Hydraulics Research
Wallingford

DISPERSAL OF DREDGED MATERIAL
Tees field study June 1985

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CONTRACT

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ABSTRACT

Both the short-term and long-term movements of dredged material disposed of at open water sites have significant ecological and engineering importance. In the short-term, the nature of the descent of the material as it is released from the hopper and falls towards the sea bed and the initial spreading of the material when it impacts on the sea bed can have a significant effect on the desirability of a particular ground for the open water disposal of dredged material. For example, entrainment of fine sediments from the descending plume into the surrounding waters and their subsequent removal by currents may well have detrimental consequences on reasonably distant locations.

To improve and extend the existing practical knowledge on dispersal an extensive field exercise was undertaken in cooperation with the Tees and Hartlepool Port Authority in June 1985. The objectives were:

(1) To investigate the feasibility of various instrumentation (in particular high resolution sonar) to monitor the short term dispersal process of dumped dredged material.

(2) To determine the concentrations of certain heavy metals attached to the sediments in the hoppers of the dredgers and on the bed of the disposal site.

(3) To measure the density structure and particle size distribution of the dredged material during the dredging operation.

The high resolution sonar was found to be very effective when deployed in certain orientations. The time varying velocity of the approaching wave front near the bed was measured using the sonar in four of the nineteen discharges of dredged material. A vertical stack of three Partech suspended solids concentration meters were used to quantify the height of the bed wave at a fixed distance from the disposal site. The Hydraulics Research Rapid Drop Profiler was used to measure the solids concentration profile through the water column at various times after disposal.

Samples of material were taken from the bed of the disposal site and from the hopper of the dredger. Analysis of the metal concentration on the silt fraction of the samples indicated that the concentrations of iron, manganese and cobalt respectively were similar for the disposal site and hopper samples.

The density structure of the material in the hopper was measured at various stages of the dredging operation. Initial density profiles (ie, when the hopper first reached full capacity) indicated that there was little variation in the density with depth, except for the lower 1m in which the density increased markedly towards the bottom of the hopper. Changes in the density structure were identified during the overdredging period and the subsequent transportation period.

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1 INTRODUCTION

1.1 Background

Both the short-term and long-term movements of dredged material disposed of at open water sites have significant ecological and engineering importance. In the short-term, the nature of the descent of the material as it is released from the hopper and falls towards the sea bed and the initial spreading of the material when it impacts on the sea bed can have a significant effect on the desirability of a particular ground for the open water disposal of dredged material. For example, entrainment of fine sediments from the descending plume into the surrounding waters and their subsequent removal by currents may well have detrimental consequences on reasonably distant locations.

In the long-term, movement of the material on the sea bed is particularly important with respect to the fate of heavy metals absorbed onto the sediments.

To improve and extend the existing breadth and depth of practical knowledge acquired by Hydraulics Research in previous research studies, an extensive field survey exercise was planned and conducted. The survey took place on the Tees with the cooperation of the Tees and Hartlepool Port Authority in June 1985 (see Fig 1 for location).

1.2 Objectives

The field study had three objectives, which were:-

(1) To investigate the feasibility of various instrumentation (in particular high resolution sonar) to monitor the short term dispersal process of dumped dredged material.

(2) To determine the concentrations of certain heavy metals attached to the sediments in the hoppers of the dredgers and on the bed of the disposal site.

(3) To measure the density structure and particle size distribution of the dredged material during the dredging operation.

1.3 Methodology

The discharge of nineteen loads of material dredged by two trailing suction hopper dredgers were monitored by a Mesotech high resolution side-scan sonar, a Rapid Drop Profiler and a stack of three Partech heads (Fig 2). These instruments were mounted on two survey crafts. The density profile in the hopper was measured using a Harwell transmission probe. Casella bottle samples and grab samples were taken of the material in each hopper load. Grab samples were also taken on a grid in the disposal site.

The short term dispersion measurements were carried out in shallow water. Details of the bulk weight of each drop and the tide conditions are given in Table 1.

2 SHORT TERM DISPERSION

2.1 Visualisation of dispersal

Sonar is a system by which objects and features on the seabed can be identified. It achieves this using a transducer which emits high frequency, high intensity pulses of sound which reflect off the seabed and are received back by the transducer. The associated electronics analyses the return signal and produces an image.

The sonar system used for this exercise comprised a portable lightweight sonar head unit connected to a control station onboard the survey craft via an underwater cable. The head unit, which was suspended from the stern of the survey craft, employed a single transducer, capable of rotating through a full 360°, or through arcs of 30°. The transducer was mounted on a cylindrical head enclosing the circuitry for controlling the movement of the transducer and for transmitting and receiving the acoustic signal. The head rotated in increments of 0.225°, transmitting and receiving a 675Hz signal each increment. The transducer was provided with a switchable option from 1.7° x 30° fan beam, to a 1.7° cone beam and had a nominal 100m range.

At the control station a processor received the return signal, recording and interpreting its slant, range and intensity. The processor digitized the intensities to 128 discrete colour levels which were displayed on a screen. For the purpose of this exercise the display was recorded on videotape to facilitate subsequent analysis. The sidescan sonar was used in various orientations and depths for drops 16 - 21.

The five orientations of the sidescan sonar used in this study are shown in Figures 3(a) to (e). Typical examples of the type of output displayed on the screen during the monitoring of a dump are shown in Plates 1 to 5.

From the sonar images recorded as the head rotated in a vertical plane following a line between itself and the dredger, two profiles of the mud wave were traced. The first was as the discharge from the dredger commenced and the second was after approximately 90 seconds. A problem with using the sonar in this manner is that the scanning head rotated at a low speed relative to the rate at which the mud wave advanced. Therefore, by the time the sonar has done a complete scan the mud wave at the end of the scan had moved a considerable distance. This made it difficult to obtain an accurate picture of what was happening.

Nevertheless, the findings from the exercise supported the current view regarding the spread of a hopper release beneath the point of discharge, ie, the material tends to mound up at the point of impact and then flow out radially to a degree commensurate with the dredged material composition. A further factor was the short period of time available following disposal, due to the speed of the event, during which useful measurements could be made.

2.2 Velocity of bed wave

The sonar was found to be very effective when deployed in certain orientations. In particular, it was possible to measure the speed of propagation of the wave front to a high degree of accuracy. With the sonar head in a stationary horizontal position and in the centre of the channel facing towards the dredger, four dredger drops, numbers 11, 12, 15 and 16 were monitored. From sonar images which showed the distance of the wave front with time, the velocity at a number of distances could be obtained from the slope of the image. Figure 4 shows the change in velocity of the wave front for drops 11, 12, 15 and 16 respectively. The overall trend is similar in that the velocity reduces steadily with distance from the dredger. By extrapolation by eye through the points it is possible to indicate the likely maximum distance that the wave travelled (ie, the intercept for zero velocity). The mean value is in the region of 50 - 70m.

The suspended solids concentration was measured optically by three Partech sensors suspended from the survey craft which also carried the sonar system. During drops 6 - 14 the sensors were arranged at 1m, 4m and 7m above the bed. All the sensors were set on a range of 0 - 10,000ppm. However, during these drops it was noted that at the time the bottom sensor went offscale the two higher sensors were still recording an insignificant concentration. Therefore, for drops 15 - 21 the positions of the sensors were adjusted to 1m, 2m and 3m above the bed.

The time taken for the bed wave to reach the Partech sensors, identified by an offscale reading, was recorded together with the distance between the dredger and survey craft. Results of four drops are given in Table 2 in which the mean velocity up until the wave passed the sensors is also calculated. The mean velocities vary in the range 0.36 - 0.83m/s. The lowest mean velocity of 0.36m/s was measured over a distance of 65m from the dredger and would indicate that the bed wave was probably almost stationary by the time it reached the Partech instruments.

A comparison of the average velocities recorded by the sonar and the Partech sensors was made for drops 15 and 16 (Table 3). It is seen that the figures compare favourably considering the practical difficulties of the measurements.

2.3 Height of wave

The Hydraulics Research Rapid Drop Profiler (RDP) was deployed during seven of the discharges of dredged material from the dredger to measure suspended solids concentration throughout the water column. The instrument generally went offscale when it reached the mud wave which enabled the height of the mud wave to be determined. Profiles were measured at an interval of 1 minute and the distance from the dredged material discharge varied from 40m to 180m downdrift.

The profiles indicated that close to the source the mud wave was clearly detectable and passed as a highly concentrated pulse of material. However, profiles further from the source showed more dispersion through the water column.

Rapid Drop Profiler data from drop 16 showing the height of the mud wave and time is shown in Figure 5. This data indicates that the mud wave front had already probably passed the Rapid Drop Profiler, by the time the first reading (after two minutes) was taken as this gave a height of 0.7m. During the following 15 minutes the height of the mud wave as determined by the RDP varied from 0.0 to 1.7m. It is probable that much of this variation can be attributed to the method of measurement.

A time series of the output from the Rapid Drop Profiler during drop 18 is shown in Figure 6. The series of figures show the passage of a dispersion cloud in the upper 8m of the water column between T = 4 mins and T = 14 mins.

2.4 Appraisal of short term monitoring techniques

The high resolution sonar was found to be very useful in visualising the plume of material as it was discharged from the hopper. The sonar was very effective when deployed in certain orientations. In particular, in a head-on position to the approaching mud wave it enabled the velocity to be accurately determined. The slow speed of rotation in its sidescan mode was, however, a considerable disadvantage. Nevertheless, this field study exercise has provided valuable experience of high resolution sonar.

The Partech and Rapid Drop Profiler instruments were satisfactory and should be used again in the future surveys as required.

3 HEAVY METALS ATTACHED TO SEDIMENT

3.1 Measurements

Samples were taken from the bed of the disposal site and from the hopper of the dredger. Each sample was analysed for the concentration of six heavy metals and for particle size distribution. The heavy metals were copper (Cu), zinc (Zn), lead (Pb), iron (Fe), manganese (Mn) and cobalt (Co). The analysis was carried out on the silt fraction of the sediment (i.e. $< 63\,\mu m$). Within the disposal site, grab samples were taken on a 500m grid at 33 different locations as shown in Figure 7.

Both grab samples and cassella bottle samples were taken in the hopper during the dispersion tests. In all, 20 grab samples and 36 bottle samples were obtained. These are identified with the drop number in Table 4.

3.2 Disposal site

The results of the size distribution analyses of the grab samples taken in the disposal site are given in terms of % silt content (ie, fraction of sample $< 63\,\mu m$), D_{50} (ie, median particle size) and D_{90} (ie, particle size for which 90% of sample is smaller) in Table 13. The % silt content of each grab sample in the disposal site is shown in Figure 16 in which contours of equal % silt content have also been drawn. The general trend is an increase in the % silt content with the downward slope of the bed in the north-eastern direction. At the western edge of the disposal site which has the shallowest water depth at around 27m LAT the silt content is in the region of 0 - 20%. Towards the north-eastern boundary where the depth is 34m LAT the silt content is much higher at 40 - 60%.

The results of the heavy metal concentrations on the silt fraction of the grab samples taken from the dredged material disposal site are given in Table 5 and in Figures 8 - 13. The mean concentrations of the six heavy metals in round figures are: Cu = 150ppm, Zn = 400ppm, Pb = 210ppm, Fe = 49000ppm, Mn = 600ppm and Co = 16ppm. In terms of the standard deviation of the concentrations, the metals copper, zinc and lead show much greater variance in proportion to their mean value than the metals iron, manganese and cobalt.

The spatial distributions of the six heavy metals over the disposal site (Figs 8 - 13) are seen to follow a broadly similar pattern. Near the centre of the disposal site there is a region of high concentration of all the heavy metals. Along the north east boundary of the disposal site the concentrations are generally lower.

The similarities in the distributions of the groups of metals copper, zinc and lead, and iron, manganese and cobalt is illustrated in Figures 14 and 15 respectively. For each set of three heavy metals, the concentrations of the individual metals have been normalised to their mean concentration (see Table 6) and plotted with the concentration of one metal in descending order. The closeness of the points in Figure 14 and also in Figure 15 indicate a strong correlation of the concentrations within each of the two groups.

The degree of correlation between each of the six heavy metals and the % silt content is given in Table 7 in the form of linear regression correlation coefficients for each pair of parameters. In broad terms, there is a very high correlation between the metal concentrations of copper, zinc and lead, and between the metal concentrations of iron and manganese. Cobalt has lower regression coefficients with all the other metals.

The underlying difference between the two groups of heavy metals may be explained with reference to Table 8 which gives a comparison of the means of the six metals for the samples taken by grab in the disposal site and for the samples taken by grab and by cassella bottle in the hopper. The most striking feature of these results is the remarkable similarity in the mean value of the samples taken in the hopper and on the bed of the disposal site for iron, manganese and cobalt. This may be interpreted as implying that the concentration of these heavy metals is independent of the distribution of size within the samples. This is shown by the concentrations of the two sets of samples taken in the hopper which had quite different size distributions and yet gave similar concentrations.

On the other hand, the mean concentrations of the other three metals (copper, zinc and lead) are not similar for the samples taken in the hopper and on the bed of disposal site. However, the concentrations in the disposal site, the hopper grab samples and the hopper bottle samples are in the same ratio of approximately 1:1.8:2.5.

3.3 Hopper

The detailed concentrations of the six heavy metals of the samples taken in the hopper are shown in Tables 9 and 10 for the grab samples and bottle samples respectively. It is interesting to note that the variances in both sets of figures are relatively larger for the three metals copper, zinc and lead. However, overall the variance of the concentrations are less than those measured in the disposal site. This is probably due to the fact that the material which was dredged during the field exercise came from one particular area of the Tees estuary, whereas, the material in the disposal site comprised material dredged from many locations throughout the estuary.

The results of the correlation coefficients for the six metals and % silt content are given in Tables 11 and 12 for the hopper grab samples and bottle samples respectively. For the grab samples it is seen that iron does not correlate with any of the other metals or with the silt content. Whereas, for the bottle samples iron correlates well with copper, zinc, lead and cobalt and less well with manganese.

3.4 Percentage silt content

The size distribution of the samples taken in the disposal site are summarised in Table 13. The percentage silt fraction and the particle sizes D_{50} and D_{90} are given. Similarly, Table 14 shows the summary of the size distributions for the grab samples taken in the hopper. Likewise, Table 15 gives these values for the bottle samples taken in the hopper. The percentage silt fractions of the samples taken in the disposal site are also shown in Figure 16. Contours of equal silt fraction indicate that in broad terms, the samples from the areas with higher bathymetry are relatively coarser.

4 DENSITY STRUCTURE OF MATERIAL IN HOPPER

4.1 Methodology

For drop numbers 2 to 21 the density profile of the material in the hopper was measured as soon as the hopper became full and then subsequently after overdredging had ceased. The density was determined at a 0.5m interval throughout the 7m depth of the hopper using a Harwell radioactive transmission probe. As previously mentioned, grab samples and bottle samples were taken from the material in the hopper. The density profiles were integrated over the depth of the hopper to give a mean bulk density measurement.

4.2 Results

The detailed results of the density profiles taken before, during and after the overdredging process are given in Table 16. Hopper loads numbers 2, 3 and 4 contained predominately sandy material which was not typical of the other hopper loads.

During each dredging operation the density of the material in the hopper was measured at the time when the hopper became full and the overflow weirs first started to spill excess fluid. This density profile was termed the initial density profile and is identified in Table 16 under the column heading '0 mins'. The mean value of the initial density is shown in Figure 17 for all the hopper loads which comprised predominantly fine material. It is seen that the initial mean specific density varied in the range of 1.038 to 1.112 with a typical value around 1.08.

Profiles of the initial density of the dredged material with depth are presented in Figure 18. The profile of the hopper material of drop 5 represents the minimum densities encountered, whereas, that of drop 10 gave the maximum densities (excluding drops 2, 3 and 4). An average profile based on all 17 drops is also shown. It may be seen that the density of the material does not vary significantly with depth except for the bottom 1m in which the density increases sharply. This bottom layer of material in the hopper is mainly the sand fraction of the dredgings which settles quickly through the overlying high concentration mud suspension.

Figures 19, 20 and 21 show the relationship between the initial hopper density and particle size. Figure 19 indicates that the D_{50} size does not influence the initial mean hopper density. Similarly, neither does the D_{90} size have an influence on initial density (Fig 20) and there is little correlation between the two sizes, D_{50} and D_{90}, as seen in Figure 21.

Dredging did not cease immediately at the time when the hopper became full. In each dredging operation a process called overdredging was employed whereby dredging continued and material was discharged into the full hopper causing excess material to be spilled over the overflow weirs. In this way it is possible to increase the weight of material in the hopper due to the fact that some of the material which is discharged into the full hopper will settle through the fluid in the hopper rather than being carried over the weirs.

The period of overdredging lasted for between 7 and 27 minutes. Table 17 presents the initial and final hopper full densities, the time of overdredging, the increase in dry density during overdredging and the D_{50} and D_{90} particle sizes of the grab samples. The influence of overdredging on the density profile is depicted in Figure 22 for an overdredging period of about 18 minutes. A significant increase in the density of the material occurred within the lower 4m of the hopper.

The changes which occur in the density profiles after overdredging are characterised by the two profiles shown in Figure 23. Each profile is an average of the results for drops 14, 17 and 20 in which the time between profiles was approximately 15 minutes. Overdredging had ceased before the first profiles were taken and hence the changes between profiles may be attributed solely to the consolidation of the material. It may be seen that generally the density of material in the lower part of the hopper has increased at the expense of the upper part. Overall, the mean specific densities of the average profiles did not vary significantly being 1.096 and 1.098 respectively.

The density structure of the material within the hopper prior to disposal may not be clearly assessed for all drops as density profiles were not taken immediately before disposal for some drops. However, a reasonable estimate of the typical density structure of the material in the hopper prior to disposal is the curve depicted in Figure 23 after 15 minutes of consolidation.

5 CONCLUSIONS

5.1 Short term dispersion

The field exercise has proved valuable in assessing the suitability of different types of instrumentation, particularly high resolution sonar, to monitor the dispersion of dredged material from the hopper of a dredger.

Sonar was very useful in visualising the dispersion process and in certain orientations it was able to accurately determine the velocity of the approaching mud bed wave.

The HR Rapid Drop Profiler was successful in approximately identifying the depth of the mud wave. Three Partech heads suspended at fixed positions above the bed enabled the velocity of the bed wave to be measured over a fixed distance. The Partech heads also gave an indication of the thickness of the wave.

It is recommended that a further field exercise be undertaken to monitor short term dispersion of dredged material. The experience gained from this survey should be used during the planning of the next survey. It would seem appropriate to employ high resolution sonar again, now that its strengths and limitations have been recognised.

5.2 Heavy metals attached to sediment

The mean concentrations of Fe, Mn and Co on the silt fraction of sediment samples taken by grab and by cassella bottle in the hopper, and by grab from the bed of the disposal site were similar and had values of about 51000ppm (Fe), 610ppm (Mn) and 16.2ppm (Co). The average silt content for the three types of samples were 40%, 83% and 27% respectively. For the three metals, Cu, Zn and Pb the mean concentrations differed considerably for the three locations of samples although the ratio of concentrations at locations were similar for each metal. The concentrations increased with silt content such that, for example, the mean concentrations of Cu were 400ppm (disposal site grab samples), 720ppm (hopper grab) and 1030ppm (hopper cassella bottle).

A further survey should be conducted in which samples of bed sediments are taken from the area surrounding the disposal site as well as from the disposal site itself. In addition, samples should be taken at a regular interval along the length of the Tees estuary. This would enable a comparison to be made between this study and the concentrations of metals in the estuary measured in a 1981 survey. It would also give a basis for assessing the average concentration of metals in the disposal site.

5.3 Density structure

The density structure of the material in the hopper was measured at various stages of the dredging operation. Initial density profiles (ie, when the hopper first reached full capacity) indicated that there was little variation in the density with depth except for the lower 1m, in which the density increases markedly towards the bottom of the hopper. Changes in the density structure were identified during the overdredging period and the subsequent transportation period.

6 ACKNOWLEDGEMENTS

The cooperation of the Tees and Hartlepool Port Authority in conducting the field study and the contribution of the British Ports Association in assisting in the funding of this research are gratefully acknowledged.

TABLES.

Table 1 Bulk weight and known tidal conditions for each dredger drop

Drop No.	Bulk weight (tons)	Mean Velocity (m/s)	Tide Direction
2	1674		
3	1691		
5	1609		
6	1646		
7	1688		
8	1688		
9	1674		
10	1724		
11	1683		
12	1662		
13	1638		
14	1635	0.18	Flood
15	1660	0.18	Flood
16	1651	0.10	Flood
17	1651	0.06	Ebb
18	1680	0.12	Ebb
19	1671	0.14	Ebb
20	1686	0.15	Flood
21	1686	0.18	Flood

Table 2 Time for bed wave to reach Partech heads

Drop No.	Distance From Drop (m)	Time Taken (s)	Velocity (m/s)
15	56.5	68	0.83
16	50.5	70	0.72
19	65.0	180	0.36
21	40.0	56	0.71

Table 3 Comparison of average velocities of bed wave

Drop No.	Velocity From Partech Data (m/s)	Velocity From Sonar Data (m/s)
15	0.83	0.61
16	0.72	0.66

Table 4 Dredger drop numbers and sample identification

Drop No.	Grab No.	Bottle No.
1	T1	
2	T2	328
	T3	
3		
4	T4	
5	T10	337
		339
6	T11	323
		330
7	T12	326
		332
8	T13	344
		331
9	T14	324
		329
10	T15	321
		311
11	T16	305
		310
12	T17	327
13	T20	303
		307
14	T21	335
		318
15	T22	320
		315
16	T23	334
		302
17	T24	322
		336
18	T25	296
		297
19	T26	298
		299
20		300
		301
21		308
		312

Table 5 Metal concentrations on silt fraction of spoil ground samples

Grab samples taken in Spoil Ground

Grab No.	Sample	Cu	Zn	Pb	Fe	Mn	Co
1	301	118.0	255.0	176.0	55000.0	660.0	16.0
2	302	153.0	439.0	287.0	56100.0	620.0	17.0
4	304	112.0	294.0	160.0	53200.0	790.0	14.0
5	305	573.0	1640.0	600.0	61400.0	1130.0	21.0
6	306	131.0	261.0	156.0	55000.0	720.0	16.0
7	307	214.0	497.0	251.0	56700.0	660.0	18.0
8	308	174.0	398.0	211.0	44800.0	530.0	18.0
9	309	87.0	235.0	165.0	40120.0	395.0	15.0
10	310	121.0	316.0	124.0	53300.0	670.0	19.0
11	311	175.0	312.0	146.0	45800.0	570.0	18.0
12	312	180.0	412.0	278.0	46430.0	510.0	16.0
13	313	329.0	419.0	245.0	47600.0	720.0	20.0
14	314	40.0	99.0	35.0	47800.0	403.0	15.0
15	315	122.0	307.0	166.0	47700.0	610.0	16.0
16	316	255.0	840.0	345.0	61000.0	930.0	20.0
17	317	303.0	890.0	536.0	58000.0	700.0	17.0
18	318	39.0	108.0	47.0	43750.0	432.0	15.0
19	319	46.0	127.0	61.0	50500.0	453.0	19.0
20	320	221.0	504.0	280.0	44200.0	474.0	15.0
21	321	192.0	520.0	279.0	50800.0	720.0	19.0
22	322	112.0	335.0	208.0	44160.0	482.0	15.0
23	323	107.0	314.0	178.0	40330.0	500.0	16.0
24	324	99.0	301.0	221.0	47690.0	570.0	16.0
25	325	192.0	474.0	260.0	34300.0	493.0	13.0
26	326	252.0	850.0	354.0	71900.0	990.0	16.0
27	327	125.0	292.0	191.0	38250.0	408.0	14.0
28	328	34.0	208.0	63.0	32020.0	345.0	13.0
29	329	115.0	335.0	202.0	44670.0	520.0	11.0
30	330	107.0	310.0	174.0	50000.0	530.0	13.0
32	332	91.0	260.0	129.0	41800.0	610.0	11.0
33	333	33.0	100.0	33.0	51100.0	640.0	17.0
34	334	130.0	396.0	226.0	50000.0	680.0	8.0
37	337	32.0	96.0	35.0	43440.0	464.0	18.0
Mean		151.9	398.3	206.7	48753.3	603.9	15.9
Standard dev.		105.7	294.0	125.2	8018.4	172.3	2.8
Minimum		32.0	96.0	33.0	32020.0	345.0	8.0
Maximum		573.0	1640.0	600.0	71900.0	1130.0	21.0

Table 6 Mean normalised metal concentrations of spoil ground samples

Grab samples taken in Spoil Ground

Grab No.	N.Cu	N.Zn	N.Pb	N.Fe	N.Mn	N.Co
1	0.8	0.6	0.9	1.1	1.1	1.0
2	1.0	1.1	1.4	1.2	1.0	1.1
4	0.7	0.7	0.8	1.1	1.3	0.9
5	3.8	4.1	2.9	1.3	1.9	1.3
6	0.9	0.7	0.8	1.1	1.2	1.0
7	1.4	1.2	1.2	1.2	1.1	1.1
8	1.1	1.0	1.0	0.9	0.9	1.1
9	0.6	0.6	0.8	0.8	0.7	0.9
10	0.8	0.8	0.6	1.1	1.1	1.2
11	1.2	0.8	0.7	0.9	0.9	1.1
12	1.2	1.0	1.3	1.0	0.8	1.0
13	2.2	1.1	1.2	1.0	1.2	1.3
14	0.3	0.2	0.2	1.0	0.7	0.9
15	0.8	0.8	0.8	1.0	1.0	1.0
16	1.7	2.1	1.7	1.3	1.5	1.3
17	2.0	2.2	2.6	1.2	1.2	1.1
18	0.3	0.3	0.2	0.9	0.7	0.9
19	0.3	0.3	0.3	1.0	0.8	1.2
20	1.5	1.3	1.4	0.9	0.8	0.9
21	1.3	1.3	1.3	1.0	1.2	1.2
22	0.7	0.8	1.0	0.9	0.8	0.9
23	0.7	0.8	0.9	0.8	0.8	1.0
24	0.7	0.8	1.1	1.0	0.9	1.0
25	1.3	1.2	1.3	0.7	0.8	0.8
26	1.7	2.1	1.7	1.5	1.6	1.0
27	0.8	0.7	0.9	0.8	0.7	0.9
28	0.2	0.5	0.3	0.7	0.6	0.8
29	0.8	0.8	1.0	0.9	0.9	0.7
30	0.7	0.8	0.8	1.0	0.9	0.8
32	0.6	0.7	0.6	0.9	1.0	0.7
33	0.2	0.3	0.2	1.0	1.1	1.1
34	0.9	1.0	1.1	1.0	1.1	0.5
37	0.2	0.2	0.2	0.9	0.8	1.1

Table 7 Correlation coefficients for metals and % silt of spoil ground samples

HEAVY METALS AND SILT REGRESSION COEFFICIENTS

Spoil ground grab samples - TEES : JUNE 1985

		1	2	3	4	5	6	7
		Cu	Zn	Pb	Fe	Mn	Co	%silt
1	Cu	1.00	0.93	0.90	0.49	0.73	0.45	-0.07
2	Zn	0.93	1.00	0.93	0.56	0.77	0.36	.00
3	Pb	0.90	0.93	1.00	0.51	0.66	0.27	-0.14
4	Fe	0.49	0.56	0.51	1.00	0.83	0.43	-0.14
5	Mn	0.73	0.77	0.66	0.83	1.00	0.39	-0.13
6	Co	0.45	0.36	0.27	0.43	0.39	1.00	0.30
7	%silt	-0.07	.00	-0.14	-0.14	-0.13	0.30	1.00

Number of data points = 33
Average % silt = 26.6

Table 8 Comparison of mean metal concentrations for spoil ground and hopper samples

	Mean Concentrations			Ratio		
Heavy Metal	Spoil Bed Samples	Hopper Grab Samples	Hopper Bottle Samples	Grab/ Bottle	Bed/ Bottle	Bed/ Grab
Cu	150	250	340	0.74	0.44	0.60
Zn	400	720	1030	0.70	0.39	0.56
Pb	210	420	570	0.74	0.37	0.50
Fe	48700	52500	51000	1.03	0.95	0.93
Mn	600	610	630	0.97	0.95	0.98
Co	15.9	16.2	16.4	0.99	0.97	0.98
%Silt	26.6	39.6	82.7	0.48	0.32	0.67

Table 9 Metal concentrations on silt fraction of hopper grab samples

Grab samples taken in hopper

Grab No.	Sample	Cu	Zn	Pb	Fe	Mn	Co
T1	338	33.0	143.0	49.0	42300.0	640.0	14.0
T2	339	107.0	203.0	139.0	43480.0	490.0	15.0
T3	340	98.0	191.0	132.0	47130.0	500.0	15.0
T4	341	97.0	186.0	132.0	55700.0	530.0	15.0
T10	342	350.0	1320.0	760.0	41000.0	750.0	18.0
T11	343	57.0	200.0	92.0	52500.0	650.0	15.0
T12	344	435.0	960.0	560.0	58300.0	610.0	19.0
T13	345	325.0	820.0	426.0	53000.0	640.0	19.0
T14	346	317.0	860.0	530.0	60000.0	540.0	18.0
T15	347	321.0	770.0	442.0	52100.0	640.0	18.0
T16	348	331.0	860.0	510.0	50000.0	530.0	15.0
T17	349	315.0	900.0	580.0	51000.0	590.0	15.0
T20	352	250.0	720.0	444.0	58100.0	530.0	15.0
T21	353	272.0	850.0	477.0	57800.0	600.0	17.0
T22	354	260.0	770.0	429.0	43700.0	600.0	14.0
T23	355	56.0	180.0	76.0	65600.0	650.0	12.0
T24	356	359.0	1090.0	600.0	66000.0	690.0	16.0
T25	357	368.0	1050.0	580.0	55500.0	690.0	16.0
T26	358	341.0	1250.0	750.0	54500.0	700.0	18.0
T27	359	398.0	1120.0	650.0	42380.0	680.0	19.0
Mean		254.5	722.2	417.9	52504.5	612.5	16.2
Standard dev.		125.6	383.1	225.1	7285.9	71.5	1.9
Minimum		33.0	143.0	49.0	41000.0	490.0	12.0
Maximum		435.0	1320.0	760.0	66000.0	750.0	19.0

Table 10 Metal concentrations on silt fraction of hopper bottle samples

Bottle samples taken in hopper

Sample	Bottle	Cu	Zn	Pb	Fe	Mn	Co
261	296	423.0	1110.0	560.0	56000.0	740.0	16.0
262	297	376.0	1080.0	530.0	48300.0	670.0	14.0
263	298	426.0	1185.0	630.0	57500.0	690.0	17.0
264	299	369.0	1020.0	620.0	44900.0	630.0	14.0
265	300	373.0	1050.0	540.0	56800.0	750.0	16.0
266	301	341.0	1030.0	640.0	47600.0	660.0	15.0
267	302	105.0	162.0	148.0	13300.0	660.0	5.0
268	303	274.0	720.0	480.0	42500.0	580.0	11.0
269	305	455.0	1170.0	640.0	51300.0	630.0	16.0
270	307	218.0	630.0	421.0	42800.0	540.0	14.0
271	308	357.0	1060.0	560.0	53000.0	760.0	16.0
272	310	360.0	980.0	570.0	50500.0	580.0	18.0
273	311	359.0	1900.0	550.0	50000.0	590.0	17.0
274	312	340.0	1215.0	550.0	50600.0	700.0	15.0
275	313	201.0	760.0	358.0	45700.0	610.0	15.0
276	315	301.0	1140.0	500.0	46600.0	600.0	17.0
277	316	338.0	960.0	507.0	55500.0	570.0	16.0
278	318	224.0	730.0	385.0	50500.0	600.0	14.0
279	320	306.0	1030.0	514.0	57700.0	630.0	15.0
280	321	400.0	1230.0	700.0	58000.0	660.0	19.0
281	322	375.0	1170.0	640.0	55000.0	750.0	16.0
282	323	446.0	1050.0	570.0	50600.0	560.0	18.0
283	324	448.0	1200.0	670.0	53400.0	610.0	19.0
284	326	436.0	1260.0	730.0	58000.0	690.0	20.0
285	327	330.0	970.0	620.0	51000.0	590.0	16.0
286	328	92.0	186.0	124.0	41200.0	450.0	16.0
287	329	405.0	1200.0	760.0	57500.0	650.0	20.0
288	330	381.0	1110.0	680.0	56800.0	570.0	19.0
289	331	378.0	990.0	630.0	50900.0	540.0	18.0
290	332	364.0	960.0	620.0	48600.0	540.0	18.0
291	334	344.0	850.0	590.0	50100.0	570.0	18.0
292	335	279.0	820.0	470.0	57400.0	590.0	17.0
293	336	359.0	1160.0	640.0	56000.0	710.0	18.0
294	337	292.0	1720.0	1190.0	59000.0	720.0	19.0
295	339	339.0	1320.0	750.0	62800.0	770.0	20.0
296	344	496.0	1070.0	610.0	48400.0	500.0	17.0
Mean		341.9	1033.3	574.9	50994.4	629.4	16.4
Standard dev.		88.0	315.8	172.0	8182.7	76.4	2.8
Minimum		92.0	162.0	124.0	13300.0	450.0	5.0
Maximum		496.0	1900.0	1190.0	62800.0	770.0	20.0

Table 11 Correlation coefficients for metals and % silt of hopper grab samples

HEAVY METALS AND SILT REGRESSION COEFFICIENTS

Hopper grab samples - TEES : JUNE 1985

		1	2	3	4	5	6	7
		Cu	Zn	Pb	Fe	Mn	Co	%silt
1	Cu	1.00	0.94	0.94	0.11	0.37	0.74	-0.01
2	Zn	0.94	1.00	0.99	0.05	0.54	0.67	0.09
3	Pb	0.94	0.99	1.00	0.04	0.47	0.67	0.05
4	Fe	0.11	0.05	0.04	1.00	0.01	-0.06	0.03
5	Mn	0.37	0.54	0.47	0.01	1.00	0.33	0.59
6	Co	0.74	0.67	0.67	-0.06	0.33	1.00	0.08
7	%silt	-0.01	0.09	0.05	0.03	0.59	0.08	1.00

Number of data points = 20
Average % silt = 39.6

Table 12 Correlation coefficients for metals and % silt of hopper bottle samples

HEAVY METALS AND SILT REGRESSION COEFFICIENTS

Hopper bottle samples - TEES : JUNE 1985

		1	2	3	4	5	6	7
		Cu	Zn	Pb	Fe	Mn	Co	%silt
1	Cu	1.00	0.66	0.62	0.60	0.22	0.58	0.08
2	Zn	0.66	1.00	0.80	0.67	0.43	0.61	0.27
3	Pb	0.62	0.80	1.00	0.67	0.40	0.66	0.20
4	Fe	0.60	0.67	0.67	1.00	0.33	0.83	-0.06
5	Mn	0.22	0.43	0.40	0.33	1.00	0.04	0.40
6	Co	0.58	0.61	0.66	0.83	0.04	1.00	-0.17
7	%silt	0.08	0.27	0.20	-0.06	0.40	-0.17	1.00

Number of data points = 36
Average % silt = 82.7

Table 13 Percentage silt content and D50 and D90 sizes for spoil ground samples

Grab samples taken in Spoil Ground

Grab No.	%silt	D50 (mm)	D90 (mm)
1	3.7	0.160	0.240
2	11.8	0.160	0.305
4	7.6	0.155	0.265
5	52.1	<0.060	1.900
6	2.7	0.175	0.280
7	6.2	0.170	0.310
8	55.8	<0.060	0.270
9	18.0	0.180	0.580
10	5.2	8.300	25.000
11	7.2	0.185	0.350
12	21.7	0.140	0.305
13	26.0	0.125	0.305
14	50.1	0.063	17.000
15	5.9	0.165	0.310
16	23.3	0.155	0.520
17	29.7	0.240	25.000
18	48.5	0.075	6.100
19	40.2	0.165	5.500
20	22.2	0.130	0.290
21	33.6	0.120	0.350
22	7.5	0.185	0.300
23	44.6	0.095	0.240
24	44.6	0.100	0.350
25	23.1	0.130	0.260
26	28.6	0.120	0.350
27	22.3	0.201	2.500
28	51.9	<0.060	0.260
29	2.8	0.170	0.330
30	17.2	0.130	0.260
32	3.5	0.240	0.700
33	72.3	<0.060	0.350
34	13.1	0.170	0.300
37	75.1	0.060	3.900

Table 14 Percentage silt content and D50 and D90 sizes for hopper grab samples

Grab samples taken in hopper

Grab No.	%silt	D50 (mm)	D90 (mm)
T1	89.6	<0.060	0.068
T2	3.7	0.165	0.360
T3	5.1	0.145	0.250
T4	4.2	0.125	0.370
T10	55.7	<0.060	0.180
T11	89.0	<0.060	0.072
T12	45.2	0.120	0.210
T13	13.1	0.185	0.340
T14	41.9	0.110	0.205
T15	66.8	<0.060	0.215
T16	14.5	0.150	0.200
T17	30.4	0.130	0.205
T20	17.4	0.140	0.190
T21	50.4	0.060	0.200
T22	18.3	0.140	0.210
T23	79.6	<0.060	0.420
T24	35.4	0.125	0.180
T25	20.9	0.150	0.210
T26	49.1	0.074	0.235
T27	62.2	<0.060	0.190

Table 15 Percentage silt content and D50 and D90 sizes for hopper bottle samples

Bottle samples taken in hopper

Bottle No.	%silt	D50 (mm)	D90 (mm)
296	78.5	<0.060	0.150
297	95.3	<0.060	<0.060
298	82.2	<0.060	0.140
299	98.1	<0.060	<0.060
300	84.5	<0.060	0.140
301	95.5	<0.060	<0.060
302	94.6	<0.060	<0.060
303	84.4	<0.060	0.086
305	68.0	<0.060	0.170
307	86.3	<0.060	0.080
308	80.0	<0.060	0.140
310	93.3	<0.060	<0.060
311	92.3	<0.060	<0.060
312	86.9	<0.060	0.077
313	92.8	<0.060	<0.060
315	86.5	<0.060	0.090
316	89.5	<0.060	0.066
318	88.5	<0.060	0.070
320	74.4	<0.060	0.150
321	74.2	<0.060	0.160
322	81.2	<0.060	0.130
323	75.2	<0.060	0.150
324	79.3	<0.060	0.140
326	80.4	<0.060	0.130
327	74.7	<0.060	0.150
328	30.6	0.110	0.210
330	80.3	<0.060	0.130
331	85.3	<0.060	0.090
332	90.6	<0.060	<0.060
334	80.0	<0.060	0.110
335	74.9	<0.060	0.150
336	94.0	<0.060	<0.060
337	82.5	<0.060	0.110
339	95.2	<0.060	<0.060
344	64.7	<0.060	0.180

Table 16 Detailed results of overdredging tests

Drop 2

overdredge = 107mins

	Depth	Volume	5mins	59mins	112mins
0:00 -0.75	0.5	195	1.006	1.017	1.122
0.75 -1.25	1.0	125	1.043	1.046	1.144
1.25 -1.75	1.5	125	1.058	1.078	1.169
1.75 -2.25	2.0	125	1.074	1.089	1.190
2.25 -2.75	2.5	130	1.071	1.085	1.506
2.75 -3.25	3.0	125	1.051	1.082	1.567
3.25 -3.75	3.5	125	1.086	1.095	1.573
3.75 -4.25	4.0	120	1.088	1.538	1.573
4.25 -4.75	4.5	115	1.080	1.534	1.573
4.75 -5.25	5.0	105	1.120	1.541	1.573
5.25 -5.75	5.5	85	1.139	1.541	1.573
5.75 -6.25	6.0	80	1.172	1.541	1.573
6.25 -6.75	6.5	65	1.172	1.541	1.573
6.75 -7.00	7.0	30	1.172	1.541	1.573
Total volume =		1550			
Mean Density =			1.080	1.249	1.412

Drop 3 — overdredge = 79mins; Drop 4 — overdredge = 82mins

	Drop 3: 0mins	Drop 3: 17mins	Drop 4: 41mins	Drop 4: 86mins	Drop 4: 102mins
	1.029	1.016	1.039	1.039	1.038
	1.038	1.037	1.069	1.044	1.036
	1.048	1.071	1.071	1.047	1.037
	1.083	1.073	1.082	1.059	1.040
	1.079	1.090	1.093	1.396	1.152
	1.095	1.084	1.104	1.489	1.519
	1.091	1.078	1.103	1.483	1.519
	1.101	1.093	1.130	1.483	1.519
	1.111	1.139	1.156	1.483	1.519
	1.130	1.167	1.411	1.483	1.519
	1.145	1.353	1.522	1.483	1.519
	1.171	1.492	1.614	1.483	1.519
	1.171	1.492	1.614	1.483	1.519
	1.171	1.492	1.614	1.483	1.519
Mean Density =	1.091	1.141	1.195	1.316	1.311

Table 16 (cont'd)

Drop 5		Drop 6		Drop 7	
overdredge = 20mins		overdredge = 22mins		overdredge = 24mins	
0mins	28mins	0mins	18mins	0mins	17mins
1.032	0.996	1.047	1.060	1.041	1.058
1.044	1.000	1.051	1.043	1.056	1.056
1.045	1.031	1.058	1.055	1.058	1.096
1.045	1.021	1.044	1.084	1.078	1.098
1.032	1.007	1.025	1.078	1.082	1.084
1.021	1.033	1.052	1.089	1.088	1.092
1.026	1.037	1.058	1.095	1.087	1.099
1.029	1.036	1.069	1.098	1.073	1.085
1.034	1.045	1.062	1.109	1.091	1.112
1.051	1.036	1.074	1.128	1.104	1.133
1.058	1.048	1.091	1.142	1.120	1.140
1.045	1.236	1.117	1.181	1.130	1.147
1.045	1.263	1.117	1.282	1.140	1.154
1.045	1.263	1.117	1.451	1.461	1.525
1.038	1.049	1.062	1.106	1.089	1.106

Drop 8			Drop 9		Drop 10	
overdredge = 22mins			overdredge = 14mins		overdredge =14mins	
0mins	19mins	39mins	0mins	16mins	2mins	19mins
1.063	1.065	1.086	1.063	1.054	1.071	1.034
1.068	1.072	1.086	1.054	1.075	1.066	1.042
1.072	1.082	1.086	1.056	1.065	1.076	1.070
1.064	1.108	1.086	1.059	1.061	1.088	1.097
1.066	1.098	1.086	1.069	1.074	1.119	1.104
1.072	1.107	1.113	1.080	1.077	1.125	1.110
1.075	1.110	1.114	1.082	1.081	1.080	1.116
1.084	1.104	1.135	1.074	1.093	1.103	1.122
1.094	1.129	1.152	1.076	1.096	1.134	1.129
1.099	1.129	1.161	1.078	1.078	1.136	1.139
1.118	1.143	1.214	1.081	1.108	1.137	1.142
1.131	1.159	1.265	1.094	1.139	1.150	1.148
1.137	1.199	1.316	1.113	1.542	1.154	1.325
1.434	1.426	1.470	1.449	1.542	1.460	1.515
1.089	1.114	1.138	1.080	1.108	1.112	1.116

Table 16 (cont'd)

Drop 11 — overdredge = 14mins; Drop 12 — overdredge = 26mins

Drop 11: 1min	Drop 11: 17mins	Drop 12: 0mins	Drop 12: 13mins	Drop 12: 36mins
1.066	1.065	1.048	1.046	1.050
1.067	1.065	1.057	1.057	1.050
1.058	1.051	1.057	1.054	1.054
1.058	1.038	1.054	1.049	1.062
1.083	1.050	1.050	1.086	1.065
1.057	1.065	1.047	1.067	1.066
1.073	1.078	1.054	1.076	1.075
1.081	1.093	1.081	1.074	1.082
1.089	1.106	1.081	1.079	1.095
1.096	1.120	1.083	1.093	1.107
1.103	1.151	1.108	1.112	1.155
1.111	1.183	1.097	1.163	1.209
1.112	1.330	1.094	1.163	1.380
1.523	1.482	1.397	1.163	1.467
1.086	1.100	1.072	1.080	1.101

Drop 13 — overdredge = 14mins; Drop 14 — overdredge = 12mins

Drop 13: 0mins	Drop 13: 18mins	Drop 13: 39mins	Drop 14: 1min	Drop 14: 24mins	Drop 14: 37mins
1.038	1.032	1.036	1.000	1.016	1.039
1.037	1.036	1.037	1.029	1.024	1.046
1.050	1.038	1.042	1.035	1.057	1.038
1.050	1.037	1.033	1.009	1.065	1.047
1.052	1.057	1.025	1.047	1.059	1.041
1.057	1.054	1.036	1.049	1.064	1.056
1.037	1.064	1.050	1.054	1.063	1.068
1.050	1.063	1.051	1.049	1.103	1.078
1.047	1.093	1.054	1.054	1.104	1.093
1.049	1.077	1.074	1.056	1.115	1.076
1.061	1.082	1.097	1.037	1.097	1.079
1.065	1.105	1.320	1.036	1.321	1.353
1.088	1.429	1.550	1.314	1.434	1.485
1.432	1.541	1.550	1.450	1.423	1.485
1.057	1.083	1.091	1.055	1.101	1.099

Table 16 (cont'd)

Drop 15		Drop 16		
overdredge = 19mins		overdredge = 27mins		
1min	24mins	1min	19mins	34mins
1.047	1.045	1.051	1.030	1.047
1.047	1.066	1.049	1.044	1.047
1.051	1.078	1.056	1.052	1.056
1.063	1.081	1.049	1.066	1.063
1.070	1.070	1.062	1.066	1.066
1.075	1.075	1.060	1.054	1.071
1.069	1.088	1.067	1.064	1.064
1.073	1.066	1.068	1.067	1.065
1.078	1.106	1.054	1.061	1.076
1.073	1.102	1.053	1.072	1.044
1.060	1.113	1.059	1.084	1.057
1.076	1.221	1.042	1.094	1.115
1.101	1.449	1.046	1.313	1.524
1.369	1.494	1.563	1.591	1.460
1.071	1.109	1.065	1.081	1.089

Drop 17			Drop 18		Drop 19	
overdredge = 11mins			overdredge = 8mins		overdredge = 7mins	
1min	14mins	27mins	4mins	14mins	1min	12mins
1.006	1.025	1.044	1.035	1.039	1.024	1.014
1.006	1.025	1.044	1.035	1.039	1.024	1.014
1.030	1.040	1.036	1.050	1.043	1.031	1.020
1.057	1.054	1.024	1.066	1.047	1.039	1.029
1.062	1.047	1.031	1.061	1.053	1.051	1.030
1.068	1.040	1.036	1.056	1.060	1.063	1.031
1.069	1.052	1.044	1.041	1.069	1.058	1.030
1.071	1.066	1.052	1.053	1.076	1.054	1.030
1.077	1.077	1.054	1.066	1.094	1.053	1.045
1.071	1.102	1.060	1.056	1.092	1.037	1.052
1.084	1.093	1.114	1.073	1.100	1.065	1.053
1.090	1.177	1.504	1.118	1.094	1.075	1.069
1.112	1.531	1.423	1.530	1.458	1.557	1.414
1.557	1.580	1.520	1.495	1.489	1.608	1.607
1.065	1.090	1.095	1.084	1.088	1.078	1.059

Table 16 (cont'd)

Drop 20			Drop 21	
overdredge = 16mins			overdredge = 19mins	
1min	15mins	33mins	1min	16mins
1.039	1.038	1.034	1.059	1.037
1.039	1.038	1.034	1.059	1.037
1.054	1.046	1.041	1.055	1.050
1.067	1.050	1.051	1.052	1.062
1.075	1.053	1.055	1.055	1.061
1.081	1.058	1.060	1.057	1.060
1.078	1.083	1.073	1.060	1.065
1.075	1.108	1.084	1.064	1.068
1.065	1.121	1.087	1.059	1.074
1.082	1.121	1.097	1.066	1.076
1.091	1.114	1.139	1.033	1.090
1.093	1.129	1.209	1.066	1.092
1.375	1.427	1.540	1.563	1.524
1.487	1.457	1.519	1.563	1.524
1.088	1.097	1.100	1.088	1.090

Table 17 Initial and final mean densities and particle sizes of overdredging tests

Drop No.	Grab No.	Initial Mean Density (g/cm*3)	Final Mean Density (g/cm*3)	Time of Overdredge (mins)	% Increase Mean Dry Density	Grab D50 (mm)	D90 (mm)
5	T10	1.038	1.049	20	29	0.060	0.180
6		1.062	1.106	22	71		
7	T12	1.089	1.106	24	19	0.120	0.210
9	T14	1.080	1.108	14	35	0.110	0.205
10	T15	1.112	1.116	14	4	0.060	0.215
11	T16	1.086	1.100	14	16	0.150	0.200
12	T17	1.072	1.101	26	40	0.130	0.205
13	T20	1.057	1.091	14	60	0.140	0.190
14	T21	1.055	1.099	12	80	0.060	0.200
15	T22	1.071	1.109	19	54	0.140	0.210
16		1.065	1.089	27	37		
17	T24	1.065	1.095	11	46	0.125	0.180
18	T25	1.084	1.088	8	5	0.150	0.210
19	T26	1.078	1.059	7	-24	0.074	0.235
20		1.088	1.100	16	14		
21		1.088	1.090	19	2		

FIGURES.

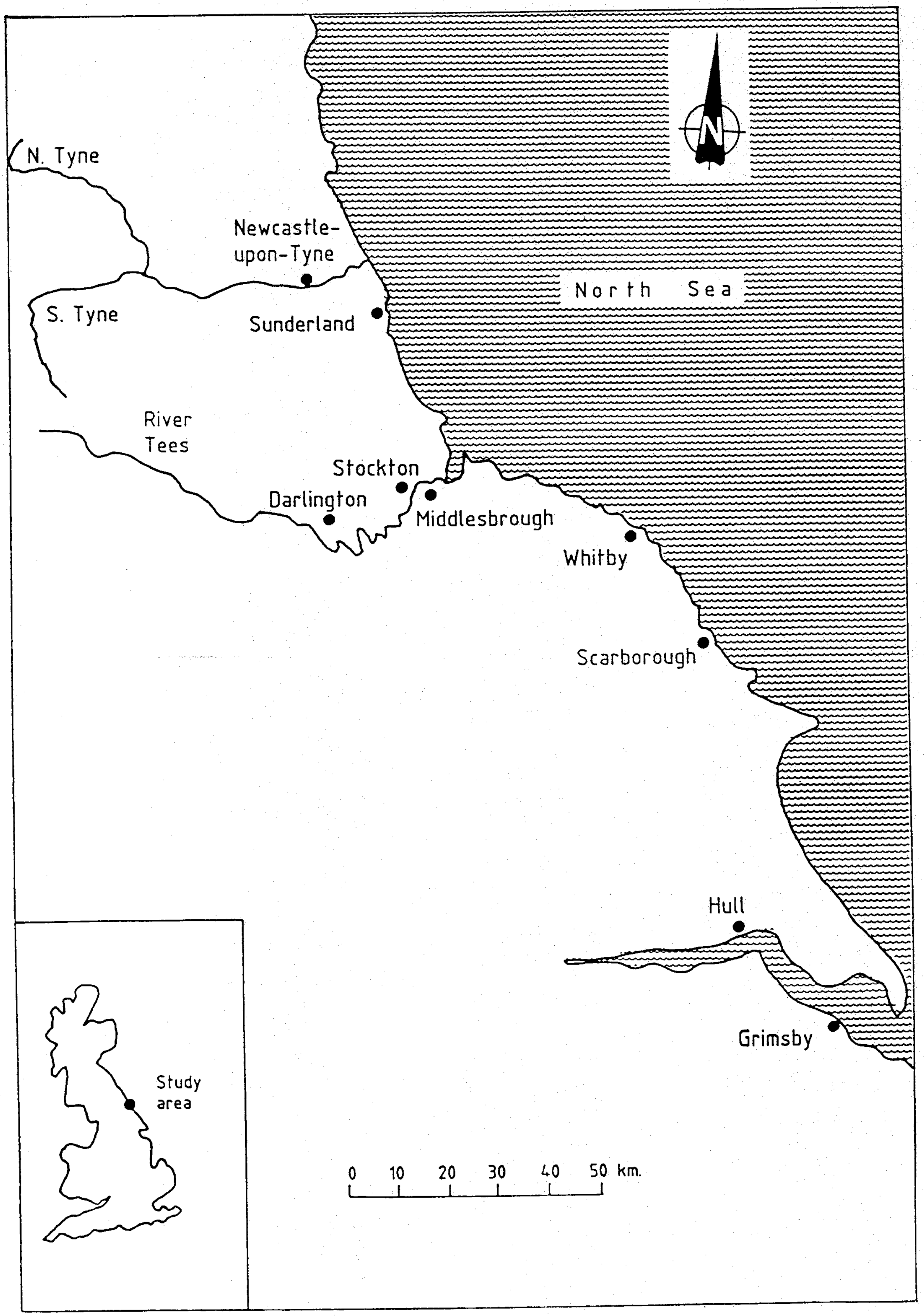

Fig 1 Location map of River Tees

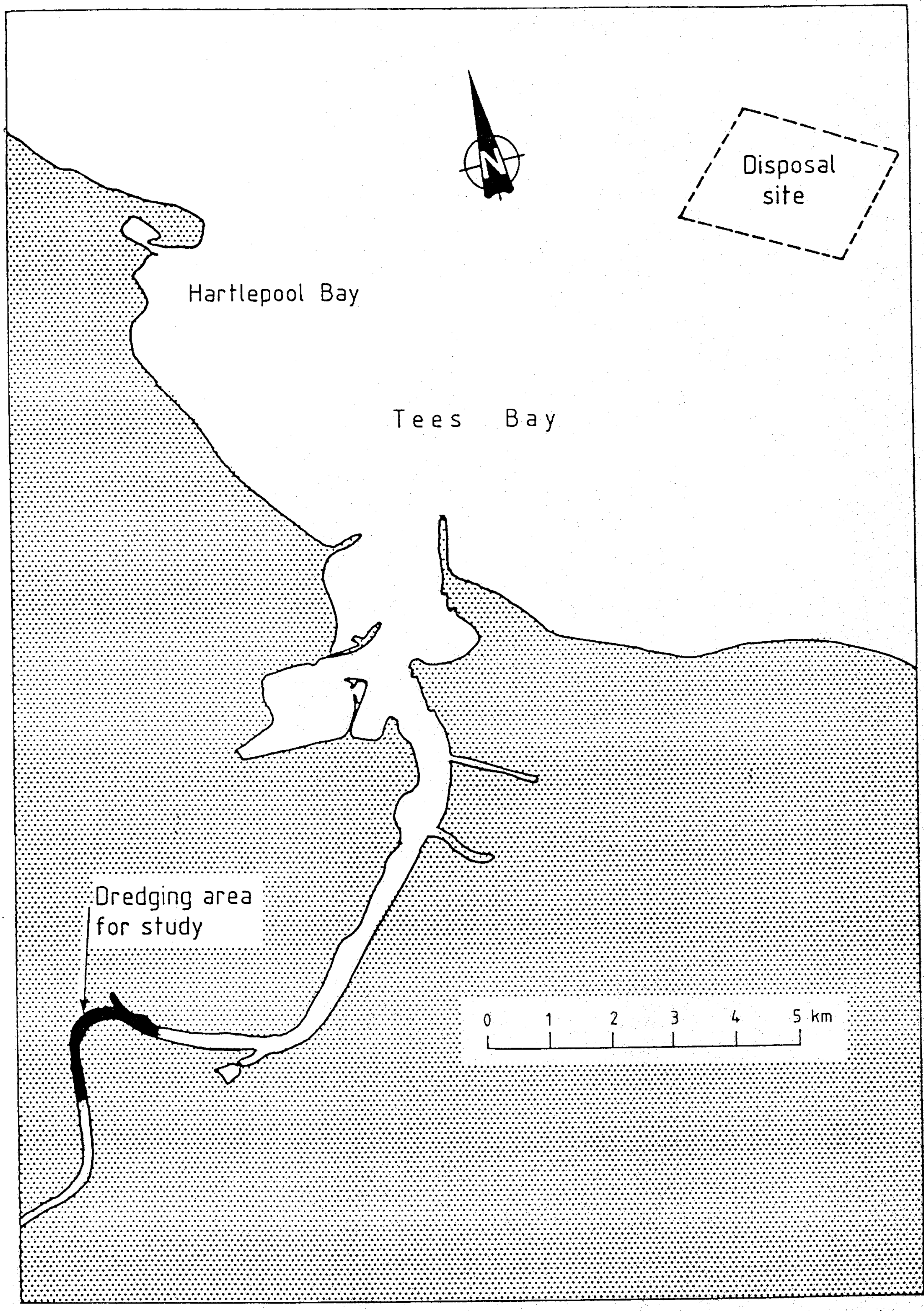

Fig 2 Location map of disposal site and dredging area for study

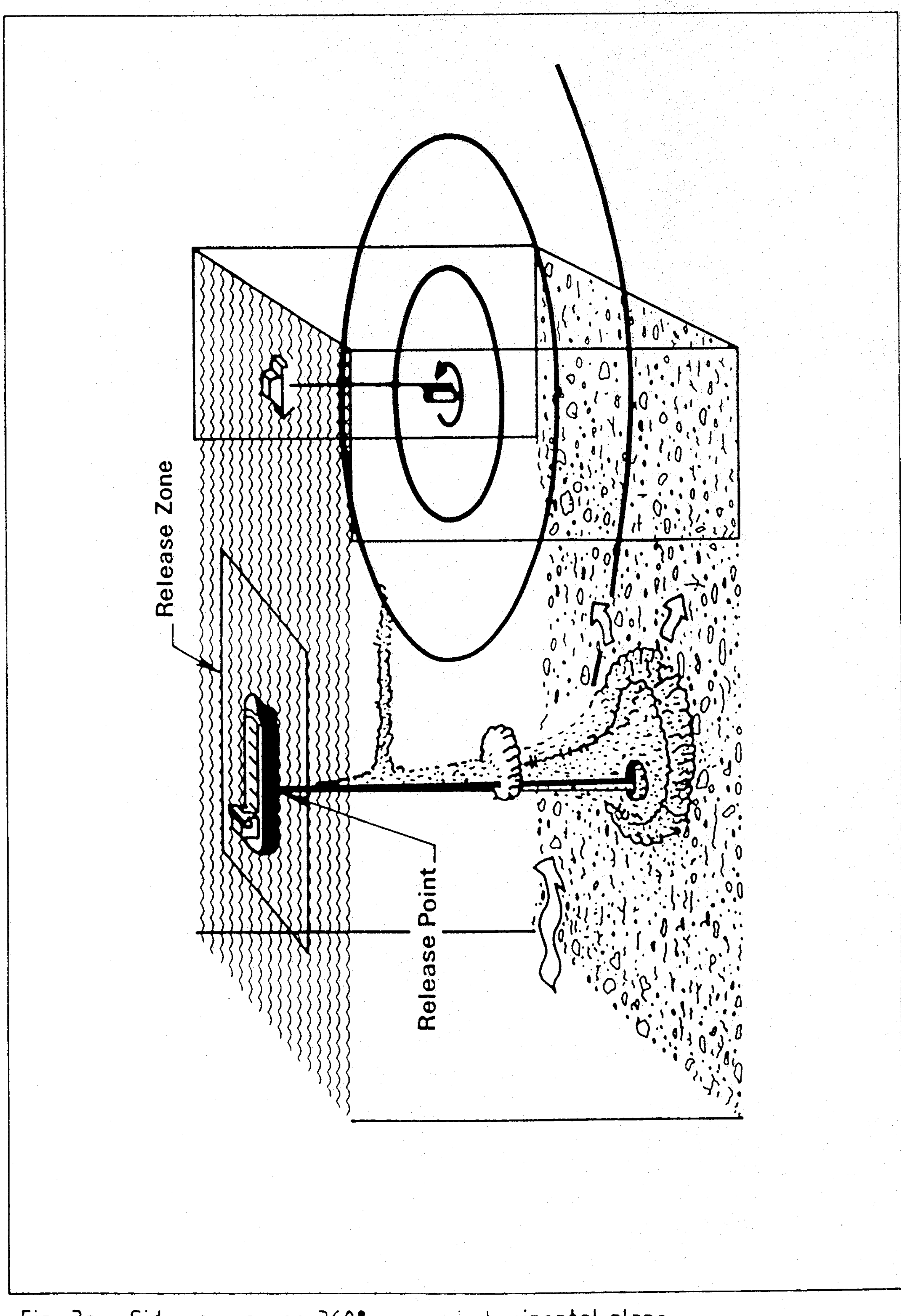

Fig 3a Side scan sonar 360° sweep in horizontal plane

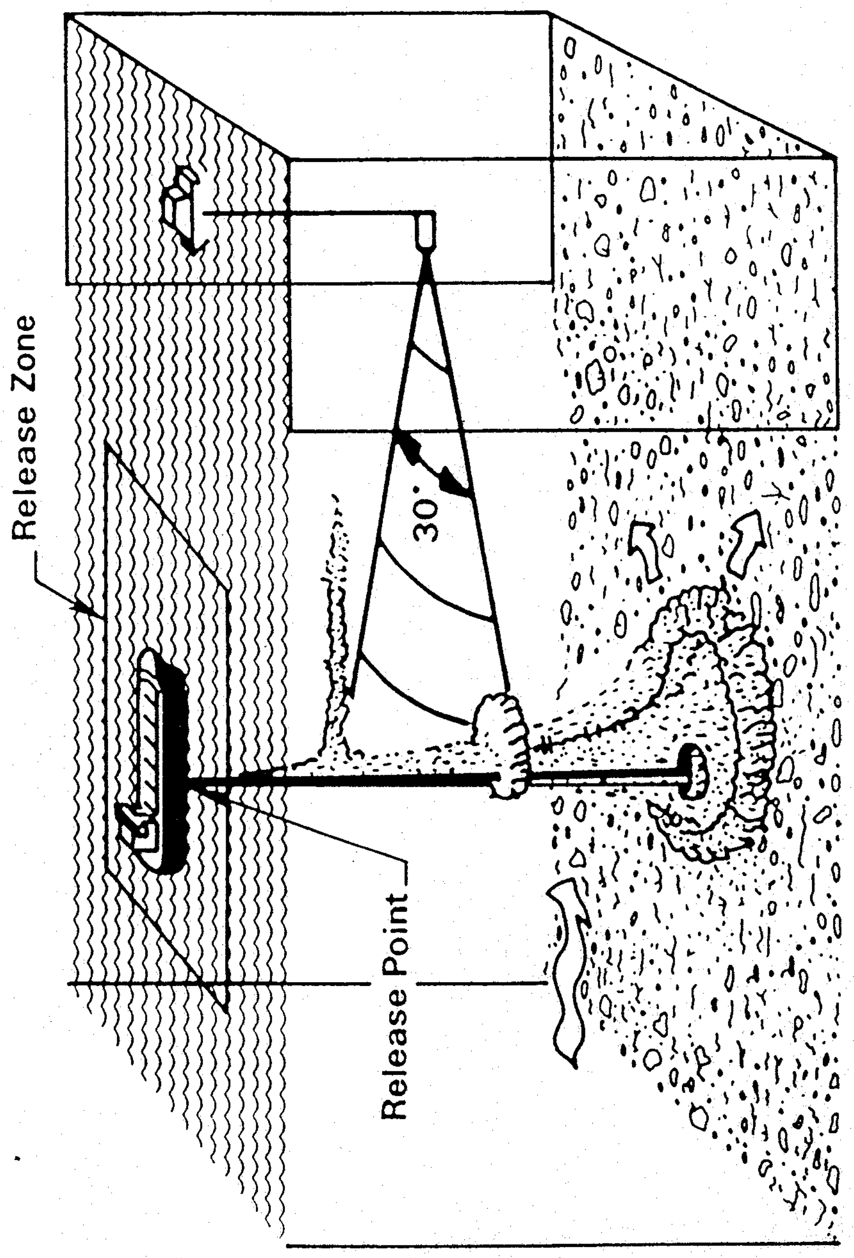

Fig 3b Side scan sonar 30° sweep in horizontal plane

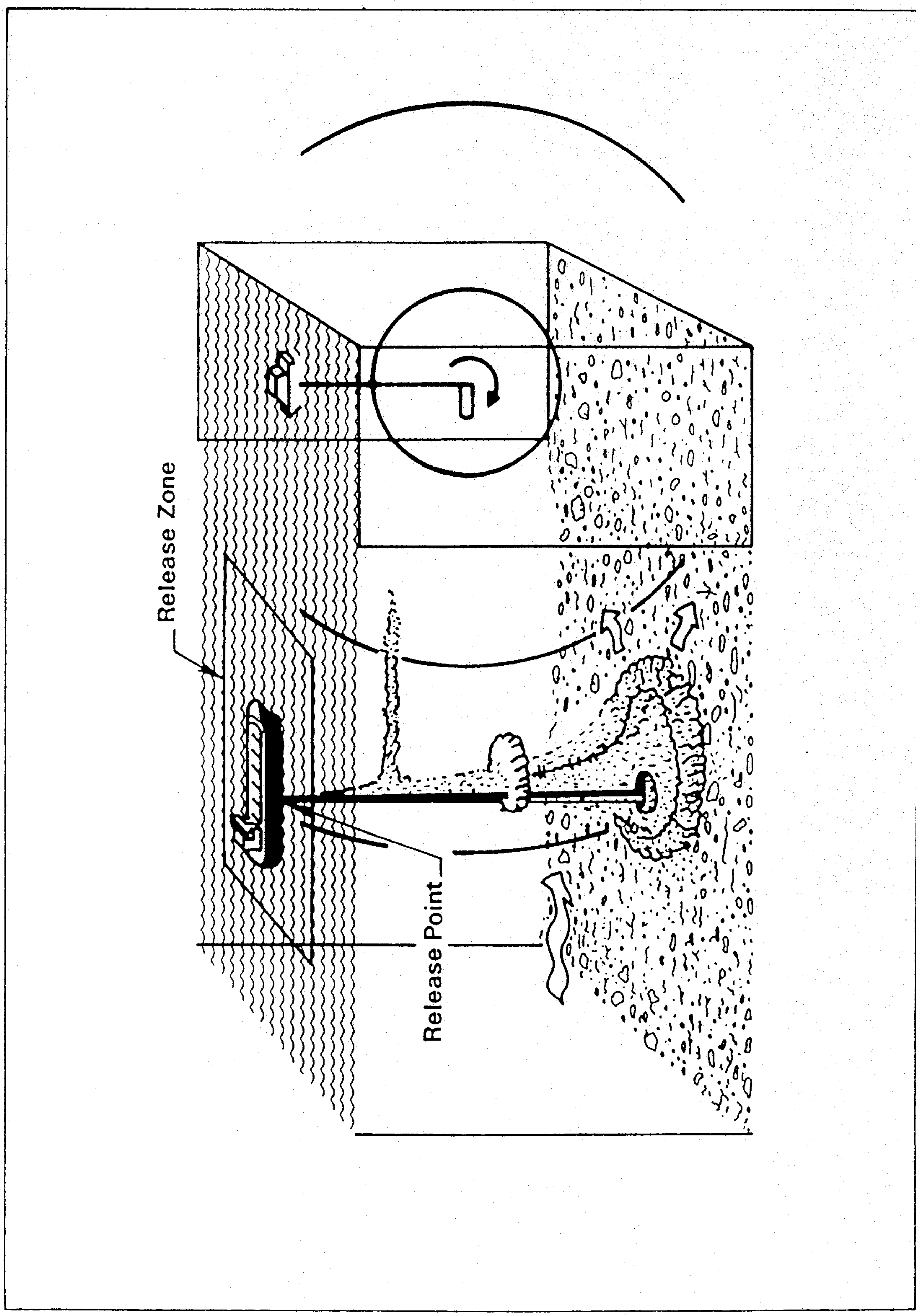

Fig 3c Side scan sonar 360° sweep in vertical plane

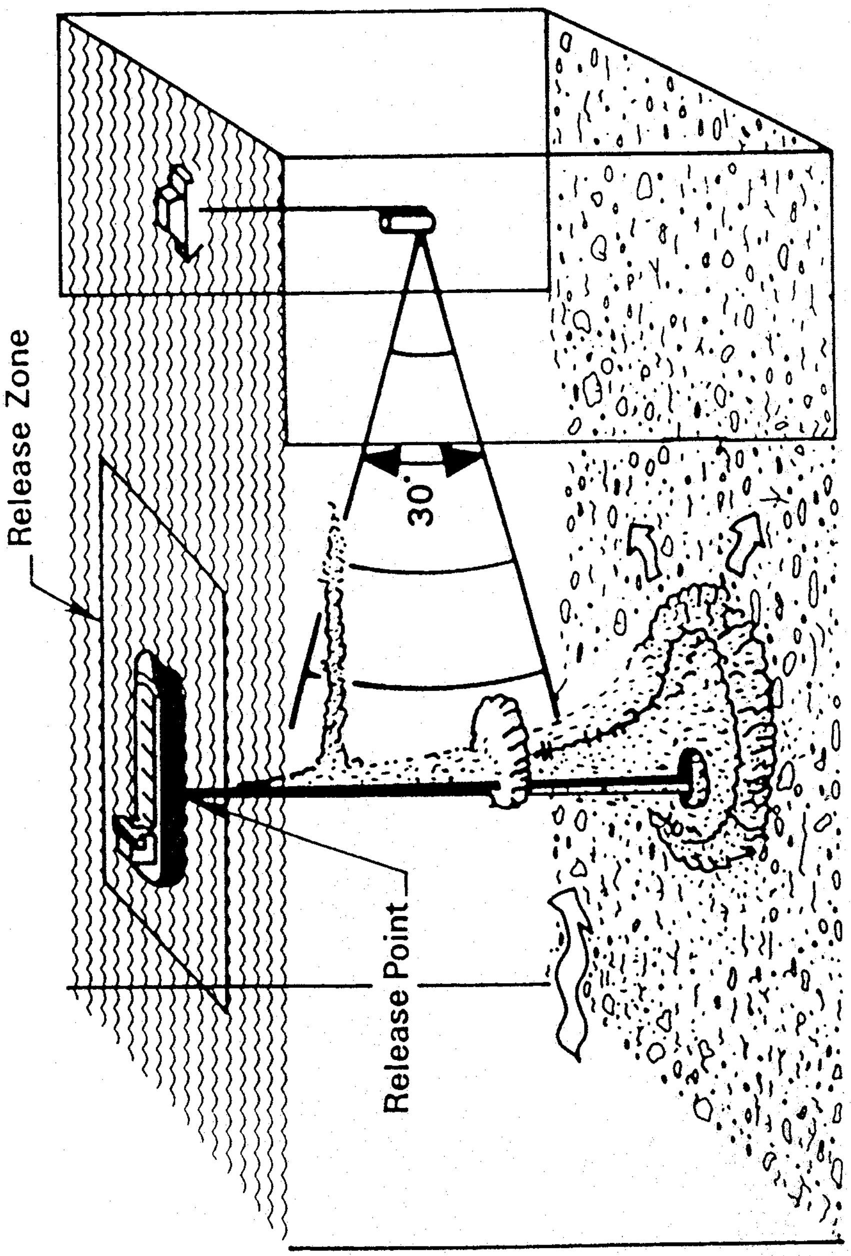

Fig 3d Side scan sonar 30° sweep in vertical plane

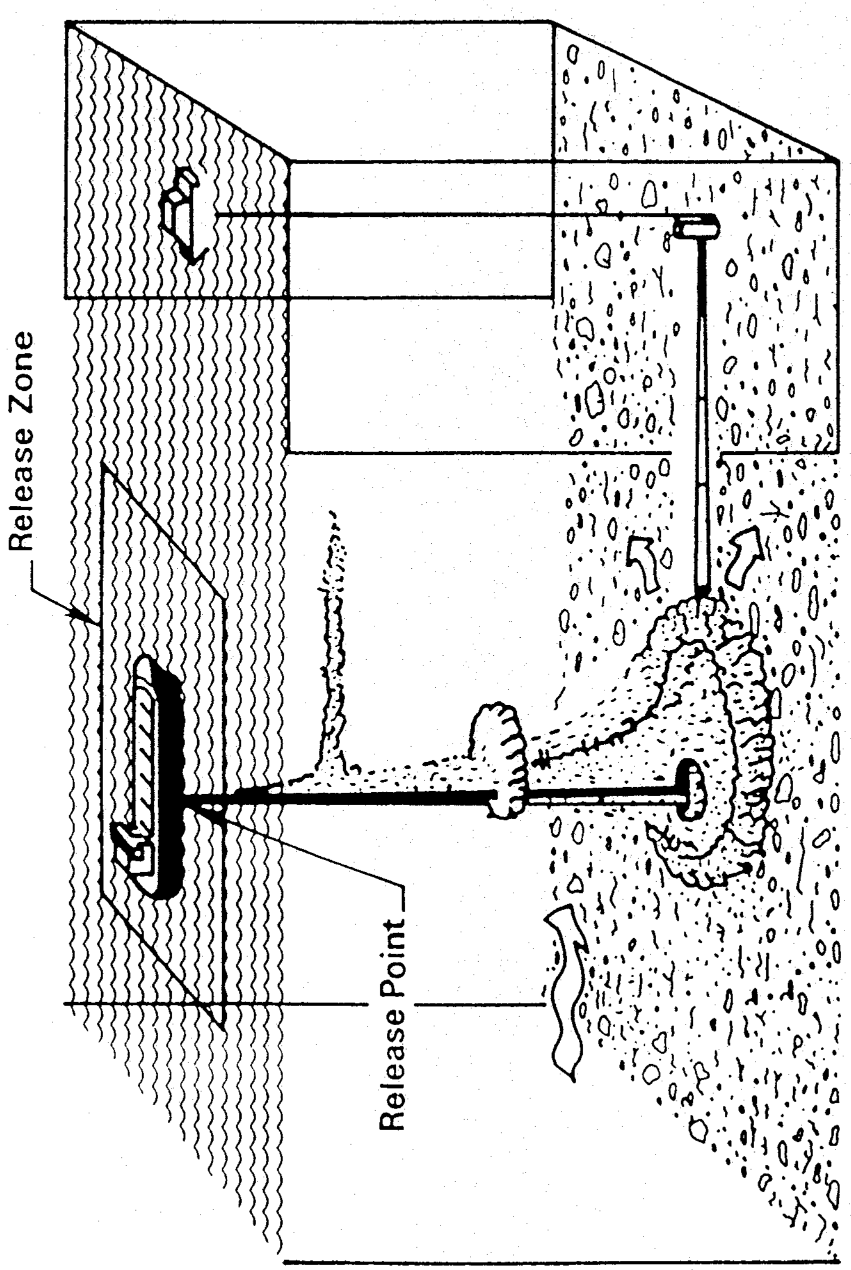

Fig 3e Side scan sonar 1,7° cone beam

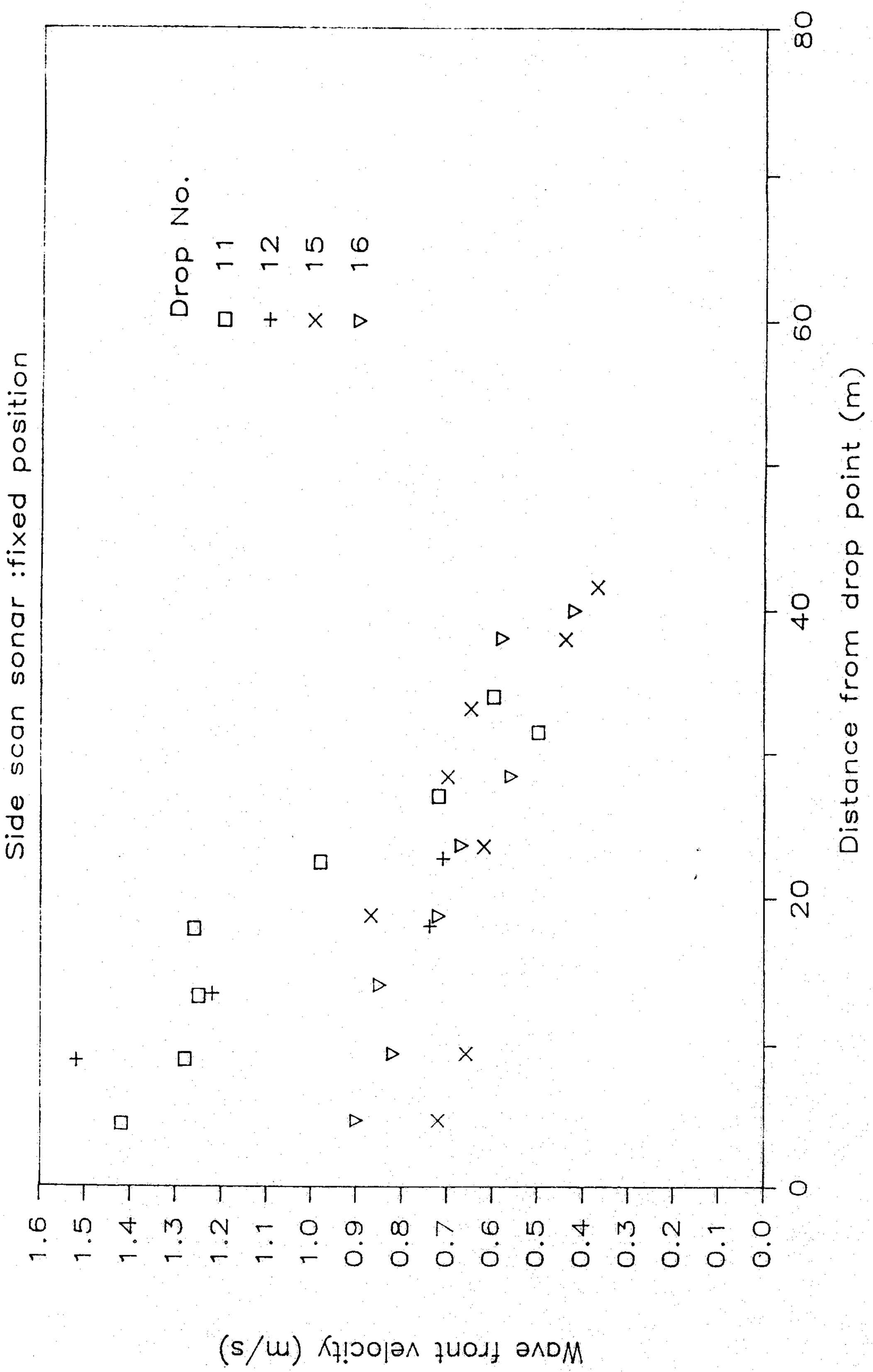

Fig 4 Side scan-sonar : wave front velocity against distance from drop point

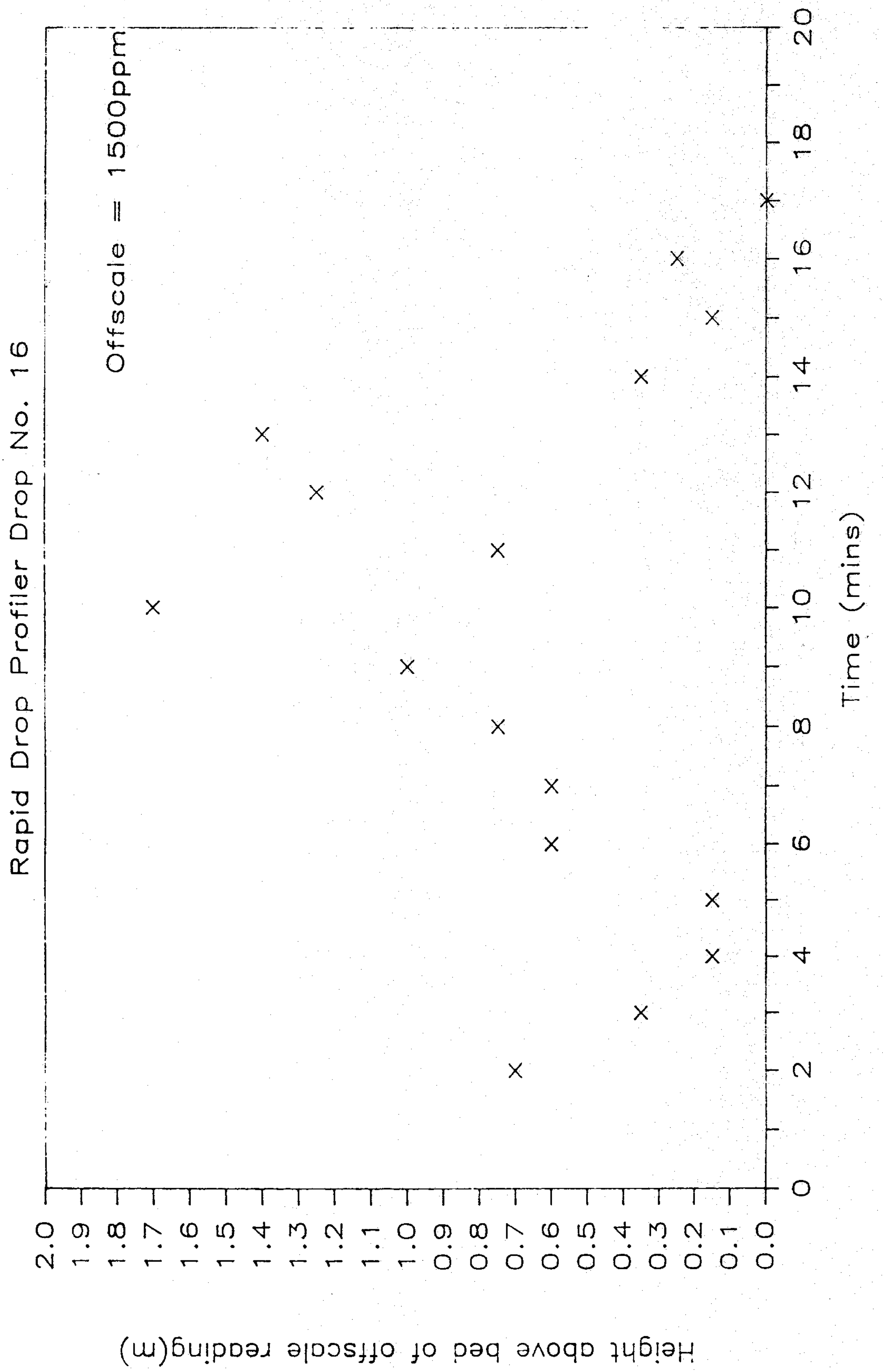

Fig 5 Rapid Drop Profiler : height above bed to offscale reading against time after drop

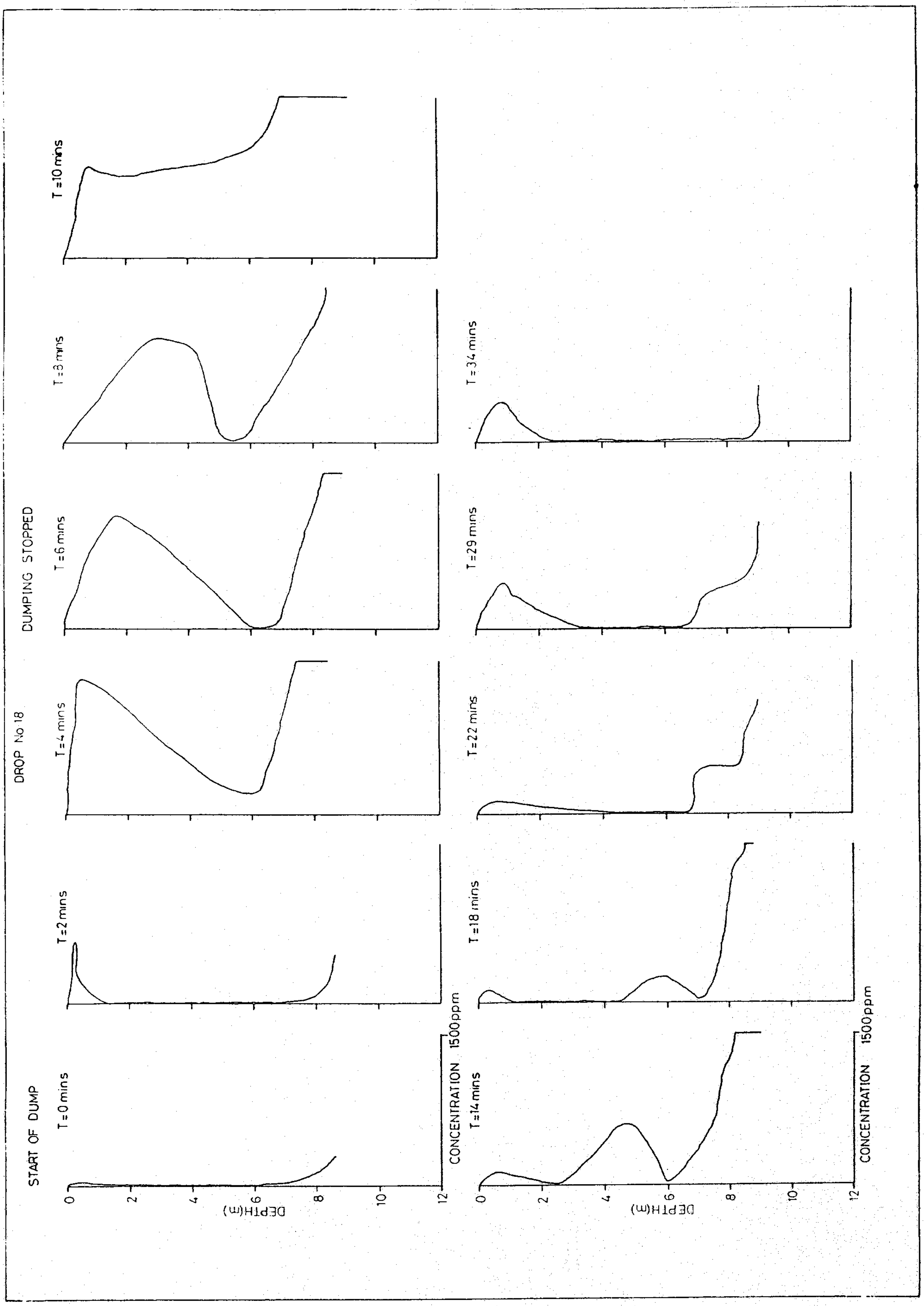

Fig 6 Rapid drop profiler : concentration against depth profiles for various times after drop

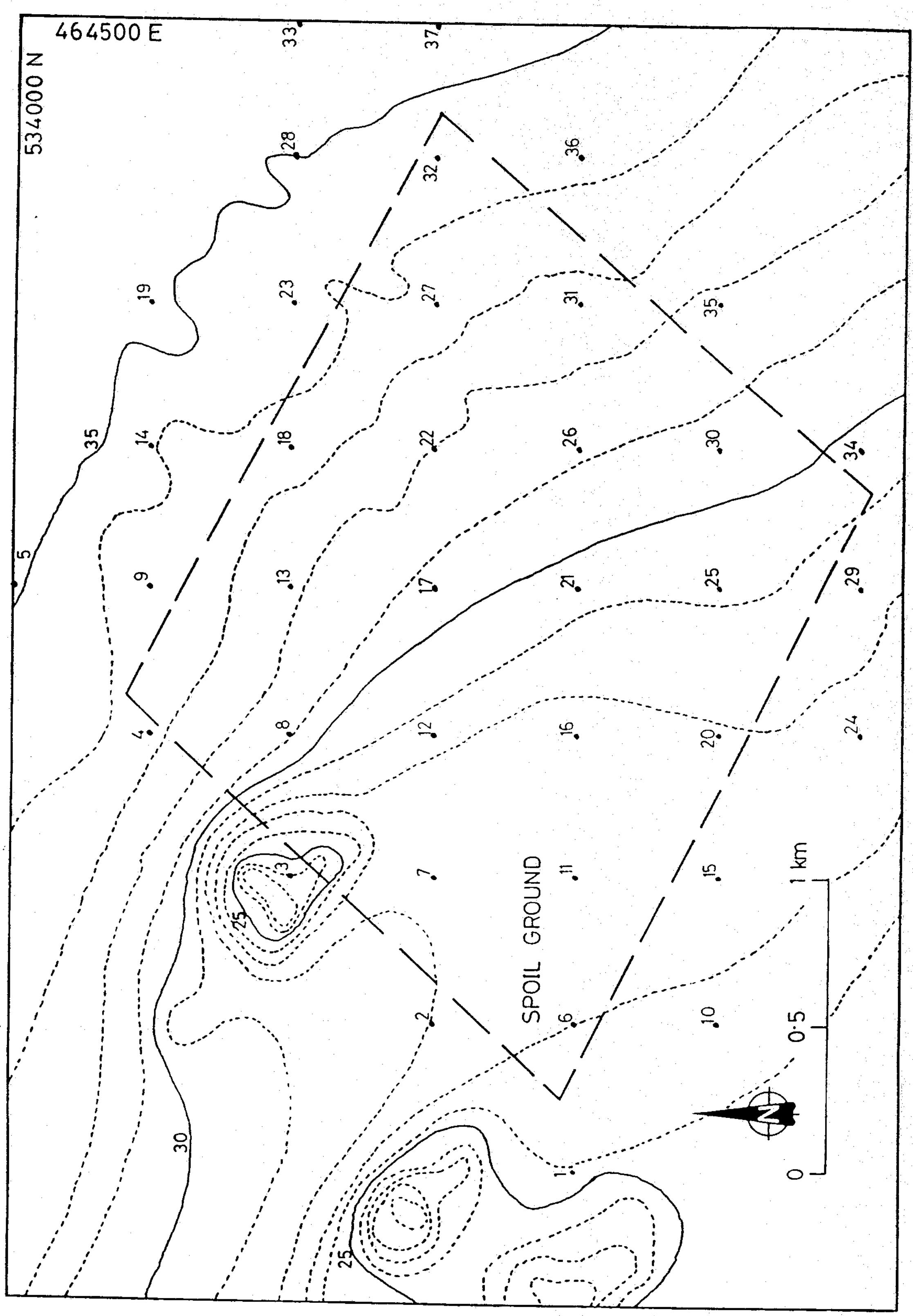

Fig 7 Location map of grab samples in spoil ground

COPPER

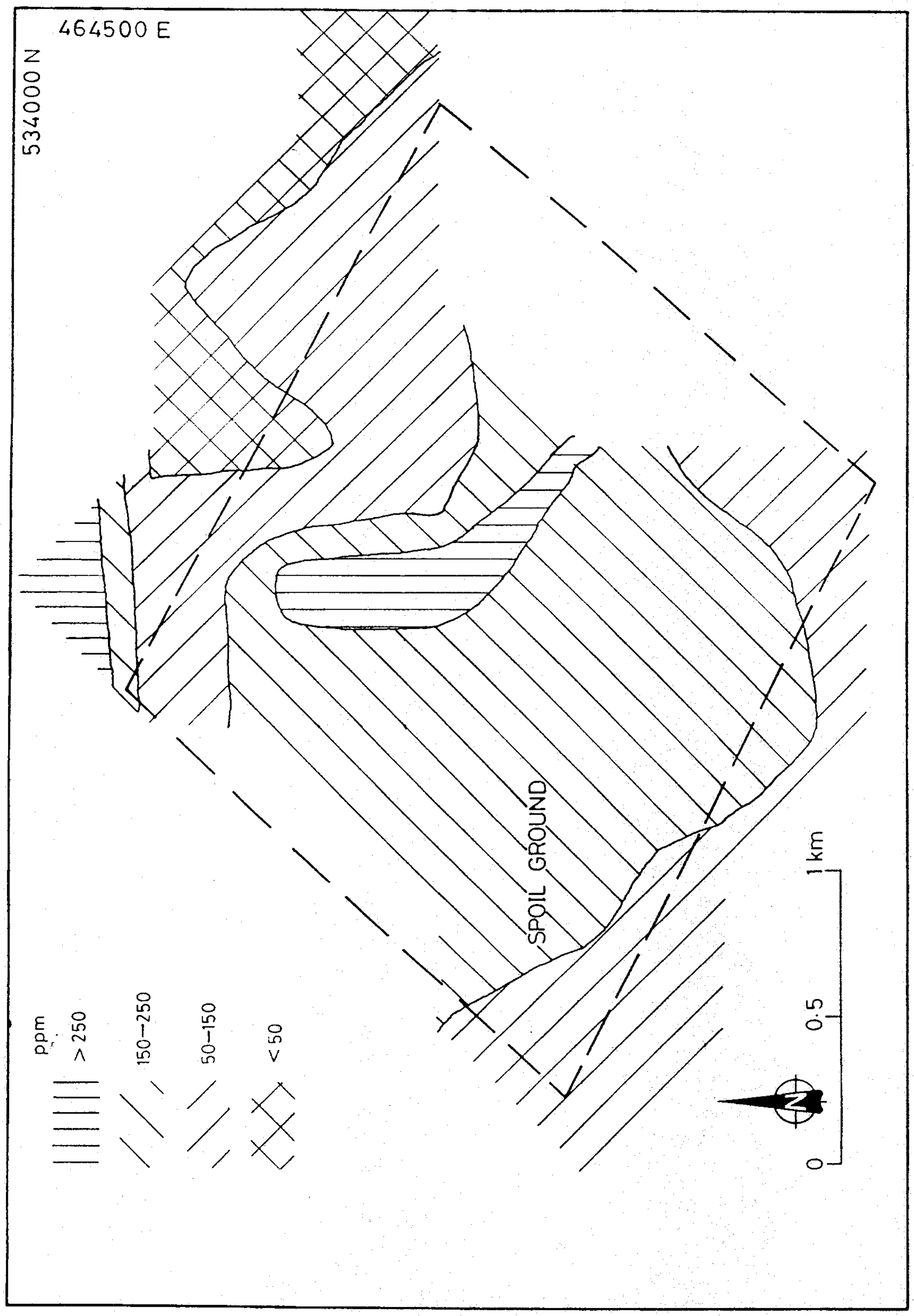

Fig 8 Distribution of copper on silt fraction of spoil ground samples

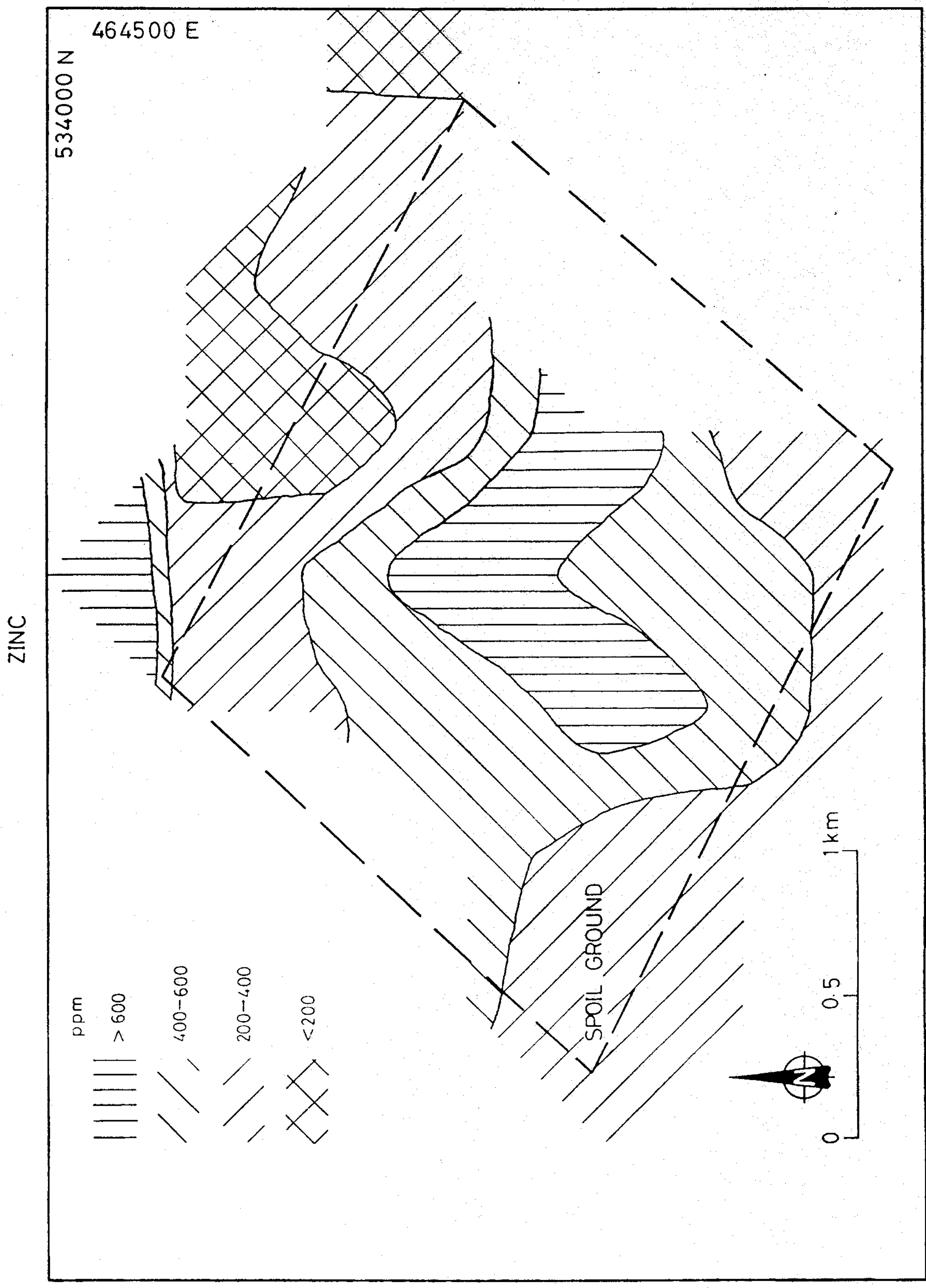

Fig 9 Distribution of zinc on silt fraction of spoil ground samples

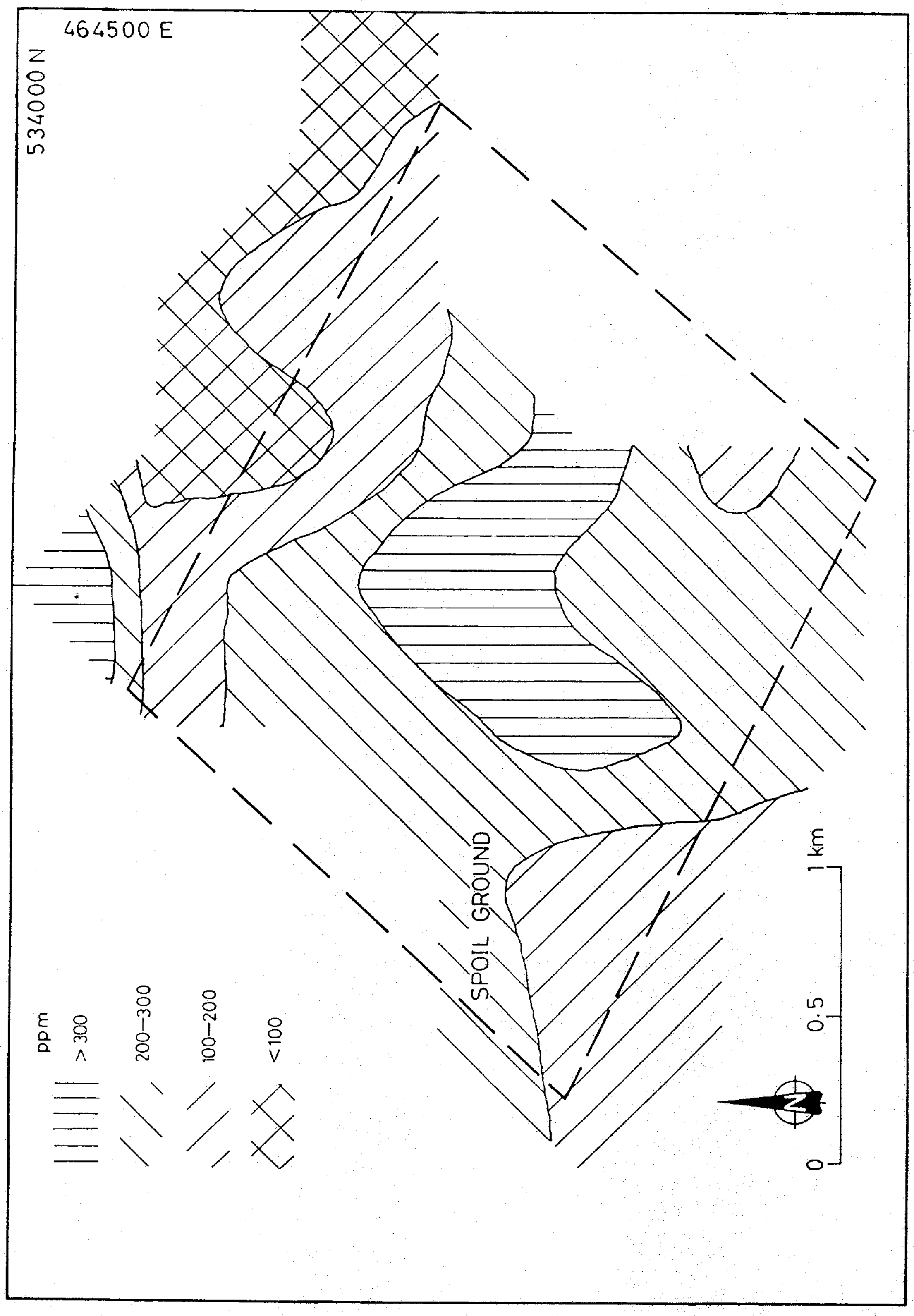

Fig 10 Distribution of lead on silt fraction of spoil ground samples

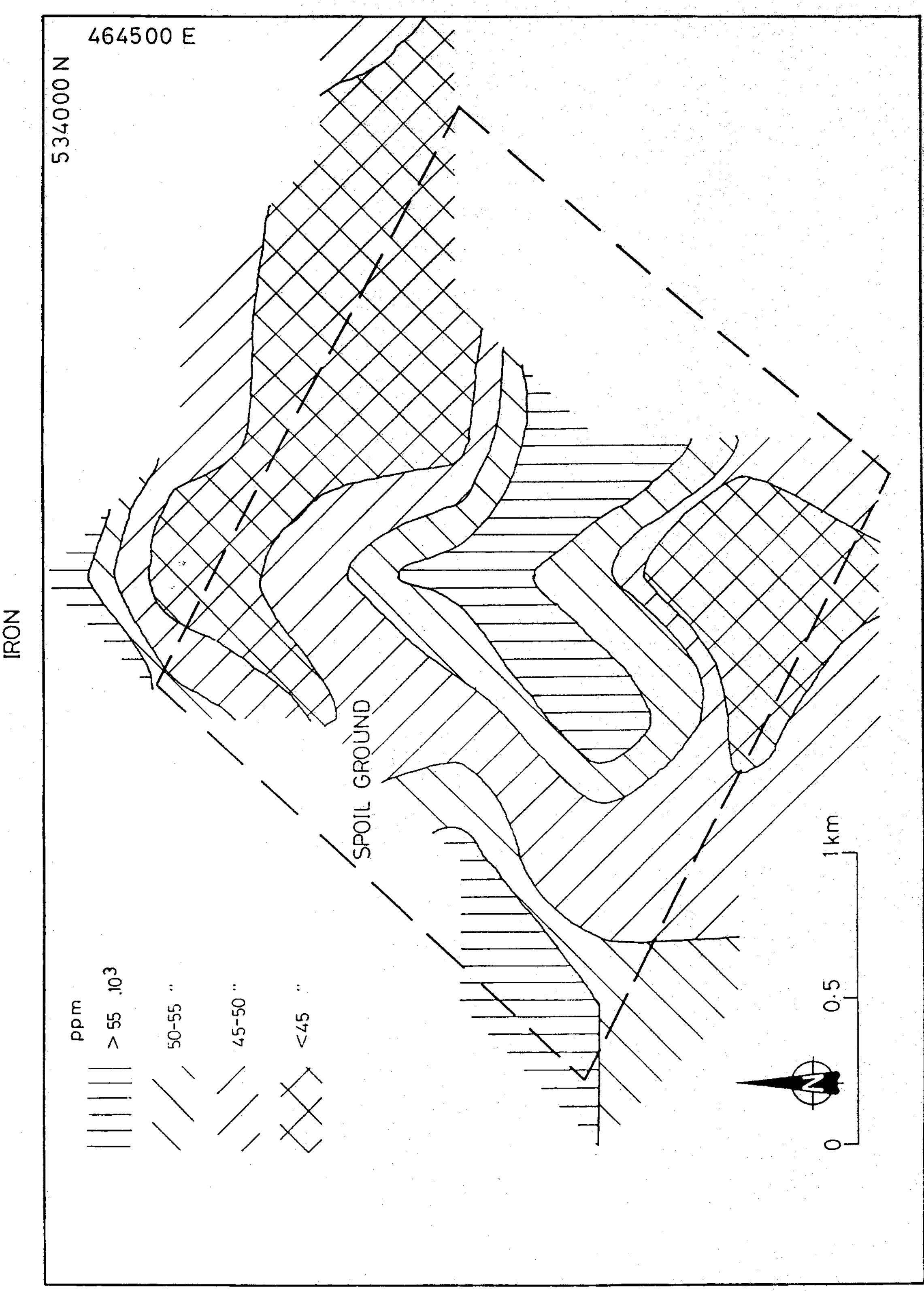

Fig 11 Distribution of iron on silt fraction of spoil ground samples

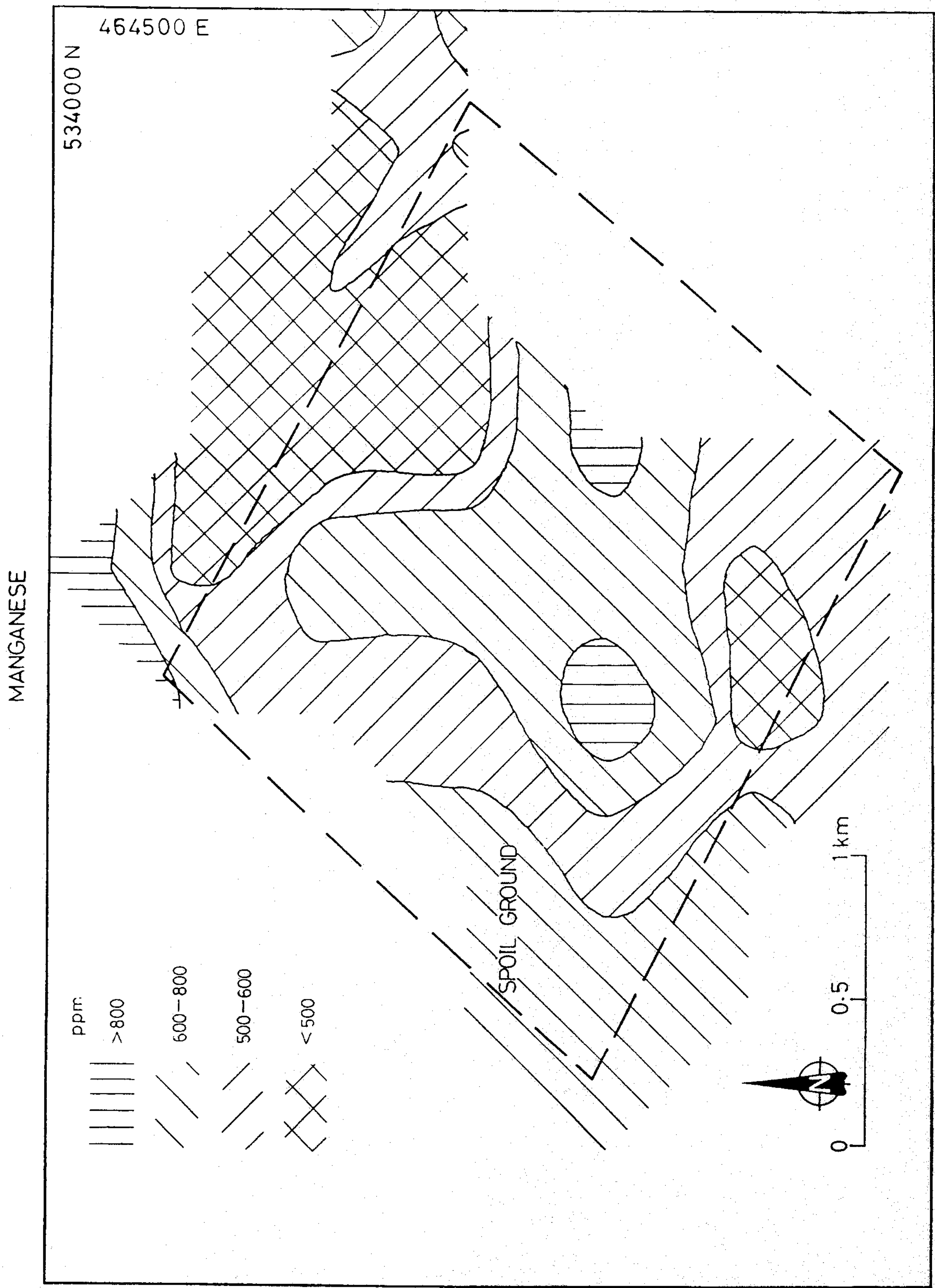

Fig 12 Distribution of maganese on silt fraction of spoil ground samples

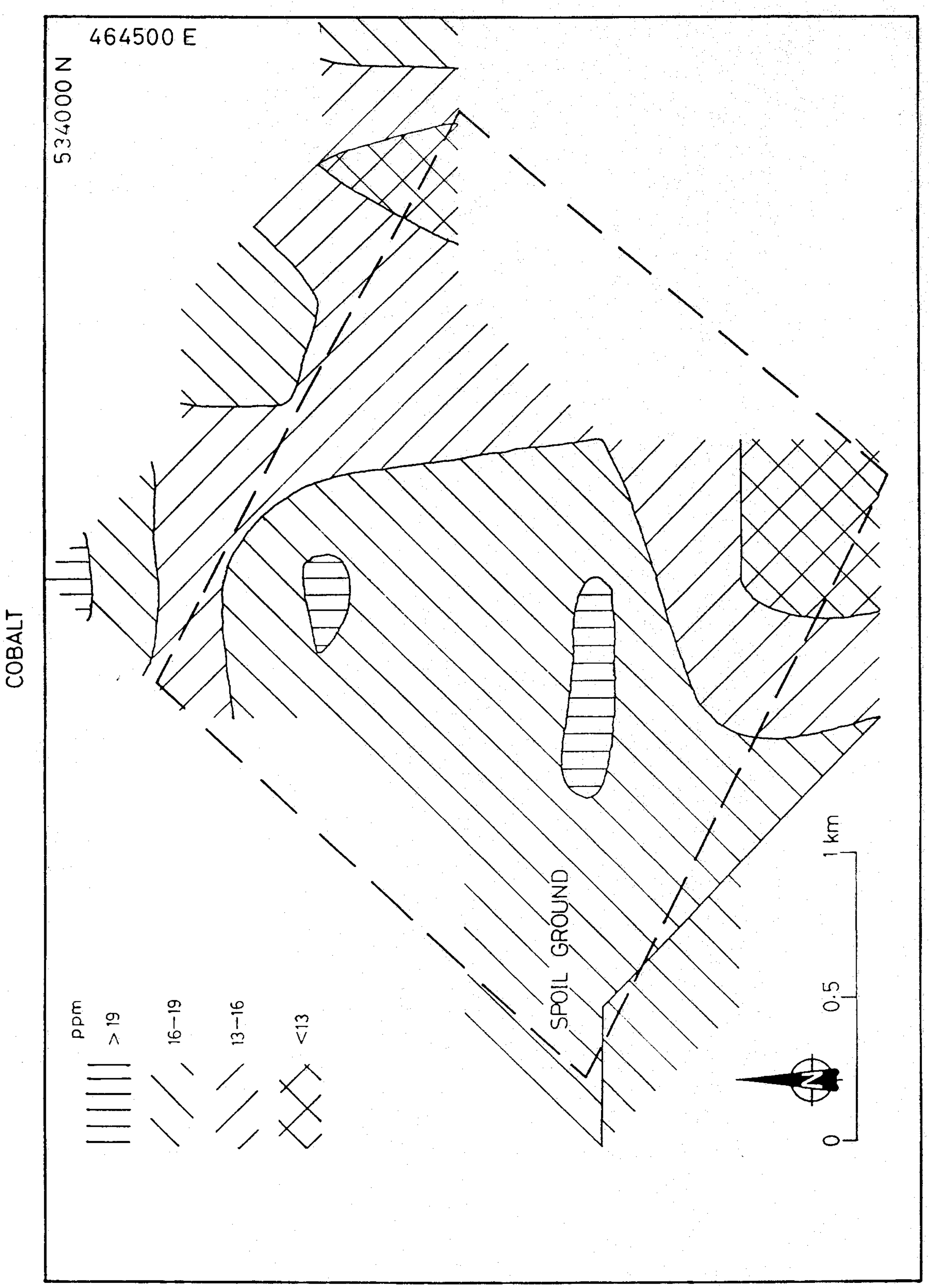

Fig 13 Distribution of cobalt on silt fraction of spoil ground sample

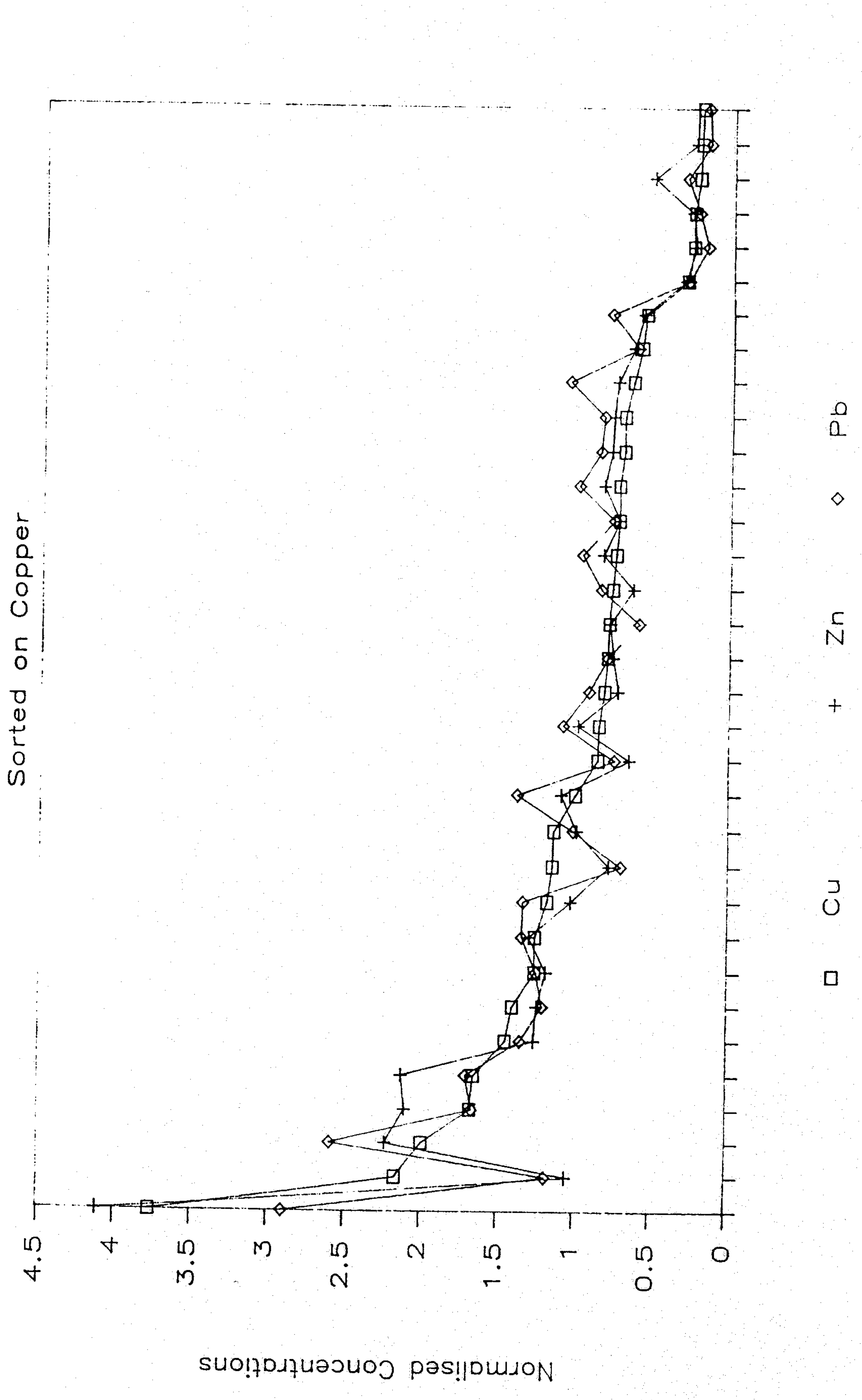

Fig 14 Normalised concentration of Cu, Zn and Pb for spoil ground samples

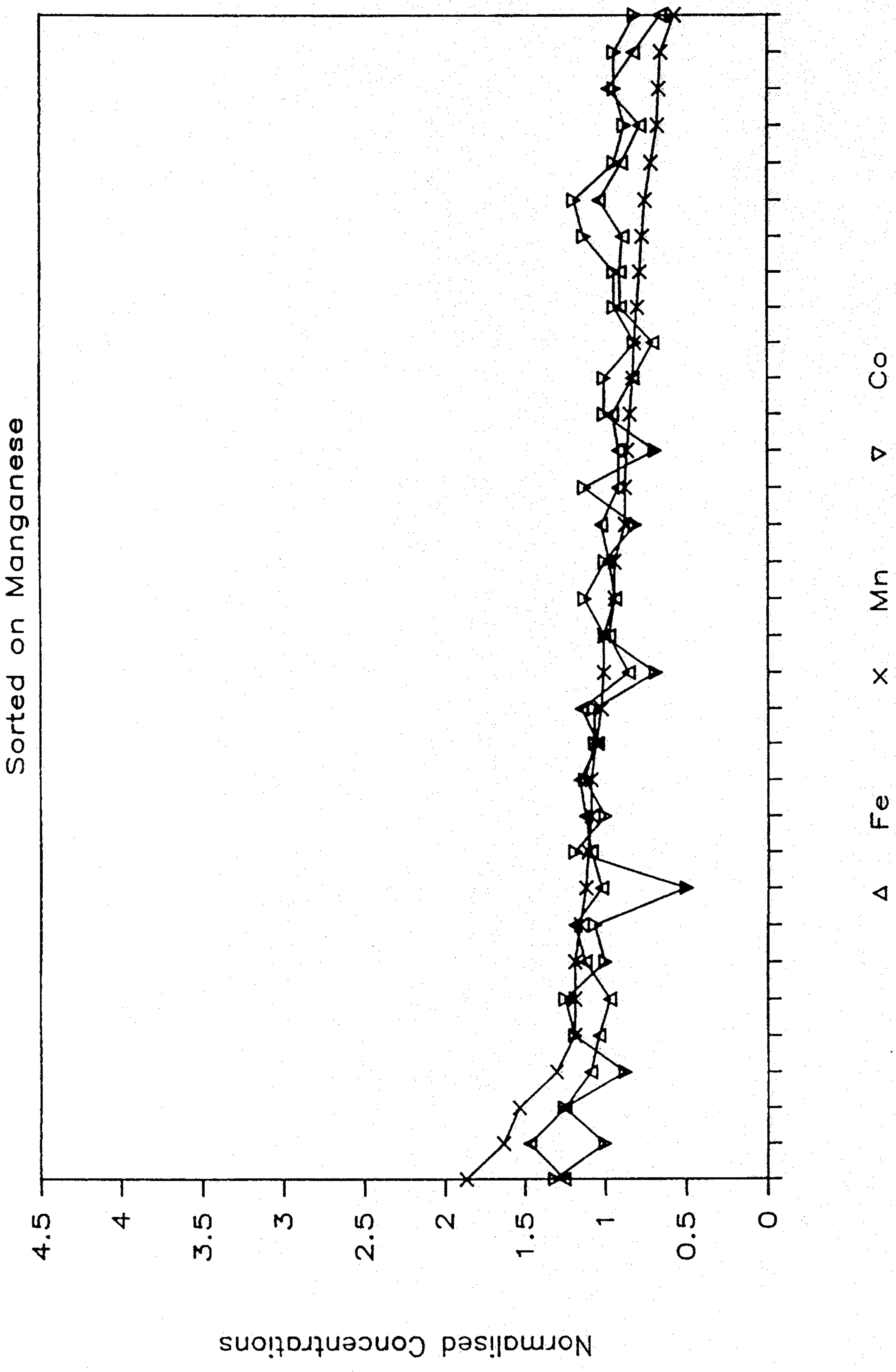

Fig 15 Normalised concentration of Fe, Mn and Co for spoil ground samples

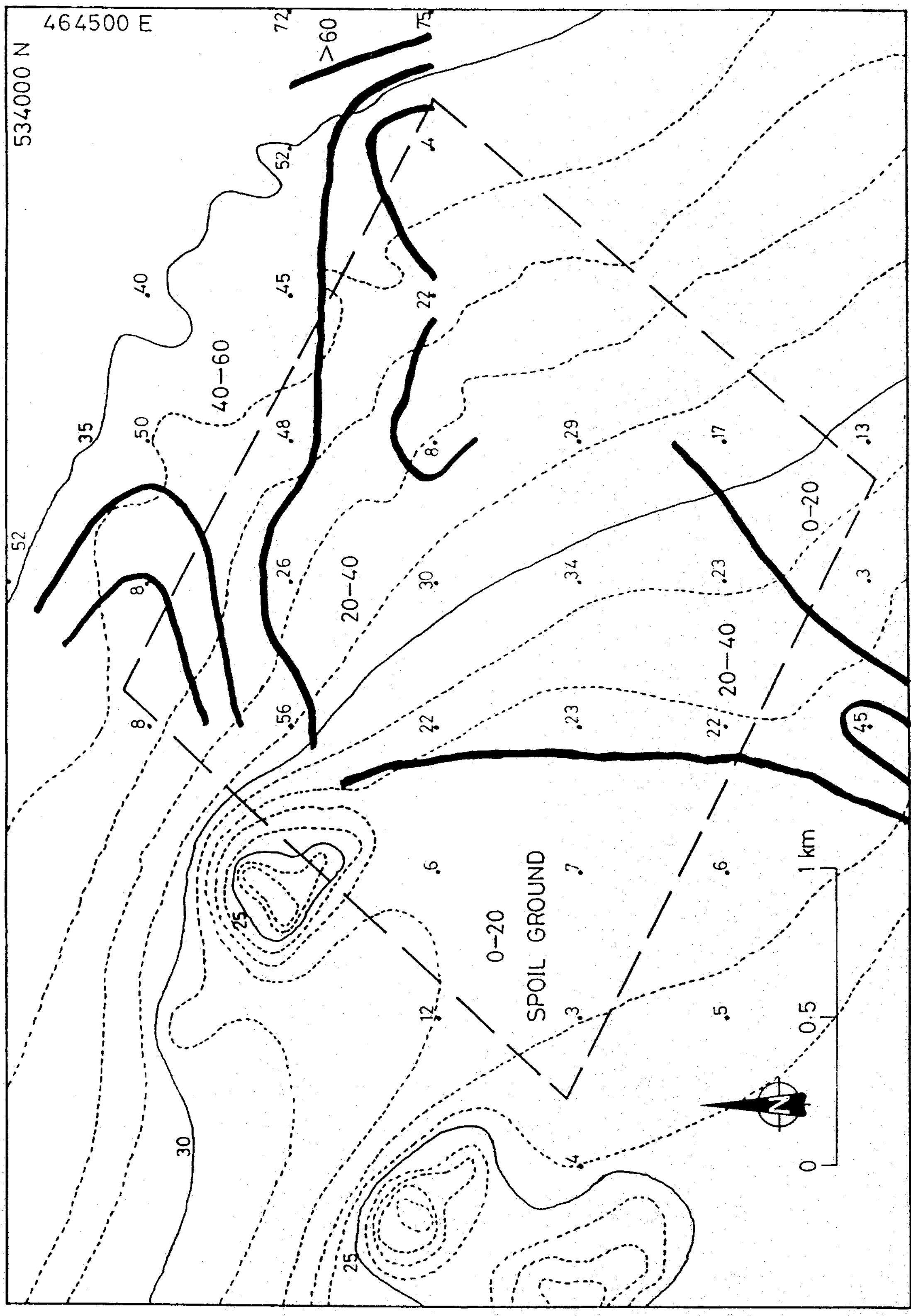

Fig 16   Distribution of percentage silt content of spoil ground sample

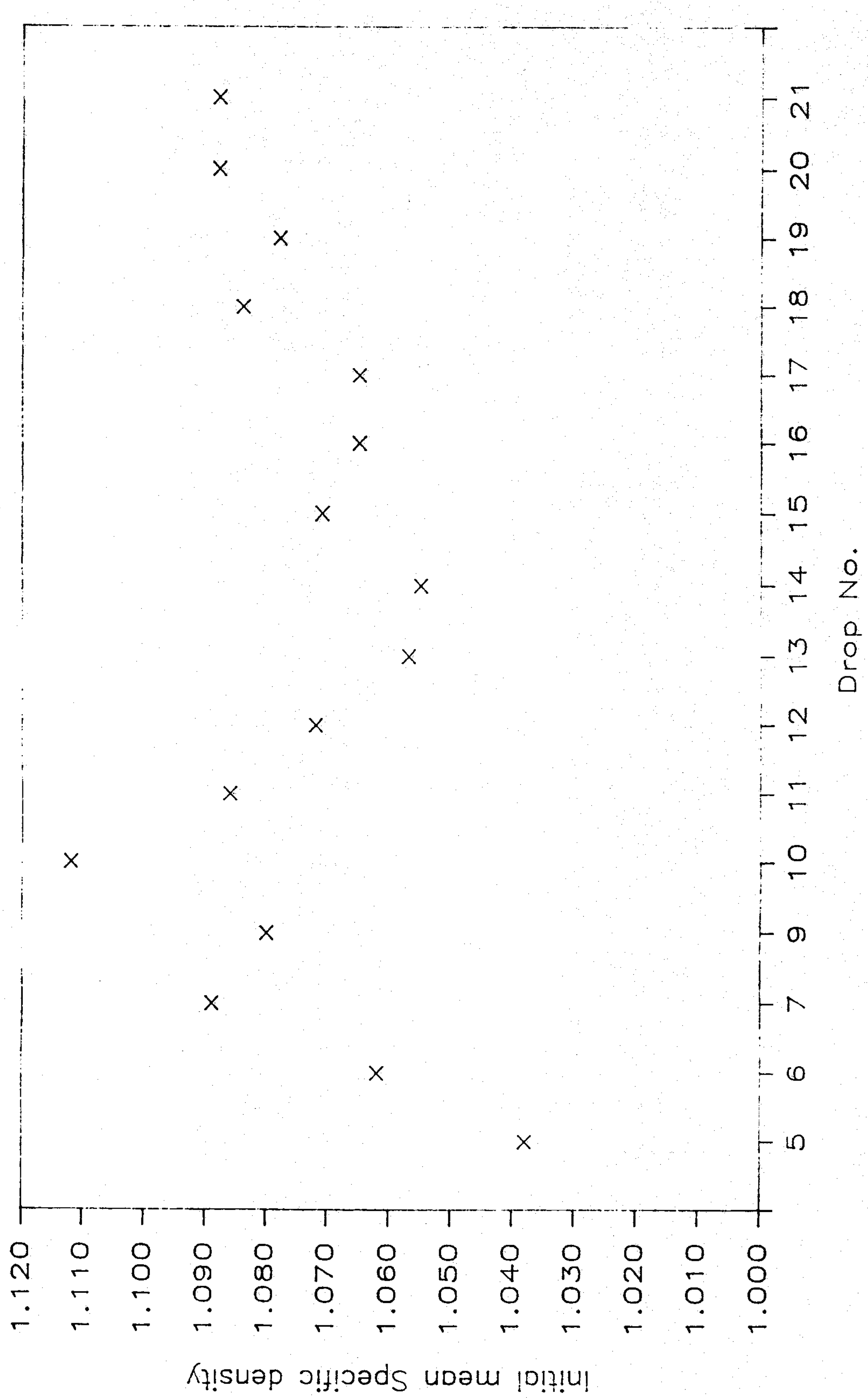

Fig 17 Initial mean specific density against drop number

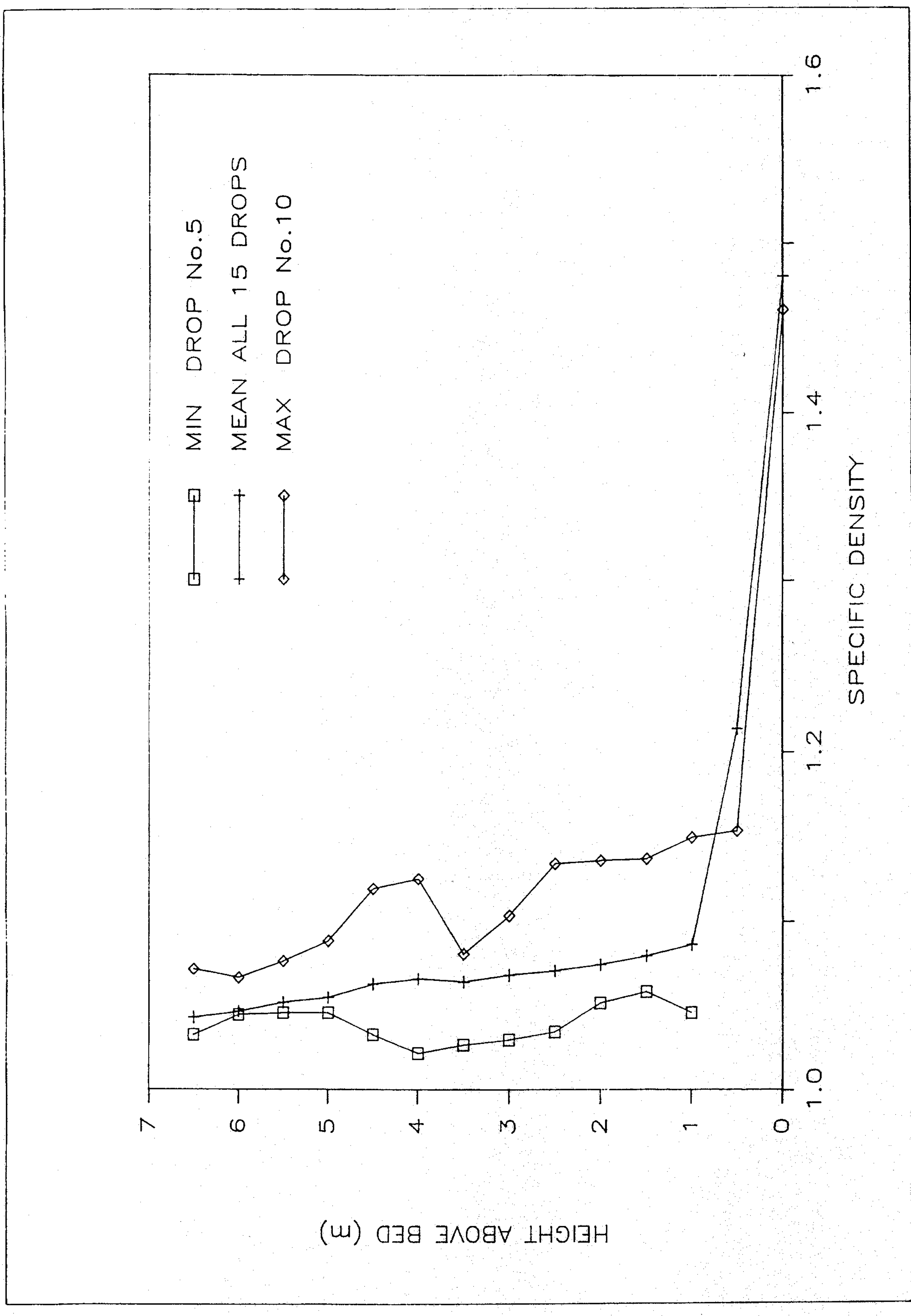

Fig 18 Initial density profiles of dredged material in hopper

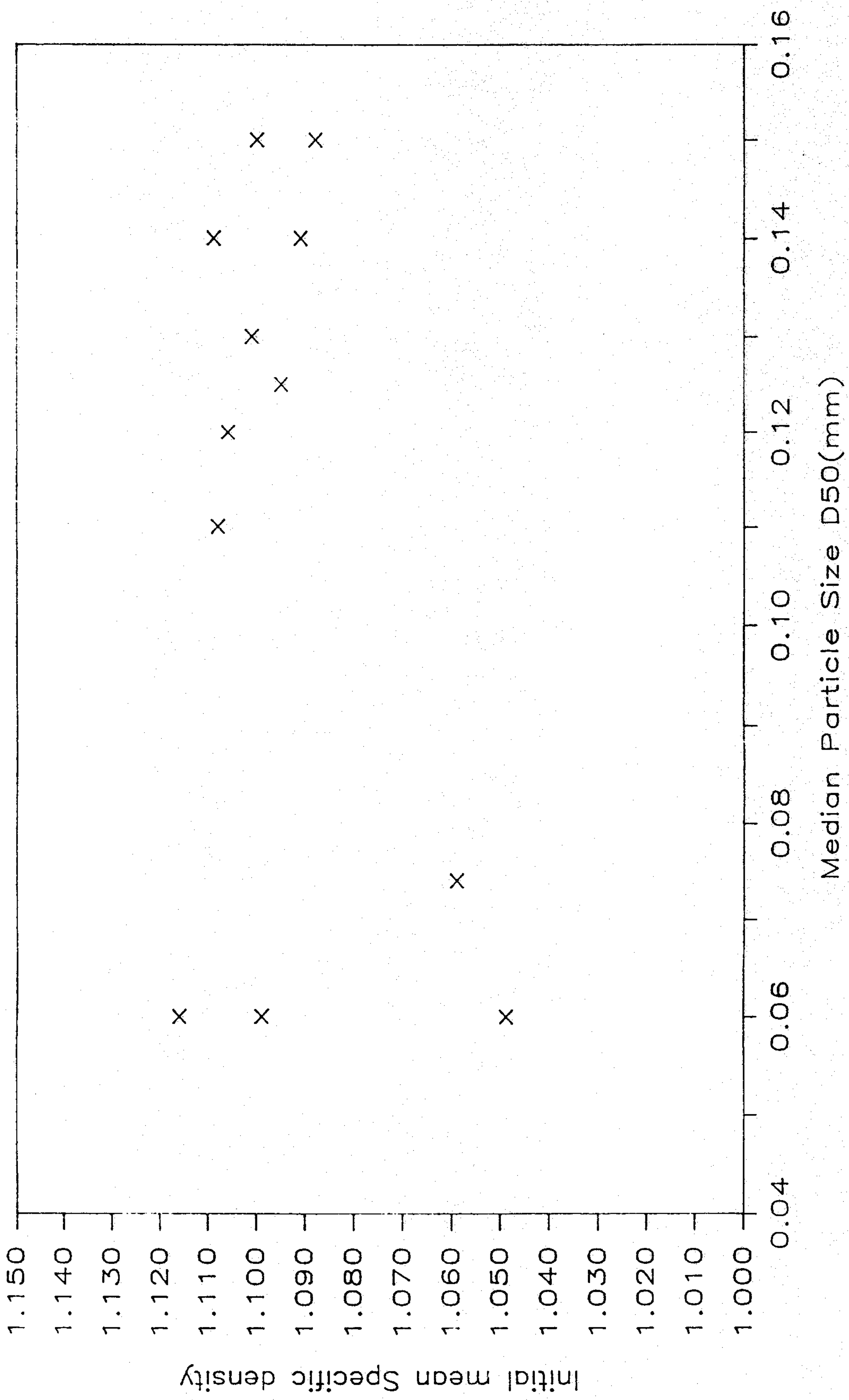

Fig 19 Initial mean specific density against median particle size, D_{50}

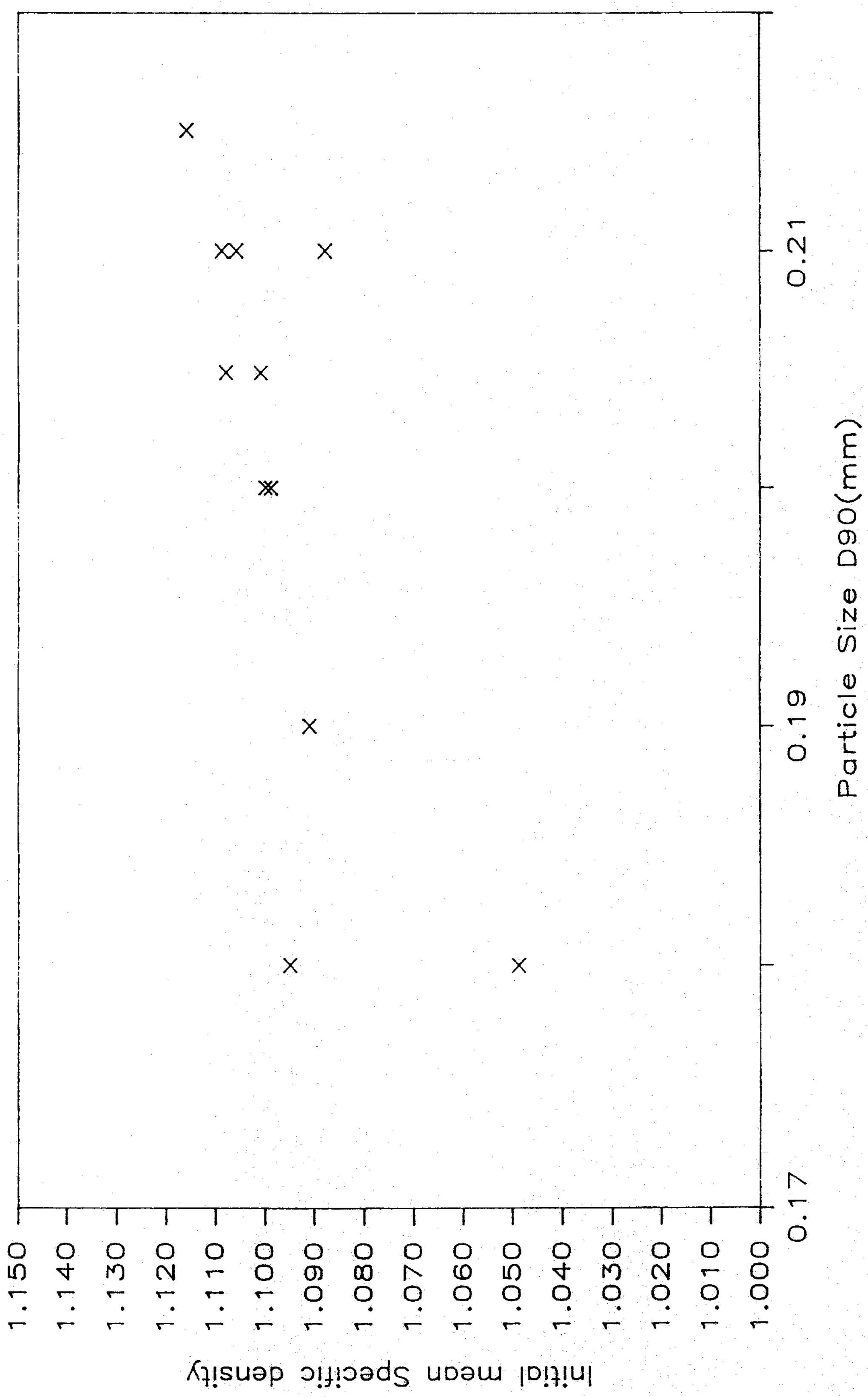

Fig 20 Initial mean specific density against median particle size, D_{50}

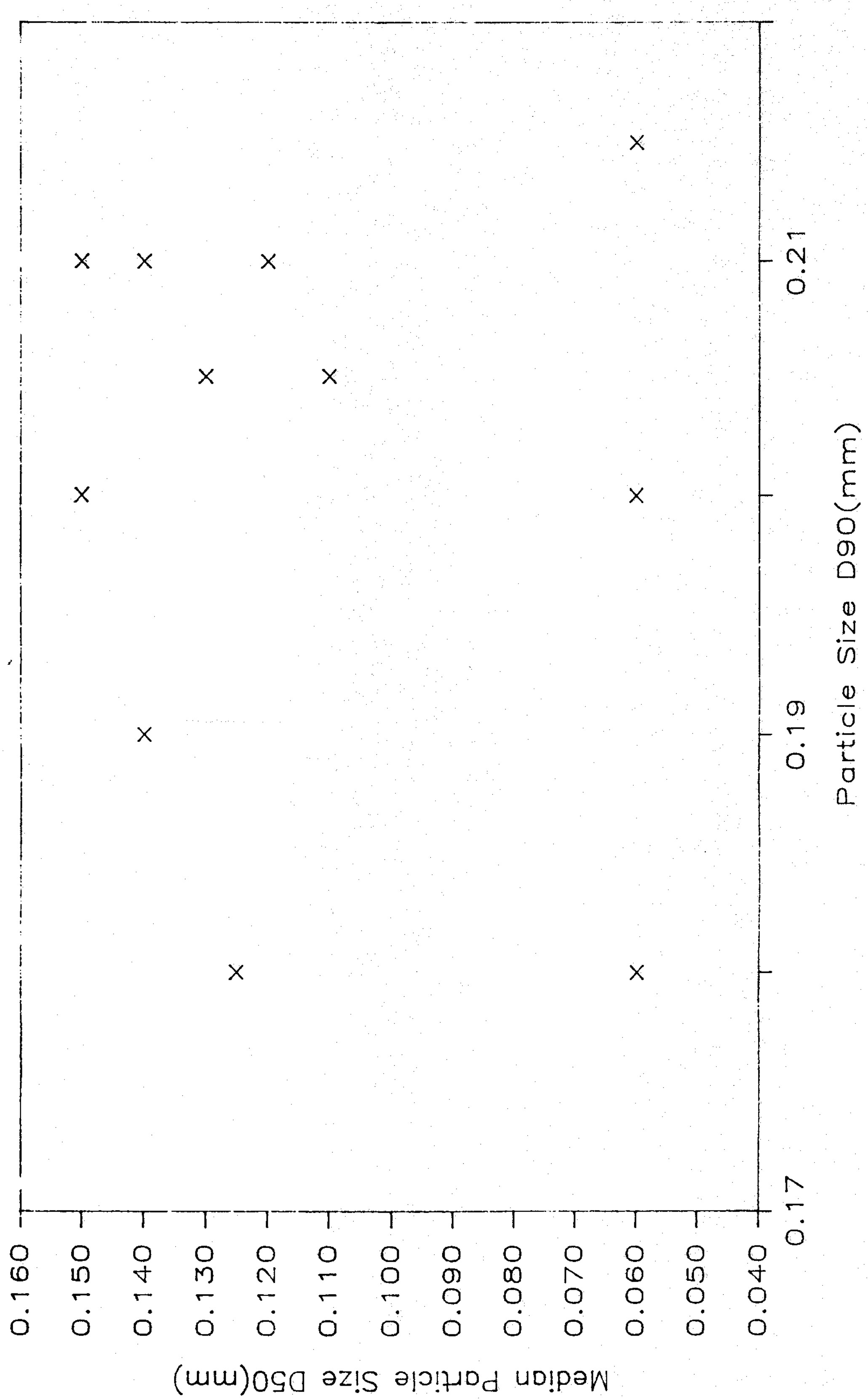

Fig 21 Median particle size, D_{50} against particle size, D_{90}

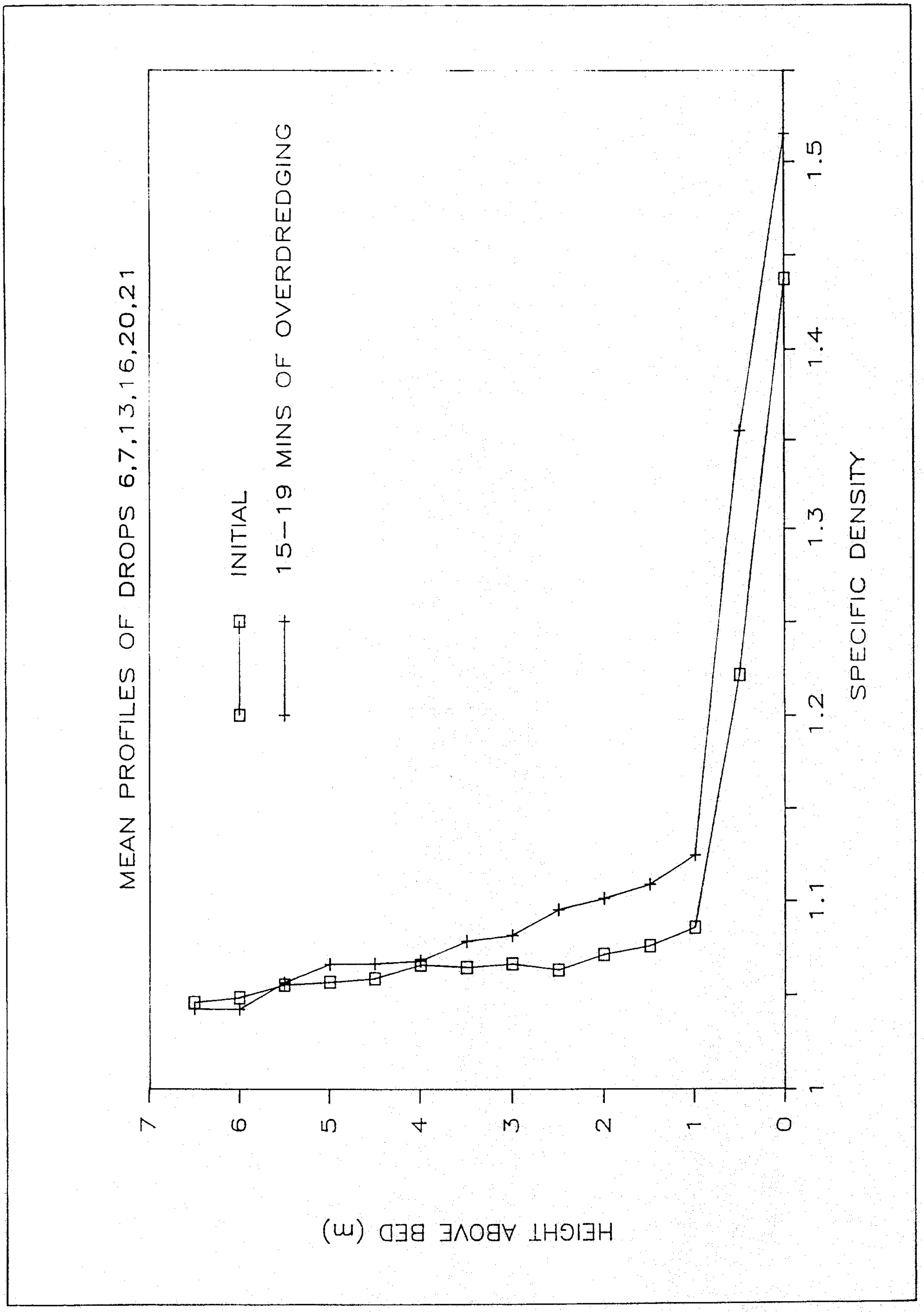

Fig 22 The effect of overdredging on the density profile

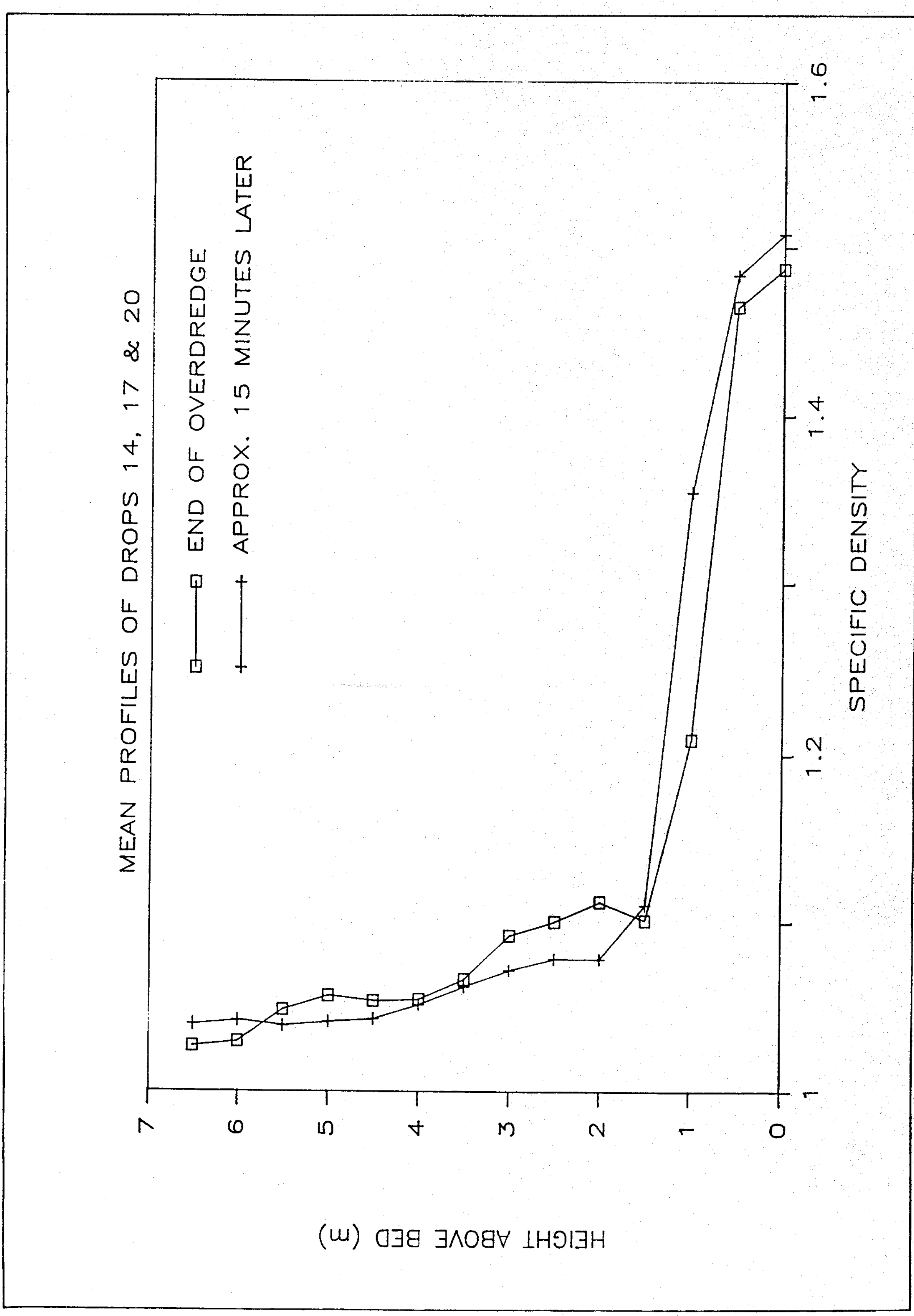

Fig 23 The effect of transportation time on the density profile

PLATES.

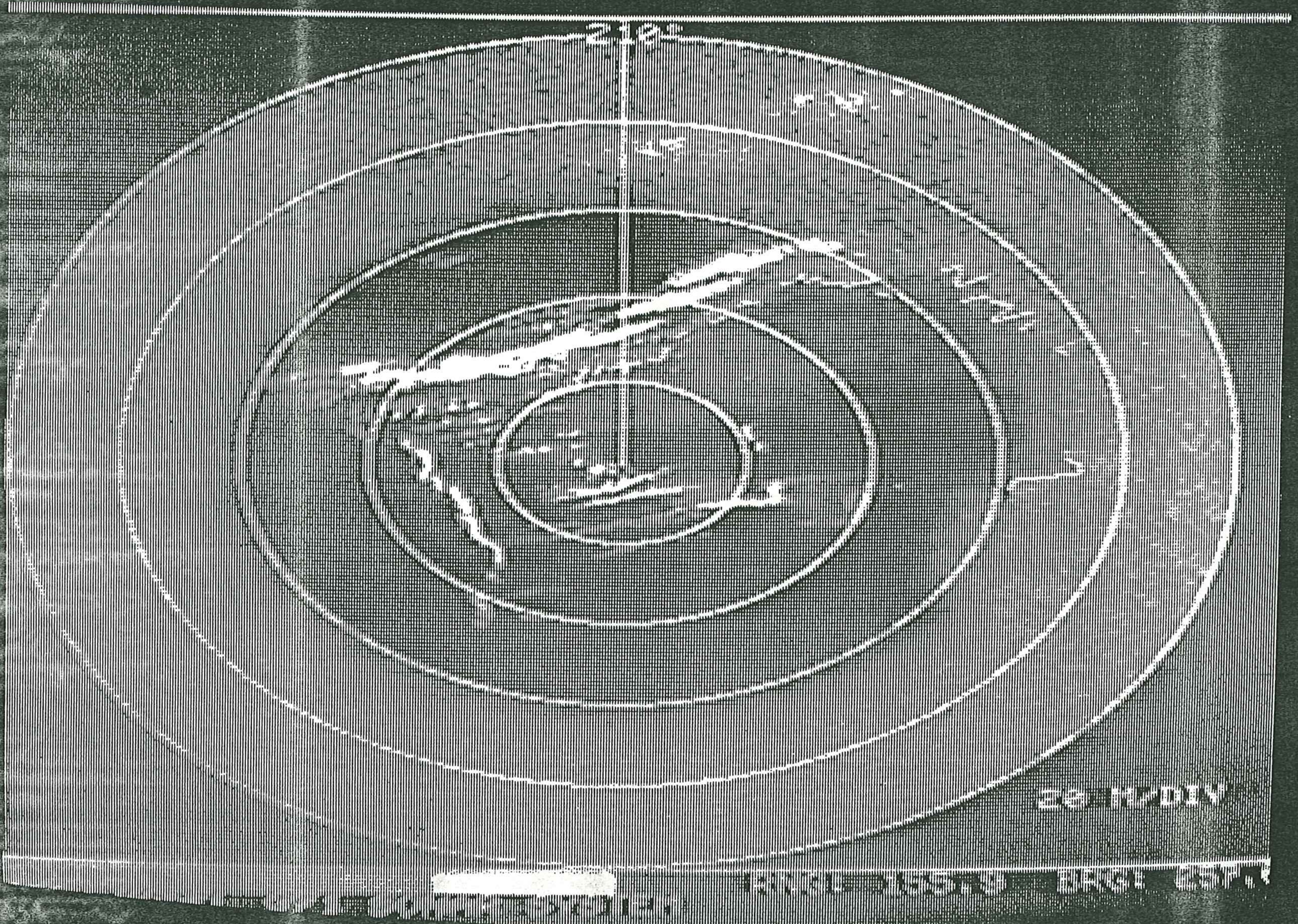

Plate 1. Sonar Scan 360° sweep in a horizontal plane.

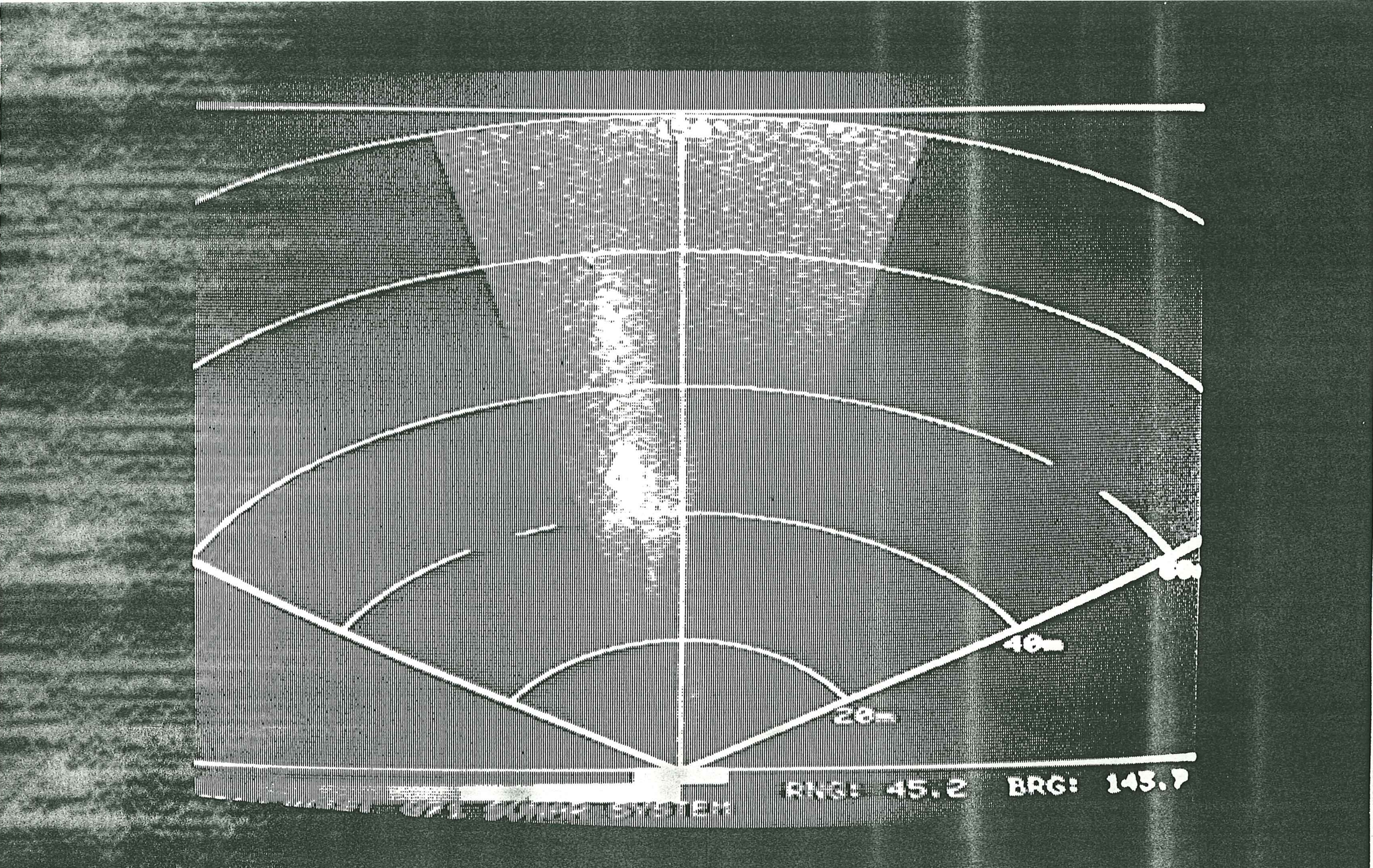

Plate 2. Sonar Scan 30^{O} sweep in a horizontal plane.

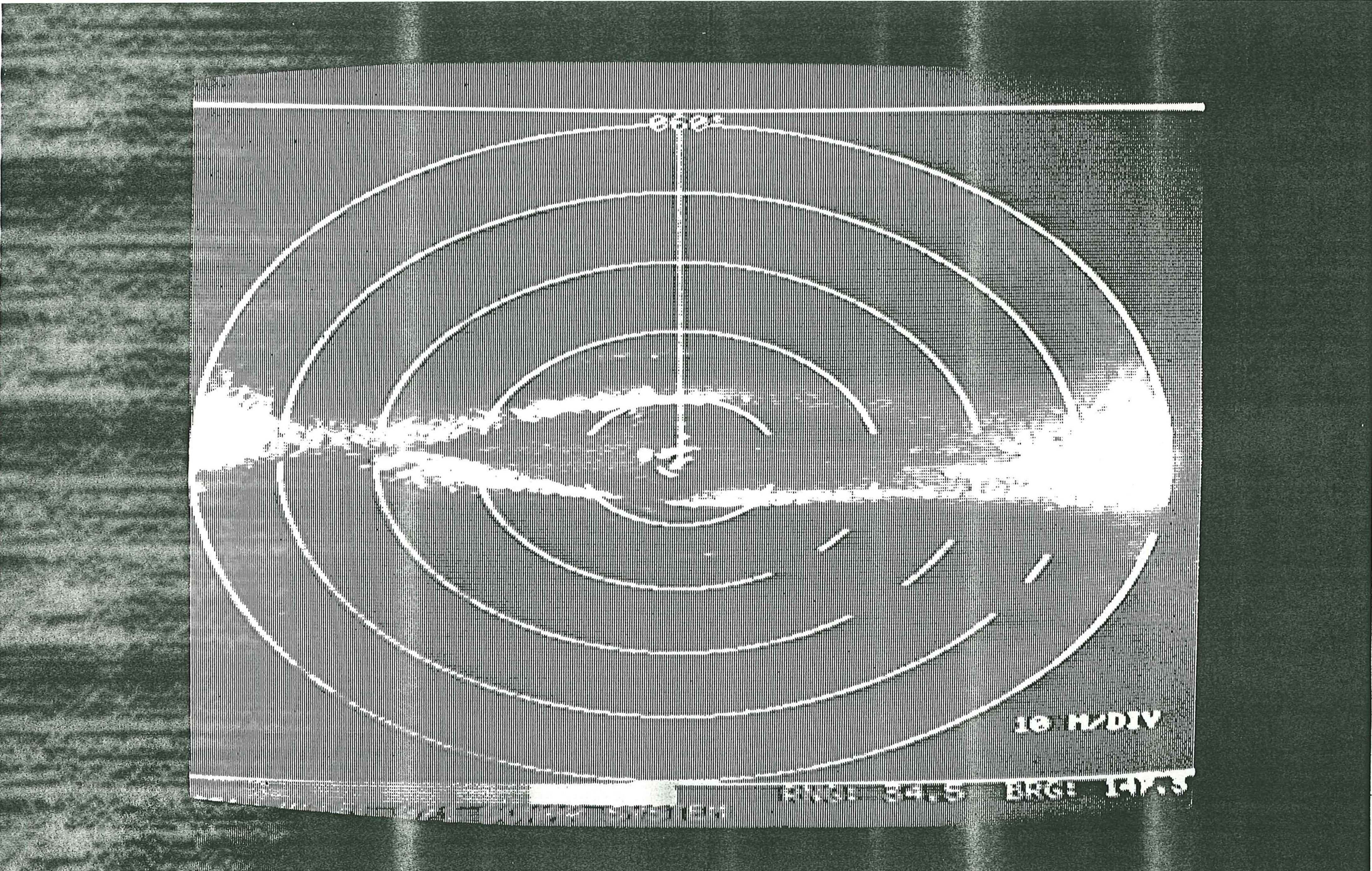

Plate 3. Sonar Scan 360^{o} sweep in a vertical plane.

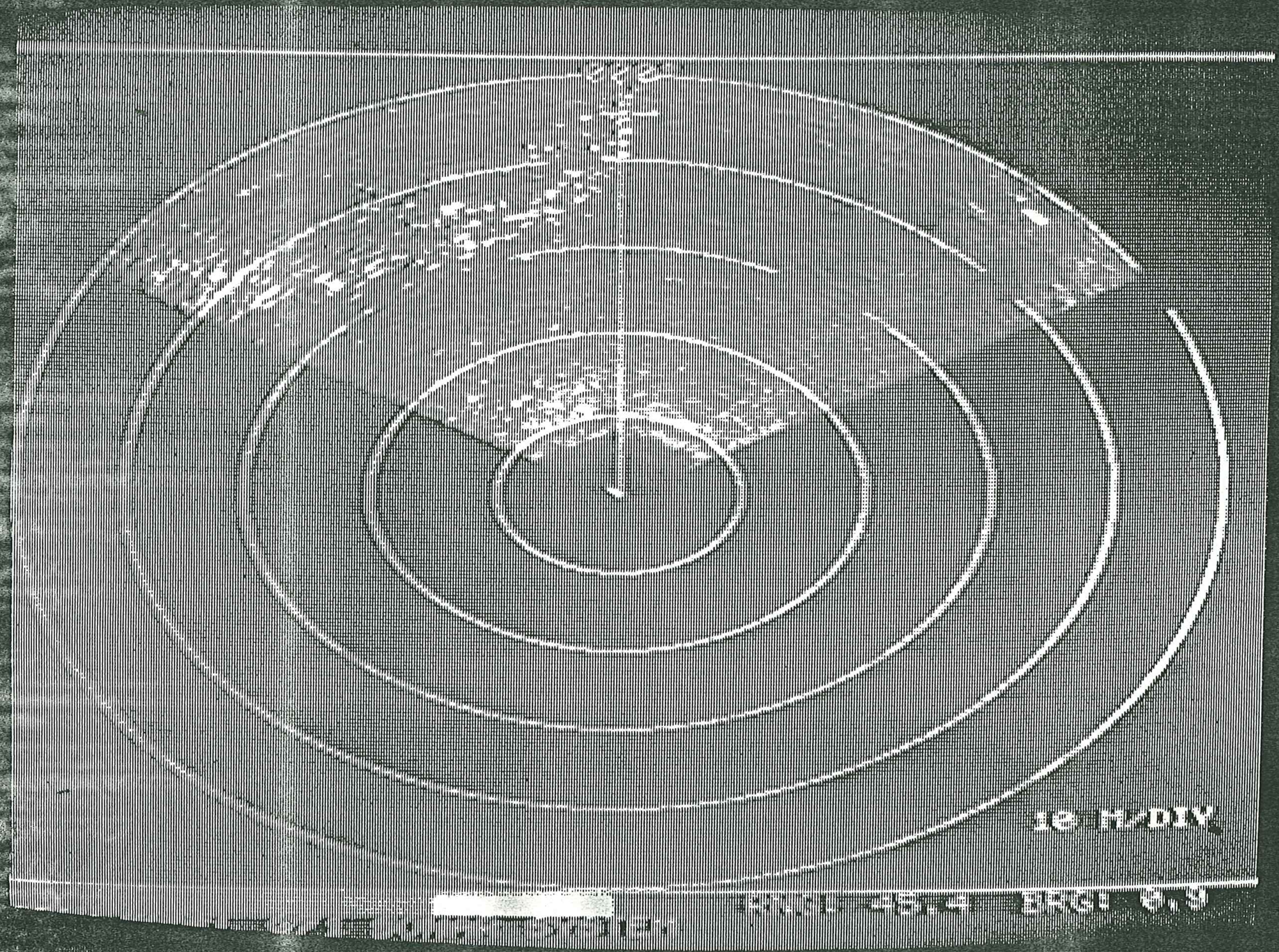

Plate 4. Sonar Scan 60^o sweep in a vertical plane.

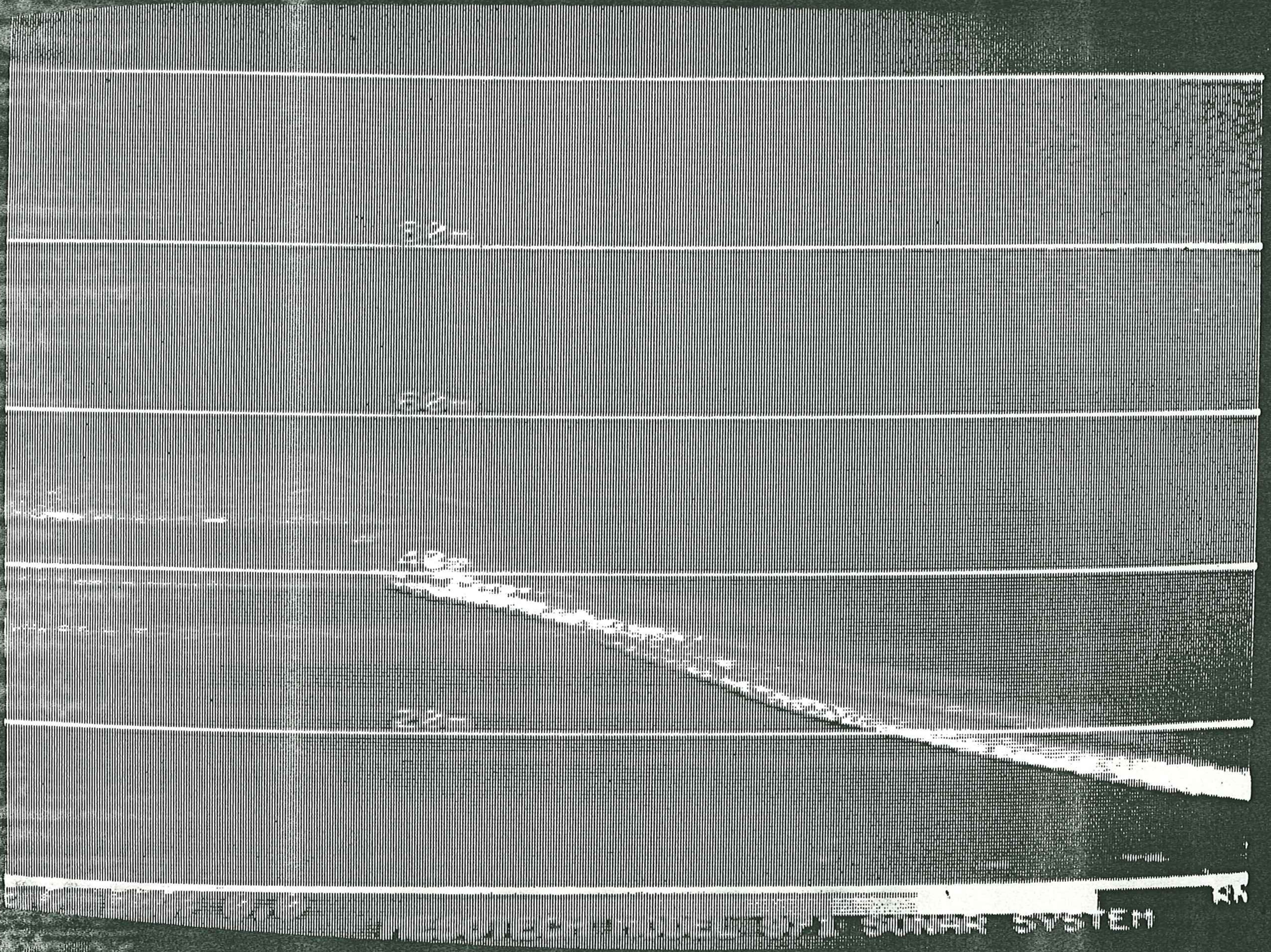

Plate 5. Sonar Scan 1·7° cone beam near bed.