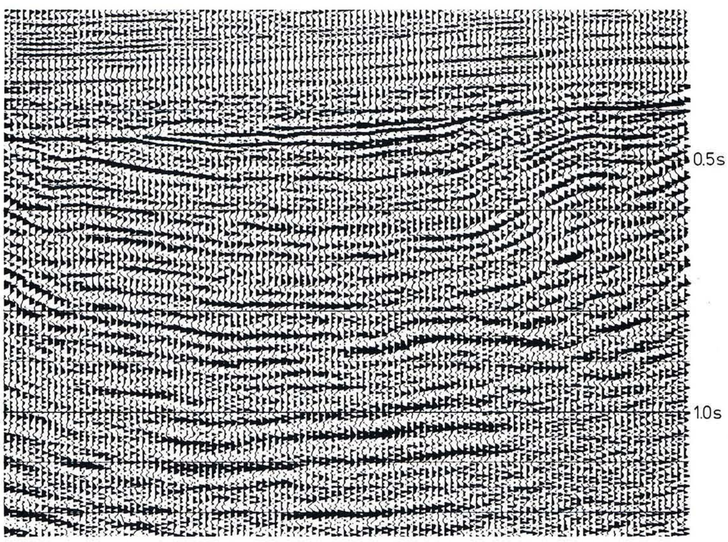


Fig. 11e: 3-D Kirchhoff Migration

It should be mentioned that a great difference in application of the 3-D Kirchhoff migration or the 3-D Finite Difference migration arises from economical aspects. The Finite Difference migration is a low-cost processing technique as it carries out a migration of the total 3-D data volume in one single process.

Appropriate data organization enables an easy display of migrated sections in any direction over the survey area.

The 3-D Kirchhoff migration works along specifically defined processing lines, which of course may be arbitrarily orientated over the survey area. The process must be applied for each vertical section separately.

Both procedures however hold their claim to application in 3-D processing.

Advantages of the Kirchhoff approach:

- a uniform data grid is not required
- sections in any direction and with arbitrary trace spacing can be produced
- steep dips can also be handled
- the signal/noise ratio is improved.

Advantages of the Finite Difference approach:

- this very economic process migrates the whole 3-D data block in one single operation
- the reflection character of input data is maintained
- strong lateral velocity variation is accepted
- vertical sections in any direction and "horizontal" sections at any travel-time can be displayed.

The application of the 3-D Finite Difference migration technique requires a special organization of the 3-D data block. As shown by the principle view in fig. 12, both the input and the output data of the migration process are organized in an "isochronous manner".
Thus at these two stadia a display of "horizontal" time slices can easily be performed for any travel-time.

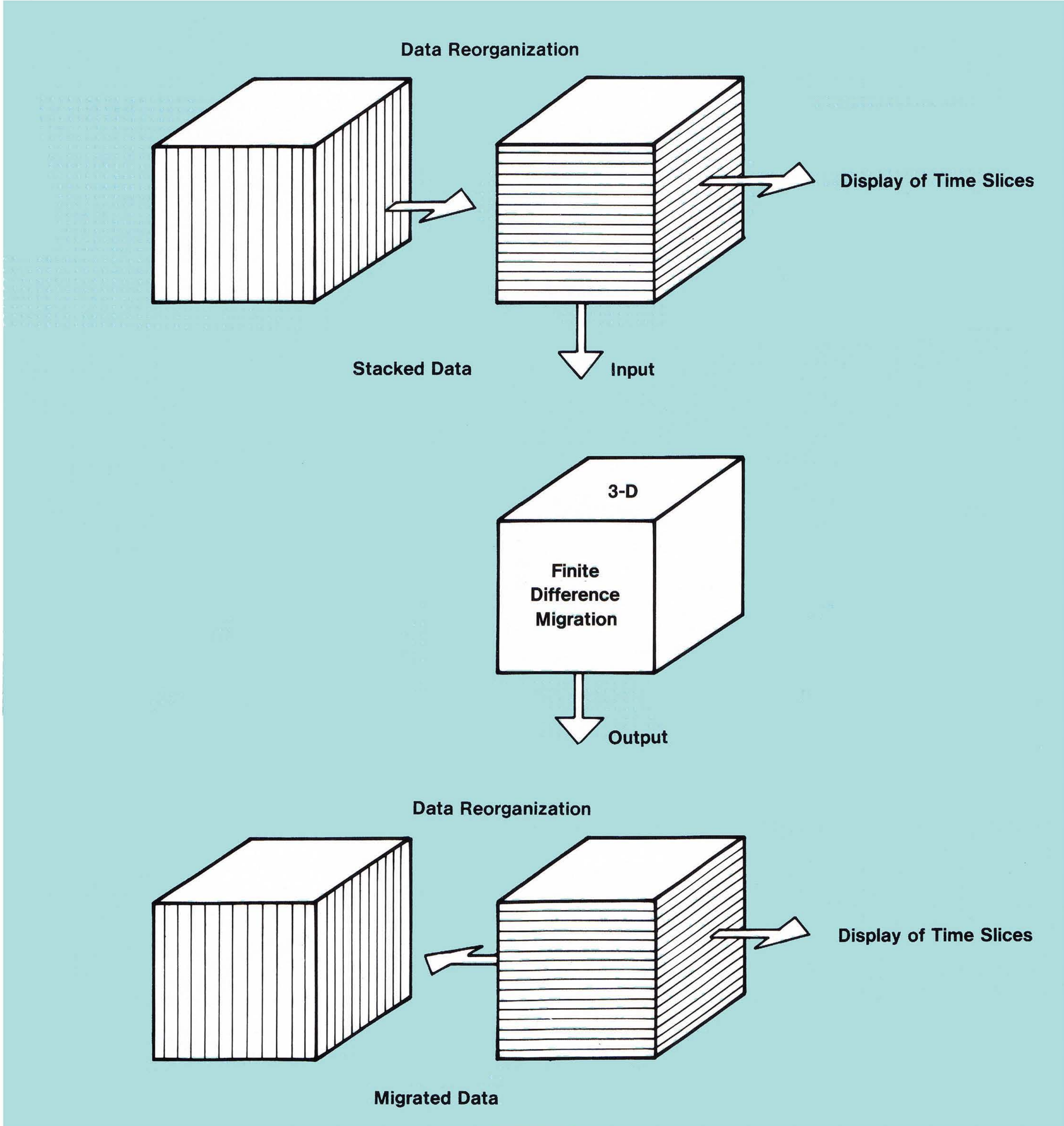
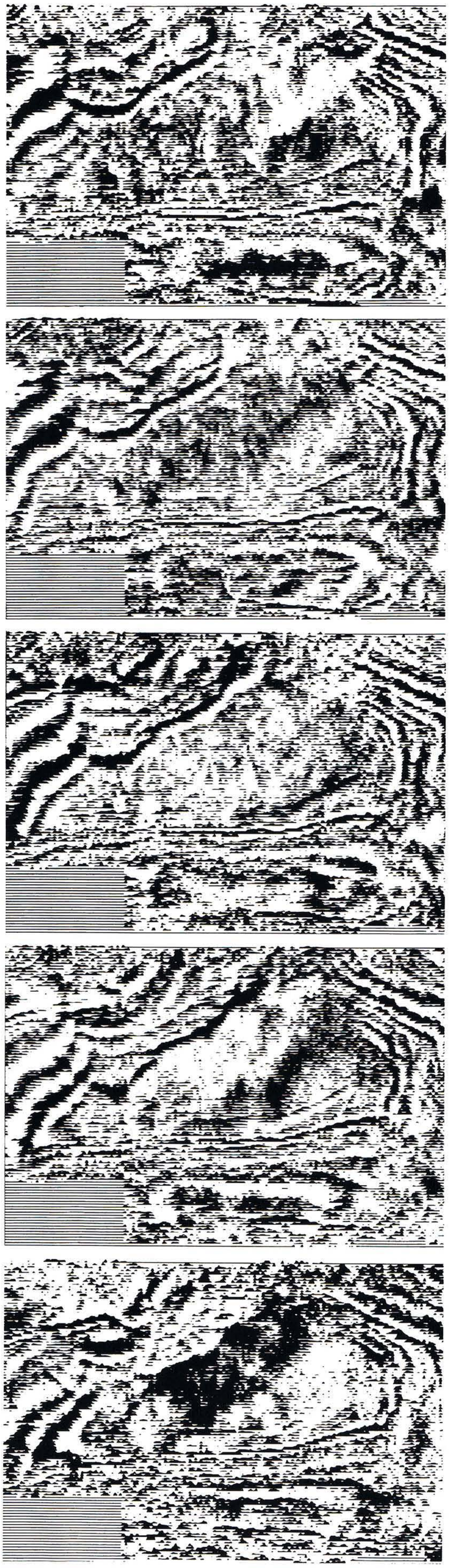


Fig. 12: Principle

Time Slices

The examples in fig. 13a and 13b show a sequence of five horizontal time slices from the areal survey mentioned on page 10 before and after 3-D migration.



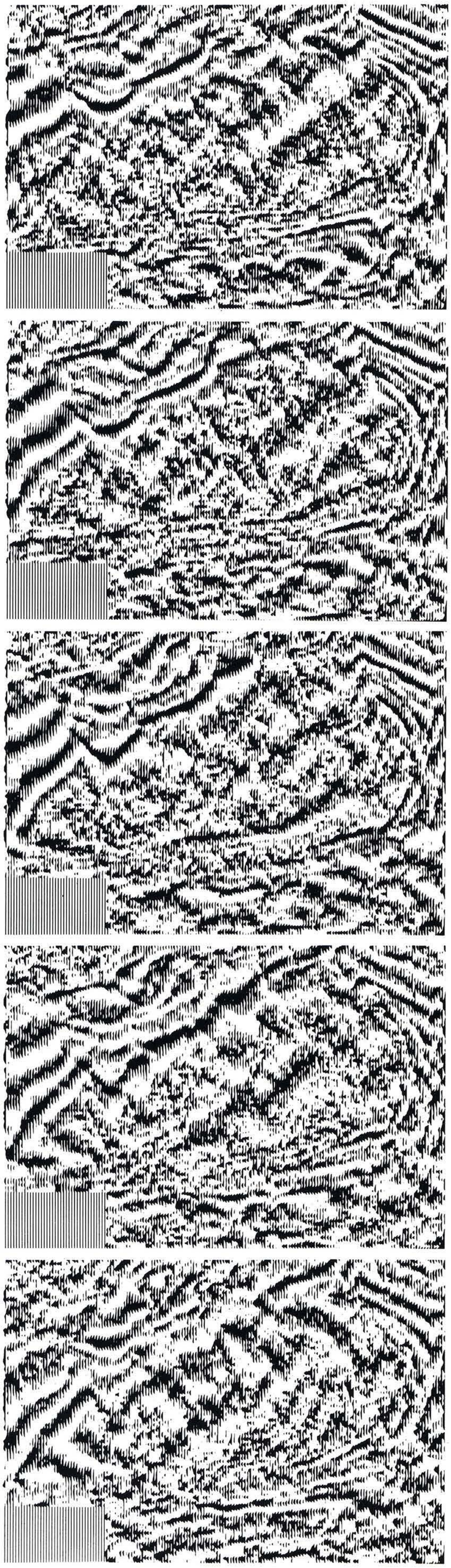


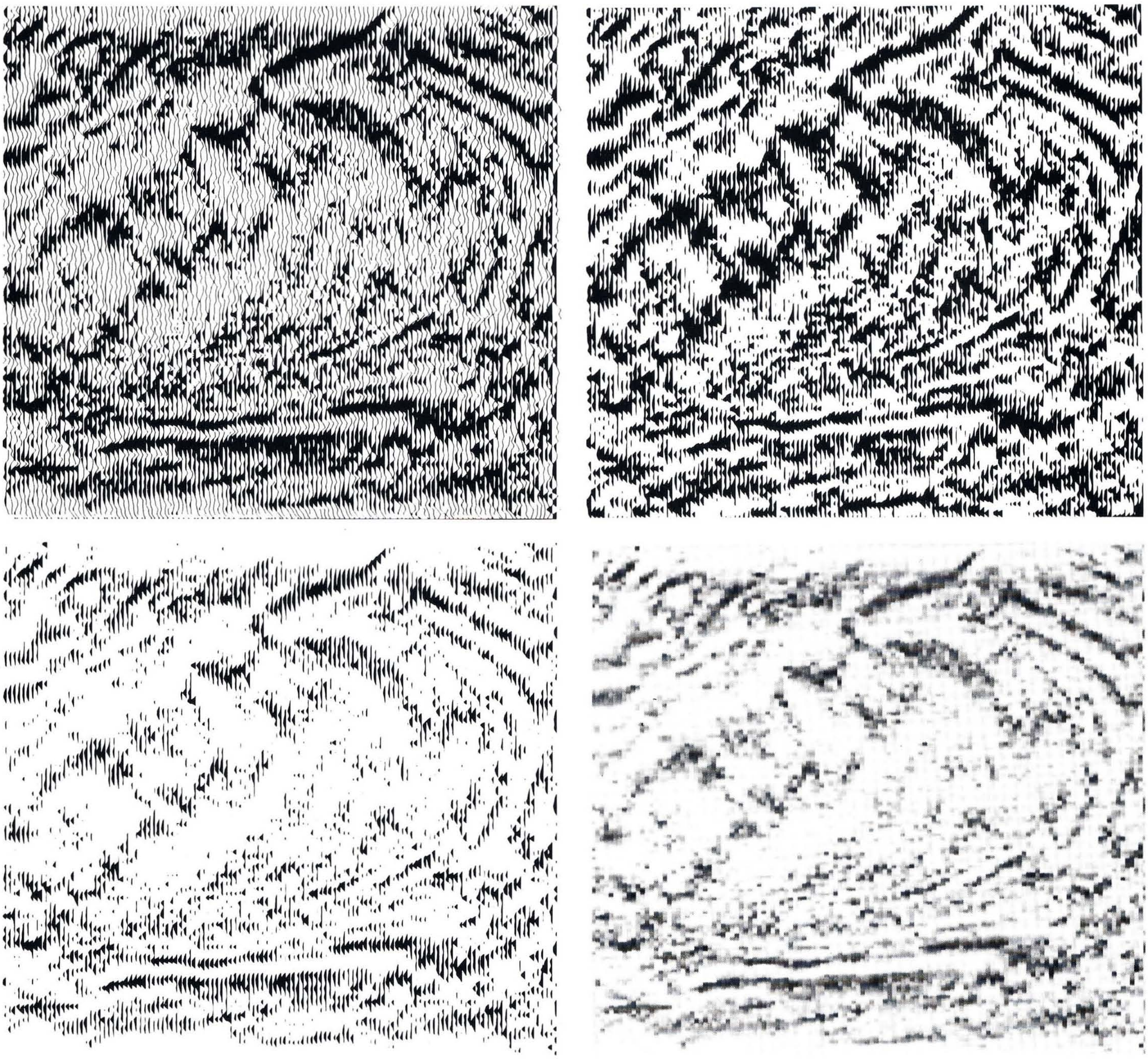
Fig. 13a: Horizontal Time Slices of stacked data

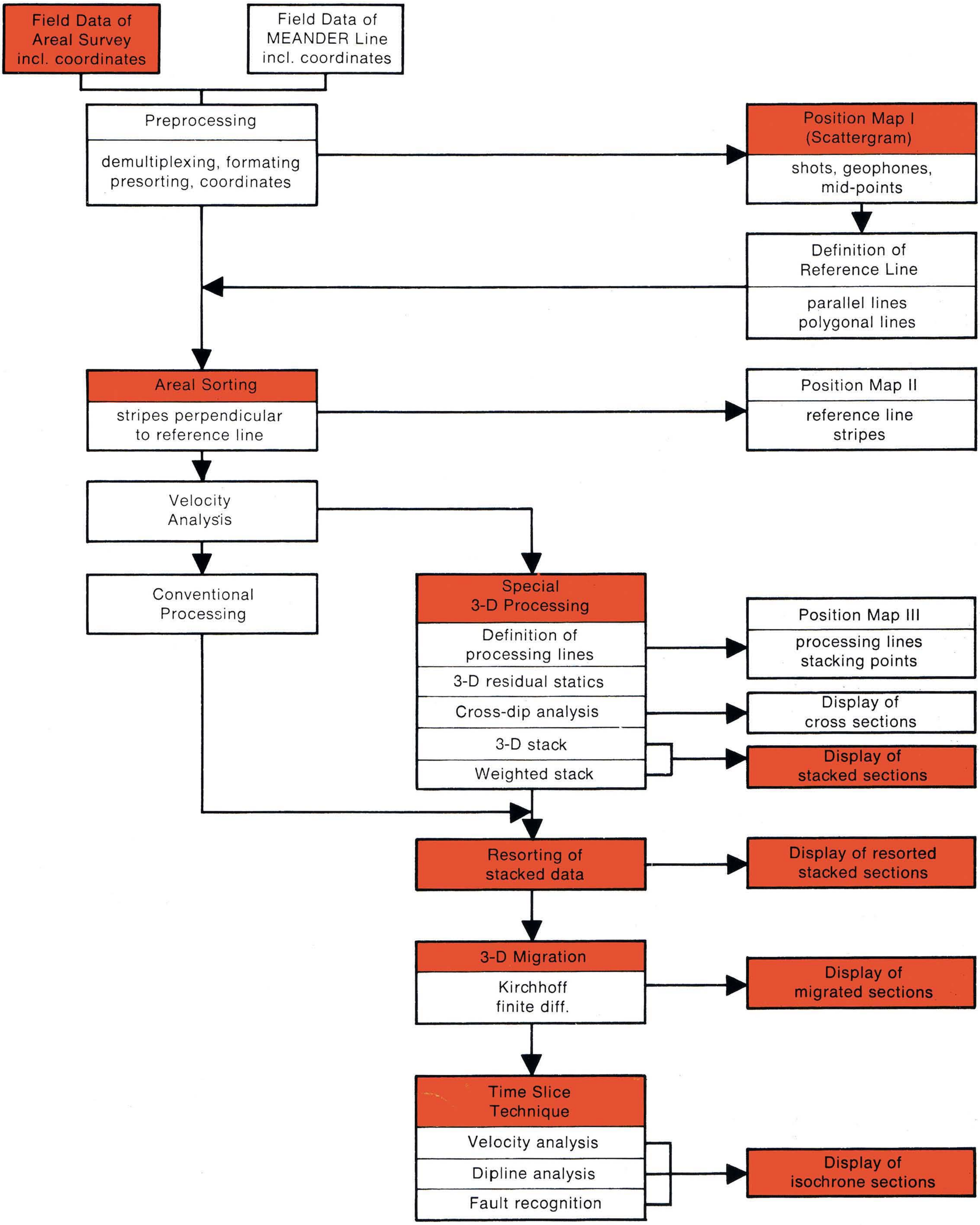
Fig. 13b: Horizontal Time Slices of migrated data

The time slices in this example are presented at intervals of 10 ms. The shape of a trough and its extension over the whole survey area is clearly visible.
This demonstrates that the display of time slices acts as a valuable tool for the interpreter enabling him to localize geological structures in their extension and changes over an area of several square kilometres at a glance. An experienced interpreter can even recognize small fault systems which cannot be seen in vertical sections.

Fig. 14:

The time slices can be displayed in several techniques and in any scale on PRAKLA-SEISMOS' various types of plotters





PRAKLA-SEISMOS GMBH · HAARSTRASSE 5 · P.O.B. 4767 · D-3000 HANNOVER 1
PHONE: 8 07 21 · TELEX: 9 22 847 · CABLE: PRAKLA · GERMANY

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