NIREX REPORT NO. 622

3-D SEISMIC REFLECTION TRIAL: DATA ACQUISITION REPORT

UNIVERSITY OF GLASGOW
DEPARTMENT OF GEOLOGY & APPLIED GEOLOGY
GLASGOW G12 8QQ

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GLASGOW

SELLAFIELD GEOLOGICAL INVESTIGATIONS FOR DEEP RADIOACTIVE WASTE REPOSITORY
REGIONAL STUDIES
FACTUAL REPORTING

UNIVERSITY OF GLASGOW
DEPARTMENT OF GEOLOGY & APPLIED GEOLOGY
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SELLAFIELD GEOLOGICAL INVESTIGATIONS FOR

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1 INTRODUCTION

1.1 Scope of this report

This factual report describes the fieldwork carried out during summer 1994 under a University of Glasgow research contract with UK Nirex Ltd (Contract no. SCRS/1231). The report includes a description of the planning and actions taken from around the time of the Contract Award meeting held at Greengarth, Cumbria on 30 June 1994, until the finish of the fieldwork on 11 September 1994.

Being factual in nature, the report describes the survey work and its execution in detail, explaining in particular why alterations were made to the work programme. Although 3-D seismic reflection surveying is a standard exploration industry technique, the project is novel in several ways:

(1) It is the first 3-D vibroseis seismic survey undertaken in the UK,
(2) It is the first 3-D seismic survey of a potential nuclear waste repository, and
(3) It is one of the most intensive 3-D test data sets ever observed.

These unusual aspects justify the detail of description given herein of the non-standard or novel methods employed.

1.2 Aims and objectives of the survey

The aim of the survey was defined in the Work Programme which formed part of the contract. This states that the aim is to determine whether a full 3-D seismic survey of the Potential Repository Zone (PRZ) using a vibroseis energy source is technically and logistically feasible, and could provide useful additional information.

The objectives of this trial stated in the contract agreement can be summarised as follows:

(1) To determine whether useful high resolution reflection energy up to 100 Hz or greater can be obtained using vibrators.

(2) To find suitable field acquisition parameters for a full-scale 3-D survey.

(3) To find the optimum use of the 4-vibrator source array, taking into account parameters such as energy efficiency, logistics of use and operational timescale.

In addition, the hope was expressed informally (but not minuted) at the Contract Award meeting that the data to be collected over the Rock Characterisation Facility (RCF), in pursuance of the project's aims, would be of intrinsic value in imaging the RCF itself. In other words, the survey should, if possible, stand alone as a useful 3-D dataset, even if a full 3-D survey were never undertaken.

2. PLANNING

2.1 Survey location

The original proposal to UK Nirex Ltd for a 3-D feasibility study, submitted in April 1994, included a square 1 km x1 km inner area encompassing the RCF region, within which full-fold 3-D coverage would be obtained, and an outer perimeter area in which data would be acquired to provide the full-fold data. For imaging down to a depth of 1 km this is the minimum desirable area; a cubic data volume of 1 km^3 would therefore have been obtained. The original surface area was reduced to a rectangular area of 1 km x 0.75 km in the proposal accepted as part of the contract. The same acquisition perimeter area was required around this inner area as before, to give a total survey dimension of 1.6 km x 1.15 km. The inner area encompassed the RCF, and the perimeter area was restricted to the area SW of the A595 trunk road, thereby avoiding the National Park. Additional criteria, such as keeping clear of the woodland of Lingbank Plantation, led to the location of the survey shown in the Work Programme fig. 1, reproduced here as Figure 1. The basemap used for this purpose was the current OS map (Sheets NY00 SW and NY00 SE, 1:10,000 scale).

Once information on crop coverage in the fields likely to be affected became available in mid-June 1994 the survey area was moved about 100 m to the NW and rotated by about 2° clockwise. The aim was to avoid the sapling plantations along the fields bordering the A595, and to minimise the access requirement into the cropped fields south of Sides Lane. This revision is shown in Figure 2.

2.2 Generation of position data

The area shown in Figure 2 is gridded at a 25 m interval in 47 rows running NW-SE and 65 columns running NE-SW. The origin of the Cartesian grid is taken as the western (lower left) corner. The grid was generated from this origin, viz.

Easting 304440.00, northing 504000.00, azimuth of columns 48°.74778, and produced a listing of 47 x 65 = 3055 positions, given in column order, to be defined in the field by numbered wooden pegs. The lowermost row and column are both 00, thus the highest row is numbered 46 and the highest column numbered 64. Pegs are given a 4-digit number. The first two digits refer to the column number and the last two to the row number. Thus the top right-hand corner of the grid, near Town End Farm, has a peg numbered 6446. Data are held in an ASCII file grid.lst. All geophysical source and receiver positions are referenced to this grid.

2.3 Base maps

There are no publicly available OS maps other than the 1:10,000 scale sheets. The preliminary working map, used at the contract award meeting, was a photographic enlargement of the OS map with the RCF boundaries drawn by hand. A larger-scale version was also printed as a presentation-style map, with the survey boundary rectangles added in colour. This was used at initial meetings with tenants and landowners.

The workmap produced and used for most of the survey was a 1:2,500 scale pen plot, to which the relevant boundaries and annotations were added by hand draughting. This is the ‘GU Workmap’ reproduced at a reduced scale as Figure 3, to which some extra labels have been added. Note that ‘top’, ‘right’, etc. of the prospect are used as shorthand for NE, SE, etc., respectively.

All the relevant fields and other areas such as roads were given identification numbers by the GU survey team. These numbers on the GU Workmap form the primary means of locating areas, together with survey peg numbers when more detail is required. All the region within the secure compound is denoted ‘RCF’. Sub-areas of the RCF are denoted when required by the primary borehole name on each drill site, viz. RCF 1, RCF 2, RCF 3, BH 2/4 and BH 5.

3. TOPOGRAPHIC SURVEY

3.1 Introduction and objectives

The primary purpose of the topographic survey was to set out 3055 pegs in a prearranged layout (Figure 3) to enable the geophone arrays and vibrators to be positioned. The locations of the points were supplied to the surveyors as national grid coordinates quoted to two decimal places (a precision of 1 cm; Section 2.2).

Secondary aims of the topographic survey comprised:

(1) Noting any alterations to field boundaries,
(2) Recording the land use (crop type, woodland, etc.), and
(3) Measuring and photographing gateways for vehicular access.

3.2 General strategy

The topographic survey was undertaken in two distinct phases. The first phase incorporated a reconnaissance of the RCF compound to assess the optimum positions of control points. These points were to be located on vantage points in order to set out as many grid pegs within the secure compound as possible. The location of these points was influenced by pending access approval to the remaining sections of farmland within the survey area, and with regard to safety considerations along with visibility around the active borehole locations.

The second phase involved the establishment of a main control traverse. This traverse consisted of 17 control points. The optimum configuration of the survey control grid was established with regard only to access approval as of 11 July 1994. Subsequent control loops were later added to provide full coverage. The final survey control network is shown in Figure 4.

3.3 Methods of measurement

3.3.1 Control

The establishment of a comprehensive control network of coordinated points was hampered by the limited access initially granted, and further access restrictions onto private land around the RCF. A short traverse of 1782 m in length, consisting of 8 control points was established, all points being within the RCF. The purpose of this traverse was to provide control for the setting out of grid points within the compound, prior to access being granted to the remainder of the section of the PRZ to be surveyed.

A larger traverse was later installed as access was approved within the PRZ area. This traverse consisted of 17 stations, being 4200 m in perimeter, and affording approximately 90% visibility of the site. Other areas of restricted access or limited visibility were set out from ‘satellite’ stations that were not part of a polygonal traverse, and as such no further control observations were made from them. Table 1 lists the coordinates of the control stations, which are shown in the diagrammatic plan of Figure 4.

Distances were all measured using semi-total station EDM TTL theodolites. The slope distances were reduced to horizontal and the local Grid Scale Factor applied prior to final calculation. Angles between stations were measured in each face, with two rounds of both Horizontal and Vertical being observed. The tribrach to tribrach method of control traversing was used as standard. Table 2 shows the closing errors in each of the four traverses, expressed in metres of Easting E and Northing N, and as a representative fraction. They are well within acceptable tolerances, to permit the setting out of pegs for the seismic survey to within less than 0.1 m error in horizontal coordinates.

Table 1. Survey control stations.

Station	Easting (m)	Northing (m)	Relative height (m above OD)
S1	305483.938	504022.364	85.196
S7	305679.683	503894.100	90.043
NIR	305593.441	503839.529	88.013
GU1	305565.821	503714.105	80.580
GU2	305434.527	503379.206	63.399
GU3	305334.572	503652.000	72.776
GU4	305171.251	503809.480	80.637
GU5	305452.311	504070.441	93.551
C5	305693.292	504346.177	104.225
G100	305981.510	503375.907	67.919
G101	305750.690	503519.604	81.657
G102	305746.748	503790.293	92.581
G103	305836.356	504064.355	107.079
G104	305785.297	504299.250	105.749
G105	305468.575	504441.353	100.600
G106	305440.799	504332.899	101.722
G107	305356.995	504418.551	96.912
G108	305079.703	504228.290	89.838
G109	305038.877	503961.234	79.291
G110	305228.899	503988.205	87.619
G111	305339.090	503922.001	85.344
G2.1	305674.229	503538.467	80.607
G112	305662.903	503405.822	68.085
G201	306043.452	503863.902	98.155
G202	305926.935	503961.009	104.567
G201.1	306276.218	503671.662	85.459
G5.1	305372.197	503738.075	76.271
G305	304989.801	503902.849	71.177
G304	305076.892	503785.637	70.768
G303	305160.562	503672.279	72.232
G302	305055.759	503483.782	54.681
K6	305212.615	503562.331	69.495
G301	305296.922	503203.152	57.173
G300	305448.487	502904.027	48.668
G108.1	305172.741	504264.009	82.563
G110.1	305128.744	504145.172	88.622
G300.1	305541.181	503004.010	44.187
G304.1	305031.460	503747.147	66.150
G302.1	304861.759	503840.416	48.336
G105.1	305338.008	504585.927	92.223
G301.1	305327.574	503464.723	62.582
G101.1	306026.496	503384.833	70.074
G301.2	305196.062	503226.273	51.378

Table 2. Closing errors of the survey control traverses.

Traverse number	Perimeter (m)	ΔE misclosure (m)	ΔN misclosure (m)	Linear error
0	1782.735	-0.006	-0.009	1:162067
1	4196.479	+0.022	+0.011	1:167589
2	1086.983	+0.070	-0.001	1:155280
4	1933.944	-0.010	-0.017	1:101787

The forced centring method of tribrach to tribrach traversing ensured a high degree of accuracy and correspondingly low misclosure values. The traverses originated at two existing coordinated points (S1 and S7). The coordinates of these permanent ground markers (PGMs) were supplied by BNFL. They were supplied as index coordinates rather than in a schedule format, which enabled the surveyor to locate all relevant and extant control within the site.

Control station K6 (Table 1 above) is the same as BNFL station T3, the coordinates of which were supplied by BNFL on 24 October 1994. They compare as follows:

	Easting (m)	*Northing (m)*	*Height (m)*
K6	305212.615	503562.331	69.495
T3	305212.689	503562.373	69.556
Difference K6-T3	-0.074	-0.042	-0.061

3.3.2. Setting out

3055 pegs were prepared for installation in a grid pattern of 65 columns and 47 rows, columns being numbered from 0 to 64 and rows from 0 to 46. The pegs were constructed of softwood 250 mm x 35 mm x 10 mm in size, each numbered uniquely on a white background. Each peg is numbered with four numbers, the first two representing the column, the second the row. Therefore the western corner of the grid is represented by peg number 0000, the southern by 6400, the eastern by 6446 and the northern corner by peg number 0046.

On hard-core areas and metalled roads surveyor’s pins were substituted for wooden pegs. They were marked with a small square of pink polythene, folded over with the location number written inside.

The pegs are set out at 25 m intervals, with the exception of those that were to be offset due to the proximity of hedge centrelines, walls, buildings, culverts, pipelines, cables etc. Omissions were also necessary in areas that were densely wooded, had restricted access or were unsuitable for vibroseis.

Six figure grid coordinates were calculated for the control and satellite stations. This allowed whole circle bearings and distances to be calculated between the control stations, and subsequently orientation of the horizontal circle of the theodolite. Setting out programmes were produced for each station, listing the range and whole circle bearing to pegs within a specified range (usually 300 m) of the appropriate station.

The pegs were set out from the total station by setting the whole circle bearing on the instrument to the appropriate value of a chosen peg, and then moving the prism until both (1) coincidence with the cross hairs was found and (2) the range to the prism also matched. At the same time the total station also computes the difference in height between the instrument and the prism. This allows the reduced level of the peg to be recorded at the same time as its installation,

At least 90% of the pegs were set out using this method, but some areas of the prospect were unable to be set out in this way, mainly due to thick vegetation and wooded areas inhibiting the line of sight or reducing the light level. In these areas the pegs were chained in using a 25 m wire attached to adjacent pegs set out from the control stations using the total stations. The reduced levels of these chained-in pegs were calculated separately from data collected using a level and staff.

3.3.3 Precision, error and accuracy in positioning of grid pegs

Eastings and northings are calculated to a precision of 0.01 m. Conversion to range and bearing using double precision arithmetic ensures that the range and bearing of the prism are also given to the same precision. The trial and error method of walking the prism to the correct range and bearing, following radio instructions from the surveyor at the theodolite, resulted in field accuracies of better than 0.1 m. This is well within the precision required of the seismic reflection method, in which errors of the order of 1 m in horizontal coordinates and 0.1 m in the vertical coordinate are acceptable.

An independent check on accuracy of the peg positioning was afforded by the visual line-up of pegs along rows, columns and diagonals. Pegs set out from different control points still lined up well, and a last check is that pegs are placed correctly in relation to cultural features. In the case of pegs within the RCF, where detailed maps or plans are available, actual peg positions could be checked against the theoretical positions, to within a fraction of a metre.

Errors in vertical measurement (the reduced levels) can be checked at the processing stage by:

(1) Re-gridding and contouring the data, to see whether anomalous peg positions stand out, and

(2) Comparing the heights with those given on the OS and RCF maps.

If and when any such errors are discovered during the data processing phase, the source of the error (e.g. arithmetic miscalculation) can be corrected, or in the worst case the erroneous vertical datum would have to be rejected and the height of the peg estimated by interpolation from surrounding pegs.

3.4 Duration of the topographic survey

The survey was initiated by Team 1 on 28 June 1994. It was initially restricted to the RCF areas, as access to surrounding land had not been approved at that time. Team 1 was joined by Team 2 on the 9 July, and on 11 July access was gained to all surrounding areas.

The main traverse was the highest priority at this time; this was undertaken by Team 1 while Team 2 continued setting out from existing control stations within the RCF. The survey was then suspended between 14 July and 22 July. Thereafter, every day was spent setting out and adding on additional traverses and satellite stations until 6 August, when Team 2 was disbanded. By this time about 80% of the prospect had been set out, but it then took another two weeks to complete the prospect with the single team, as only the difficult blind spots and wooded areas remained to be filled in. The topographic survey finished on 23 August 1994.

3.5 Problems

Set-out pegs sometimes disappeared. This was due to:

(1) Removal of pegs by livestock.
(2) Covering over by new earthworks, e.g. on the RCF1 pad,
(3) Regrading of hard-core on the RCF roadways.

Reinstatement of these pegs required a total of a couple of team-days of work.

3.6 Results

The results of the survey give each unique peg its National Grid easting and northing, and its reduced level with respect to mean sea level. A standard UKOOA (SEG-P1/90) format tape or floppy disk will be produced from these data during the processing phase.

4 PREPARATION FOR SEISMIC SURVEY

4.1 Introduction

Section 4 describes the activities such as access, permitting, site preparation, mobilisation, and equipment testing and calibration. All these activities took place, most in parallel, between the end of June and the start of seismic recording on 15 August 1994.

4.2 Access for seismic survey

4.2.1 Public roads and lanes

Access to the site is from the 1.5 km section of the A595 trunk road between New Mill and Gosforth. Although the final survey location crosses this road at the northern corner (Figure 2) it was to be understood that no survey work would actually be carried out on or to the NE of the road. Furthermore, it was decided that the vibrator convoy should only use this busy public road when no alternatives existed.

Access to the site is available from Sides Lane, entered either from the A595, from Newton Lane, or from the RCF gates at Borehole Sites 2 and 4. These gates were only to be used for the vibrator convoy, and not for routine access to and from the RCF.

Newton Lane runs in an L-shape around the bottom and left-hand sides of the site. It is entered either from there A595 or from Sides Lane.

Notwithstanding the high priority of not inconveniencing the tenant farmers and local populace, the two lanes (Sides Lane and Newton Lane) were to be extensively used by survey vehicles. Fortunately both lanes are quiet, and it was found that there was no need to take the vibrator convoy along the slightly busier part of Newton Lane, between Lingbank Moor and New Mill (Figure 2). However, cables were protected from traffic by cable mats which were laid over the cables, across the lanes.

4.2.2 Permitting

Initial contact with local farmers was made by Nirex's land agent. A specialist permit man was then appointed as Liaison Officer to fulfil the following duties:

(1) Liaison with farmers through Dixon Webb,
(2) Arranging access,
(3) Devising access plans and timetable, and
(4) Assisting vibroseis crew during survey

The working relationship of the Liaison Officer with Dixon Webb, the farmers, etc. is shown diagrammatically in the organogram of Figure 5.

All the land to come under the survey is owned by BNFL. Some of it is woodland, not used by tenants. Woodland could be accessed by the geophone arrays, but would normally be inaccessible to the vibrators. Ninety-five percent of the rest of the survey area is tenanted by five farmers; this facilitated permitting.

Criteria for access were established, taking into account difficulty of access, crop value, etc. with the land agent prior to seeking direct permit. As well as field 19, fields 48, 50 and 51 were omitted. The field boundaries and numbers are shown in Figure 3.

4.2.3 Access priorities

Notes, together with 4 maps, were supplied to Nirex on 24 June 1994. These notes define four priorities of cropped field from highest (A) to lowest (D), together with the resulting maps estimating the seismic source and receiver coverage that would be obtained.

A report, ‘Access information’ was supplied to Nirex on 27 June 1994. This report showed the overlapping regions of survey occupation; the central strip would require to be occupied by vibrators three times, in comparison with the edge strips where access was only required once. Clearly fields requiring multiple entry have a higher priority (other things being equal) than fields which are only required on one occasion.

Access had to be negotiated on a field-by-field basis. Although the shift in the area illustrated by the difference between Figures 1 and 2 meant that the left-hand edge of the area now included a part of fields 22 and 23, it was decided in the first week of July that access would not be sought to any areas NW of Newton Lane. However, access was sought to fields 38, 40 and 43 in the bottom right-hand corner; these fields had been excluded from the first round of negotiations.

4.2.4 Gate widening and fence erection

Part of the surveying team’s task included measuring and recording every possible gate and entrance to all the fields. The vibrators are 3.0 m wide, and although these ‘buggies’ are very manoeuvrable for their length of 9.5 m, they require space to turn through a right-angle. The condition of gates was recorded on cards, as well as a photograph or two taken of each in case of subsequent damage claims. All this work was completed before seismic crew mobilisation.

Once the seismic crew were on site it was decided between the vibrator drivers, the Liaison Officer and Dixon Webb that a few entrances would be essential for vibrator access, but would need to be widened. This was carried out during the course of the survey by an experienced local contractor. In general, 3 m gates were widened permanently to 4 m, with preservation of the characteristic traditional red sandstone posts of the region.

During the survey an existing but dilapidated hedgerow (field 25/28 boundary) was augmented by the same contractor with the addition of a wire fence, so that livestock could be contained in areas away from the geophone spread. The cost of this can be offset against the time which would have been lost in picking up and re-laying part of the spread every day.

4.3 Equipment checks, mobilisation and testing

4.3.1 Checking

Calibration of the vibrators (similarity, drive level and phase), geophone strings (leakage checks) and recording equipment (telemetry boxes) was carried out at a survey depot of subcontractors IMCL in Howden, Yorkshire, on 10-11 August 1994.The Consultant’s Field Supervisor (CFS; John Laws of J A Arthur & Associates) and a Nirex representative were present to witness the checks. Relevant calibration records have already been supplied to the Consultant.

4.3.2 Mobilisation to site

Shipping of equipment to site began on Thursday 11 August 1994 and was completed on Saturday 13 August 1994.

4.3.3 Equipment testing on site

The first part of swath A was laid out between Thursday 11 and Sunday 14 August 1994. There were sufficient numbers of ground equipment units (nearly 400 sets of cables, telemetry boxes and geophone strings) for swaths A1-A4 to be laid at once.

Figure 6 shows the layout of the 5 sub-swaths within each of the 3 main swaths A-C. Testing comprised leakage and continuity measurements carried out in the recording truck. About 2% of the gear was found to be faulty when laid, apart from faults arising from mis-connection of plugs by the inexperienced GU field crew.

Vibrators were checked by wireline similarity testing, which was initially done twice a day, before and after each daily survey period. This comprises hooking up the vehicles by wire to the recording truck, which then runs tests to check the quality of the sweep produced by each. In particular, the gain or drive level of each vehicle is adjusted to the same value. During the course of the survey the second (evening) set of wireline tests was discontinued to increase productivity.

4.4 Safety

4.4.1 Achieved safety

Before the start of seismic operations two safety briefing meetings were held on-site; one for the GU personnel and one for the IMCL personnel, who had arrived later.

No reports of damage (or of attempts to claim damage) as a result of vibrations from the vibroseis operation were reported during the survey. Monitoring of vibration levels at sensitive places showed that measured ground velocities were all well under the safe limits (section 5.4.5 below). Damage to field surfaces as a result of vehicle movements was minor to minimal.

The GU Nissan van was written off as a result of a collision off-site. Fortunately no personal injury resulted.

4.4.2 Establishment of safety distances

Safe distances to various structures for 2- and 4-vibrator arrays operating at 50% drive level were predicted by extrapolation of ground particle velocities measured from the 30% and 10% levels. Table 3 shows these safe distances for various structures. The star in the Table indicates that a safe distance limit of 25 m was set by independent recording of ground particle velocities at a well head and not by the extrapolation method.

Table 3. Safe distance guidelines for vibrator arrays.

Building/service	**4 vibrators High drive (30%)**	**4 vibrators Very high drive (50%)**	**2 vibrators Very high drive (50%)**
Strong industrial buildings	15	20	12
Houses - good/fair condition	30	65	23
Well heads (with strings)	*	70	30
BNFL pipes	50	70	30
Listed or weak buildings	75	100	70
Listed/fragile buildings & Gosforth	100	110	80
Fragile retaining/dry stone walls	25	60	20
High pressure water/gas pipes	65	90	65

5 SEISMIC RECORDING

5.1 Personnel

Glasgow University provided a total of 23 staff, and IMCL provided 12 staff. Not all these staff were present all the time; on average there were about 15 GU staff and 10 IMCL staff present at any one time during the seismic survey period.

5.2 Recording parameters

Most of the recording parameters are either constrained by the equipment, or had been decided during the submission and approval of the GU Work Programme. They are tabulated in Table 4 and marked by a star.

5.2.1 Sweep type

The recording parameters that remained to be determined at the start of the survey were those pertaining to the sweep type and duration (Table 4, parameters not marked by a star). Normally these are determined during wave tests undertaken before production mode recording starts. However, the whole seismic reflection trial survey is essentially a wave test to determine the best parameters and operation logistics for a full-scale survey, so after discussions between the Contractor and the Consultant, it was agreed that a moderate length, broad-band, simple sweep would be used throughout the survey.

The 12 s, 12-120 Hz linear sweep was chosen because it would permit the acquisition of high frequencies, if the target zone did not attenuate them too much, but on the other hand there is adequate energy in the lower band (12-60 Hz) for orthodox processing and interpretation, should the attempt to get high frequencies back prove to be unsuccessful. A non-linear sweep, with more time spent at the upper end of the band (at the expense of time at the lower end) might have been too risky if the high frequencies did prove to be elusive, unless the total duration of the sweep were also lengthened to maintain the time spent at lower frequencies.

Table 4. Recording parameters.

Station interval	25 m	*
Geometry	10 rows x 24 columns	*
No. of stations	240	*
Source array	Nominal 4	*
Source type	Failing Y1100 on Geogator buggy	*
Source interval	25 m	*
Sweeps per VP	Nominally 5 (unsummed)	*
Moveup	5 m	*
Nominal fold of coverage	300	*
Maximum offset	560 m	*
Sweep length	12 s	
Sweep	12-120 Hz	
Sweep type	Linear	
Taper	250 ms, cosine	
Correlation taper	250 ms, cosine	
Recording instrument	Sercel SN348	*
Sample interval	2 ms	*
Record length	2 s	*
Low cut filter	8 Hz, 12 dB/Oct	*
High cut filter	125 Hz, 72 dB/Oct	*
Early gain	2EXP4	*
Notch	Out	*
Geophone type	Sensor SM4 10 Hz	*
Geophone array	12 element linear in-line (along rows)	*

5.2.2 Source array dimensions

The source array was to be four vibrators operating in-line parallel to columns, at right-angles to the linear geophone array. However, the array dimension was not decided until just prior to the start of the survey, as it depended upon the opinion of the vibrator drivers as to how close together the vehicles could reasonably operate.

One convenient unit of dimension to use was 5 m, the same as the move-up distance. The four vibrators could be spaced at 10 m apart, to give an array length of 30 m. An advantage of this is that when the array is static, for example when it has moved up to an obstruction, more array mid-points can be obtained by successive sweeps with the rear vibrator omitted in turn. This is illustrated in Figure 7. Mid-points of the reduced array advance by 5 m, the same as the advance of the full array during conventional move-ups. However, a 10 m spacing of the vehicles was considered to be too difficult to operate efficiently, as they are 9.5 m long.

Another natural unit to use is 12.5 m, i.e. half of the 25 m unit dimension of the survey, with a 3 m gap between vehicles. Alternate vibrators can also line themselves up visually on the 25 m spaced pegs. This spacing gives a 37.5 m total array length for a single sweep, and 37.5 + 20=57.5 m array length for a summed 5-sweep VP. This is somewhat longer than ideal for high-frequency, steep-dip acquisition, because the array directivity (vertically downwards) becomes too pronounced at high frequencies, so that the reflected energy from steep structures may be low. Nevertheless, it was decided to use this array dimension.

5.2.3 Source array positioning

The source array moved up and down along columns of the survey grid. The default offset was 12.5 m to the right of a column, i.e. mid-way between two adjacent columns of pegs. In the daily instructions to vibrators, the offset is defined to be positive when to the right of a column, irrespective of the direction in which the vibrator convoy is facing.

The vibrator drivers require visual cues to place their vehicles correctly. Preferably they should be able to line themselves (in the cab) opposite a peg or marker at the start of the five sweeps of a vibrator point (VP). After five sweeps with a 5 m move-up, they move 5 m again and they are back to the same relative peg position as at the start, but the VP is the next one higher or lower.

When the five sweeps of a VP are summed, it is convenient that the weighted sum centre of the array (the barycentre) be at the reference VP. It turns out that this is the case when the second and fourth cabs of the vibrator array lie opposite a peg at the first sweep. The reference peg is the one opposite vibrator no. 2. Figure 8 illustrates this geometry, in which the crosses represent successive cab positions. The barycentre of the cabs in the five-fold sum is 3.75 m ahead (high) of the reference VP, but that is exactly the distance that the pad of the truck lies behind the driver’s head. So the summed sweep lies opposite the VP. If the offset was the default 12.5 m, then the summed VP lies on a row, midway between two pegs.

5.2.4 Geophone string geometry

The 12 elements of the geophone string were laid in a linear pattern along the rows and parallel to the rows at a spacing of just over 2 m. The string runs to the right of the reference peg, with the first geophone planted 1 m from the peg. The last (12th) geophone ends up 1 m from the peg in the same row but one column higher. The barycentre of the geophone array is therefore mid-way between pegs on a row, viz. coincident with the source VPs after 5-sweep summing. This coincidence of source and receiver positions is better for processing, in that source and receiver statics are tightly coupled.

Obstructions sometimes forced the geophone pattern to be altered. It was sometimes offset laterally, i.e. fractionally towards a higher or lower row, but still parallel to the rows. If the surface over which the array was to be planted varied by more than 2 m in elevation over the 25 m distance, then the geophones were bunched up so that the relative heights of individual elements did not vary by more than 2 m. Enforced gaps, such as roadway crossings, meant that elements had to be bunched on either side. In all cases the aim was nevertheless to obtain the barycentre of the string to be as close as possible to the desired mid-point position.

5.3 Daily instructions

5.3.1 Introduction

This trial was the first 3-D vibroseis survey ever to have been conducted in the UK. A system of instructions for vibrator movements was developed for this survey by modifying those in use for 2-D surveys.

5.3.2 Recording advisory sheets

Permitting and access information was summarised in sets of recording advisory sheets. These were divided into the three swaths A, B and C, and arranged in column order. In swath A the sheets cover rows 46 down to 21; there are 65 such sheets from column 00 to column 64. There is a data overlap with swath B, which includes rows 36 down to 11, and similarly swaths B and C overlap, since swath C includes rows 26 down to 00. An extract from a column advisory sheet is shown in Table 5.

Table 5. Header part of a typical recording advisory sheet.

viba43.xls			**University of Glasgow 3-D vib programme**				
			Recording advisory sheet				
Prospect: Sellafield			Date	Aug-94			
	Swath	**A**	Column	**43**	No. VPs	26	
VP	**Prog**	**Offset**	**Drive**	**Surface**	**Dirn.**	**Fiel d**	**Remarks**
			%		**Up/Dn**	**no.**	
46							
↓							
21							

Entries in the columns of the advisory sheet are as follows:

VP: numbered in rows from 46 down to 21 in the case of swath A.

Prog: The vibrator programme for that sweep. Descriptions follow 2-D usage, and include:

OL - online (viz. the second and fourth cab, first sweep of 5)

OS - offset from the default

SH - standing high, i.e. further advanced up or down the column than the default, relative to the direction in which the array is moving

SL - standing low, the opposite of SH

SS - standing sweeps, no move-ups

Omit - this VP is to be omitted.

Offset: The offset in metres, if other than the default 12.5 m.

Drive %: The drive level, one of three settings; 10% (low), 30% (high) or 50% (very high).

Surface: Grass, stubble, hard-core, etc. on which vibration occurs.

Dirn Up/Dn: Direction up means to higher row numbers; down is the opposite. The sense is the same as the orientation of the map of Figure 3.

Field no.: Field number, as in Figure 3.

Remarks: Includes reasons for omissions, number of metres high or low, number of vibrators to use, or when to alter the drive level.

5.3.3 Maps

A4 size copies of the relevant parts of the GU workmap formed part of the daily instructions. The maps showed the direction of up and down movement of the vibrator convoy within each field.

5.3.4 Work Programmes

Work programmes were made up on an approximately daily basis. Thirty-two were issued during the twenty-five days of the survey. They comprised an instruction cover sheet approved by the Surveyor, Liaison Officer, Party Chief and Consultant’s Field Supervisor, together with a map of the relevant fields and copies of the relevant column advisory sheets.

After Programme 6 the column advisory sheets were omitted. It was found that it was awkward for the vibrator drivers to have to keep referring to various sheets while in one field. Instead, all the column advisory data for a particular field were abstracted and made into a separate spreadsheet for that field. The VPs for a whole field could then be displayed in the order in which they were to be done, on one or two sheets rather than spread over a dozen or more.

5.3.5 Seismic data recording and transmittal

Correlation of each sweep was carried out in real time in the recording truck. This reduces the 14 s record (12 s sweep time plus 2 s listening time) to 2 s of correlated data. Data were recorded onto 10” diameter nine-track magnetic tape in SEG-B 6250 BPI format. No sweep summing (stacking) was done; each correlated sweep is preserved as a separate file on tape. At the end of each day’s recording the magnetic tapes and Observer’s Logsheets were passed to the Party Chief. These were dispatched at intervals to the processing centre by courier.

5.4 Summary of progress

5.4.1 Daily production

Table 6 summarises the daily production of seismic data arranged field by field in the order in which it was carried out.

The day number starts with day 1 on Tuesday 16 August, ending on day 25 on Friday 9 September 1994. The totals given in Table 6 differ slightly from those calculated by the Consultant's Field Supervisor. The reason for the difference is that Table 6 includes repeated VPs, whereas the CFS version excludes repeated work. The daily seismic production is shown in graphical form in Figure 9. The total number of VPs shot is 2148.

5.4.2 Start of recording

Monday 15 August should have seen the start of acquisition, but various line problems were encountered. It was discovered that vandals had hammered panel pins through four of the telemetry cables laid near Sides Lane. This could have occurred at any time within the previous couple of days. The next day three more vandalised cables were found. Together with other line problems, this delayed the start of acquisition until noon on Tuesday 16 August.

A short set of test sweeps had been programmed as a wave test, but in view of the delay recording started with production mode shooting in field 5, and no wave tests were ever carried out.

Table 6. Summary of daily production of seismic data.

Key to columns: **Field** - field number; **Prog** - daily work programme number; **VPs** - no. of VPs in the field; **Day** - day number; **VP/d** - total number of Vps/day.
Note: Days 13 and 21, during which equipment was being moved and no shooting was carried out, are excluded from this table.

Swath A					Swath B					Swath C				
Field	**Prog**	**VPs**	**Day**	**VP/d**	**Field**	**Prog**	**VPs**	**Day**	**VP/d**	**Field**	**Prog**	**VPs**	**Day**	**VP/d**
5	1	18	1		20	21	33	14		25	29	49	22	
7	1	26	1	44	26	21	34	14		28	29	40	22	
8	2	11	2		21A	21	22	14		29S	29	29	22	118
10	2	15	2		29N	23	11	14	100	29S	29	16	23	
11	2	13	2		25	23	27	15		30	29	25	23	
12	2(add)	16	2		30	23	29	15		39N	30	30	23	
31	2	13	2	68	29N	23	17	15	73	41A	30	14	23	
4	1	37	3		28	23	39	16		41B	30	14	23	
7	1	20	3	57	29S	23	43	16		39S	31	21	23	120
31	2	33	4		25	23	54	16	136	47N	31	13	24	
33	3	20	4		3	22	42	17		45	31	51	24	
34	3	10	4	63	5	22	7	17		42	31	58	24	
3	4	55	5		6	22	45	17		39S	31	10	24	132
6	4	12	5		9	22	20	17		39S	31	26	25	
9	2	47	5	114	33	22	21	17	135	25W	32	30	25	
RCF	6	16	6		31	26	50	18		41W	32	5	25	
6	4	29	6		34	22	11	18		46	32	4	25	
32W	5	19	6	64	32E	26	11	18		44	32	40	25	105
RCF	6	41	7		32W	26	19	18						
14	5	28	7	69	RCF	24	17	18	108					
13	(5)7	8	8		45	27	29	19						
15	8	23	8		46	27	4	19						
16	9	16	8		RCF	24	34	19						
30	10	32	8	79	RCF	25	13	19						
18	11	65	9		RCF	24	9	19	89					
29N	12	14	9	79	39	28	30	20						
25	14	45	10		42	27	21	20						
26	14	11	10		RCF	28	49	20						
28	13	39	10		41A	28	10	20	110					
29N	12	14	10											
29S	(12)15	17	10	126										
RCF	17	19	11											
RCF	18	8	11											
20	16	23	11											
21A	16	46	11											
26	14	24	11	120										
RCF	19	25	12											
RCF	20	14	12	39										
Totals		**922**		**922**	**Totals**		**751**		**751**	**Totals**		**475**		**475**

5.4.3 Rate of progress

Initial progess proved to be slower than anticipated due to the difficulties in manoeuvring the vibrator array in small fields, the delay in start-up, and general inexperience of the layout crew. A progress meeting was held on 22 August 1994 (day 7 of recording). Five proposals were adopted to try to improve progress:

(1) Reducing the vibrator array from four to two, but use them at higher power,
(2) Omitting some VPs in some fields,
(3) Omitting some small fields altogether,
(4) Omitting the left-hand side of the area (‘western’ end in the meeting minutes), and
(5) Extending the working day.

These proposals implied some changes to field operations, as summarised in the following sections.

Figure 10 shows the daily accumulated seismic production, from which it can be seen that the rate of acquisition speeded up during the survey, mainly as a result of these changes. The average rates are as follows (days 13 and 21 have been omitted in the calculation as these days were devoted to swath shifting, not production):

Swath A (days 1-7)	68 VP/day	(before the operational changes)
Swath A (days 8-12)	89 VP/day	(after the operational changes)
Swath B (days 14-20)	107 VP/day	
Swath C (days 22-25)	119 VP/day	

At the second progress review meeting, held on Friday 26 August 1994 (day 11) it was agreed that an extension to the survey period would be considered. As a result the survey was later extended from 20 days to 24 days, and lastly a further day was authorised, making the total of 25 days.

5.4.4 Two-vibrator array

The four vibrator array was operated at a nominal 30% drive level - in practice at about 13,000 lbs force, or a little under half of the nominal peak force of 27,000 lbs.

A two-vibrator array was decided upon at the 22 August progress meeting, so that movements could be speeded up. In addition a second array could be set up ready to start a new field as soon as the first array had completed a field, thus saving the detour time of moving from one field to another. The geometry of the new array is shown in Figure 11. The cab of the front (no. 1) vehicle is now the reference point for positioning, and the barycentre of the five-fold sum of sweeps is at the VP, as before (Figure 8). The summed pattern is 25 m shorter, at 32.5 m instead of 57.5 m. This is preferable for imaging steep structure, although as an array it is less effective than the four-vibrator pattern for cancelling in-line horizontally travelling waves.

The new normal drive level was set at a nominal 50%, which is about 80% of the nominal peak force. The low level for operating near potentially destructible edifices was now the 30% previously used as the high level. The 10% drive level was considered too low with only two vibrators to be worth using at all. The new array with these new drive levels was operated starting on day 8, Tuesday 23 August, with Programme 7.

5.4.5 Vibration monitoring

Vibration monitoring was conducted by GU whenever vibrator pads were:

(1) Within 50 m of a borehole with a Westbay string,

(2) Near Gosforth village, at the start of the survey,

(3) Near Longlands Farm, and

(4) Within 50 m of the BNFL cast-iron water pipes from Wasdale, which traverse the southern part of the survey area.

All vibroseis vibration levels were found to be well under the prescribed safe levels.

The BNFL pipe was additionally monitored by Peter Jackson of Spectrum Acoustic Consultants as subcontractor to GU.

5.4.6 Review of data quality during survey

A hard copy camera printout of any correlated data file could be run off at the same time that the data were being dumped to tape. This was normally done every tenth sweep or so. However, the occasional record with a severe apparent first break ‘multiple’ was seen and thereafter a hard copy of every sweep was taken. Whenever such a sweep was seen the vibrators were instructed to repeat the sweep.

About one record in 50 or 100 had the problem, which was ascribed to a possible arithmetic error arising in the correlator. The multiple data always appeared at 1.2 s below the primary data such as the first breaks. Records with a 4 s correlated length were run for a time to see whether there was a correlation side-lobe at 1.2 s when the rogue records appeared, but there was not. The source of the occasional error was never discovered. Although this is unsatisfactory in principle, the target zone of the survey is all much shallower than 1 s, so the apparent side-lobe or multiple-type error in the few records will not affect the survey results in practice, even after migration.

Copies of preliminary, pre-processed data were returned to the site periodically. These shot gather display panels demonstrated that data collection was satisfactory.

The MESA 3-D survey planning software package was set up, and position data to date were entered at the end of swath B recording (day 20). The aim was to check that no holes or gaps in coverage would be left during the acquisition of swath C in the remaining days. This proved to be useful, because the MESA fold of cover display showed that fold in bins near to Borehole 5 was dropping off rather rapidly to the bottom left-hand corner. Effort in the last two days of the survey was expended in improving this fold, rather than shooting long-offset data in the extreme bottom right-hand corner of the area (Figure 3, fields 37, 38 and 40). The final subsurface fold of coverage is shown in Figure 12.

5.4.7 Omission of the left-hand edge

One of the decisions at the first progress review meeting (22 August 1994) was to omit shooting of the 8 columns (00 to 07) on the left-hand side. Swaths A4, A5, B1, B2, C4 and C5 were not recorded. This meant that within each swath there was enough ground equipment to lay out the swath fully, and that switching between sub-swaths (e.g A1 to A2) was simply a matter of operating a switch in the recording truck. Whole fields could therefore be programmed to be done at once, even if adjacent columns were to be shot into different sub-swaths. The full-fold area resulting from this shrinkage is now 750 m x 750 m, and not 750 m x 1000 m as originally planned (Figure 2).

5.4.8 Vibrator logistics

The vibrators were accompanied at all times by the Liaison Officer or a deputy walking with the trucks. This was to help them get positioned correctly, pointing out peg numbers, for example, and liaising with the Observer or Party Chief whenever a problem or query arose. Field alterations to the programmes were noted on a copy of the programme.

All crucial movements of the vibrators, where there was a possibility of damage to field surfaces or gateways, were recorded on VHS-C video with a date/time stamp.

The vibrators frequently had to cross the rows of geophone and signal cables. These were protected from damage by a mat-laying crew which preceded and followed the vehicles.

Silage crops grew rapidly after the setting out of the survey grid pegs, which soon became invisible from a distance. One metre long canes with a small polythene flag were planted in those fields, to reveal the grid. In addition, the mid-way line between columns was marked at top and bottom of some fields by another cane with a different coloured flag. This gave the vibrator drivers a line to follow.

5.4.9 Vibrator similarity checks

It is usual IMCL practice to carry out the similarity checks before and after recording each day. This procedure was adopted to begin with, but an instruction was given to cease doing the evening checks, with effect from day 7 (Monday 22 August). This was part of the effort adopted to maximise the recording time available.

5.4.10 Night watch and sheep watch

A night watch comprising two field assistants in a Land Rover was detailed to patrol the Sides Lane area every night after the vandalism episode. There were two watches, one running from the end of recording at about 1830-1900 till 2200 h, and a later watch taking over till 0300 h. No suspicious persons or incidents were reported. The aim was to act as a possible deterrent by being seen to be present.

By the start of Swath C (6 September) darkness was falling at around 2000 h, and the weather had deteriorated considerably, so the Party Chief decided to discontinue the

2200-0300 watch. However, sometime overnight on 7/8 September 27 ground cables were severed with a knife. Again, all cables affected were in the Sides Lane area. The night watch was re-instituted as a result.

A sheep watch had to be observed during the day in fields with ground equipment, to avoid cables getting chewed. At night the equipment had to be lifted and re-laid the next morning, causing delay in starting recording. Curtailment of the recording area (section 5.4.7) helped to minimise this inconvenience. The livestock grazing problem was finally solved with the erection of a fence (section 4.2.4) so that the sheep were kept away from the spread.

5.4.11 Down time

Down time is defined as time lost to production recording because of unforeseen events, breakdowns, etc. It excludes the necessary daily travel time and equipment checking. Over the 25 survey days the amount of down time was approximately as follows:

(1) Line faults	7.0 h
(2) Recording truck problems	5.5 h
(3) Vibrator problems	1 h
(4) Absence of instructions	0.75 h
(5) Vandalism	7.5 h
(6) KSW site instructions	2.5 h
Total	*24.25 h*

This lost time was more than compensated for by an agreement to increase the length of the working day from its normal 10 h duration to 12 h, with effect from day 8. Alterations to the Work Programmes, starting on day 8, after the progress meeting on day 7 (see section 5.4.3 above), caused the loss of 3/4 h while the vibrators had to await new instructions.

The two episodes of vandalism (discussed in sections 5.4.2 and 5.4.11 above) cost the survey some 7.5 h in total. Two instructions from the site managers KSW on day 12 to observe complete radio silence delayed acquisition for a total of 2.5 h.

5.4.12 Clear-up

Pegs from swaths A and B were removed by the GU field crew during shooting of swath C, and after the last day of production one and a half days were required to remove ground equipment and the remaining pegs. All survey control pegs were removed as well.

6 RESULTS

6.1 Fold of coverage

6.1.1 Theoretical maximum

Had every VP on each swath been shot, there would have been a total of 4503 VPs. This calculation assumes that the eight columns on the left-hand side of the area are omitted. For every VP there are four bins 12.5 m square. The fold of coverage, taking an average over the CMP area (the perimeter of which lies halfway between the swath area and the survey edge) would have been 154.

An alternative method of estimating an average would be to assume that all the CMPs lie in bins within the full-fold area of the swaths. In this case the fold would have been 273. However, this is a slight over-estimate of the coverage within the swath area, as some of the CMPs lie outside it.

6.1.2 Actual fold of coverage achieved

A total of 2148 VPs were shot, or 48% of the theoretically possible number. The average fold of cover, assuming all the CMPs to lie within the full-fold swath area of 750 m x 750 m, is 130. This is several times higher than the normal industry standard.

However, the distribution of the subsurface coverage is uneven. Figure 12 depicts the MESA display of the subsurface (i.e. CMP) coverage in the 12.5 m bins. The coverage is greater than 100-fold within the target swath area, except at the bottom left-hand corner and marginally along the lower half of the right-hand side. These deficiencies relative to the upper part are due to the relative lack of access for the vibrators in the bottom one-third of the survey area. Note that this CMP coverage map only presents an accurate picture of true subsurface coverage for planar flat-lying layers. It will be modified in practice due to geological structures.

6.2 Data for seismic processing

The seismic data comprise correlated shot files of 240 channels. There are 2148 VPs, and normally 5 sweeps per VP. The individual sweeps have been recorded as separate files. Record length is 2 s, and the sample interval is 2 ms. The data are stored on nine-track tape at 6250 BPI density, phase encoded, in SEG-B multiplexed format.

Accompanying the data are the Observer's Logs (paper), and a location file (floppy disk) in UKOOA-P1/90 format.

6.3 Logistics of the 3-D trial

6.3.1 Feasibility of vibroseis as a source

The acquisition phase of the trial has provided valuable information about the feasibility of carrying out a 3-D survey of the PRZ using a vibroseis source. It appears that vibrators can deliver enough high frequency energy, approaching that of the alternative source, dynamite in deep shot holes. The two-unit array apparently delivered sufficient energy for the purpose, and doubled the rate of production compared with the four-vibrator array. The availability of the extra two vehicles reduced the down time caused by detours from one field to another.

Damage to fields caused by the vibrator array was minimal. However, the survey was conducted during a period of dry weather in late summer. Damage would be expected to be considerable during winter. The high manoeuvrability of the buggy type of vibrator vehicle was essential in the many small fields. Crab tractor units or other types of fixed-chassis vehicles would be less suitable unless they could match the tight turning circle (about 10 m in diameter) of the buggy. Although consideration could be given to using a single very large vibrator in future, in place of the two medium-size units employed in 1994, the width of any such single large unit should be no larger than the 3.0 m of the vehicles used in 1994, otherwise many more gates would have to be removed for access.

Since variations in phase of the energy going into the ground are probably the main limitation on the current usefulness of the energy at high frequencies, it would have been useful to record various parameters of the vibrator behaviour, so that the phase and amplitude could have been measured. Equipping vibrators with pressure sensing plates bolted underneath each baseplate would be a useful addition for a future survey.

6.3.2 Recording equipment

Approximately 400 sets of ground equipment were laid at once, although only 240 of these were live at any one time. A doubling of rate of progress could be obtained if the receiver spread were increased to at least 480 channels. This implies, in effect, that 700-800 sets of ground equipment be laid out at any one time to enable efficient roll-along of the receiver array. The extra ground equipment laid out would, however, reduce efficiency indirectly due to the corresponding increase in anti-vandalism and anti-theft precautions required.

It was considered impracticable for the Sercel SN348 recording instrument to record uncorrelated traces as the archive dataset, as field time would have been lost writing data to the rather obsolete nine-track magnetic tape drive. In addition there would have been a significant extra cost in storage media. However, with more up-to-date recording systems the extra cost of recording uncorrelated data would be minimal.

6.3.3 General comments

Experience gained during this trial survey shows that consideration needs to be given to the following planning and logistical matters in any future survey.

All the land was owned by BNFL and tenanted by only five farmers. Initial contact with local farmers was made by Nirex's land agents Dixon Webb. A specialist permit man, familiar with the problems of a seismic survey, was then appointed as Liaison Officer. This dual arrangement worked very well, but in contrast, neither party acting alone could have done the required job. These permitting logistics were therefore much simpler than will be the case for a full survey.

It would have been useful for information on crop coverage, ownership, access, obstructions, sensitive structures etc. to have been added to a digital map database as early as possible, under the direct control of the planning crew. An in-house, on-site GIS package would be necessary for a future full-scale survey. This would enable efficient timetabling of the entry to fields to minimise compensation for lost or damaged crops. Note that entry to fields implies access for the survey crew to set out the grid of survey pegs. Farmers have to be able to cut or harvest crops before pegs are set out, whereas livestock need not be moved until the seismic equipment is to be laid.

After the initial vandalism episode a continuous watch had to be kept; this is one argument against the case for speeding up progress by having many more live recording channels, since the effort required in guarding the ground gear will cancel out the potential savings in survey effort. An important part of the specification for a future survey will be ways of minimising vandalism.

The MESA on-site survey planning software package proved to be useful in checking for flaws and unforeseen gaps in the coverage being obtained. This type of effort would be needed even more for a large-scale survey, but with the field geometry data entered in advance and then updated as the survey progresses.

The off-site, remote processing proved to be of limited use for modifying parameters during the course of the survey. Much of the processing of a land survey can be done during the course of acquisition, and rapid feedback is thereby gained. This would be especially effective if it could be done on-site rather than remotely, as was the case in 1994.

Features for which vibroseis operational safety distances are required need to be better defined. Since dry stone dykes were classified as ‘retaining walls’, for example, the movements of the source array were severely curtailed. The definition of certain features such as ‘retaining wall’ needs to be clarified well in advance of any future survey.

Radio communication proved to be vital during the seismic survey; not just the expected two-way traffic between the recording truck and the vibrator convoy, but also between both of these elements and the survey base. There were a few occasions during which radio communication had to be stopped for safety reasons when dynamite was being handled by another Site contractor.

GLOSSARY

The context within a word or phrase is used herein is shown, where necessary, in square brackets thus [ ]. Cross-referenced terms are shown in *italics*.

3-D [seismic survey] Three-dimensional configuration in which there are two horizontal spatial directions parallel to the earth's surface and one vertical time or depth dimension.

Aperture [seismic survey] The surface area (3-D) or line (2-D) over which sources or receivers are laid out in order to image a *target*.

Array [seismic survey] Set of *source* or *receiver elements* summed into a pattern.

Barycentre [seismic survey] The geometrically weighted centre [of an *array*].

Bin [seismic survey] One of a set of small square areas into which 3-D seismic data are sorted; the exact position within the bin is by definition unimportant.

Buggy [seismic survey] *Vibrator* truck which steers by articulation of two rigid front and rear halves, making it very manoeuvrable for its length.

Chaining [topographic survey] Measuring the distance from one point to another by a calibrated length of wire.

Common mid-point [seismic survey] The geometric half-way point between the *source* and *receiver* positions. In reflection processing, the subsurface location of reflections on a seismic trace is initially assumed to be at this point (often abbreviated CMP).

Continuity [seismic survey] Correct electrical connection of the *ground equipment*. [seismic processing] A measure of the quality of reflectors as judged by phase correlation from trace to trace.

Control point [topographic survey] Known position in a *control traverse*.

Control traverse [topographic survey] Set of connected, calibrated known positions, usually forming a closed polygon in plan view, used as the framework from which survey points can be *set out*.

Correlation [seismic survey] The digital process of comparing the recorded seismic data with the *sweep* to convert the long-duration signals into short pulses; usually carried out in real time by a dedicated computer in the *recording truck*.

Coupling [seismic survey] In the context of *static corrections*, the interdependence of two sets of simultaneous equations, one for the *source* and one for the *receiver*. In the context of acquisition, the connection of *sources* or *geophones* to the ground.

Element [seismic survey] Unit of the *source* or *receiver*, made up into *arrays*.

Early gain [seismic survey] The fixed amplification factor in a *telemetry* box.

Fold of cover(age) [seismic survey] The multiplicity in which unit segments (line or area) of the earth are observed by repeated observations.

Coverage [seismic survey] Abbreviation of *fold of coverage.*

Geophone [seismic survey] Sensor connected to the ground to measure the ground motion (usually the vertical component of ground velocity, converted to a low-impedance electrical analogue signal).

Geophone string [seismic survey] Set of *geophones* connected together in series.

Leakage [seismic survey] Undesirable electrical connection from the *ground equipment* to earth, usually caused by water.

Ground equipment [seismic survey] The set of cables, *telemetry* boxes and *geophone strings* comprising the *receiver arrays.*

Line [seismic survey] In 3-D work, a row of receiver *ground equipment*.

Linear pattern [seismic survey] Set of *elements* of a *source* or *receiver* with an equal spacing, and electrically or mechanically summed together.

Move-up [seismic survey] The distance by which the *source array* is advanced during *shooting*.

Linear sweep [seismic survey] *Sweep* in which the rate of increase or decrease of instantaneous frequency is constant.

Multiple [seismic survey] Secondary, undesired reflection data coming in later than the desired primary data.

Notch [seismic survey] Filter centered upon a specific frequency, usually designed to reject 50 Hz electrical pickup.

Offset [seismic survey] The distance from *source* to *receiver*.

Permitting [seismic survey] The activity undertaken to gain access.

Pogo stick [topographic survey] Calibrated adjustable vertical pole to hold the *prism*.

Potential Repository Zone Region in which it is considered that a deep radiocative waste repository might be located.

Pre-processing [seismic survey] Preliminary, routine sorting out of digital seismic data, not requiring knowledge of the geology or physical characteristics of the *prospect*, undertaken before processing can be done.

Prism [topographic survey] Corner-cube reflector sighted upon by a *theodolite*.

Processing centre [seismic survey] Offsite, remote location at which bulk, intensive processing of seismic data is conducted.

Production (mode) [seismic survey] The routine collection of the survey data with fixed *recording parameters* determined during a preliminary *wave test*.

Prospect [seismic survey] The locality or *target* zone of the survey.

Receiver [seismic survey] The instrument (usually a *geophone string*) which picks up the reflected waves from the subsurface.

Recording advisory sheet [seismic survey] The tabulated outcome of *permitting* and access investigations, to tell the survey crew where to go and what to do.

Recording parameters The set of instrument settings and survey geometry decided upon as being the most appropriate; not normally altered in the course of the survey.

Recording truck [seismic survey] Field vehicle containing the seismic recording, control and test equipment.

Rock Characterisation Facility A proposed underground laboratory where subsurface investigations of the Potential Repository Zone are planned to be carried out.

Sample interval [seismic survey] The time between successive instants at which an analogue signal is converted to a digital number.

Set out [topographic survey] The process of marking pre-determined survey coordinates on the earth.

Shooting [seismic survey] The process of setting off the *source* in a seismic survey; although referring originally to dynamite shots, it is also used in *vibroseis*.

Shot-point [seismic survey] The place at which a seismic shot (pulse source) is to be fired; used also loosely for *vibroseis* work.

Side-lobe [seismic survey] Unwanted concentration of energy before or after the (central) peak of a *correlated* seismic signal.

Source [seismic survey] The origin of the signal used to generate seismic reflections from the subsurface.

Spectral analysis Method of transforming time-series signals to view the frequency content.

Static corrections Fixed, location-dependent corrections to seismic data to correct for relative delays in the upward or downward passage of seismic reflections due to the low-velocity, unconsolidated material at the earth's surface.

Steep structure [seismic survey] Geological structures amenable to the seismic reflection method, but which dip at greater than about 45°.

Swath [seismic survey] Parallel set of *lines* of *sources* or *receivers*, forming a rectangular area.

Sweep [seismic survey] The long-duration signal, sinusoidal in character, but with the frequency increasing or decreasing with time, generated by a *vibrator*.

Target [topographic survey] The prism observed by the *theodolite*.

[seismic survey] The zone of the subsurface in which the survey is to concentrate.

Telemetry [seismic survey] Conversion of data received at a *receiver* for transmission digitally by wire or radio to the recording instrument on demand.

Total station [topographic survey] The set of instruments required to set out survey control and then survey or set out points.

Theodolite [topographic survey] Precision topographic surveying instrument.

Tribrach [topographic survey] Three point device to hold a *prism* level on a tripod.

Vibrator [seismic survey] Servo-hydraulic device mounted on a truck or *buggy* to generate sweeps transmitted into the earth.

Vibroseis [seismic survey] The technique of using a quasi-sinusoidal low-power but long-duration burst of energy into the earth using a *vibrator*.

Wave test [seismic survey] The preliminary process to the *production mode* of a seismic field survey, of observing the potentially interfering waves and other unwanted signals and noise, with the aim of minimising their effect by setting the most appropriate *recording parameters*.

Wireline similarity [seismic survey] Test of *vibrators* in which the vehicles are connected by wire to the *recording truck* to ensure that the *elements* of the *array* are all calibrated identically.

ABBREVIATIONS

ASCII	American Standard Computer Information Interchange [format for computer data]
BNFL	British Nuclear Fuels [plc]
BPI	Bits per inch
CFS	Consultant's Field Supervisor
CMP	Common mid-point
EDM	Electronic distance measuring
GU	Glasgow University
IMCL	International Mining Consultants Ltd
Nirex	United Kingdom Nirex Limited
PRZ	Potential Repository Zone
RCF	Rock Characterisation Facility
SEG	Society of Exploration Geophysicists
SEG-B	SEG standard for seismic field data tapes
SEG-P1/90	SEG/UKOOA standard for exchange of position data (1990 version)
TTL	Through the lens
UKOOA	United Kingdom Offshore Operators' Association
VP	Vibration point

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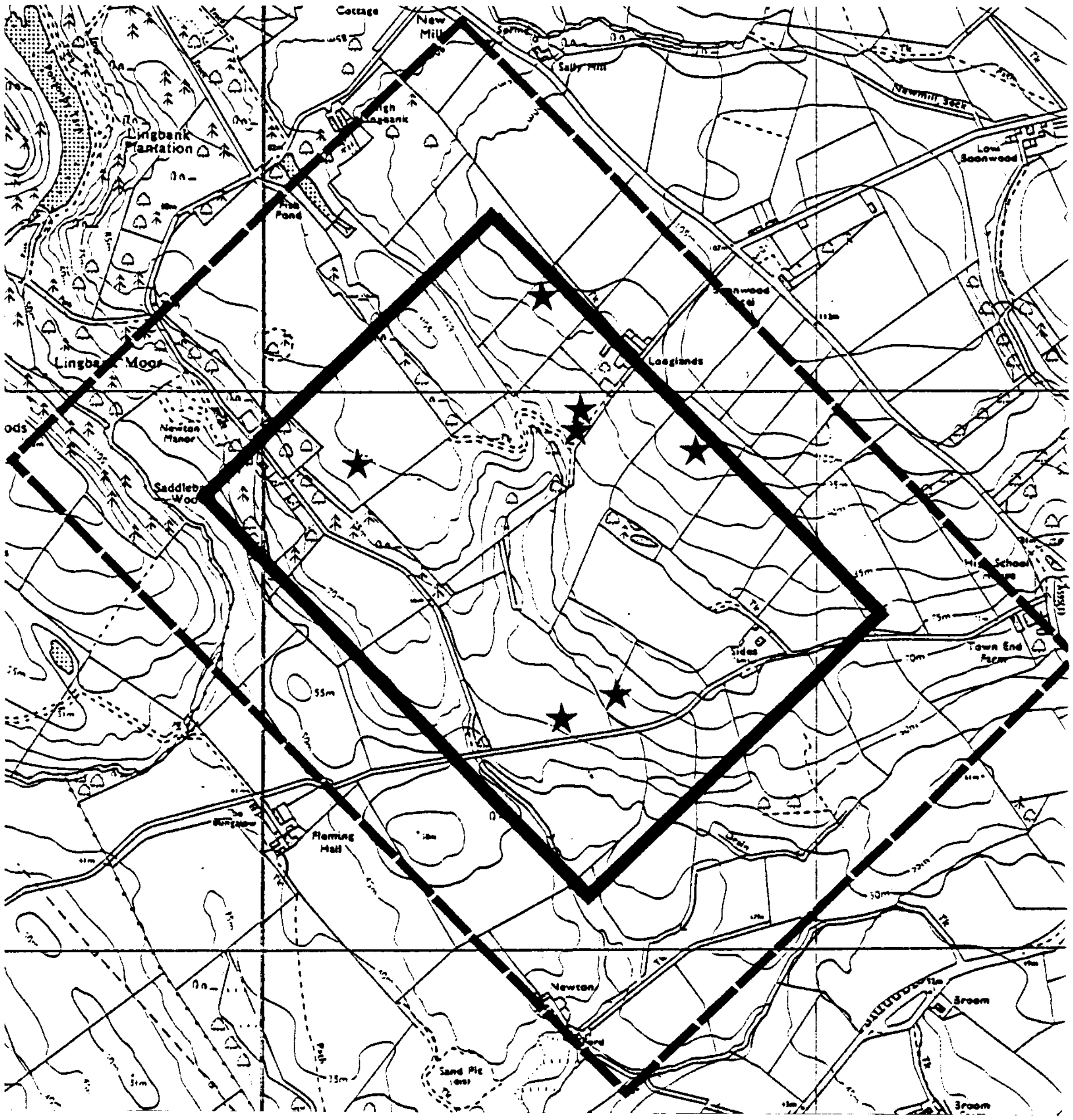


Figure 1. Proposed area of 3-D trial.

Note: Map shows proposed 3-D test survey area (heavy solid line). Full subsurface coverage is obtained inside this area, but the field survey must extend as far as the edge of the dashed-line area in order to obtain this. Subsurface coverage diminishes progressively from full to zero between the solid and dashed lines. It reduces to zero halfway between the two boundaries. Existing boreholes are shown by stars.

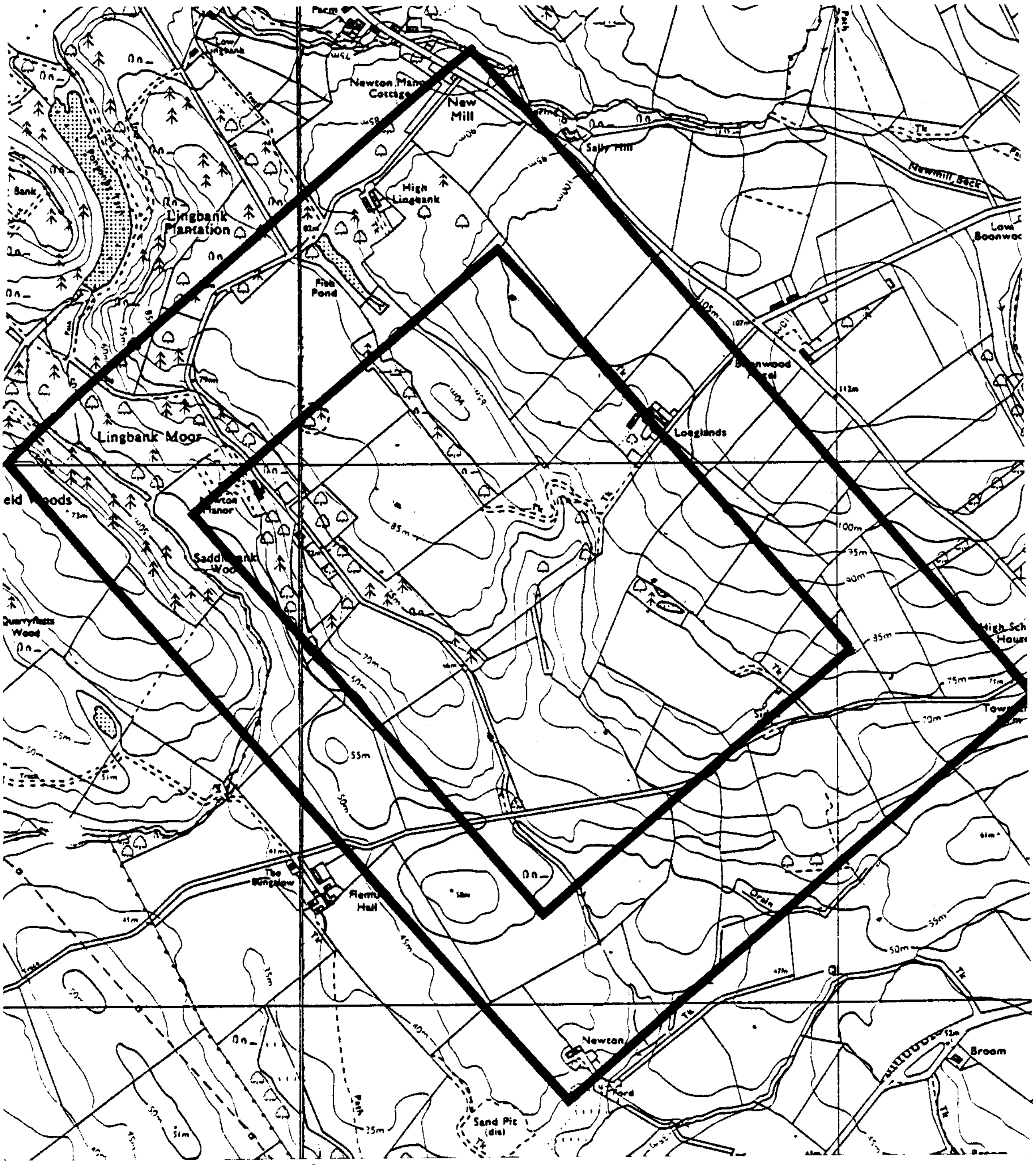


Figure 2. Area of 3-D trial after location shift.

Note: Alteration of the area of Figure 1 carried out on 23 June 1994. The survey was carried out in this area.

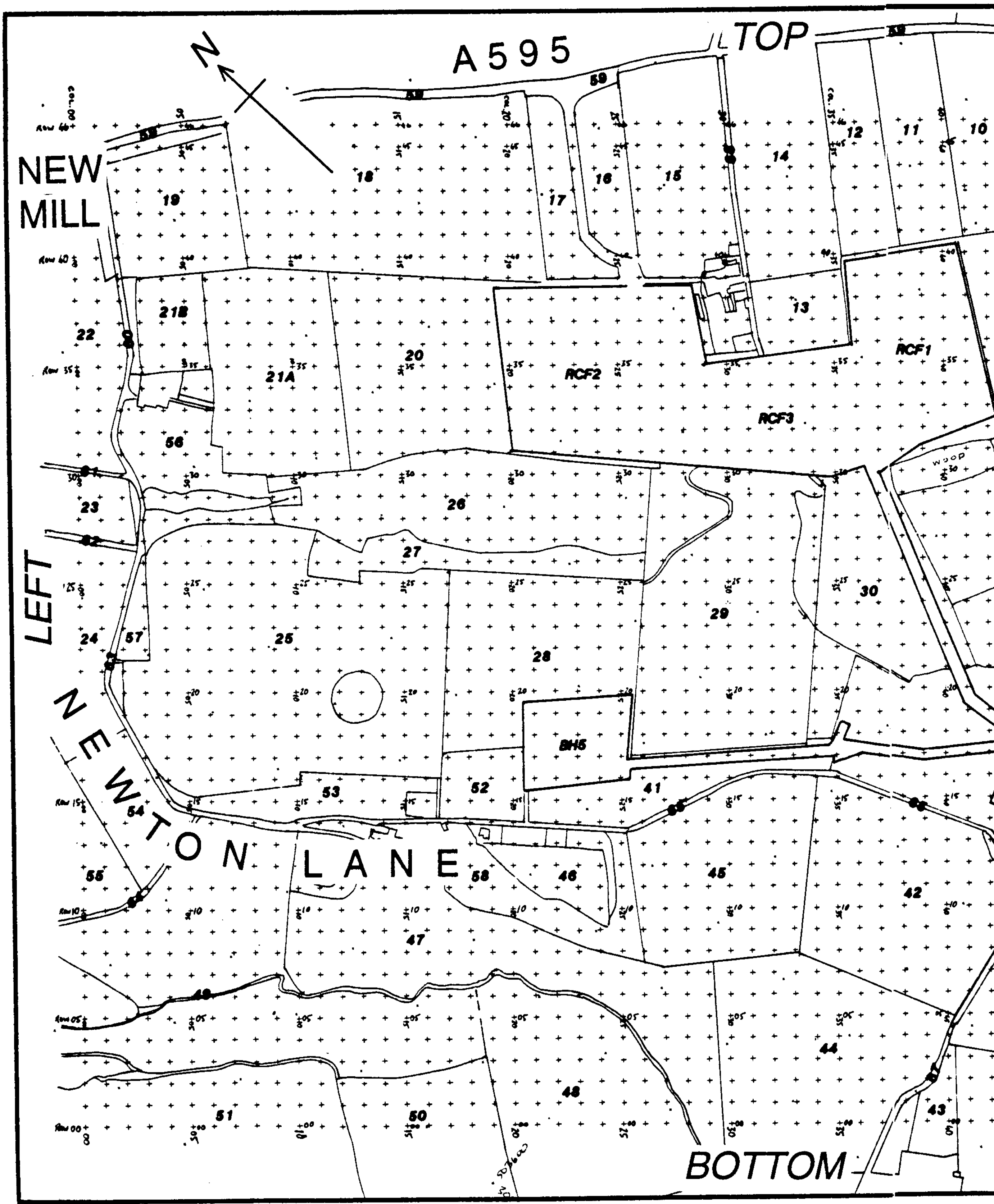
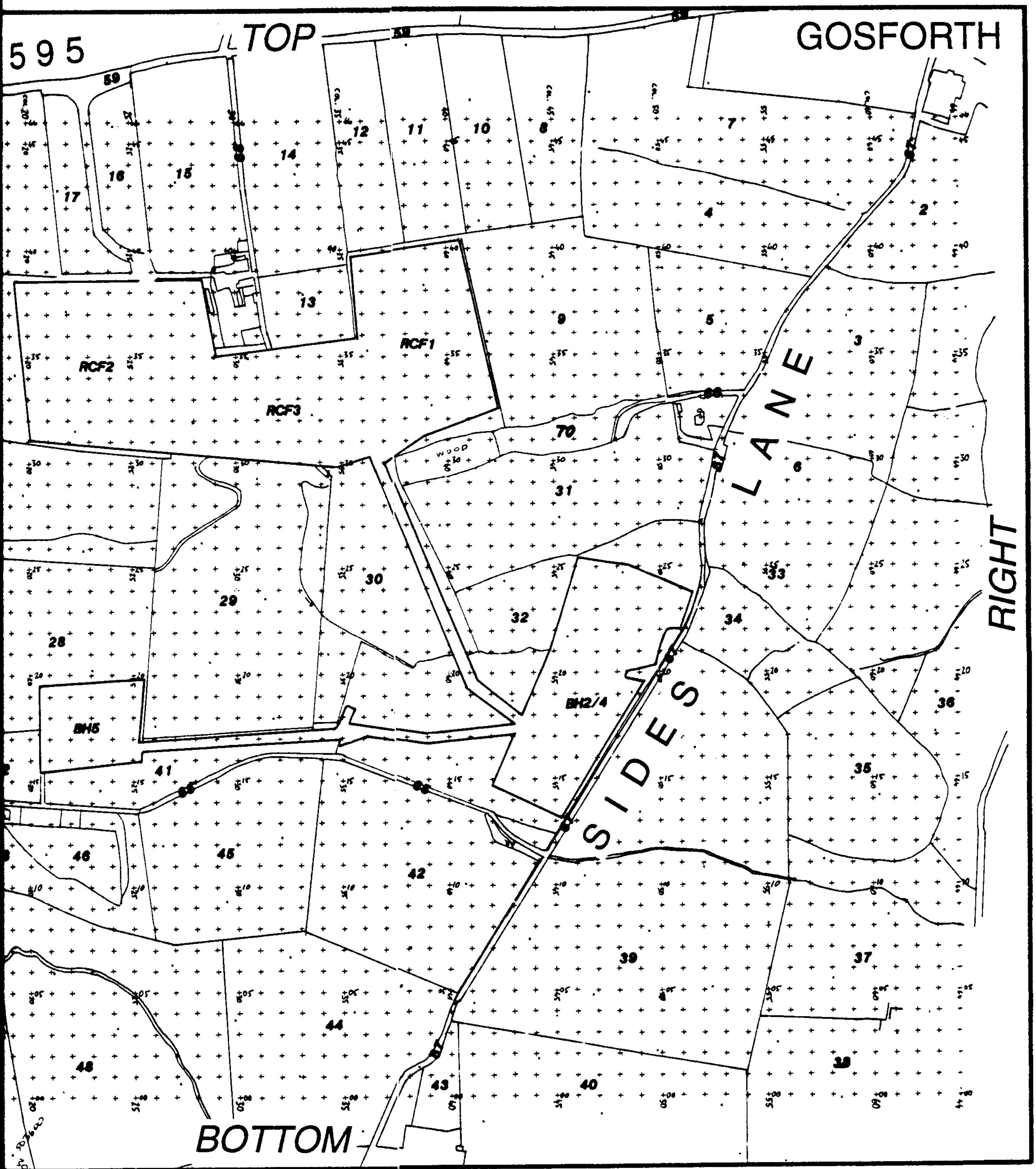


Figure 3. Annotated copy of the GU workmap (reduced).


595
TOP
GOSFORTH
LANE
SIDES
RIGHT
BOTTOM
RCF1
RCF2
RCF3
BH2/4
BH5
WOOD

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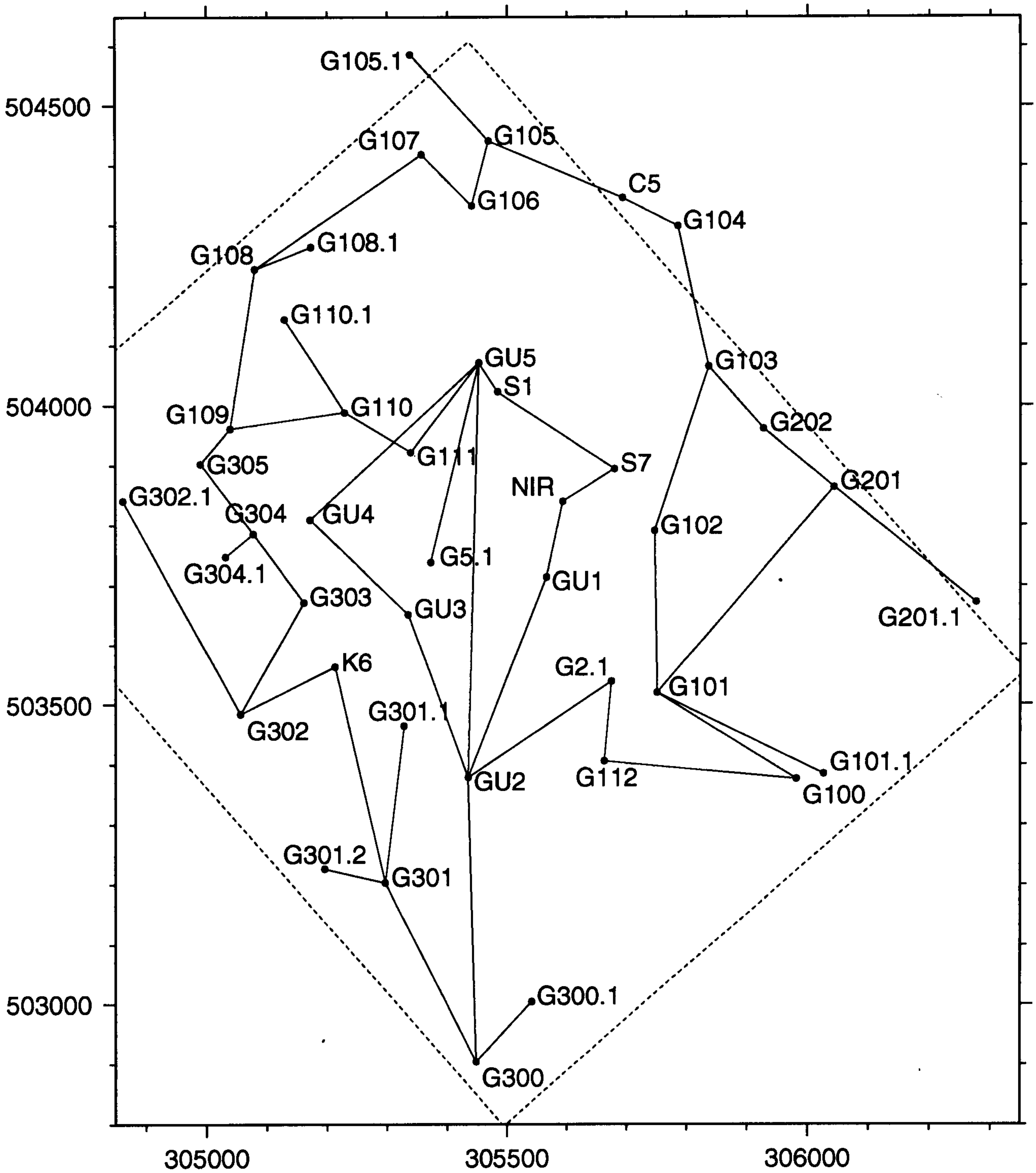
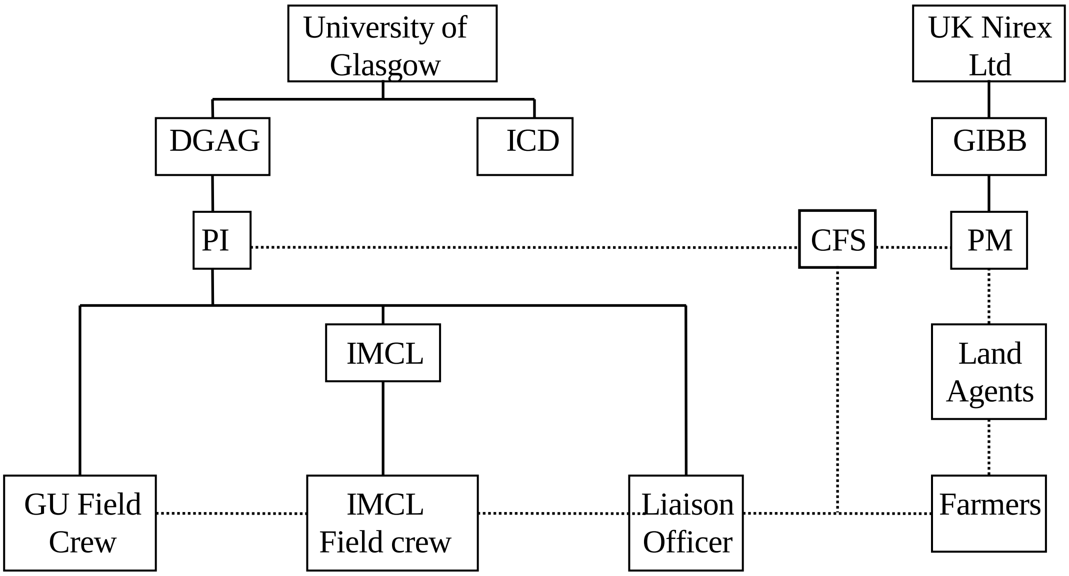


Figure 4. Topographic survey control traverses (coordinates of the stations shown are tabulated in Table 1). Dashed line is outer perimeter of the survey area shown in Figure 2.

Organisation Chart



Key:

Line management: ————

Interface: ··········

Abbreviations:

DGAG:	Dept. of Geology & Applied Geology
ICD:	Industrial & Commercial Development (GU)
GU:	Glasgow University
PI:	Principal Investigator
PM:	Project Manager
IMCL:	International Mining Consultants Ltd
CFS:	Consultant’s Field Supervisor

Contractual matters:

These are handled on behalf of the University of Glasgow by ICD.

Figure 5. Organisation chart for the field acquisition.

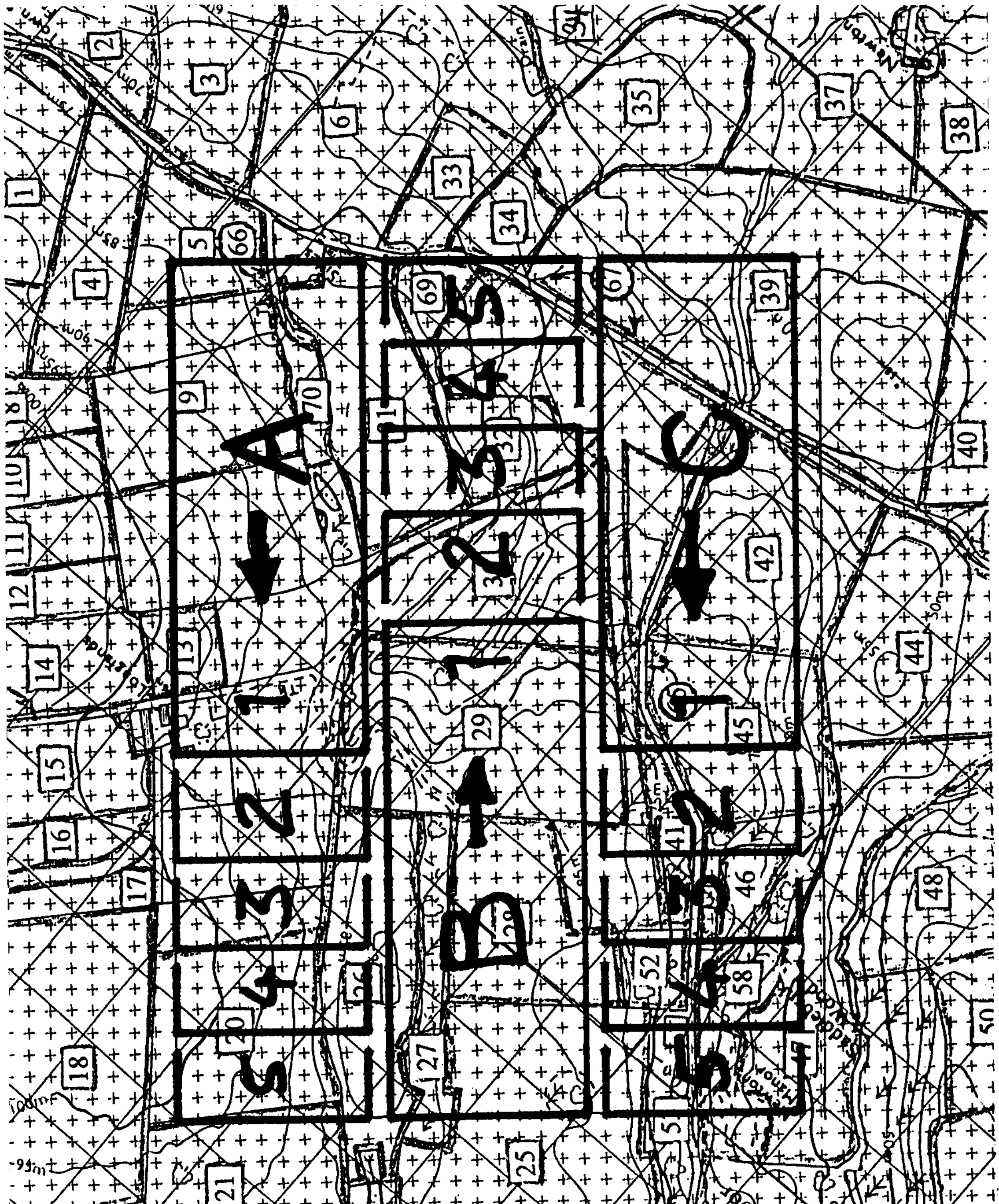


Figure 6. Location of geophone swaths A-C (each divided into sub-swaths 1-5. Arrows show direction in which swaths are rolled).

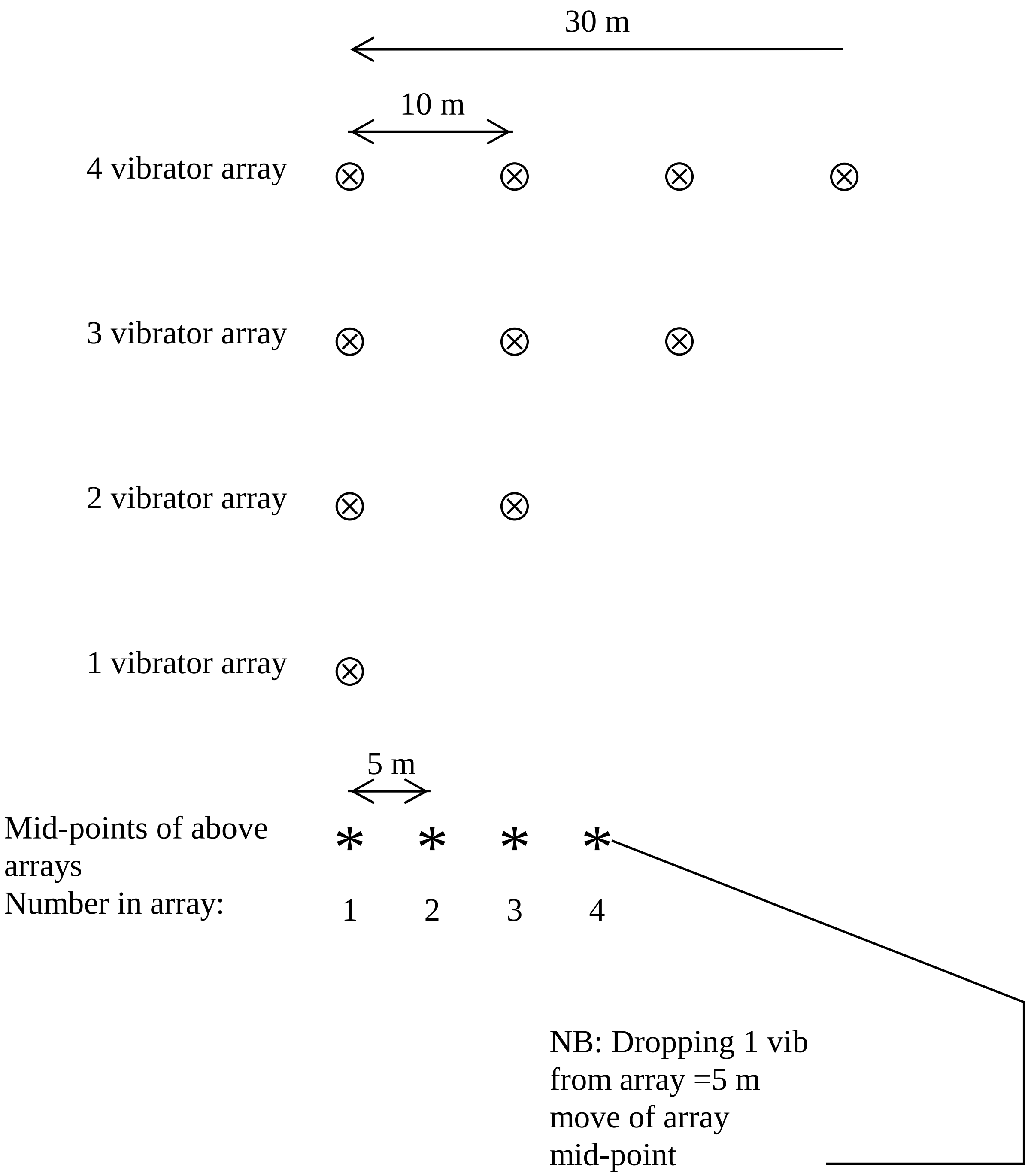


Figure 7. Four vibrator array: move-up scheme.

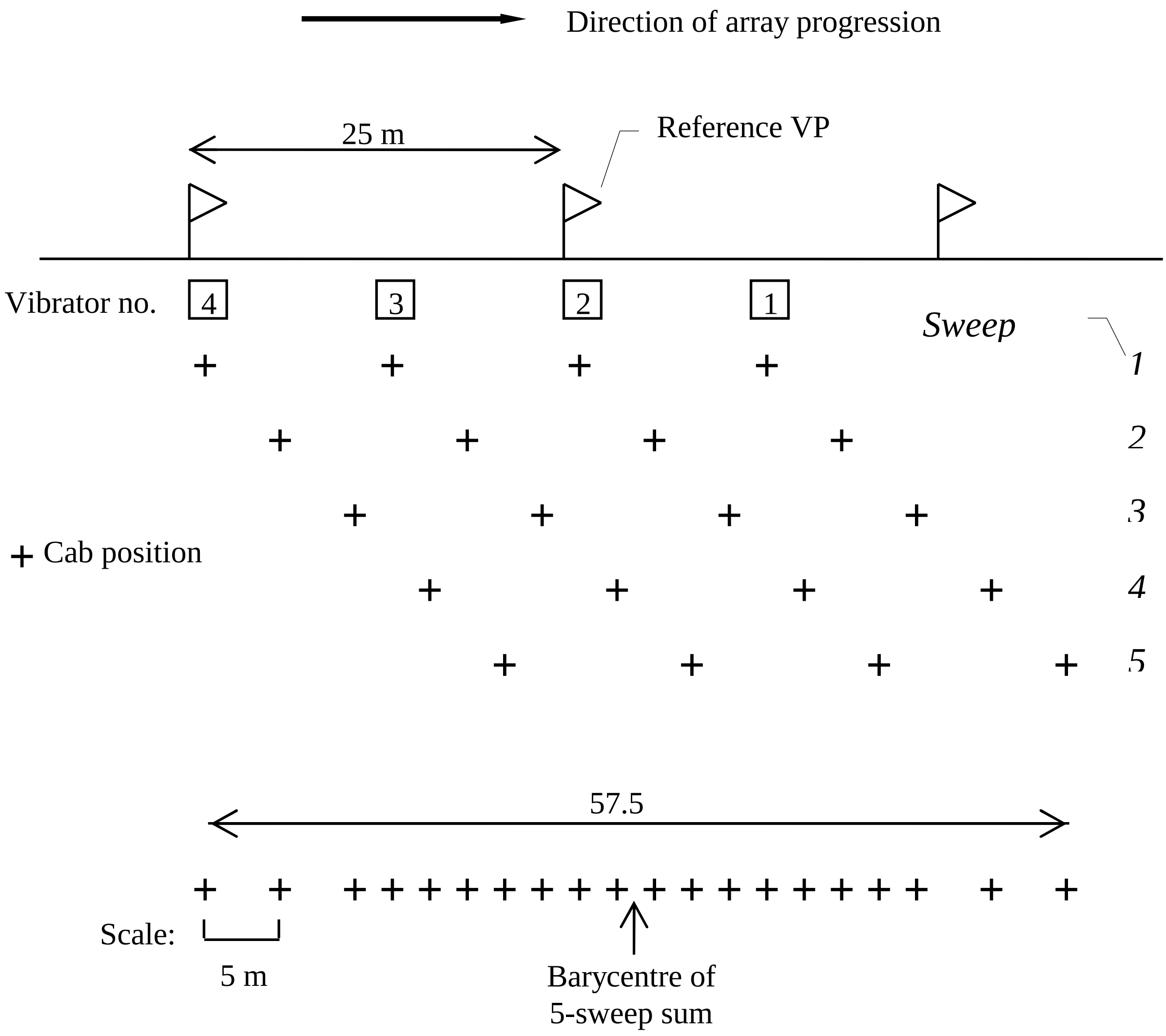


Figure 8. Sum of 5 sweeps with 4 vibrators spaced at 12.5 m.

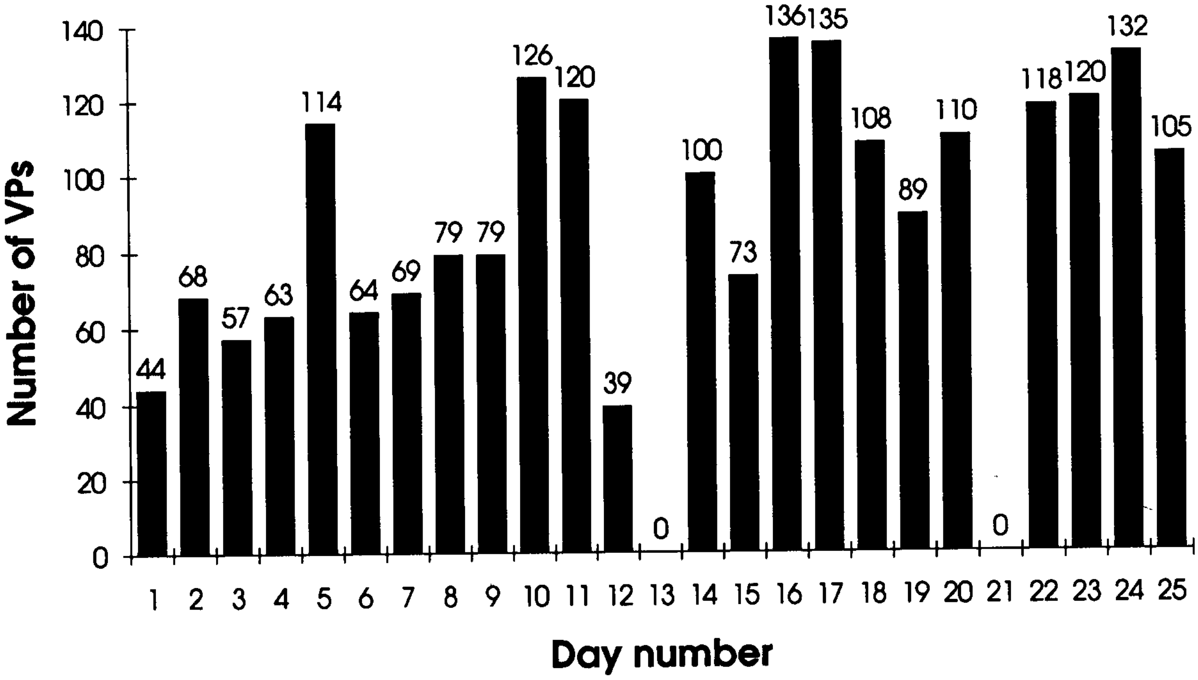


Figure 9. Daily seismic production (total number of VPs shot is 2148).

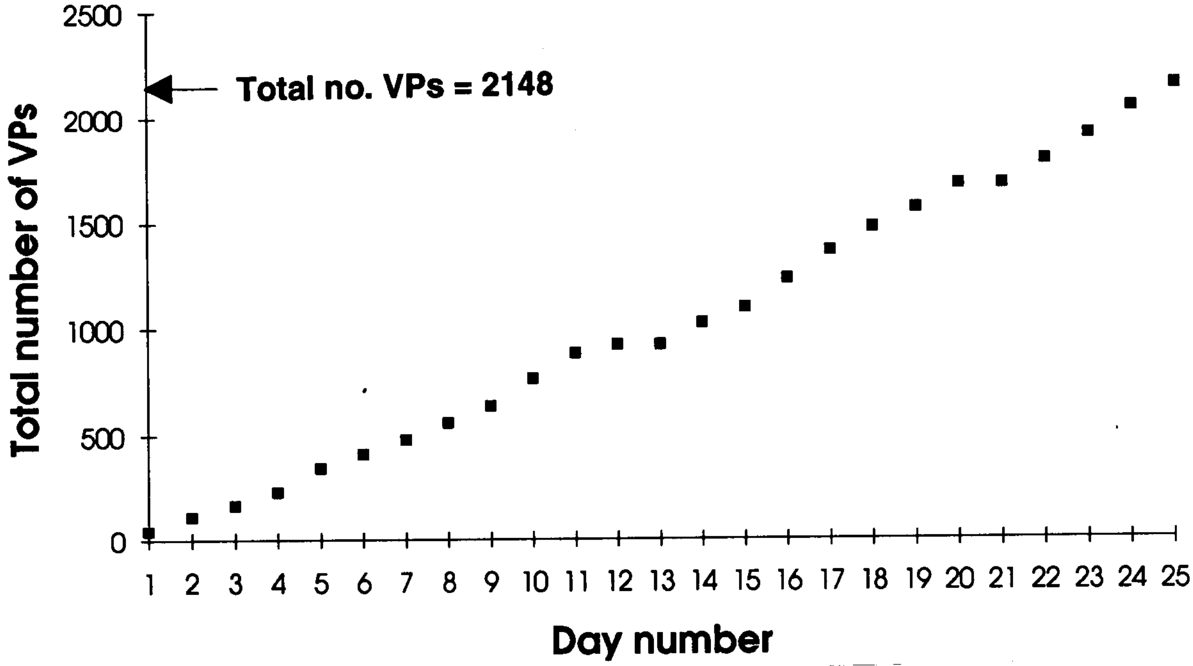


Figure 10. Cumulative seismic production (total number of VPs shot is 2148).

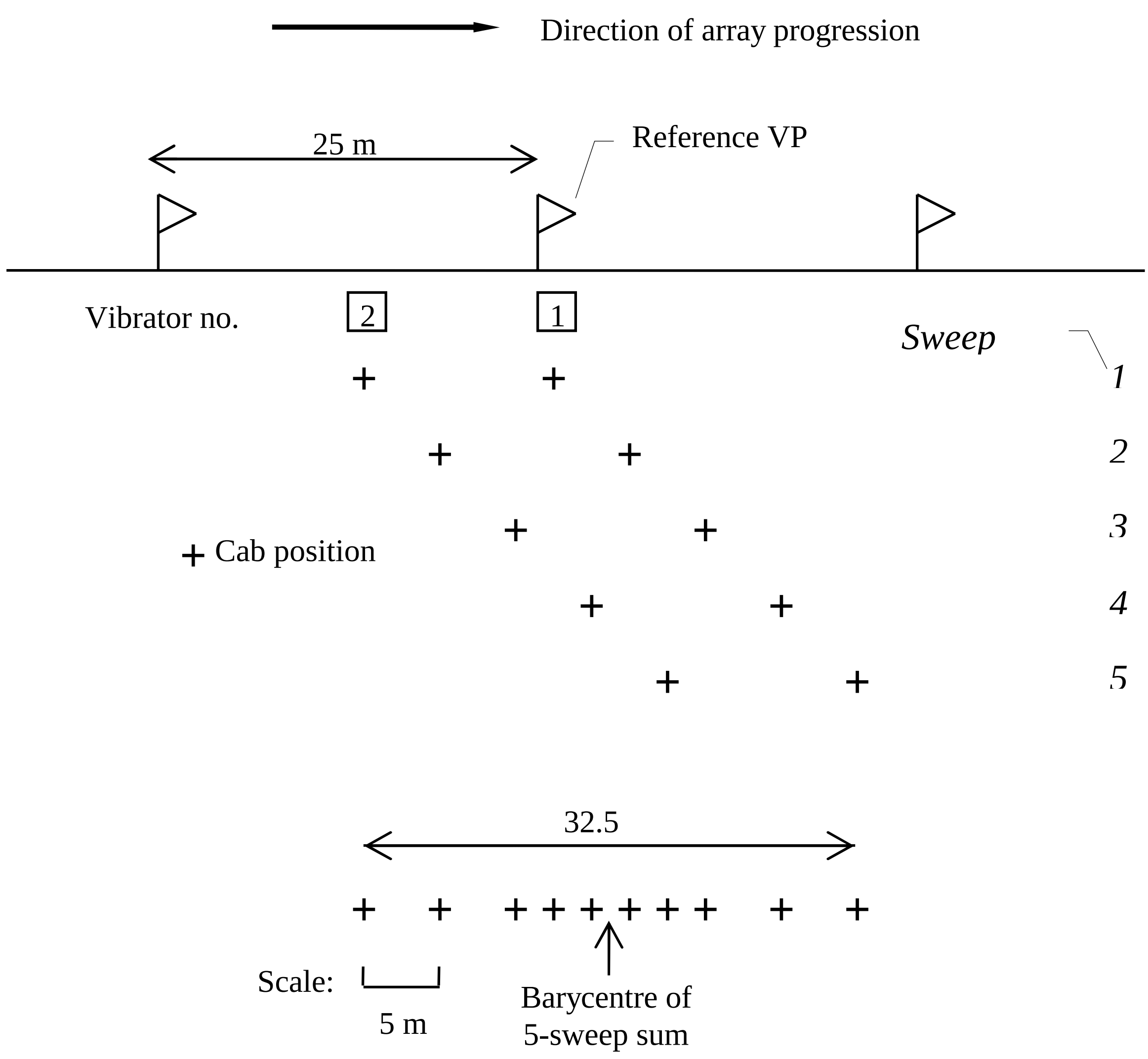


Figure 11. Sum of 5 sweeps with 2 vibrators.

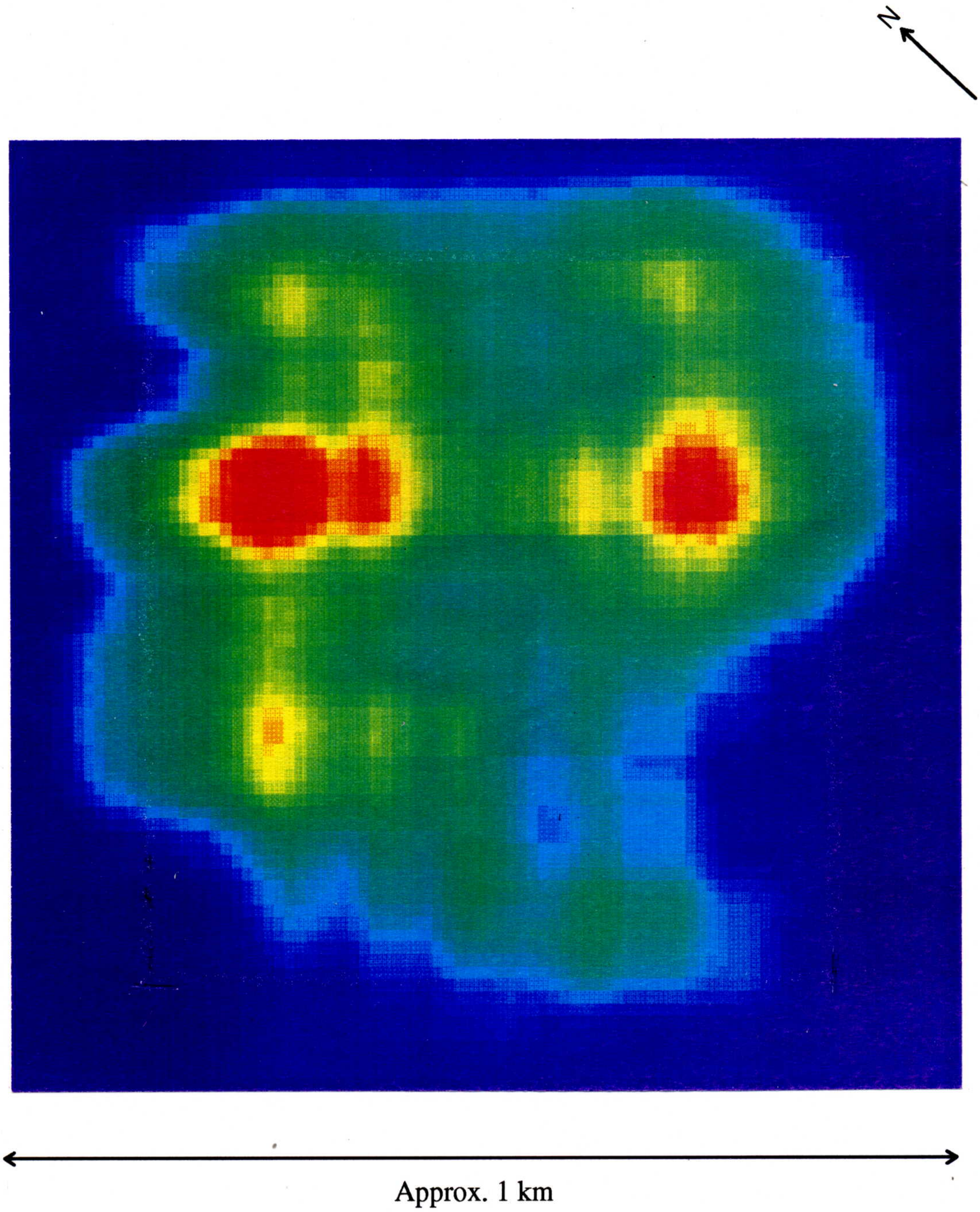


Figure 12. CMP fold of coverage.

Note: Coverage as at completion of data acquisition. Colour code for fold is light blue - 50-80; green - 100-170; yellow - 170-200; red - 200-255. Scale of this ProMAX/3D screendump is stretched in the inline direction (NE-SW) relative to the crossline direction (NW-SE).