3-D Reflection Seismic Survey of the Area around the KTB Drilling Site

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Abstract:

A brief description is given of the field geometry of the 3-D reflection seismic survey of the area around the KTB (Continental Deep Drilling Project) borehole site and the initial processing results of the DEKORP Processing Center (DPC) in Clausthal. This survey was the main part of the experiment ISO '89 (Integrated Seismics Oberpfalz). The objectives and the resulting array set-up are discussed, as well as the planned course of the survey. The problems of the actual survey and their solutions are then described.

The parameters needed for processing the survey data are discussed: geophone groups, shot points, seismic traces, data and bins, CDP distribution, offset and angle distributions. The geology, topography, and the technical data for the survey are presented.

The SSL software system for 3-D processing is briefly introduced. The processing steps for handling the geometry and the checking of the data are discussed as well as the planned processing sequence. An example of the raw data is given in which the reflections from the Erbendorf structure can be distinctly recognized.

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1. The Survey Area and Planning of the Field Work

The objective of the 3-D seismic survey of the area around the KTB borehole site is to extend the results of the KTB pilot borehole to the surrounding area and clarify the relationships between the geological structures. This seismic survey connects the previously surveyed profiles DEKORP 4 and KTB 8502 with the pilot borehole, making it possible to directly determine the physical and lithological properties of the reflectors in the crystalline basement, permitting predictions for the main KTB borehole, which is to be begun in September 1990. ISO '89 as a whole was conducted within the framework of DEKORP (Deutsches Kontinentales Reflexionsseismisches Programm) and financed by the BMFT (Federal Ministry for Research and Technology).

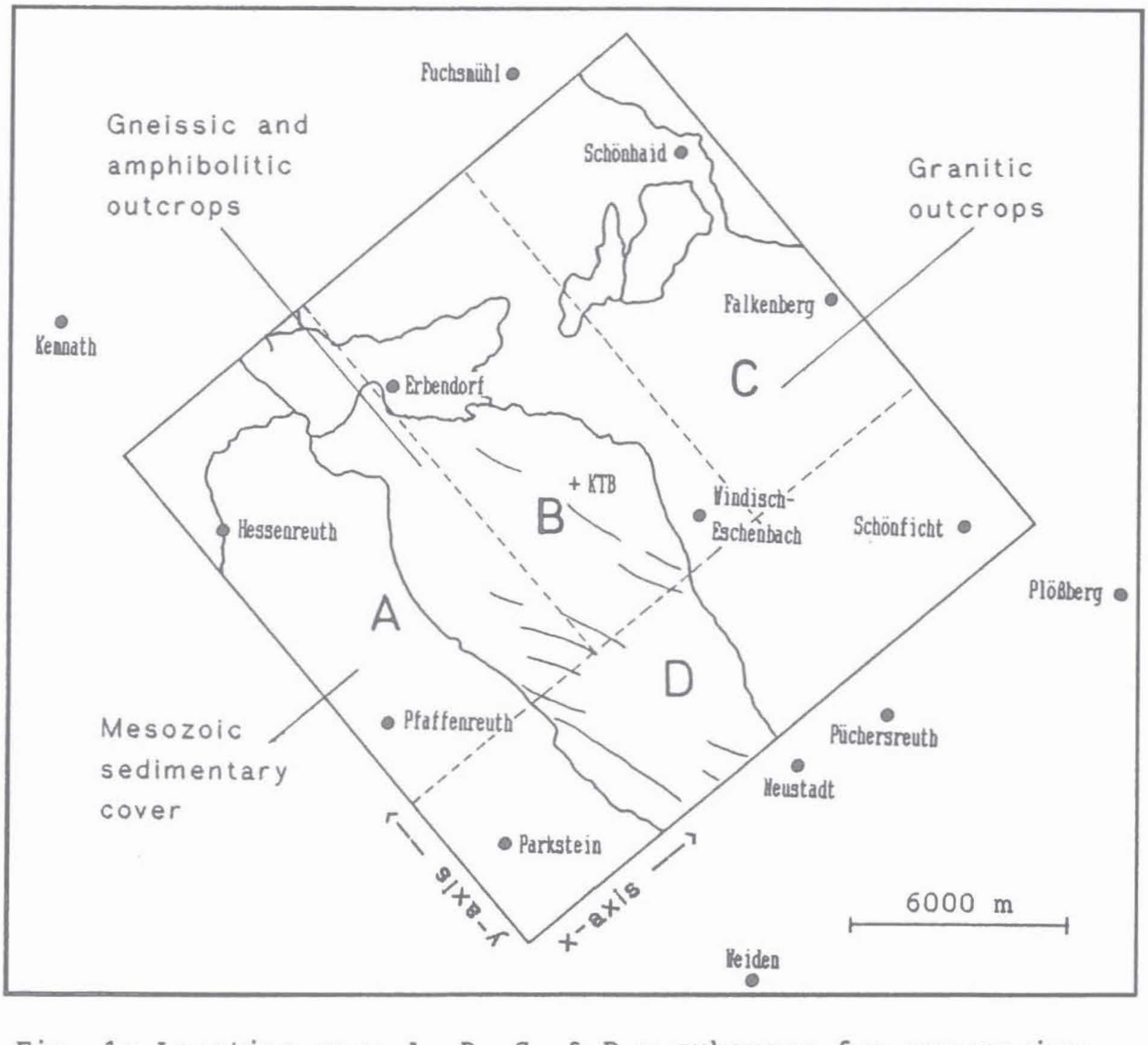

Fig. 1: Location map; A, B, C, & D = subareas for processing

The approximate center of the survey area of about 20x20 km was the KTB drilling site near Windischeschenbach (Fig. 1). The area can be divided geologically into two subareas. In the northeast the basement has a high seismic velocity and extends up to ground level. In the southwest, mesozoic and paleozoic sediments with mainly low velocities extend to a depth of up to more than 3 km. These two areas are separated by the Franconian Line, which passes through the area from NW to SE. For processing, the survey area had to be divided into four subareas of about equal size because disk capacity was not sufficient to process the area as a whole.

The array set-up was designed by H. Horstmeyer and M. Stiller, together with Professors Bortfeld and Krey, at the DPC Clausthal. Required was a 12 - 15-fold coverage for a minimum volume of about 10x10x10 km after migration. Two types of single array set-ups (type A and B) were used, differing only in the sequence of shot point separations (Fig. 2). The two types were alternated so that the shot points of the one set-up were opposite the gaps between shot points of the other (please note that in seismic processing the denotation 'shot' is commonly used even when it was a 'vibration' in reality). Each set-up consisted of 10 geophone lines each with 48 geophones groups. The distance between geophone lines was 400 m, the geophone group centers were placed 100 m apart. The shot point lines were laid out perpendicular to the geophone lines, an arrangement called a cross array.

The shot point lines were 8 km long (defined as parallel to the y-axis) with 40 shot points each. The shot locations were spaced in a recurring pattern of 200 m, 300 m, 200 m, 100 m. For each swath of 10 geophone lines across the entire survey area (parallel to the x-axis) there were 21 shot point lines 800 m apart, giving a total of 840 shot points. Four swaths of 10 geophone lines were needed to cover the survey area, giving 3360 shot points. Because the shot point lines overlap by 20 shot points, each line contains 100 shot points. Thus, 60 % of the shot points were in two groups of geophone lines and only 2100 different shot locations were necessary. The theoretical source-receiver offsets were between 72 and 6212 m.

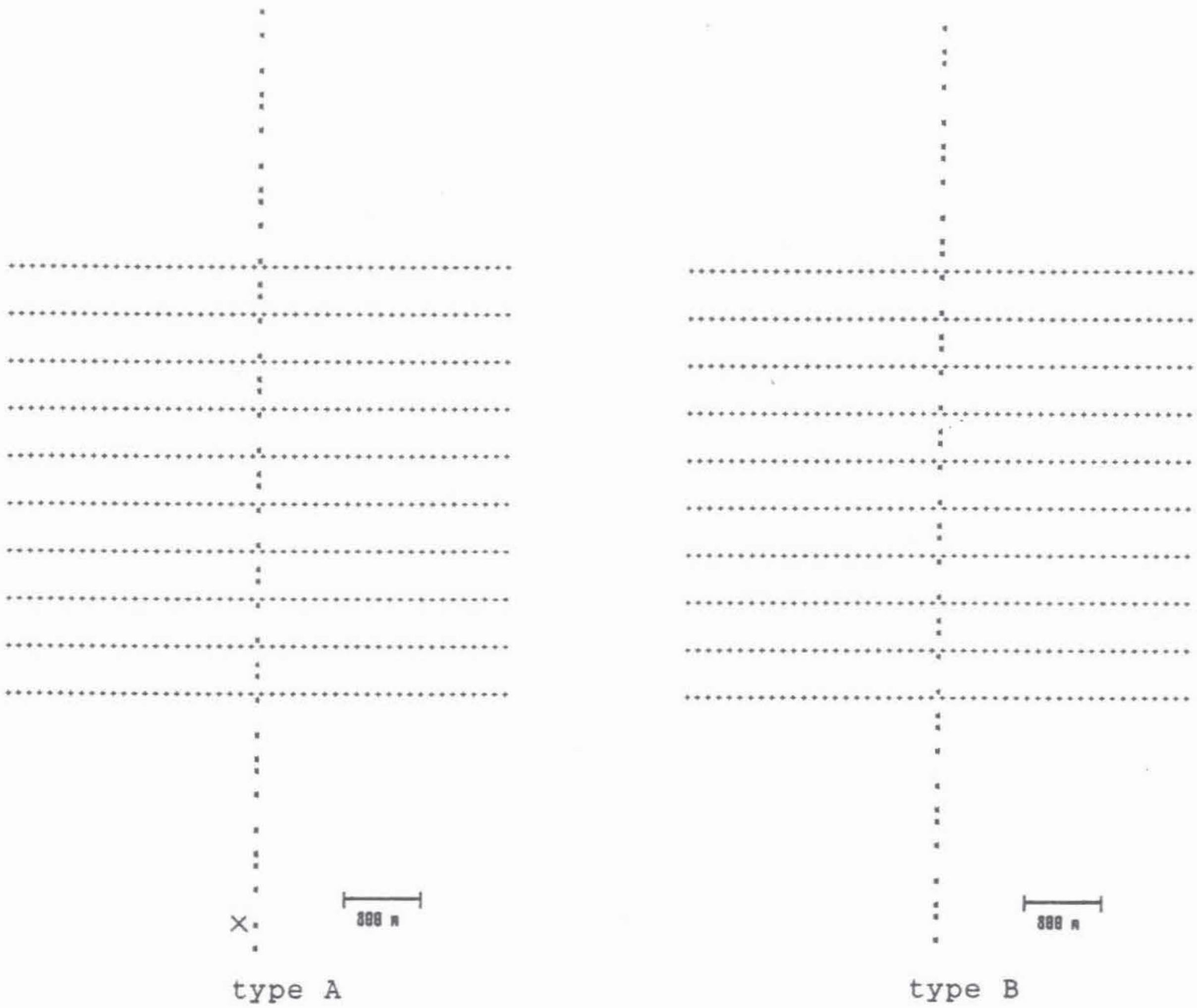

Fig. 2: Array set-ups
vertical : shot point lines
horizontal: geophone lines
X : see chapter 5.

The Franconian Line separates a crystalline basement area in the northeast from a sediment area in the southwest. The large difference in velocities between these two areas presented a problem for the orientation of the array.

Generally, the largest offsets should be in the direction of strike so that minimum offset-dependent traveltime errors are obtained during processing. These errors are difficult to correct for and would lead to inexact values for the stacking velocities or even make it impossible to determine them. However, the strike was not uniform throughout the area; it could be distinctly observed only locally and changed with depth.

In order to minimize traveltime problems, it was agreed to choose the direction of the Franconian Line for the orientation of the array. Because the maximum offsets in the array set-up used for this survey are in the direction of the shot point lines, these lines had to be arranged parallel to the Franconian Line. Thus, the shot point lines were laid out NW-SE (323.2°), the geophone lines aligned NE-SW (53.2°).

With this survey scheme, an area of 17.8x18.4 km was covered with one-fold coverage or more and an area of 14.4x15.2 km was covered 15-fold. The variation of the coverage is shown in Figure 3. The theoretical shot and geophone locations are shown in Figure 4. An advantage of this array set-up is that already the seismic traces in the offset range of 0 - 850 m provide one-fold coverage of nearly the entire area (Fig. 5). Taking initial trace muting into consideration, there will be full coverage after about one second of traveltime.

To calculate the subsurface coverage, the area was subdivided into 50x50 m squares (the so-called bins). The reason for this bin size is that the best resolution is 50x50 m, resulting from the geophone group spacing of 100 m. Thus, the 17.8x18.4 km area contains a total of 131,008 bins (356x368) and the 14.4x15.2 km area with 15-fold coverage contains 87,552 bins (288x304), which corresponds to 66.8 % of the total area.

An area of 2.4x5.8 km is covered by a type A array. Owing to its different shot point sequence, the type B array covers an area of 2.4x5.7 km. A single array set-up provides a maximum of 5-fold coverage. Thus, three set-ups, shifted 800 m along the geophone line (i.e. along the x-axis), are needed to obtain the desired 15-fold coverage.

A group of ten geophone lines was surveyed for 21 shot point lines (i.e. one swath). The equipment was then moved 4 km along the y-axis and the process repeated (Fig. 6). In this way the required 15-fold coverage was obtained at the overlapping edges of adjacent swaths. Neighboring shot point lines alternated between type A and B in order to guarantee a homogenous distribution of small offsets.

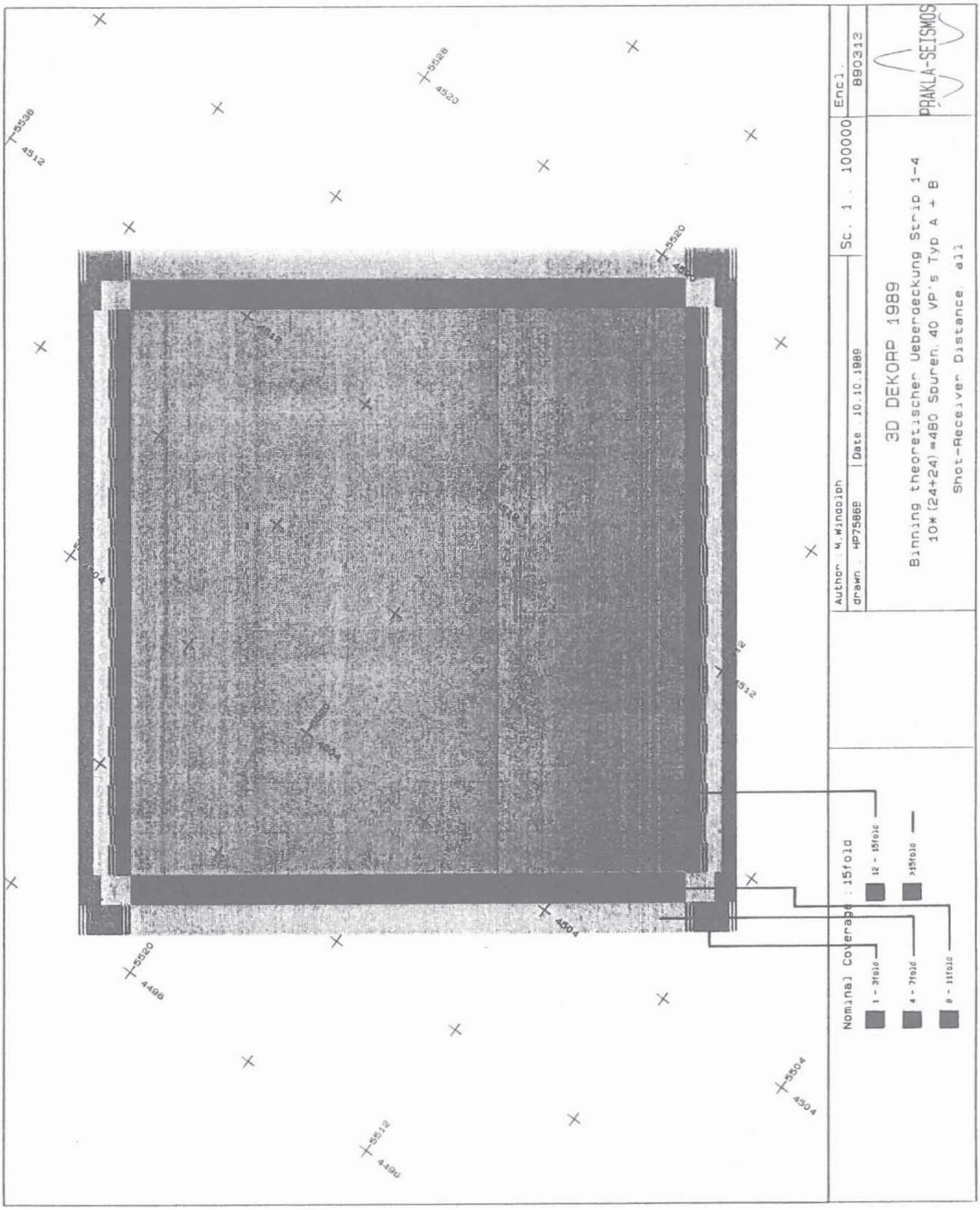

Fig. 3: Theoretical coverage, all source-receiver offsets
(prepared by Prakla-Seismos AG)

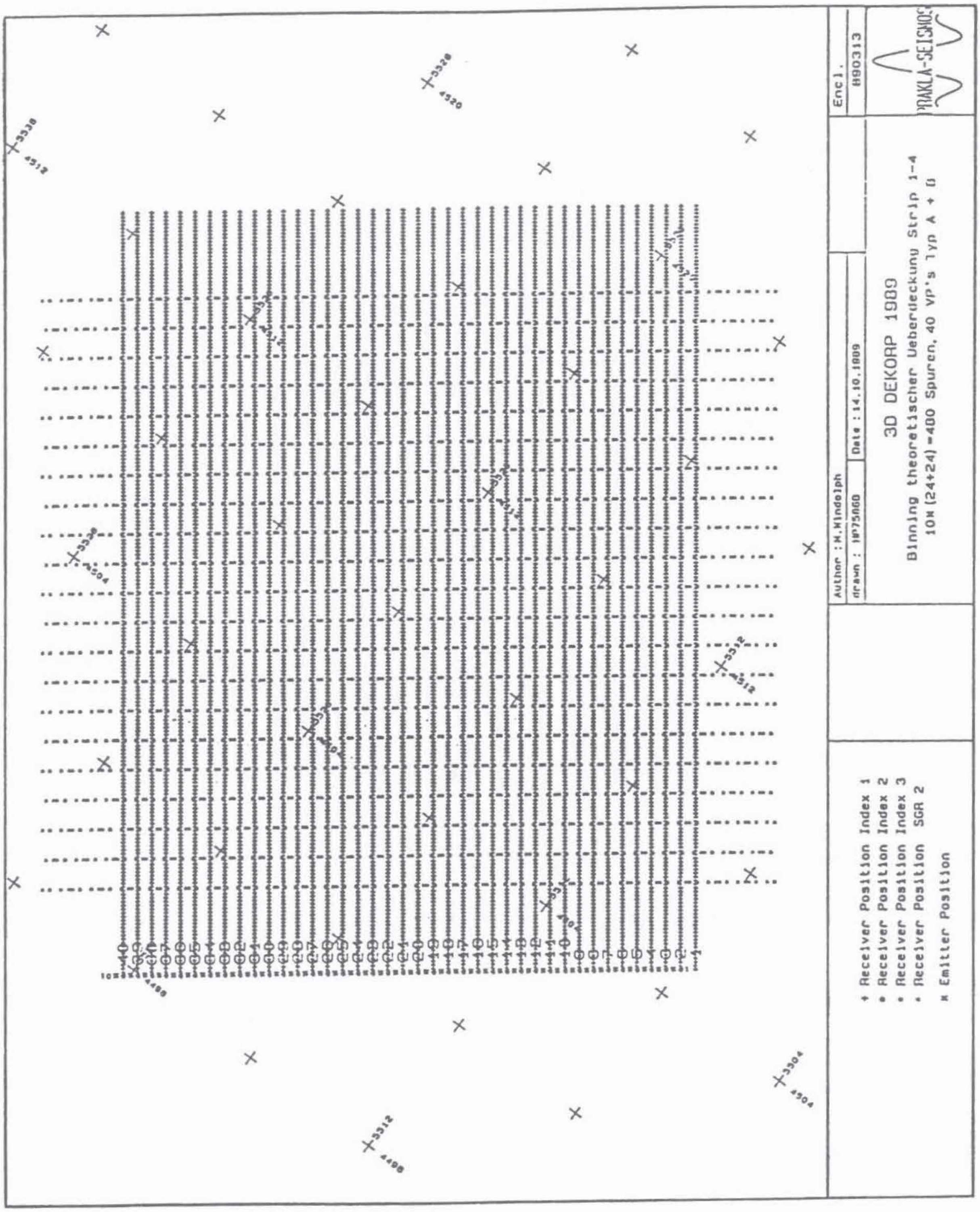

Fig. 4: Theoretical shot and geophone locations
(prepared by Prakla-Seismos AG)

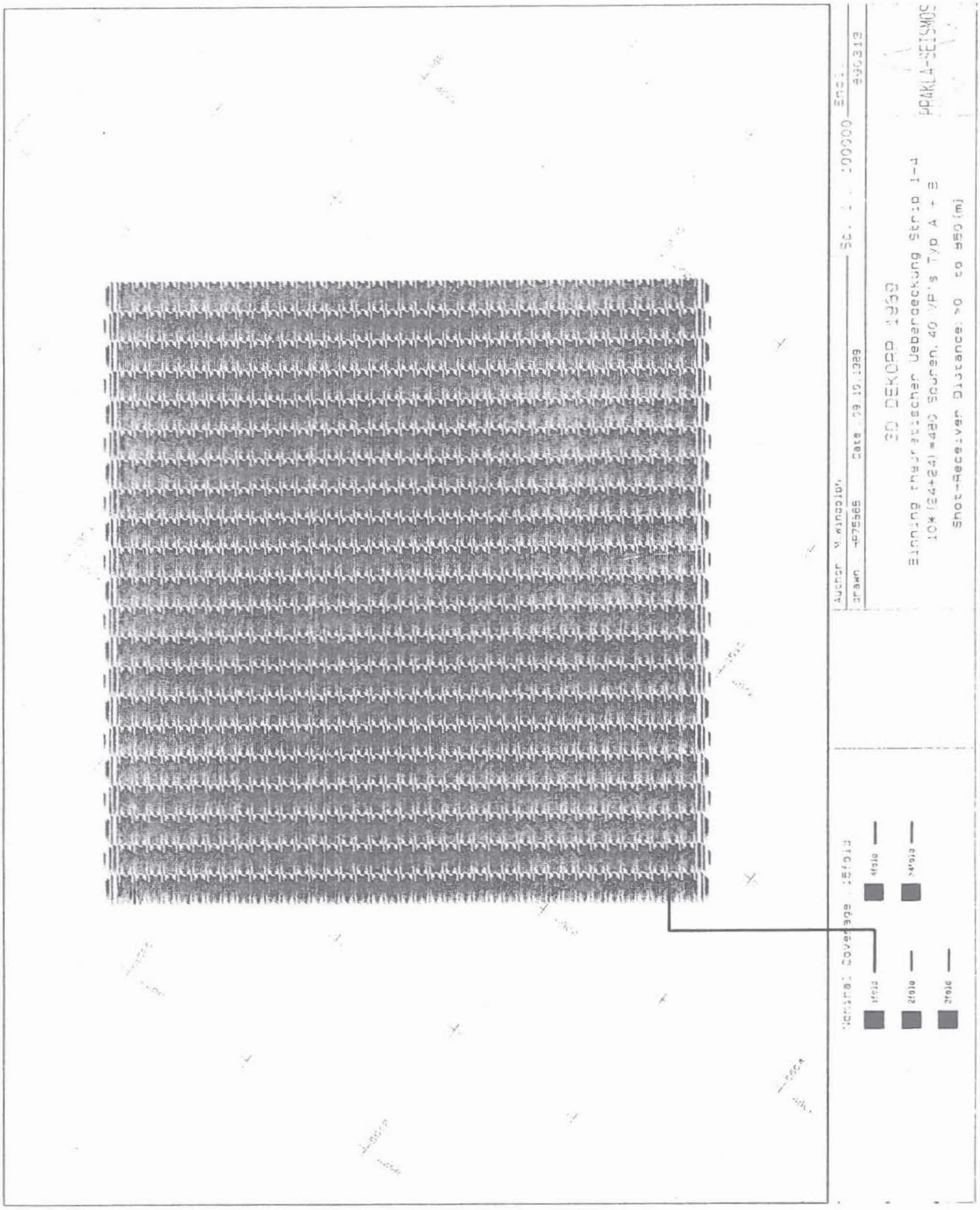

Fig. 5: Theoretical coverage, shot-receiver offsets 0 - 850 m
(prepared by Prakla-Seismos AG)

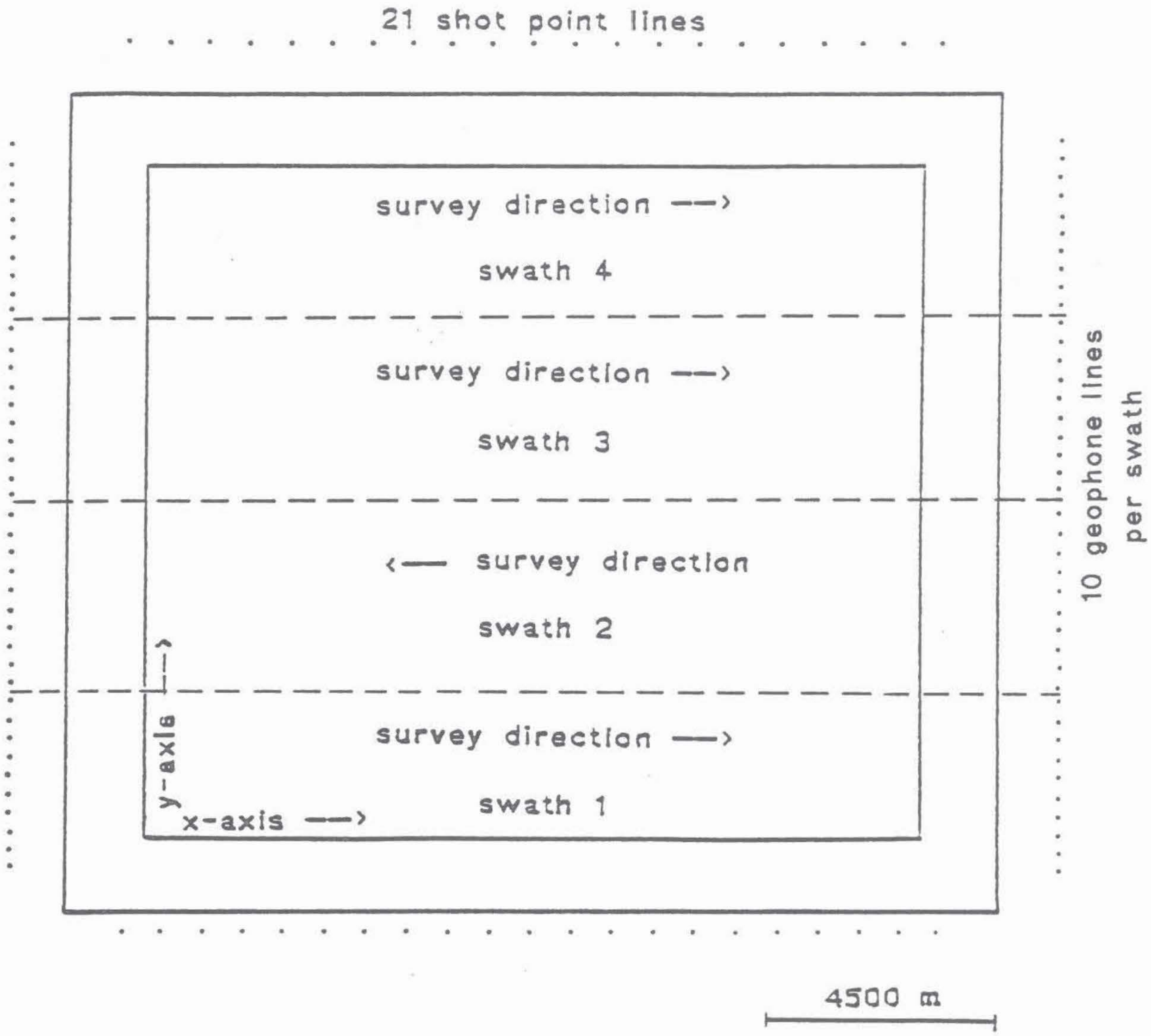

Fig. 6: Scheme for carrying out the survey

With a theoretical number of 3360 shots with 480 channels each, 1,612,800 seismic traces are possible. It is known from experiences in 2-D vibroseismics that not any shot point is realizable in this kind of area. Owing to the used frequency range of the sweep, it is not possible to vibrate within villages, and a lot of forest-roads and field-paths is not practicable with vibrators. With an estimated loss of 20 %, at least 1,290,240 traces could be expected. The survey was planned to be completed within 70 work days in late summer and fall of 1989 (Aug. 7 - Nov. 15).

2. The Survey

The field work was carried out by Prakla-Seismos AG. The seismic work was done from August 7 to November 21, topographical surveying was started one month before. A reflection time of 12 s with a sampling rate of 4 ms was recorded on a 480 channel SERCEL SN 368 via telemetry. The seismic vibrations (up-sweep 12 - 48 Hz, length 20 s) were produced by five vibrators. The vertical stacking varied between five- and eight-fold.

To carry out the scheme shown in Figure 6, detailed knowledge of the survey area was necessary. Because only a few of the theoretical shot locations could be reached with the vibrator trucks, the main problem was to find the most appropriate substitute sites. The area was visited for several weeks in early 1989 to locate (and mark on a 1:25 000 topographic map) all tracks that could be driven with vibrators.

In Clausthal these maps were then placed on a digitizing table so that an interactive program prepared by DPC staff members could be used to determine the suitability of all reachable sites as substitute shot locations. These substitute sites were then plotted on topographic maps.

Thus, it was possible to specify all 2100 shot locations before the field work was started and to guarantee by performing a full pre-binning that the desired coverage could be obtained in all bins. These topographic maps were also the base maps for the surveyors in the field. There were two requirements for all surveyed sites:

(a) The difference between the planned and actual shot locations was not to exceed 35 m in order to achieve placement of the reflection points within the proper bin.

(b) The survey results had to be influenced as little as possible by unavoidable last-minute shifts in shot point sites.

These two aspects were not critical for the geophone positions, which are not dependent on the road net. But despite thorough preparatory field work, a number of shot points had to be shifted on the spot, e.g. due to road construction work, forestry work, harvesting, danger of damage to fields, presence of pipelines or nearby houses.

Thus, it was necessary for two staff members of the DPC to accompany the field work to optimize any last-minute shifts in shot points. One of their tasks was to check that the coordinates of all sites marked in the field by the surveyors corresponded to the planned positions. If the deviation was more than 35 m, the point had to be resurveyed and rechecked until all seismic traces were within the proper bin. The geophone locations were handled just as carefully, ensuring that all of the source and receiver positions were properly sited before the seismic records were made.

A further task of the two Clausthal staff members was to check whether the set-up of the geophone groups was done properly. A geophone group contained 18 geophones arranged in the shape of a 3-vane fan (Fig. 7). This arrangement allows the suppression of surface waves from all directions.

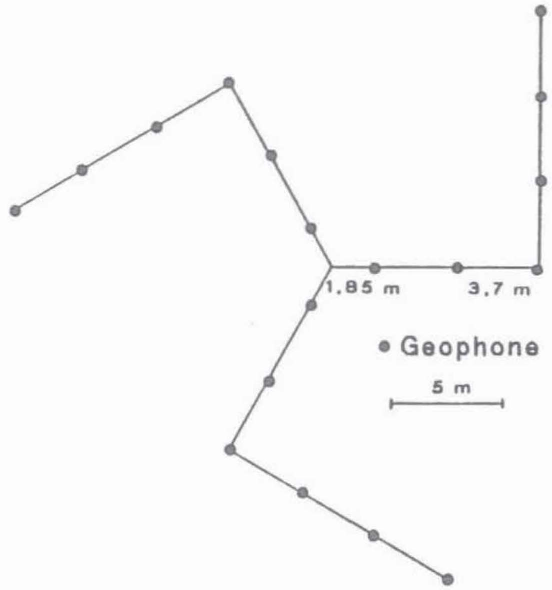

Fig. 7: Geophone group, arranged in a 3-vane fan

Wherever possible, shot points were shifted only laterally and changes in the in-line coordinates were avoided. The necessity for this is clear if the effect of shifting a shot position on the results is understood:

(a) Lateral shift (Fig. 8):
Shifting a shot point 100 m perpendicular to the shot point line will result in loss of a trace in each of 10 bins on one side (black) and addition of an undesired trace in each of 10 bins on the other side (hatched) of the area covered by a single array set-up. Thus, for a single use of this shot position there is a change in 20 bins, for a double use there is a change in 40 bins. The number of affected bins changes proportionally to the distance of the shift.

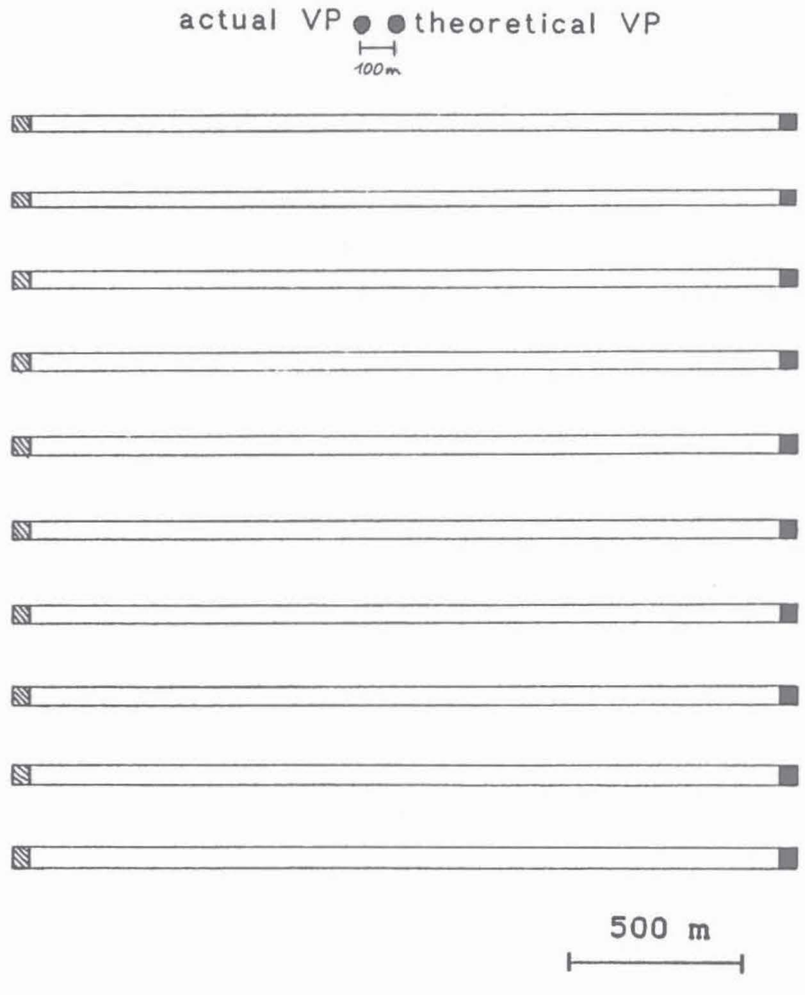

Fig. 8: Effect of a lateral shot point shift

(b) In-line shift of 50 - 350 m (Fig. 9):

If the shot point is shifted along the shot point line 100 m, for example, 48 bins per geophone line will lack a trace (black) and 48 bins per geophone line will have an additional trace (hatched), i.e. a total of 960 affected bins for a single use of this shifted position or 1920 bins for a double use, which is nearly 50 times more than for a lateral shift of 100 m.

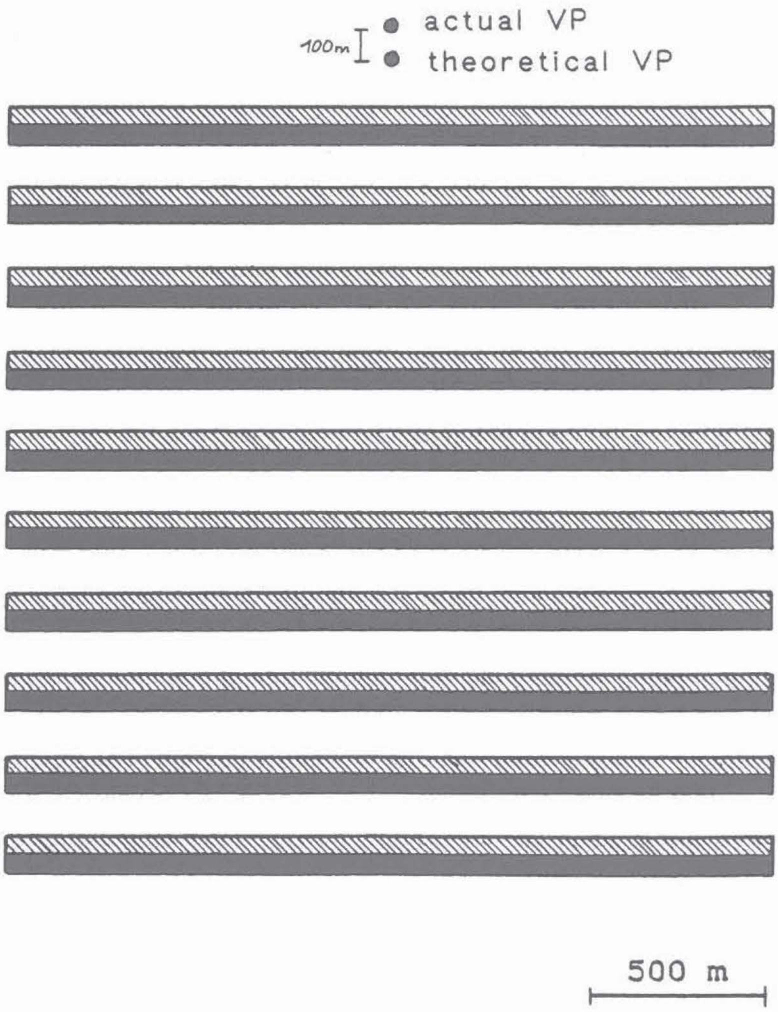

Fig. 9: Effect of an in-line shift of 50 - 350 m

(c) In-line shift of 350 - 450 m (Fig. 10):
For an in-line shift of 400 m, for example, the number of affected bins is reduced to 96, because most of the reflection points are again in the proper bin. On one side of the covered area there will be 48 bins in which a trace is lacking (black) and on the other side 48 bins will have one trace too many (hatched). All the other bins will have the proper number of traces. For double use of this shifted shot point, 192 bins will be affected, which is about 5 times more than for a lateral shift of 100 m.

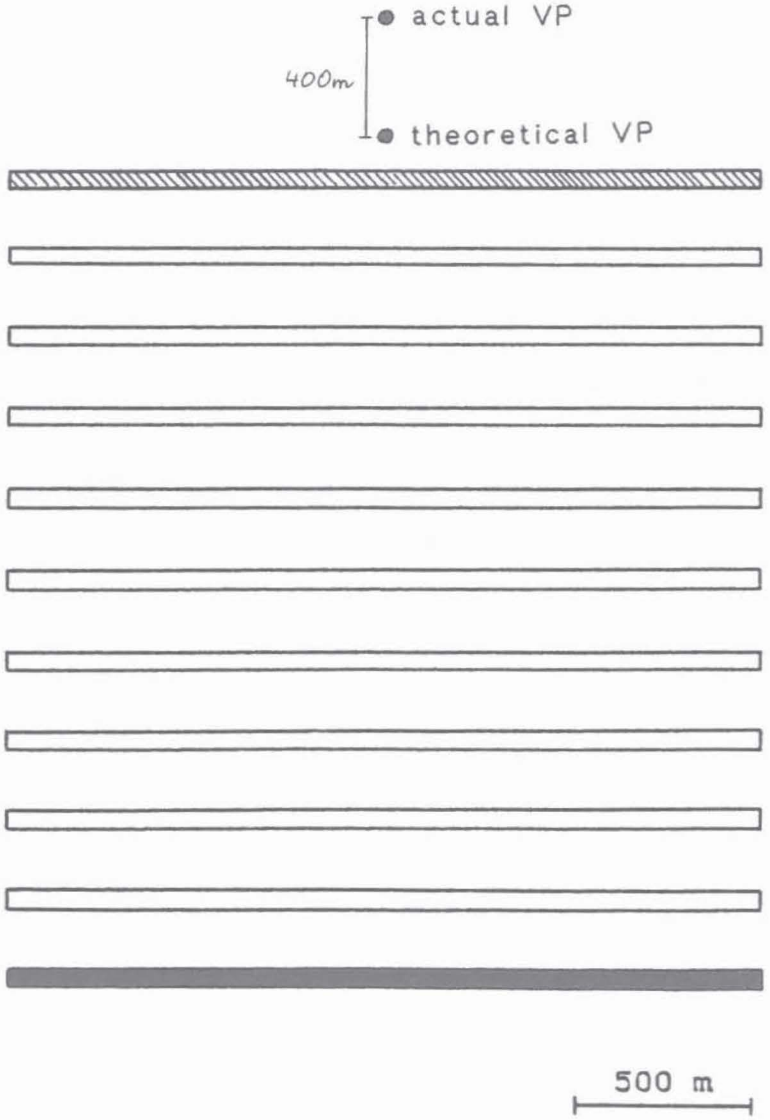

Fig. 10: Effect of an in-line shift of 350 - 450 m

Thus, in order to hold the number of changed bins to a minimum, it was necessary to permit only lateral shot point shifts as far as possible. It was better to allow a relatively large lateral shift than a rather small in-line shift.

A further consideration was that a clear bin assignment should be possible after the shift. This is illustrated in Figure 11. Let us assume that shot point A is to be shifted. For the theoretical shot position, the reflection points are in the middle of each of the marked bins. For a shift of less than 35 m, i.e. within the gray square, the reflection points fall within the white squares of the marked bins and are thus clearly within the bins. For a larger shift, the reflection points would be too close to the edge of the marked bins.

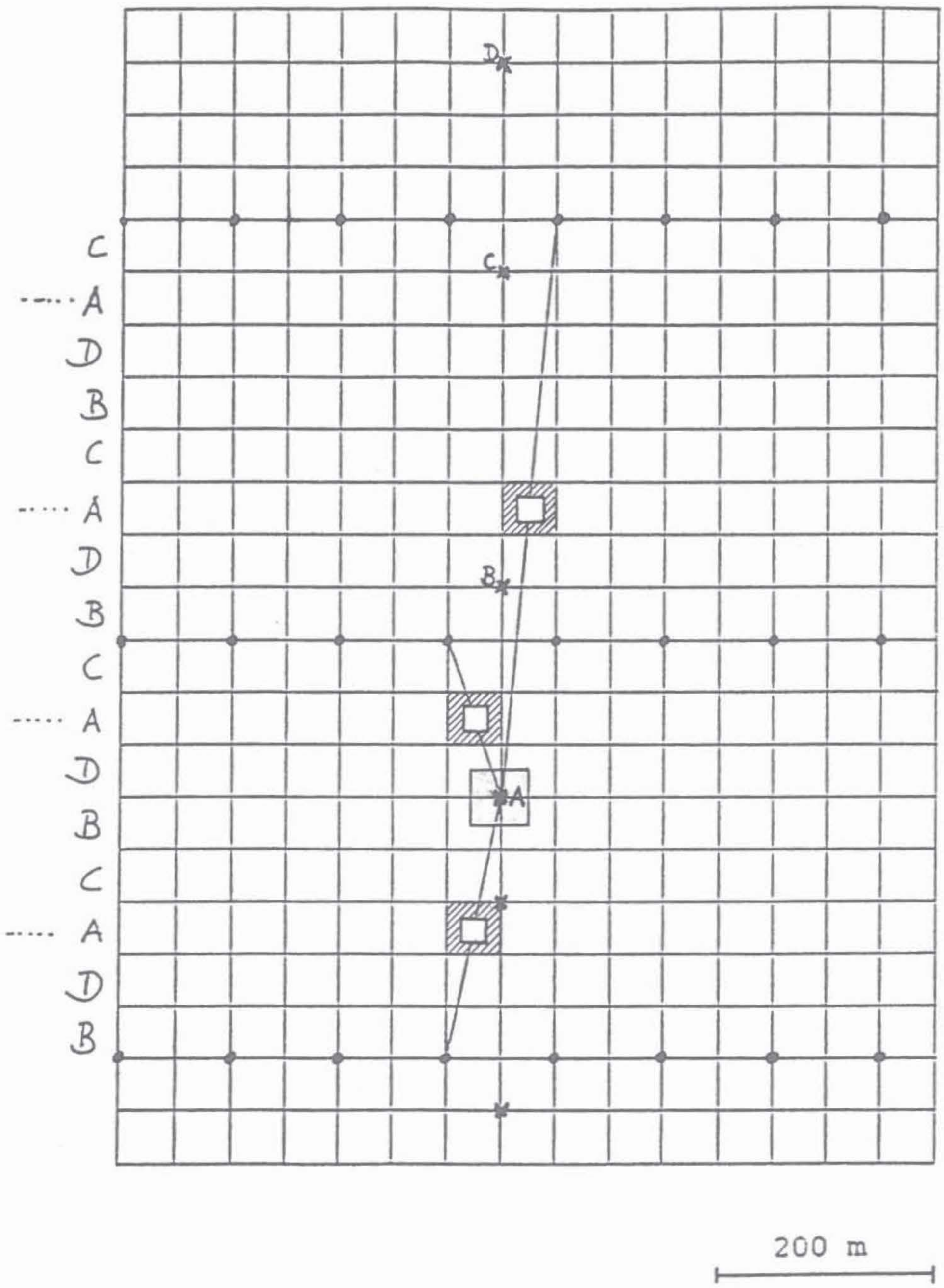

Fig. 11: Bin assignment for a shift of less than 35 m

To make sure the shifts are unambiguously within the proper range, a forbidden zone (n+25 to n+75 m) and an allowed zone (n+75 to n+125 m) were introduced, where n = 0, 100, 200 m, ... These zones can be recognized by the irregular shape of the histogram of the lateral offsets of all 3327 shots. Of the 3309 necessary lateral shifts, 1431 positions were in forbidden zones and 1878 in allowed zones (Fig. 12). Of the 3319 in-line shifts, only 17 were greater than 50 m, 3229 were less than 35 m, i.e. within the range for which bin assignment is unambiguous. Thus, only 90 in-line shifts, 2.79 % of all shot point shifts, were in a problematic range (Fig. 13).

In the field, a transparent sheet was used to recognize allowed and forbidden zones on the map. This was useful when it was necessary to make shot point shifts on the spot. By working closely with the surveying team and the field supervisor, nearly all of the 2100 shot locations were positioned so that the desired 12 - 15-fold coverage was obtained in almost all of the bins. In a small number of bins up to a 19-fold coverage was attained (Fig. 14). This happened when the shifts caused neighboring shot point lines to be rather close together. On the other hand, increased shot point line separations resulted in bins in which the 12 - 15-fold coverage was not obtained.

A good approximation of the desired at least one-fold coverage for source-receiver offsets of 0 - 850 m was also obtained (Fig. 15). This is even more surprising when it is considered that the actual shot and geophone locations (Fig. 16) are seldom close to the theoretical ones shown in Figure 4.

Instead of the planned 480 channels per shot, only 478 were recorded because the field correlator had a storage capacity for only this number of traces. Thus, always the first two geophone groups of each single array set-up were disconnected. Instead of the planned overall 8-fold vertical stacking, only 5-fold stacking was done for some of the shot points between the geophone lines. In a few cases at particularly vulnerable sites (gas lines, dikes, etc.) only three vibrators with lower energy output were used instead of the planned five vibrators.

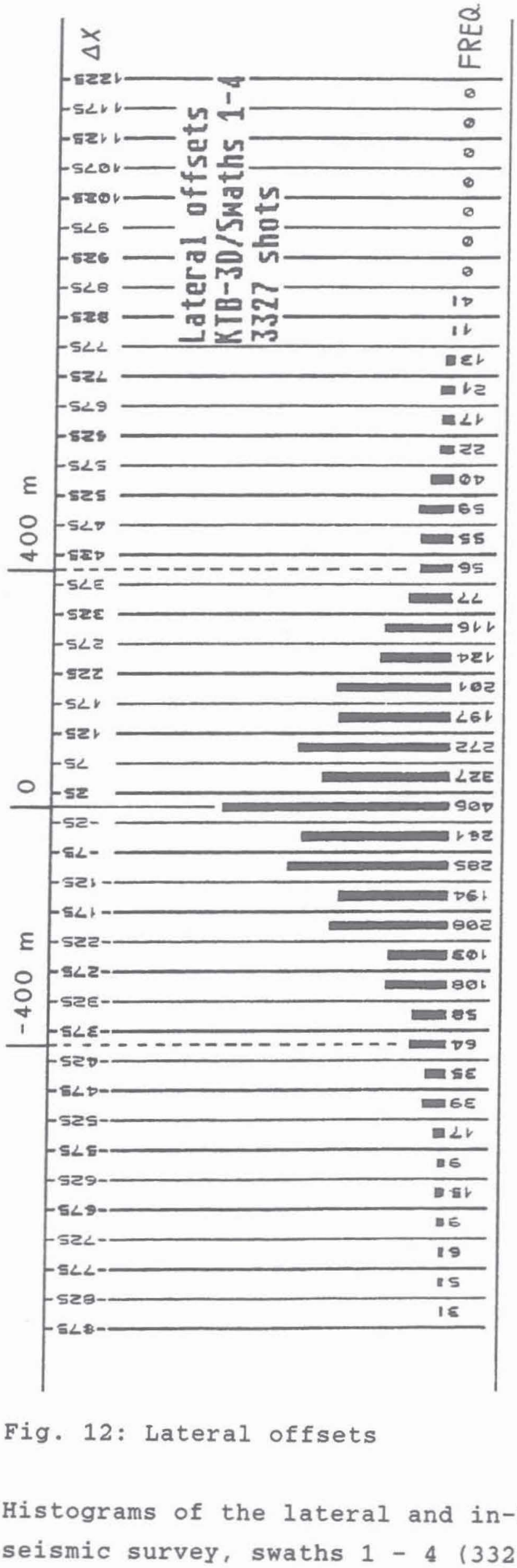

Fig. 12: Lateral offsets

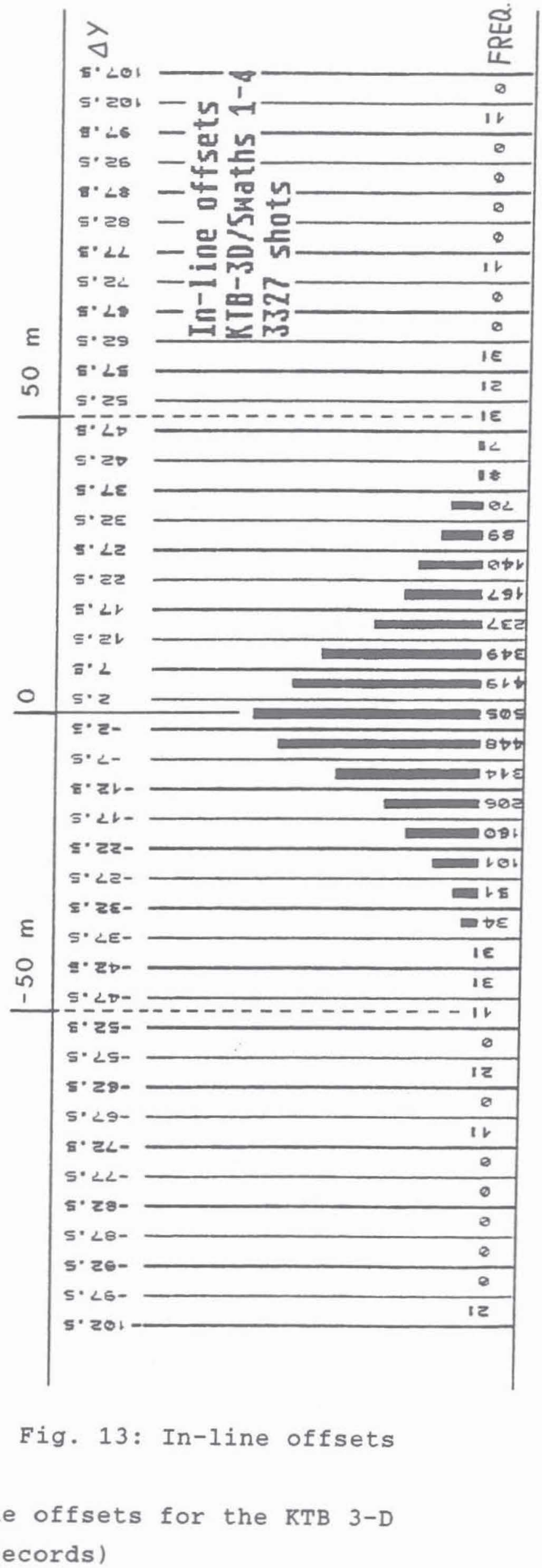

Fig. 13: In-line offsets

Histograms of the lateral and in-line offsets for the KTB 3-D seismic survey, swaths 1 - 4 (3327 records)

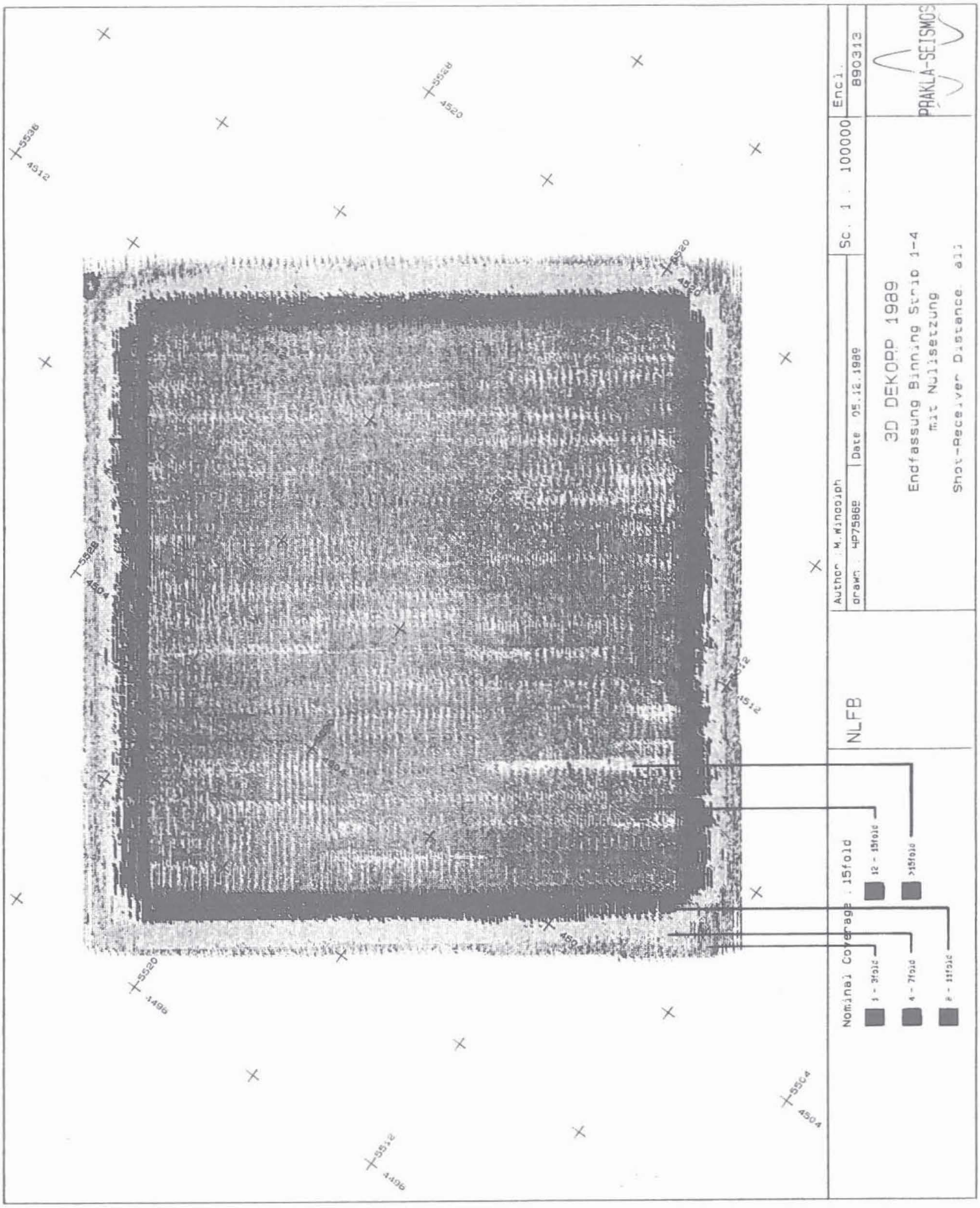

Fig. 14: Actual coverage, all source-receiver offsets
(prepared by Prakla-Seismos AG)

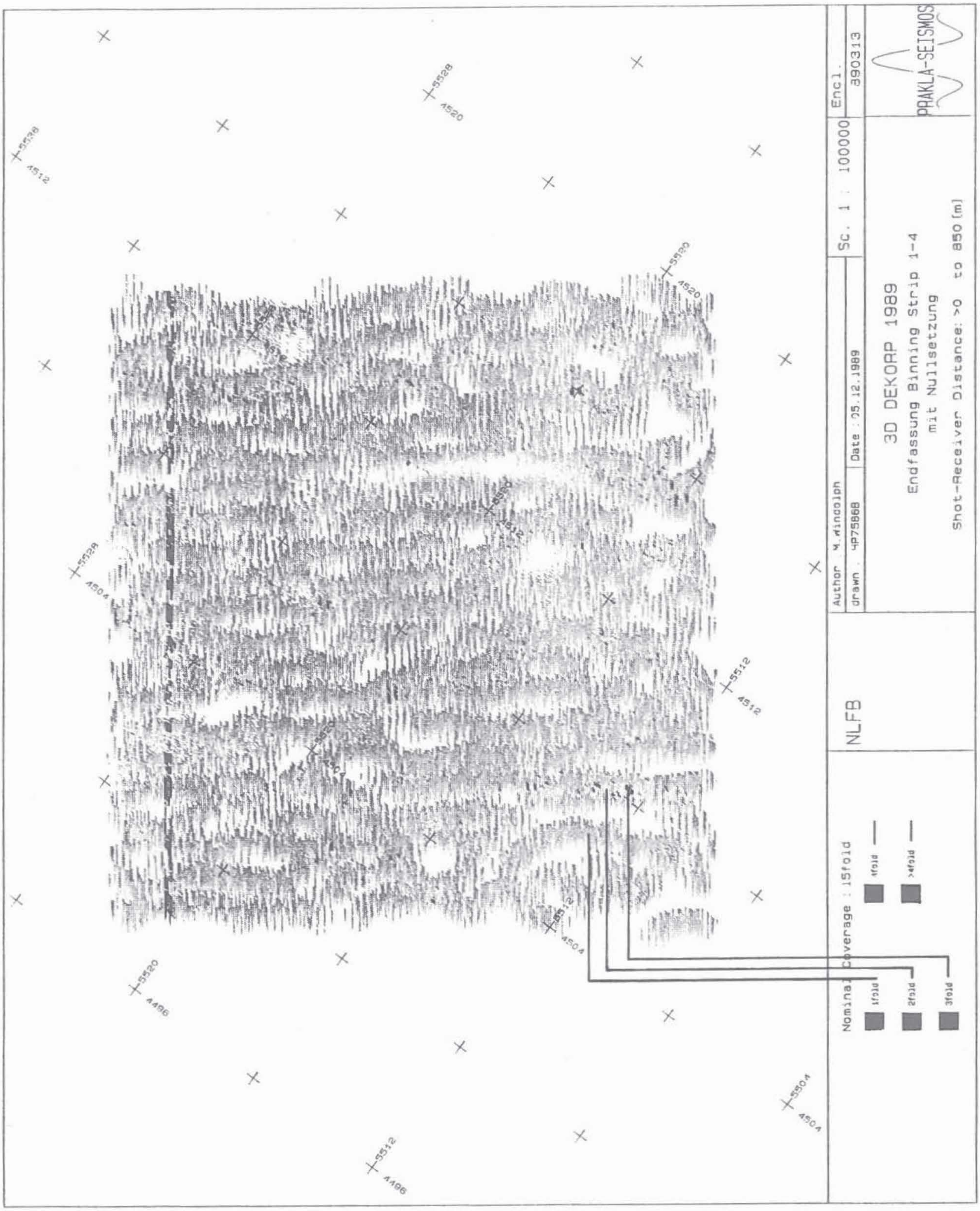

Fig. 15: Actual coverage, source-receiver offsets 0 - 850 m
(prepared by Prakla-Seismos AG)

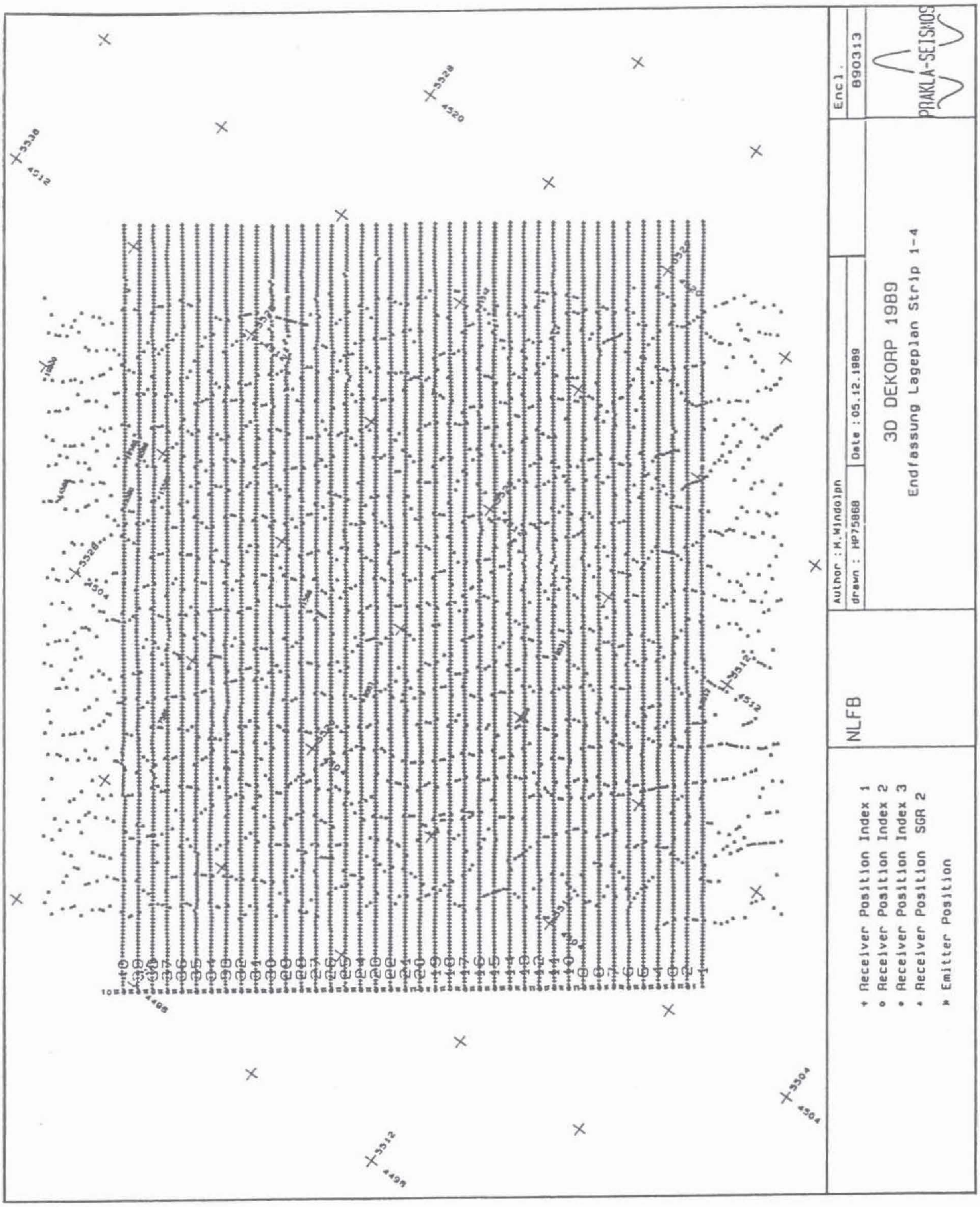

Fig. 16: Actual shot and geophone locations
(prepared by Prakla-Seismos AG)

Because special situations had to be taken into consideration (e.g. harvest time and the beginning of winter, which would have made many tracks impassable) the work was not done in a uniform manner, e.g. work was begun in swath 4 from SW to NE, as was also done in swath 3. Swath 2 was worked in the opposite direction, i.e. from NE to SW, and swath 1 was worked from SW to NE (Fig. 6). The survey took one week longer than planned.

3. Statistics

3.1 Geophone Groups, Shots, Seismic Traces, Data, and Bins

Because numerous geophone positions were the same for different array set-ups, only 8320 geophone positions needed to be surveyed. Owing to the reduction of channels per shot from 480 to 478 the theoretical number of seismic traces was also reduced from 1,612,800 to 1,606,080.

A total of 3327 shots were made. The difference between the actual and theoretical number of shots was only 33, or only 0.98 %. Trace loss owing to temporarily dead geophone locations amounted to 27,628 traces or 1.7 %. Total trace loss amounted to 50,122, or only 3.1 %, and thus was much less than the allowed maximum of 20 %. The total amount of data was more than 18 Gigabytes (1,562,678 traces) for a reflection time of 12 s. More than 250 magnetic tapes were necessary to record this data. By editing and arranging selected traces in an appropriate way 20 cross and 20 in-line single-fold sections were produced already during the seismic survey to allow an initial interpretation.

After the survey was finished the processing of the entire data immediately started including the first 7 s of reflection time, which amounts to 11.1 Gbytes. The covered area was divided into 50x50 m bins as planned. Owing to the lateral shifts of shot points at the edges of the survey area, the actual size of the at least one-fold covered area was 136,374 bins (357x382) instead of 131,008 bins (356x368) in the theoretical scheme.

3.2 CDP Distribution

In the theoretical scheme, the reflection points (called CDPs) are all in the bin centers. However, the lateral and in-line shifts in the field also shift the reflection points, so that in the real case they are distributed throughout each bin.

The first step after carrying out the 3-D binning (e.g. subdividing the area by a grid into bins) was the construction of a CDP bin and CMP scatter plot showing the distribution of the reflection points within each bin. A section of this plot is shown in Figure 17.

The CDP fold plot corresponding to this section is shown in Figure 18. The number in each sqare gives the number of the seismic traces within the respective bin, i.e. the subsurface coverage. The presence of a homogenous distribution of the desired 12 - 15-fold coverage can be clearly seen over this area.

To check the position of each reflection point within the bins, each bin was divided into 10-cm squares and a computer program counted the reflection points within each of these squares. The result is shown in Figure 19 in the form of frequency distribution curves for the distance of the reflection points from the bin edges (one for the left edge and one for the bottom edge). It can be seen that most of the points are near the bin center, as they should be (maxima at 25 m on x-axis and 25 m on y-axis). Thus, there was an optimum selection of origin and orientation of the defined grid of 50x50 m bins.

The ratio of maximum to minimum frequency is about 10 times greater for the y-axis than for the x-axis. The reason for this is that the in-line shifts in shot positions (allowed max. 35 m) were considerably less than those in the lateral direction (allowed max. 800 m).

The 25 bins within the marked square in Fig. 17 represent the area around the KTB borehole site. In this area the scatter of the points is close to the mean or smaller.

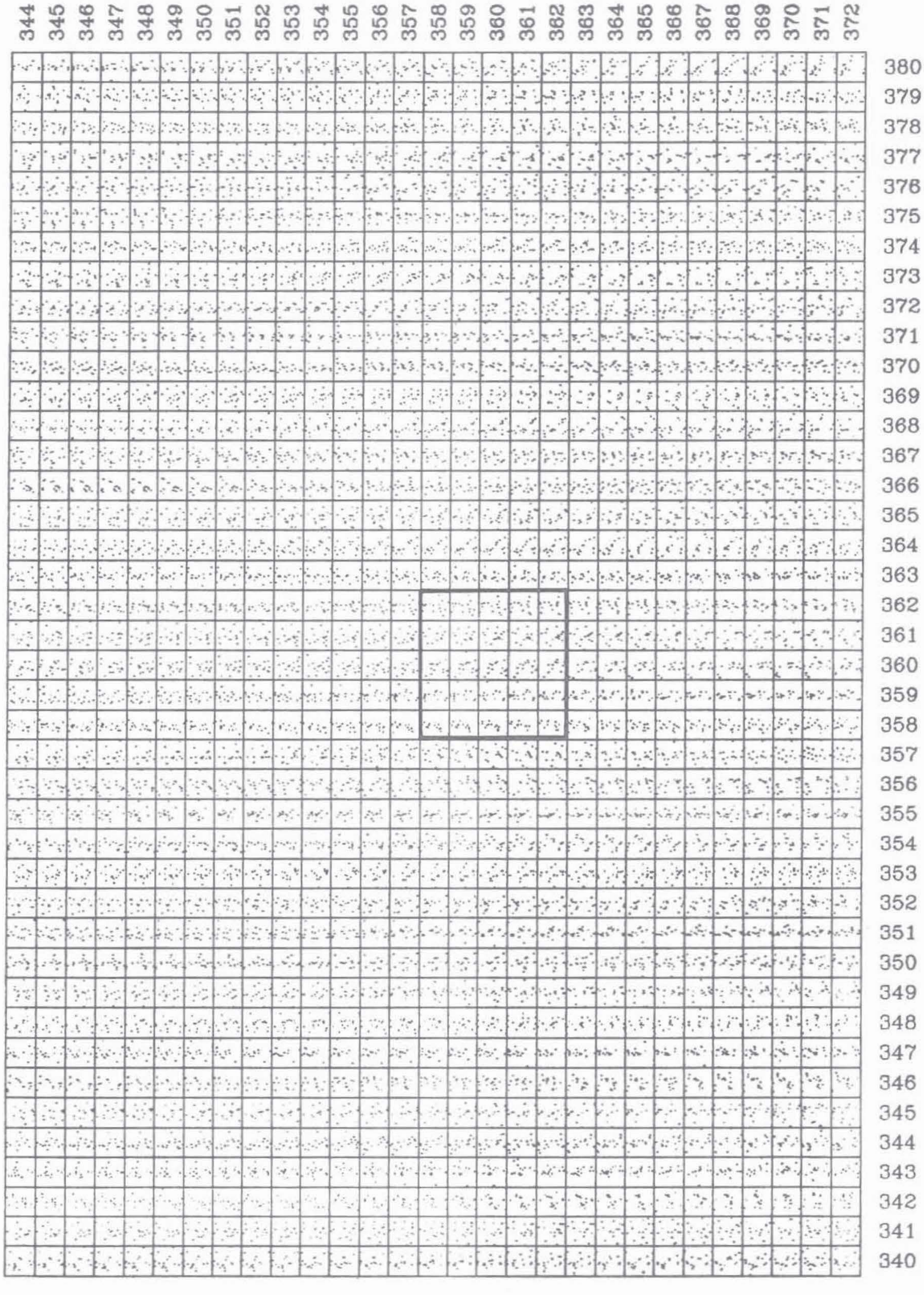

Fig. 17: CDP bin and CMP scatter plot

344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	
13	14	15	15	14	15	15	15	14	16	15	15	16	15	16	16	16	14	16	15	16	13	15	14	15	17	16	16	14	380
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14	15	15	15	15	16	16	16	15	16	16	17	15	17	16	16	18	14	16	15	15	16	14	14	15	16	16	16	14	356
15	15	15	15	15	15	15	15	16	16	16	14	14	15	16	16	16	16	15	14	15	15	15	15	16	16	17	15	16	355
15	16	15	15	15	15	15	15	13	13	13	16	15	15	14	15	15	15	15	15	15	15	15	13	15	15	15	15	14	354
15	15	15	15	15	15	15	15	14	16	15	15	16	15	15	16	16	15	16	15	16	15	15	14	14	16	15	17	16	353
15	15	15	14	16	15	15	15	15	16	16	16	15	15	15	15	16	16	16	16	15	15	15	14	15	15	16	16	15	352
15	15	15	15	14	15	16	15	15	16	16	14	15	15	16	16	16	16	15	15	15	15	14	15	16	16	16	16	16	351
16	15	15	15	15	15	15	15	13	13	13	15	15	16	15	15	15	15	14	15	15	15	17	13	16	15	15	15	15	350
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16	15	15	14	15	15	15	15	15	16	16	16	15	14	16	17	16	17	15	16	14	14	16	14	15	16	18	16	15	348
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14	15	15	16	16	16	15	16	16	16	15	17	16	16	16	16	16	16	16	15	15	16	16	13	14	15	16	16	15	344
15	15	14	15	15	15	15	15	16	15	15	14	15	16	16	15	16	15	14	14	15	14	14	15	17	14	16	15	15	343
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12	14	14	14	14	14	14	14	12	15	15	15	16	16	16	16	15	15	15	15	14	15	15	15	15	13	14	17	17	341
15	14	14	16	16	17	16	16	16	15	16	14	16	14	16	16	17	16	17	15	15	16	13	14	14	15	16	17	15	340

Fig. 18: CDP fold plot

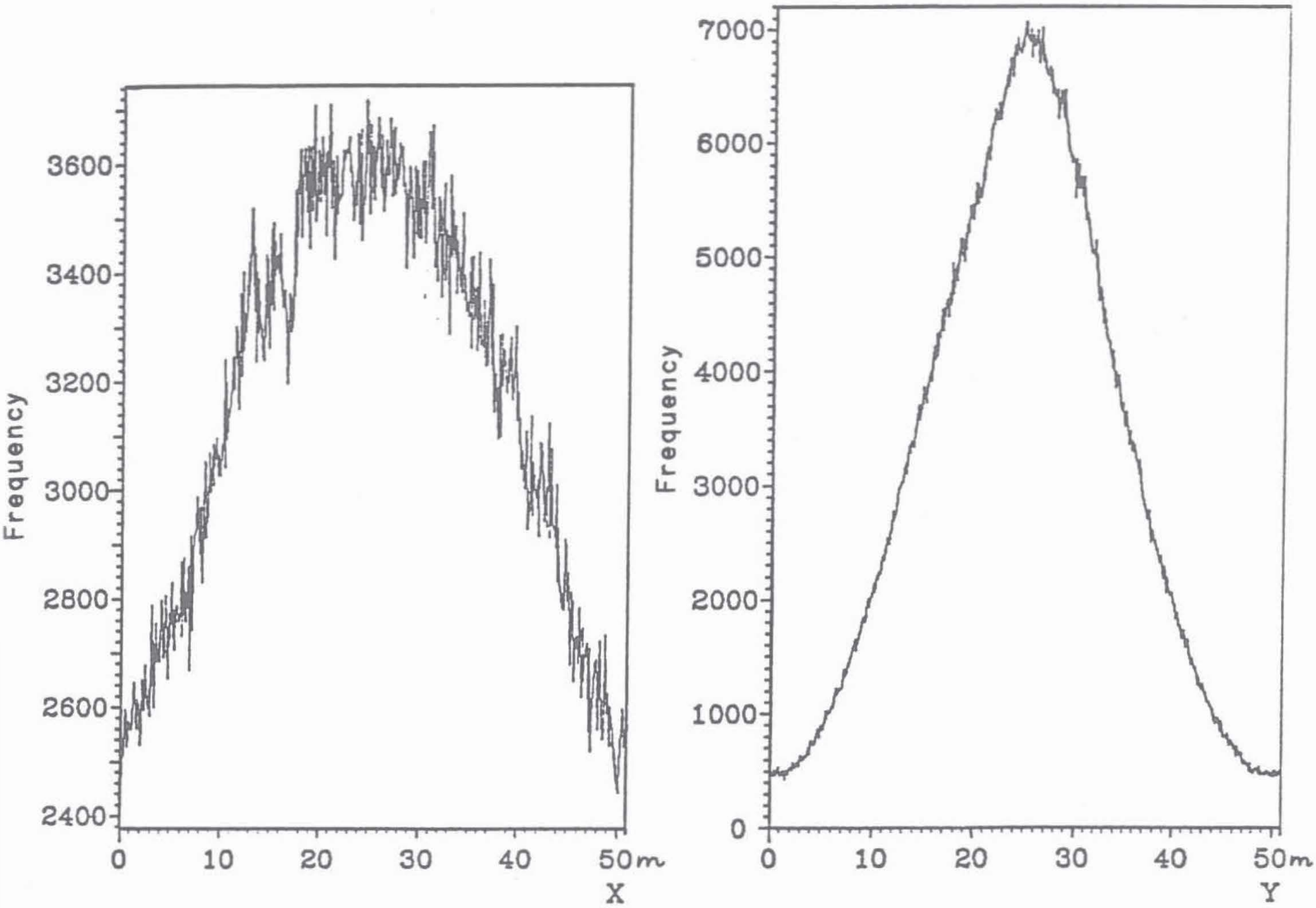


Fig. 19: Frequency distribution curves for the distance of the CMPs from the edges of the bins
left : distance from the left edge
right: distance from the bottom edge

3.3 Offset and Angle Distributions

Owing to the unavoidable in-line and lateral shifts of shot points, the actual source-receiver offset range (2 - 6580 m) was somewhat larger than the theoretical one (72 - 6212 m). The frequency distribution of the offsets for the 3360 theoretical shots points is shown in Figure 20. It can be seen that the frequencies for some offset ranges (e.g. 2300 - 2400 m and 2700 - 2800 m) deviate considerably from a smooth distribution curve, whereas the histogram for the 3327 actual shot points (Fig. 21) is significantly smoother, because of statistical equalization.

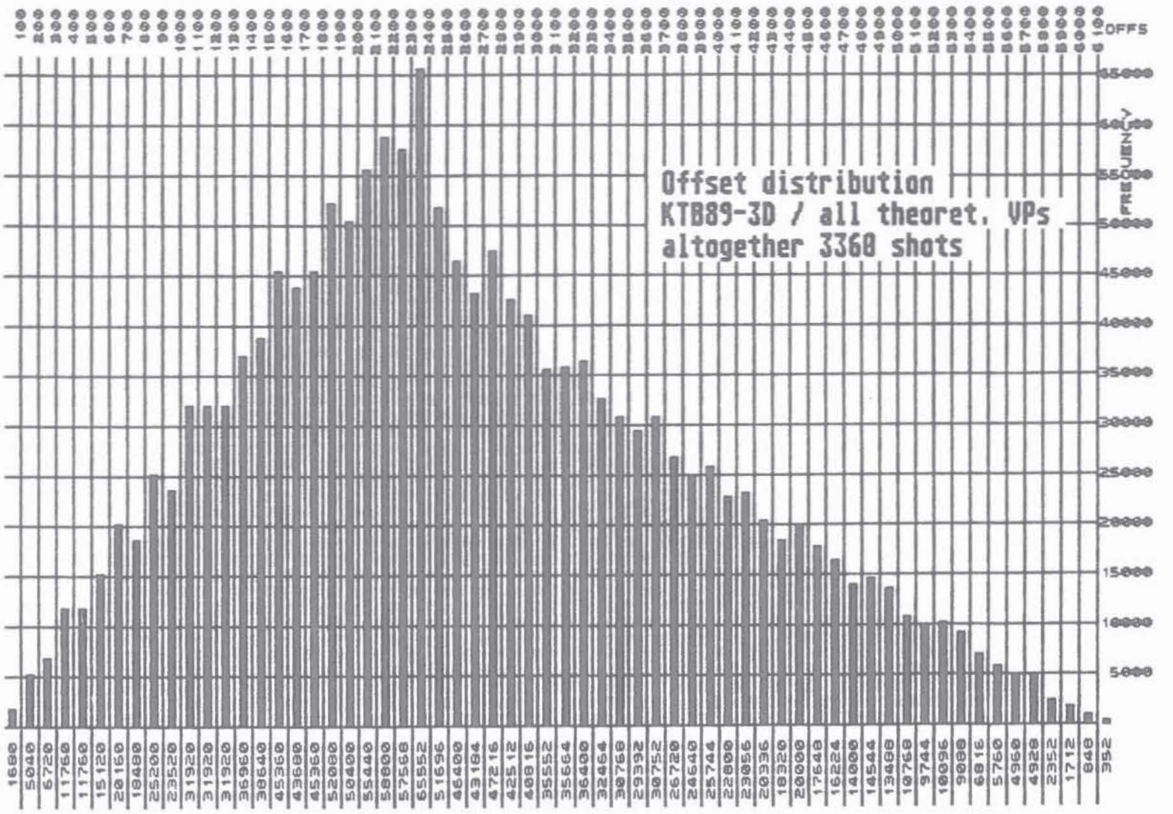


Fig. 20: Frequency distribution of the source-receiver offsets for the theoretical shot points

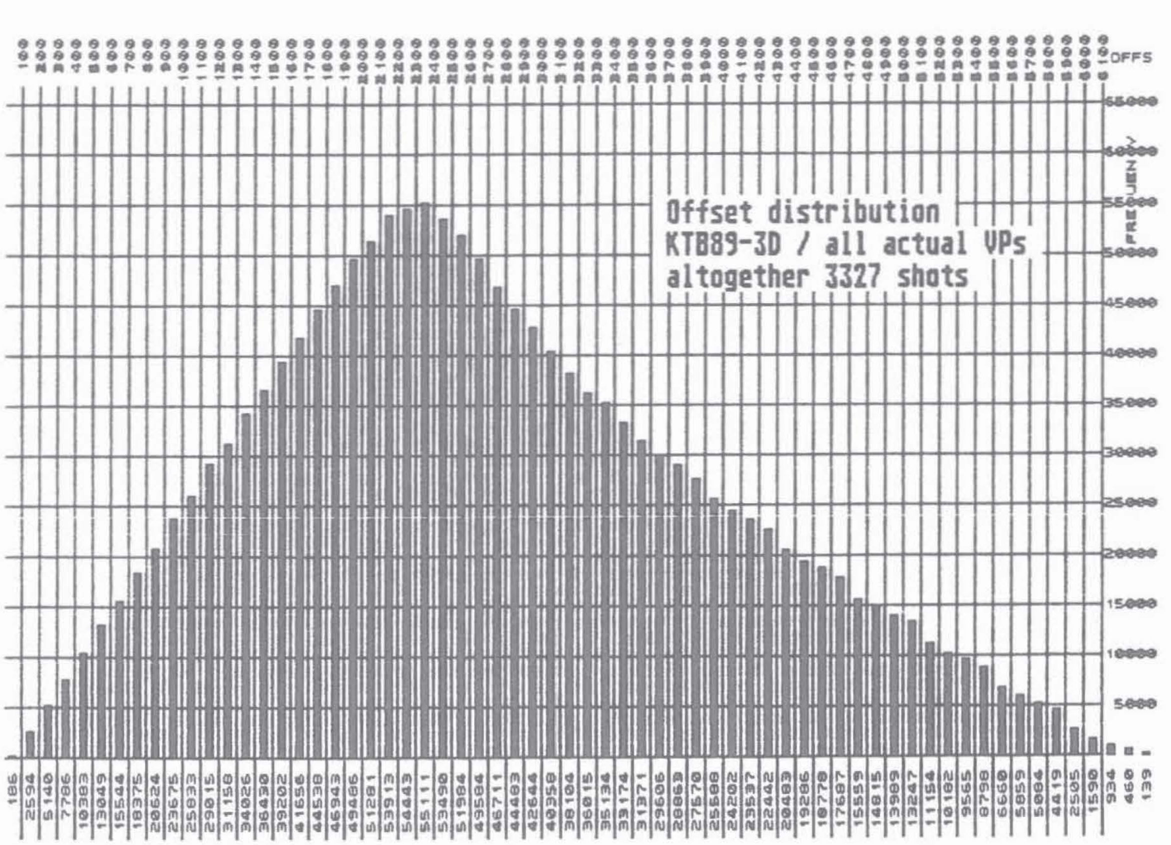


Fig. 21: Frequency distribution of the source-receiver offsets for the actual shot points

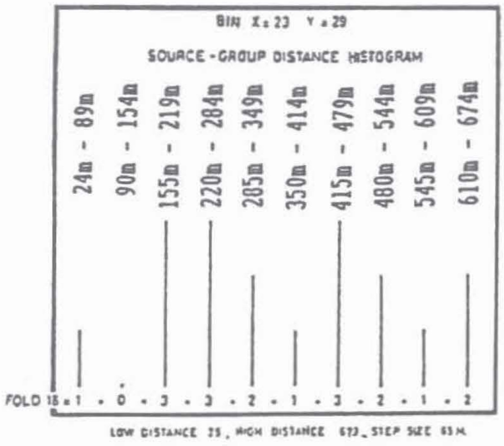


Fig. 22:

Histogram of the source-receiver offsets for one bin

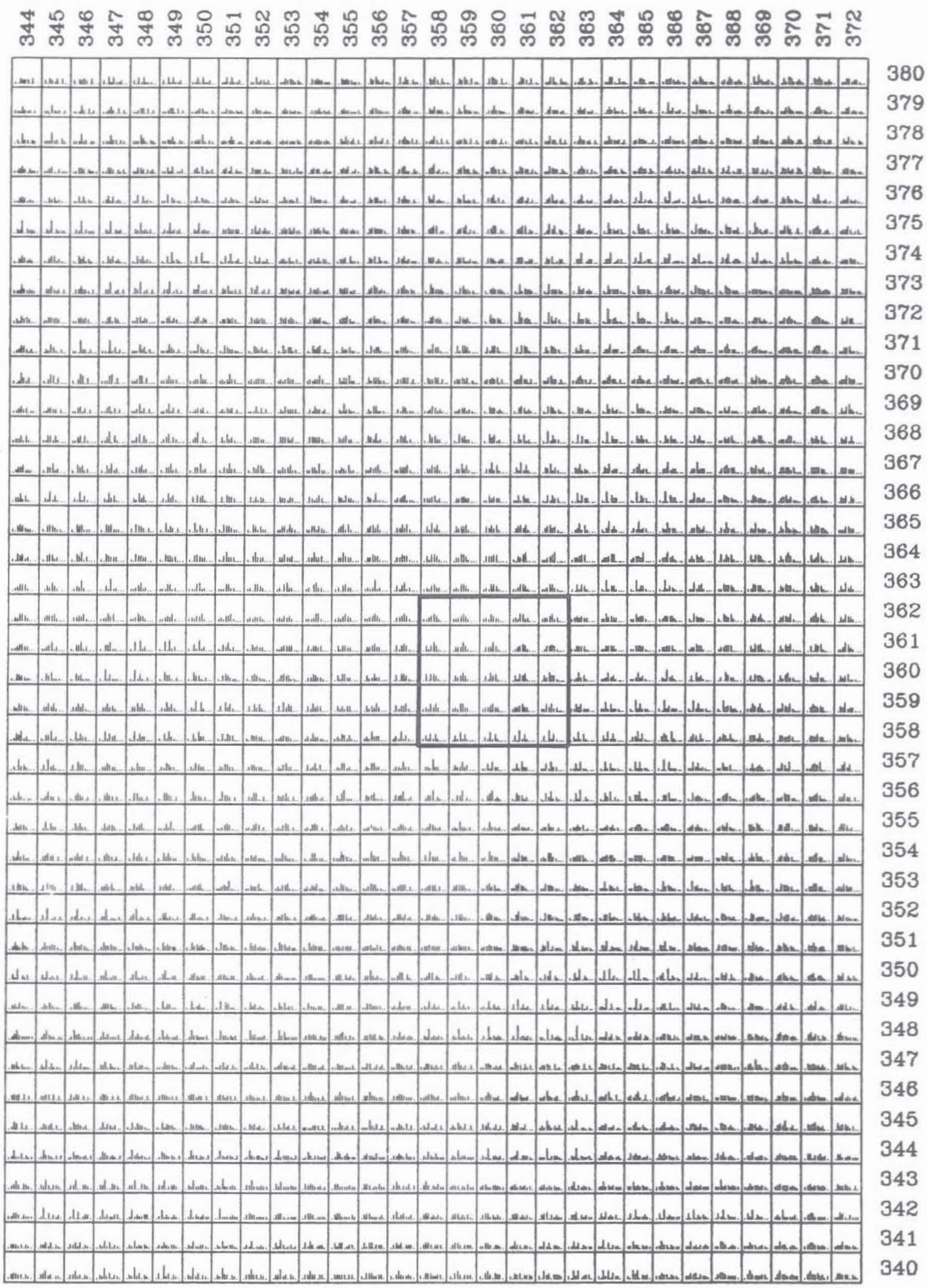
The distribution of source-receiver offsets for a selected bin is shown by the histogram in Figure 22. The offset distributions in the area around the KTB drilling site are shown in Figure 23. In the marked 25 bins immediately around the KTB borehole the distribution is close to the mean or somewhat poorer.

The most frequent offsets are in the 2300 - 2400 m range. The connection lines between sources and receivers for a single array set-up are shown for this offset range in Figure 24. It can be seen that nearly every source-receiver azimuth is present.

A relatively large number of angles occur also for very small offsets, as can be seen in Figure 25 for the source-receiver offset range of 300 - 400 m. Only the azimuths close to the direction of the geophone lines are underrepresented.

A different situation is seen for the range of very large source-receiver offsets (e.g. the range from 5600 - 5700 m shown in Fig. 26). The azimuths here are all in the range of 10 - 23° from the direction of the shot point lines.

For 3-D seismics, it is very important that the azimuth distribution is homogeneous, in contrast to 2-D seismics, for which all connection lines between sources and receivers have nearly the same direction (i.e. the profile direction).




```
smallest offset :   19 m
largest  offset : 6460 m
offset interval :  644 m
```

Fig. 23: Distribution of the source-receiver offsets in the area around the KTB borehole site

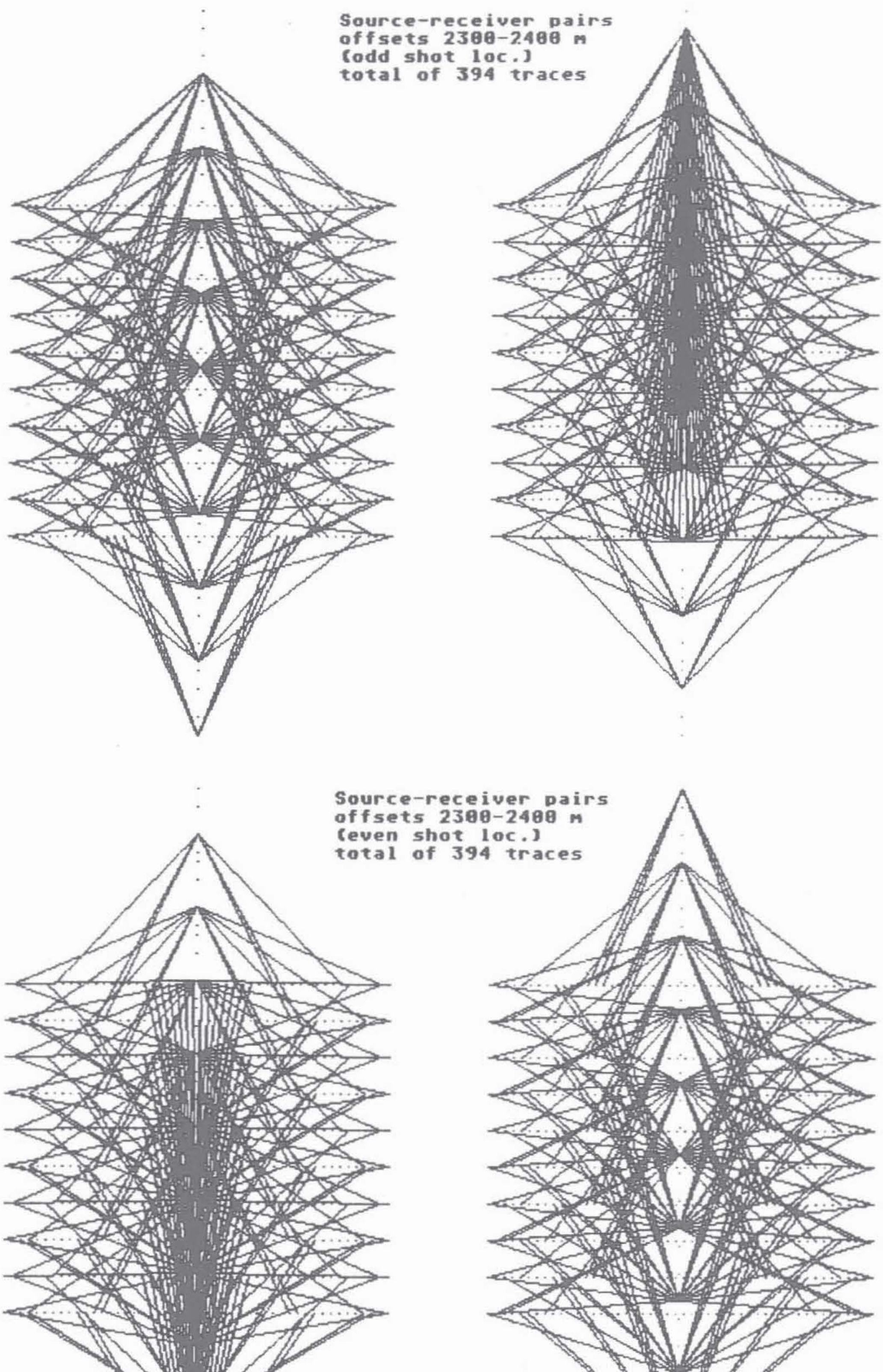


Fig. 24: Connection lines between sources and receivers for the offset range from 2300 - 2400 m

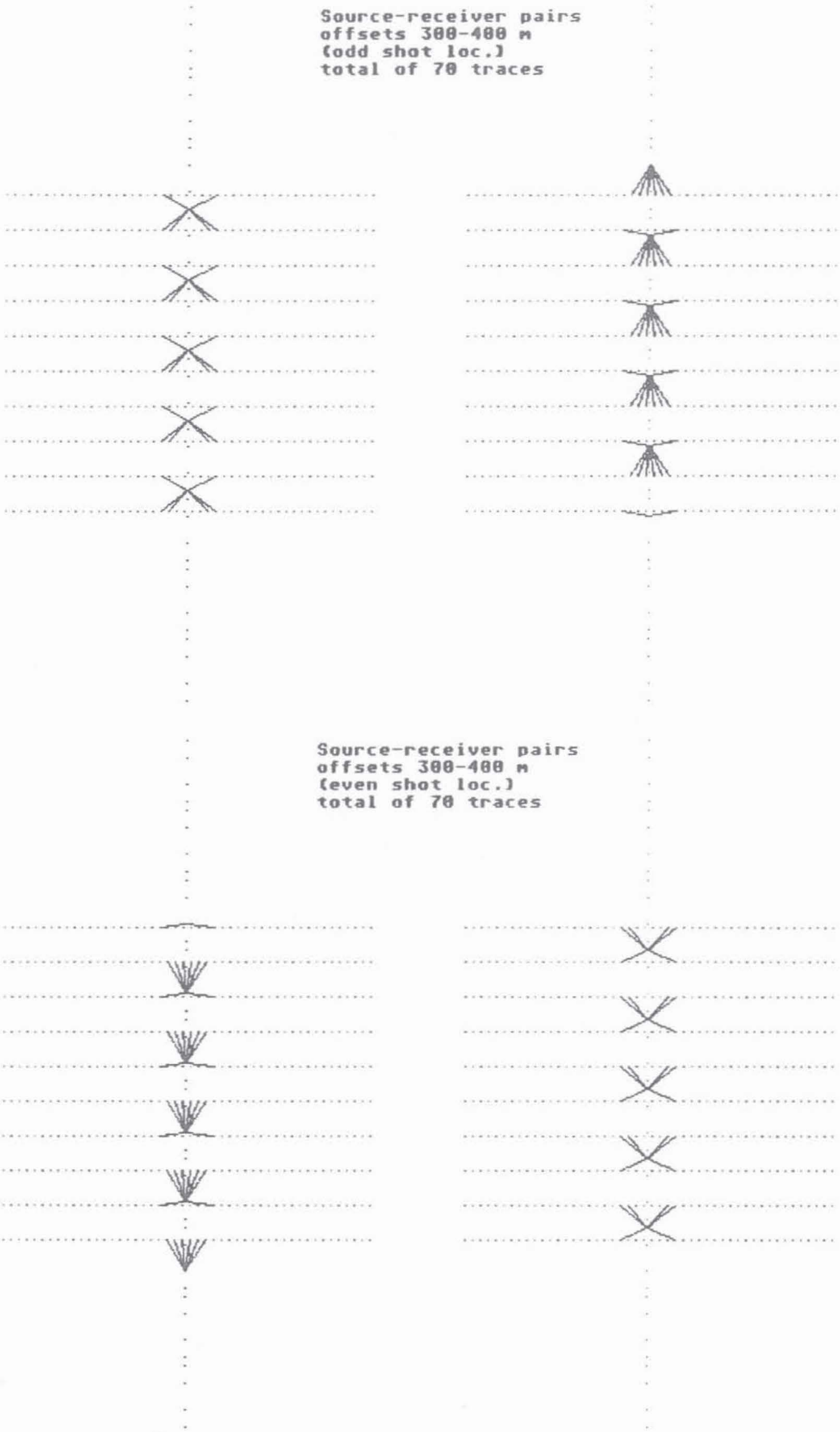


Fig. 25: Connection lines between sources and receivers for the offset range from 300 - 400 m

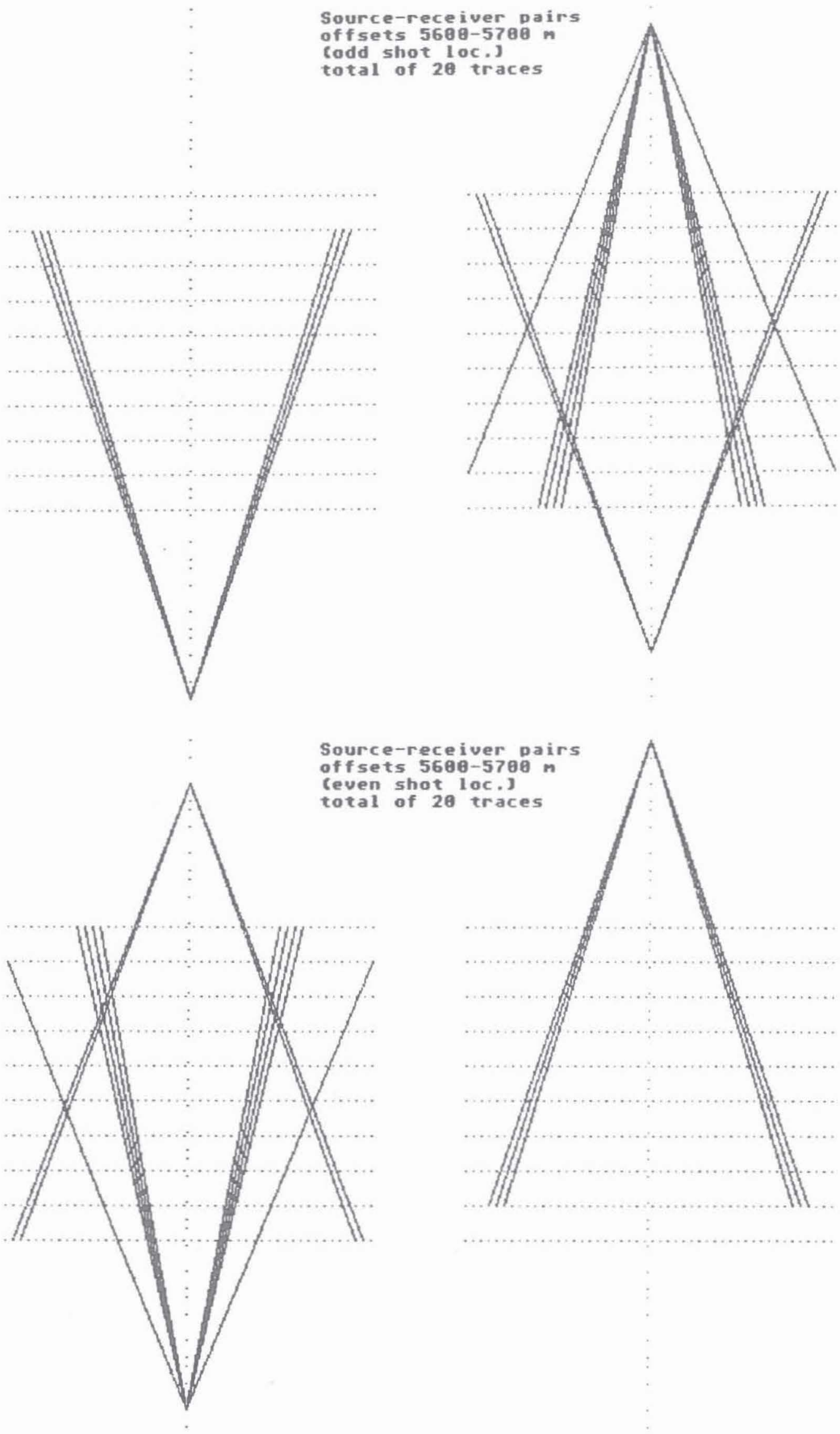


Fig. 26: Connection lines between sources and receivers for the offset range from 5600 - 5700 m

Whereas in 2-D seismics only a single stacking velocity can be used for a specific horizon (due to uniform source-receiver azimuths), in 3-D seismics the stacking velocity for the same horizon changes with the source-receiver azimuth. The largest stacking velocity is for an azimuth parallel to the dip direction, the smallest one is for an azimuth parallel to the direction of strike. Thus, for an event produced by a dipping horizon on different traces of a bin the dynamic corrections are a function of the source-receiver azimuth, even when the source-receiver offsets are the same.

When the stacking velocities for all azimuths of a dipping horizon are plotted, an ellipse is obtained (Fig. 27). The short axis represents the stacking velocity parallel to strike, the long axis represents the stacking velocity parallel to the dip. The angle β represents the angle between the direction of dip and the connection line between shot point and geophone group.

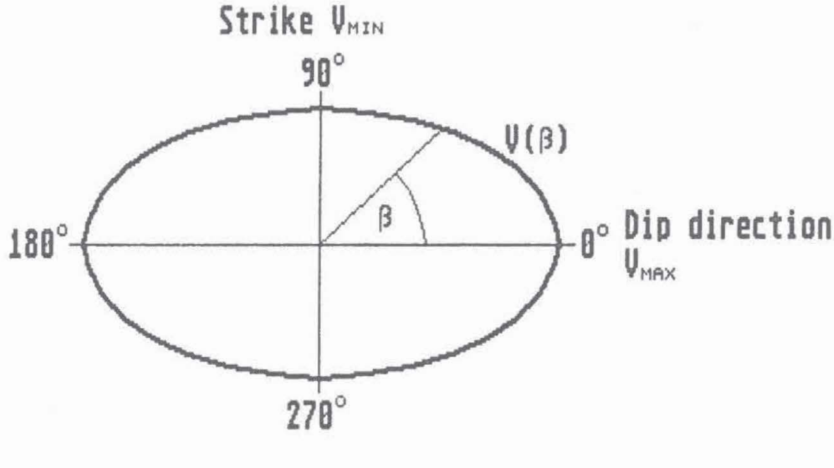


Fig. 27: Ellipse of stacking velocities for a dipping layer

When 3-D data is processed, the stacking velocity is determined for four direction ranges separated by 45° (Fig. 28). For this purpose, a half circle is divided into four 45° ranges, yielding the angles α_i (i=1,2,3,4) in the middle of each range. The ranges 180°+α_i are treated in the same way as the ranges α_i, since they represent only the exchange of source and receiver. The optimum stacking velocities for the four azimuth ranges α_i are used to construct a velocity ellipse (least squares method). This ellipse is then used to calculate the dynamic correction for each individual source-receiver azimuth.

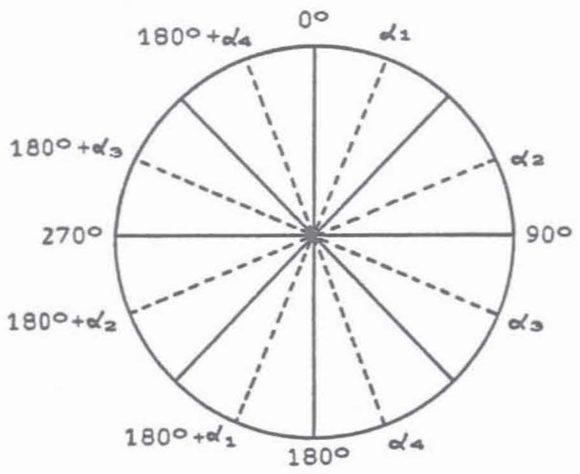


Fig. 28:

Division of a circle into 45° azimuth ranges

The length of each line in an angular distribution plot for one bin (Fig. 29) represents the number of traces in that azimuth range. A poor distribution of angles is indicated by the presence of lines considerably longer than the others. Lines of uniform length indicate a good distribution of source-receiver azimuths and nearly the same number of traces in all directions.

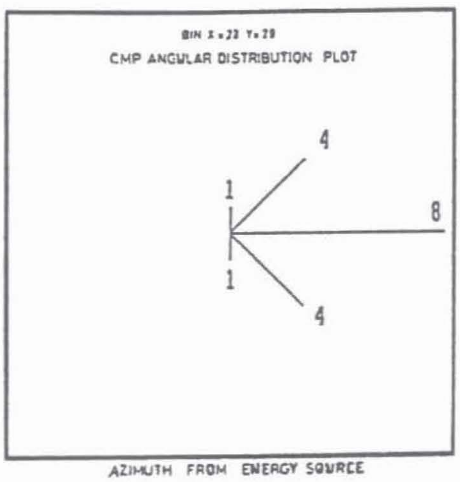


Fig. 29:

CMP angular distribution for one bin

There is a uniform distribution of angles in the 25 bins marked in Figure 30, representing the area immediately around the KTB borehole site. The frequency distribution of the source--receiver azimuths of the 3360 theoretical shot points is shown in Figure 31. The azimuths in geophone line direction are somewhat less frequent than those in the direction of the shot point lines. The histogram for the 3327 actual shot points (Fig. 32) is again smoother because of statisical equalization.

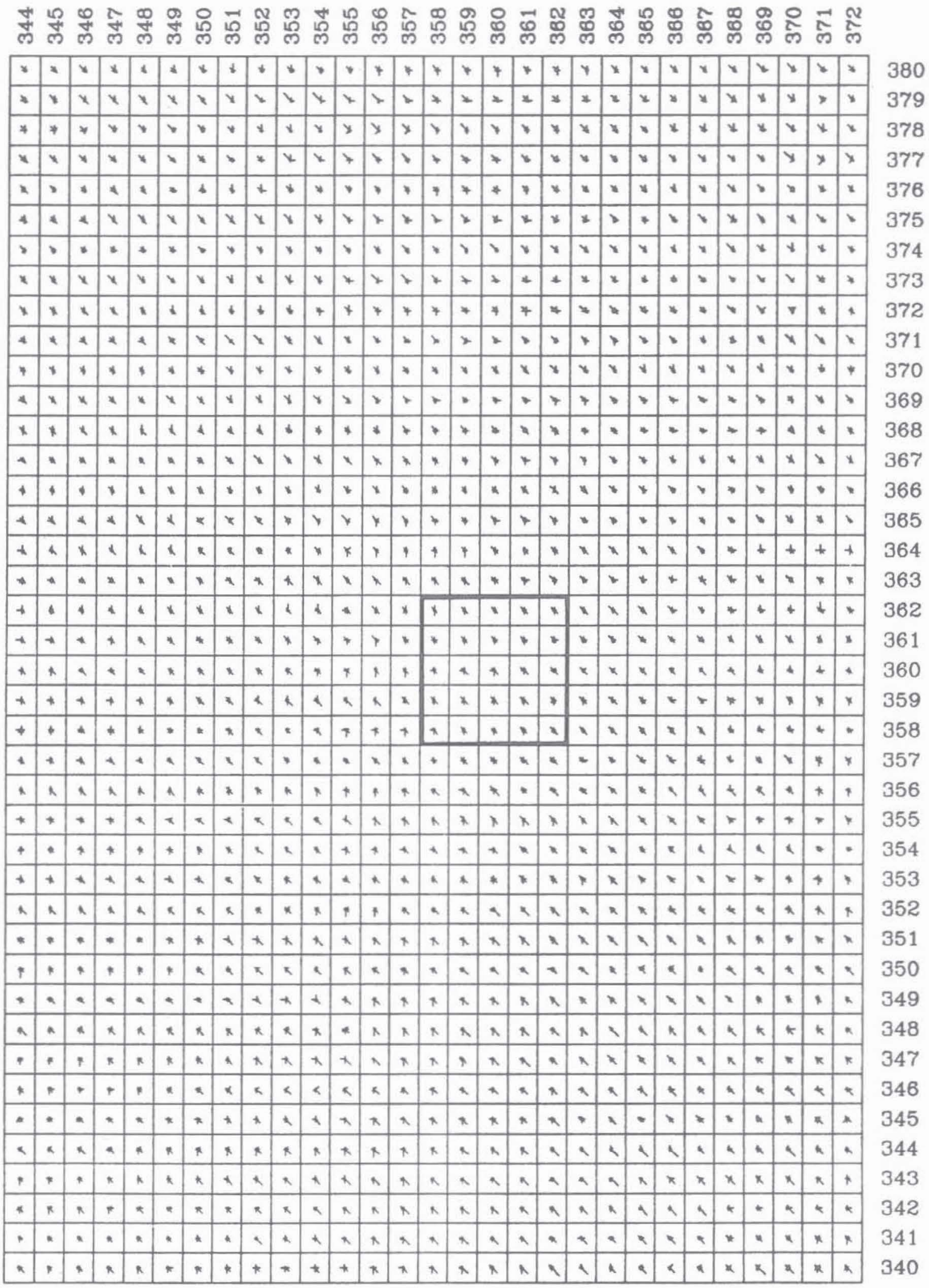


Fig. 30: Distribution of source-receiver azimuths in the area around the KTB borehole site

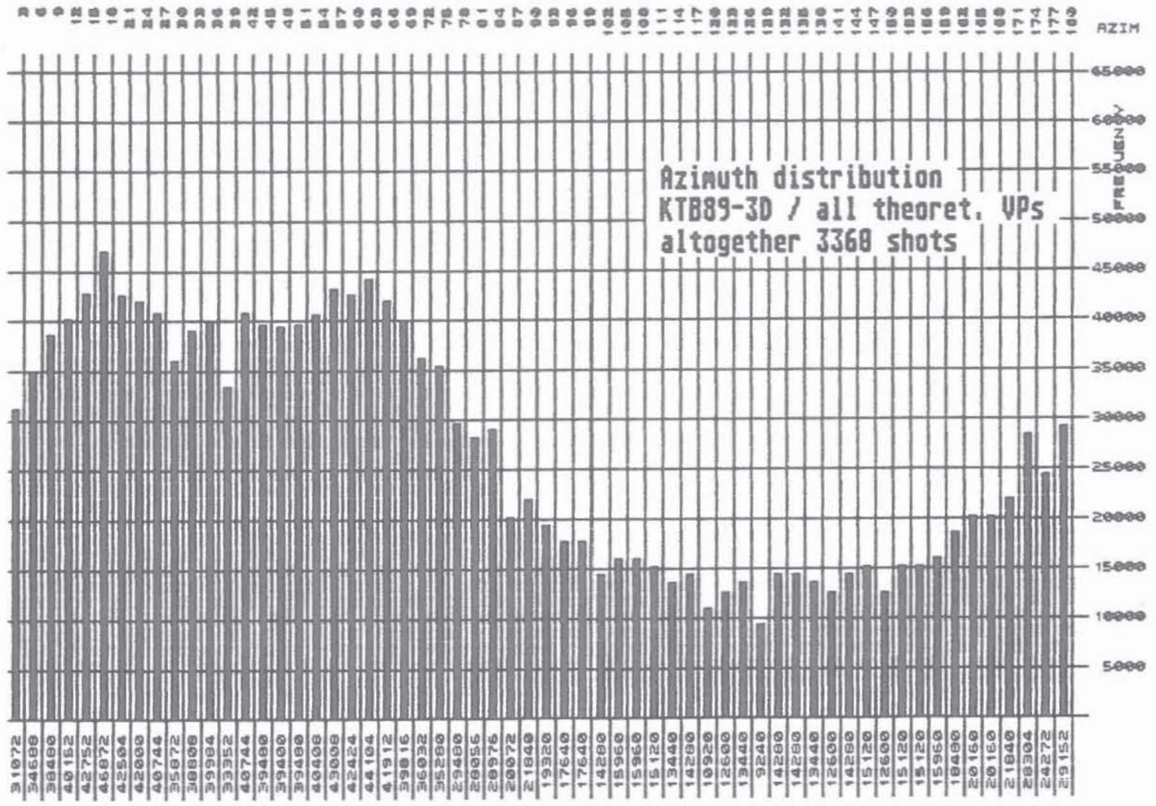


Fig. 31: Frequency distribution of the source-receiver azimuths for the theoretical shot points

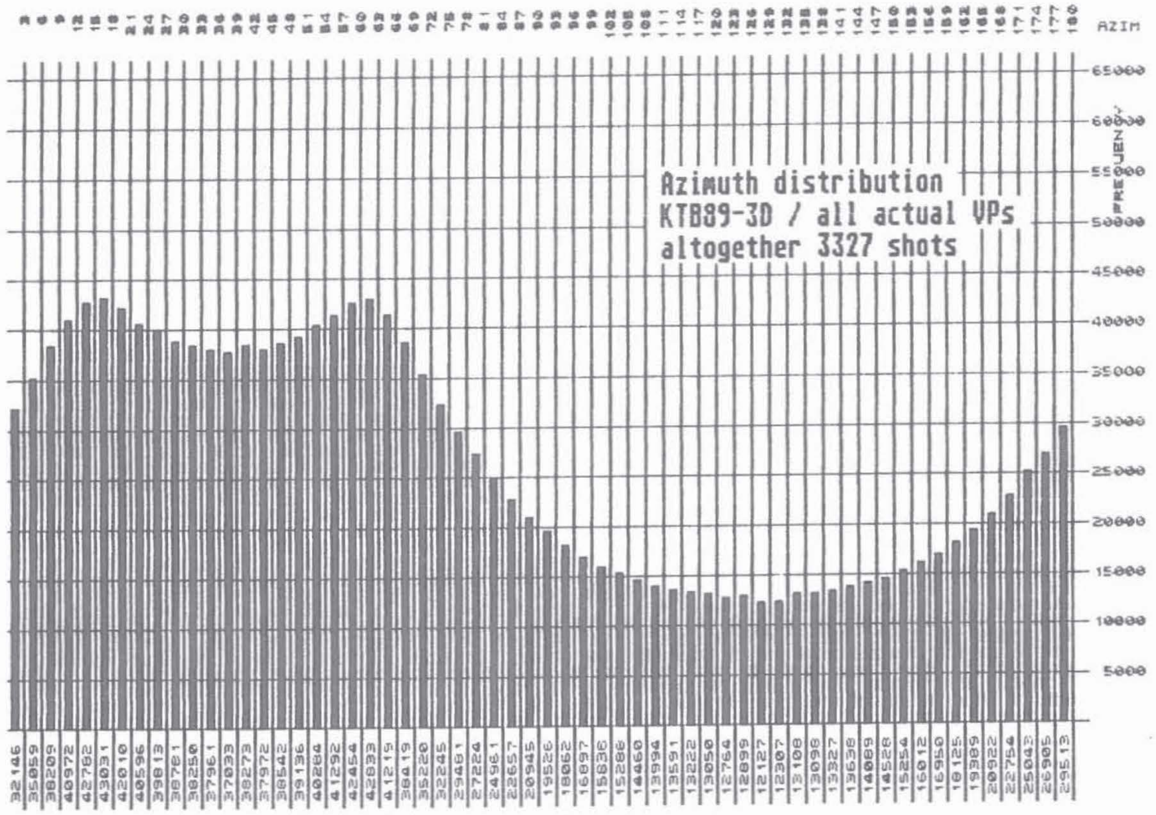


Fig. 32: Frequency distribution of the source-receiver azimuths for the actual shot points

The following table summarizes all important survey parameters:

method:	Vibroseis	
equipment:	SERCEL SN 368 (telemetric)	
sampling rate:	4 ms	
instrument filter:	8Hz 18db/o. 88.8Hz 72db/o.	
source:	5 vibrators VVEA	
vertical stacking rate:	5 - 8 fold	
sweep frequency:	12 - 48 Hz (up-sweep)	
sweep length:	20 s	
reflection time:	12 s (after correlation)	
recording configuration:	cross array	
datum level:	500 m above msl	
number of swaths:	4	
separation between swath centers:	4 km	
geophone lines per swath:	10	
total number of geophon lines:	40	
separation between geophone lines:	400 m	
geophone groups per geophon line and swath:	208	
geophone groups per shot:	478 (theor. 480)	
geophone groups per geophon line and shot:	48 (first line 46)	
separation between geophone groups:	100 m	
geophones per geophone group:	18 (3-vane fan)	
total number of geophone locations:	8320	
shot point lines per swath:	21	
separation between shot point lines:	800 m	
shot points per shot point line and swath:	40	
total number of shot points per shot line:	100	
separation between shot points:	100 - 300 m	
total number of shots:	3327 (theor. 3360)	
total number of shot locations:	2084 (theor. 2100)	
bin size:	50x50 m	
area covered by a single array set-up:	2.4x5.8 km	
one-fold covered area:	17.9x19.1 km	(theor. 17.8x18.4 km)
15-fold covered area:	15.2x14.4 km	
total number of bins:	357x382=136.374	(theor.356x368=131.008)
total number of traces:	1.562.678	(theor. 1.612.800)
source-receiver offset:	2-6580 m	(theor. 72-6212 m)
maximum fold:	19	(theor. 15)
average fold:	11.5	(theor. 12.3)

3.4 Elevations

The elevations surveyed during this seismic survey have been processed into a relief model of the survey area, shown for subarea B (see location map in Fig. 1) in Figure 33.

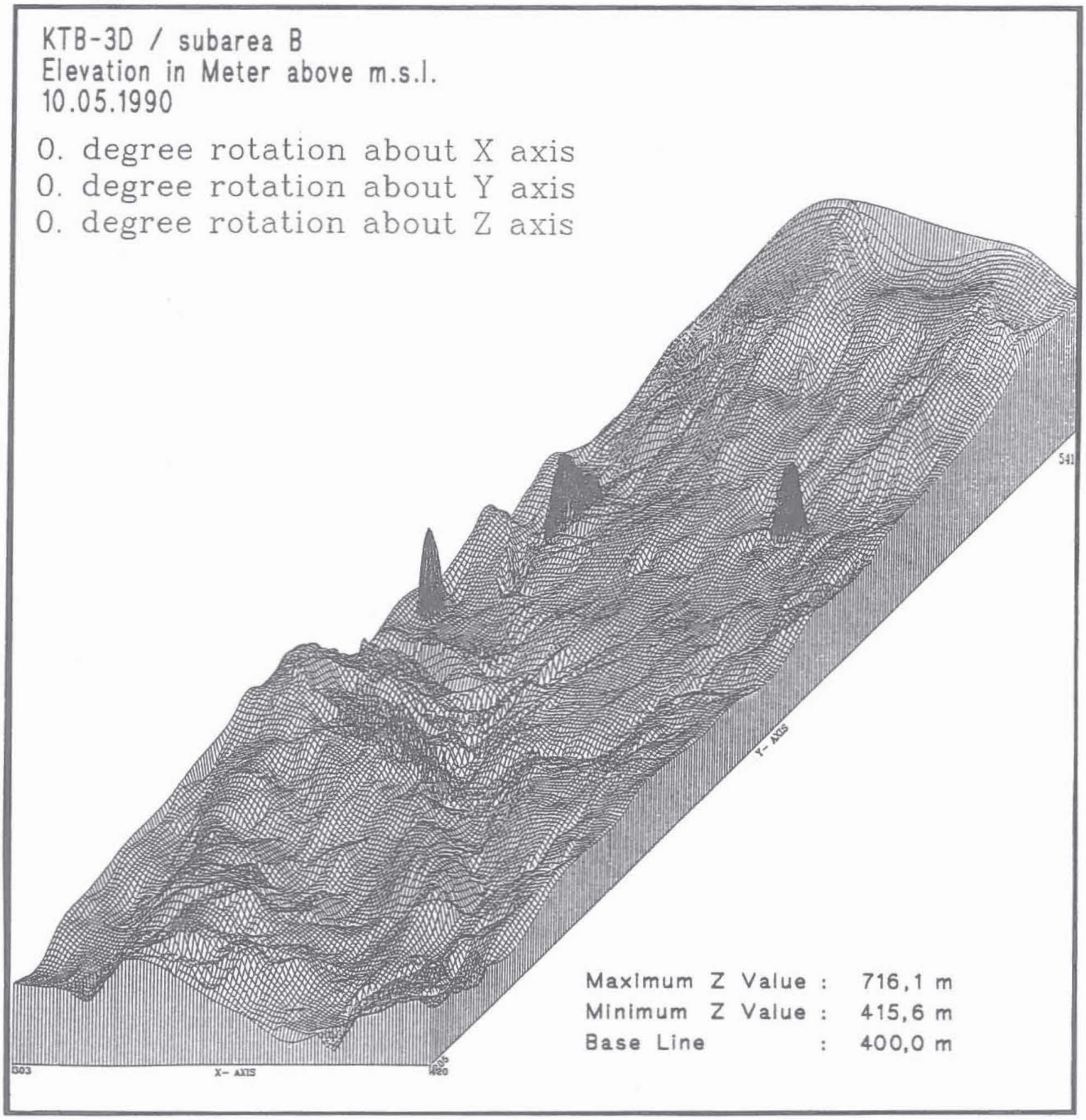


Fig. 33: Relief model of surveyed elevations of subarea B

In the northeast part of the survey area, the hilly Bohemian Massif is represented by metamorphic and plutonic outcrops with elevations of 600 - 800 m. The sediments in the southwest part of the area present a hilly landscape with elevations of 400 - 600 m. There is good overall agreement between this computer model and the topographic map of the area.

The course of the Fichtelnaab River, which flows from north to south through the area, can be clearly seen on the relief plot. It enters the area at an elevation of about 470 m and leaves the area at an elevation of about 410 m. Hills rise to the left and right of the river to elevations of 460 to 550 m. The Steinwald area adjoins to the northeast with elevations of 600 - 700 m. This area can also be clearly recognized on the model of subarea B, although at the edges of the area the relief is unnaturally smooth because there were not enough points for correct interpolation.

There are four areas within the model that show extremely high gradients (as much as 100 m between two neighboring points). These few incorrectly surveyed points have been corrected so that they will not influence the final static corrections.

3.5 Equipment

The following items provide an indication of the amount of work necessary for this seismic survey:

The following equipment was in daily use:

800	electrical cables (totalling 90 km)
18,000	geophones
800	telemetry boxes
about 150	repeater boxes
40 - 45	vehicles (in October an additional 35 mobile drilling rigs were needed for the wide-angle seismic measurements)
50	2-way radios in the vehicles and
30	2-way portable radios
2 - 4	relay stations.

The field work was carried out by:

80 personnel (plus an additional 40 in October for the wide-angle seismic measurements)

50 students.

In addition, the following items were used during the survey:

4,900 kg explosives (for the wide-angle seismics)

500 ignition fuses (for the wide-angle seismics)

300 electrical cables were replaced due to damage

150 boreholes, each 30 m deep for a total of 4500 m (for the wide-angle seismic measurements)

500,000 km were driven, more than 100,000 l fuel consumed.

4. Processing

4.1 Seismic Software from Seismograph Service Limited

The land 3-D software from SSL is a disk-oriented program package with two database structures: one for the pre-stack parameters and one for the post-stack parameters. The parameters of the individual traces, mainly the geometry data, are handled in the former; the parameters of the individual bins, mainly stacking velocities, are handled in the latter. The databases can be divided into subsets. For this survey they had to be divided into four subsets, corresponding to the four subareas shown in Figure 1. A description of the relations between the seismic traces and the controlling databases will be given in Chapter 4.4.

4.2 Field Geometry and Pre-stack Database

Very exact geometry data is needed for processing 3-D seismic surveys. In addition to the coordinates of the geophones and shot points, as well as the elevations and static corrections, a file must contain the actual array set-up for each shot. This makes it possible to arrange the seismic data in CSP order (common shot point) as well as in CMP order (common midpoint).

First, the geometry data is entered in the pre-stack database. A grid of bins over the entire area is defined. Each trace is then assigned to the bin midway between source and receiver location on the assumption that this bin represents the location of the reflection points.

Each bin is assigned a number, analogous to the CDP numbers in 2-D processing. So that each bin can be easily located within the grid, it is also assigned x and y bin numbers.

4.3 Checking the Data and First Arrival Times

The seismic data and nonseismic data must be in complete agreement if the 3-D processing is to produce valid results. Thus, the data must be checked for a one-to-one match between the input traces and the related databases.

The first arrival times are also checked: The program takes from the geometry file the source-receiver offset for each trace and calculates the corresponding first arrival time from an estimated velocity and depth for the weathering layer. The trace is then followed in a time window and tested for changes in amplitude. If there is no significant change within the expected time range, the trace is marked as faulty.

An example of checking first arrivals is shown in Figure 34. The curve above the first arrivals represents the calculated first arrival times minus a user-given constant (40 ms in the example). This constant is applied to separate the calculated from the actual first arrival to allow a visual comparison.

If all traces for a shot are labeled as "bad traces", either a "misfiring" occurred or there is an error in the field geometry (e.g. incorrect coordinates and thus incorrect source-receiver offsets). After the exact one-to one match and the quality of all seismic traces contained on the field tapes have been checked, the data of one subarea are written to disk and the controlling databases can take the handling for all further processing steps via disk pointers.

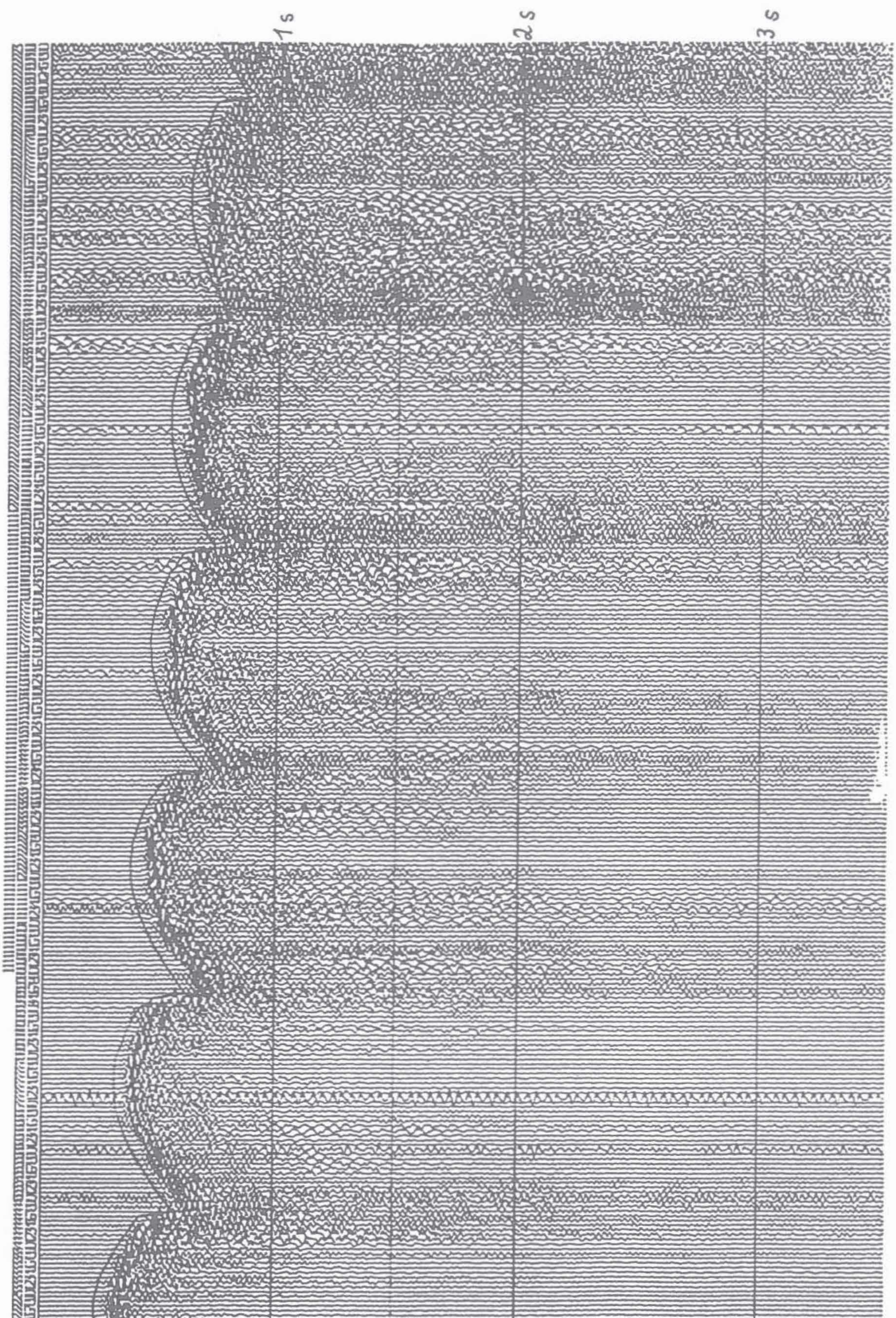


Fig. 34: An example of checking first arrivals

5. Example of the Data and Processing Plan

The ten geophone lines of a single array set-up were lined up one after the other to produce the seismic section shown in Figure 35 as an example of the data quality. This section is for the raw traces from shot position 17542, located about 4.5 km ENE of the KTB borehole and about 2 km below the respective geophone lines (marked with an x in Fig. 2). For this location relative to the geophone lines, the increase in the first arrival times from geophone line 1 (left) to geophone line 10 (right) can be distinctly seen.

The reflections from the Erbendorf structure can be easily recognized for the eight inner geophone lines. They are shown in gray in the figure and are about 3.6 s below the first arrivals, which have traveltimes of 0.4 - 1.1 s. Only for geophone lines 1 and 10 are the events not distinct. The reflections from the Erbendorf structure, one of the objectives of the main KTB borehole, are present in almost the entire survey area. In many other records there are indications of steeply inclined structures (60° true dip and more) in a traveltime range of 0.5 - 2.2 s.

Figure 36 shows the planned processing sequence of this 3-D survey and the relational structures between seismic data and controlling databases in the form of a generalized flow chart.

The circular symbols at the top of the figure characterize the magnetic tapes supplied by the contractor. The thin-framed rectangles represent the mathematical procedures to apply, and the broad arrows at the right indicate the flow of all seismic data from the field tapes to an interpretable 3-D data block.

The thick-framed rectangles symbolize the basic data files stored on disk (seismic data and controlling databases) and the broad bidirectional arrows indicate the relational structure, e.g. the pre-stack database has access to the pre- and post-stack data, and the post-stack database has also access to the pre- and post-stack data.

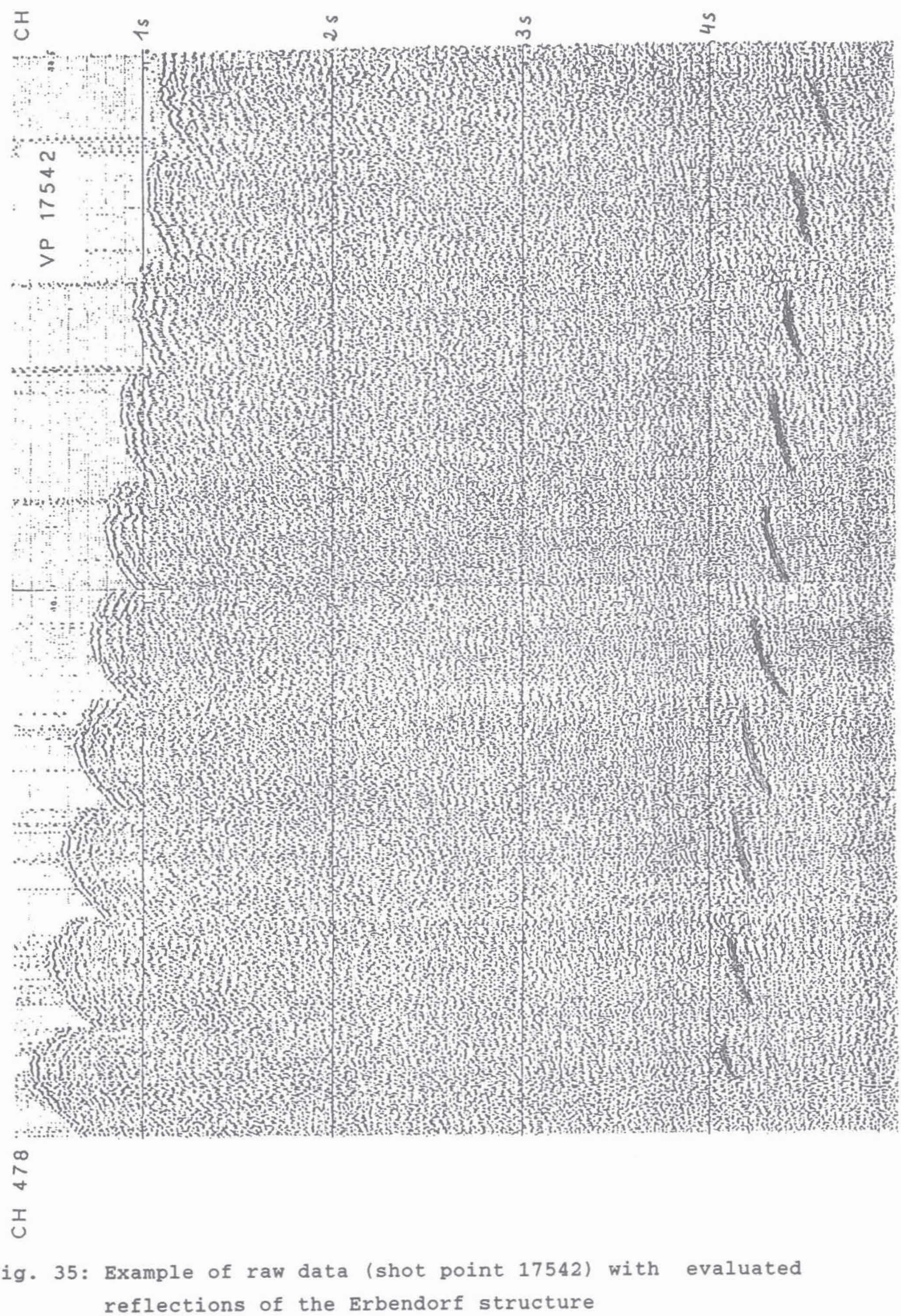


Fig. 35: Example of raw data (shot point 17542) with evaluated reflections of the Erbendorf structure

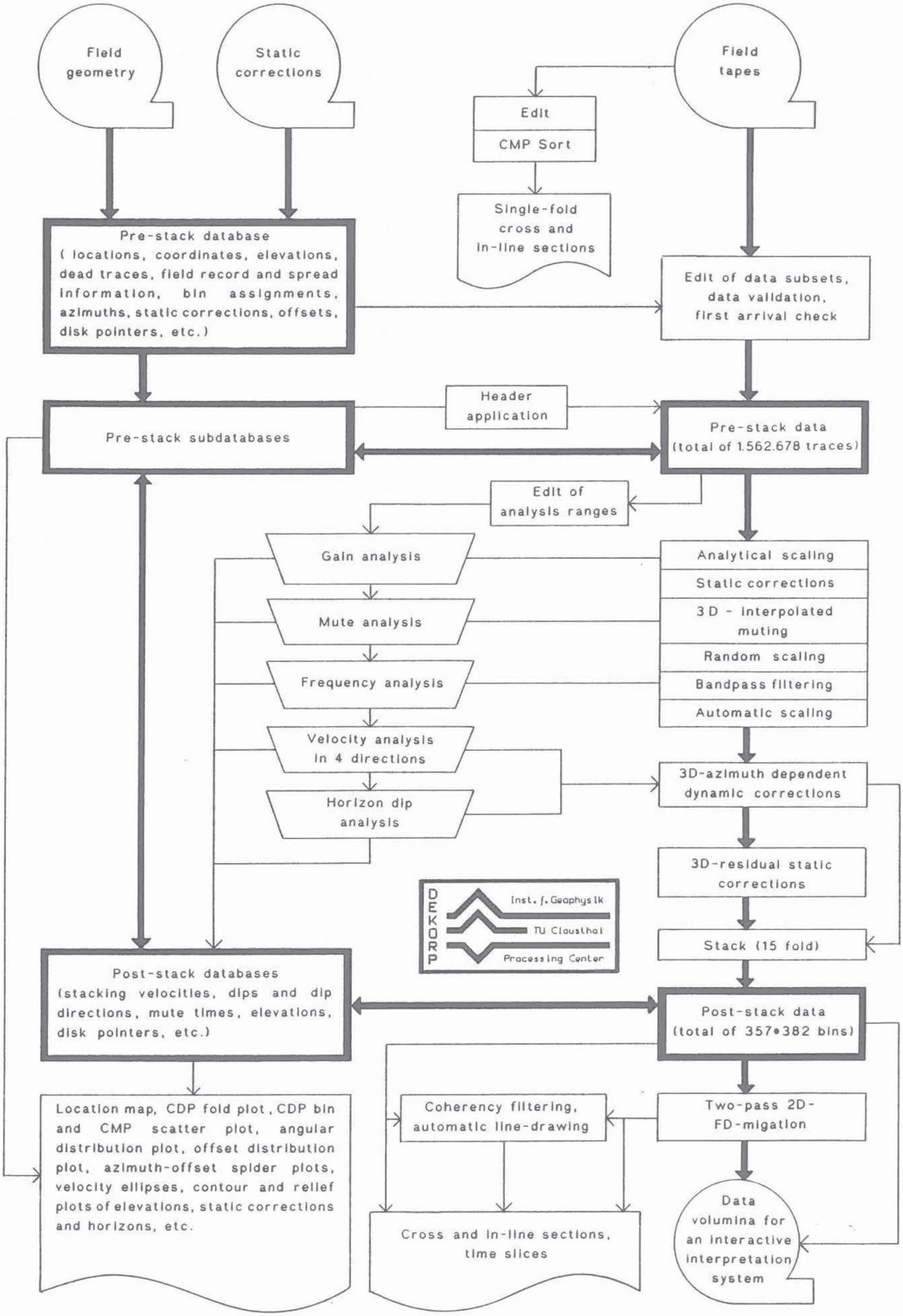


Fig. 36: Flow chart of the planned 3-D processing sequence

The trapezoids in the center of Figure 36 represent the analyses necessary for the determination of optimum processing parameters, and the paper symbols at the bottom of the figure characterize the plots available for evaluation.

The final processing of this extensive 3-D survey will last until spring 1991 at least, however, unmigrated data volumina will be fed to an interactive interpretation system at an earlier stage facilitating geo-tectonic predictions before the start of the drilling of the main KTB borehole.

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