PRAKLA-SEISMOS INFORMATION No.35

3-D Onshore Seismics

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This Information No. 35 replaces three of our earlier publications in this field:

- No. 3 "Areal Reflection Seismics" (May 1977),
- No. 18 "3-D Seismic Processing" (May 1979),
- No. 19 "3-D Seismics" (May 1979).

The new brochure is conceived as the counterpart to our Information No. 32 "3-D Offshore Seismics" (September 1981). It shows just a selection of our 3-D land seismic data acquisition systems and illustrates the results of appropriate 3-D processing techniques.

3-D offshore data acquisition is usually based on the single boat method using a standard streamer configuration for collecting the seismic data on parallel closely spaced lines. This *"parallel-profiling method"* is emitter-intensive: it makes use of a relatively large number of shots whereas the number of receiver stations in the streamer is normally restricted to 48 or 96. When cross currents provide controllable drifting, then a somewhat areal coverage rather than line data is collected.

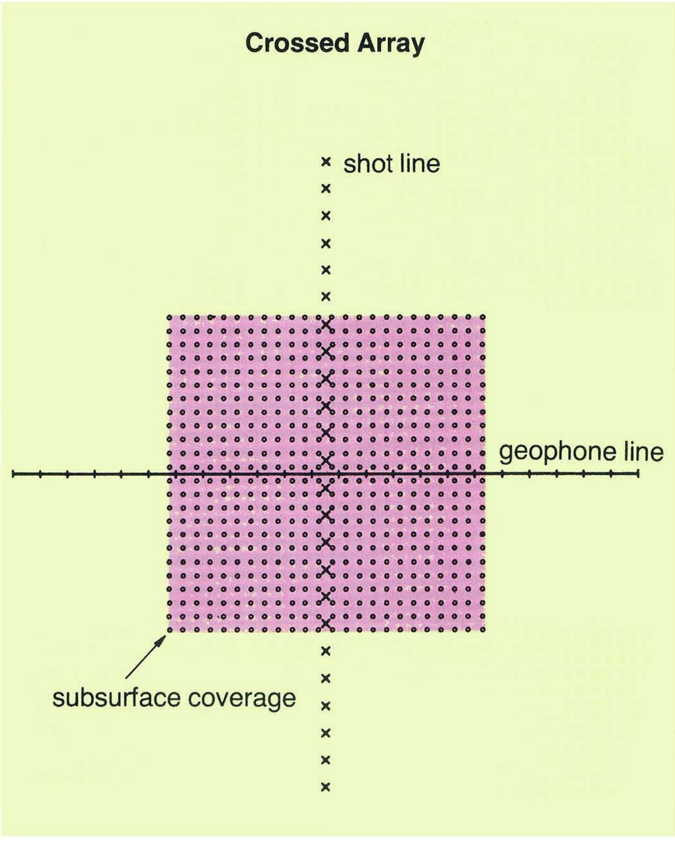
3-D onshore data acquisition is based generally on the *"crossed-array method"* (the principle is shown below). This method is receiver-intensive: a quite large number of geophone stations (up to 480) along a line – or along several parallel lines – receive the signals from sources arranged on another line, usually perpendicular to the receiver lines. The comparatively small number of sources – say 70 or a maximum of 100 per day – is dictated by fieldwork capacity limitations.

Three examples of strictly regular emitter/receiver configurations and, consequently, regular-subsurface gridding are demonstrated on pages 4 and 5. The relevant figures show the potential and the economy of *"extended crossed-array systems"*. These systems lead to multiplicities in both the x-(geophone line) and y-(shot line) directions, thus ensuring close ties between the single survey strips composing the total area surveyed. These inter-relations are a pre-requisite for the success of subsequent derivation of automatic surface-consistent residual statics.

Example IV (Prospecting in Mountainous Areas) and example V (Rhine Survey) are quotations taken from our earlier Information No. 19. They demonstrate that extreme situations are challenges which can be overcome by adapted 3-D data acquisition concepts: *irregular emitter-receiver configurations,* which necessarily lead to irregular subsurface gridding.
The third dimension in seismic surveying has made the spatial sampling theorem a significant factor for the effectiveness of certain processing procedures concerning lateral resolution and aliasing problems. As the information density required for 3-D migration processing – and that is usually the essence of every 3-D survey – is expensive, 3-D seismics is to be seen as a tool for the development of producing fields rather than for general exploration. It is therefore necessary to optimize the techniques for both data acquisition and subsequent processing: undersampling may endanger the success of a 3-D survey, and oversampling may be prohibitive for a project because of the high costs involved. However in several cases adequate data may be provided also by consequent application of *trace-interpolation techniques* during the processing stage, as in our example 1 for instance, where the sampling in the general geological strike has been done in a 2 : 1 ratio compared with sampling in dip, but a 1 : 1 ratio has been achieved by such interpolation.

The extension of standard seismic *processing techniques* from 2-D to 3-D does not only attack data organizational aspects but often requires a completely different concept considering the areal distribution of dense seismic information. Some of the most relevant procedures in processing of 3-D land data are outlined in this brochure with the help of recent field examples.

- The evaluation of the proper *velocity field* is of prime importance for the stacking as well as the migration process.
- An areal derivation of surface consistent *residual statics* is an essential pre-requisite for the production of optimally stacked sections in any direction through the survey area.
- *3-D migration* has evolved as the final procedure in any 3-D data processing sequence, providing true geological sections for interpretation work.



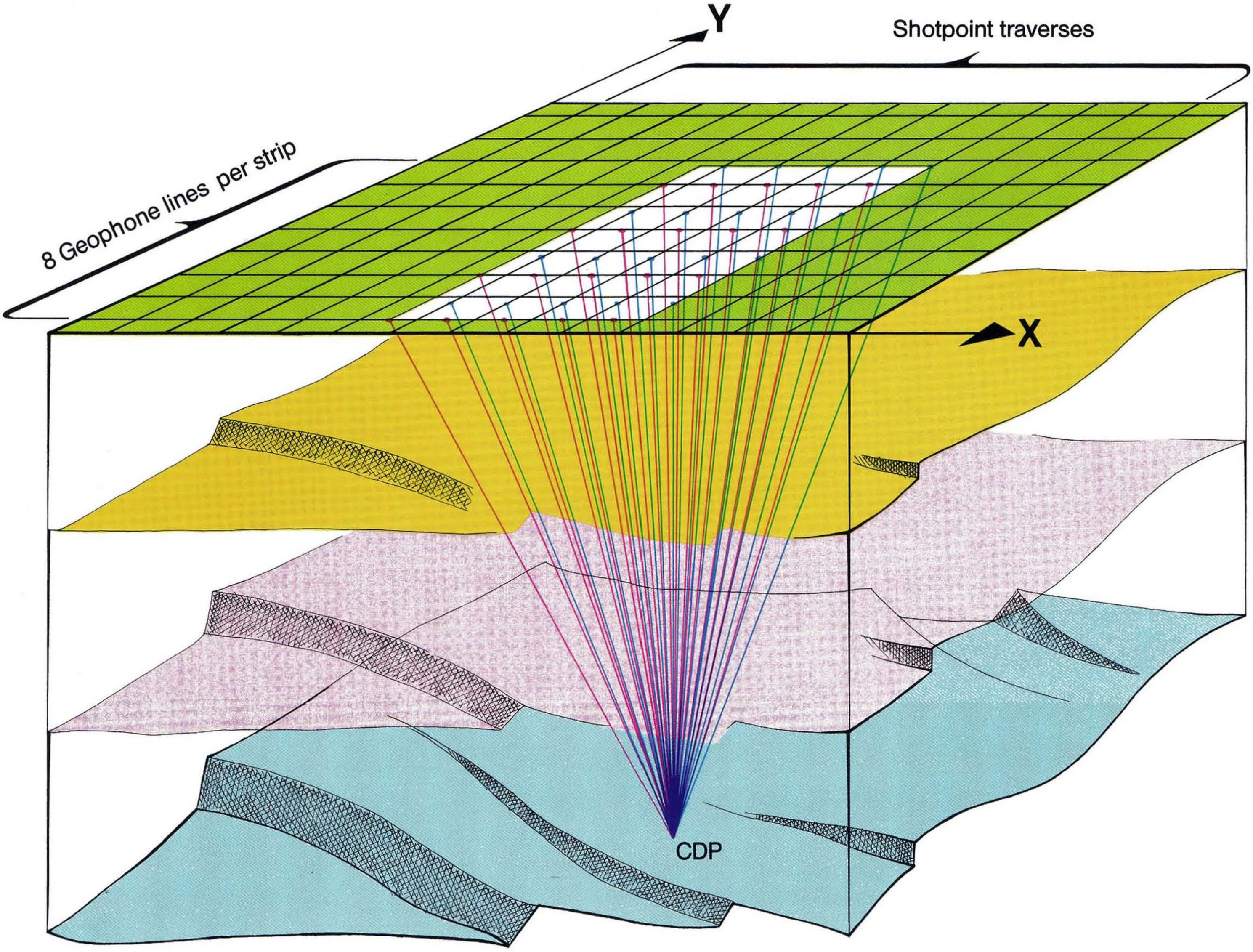


Fig. 1: Single CDP family built up by 20-fold areal coverage. Multiplicities in x and y = 5 and 4, resp. (see example I on next page)

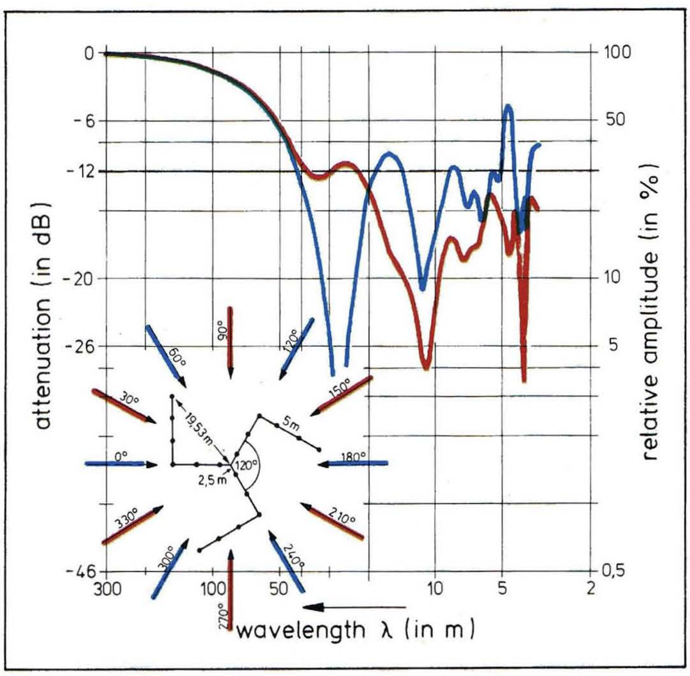


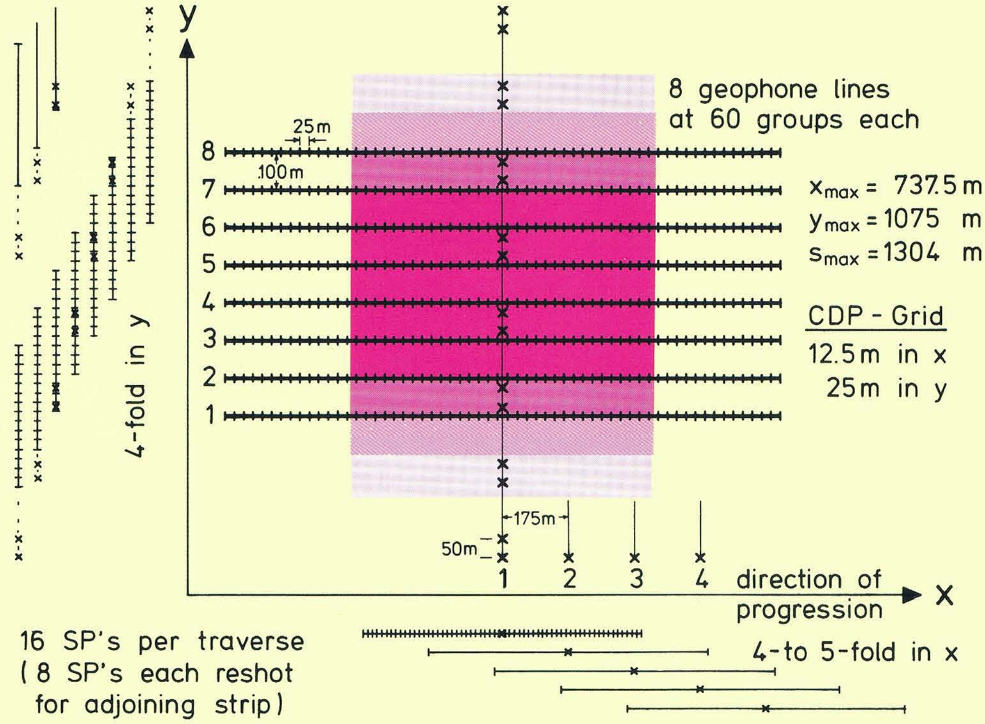
Fig. 2: Omnidirectional geophone pattern and its response. This figure shows the layout of an areal geophone pattern (3-arm windmill, 18 geophones), and two response curves showing the omnidirectional reject power of about 12 dB.

Example I: 480 channels, 16 to 20-fold areal coverage, strictly regular grid

3-D survey for development of a shallow oilfield with dips up to 30°

- **Target depth:** 750 to 1000 m; area covered : 31 km^2
- **Recording:** Sercel Telemetry Instrument SN 348 (with two line-input modules) for simultaneous recording of 8 lines of 60 stations. Sampling rate 4 ms; 3682 shots recorded in 630 fieldwork hours resulting in 98700 CDP's.
- **Multiplicity:** in x = 4 to 5, in y = 5, total = 17.14
- **Rational data gather** by consideration of different requirements for spatial sampling in the CDP domain: 12.5 m in dip direction, 25 m in strike direction (the latter attained by pairs of shots separated by 50 m).

Fig. 3

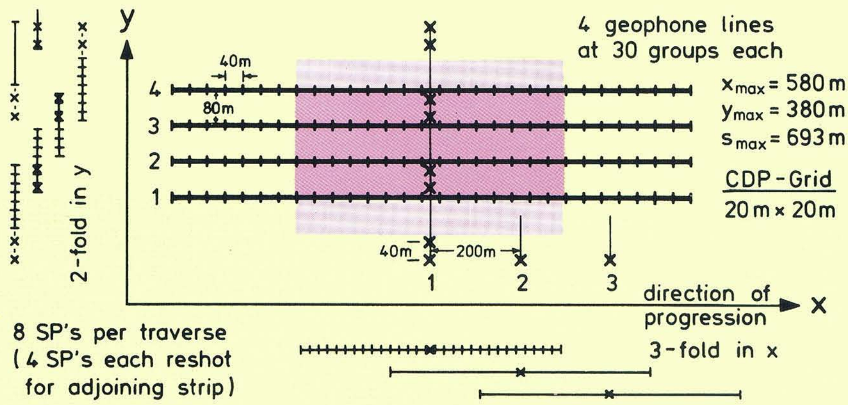


Example II: 120 channels, 6-fold areal coverage, strictly regular grid

3-D survey for detailing in a coal-mine forefield

- **Target depth:** 700 to 1200 m; area covered : 5.3 km^2
- **Recording:** Sercel Telemetry Instrument SN 348 (with one line-input module) for simultaneous recording of 4 lines of 30 stations. 590 shots recorded in 130 fieldwork hours resulting in 13344 CDP's.
- **Multiplicity:** in x = 3, in y = 2, total = 6
- **High resolution,** using 1 ms sampling rate, 40 m receiver station spacing and pairs of shots separated by 40 m yielding a 6-fold regular 20 m CDP-grid.

Fig. 4



The shaded areas in figs. 3 to 6 outline extent and degree of subsurface coverage produced in a single block.

Example III: 240 channels, 6-fold areal coverage, strictly regular grid

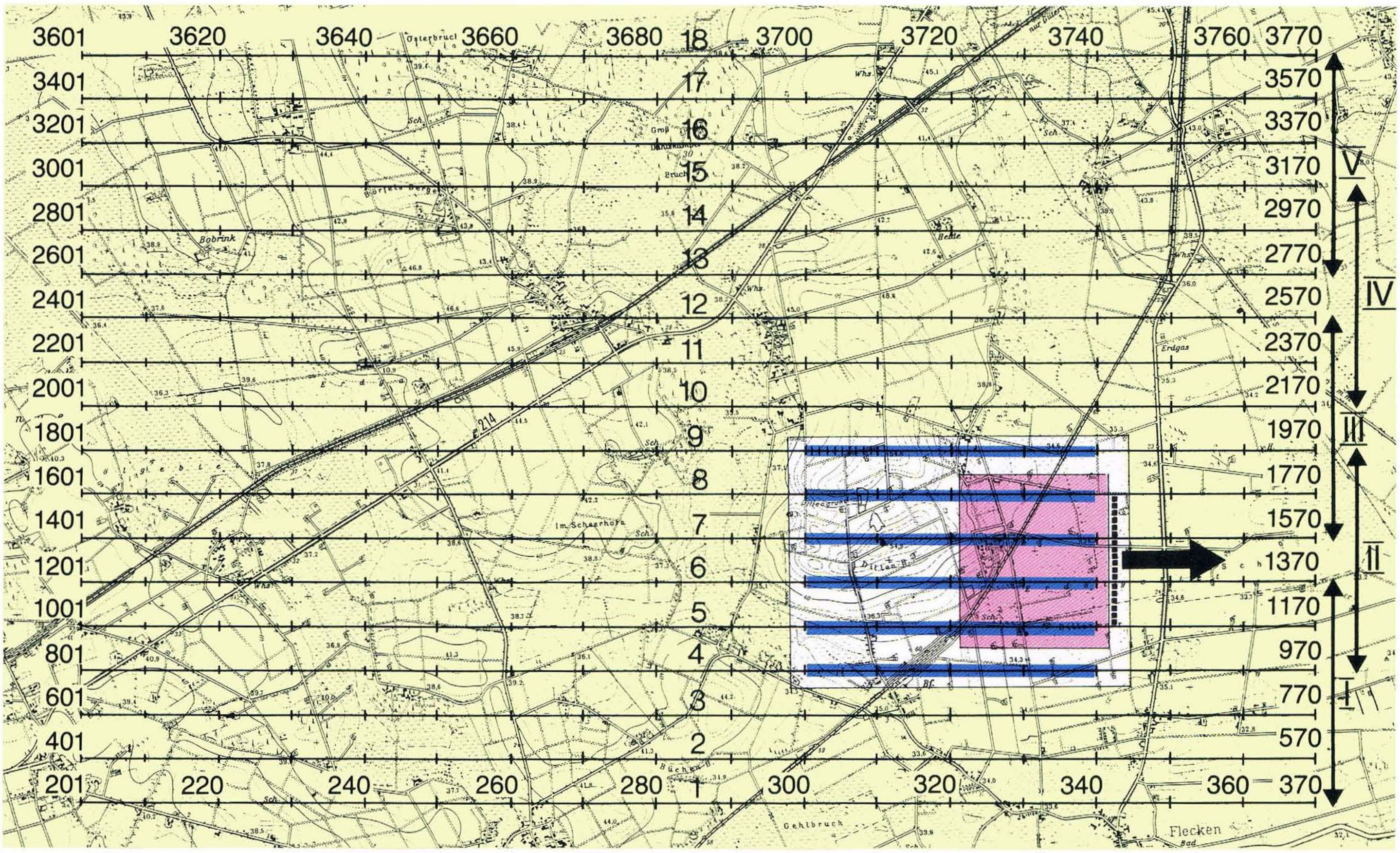
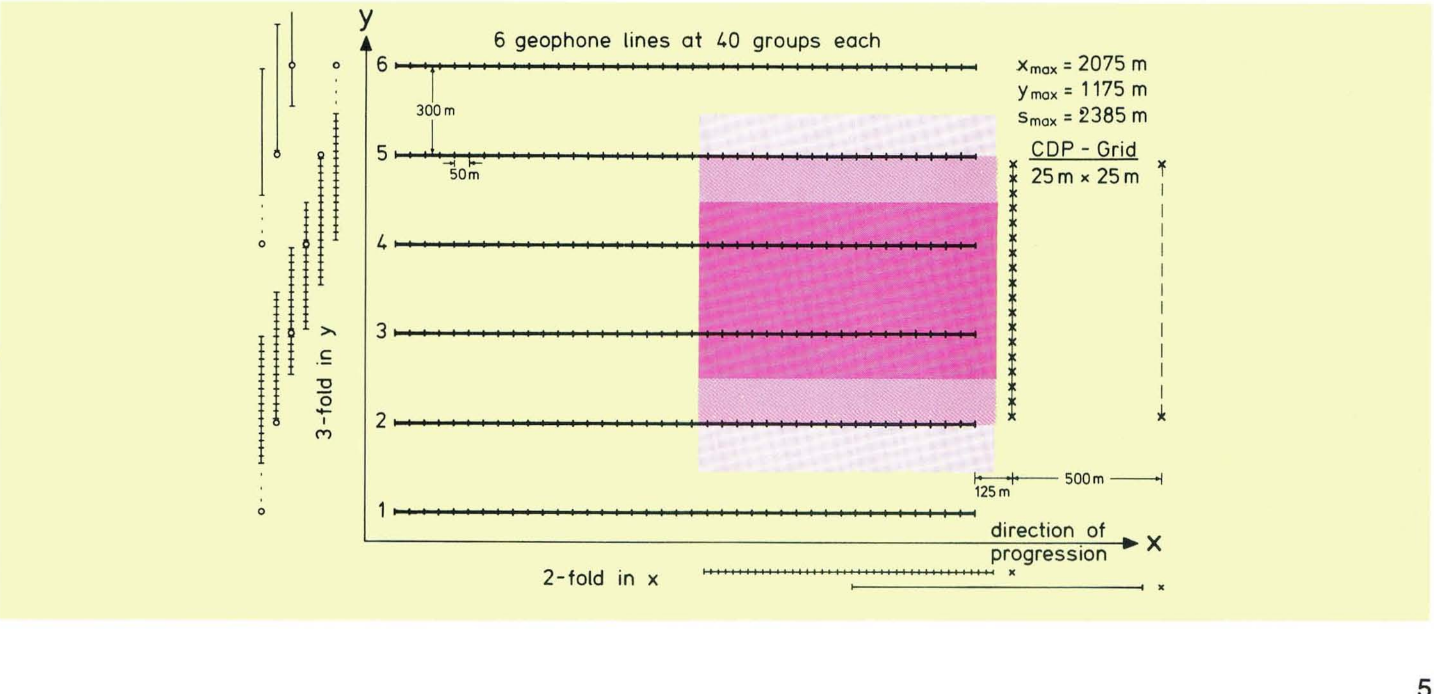


Fig. 5: 3-D survey for development of two gasfields ▲

- **Target depth:** 3000 m; area covered : 41 km²
- **Recording:** 2 DFS V instruments with 120 channels each simultaneously; sampling rate 2 ms. Area subdivided by 5 strips of 6 geophone lines each, every line consisting of 170 stations; half the geophone layout re-used each time for the adjacent strip. 1420 shots recorded in 230 fieldwork hours, resulting in a total of 65 280 CDP's.
- **Multiplicity:** in x = 2, in y = 3, total = 6

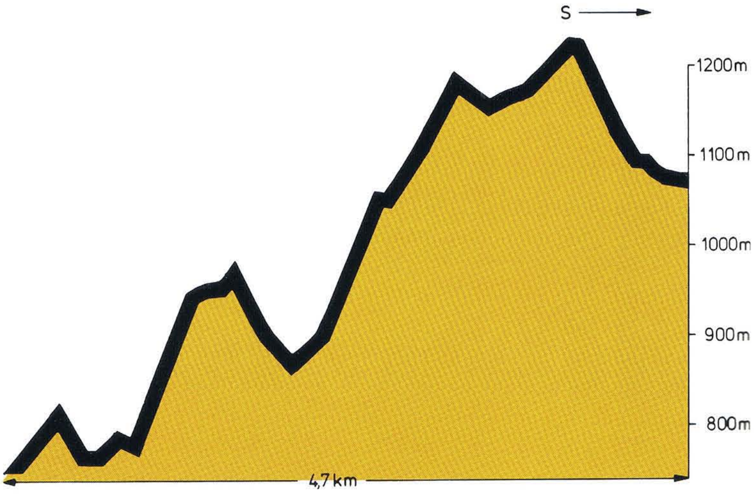
Fig. 6: Single block of 240 stations shot from 18 SP's on a traverse in front of the block and perpendicular to the lines. Coloured area shows the respective subsurface coverage (1 to 3-fold in y). ▼



Example IV: Prospecting in Mountainous Areas (48 channels, 4-fold coverage, irregular grid, VIBROSEIS*)

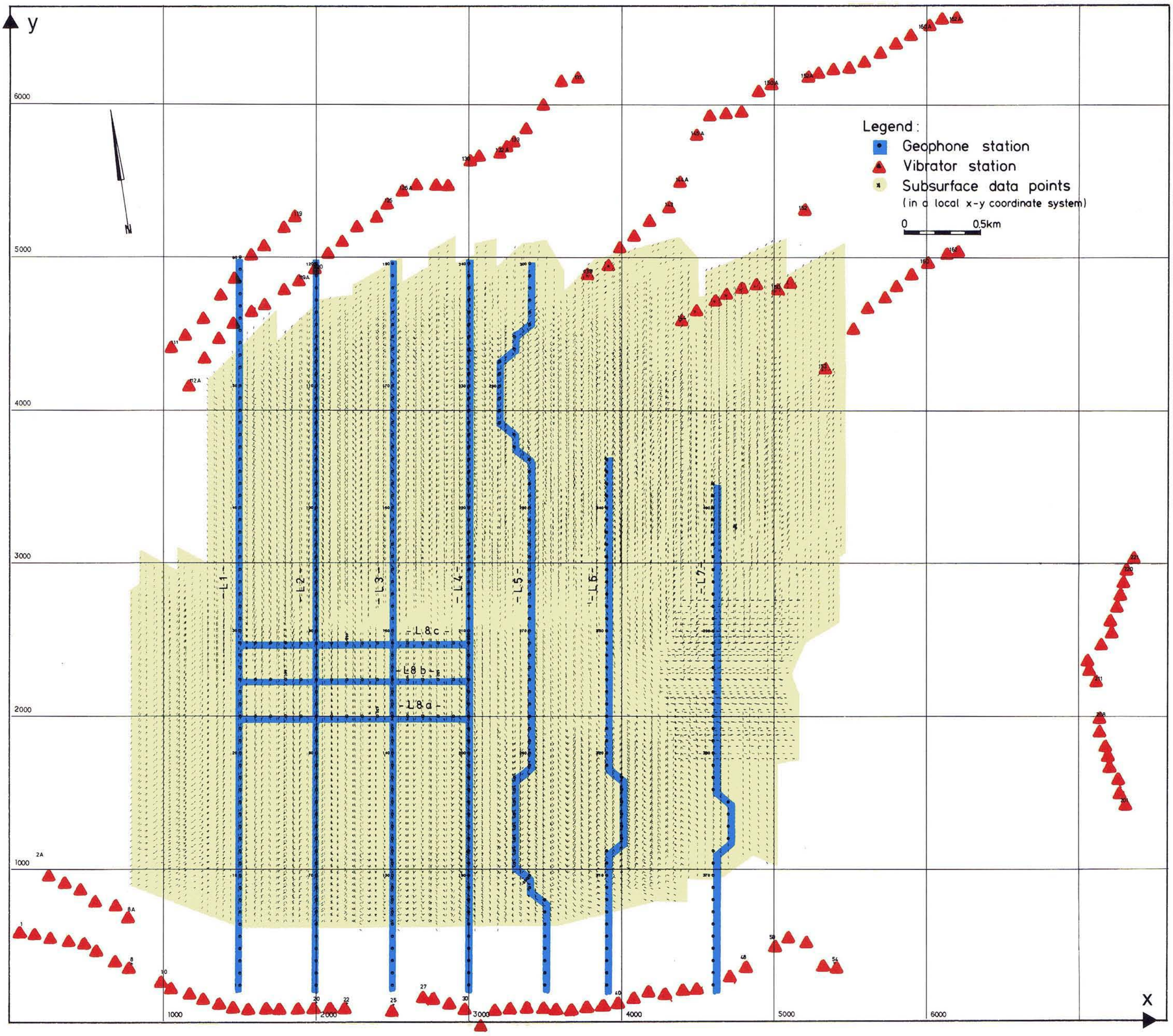
One line consisting of about 60 geophone stations only; vibrating from each line end along accessible roads and tracks at 40 stations; recording in each case the 48 emitter far receiver groups. Thus a 4-fold coverage was obtained. Surface spacing △ y was 80 m, △ x 100 m.

- **Target depth:** > 4000 m (~ 1.7 s), area covered: 17.4 km².
- **Recording:** DFS IV VIBROSEIS*, 48 channels, sampling rate 4 ms. 561 vibrator stations recorded in 87 seismic fieldwork hours, resulting in 6732 4-fold (CDP-) bins or about 1680 16-fold bins for the processing of the data.
- **Multiplicity:** 4-fold coverage originally, 16-fold after summation in rectangular bins 80 m x 100 m in y and x, respectively.



▲ **Fig. 7:** Relief of geophone line L4

Fig. 8: Scattergram showing the scatter of the subsurface data points, geophone lines L1 to L8, and the vibrator stations. ▼



* Trademark of Conoco Inc.

Example V: Rhine Survey (96 channels, 8-fold areal coverage, irregular grid, Airgun)

A 6-km section of the meandering River Rhine was covered by an areal survey within one week. The mean degree of coverage was 8-fold. Comprehensive knowledge of the subsurface structure was thus obtained in a former white zone in seismic mapping.

Field technique applied: Airgun pops fired at 25 m intervals from a ferry along traverses across the river; recording on two 48-channel recording instruments, one on each river bank. Four geophone lines in 200 m intervals and with 12 stations each on both river banks were recorded from each SP-traverse, the traverse interval being 100 m. The total number of lines produced was 113, each being 1 km in length, the area covered thus being 5.75 km².

Stacking was performed in the direction of the geophone lines. The sections shown are the result of re-arrangement parallel to the river (see red lines in the map) and of subsequent 3-D (Kirchhoff) migration (figure 10).

Fig. 9: Location Map with re-arranged sections (red)

An amphibious survey:
- geophone stations on land
- airgun pops in the river

using a hybrid areal method:
- average 4-fold in x- (geophone line) direction by parallel profiling
- 2-fold in y by shooting twice into each line from different shot traverses

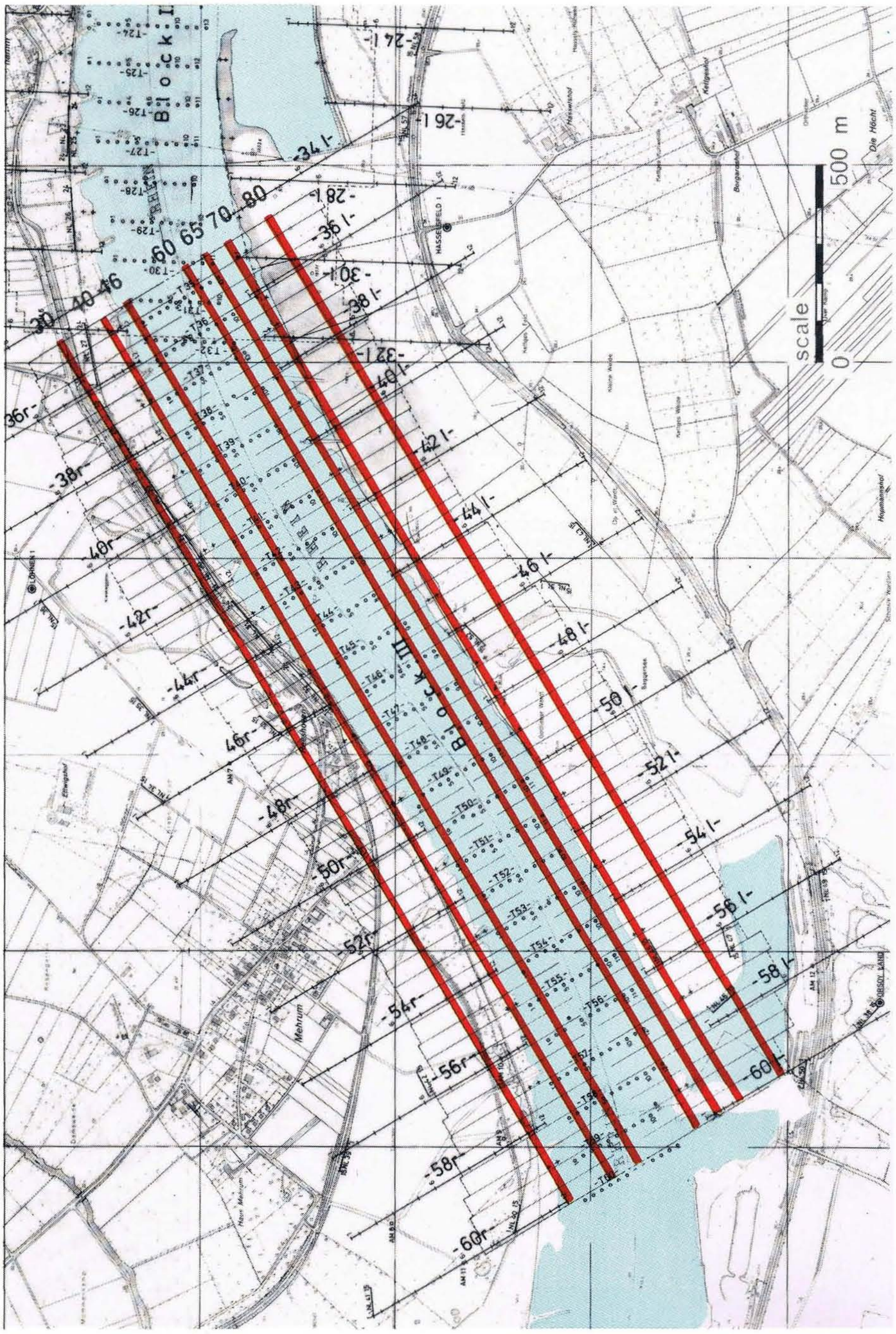
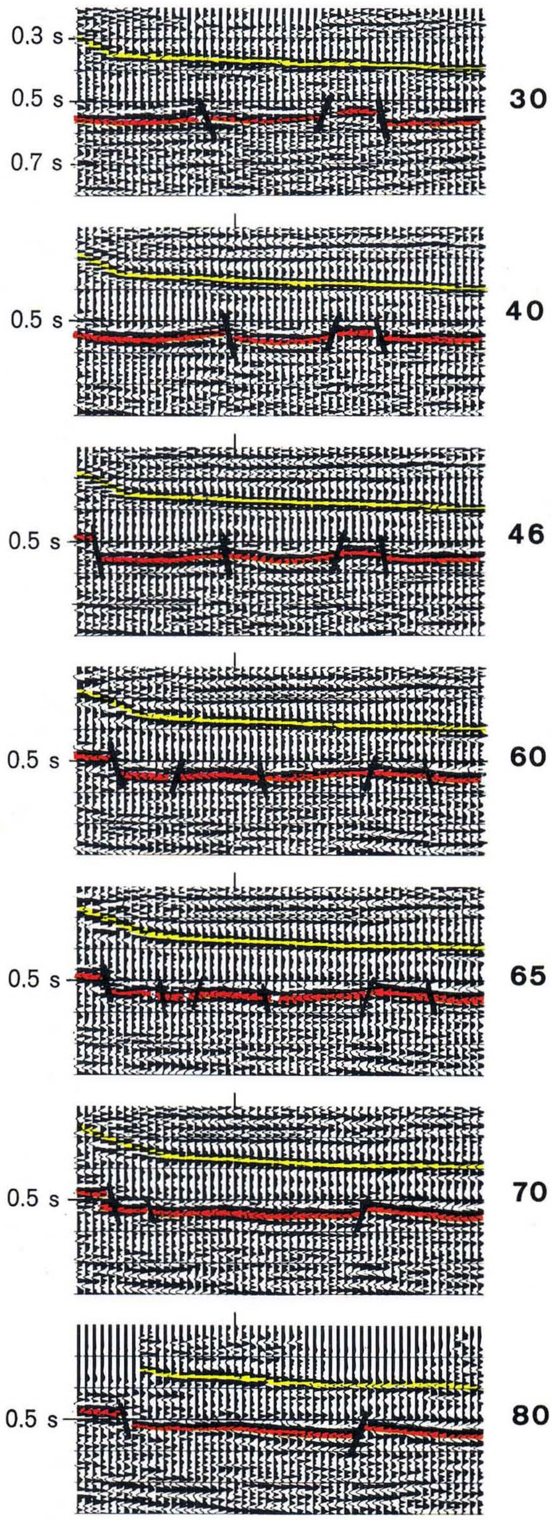


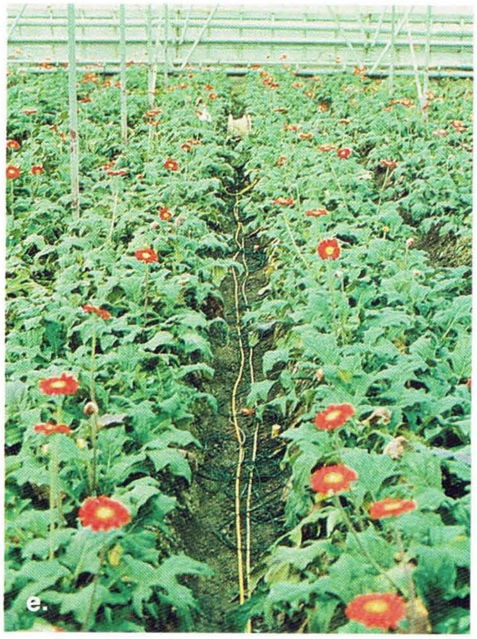
Fig. 10: Migrated Sections

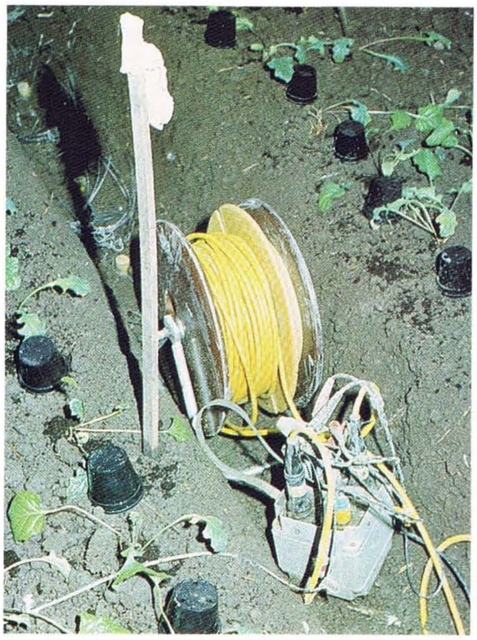


a. Layout in a Park
b. All geophone cables lead to the recording truck
c. Layout hindered by ditches and greenhouses

Field Work in Greenhouses

d. Drilling (lancing)
e. Geophone layout
f. Telemetry station
g. Shooting





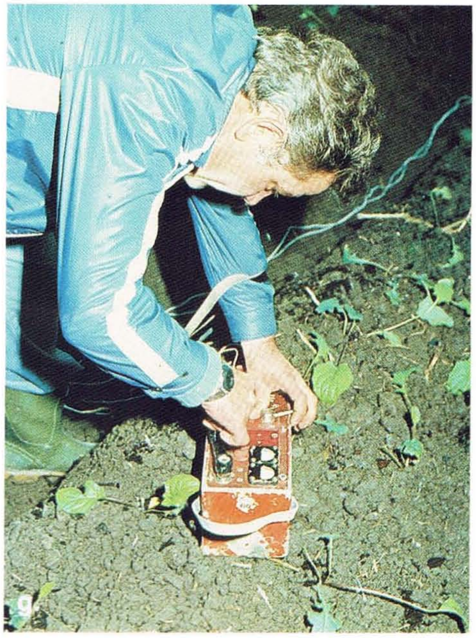
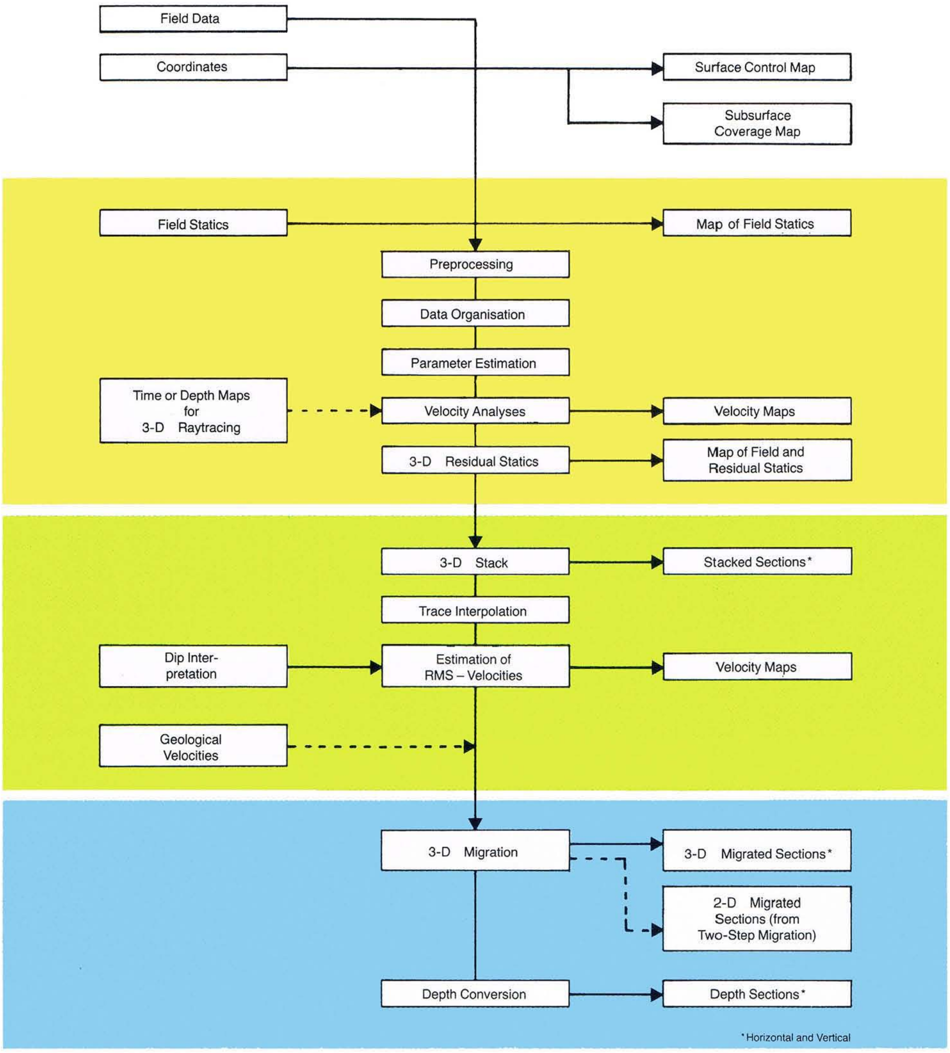


Fig. 11

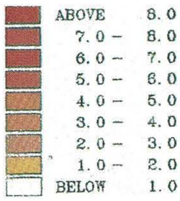


The **3-D processing sequence** consists of 3 main phases:

1. Pre-Stack Processing, including velocity analyses and 3-D residual statics
2. Pre-Migration Processing, including final 3-D stacking, derivation of migration velocities and, if required, trace interpolation procedures
3. 3-D Migration, including depth conversion and display of the data volume in any direction

The coloured **subsurface coverage map** is used as a control device before commencing the processing, providing information concerning the quality of coverage distribution in connection with the direction of shot-geophone vectors for each CDP. It also helps to define representative reference points for stacking velocity analyses.

Coverage



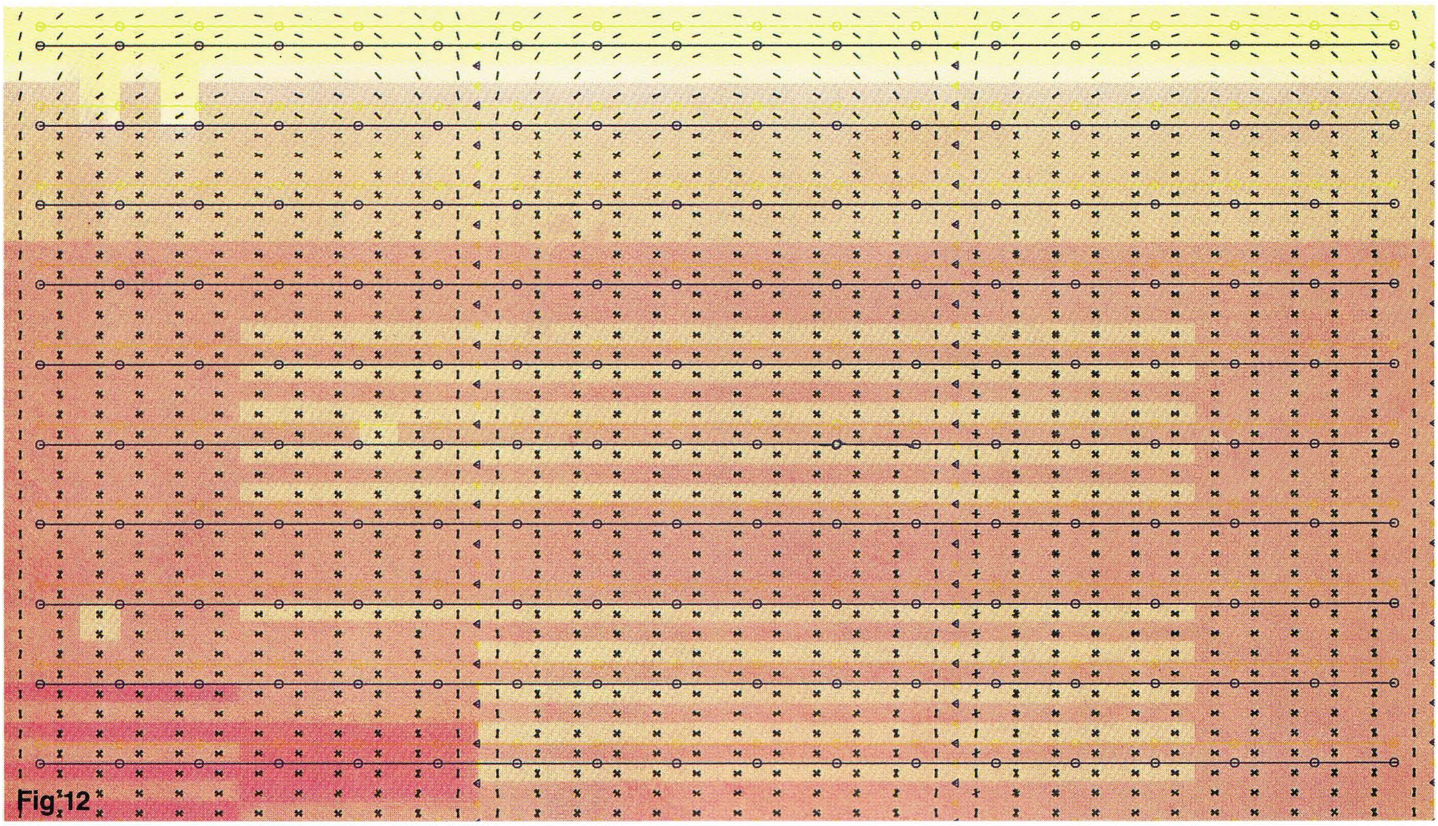


Fig. 12

Proper stacking of three-dimensional seismic CDP-data theoretically requires the knowledge of normal moveout velocities in all source-receiver directions contributing to a CDP-gather. The azimuthal variation of the stacking velocities mainly depends on the dip of the seismic interfaces.

Two techniques are available to derive the spatial NMO- velocity distribution:

3-D Raytracing Technique

For the application of raytracing techniques a preliminary 3-D computer model containing interval velocities between key horizons is necessary, which is generally derived from various geological and/or geophysical information relevant to the survey area: e.g. proved velocity information from well data or seismic data of former 2-D surveys, reflection time gradients or time maps etc. (see Fig. 13).

The model can be improved iteratively by the aid of interactive corrections using modelling techniques. The success of 3-D raytracing methods, however, depends on the reliability of input data concerning, for example, dip interpretation.

Sector Analysis

The need for a routine 3-D analysis method resulted in the development of a special sector-related data organisation of a CDP gather to enable the application of standard velocity determination procedures. At least three estimates in different directions are necessary to derive the full azimuthal velocity variation, characterized by the large and the small main axis and the orientation of the velocity ellipse.

Fig. 14 illustrates the principle of sector analysis:

A computer model was designed for three dipping and curved layers with the help of a 3-D raytracing program. A CDP spider configuration at the surface shows a wide range of shot-geophone combinations with distances up to 2400 m. For better illustration of the NMO-effects a high coverage was used. Four different sectors of 45° have been defined for velocity analysis.

Fig. 13: 3-D Raytracing Method

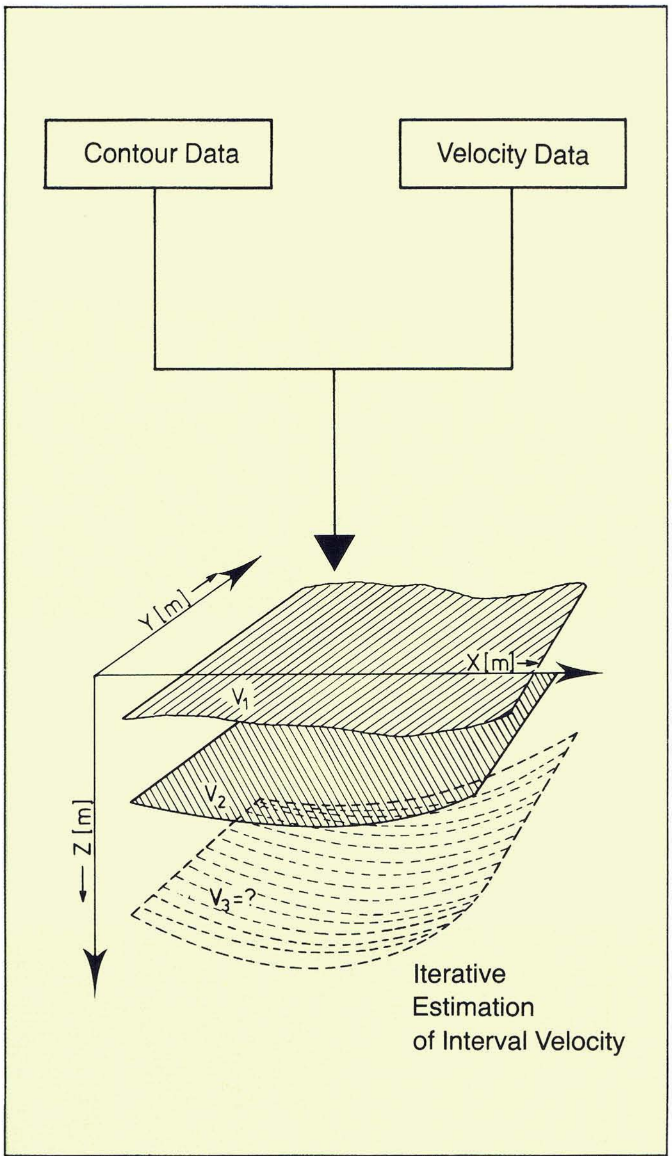
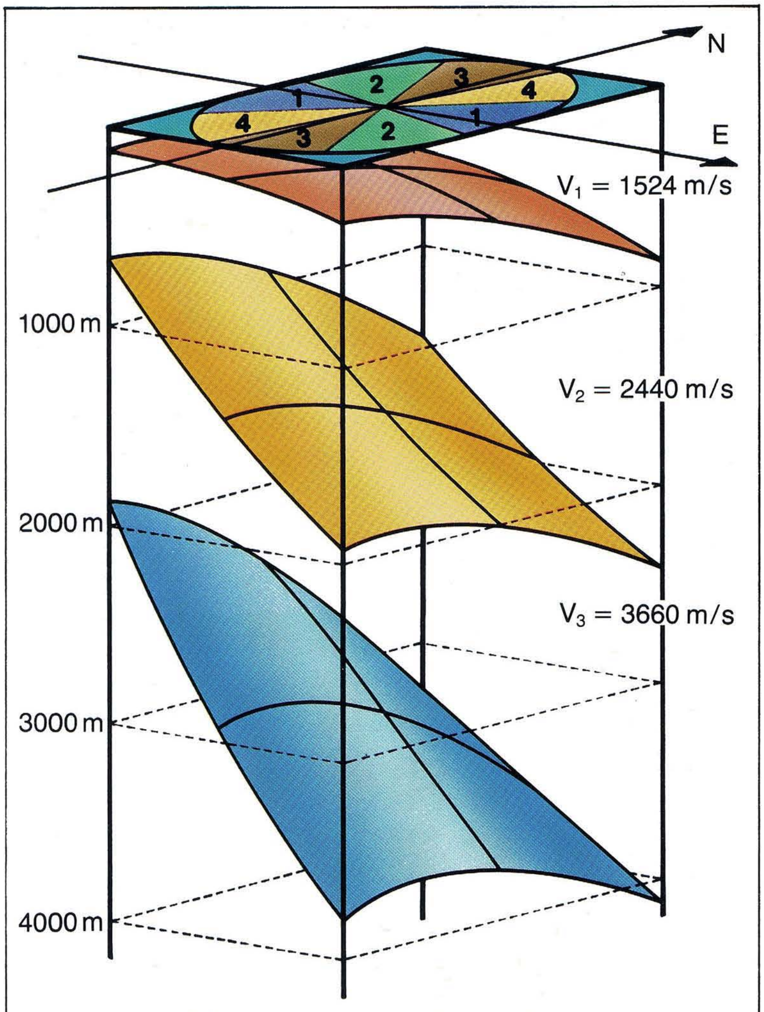


Fig. 14: Computer Model for 3-D Sector Analysis



Dip components at the centers of

1st interface:	12° to N	6° to E
2nd interface:	15° to N	20° to E
3rd interface:	20° to N	30° to E

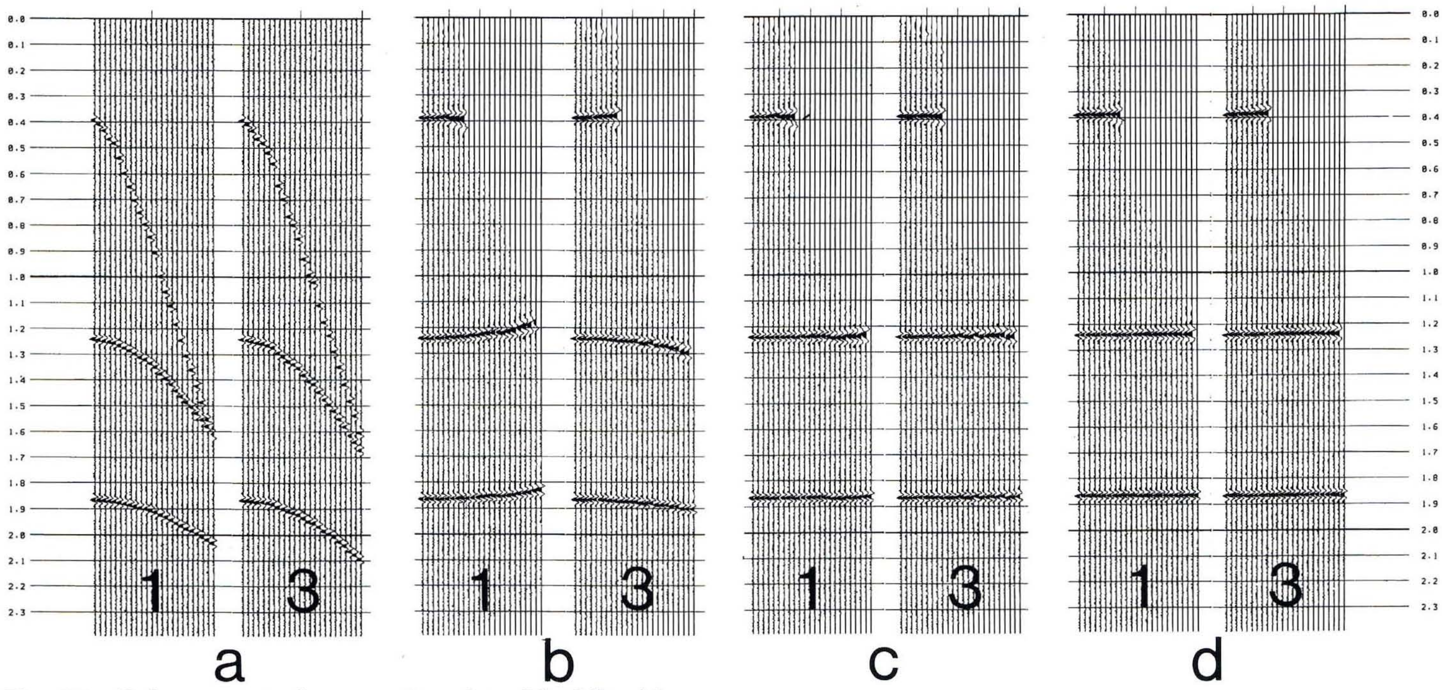


Fig. 15: Seismograms from sectors 1 and 3 of fig. 14
a) Input data
b) Results after NMO-correction applying an averaged velocity function
c) Results after NMO-correction applying sector velocity functions
d) Results after NMO-correction applying azimuth-corrected velocity functions

Fig. 15 shows for the two representative sectors 1 and 3 the input data (a) and the results after application of an averaged velocity function (b) and of improved sector velocity functions according to two different concepts: a velocity function kept constant for the sector (c) and velocity functions with full azimuthal corrections (d), individually related to the subsurface situation. Azimuthal variations of the NMO-velocities are more effective for long offsets or shallow events. Thus the effort concerning 3-D velocity analyses should be related to the range of shot-geophone distances and their azimuthal distribution and to the amount of dip; corresponding modelling can be of assistance.

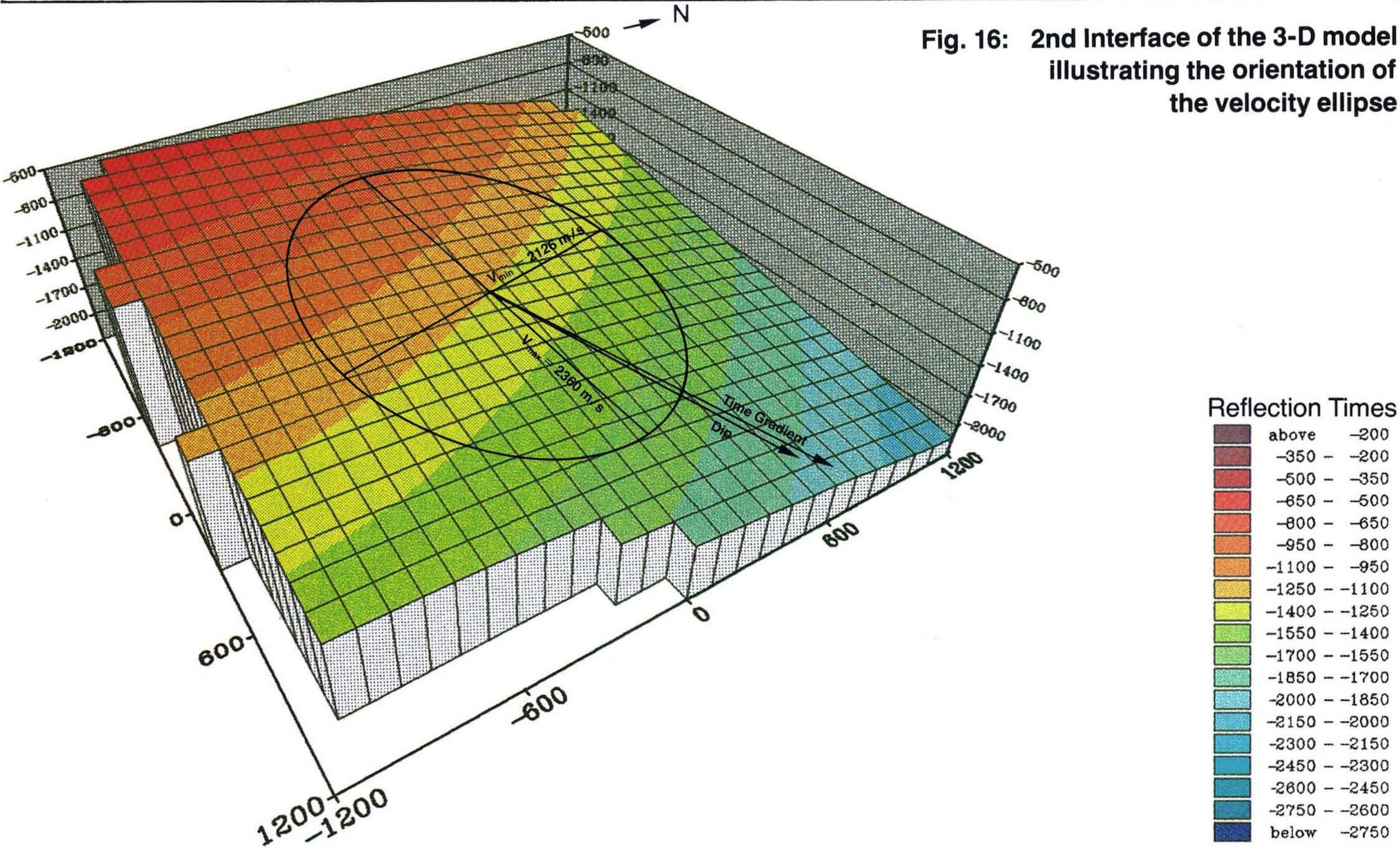


Fig. 16: 2nd Interface of the 3-D model illustrating the orientation of the velocity ellipse

The residual statics problem for areal data has been solved by the iterative procedure **3-D ASTA.** Two main points have been tackled: the calculation of traveltime shifts and the splitting of the time differences into shot and geophone corrections. The processing sequence can be derived from the 2-D procedure (see also PRAKLA-SEISMOS Information No. 9).

For calculation of 3-D residual statics reference traces are used which are established by applying 3-D multichannel filters to the raw stacked data.

For each CDP, time-differences Δt are determined between its component field traces and the reference trace, whereby the high signal/noise ratio of the reference traces guarantees a reliable estimate of Δt. Each Δt-value is split into a shot component, a receiver component and a noise term.

The shot and receiver components are applied to the field traces thus improving the stacked data. An iterative procedure delivers an optimum stack after two or three runs.

Isoline displays of field and final statics prove the effectiveness of the process for compensating irregularities in field statics (see Figs. 19 and 20).

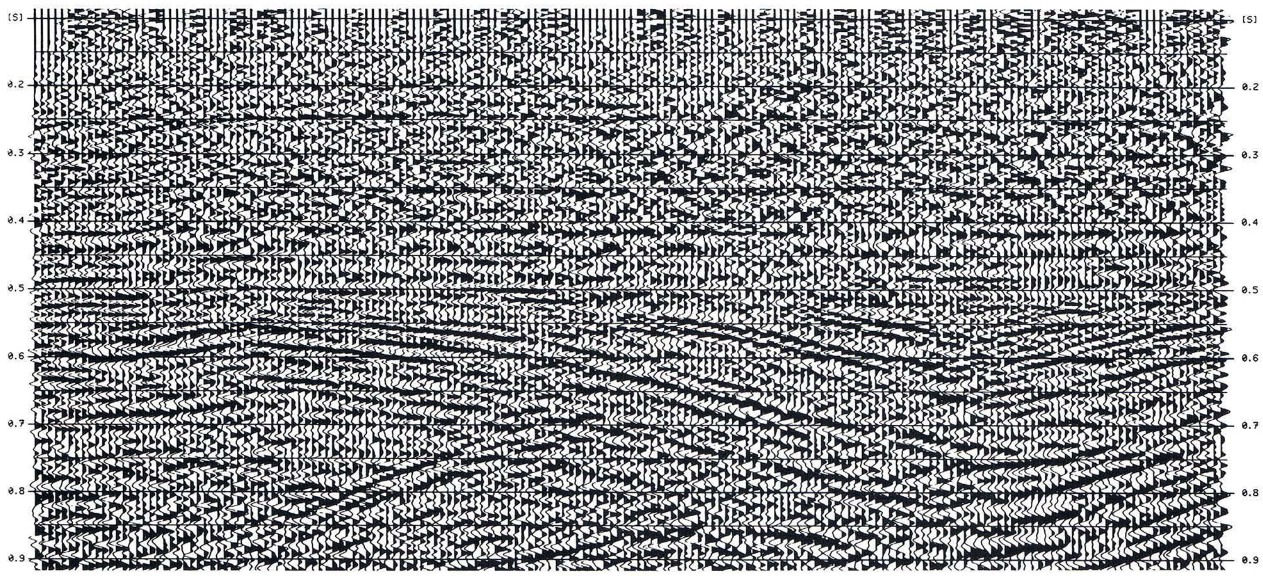


Fig. 17: X-line before 3-D ASTA

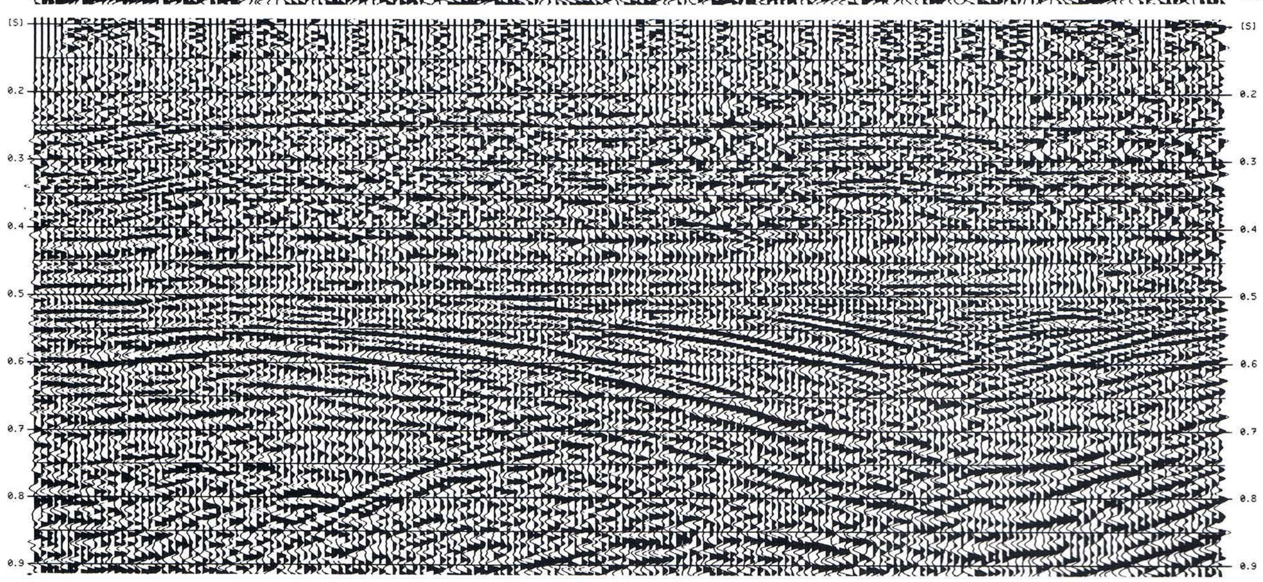


Fig. 18: X-line after 3-D ASTA

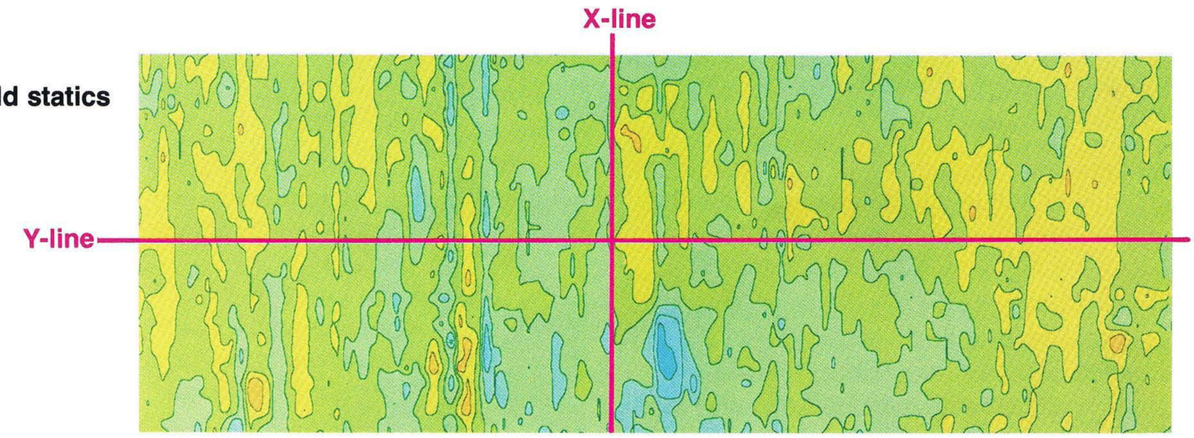


Fig. 19:
Isoline display of field statics with indication of the X- and Y-line presented below

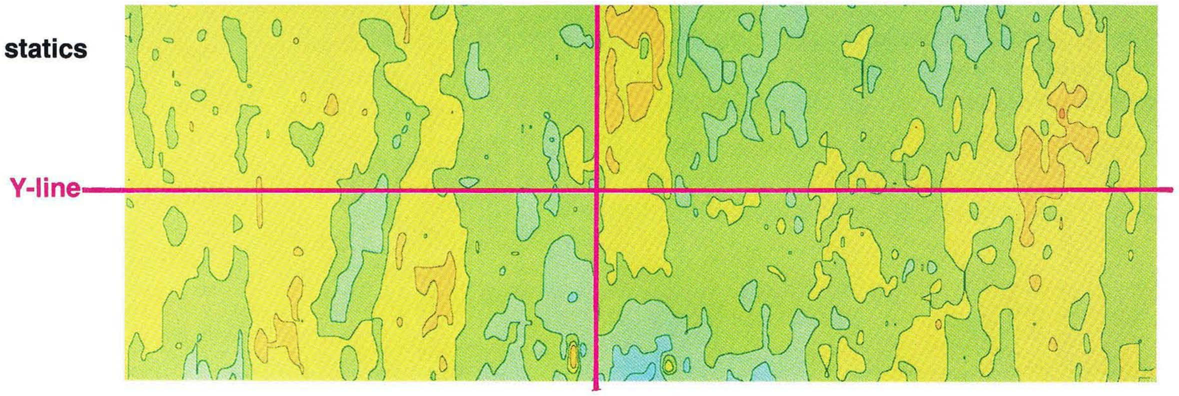


Fig. 20:
Isoline display of final statics

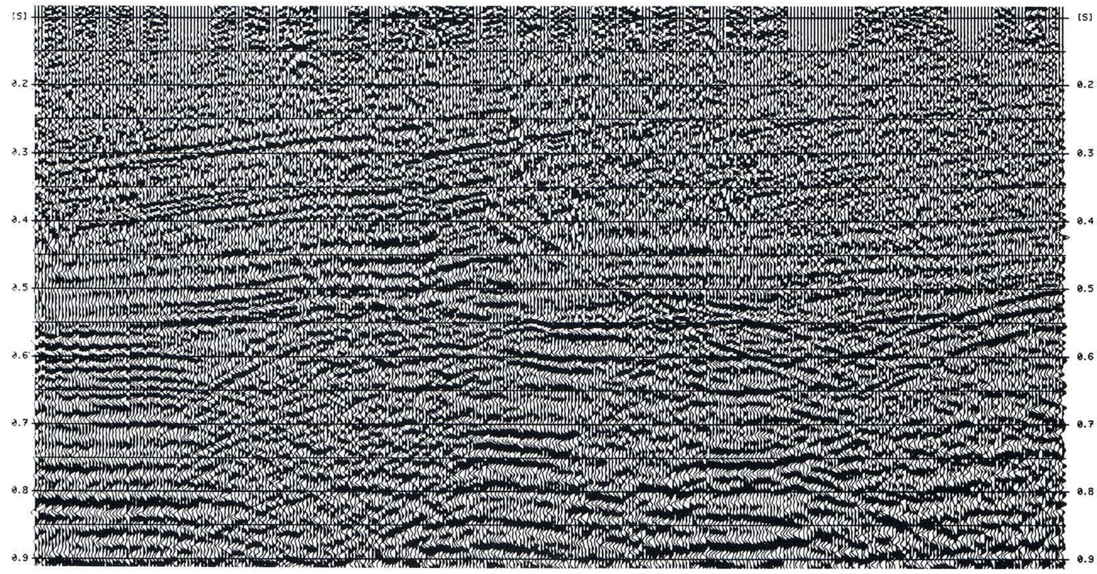


Fig. 21:
Y-line before 3-D ASTA

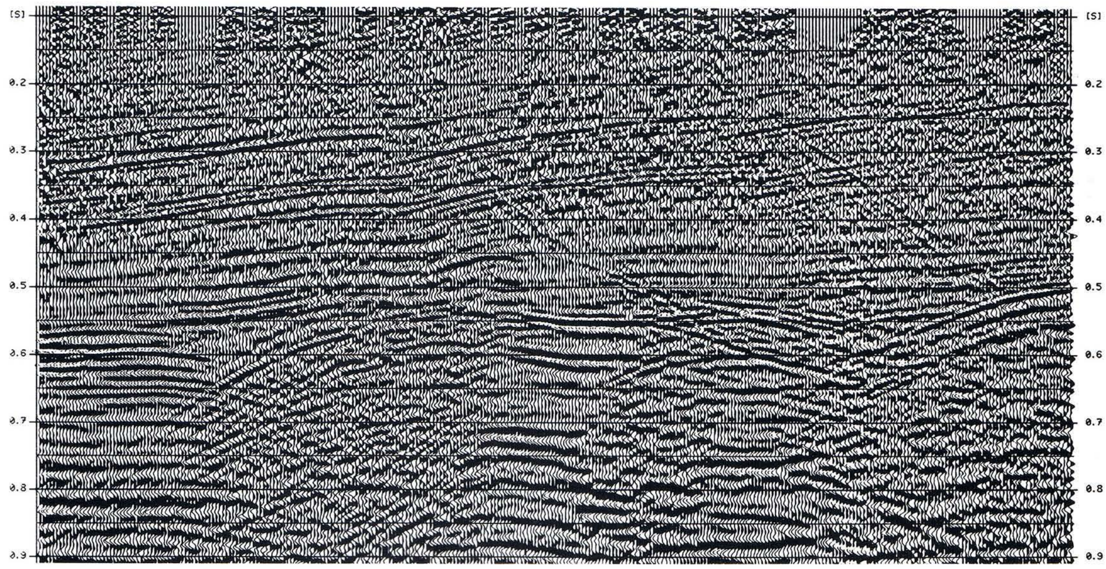


Fig. 22:
Y-line after 3-D ASTA

3-D migration is also subject of **"PRAKLA-SEISMOS Information No. 31".** There the different techniques commonly applied in 3-D processing are outlined.

3-D migration is the central procedure in any 3-D data processing sequence. It corrects for events reflected from outside the plane of stacked data and thus provides true geological sections for interpretation work.

To emphasize the effectiveness of 3-D seismics after 3-D migration the result of a 2-D migrated line in Fig. 23, produced as the first step of an F,X-two-step migration, is shown in comparison to the 3-D migrated section (after the second step) presented in Fig. 24.

The success of migration is strongly related to the *spatial sampling interval,* the *dominant frequency* of the data, the *amount of dip* encountered and the *length of the operator.*

From the theoretical point of view seismic data should be arranged on a square grid for 3-D migration. This can be achieved e. g. by an advanced trace interpolation procedure, carried out in the f,k-domain. Another possibility for compensation of disproportion of x- and y-spacings is the *modification of the migration operator.*

Figs. 27 a and 27 b on the back cover illustrate the migration response (Finite Difference method) of a single diffracting point in the subsurface sliced at certain travel times for the grid spacings 12.5 x 12.5 m and 25 x 50 m respectively. The clear presentation of the dominant amplitudes in a good approach to a circular output is evident for the 12.5 x 12.5 m grid, whereas increasing dispersion effects and noticeable deviation from circular symmetry can be observed for the 25 x 50 m grid. In Fig. 27 c the migration operator has been adjusted according to the different grid spacings in x- and y-direction, resulting in a more circular output. Dispersion effects in these operator presentations are due to the high frequency wavelet used for migration and are of less importance with real data, where destructive interference prevails.

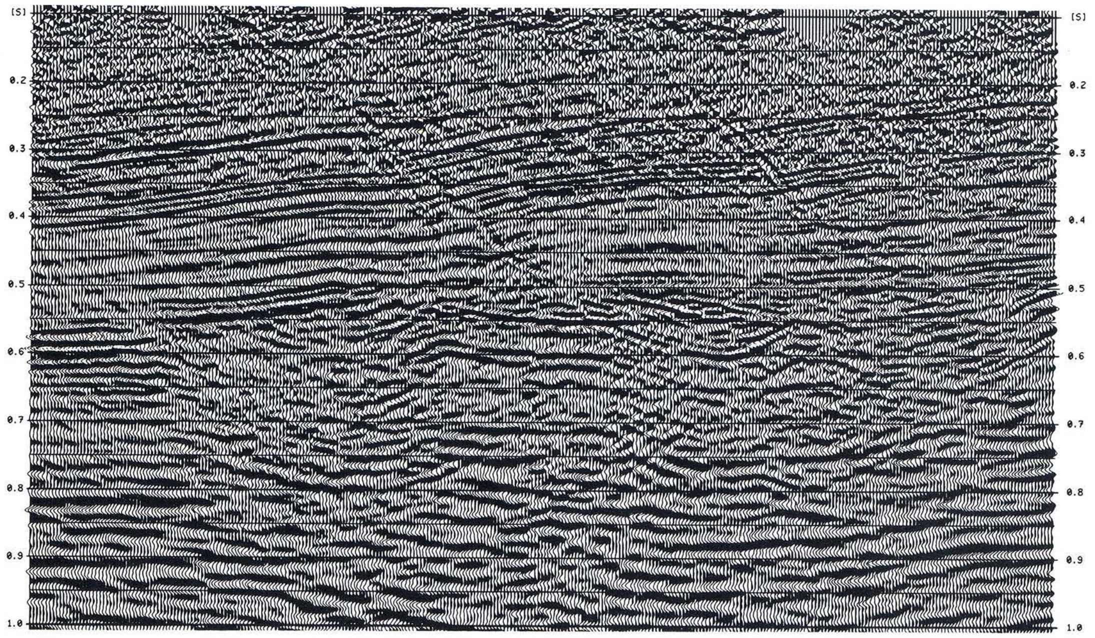


Fig. 23: 2-D migrated line

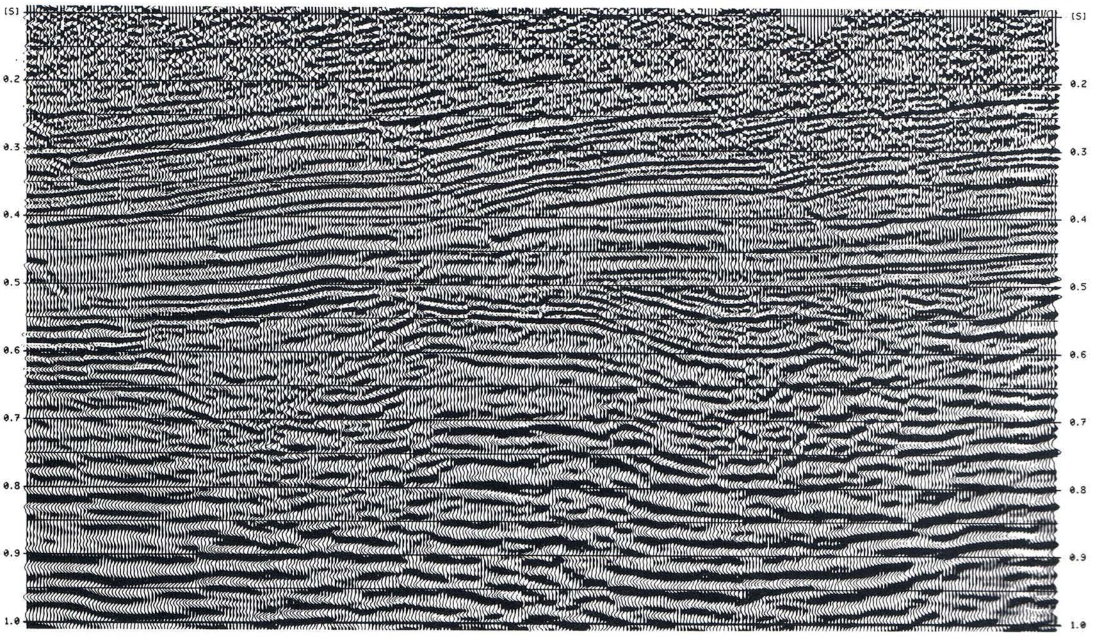
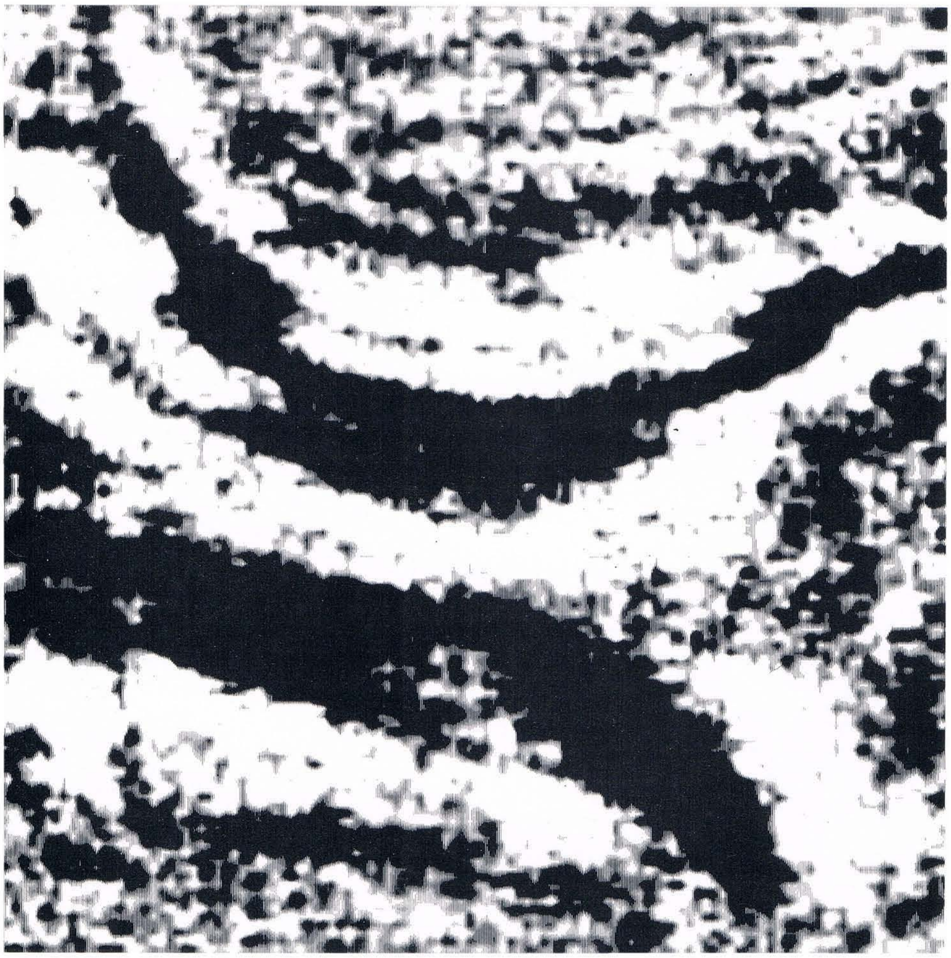
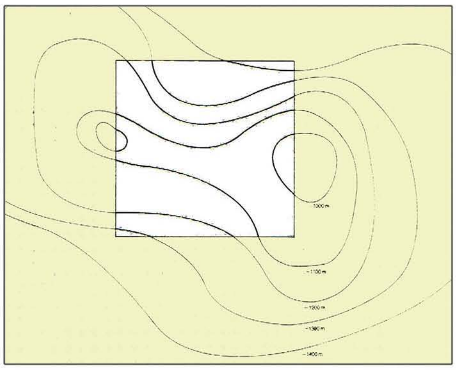


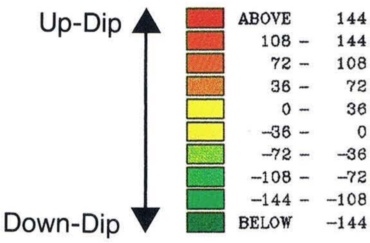
Fig. 24: 3-D migrated line



The use of colour allows many possibilities of differentiating and separating seismic information. For example the presentation of the phase angle, which can be derived from the seismic data with the help of the Hilbert Transformation, shows a more detailed image with structural refinements. The direction of dip can also be indicated by selecting an appropriate colour code for the instantaneous phase.

Fig. 25: Horizontal Seismic Section





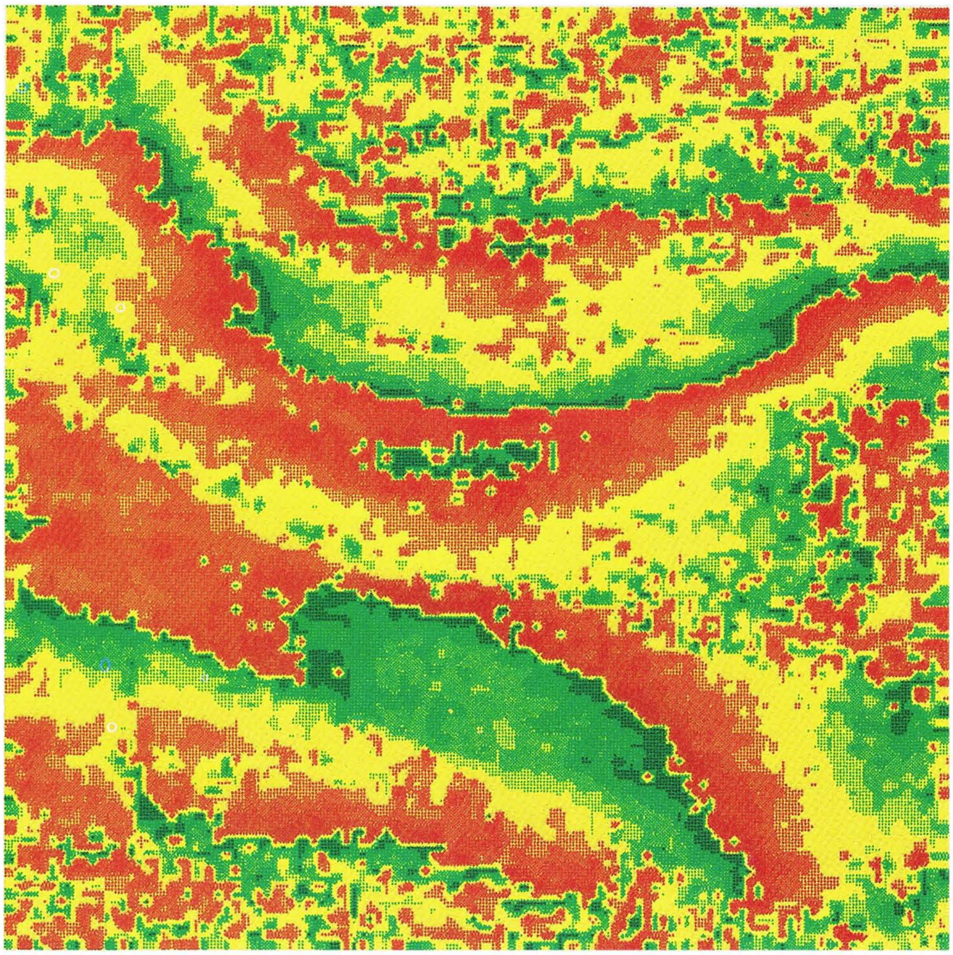
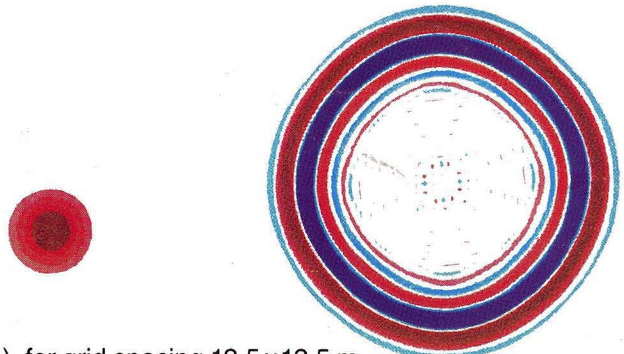
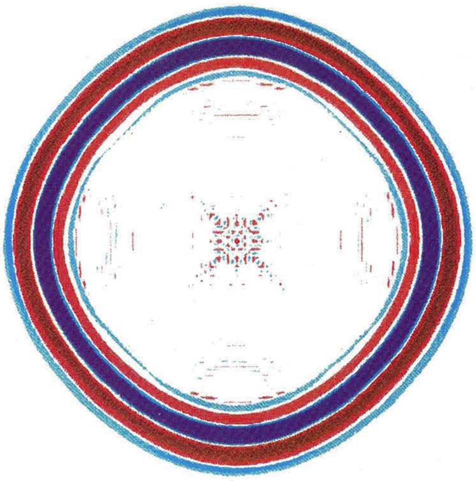
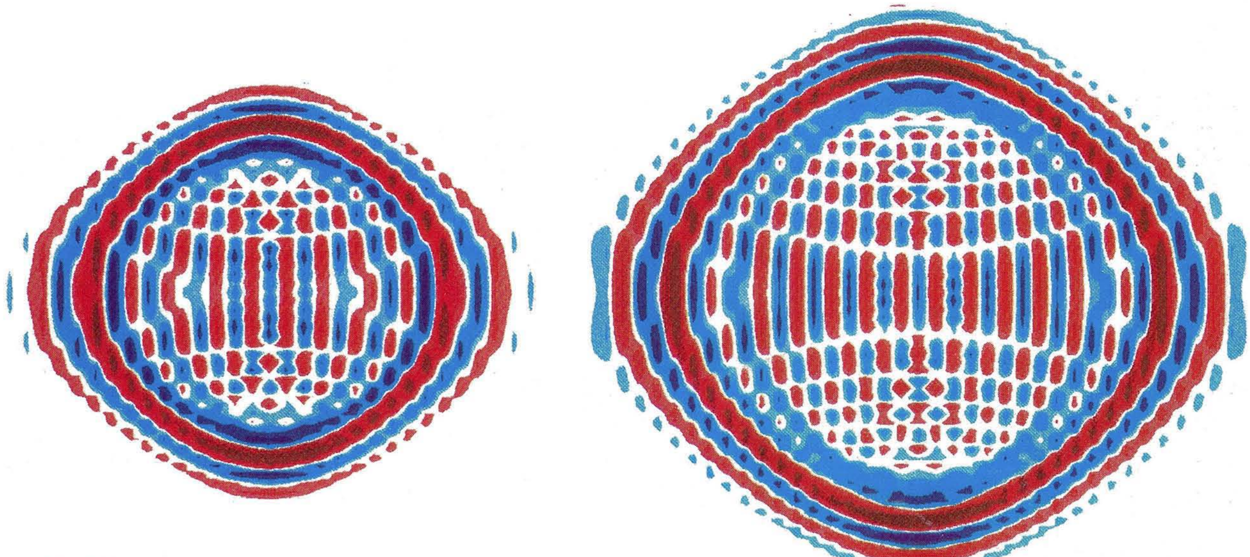


Fig. 26: Horizontal Section of Instantaneous Phase, the colour code indicating Dip Direction

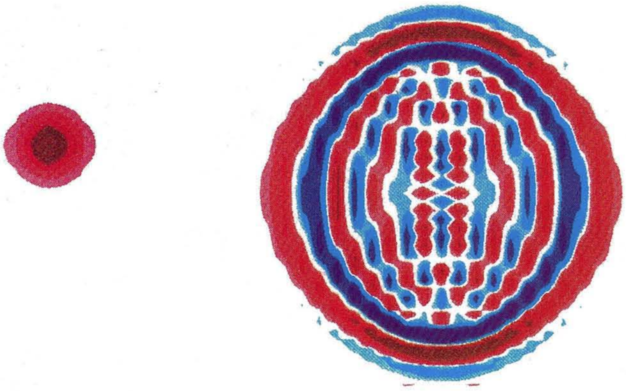
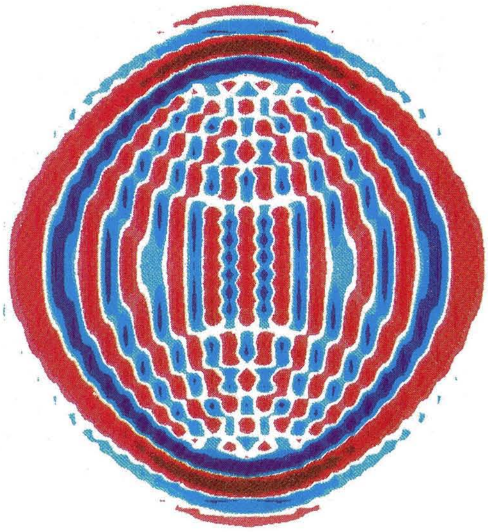
Fig. 27: Migration operator response of a point diffractor at 800, 720, 640 ms

a) for grid spacing 12.5 x 12.5 m



b) for grid spacing 25 x 50 m

c) for grid spacing 25 x 50 m (adjusted operator)

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