INSTITUTE OF GEOLOGICAL SCIENCES

CONTINENTAL SHELF DIVISION

MARINE GEOPHYSICS UNIT

Report No. 089

Project 77/02. Gravity Survey of North Sea, north of 54° on m.v. Sperus

Edited by

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CONTENTS

INTRODUCTION

In 1976 the Department of Energy commissioned the Institute of Geological Sciences to undertake a gravity and magnetic survey of the British sector of the North Sea from 51^{o}N to 62^{o}N. The Marine Geophysics Unit of IGS commenced work on this survey in the latter half of 1976. The 1976 part of the survey was designated MGU project 76/04 and was reported on in MGU report number 088.

During 1977, it was proposed to complete as much of the area north of 54^{o}N as possible. This area was subdivided into areas A to E which were given priorities in alphabetical order of importance (figure 1). Area C coincided with one for which regional geophysical coverage was required. For this area, the gravity and magnetic data collected during the regional programme have been integrated into those collected during the main gravity and magnetic survey. The regional survey, MGU project 77/07, is described in MGU Report No. 85.

The ship, m.v. Sperus, chartered for both project 77/02 and 77/07, was the same as used for the first phase of the North Sea gravity survey in 1976. Before commencing work in 1976, m.v. Sperus was considerably modified to suit MGU requirements. Further minor modifications were carried out this year.

The charter period was divided into 14 legs of which legs 1-6 and 12-14 belong to project 77/02 and legs 6-11 belong to project 77/07.

SENIOR SCIENTIST'S REPORT

Mobilisation

MV Sperus was made available to IGS at Leith on 28 March 1977 and the installation of the equipment proceeded on a "system by system" basis. A lack of constant and reliable AC power supply meant that some time was lost. An engineer from LaCoste and Romberg assisted IGS staff in the installation of the LaCoste and Romberg air-sea gravity meter S75. Similarly, an engineer from Magnavox assisted with the satellite navigation system which included the fitting of a new MX610 doppler sonar. Technical staff from MSES, IOS Barry installed the Askania GSS-3 gravity meter with associated Brown platform, Barringer magnetometers and intercom system. The Edig interface unit of the Atlas Deso 10 echo sounder proved to be unserviceable upon installation and was therefore offloaded for repair.

The ship was dry-docked on 4 April for an on charter survey inspection of IGS doppler sonar and pinger transducer fittings. Mobilisation was completed on 7 April and, following alongside gravity base checks, Sperus sailed on 8 April for general trials and instrument calibration.

Leg 1 8-20 April.

The engineers from LaCoste and Romberg and Magnavox sailed with the ship. After two days, both systems appeared to be working well and the engineers disembarked by pilot boat off Inchkeith (Firth of Forth). The ship made a short call into Leith for base ties mid-way through this leg. During this call delegates to the UK Geophysical Assembly, which was being held in Edinburgh, visited the ship. Prior to this port call, there were problems with the AC power supply and the magnetometer was excessively noisy. After the port call, it proved impossible to reach a completely satisfactory calibration of the satellite navigation system and the shortcomings with the AC power supply persisted.

Leg 2. 21 April-3 May

A satisfactory calibration of the satellite navigation system was obtained by 26 April. After this, routine surveying with two gravity meters, pinger and echo sounder began but with the magnetometer not operational until 29 April. Weather for most of the leg was good, force 5 or less, but there was one day of near gale conditions.

Leg 3. 4-17 May

During the early part of this leg effort was concentrated on closely monitoring the performance of the two gravity systems, with assistance from a LaCoste engineer. Four N-S lines were run across the Silver Pit gravity range. In good weather the meters agreed closely but as weather deteriorated, a divergence of up to 10mGal occurred with the Askania always reading higher than the LaCoste and Romberg S75. It was found to be possible to run survey lines with both engines running at 200 rpm producing speeds of up to 12 knots. A 70km surface meter gravity range was established at the entrance to the Firth of Forth (lines 30 and 31) (Figure 4).

Leg 4. 18-31 May

The first six days of leg 4 were spent carrying out a detailed gravity survey for a commercial company (MGU project 77/05) which has been reported on separately. At the end of the previous leg, the Askania GSS-3 gravity meter system was off-loaded from mv Sperus and the NERC LaCoste and Romberg S40 meter was installed in its stead. For the latter half of this leg, the normal gravity programme was adhered to, with good weather conditions until 29 May when a heavy swell built up from the NNE and persisted until the end of the leg.

Leg 5. 1-14 June

During legs 1-4, surveying was concentrated in Area A. By 4 June, this area was completed and Sperus moved to Area B. On 8 June, a gyro failed in the LaCoste S75 meter and the replacement was found to be defective. The survey continued using the S40 alone until a replacement gyro had been delivered and fitted on 10 June. Prior to installation of the new gyro, the weather deteriorated from the north and while heading west for Lerwick, the ship was hit by a freak wave which carried away 3 metres of ship's rail and with it the ship's oxyacetylene gear as well as a spare magnetometer fish. Both had been securely lashed to this section of rail. Weather was moderate to poor throughout this leg.

Leg 6. 15-28 June

At the end of leg 5, the LaCoste S40 gravity meter was off-loaded. For the remainder of the project, there was only one gravity meter on board, the LaCoste and Romberg S75. Weather conditions for the first four days were poor with gales from the north but were good to fair for the remainder of the leg. During this leg, four E-W lines (89, 91, 95 and 97) were run as far as the Norwegian coast with coastal tie lines (90 and 96). During both leg 5 and leg 6, due to weather conditions, it was expedient to continue some lines from Area B into Area C.

Leg 12. 7-19 September

Sperus sailed from Dundee on 7 September and until 10 September carried out a small detailed gravity survey for a commercial company (MGU Project 77/09). The normal gravity programme was then continued in Area B. Gale or near gale conditions persisted from 12/17 September without interruption. Winds were from north to north-west from which there was very little shelter, and a heavy northerly swell built up. The fact that useful results were obtained is a tribute to the quality of the gravity meter and good position fixing through integration of Decca Main Chain into the satellite navigation system.

Leg 13. 20-26 September

During this leg, the southern sector of Area C was completed, also Area B. Again weather conditions were poor and the leg was curtailed by 36 hours.

Leg 14. 27 September-6 October

Bad weather at the beginning of this leg meant that only four days were left in which to survey. Sufficient lines were run in Area D so that with data from previous surveys in this area, there is now adequate coverage to compile Bouguer Anomaly maps at 1:250 000, contoured at 5mGal.

The ship demobilised at Sunderland from 6-10 October.

SENIOR TECHNICIAN'S REPORT

Throughout this project all the equipment functioned very well with only minor problems. For simplification of presentation of these problems, each item of equipment will be dealt with separately.

Gravity meter systems

(a) LaCoste and Romberg S75.

During leg 3, the bottom shock cords on the platform were tightened up to give more rigid reference for the platform servos to drive against. Also, a cross-coupling amplifier was replaced. On leg 5 the long gyro failed due to worn bearings. The system was inoperable for two days until a new gyro was obtained and installed. The delay was caused by the malfunction of the spare gyro carried on board - its rotor did not spin. The meter thermostating ratio was adjusted on leg 12.

On leg 2, the associated 9400 logger failed and was out of commission for a day. The symptom was that no data were being fed to the printer and magnetic tape. Inexplicably, the fault cleared itself.

(b) LaCoste and Romberg S40.

On leg 4, the long gyro thermostat was not cycling and had to be replaced.

(c) Askania GSS-3 and Brown platform

System functioned correctly throughout. At the start of leg 2, the compass, which was required to help investigate problems with the satellite navigation system, was swapped for the Mk 1c.

Barringer Magnetometers

During legs 1 and 2, excessive noise was experienced with both magnetometers. It was believed that the problem might have been associated with flexing of the tow cable, so a new cable was fitted at the end of leg 2.

There was a continual problem with connectors. On leg 3, the inboard connector was replaced. On leg 5, the outboard plug of the inboard cable was re-made. The connection plug and socket were generally noisy and water had leaked in on two occasions. On leg 12, the precession signal was excessively noisy. Connectors at the end of the tow cable and inboard cable were re-made. Faults on the data logger magnetometer interface gave rise to periods of inaccurate analogue records, so the data logger connection was unplugged. On leg 13, there was a broken screen connection on the outboard plug, which had to be re-made.

Atlas Deso 10 Echo Sounder and Edig 10

Functioned well throughout the project. On leg 13, the Edig 10 was not showing depth accurately. The problem was caused by the 33kHz adjusts on the Atlas Deso being incorrectly set.

Edo Western Pinger

Apart from minor problems with the associated EPC recorder this system functioned well until leg 10, project 77/07, when no return signal from the transducer assembly was detectable. On leg 12, trials with an Edo Western towed fish suspended a few feet below the surface of the water indicated that the fault lay in the hull mounted transducer assembly, associated transformer or connecting cables. The system remained inoperative until the end of the project as it was not feasible to use the towed transducer at the survey speed of approximately 12 knots during the predominantly poor weather conditions which were experienced.

Data Logger

The system operated satisfactorily for most of the survey. On leg 5, the SE data 8000 tape deck failed due to bad connector contacts. A voltage regulator card on the 10500 tape deck had to be replaced. On leg 12, trouble was experienced with the magnetometer interface board (signal conditioner) which needed all the i/c components replacing. There were some problems with automatic deck changeover which were unresolved at the end of survey.

Magnavox Satellite Navigation System

On leg 2, the fore-aft inclinometer was intermittent in operation. This was repaired. On leg 3, the RF mixer module was replaced due to odd missing doppler counts. On leg 4, dead reckoning printout appeared to be losing the occasional second. This was resolved by disconnecting the 100kHz clock output to the data logger. On leg 13, the RX board of the MX702A unit was replaced. Throughout the project there was an intermittent fault on the automatic changeover of tape decks and from leg 13 onwards, only deck No 1 was used.

Power Supply

No problems were encountered with either the generators or the UPS.

SATELLITE NAVIGATION REPORT

Calibration

Throughout leg 1 calibration of the system was attempted. Along-course updates were consistently excellent. No apparent problems were encountered with the new MX610 doppler sonar. However, cross-course dead reckoning was a continual source of inaccuracy, the problem being more difficult due to its intermittent nature. Using values for latitude torquing (-5.46) and speed torquing (-96) which were established during laboratory calibration of the gyro compass, various values of ABIA were obtained, varying from -5.3 to -1.4. These variations were ascribed to maladjusted speed torquing and was reduced to -60, with subsequent reduction in variation of ABIA. There was an indication that the speed torquing was too low therefore it was increased to -80. A line run in a southerly direction gave good results with cross-course drift rate of approximately 70 metres/hour. However, on a line running northwards, the cross-course drift was of the order of 200 metres/hour. The speed torquing constant was changed to the original value of -96 and the latitude torquing constant reduced to -4 but still the calibration was inconclusive. The geometry of orbits of satellites during leg 1 meant there were long periods without acceptable updates. During port call on 20-21 April, thorough check of the system was carried out. Calibration continued at the start of leg 2 with cross-course dead reckoning inconsistencies still occurring. Eventually it was noted that the roll axis inclinometer was erratic. Following rectification of the inclinometer fault, the calibration was successfully completed.

Survey

Gravity data was collected on most of the calibration lines. To facilitate the calibration, updates were supressed and errors allowed to accumulate. Decca Main Chain 2A was logged at the same time so it can be utilised where the satellite navigation data is unacceptable. In the area north of 54^{O} 30'N and west of 1^{O}E, the Decca accuracy is of the order of 150 metres, degrading to around 300 metres on the eastern and southern fringes of Area A.

The problems caused by coincidence of satellites on leg 1 eased greatly during leg 2. On leg 3, the calibration constants were further refined - TADJ by approximately 0.1% and ABIA by -1.15^{o}. The mean drift rate for the whole leg was 75 metres/hour, which is very comparable to the 85 metres/hour observed on the previous leg. On leg 4, Decca Main Chain was successfully integrated into the system with .KI. = .001 and LORL = 5. Other values for these constants caused problems at night and on turns. The only refinement to the calibration was altering ABIA by +0.1 to -2.0. On leg 5, TADJ was reduced to 1.0165 to reduce the consistently negative along course updates. Again there was interference between satellites and this combined with poor weather conditions, affected dead reckoning accuracy, meant that otherwise good satellite passes failed to update automatically and had to be manually updated. On leg 6, the mean accuracy was approximately $\pm$ 100 metres. There was a minor adjustment to TADJ. Several lines were run over the Norwegian Trench, with water depths as great as 380 metres. In moderate sea conditions - force 4 - bottom track on the MX610 occurred continually down to 310 metres and intermittently to 325 metres. In fine weather, continuous bottom track was observed to 340-350 metres. For those lines, Decca Main Chain ØE was integrated with the system. A drop in speed of approximately 1 knot was noted on transition from bottom to water track. With .KI. = .001, bottom track dead reckoning accuracies were good but response time was too great to compensate for the large velocity error introduced by water tracking. .KI. = .005 produced more realistic correction velocities and a better dead reckoning accuracy. However, this value proved somewhat unstable when sonar was in bottom track. A compromise value of .004 was used with some success.

Weather conditions on legs 12-14 were generally poor. This was reflected in dead reckoning accuracies. Average updates were of the order of 100-150 metres with a marked degradation of along course accuracy when the ship was pitching heavily. Decca Main Chain was used on a number of occasions to supplement dead reckoning data from the gyro compass and sonar. When used, the updates were noticeably smaller in heavy weather but courses tended to be erratic during the hours of darkness towards the outer limits of chain coverage. Again, there was a tendency for satellites to come in groups, this being at its worst in leg 13.

GEOPHYSICS REPORT

Gravity

The LaCoste and Romberg S75 and the Askania GSS-3 gravity meters were operational for legs 1-3. Both systems performed well without any major equipment failure. The results obtained from the meters did, however, reveal a slight discrepancy between the two systems which appeared to be weather dependent.

Weather conditions during these legs varied from very calm sea states to periods of moderate swell. An analysis of the anomaly values produced by both meters showed that during calm weather the values were in very good agreement, being typically within one or two milligals. However, it appeared that during periods of swell, the values diverged such that the Askania was giving higher gravity values than the LaCoste and Romberg. This difference seemed to be dependent upon the swell amplitude and, in periods of heavy swell, the difference between the meters rose to eight or nine milligals. It was difficult to know which of the meters was in error for such periods, although a preliminary study of the crossovers for the LaCoste and Romberg and Askania seemed to indicate that the values obtained by the LaCoste were more consistent than those obtained by the Askania. For a fuller analysis of the performance of the two meters, reference should be made to MGU Report Nos 77 and 79.

The LaCoste and Romberg S40 meter was installed in place of the Askania for legs 4 and 5. The average output of the S40 was 2mGal lower than that of the S75. The results from both meters varied from being within 1-2mGal of each other to a divergence of over 5-6mGal. In rough seas and while heading into a swell, the S40 showed up to nearly 50mGal of cross-coupling compared with the S75 which showed only 5 to 6mGal. A more detailed account of the performance of those two meters is given in MGU Report No. 80.

During leg 5, area A was completed. All the data were reduced to Free Air and Bouguer Anomalies. The Bouguer Anomaly values were plotted and contoured at 5mGal interval on 1:250 000 scale. The mean mistie for the data from the S75 was 1.54mGal which was based on over 400 cross-ties.

For legs 6 and 12-14, there was only one meter on board - the LaCoste and Romberg S75. During the latter half of leg 5 and the subsequent legs, the weather was moderate with several spells of near gale to gale conditions. By the end of leg 13, Area B was completed. The mean mistie value was 1.35mGal for 293 cross ties. The mean mistie value is made up as follows:-

Mistie value (mGal)	No of Cross Ties	Percentage
0	95	32.4%
1	83	28.3%
2	70	23.9%
3	24	8.2%
4	7	2.4%
5	11	3.8%
6	3	1%

All Bouguer Anomaly values for this area were plotted and contoured at 5mGal intervals on 1:250 000 scale.

A few lines were run in Area C to complete the coverage already obtained during project 77/07. The data quality in this area was very good and it was possible to contour the plotted Bouguer Anomaly values at 2mGal intervals with the mean mistie being approximately 1mGal.

Area D had been surveyed on a more open grid a few years ago during MGU project 72/04 (see MGU Report No. 34) and MGU project 73/08. Some additional lines were surveyed along lines where previous data was of poor quality. In addition, the original grid was augmented by extra data to give better coverage. At the end of this project the mean mistie value for old and new data combined was 1.45mGal based on over 200 cross ties. Onboard ship the plotted Bouguer Anomaly values were contoured at 5mGal intervals.

<u>Magnetics</u>

Magnetic data were not collected until midway through the second leg. The fish was towed approximately 200m astern of the ship, but this was shortened considerably in areas of shallow water.

For Area A, the total magnetic field intensity values were plotted for each 10 minute position fix on 1:250 000 scale. Misties were normally small, generally less than 45γ and often around 10γ but there were a few instances where they were as great as 100γ. The plotted values were contoured at an interval of 50γ. The contour map showed a very smooth increase northwards from $48{,}500\gamma$ at 54°N to $49{,}100\gamma$ at 56°N (ie approximately 2.5γ/km). Superimposed on this regional were several anomalous features. The most prominent was a

NW-SE striking high of approximately 150γ centred on $55^{\circ}15'$N, $02^{\circ}00'$E with minor lows ($\sim$ 50γ) to the north. North of this high at $55^{\circ}50'$N, $02^{\circ}00'$E, there was a N-S striking high of $\sim$100γ with no obvious associated lows. At $55^{\circ}45'$N, $01^{\circ}00'$E there is a broad NE-SW striking high ($\sim$100γ).

The magnetic data between Areas C and B and the Norwegian coast revealed that for the most part the area has a "quiet" magnetic character with smooth, low amplitude variations in the total field intensity which is dominated in a N-S direction by the regional gradient. The notable exception to this was the NW-SE line 96 across the Norwegian Caledonide Belt between Bergen and Stavanger and east of the Horda Fault system, where basement crops out at seabed; this line displayed very steep magnetic gradients. In Area B, as in Area A, the total magnetic field values at each fix were plotted at 1:250 000 and roughly contoured. The misties were of a similar order to those of Area A. An anomalous high area was centred on $59^{\circ}30'$N, $1^{\circ}30'$E and consisted of three peaks with values in excess of 50200γ exhibiting a N-S trend. As associated low of 49860γ centred on $59^{\circ}30'$N, $00^{\circ}30'$E had a NW-SE trend. There was a major high of 50800γ lying off the east coast of Shetland at $59^{\circ}55'$N, $1^{\circ}10'$W. Over the rest of the area, the magnetic gradients were gentle of the order of 2.5γ/km. In Area D, there was insufficient data from this project to provide much detail on the anomaly pattern.

Pinger

No onboard interpretation of the pinger records was carried out although a careful watch on data quality was maintained.

CONCLUSION

This was a very successful project. Complete gravity coverage was obtained in Areas A, B, C and D. Due to the prolonged periods of poor weather from the end of August to the end of the project in October, no attempt was made to obtain coverage in Area E. In all, 24,732km of gravity data were collected, and the data quality throughout was good.

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TABLE 1

Personnel for Project 77/02

<u>Leg 1</u>
<u>8 April-20 April</u>

R A Floyd	Senior Scientist	Marine Geophysics Unit	
M C Tully		Marine Geophysics Unit	
A S Mould		Marine Geophysics Unit	
N Kenolty		Marine Geophysics Unit	
P Mulholland		Marine Geophysics Unit	
A J Davies		Marine Geophysics Unit	
M Beney		MSES, IOS Barry	
R Robinson		MSES, IOS Barry	
J Bishop		LaCoste & Romberg	8-10 April
T O'Brien		Magnavox	8-10 April

<u>Leg 2</u>
<u>21 April-3 May</u>

M C Tully	Senior Scientist	Marine Geophysics Unit
J Donato		Marine Geophysics Unit
A S Mould		Marine Geophysics Unit
N Kenolty		Marine Geophysics Unit
D K Smythe		Marine Geophysics Unit
P Roberts		Marine Geophysics Unit
A Dobinson	21-27 April	Marine Geophysics Unit
M Beney		MSES, IOS Barry
R Robinson		MSES, IOS Barry

<u>Leg 3</u>
<u>4 May-17 May</u>

A Dobinson	Senior Scientist	Marine Geophysics Unit	
J A Chalmers		Marine Geophysics Unit	
M Glen		Marine Geophysics Unit	
A K Rochester		Marine Geophysics Unit	
J Bulat		Marine Geophysics Unit	
A J Davies		Marine Geophysics Unit	
G Smith		Marine Geophysics Unit	
C Poulson		MSES, IOS Barry	
J Bishop		LaCoste & Romberg	4-8 May

Leg 4
18 May-31 May

A S Mould	Senior Scientist	Marine Geophysics Unit
S E Deegan		
G A Day		
P Towle		
D Ham		
A Milne	26 May-31 May	
A J Davies		
A Cumming		MSES, IOS Barry
P Armitage		
P McKenna	18-26 May	Decca Survey Ltd
D Young	18-26 May	
E Jacobson	18-26 May	Total Oil Marine Ltd
G Fishburn	21-26 May	

Leg 5
1 June-14 June

N Kenolty	Senior Scientist	Marine Geophysics Unit
M C Tully		
D Ham		
A K Rochester		
P Mulholland		
C Dewar		
P Armitage		MSES, IOS Barry
S Audley		
P Mason		

Leg 6
15 June-28 June

R A Floyd	Senior Scientist	Marine Geophysics Unit
A S Mould		
P Towle		
P Western		
M Glen		
A Fernie		
A J Davies		
P Mason		MSES, IOS Barry
R Robinson		

Note: Legs 7-11 covered in MGU Report No. 085.

Leg 12
7 September-19 September

A S Mould	Senior Scientist 11-19 September	Marine Geophysics Unit
P Mulholland		
D Ham		
D Milas		
M Muir		
A J Davies		
R A Floyd	Senior Scientist 7-11 September	
R McQuillin		
M C Tully		
K Robertson		MSES, IOS Barry
A Clarke		

Leg 13
20 September-26 September

R A Floyd	Senior Scientist	Marine Geophysics Unit
M C Tully		
M Glen		
P Western		
P Burke		
J Wilkie		
A Oliver		
J Price		MSES, IOS Barry
P Taylor		

Leg 14
27 September-6 October

M C Tully	Senior Scientist	Marine Geophysics Unit
P Western		
D Ham		
M Glen		
A Milne		
A Oliver		
J Price		MSES, IOS Barry

TABLE 2

Ports of Call

DATES	BERTH AND PORT	REASON
28 March-8 April	8/9 Berth, Edinburgh Dock Leith	Mobilisation and gravity base check
13-14 April	8/9 Berth, Edinburgh Dock Leith	Gravity base check and visit of delegates to UK Geophysical Assembly.
20-22 April	No 4 Berth, Imperial Dock Leith	Gravity base check and crew change.
3-4 May	Berth 27, Newcastle Quay, Newcastle	Gravity base check and crew change.
18-20 May	8/9 Berth, Edinburgh Dock Leith	Gravity base check and crew changes.
26 May	Victoria Dock, Hartlepool	Gravity base check and crew change.
31 May-1 June	Berth 25, Newcastle Quay, Newcastle	Gravity base check and crew change.
14-15 June	8/9 Berth, Edinburgh Dock Leith	Gravity base check, equipment and crew changes.
19-21 June	Victoria Pier, Lerwick	Bad weather and ship's crew change.
28 June-4 July	Factory Quay, Tyne Dock, South Shields.	Gravity base check, ship's maintenance, mobilisation for project 77/07 and crew change.
5-7 September	King George V Quay, Dundee	Gravity base check, demobilisation at end of 77/07 and crew change.
19-20 September	King George V Quay, Dundee	Gravity base check and crew change.

DATES	BERTH AND PORT	REASON
26 September-1 October	King George V Quay, Dundee	Gravity base check, crew change and bad weather.
5-10 October	Corporation Quay, Sunderland	Gravity base check and demobilisation.

TABLE 3

Types of Equipment Installed on m.v. Sperus

1. LaCoste and Romberg air-sea gravity meter S75.

1a LaCoste and Romberg 9400 data acquisition system.

2. Askania GSS-3 gravity meter and Brown platform, 1 April-19 May.

3. LaCoste and Romberg air-sea gravity meter S40, 19 May-14 June.

4. Barringer magnetometer.

5. Edo Western pinger with hull mounted transducer.

6. Atlas Deso 10 echo sounder with hull mounted transducer, and digital readout unit (Edig 10).

7. Magnavox satellite navigation system integrated with MX610 doppler sonar.

8. Decca Mk 21 main chain receiver.

9. Decca data logger.

10. Three 60 KVA AC generators.

11. Stabilised no-break power supply system (UPS).

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L+R S75	L+R S40	GSS-3	
1	56	160	SN + DS	✓	✓	—	✓	✓	—	✓	✓
2	89	200	SN + DS	✓	✓	—	✓	✓	—	✓	✓
3	47	112	SN + DS	✓	—	—	✓	✓	—	✓	✓
4	54	127	SN + DS	✓	—	—	✓	✓	—	✓	✓
5	42	107	SN + DS	✓	—	—	✓	✓	—	✓	✓
6	36	98	SN + DS	✓	✓	—	✓	✓	—	✓	✓
7	56	130	SN + DS	✓	✓	—	✓	✓	—	✓	✓
8	30	82	SN + DS	✓	✓	—	✓	✓	—	✓	✓
9	48	114	SN + DS	✓	✓	—	✓	✓	—	✓	✓
10	74	105	SN + DS	✓	✓	—	✓	✓	—	✓	✓
11	79	87	SN + DS	✓	✓	—	✓	✓	—	✓	✓
12	89	226	SN + DS	✓	✓	—	✓	✓	—	✓	✓
13	59	69	SN + DS	✓	✓	—	✓	✓	—	✓	✓
14	30	68	SN + DS	✓	✓	—	✓	✓	—	✓	✓
15	30	69	SN + DS	✓	✓	—	✓	✓	—	✓	✓
16	120	310	SN + DS	✓	✓	✓	✓	✓	—	✓	✓
17	112	294	SN + DS	✓	✓	✓	✓	✓	—	✓	✓
18	105	283	SN + DS	✓	✓	✓	✓	✓	—	✓	✓
19	20	59	SN + DS	✓	✓	✓	✓	✓	—	✓	✓
20	94	234	SN + DS	✓	✓	57.94	✓	✓	—	✓	✓
21	88	236	SN + DS	✓	✓	✓	✓	✓	—	✓	✓
22	87	230	SN + DS	✓	✓	1-75	✓	✓	—	✓	✓

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED: ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER: L+R S75	L+R S40	Gss-3	9400 LOGGER
23	86	230	SN+DS	✓	✓	16-86	✓	✓	—	✓	✓
24	100	260	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
25	36	97	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
26	43	125	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
27	80	233	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
28	116	315	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
29	24	70	SN+DS	✓	✓	—	✓	✓	—	✓	✓
30	27	85	SN+DS	✓	✓	—	✓	✓	—	✓	✓
31	25	72	SN+DS	✓	✓	—	✓	✓	—	✓	✓
32	46	139	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
33	93	276	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
34	100	272	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
35	88	265	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
36	73	250	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
37	62	222	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
38	65	217	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
39	70	222	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
40	69	220	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
41	57	197	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
42	59	203	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
43	59	212	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
44			SN+DS (1-17)	✓	✓	✓	✓	✓	—	✓	✓

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L+R S75	L+R S40	Gss-3	
44			M/c 2A (18-24)	✓	✓	✓	✓	✓	—	✓	✓
	67	240	SN+DS (25-67)	✓	✓	✓	✓	✓	—	✓	✓
45	63	213	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
46	55	194	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
47	33	105	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
48	44	142	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
49	30	102	SN+DS	✓	✓	✓	✓	✓	—	✓	✓
50	28	92	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
51	63	140	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
52	86	206	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
53	85	220	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
54	80	219	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
55	27	93	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
56	67	227	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
57	80	227	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
58	66	228	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
59	6	18	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
60	7	19	SN+DS	✓	✓	—	✓	✓	✓	—	✓
61	5	8	SN+DS	✓	✓	—	✓	✓	✓	—	✓
62	81	283	SN+DS	✓	✓	7-81	✓	✓	✓	—	✓
63	82	283	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
64	81	284	SN+DS	✓	✓	✓	✓	✓	✓	—	✓

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L&R S75	L&R S40	GSS-3	
65	22	75	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
66	22	75	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
67	87	296	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
68	155	494	SN+DS	✓	✓	1-9 & 14-155	✓	✓	✓	—	✓
69	36	120	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
70	20	67	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
71	94	314	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
72	90	309	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
73	36	104	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
74	72	182	SN+DS	✓	✓	✓	✓	1-61	✓	—	✓
75	66	226	SN+DS	✓	✓	✓	✓	—	✓	—	✓
76	16	46	SN+DS	✓	✓	✓	✓	—	✓	—	✓
77	61	206	SN+DS	✓	✓	✓	✓	—	✓	—	✓
78	12	37	SN+DS	✓	✓	✓	✓	—	✓	—	✓
79	35	113	SN+DS	✓	✓	✓	✓	—	✓	—	✓
80	60	202	SN+DS	✓	✓	✓	✓	—	✓	—	✓
81	10	33	SN+DS	✓	✓	—	✓	✓	✓	—	✓
82	81	232	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
83	83	292	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
84	35	116	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
85	105	354	SN+DS	✓	✓	✓	✓	✓	✓	—	✓
86	56	195	SN+DS	✓	✓	✓	✓	✓	✓	—	✓

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L+R S75	L+R S40	Gss-3	
109	156	549	SN+DS	✓	✓	✓	—	✓	—	—	✓
110	108	322	SN+DS	✓	—	✓	✓	✓	—	—	✓
111	128	328	SN+DS	20-128	—	✓	✓	✓	—	—	✓
112	11	25	SN+DS	✓	—	✓	✓	✓	—	—	✓
113	21	61	SN+DS	✓	—	✓	✓	✓	—	—	✓
114	16	30	SN+DS	✓	—	1-11	✓	✓	—	—	✓
115	53	171	SN+DS	✓	—	✓	✓	✓	—	—	✓
116	63	146	SN+DS	✓	—	✓	✓	✓	—	—	✓
117	4	10	SN+DS	✓	—	✓	✓	✓	—	—	✓
118	50	153	SN+DS	✓	—	✓	✓	✓	—	—	✓
119	83	238	SN+DS	✓	—	✓	✓	✓	—	—	✓
120	40	131	SN+DS	✓	—	✓	✓	✓	—	—	✓
121	28	59	SN+DS	✓	—	✓	✓	✓	—	—	✓
122	33	86	SN+DS	✓	—	✓	✓	✓	—	—	✓
123	50	118	SN+DS	✓	—	✓	✓	✓	—	—	✓
124	13	33	SN+DS	✓	—	✓	✓	✓	—	—	✓
125	51	113	SN+DS	✓	—	✓	✓	✓	—	—	✓
126	18	49	SN+DS	✓	—	✓	✓	✓	—	—	✓
127	75	184	SN+DS	✓	—	✓	✓	✓	—	—	✓
128	42	111	SN+DS	✓	—	✓	✓	✓	—	—	✓
129	35	111	SN+DS	✓	—	✓	✓	✓	—	—	✓
130	37	114	SN+DS	✓	—	✓	✓	✓	—	—	✓

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L+R S75	L+R S40	Gss-3	
87	72	226	SN+DS	✓	✓	✓	✓	✓	—	—	✓
88	200	586	SN+DS	✓	✓	✓	✓	✓	—	—	✓
89	60	195	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
90	26	90	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
91	47	151	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
92	18	57	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
93	68	227	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
94	28	95	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
95	38	128	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
96	40	137	SN+DS+MC	✓	✓	✓	✓	✓	—	—	✓
97	54	181	SN+DS	✓	✓	✓	✓	✓	—	—	✓
98	47	153	SN+DS	✓	✓	✓	✓	✓	—	—	✓
99	36	121	SN+DS	✓	✓	✓	✓	✓	—	—	✓
100	35	119	SN+DS	✓	✓	✓	✓	✓	—	—	✓
101	35	115	SN+DS	✓	✓	✓	✓	✓	—	—	✓
102	35	121	SN+DS	✓	✓	✓	✓	✓	—	—	✓
103	16	54	SN+DS	✓	✓	✓	✓	✓	—	—	✓
104	55	186	SN+DS	✓	✓	✓	✓	✓	—	—	✓
105	96	297	SN+DS	✓	✓	✓	✓	✓	—	—	✓
106	20	59	SN+DS	✓	✓	✓	—	✓	—	—	✓
107	37	115	SN+DS	✓	✓	✓	—	✓	—	—	✓
108	21	66	SN+DS	✓	✓	✓	—	✓	—	—	✓

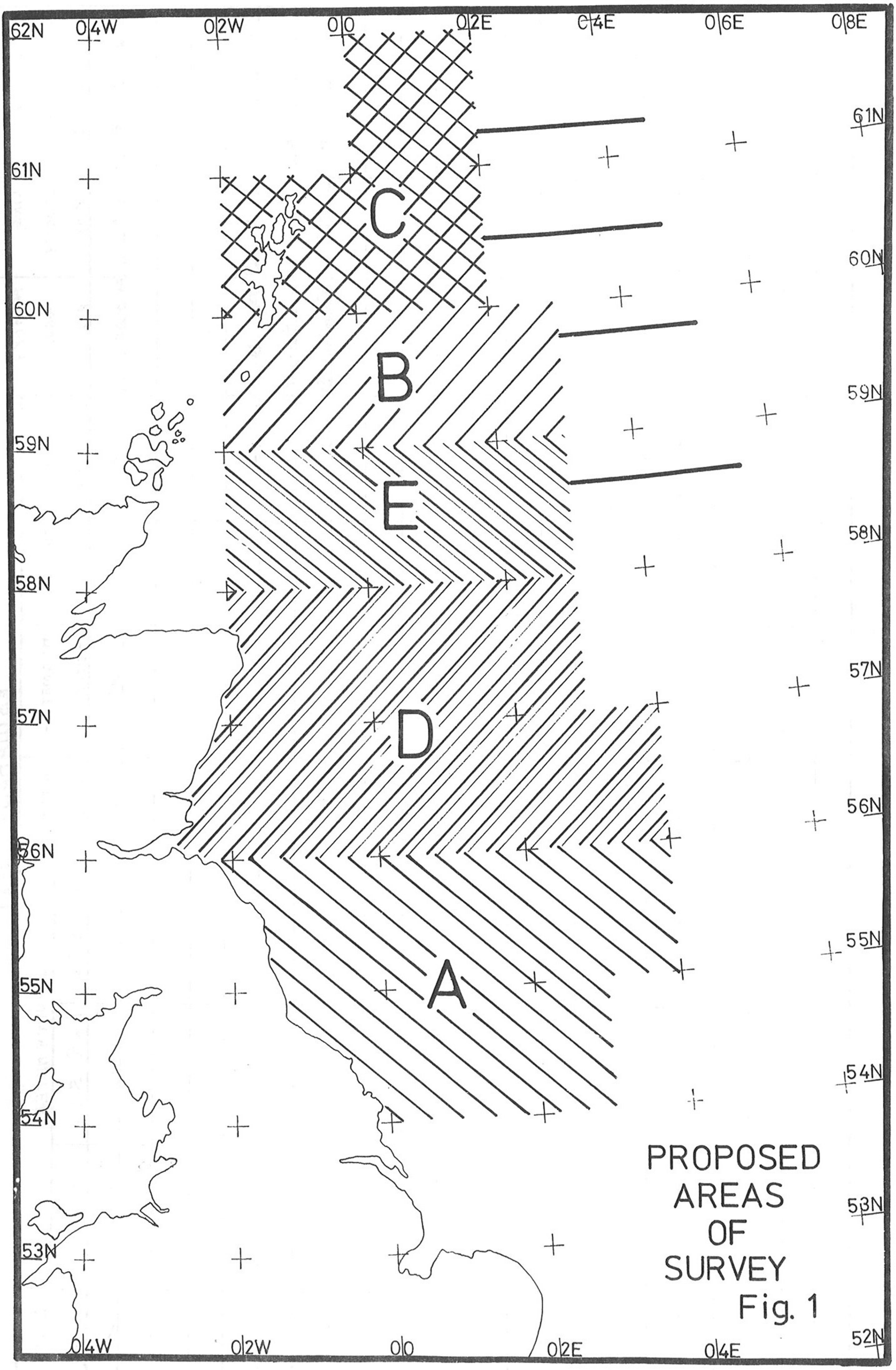
TABLE 4

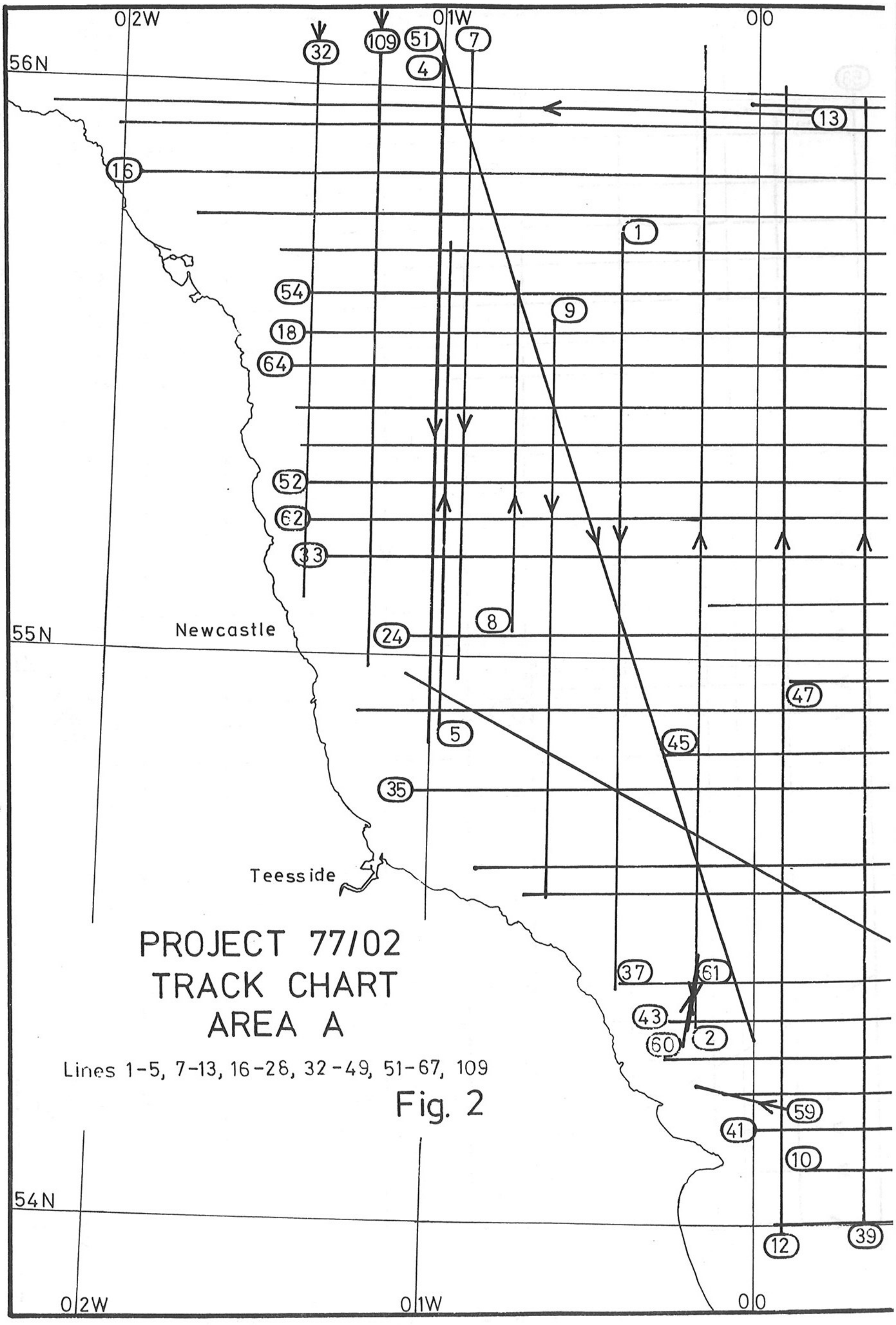
LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L+R S75	L+R S40	Gss-3	
131	35	114	SN+DS	✓	—	✓	✓	✓	—	—	✓
132	17	51	SN+DS	✓	—	✓	✓	✓	—	—	✓
133	22	77	SN+DS	✓	—	✓	✓	✓	—	—	✓
134	9	28	SN+DS	✓	—	✓	✓	✓	—	—	✓
135	40	106	SN+DS	✓	—	—	✓	✓	—	—	✓
136	69	198	SN+DS	✓	—	52-69	✓	✓	—	—	✓
137	34	101	SN+DS	✓	—	✓	✓	✓	—	—	✓
138	24	62	SN+DS	✓	—	✓	✓	✓	—	—	✓
139	24	67	SN+DS	✓	—	✓	✓	✓	—	—	✓
140	57	165	SN+DS	✓	—	✓	✓	✓	—	—	✓
141	25	75	SN+DS	✓	—	✓	✓	✓	—	—	✓
142	37	115	SN+DS	✓	—	✓	✓	✓	—	—	✓
143	34	111	SN+DS	✓	—	✓	✓	✓	—	—	✓
144	38	112	SN+DS	✓	—	✓	✓	✓	—	—	✓
145	41	128	SN+DS	✓	—	✓	✓	✓	—	—	✓
146	76	186	SN+DS	✓	—	✓	✓	✓	—	—	✓
147	24	71	SN+DS	✓	—	✓	✓	✓	—	—	✓
148	30	83	SN+DS	✓	—	—	✓	✓	—	—	✓
149	129	373	SN+DS	✓	—	✓	✓	✓	—	—	✓
150	78	225	SN+DS	✓	—	✓	✓	✓	—	—	✓
151	73	225	SN+DS	✓	—	✓	✓	✓	—	—	✓
152	35	113	SN+DS	✓	—	✓	✓	✓	—	—	✓

TABLE 4

LINE NO.	NO. OF FIXES	LINE LENGTH (KM)	PRIMARY NAV. AID	EQUIPMENT USED							
				ECHO SOUNDER	PINGER	MAGNETO-METER	DATA LOGGER	GRAVITY METER			9400 LOGGER
								L+R S75	L+R S40	GSS-3	
153	38	112	SN+DS	✓	—	✓	✓	✓	—	—	✓

NOTE : SN = Satellite Navigation
DS = Doppler Sonar
MC = Main Chain Decca

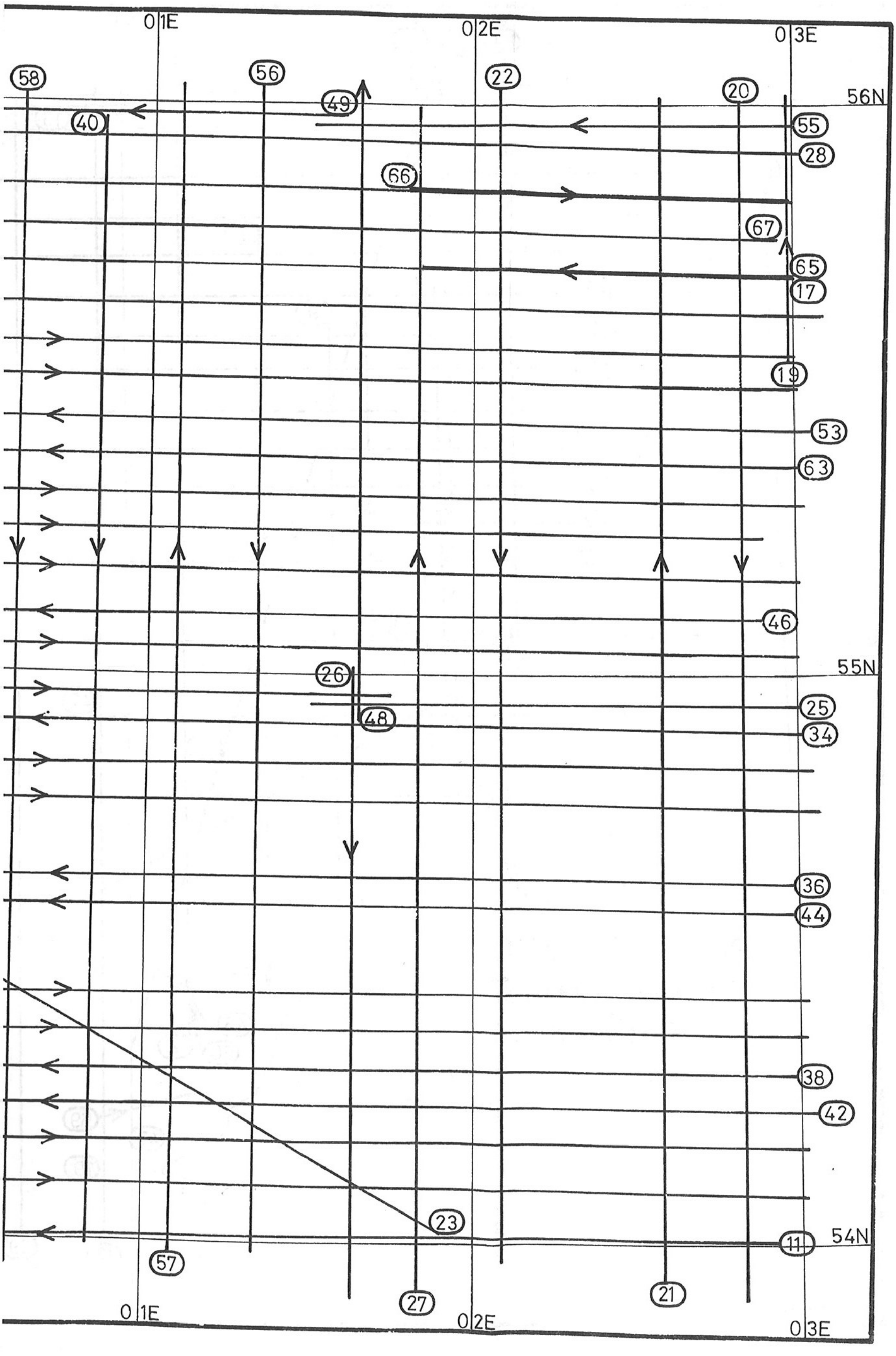

62N
04W
02W
00
02E
04E
06E
08E
61N
60N
59N
58N
57N
56N
55N
54N
53N
52N
C
B
E
D
A
PROPOSED
AREAS
OF
SURVEY
Fig. 1



PROJECT 77/02
TRACK CHART
AREA A

Lines 1-5, 7-13, 16-28, 32-49, 51-67, 109

Fig. 2



0 1E
0 2E
0 3E
56N
55N
54N
58
56
22
20
49
40
55
28
66
67
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63
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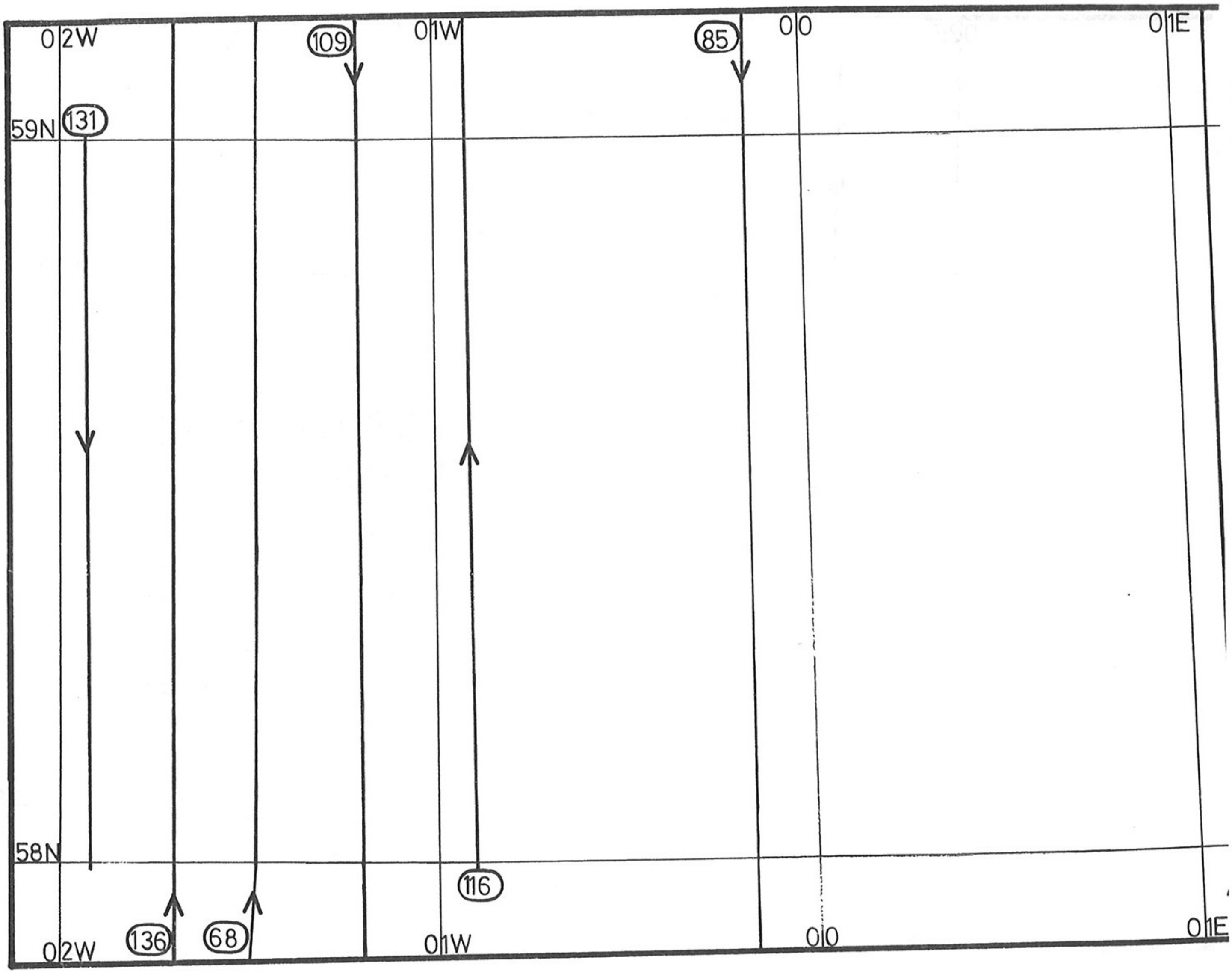
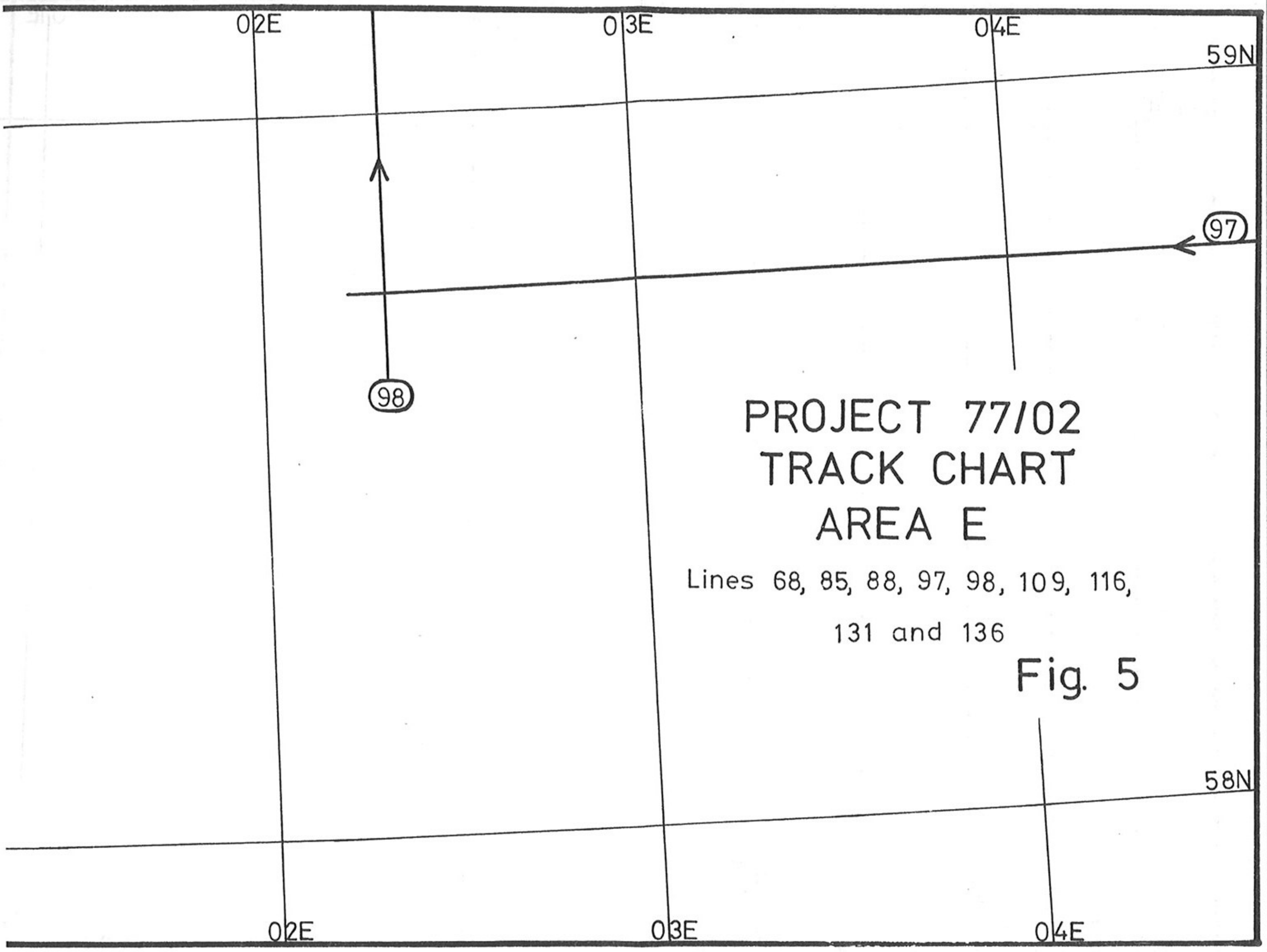
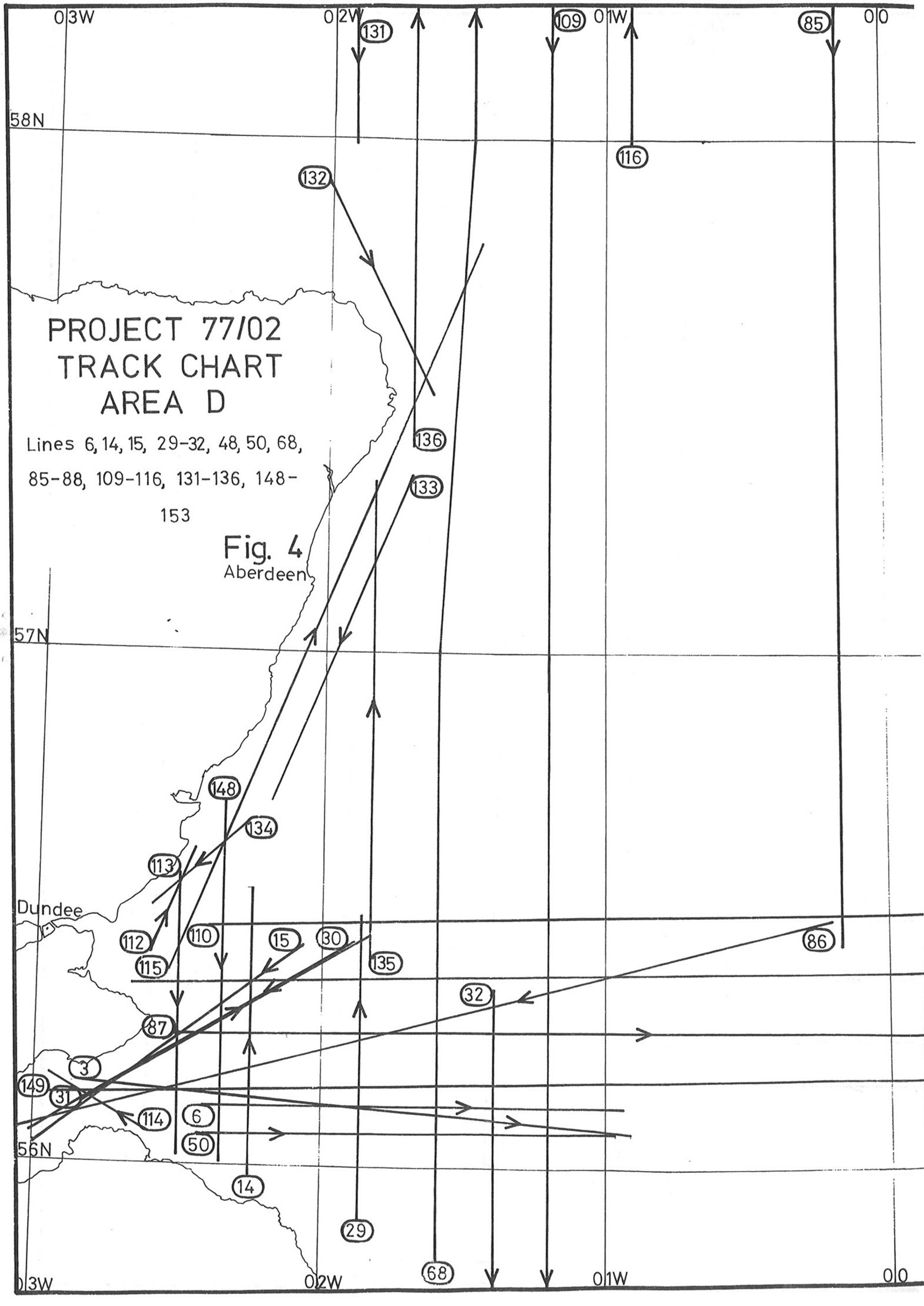
23
11
57
27
21

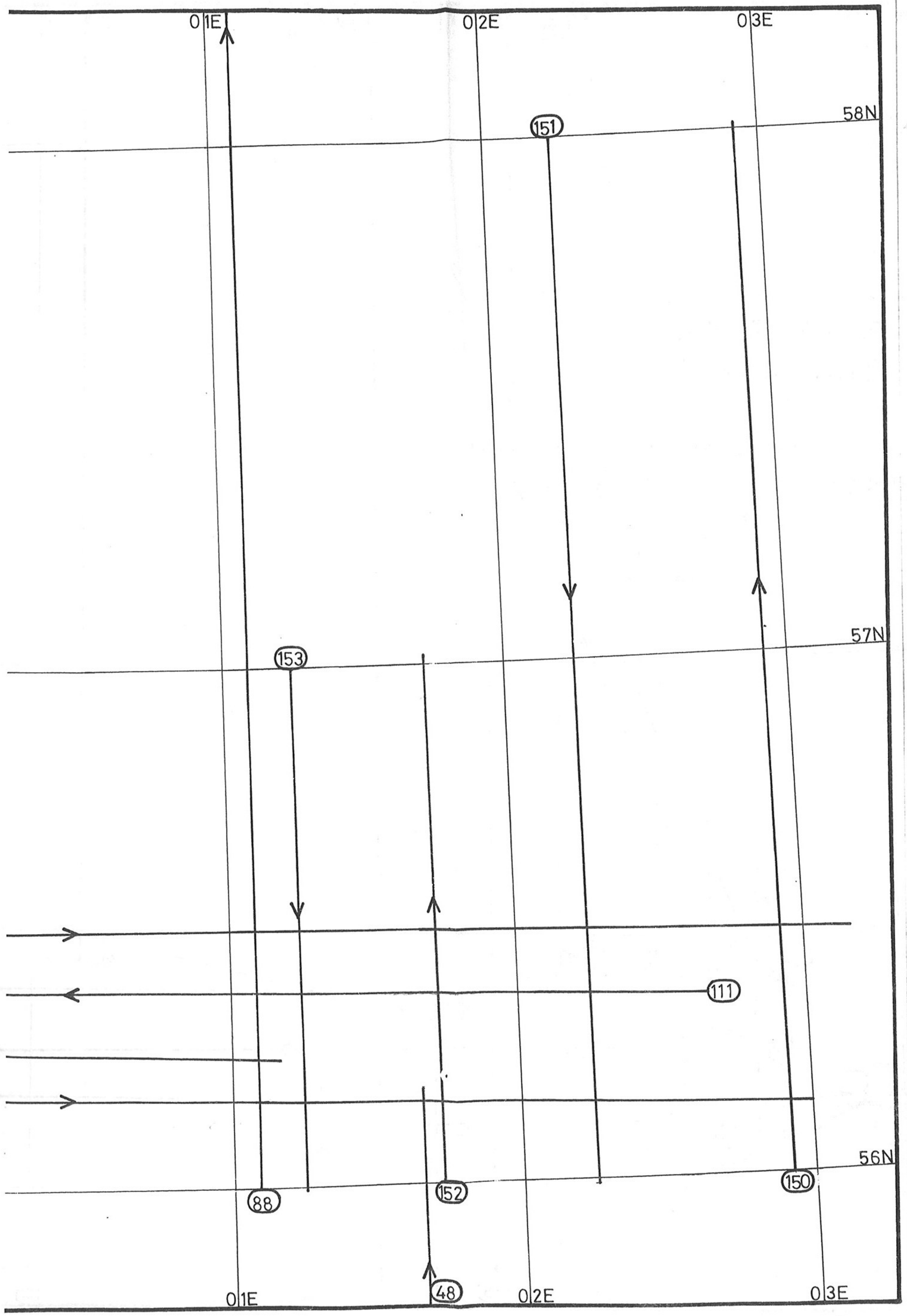


02W
01W
00
01E
59N
58N
131
109
85
116
136
68

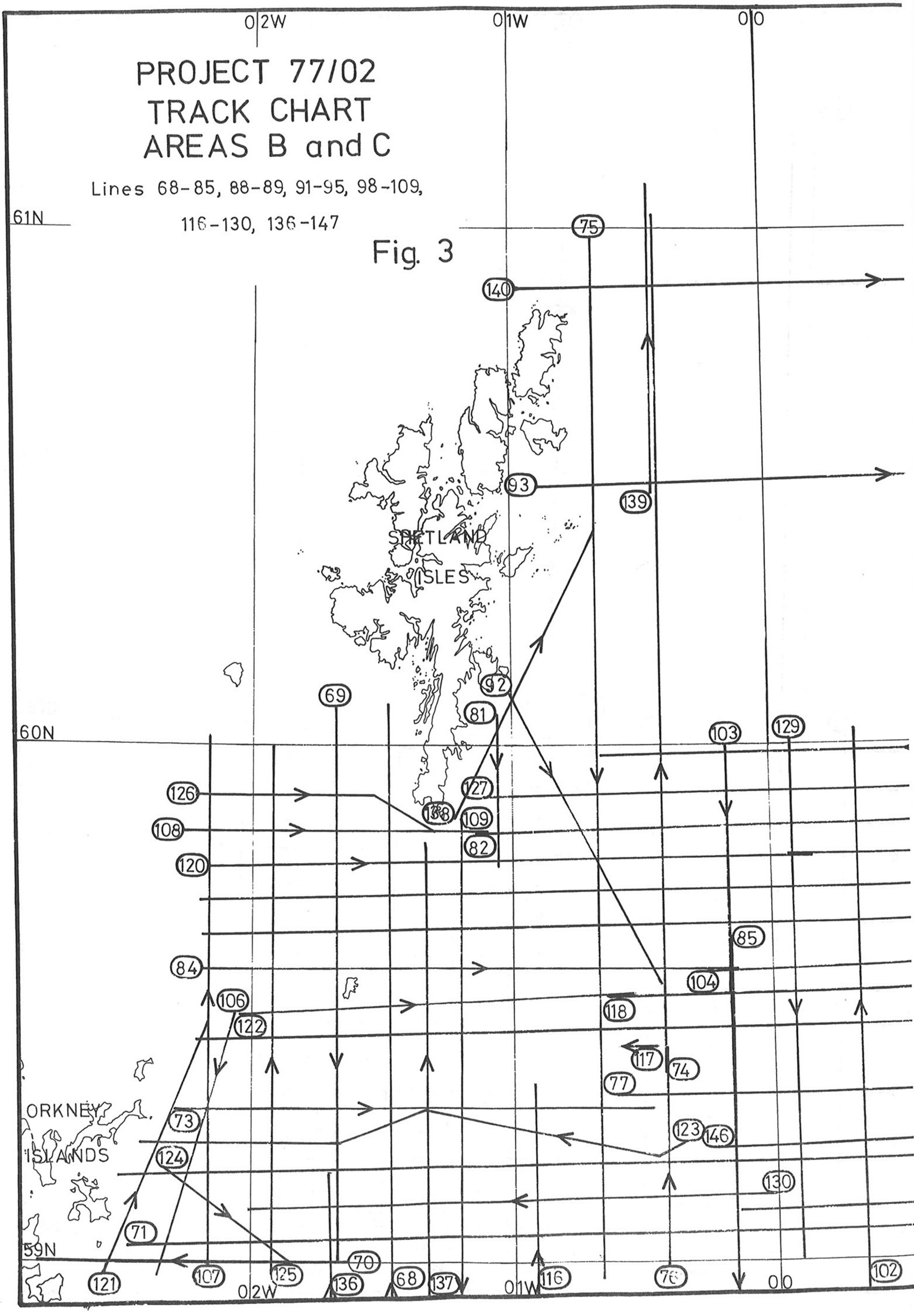

02E
03E
04E
59N
97
98
PROJECT 77/02
TRACK CHART
AREA E
Lines 68, 85, 88, 97, 98, 109, 116,
131 and 136
Fig. 5
58N
02E
03E
04E



PROJECT 77/02
TRACK CHART
AREA D
Lines 6, 14, 15, 29-32, 48, 50, 68, 85-88, 109-116, 131-136, 148-153
Fig. 4
Aberdeen
Dundee
03W
02W
01W
00
58N
57N
56N
131
109
85
116
132
136
133
148
134
113
112
115
110
15
30
135
86
32
87
3
149
31
114
6
50
14
29
68



01E
02E
03E
58N
151
57N
153
111
56N
88
152
150
48
01E
02E
03E



PROJECT 77/02
TRACK CHART
AREAS B and C
Lines 68-85, 88-89, 91-95, 98-109,
116-130, 136-147
Fig. 3
0 2W
0 1W
0 0
61N
60N
59N
SHETLAND
ISLES
ORKNEY
ISLANDS
75
140
93
139
92
69
81
103
129
126
127
138
109
108
82
120
85
84
104
106
118
122
117
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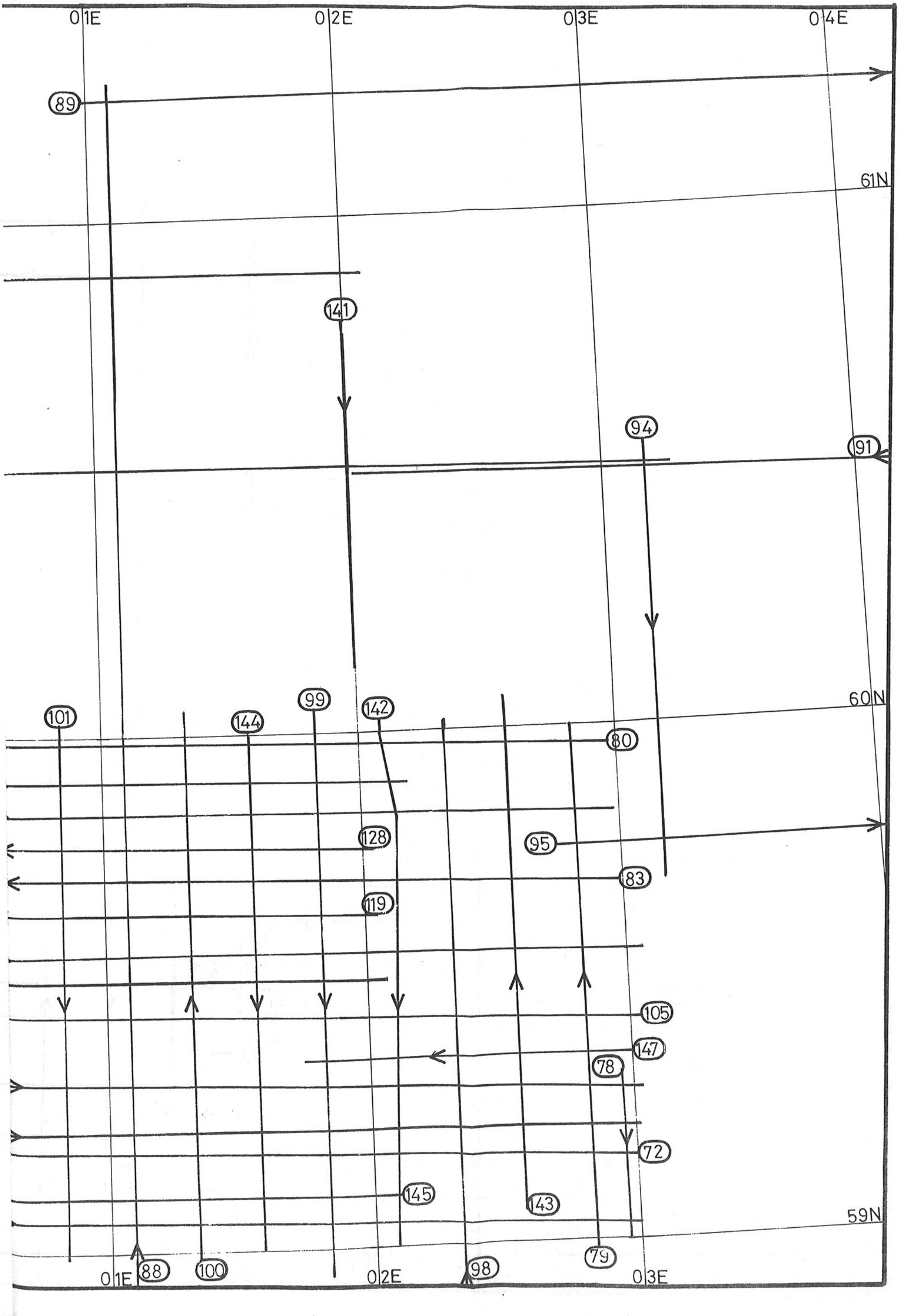
137
116
76
102


01E
02E
03E
04E
89
61N
141
94
91
60N
101
144
99
142
80
128
95
83
119
105
147
78
72
145
143
59N
79
01E
88
100
98
02E
03E