Hydraulics Research
Wallingford

SLUDGE DISPOSAL TO SEA

Liverpool Bay bed ripple survey 1984

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ABSTRACT

For economical and practical reasons a significant amount of the UK's sewage sludge is disposed to British coastal waters. The consequences of this form of disposal on the marine environment and coastline are of great importance and have been the subject of intensive investigation.

Hydraulics Research has been involved for many years in studying the behaviour of sewage sludges discharged into the marine environment. Recent laboratory research concerned with the deposition and erosion of sludge on a rippled sand bed revealed a lack of suitable field data on near-bed velocities and associated movement of a sand bed. Hydraulics Research mounted a survey in Liverpool Bay, an area where sewage sludge is dumped, in order to measure these variables. Some instrument failure during the survey resulted in data loss but sufficient data was collected to provide a useful field record. This report presents the data obtained on the survey and comments on the results.

CONTENTS

1 INTRODUCTION

Hydraulics Research (HR) has been commissioned by the Department of the Environment (DoE) to carry out a program of research into various aspects of sewage sludge disposal to sea.

Previous laboratory research conducted by HR investigated the depositional and erosional characteristics of sludge on a rippled sand bed and is reported in Reference 1. The sludge used in these experiments was obtained from Davyhulme Treatment Works, Manchester, which disposes of its sludge via sludge vessels discharging into Liverpool Bay. The tests were carried out using near-bed velocities which were typical of field values in general but were not based on actual data from a known sludge-dumping ground as the latter was unavailable. To fill this data gap (and to ensure the relevance of the laboratory tests) the report recommended that:

(i) field velocity data should be obtained from a known sand bed area of Liverpool Bay, paying particular attention to the near-bed velocity profile.

(ii) an attempt should be made at the same time to observe sand ripple movement, preferably during a spring tide.

HR consequently conducted a field survey to satisfy these recommendations. The survey was carried out on the spring tides of 16 and 17 February 1984 at a position where sand had been identified in other surveys (Ref 2) and where ripples were expected to exist. The location of this position, known as T10, is shown in Figure 1. This report outlines the measurement techniques adopted on the survey, presents the obtained data and comments on the results.

2 VELOCITY AND SUSPENDED SOLIDS MEASUREMENTS

2.1 Through-the-depth velocities

Velocity measurements were made using a Braystoke BFM 008 Mark III directional current meter, weighted and suspended from the survey vessel. Water depth measurements were made using a transducer fixed onto the sinker weight attached to the current meter. The records of total water depth, water speed and direction of flow observed on 16.2.84 are presented in Table 1 and those observed on 17.2.84 are presented in Table 2. It should be noted that measurements of near-surface flow directions may have been affected by the steel hull of the survey vessel and this data should be treated with a degree of caution.

The velocity data has been analysed to obtain computed best-fit velocity curves for each profile. This has been calculated assuming a curve of the form:

$$u = a + b \log_{10} h$$

where

u = velocity (m/s)
h = depth (m)
b = slope of line
a = constant

The actual velocity data points, together with computed best-fit curves are presented in Figures 2 and 3 for measurements taken on 16.2.84 and 17.2.84 respectively. Numerical values for the coefficients (a and b) of the computed best-fit velocity curves, along with the correlation index (r) and calculated shear velocity (u^*) are presented in Table 3. Shear velocities have been determined using the equation

$$u^* = \frac{b}{5.75}$$

These values of shear velocity fall between the limits of 0.01m/s and 0.08m/s with maximum u^* occurring in the first half of the flood tide on 17.2.84 (Profile 18/2010-2018 GMT).

Predicted tidal information for the Port of Liverpool during the survey period, extracted from Admiralty Tide Tables for 1984, is given below:

Date	Time (GMT)	Tidal height (m)
16.2.84	0501	1.3
	1040	9.3
	1736	0.8
	2306	9.5
17.2.84	0550	0.8
	1127	9.8
	1825	0.3
	2353	9.8

2.2 Near-bed velocities

A different technique was used to measure near-bed velocities. A small Braystoke current meter was mounted to a bed frame which was lowered from the survey vessel, aligning itself with the flow on its way down to rest on the sea-bed. The current meter, a non-directional instrument, was driven by signals from the survey vessel to measure velocities at 0.1, 0.3 and 0.6m above the bed. The velocity data is presented in Tables 4 and 5. Velocity variation with time at each of the three heights for the two days of observations is shown in Figure 4. Grit in the impellor on 17 February may have distorted the flood tide measurements that day.

2.3 Suspended sediment

Suspended sediment measurements utilised a small water sampling intake nozzle attached alongside the current meter to the bed frame, the intake position being determined by signals from the survey vessel. Pumps on board the survey vessel drew water from the intake and up to the vessel via a plastic tube. Once on board the survey vessel a measured volume of water was extracted and passed through a filtering mechanism, the filters were then returned to the HR Sedimentology Laboratory for analysis. The quantity of sediment retained on the filter was determined using standard dry weight procedures (Ref 3) and the results are presented in Tables 4 and 5.

Particle size analyses were also carried out on the suspended sediment. Initially the retained filter material was divided into two size fractions, that > 40 microns and that < 40 microns. If the weight of the fraction > 40 microns was > 0.03g further analysis was performed on the sample to determine the proportions of the different sand fractions. The results of this analysis, where applicable, is also given in Tables 4 and 5.

3 SAND RIPPLES

3.1 Bed composition

To establish the grading and uniformity of the bed sediments, grab samples of the sea bed surface were taken from the survey vessel using a Van Essen clam-shell type grab sampler. A total of six samples was taken, three each day. The position from which each sample was taken varied as, depending on tidal conditions, the survey vessel swung slightly while anchored.

Particle size analyses of the grab samples were carried out in the HR Sedimentology Laboratory using a standard size grading technique (Ref 3). Size grading curves for each of the samples were found to be virtually identical and are represented by the curve for sample D in Figure 5. The median grain size (D_{50}) of each of the six samples is given below:

Date	Time (GMT)	Sample No	D_{50} (mm)
16.2.84	1000	A	0.37
	1715	B	0.33
	?	C	0.32
17.2.84	1406	D	0.33
	1730	E	0.33
	1900	F	0.31

All the D_{50} values fall within the band 0.3 to 0.4mm diameter (medium sand). This indicates that the composition of the sea bed in the vicinity of position T10 remained consistent for the duration of the survey.

3.2 Sand ripple movement

Profiles of the sea bed surface at position T10 were obtained using an instrument recently developed by HR. This instrument, a precision echo sounder, was mounted on a similar but separate bed frame than that used for near-bed velocity and suspended sediment measurements. The echo sounder worked at 2 Mhz, the nominal working range was between 500mm and 1000mm with a resolution of ±1mm and beam width of approximately 25mm.

The echo sounder transducer, controlled by a drive system from the survey vessel, was moved along a trackway supported by the bed frame 800mm above the sea bed. The length of traverse was 1300mm and as the transducer moved along the trackway, the distance between it and the sea bed were reproduced graphically onto a two channel chart recorder. One channel recorded the transducer output information while the other recorded its length of traverse. During the survey period 49 separate profiles of the sea bed were obtained using this instrument, 39 recorded over two ebb tides and 10 over a single flood tide. Technical problems with the instrument forced the abandonment of work. The profiles are represented by Figures 6 and

7, each figure representing a series of profiles obtained under different tidal conditions. Figure 6 shows profiles obtained during the early ebb tide of 16 February and Figure 7 shows those obtained during the mid flood of 17 February. The lines in each figure represent the surface of the sea bed parallel to the direction of flow (ie longitudinal profiles).

Inspecting these profiles it can be seen that the trace lengths vary slightly. These variances were due to different traverse speeds caused by water leakage into a cable. Each trace, however, is still representative of 1300mm of the bed. It proved impossible to maintain the same instrument position throughout the duration of the survey but the profiles in each figure are from the same location.

The profiles presented in Figure 6 clearly show little ripple movement in the first half hour of the ebb tide but slight advancement (~ 0.03mm/s) in the second half hour when u^* was estimated as being 0.04m/s. Conversely the profiles presented in Figure 7 show rapid ripple movement (~ 0.50mm/s) coinciding with a u^* of 0.07m/s.

The following table summaries the approximate rate of ripple advancement calculated from the profiles, along with their coincident value of u^*. Ripples advancing at a rate < 0.03mm/s were not monitored.

u^* (m/s)	ripple advancement (mm/s)
0.04	0.03 - 0.05
0.05	0.08
0.06	0.20
0.07	0.50
0.08	> 0.50

4 SUMMARY AND CONCLUSIONS

1. Shear velocities (u^*), calculated from through-the-depth velocity profiles, ranged from

0.01m/s to 0.08m/s. Maximum u^* was measured early in the flood tide at HW - 3¾ hours on 17.2.84

2. Maximum recorded velocity at the bed (+ 0.1m) was 0.45m/s, measured early in the same flood tide between HW - 4 hours and HW - 3½ hours.

3. Mean suspended solids concentration near the bed was 0.01g/l. The concentration of sediments $< 40 \mu m$ remained fairly constant throughout the tidal cycle but the concentration of sediments $> 40 \mu m$ increased noticeably when u^* values reached > 0.06m/s and reached a peak of 0.13 g/l between HW - 3½ and HW - 3 hours on 17.2.84 when u^* was 0.07 - 0.08m/s.

4. Median grain size of the bed material at T10 was 0.33mm.

5. Sand ripples on the sea bed at position T10 were identified and their movement recorded. Ripple advancement of between 0.03 and 0.05mm/s was measured when u^* was 0.04m/s, suggesting a threshold of movement when u^* is < 0.04m/s. Ripple advancement of > 0.50mm/s was measured when u^* was ~ 0.08m/s.

6. In the previous HR laboratory investigation, which used sand with a D_{50} of 0.19mm, the threshold of ripple movement (ie, 0.01mm/s) occurred when u^* was ~ 0.036m/s. This compares well with the recorded field values and indicates that the laboratory tests were representative of bed conditions in Liverpool Bay.

7. Despite some instrument failure during the survey resulting in incomplete records, the data collected provides a useful account of activities at the bed in Liverpool Bay; the objectives of the exercise have been achieved.

5 REFERENCES

1. BURT, T N and TURNER K A. Deposition of sewage sludge on a rippled sand bed. Hydraulics Research Report No IT 248, June 1983.

2. "Out of sight out of mind". Report of a Working Party on sludge disposal in Liverpool Bay, Vol 4, HMSO, 1976.

3. KIFF, P R. Sedimentation Methods Manual. Hydraulics Research, August 1978.

TABLES

TABLE 1 Velocities at Position T10 on 16.2.1984

Profile No	Time (GMT)	Total depth (m)	Instrument height above bed (m)	Velocity (m/s)	Direction (° True)
1	1122	14.8	0.5	0.20	264
	1125		1.0	0.22	274
	1127		1.5	0.27	267
	1130		2.0	0.28	267
	1133		4.0	0.38	273
	1138		8.0	0.46	277
	1140		13.8	0.53	262
2	1159	14.1	0.5	0.38	267
	1201		1.0	0.40	264
	1203		2.0	0.43	278
	1205		4.0	0.60	278
	1209		8.0	0.66	273
	1211		13.1	0.65	271
3	1239	12.9	0.5	0.52	284
	1242		1.0	0.46	284
	1244		2.0	0.66	283
	1247		4.0	0.66	287
	1250		6.0	0.75	281
	1254		11.9	0.77	273
4	1336	11.3	0.5	0.60	293
	1338		1.0	0.38	297
	1341		2.0	0.70	288
	1344		4.0	0.75	294
	1348		8.0	0.79	277
	1350		10.3	0.77	277
5	1435	9.6	0.5	0.51	288
	1437		1.0	0.48	297
	1440		2.0	0.75	290
	1443		4.0	0.72	293
	1445		8.0	0.74	281
6	1504	8.9	0.5	0.41	311
	1507		1.0	0.45	287
	1511		2.0	0.60	291
	1512		4.0	0.61	294
	1514		8.0	0.65	281
7	1542	8.0	0.5	0.33	297
	1544		1.0	0.46	298
	1547		2.0	0.50	303
	1549		4.0	0.52	282
	1552		7.6	0.46	283
8	1609	7.8	0.5	0.23	303
	1612		1.0	0.29	297
	1614		2.0	0.29	293
	1618		4.0	0.40	283
	1622		6.8	0.31	278
9	1651	7.3	0.5	0.10	298
	1653		1.0	0.14	273
	1655		2.0	0.14	277
	1657		4.0	0.15	293
	1702		6.8	0.13	273

TABLE 2 Velocities at Position T10 on 17.2.1984

Profile No	Time (GMT)	Total depth (m)	Instrument height above bed (m)	Velocity (m/s)	Direction (° True)
10	1413	11.4	0.5	0.53	293
	1417		1.0	0.59	287
	1422		2.0	0.67	288
	1424		4.0	0.77	288
	1426		8.0	0.85	281
	1429		10.4	0.90	277
11	1444	10.5	0.5	0.48	288
	1448		1.0	0.69	288
	1449		2.0	0.66	284
	1451		4.0	0.79	291
	1453		8.0	0.90	278
	1456		9.5	0.97	278
12	1512	9.6	0.5	0.41	313
	1514		1.0	0.62	297
	1517		2.0	0.66	294
	1520		4.0	0.75	288
	1522		8.0	0.91	277
	1523		9.1	0.86	278
13	1541	8.9	0.5	0.53	298
	1544		1.0	0.64	303
	1547		2.0	0.69	298
	1550		4.0	0.77	287
	1553		8.0	0.84	282
14	1616	7.8	0.5	0.47	297
	1618		1.0	0.51	294
	1624		2.0	0.58	291
	1627		4.0	0.63	288
	1628		7.3	0.70	278
15	1647	7.7	0.5	0.41	303
	1648		1.0	0.38	293
	1651		2.0	0.48	293
	1655		4.0	0.53	287
	1657		7.2	0.60	278
16	1715	7.1	0.5	0.28	298
	1716		1.0	0.31	294
	1718		2.0	0.32	293
	1720		4.0	0.46	287
	1723		6.6	0.56	282
17	1925	8.7	0.5	0.51	128
	1929		1.0	0.53	128
	1932		2.0	0.63	121
	1934		4.0	0.78	144
	1937		8.0	0.93	173
18	2010	10.6	0.9	0.65	123
	2013		2.0	0.90	124
	2015		4.0	0.97	128
	2018		8.0	1.11	171
19	2036	11.8	0.5	0.60	-
	2039		1.0	0.65	113
	2042		2.0	0.86	112
	2045		4.0	0.97	114
	2047		8.0	1.06	147
	2049		11.3	1.13	177
20	2109	13.0	0.5	0.64	114
	2111		1.0	0.75	114
	2113		2.0	0.77	117
	2116		4.0	0.84	113
	2118		8.0	0.88	138
	2123		12.0	0.96	178
21	2138	14.1	0.5	0.49	117
	2142		1.0	0.59	107
	2144		2.0	0.55	114
	2149		4.0	0.58	117
	2152		8.0	0.59	134
	2154		13.1	0.74	177
22	2210	15.3	0.5	0.38	117
	2213		1.0	0.43	114
	2215		2.0	0.38	113
	2218		4.0	0.45	117
	2225		8.0	0.49	113
	2227		14.3	0.51	178

TABLE 3 Values of computed best-fit velocity curves

Date	Profile No	Profile time (GMT)	Constant (a)	Slope (b)	Correlation (r)	u^* (m/s)
16.2.84	1	1122 - 1140	0.24	0.23	0.98	0.04
	2	1159 - 1211	0.42	0.23	0.95	0.04
	3	1239 - 1254	0.55	0.23	0.91	0.04
	4	1336 - 1350	0.56	0.23	0.74	0.04
	5	1435 - 1445	0.57	0.23	0.83	0.04
	6	1504 - 1514	0.48	0.21	0.95	0.04
	7	1542 - 1552	0.42	0.12	0.69	0.02
	8	1609 - 1622	0.28	0.09	0.72	0.02
	9	1651 - 1702	0.12	0.03	0.61	0.01
17.2.84	10	1413 - 1429	0.60	0.28	0.99	0.05
	11	1444 - 1456	0.61	0.25	0.96	0.04
	12	1512 - 1523	0.56	0.35	0.97	0.06
	13	1541 - 1553	0.62	0.25	0.99	0.06
	14	1616 - 1628	0.52	0.21	0.99	0.04
	15	1647 - 1657	0.43	0.18	0.94	0.03
	16	1715 - 1723	0.32	0.25	0.93	0.05
	17	1925 - 1937	0.57	0.37	0.97	0.06
	18	2010 - 2018	0.70	0.46	0.98	0.08
	19	2036 - 2049	0.70	0.42	0.99	0.07
	20	2109 - 2123	0.72	0.21	0.98	0.04
	21	2138 - 2154	0.54	0.11	0.81	0.02
	22	2210 - 2227	0.40	0.09	0.88	0.02

Based on equations ; $u = a + b \log_{10} h$

$$u^* = b/5.75$$

TABLE 4 Near-bed measurements at Position T10 on 16.2.84 (ebb tide only)

Profile No	Time (GMT)	Instrument height above bed (m)	Velocity (m/s)	Sample volume (l)	Sample duration (min:secs)	Weight of sediment on filters (g) > 40 µm	Weight of sediment on filters (g) < 40 µm	Weight of sediment > 40 µm retained on sieves (g) < 63 µm	63 µm	106 µm	180 µm	300 µm
1	1100	0.1	0.08	20.04	8 00	0.004	0.017					
		0.3	0.10	20.07	5 00	0.003	–					
		0.6	0.12	20.05	6 50	0.009	0.07					
2	1148	0.1	0.20	20.01	8 01	0.013	0.041					
		0.3	0.25	20.06	4 30	0.003	0.027					
		0.6	0.29	20.04	5 52	0.014	0.046					
3	1227	0.1	0.28	20.03	8 11	0.030	0.067					
		0.3	0.36	20.07	4 50	0.001	0.006					
		0.6	0.40	20.06	5 51	0.011	0.027					
4	1322	0.1	0.41	20.01	8 47	0.067	–	0.003	0.018	0.006	0.032	0.008
		0.3	0.49	20.06	5 20	0.020	0.014					
		0.6	0.53	20.05	6 10	0.028	0.046					
5	1356	0.1	0.38	20.03	9 26	0.184	0.11	0.12	0.018	0.008	0.032	0.006
		0.3	0.46	20.06	4 17	0.004	0.05					
		0.6	0.53	20.05	6 14	0.026	0.10					
6	1449	0.1	0.06	14.57	6 35	0.091	0.09	0.017	0.033	0.014	0.021	0.006
		0.3	0.37	20.06	4 48	0.019	0.10					
		0.6	–	20.10	3 56	0.052	0.09	0.010	0.028	0.005	0.005	0.004
7	1531	0.1	0.22	20.04	7 29	0.095	0.12	0.030	0.040	0.007	0.014	0.004
		0.3	0.28	20.10	4 31	0.037	0.10	0.010	0.018	0.003	0.005	0.001
		0.6	0.32	–	–	–	–					
8	1556	0.1	0.20	20.54	7 42	0.047	0.14	0.019	0.018	0.003	0.005	0.002
		0.3	0.24	13.08	2 59	0.020	0.05					
		0.6	0.27	20.04	6 21	0.041	0.10	0.016	0.019	0.002	0.003	0.001
9	1648	0.1	0.14	20.03	6 41	0.079	0.047	0.046	0.025	0.002	0.003	0.003
		0.3	0.16	20.05	5 02	0.036	0.083	0.022	0.011	0.001	0.002	–
		0.6	0.18	20.03	6 00	0.065	0.113	0.037	0.018	0.004	0.003	0.003

TABLE 5 Near-bed measurements at Position T10 on 16.2.84 (late ebb/early flood tide)

Profile No	Time (GMT)	Instrument height above bed (m)	Velocity (m/s)	Sample volume (l)	Sample duration (min:secs)	Weight of sediment on filters (g)		Weight of sediment > 40 μm retained on sieves (g)				
						> 40 μm	< 40 μm	< 63 μm	63 μm	106 μm	180 μm	300 μm
10	1412	0.1	0.13	20.03	6 03	0.204	0.063	0.018	0.053	0.024	0.089	0.020
		0.3	0.52	20.06	4 14	0.046	0.045	0.005	0.018	0.008	0.011	0.004
		0.6	0.58	20.05	4 56	0.069	0.052	0.007	0.032	0.014	0.010	0.006
11	1440	0.1	0.05	20.05	6 52	0.197	0.038	0.006	0.040	0.023	0.090	0.038
		0.3	0.46	20.06	5 20	0.096	0.067	0.010	0.044	0.019	0.016	0.007
		0.6	0.52	20.03	6 04	0.197	0.164	0.017	0.043	0.012	0.012	0.002
12	1512	0.1	0.18	20.08	4 24	0.144	-	0.006	0.034	0.016	0.064	0.024
		0.3	0.53	20.06	6 03	0.086	0.066	0.017	0.048	0.018	0.020	0.004
		0.6	0.58	20.06	5 04	0.103	0.037	0.029	0.052	0.013	0.008	0.001
13	1541	0.1	0.31	20.06	4 28	0.229	0.067	0.022	0.060	0.023	0.082	0.042
		0.3	0.39	20.06	5 07	0.160	0.060	0.030	0.077	0.023	0.024	0.006
		0.6	0.44	20.00	6 11	0.164	0.070	0.042	0.081	0.024	0.012	0.005
14	1614	0.1	0.40	20.05	4 31	0.121	0.085	0.019	0.058	0.015	0.021	0.008
		0.3	0.45	20.03	6 39	0.136	0.147	0.039	0.071	0.017	0.007	0.002
		0.6	0.48	20.05	5 21	0.155	0.165	0.050	0.085	0.017	0.003	-
15	1643	0.1	0.28	20.04	4 47	0.077	0.159	0.018	0.045	0.005	0.009	0.002
		0.3	0.33	20.04	6 42	0.098	0.167	0.037	0.051	0.005	0.003	0.002
		0.6	0.37	20.03	6 08	0.106	0.241	0.042	0.056	0.006	0.002	-
16	1714	0.1	0.17	20.04	5 15	0.083	0.239	0.039	0.035	0.003	0.003	0.003
		0.3	0.21	18.52	6 56	0.123	0.295	0.050	0.045	0.006	0.002	0.002
		0.6	0.26	5.00	1 25	0.022	0.078					
17	1922	0.1	0.27	17.38	4 33	0.169	0.123	0.021	0.031	0.042	0.070	0.005
		0.3	0.34	14.14	5 09	0.096	0.170	0.040	0.036	0.009	0.007	0.004
		0.6	0.38	-	-	-	-					
18	1957	0.1	0.45	20.16	5 09	0.594	0.155	0.043	0.085	0.024	0.038	0.017
		0.3	0.50	6.87	2 34	0.110	0.107	0.031	0.047	0.014	0.014	0.004
		0.6	0.52	14.81	5 49	0.199	0.220	0.061	0.091	0.025	0.020	0.002
19	2023	0.1	0.04	20.05	5 17	2.649	0.094	0.113	0.238	0.145	1.588	0.565
		0.3	0.60	20.03	6 39	0.622	0.179	0.066	0.169	0.087	0.244	0.056
		0.6	0.21	20.04	7 53	0.503	0.146	0.094	0.188	0.076	0.126	0.019
20	2056	0.1	0.05	20.55	5 07	1.582	0.068	0.046	0.173	0.138	0.878	0.347
		0.3	0.64	20.04	5 45	0.618	0.106	0.048	0.173	0.113	0.238	0.046
		0.6	-	20.05	7 47	0.607	0.111	0.075	0.226	0.119	0.162	0.025
21	2122	0.1	0.08	20.06	4 57	0.556	0.160	0.014	0.120	0.084	0.264	0.074
		0.3	0.53	19.97	5 49	0.390	0.130	0.040	0.150	0.081	0.101	0.018
		0.6	0.56	20.05	7 00	0.348	0.101	0.033	0.154	0.082	0.067	0.012
22	2152	0.1	0.18	2.85	0 50	0.030	-	0.003	0.017	0.002	0.005	0.003
		0.3	0.36	2.98	1 25	0.036	-	0.005	0.015	0.010	0.006	-
		0.6	0.37	20.05	7 07	0.108	0.120	0.071	0.002	0.025	0.009	0.001

FIGURES

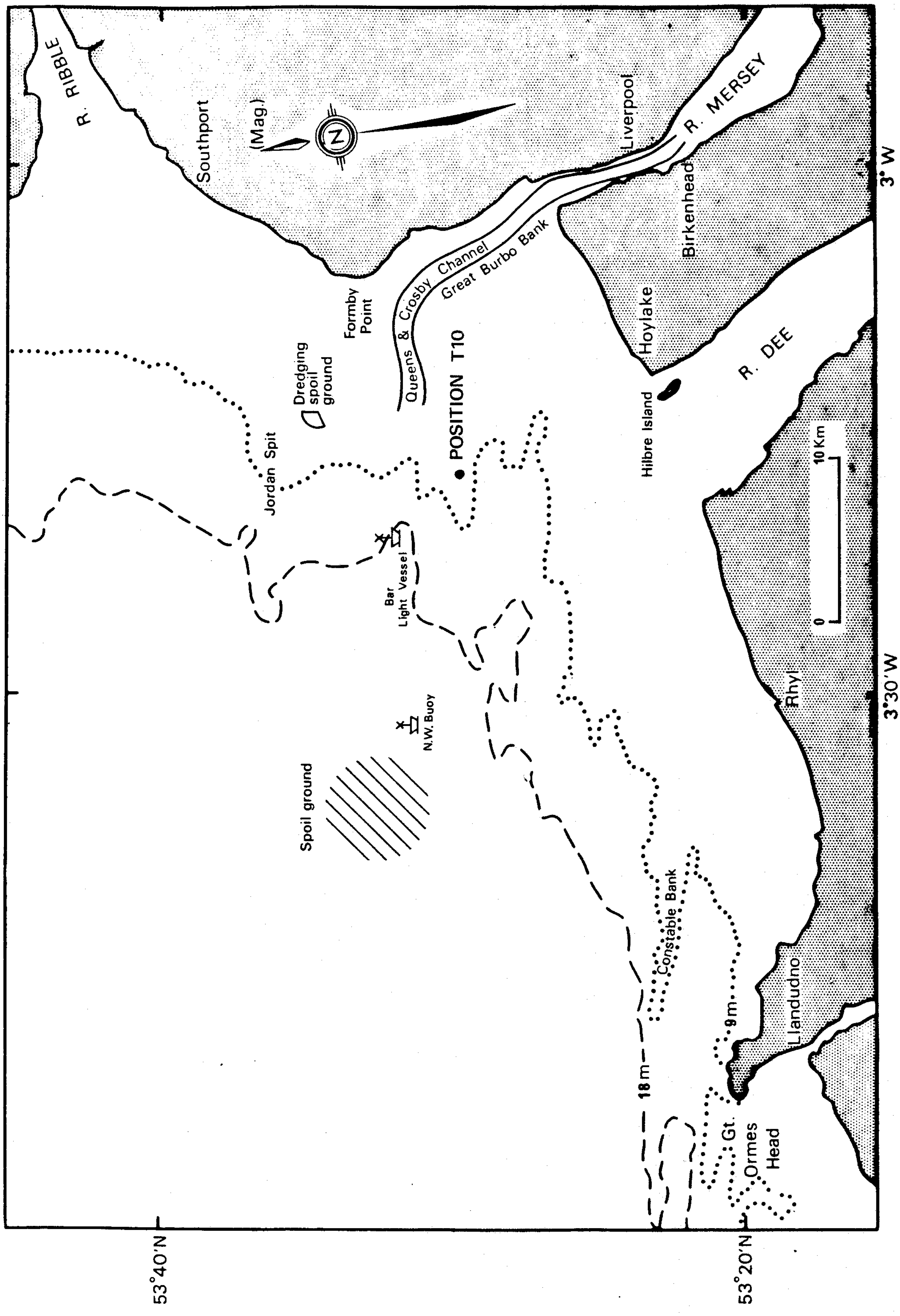

Fig 1 Location map of survey position

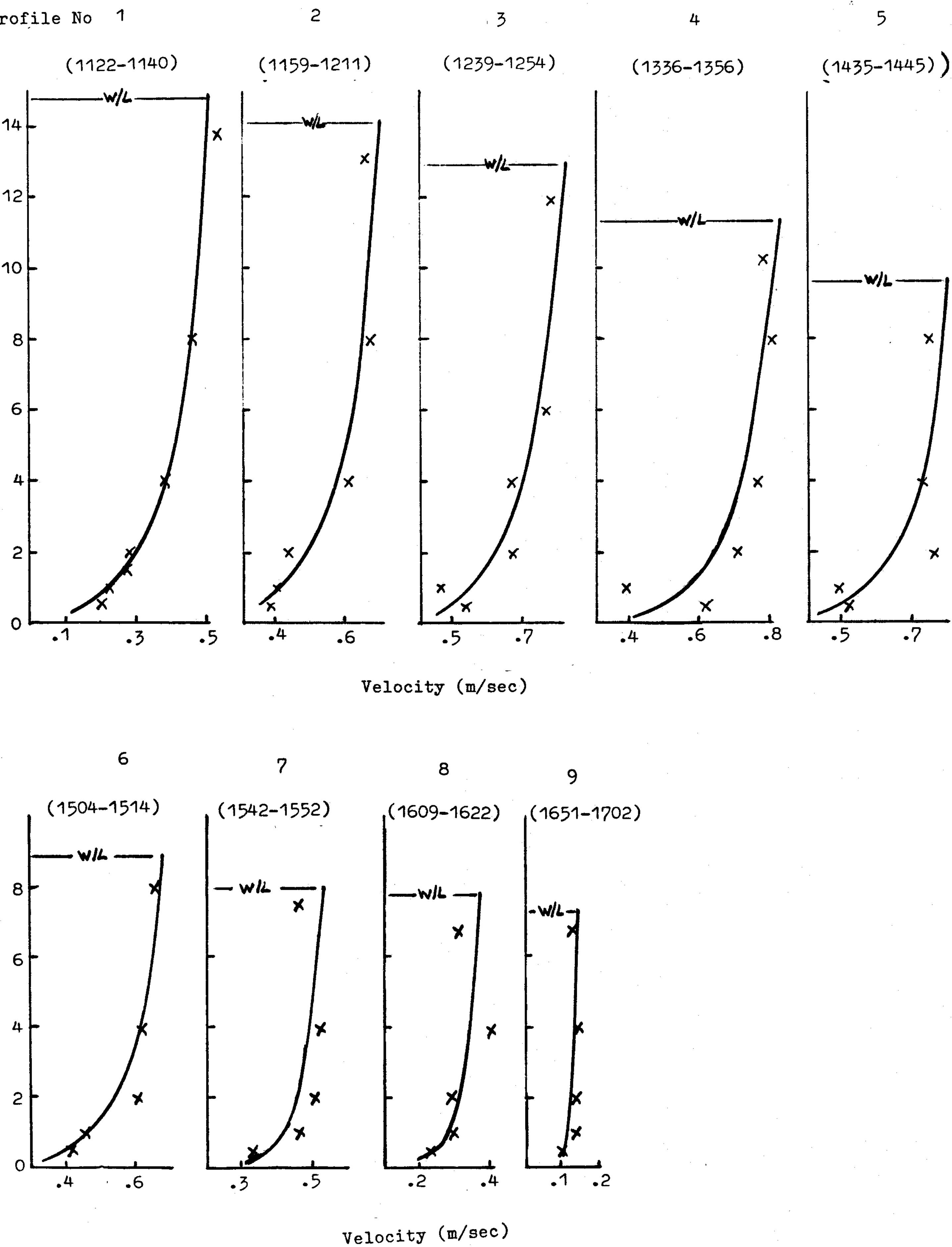

Fig 2 Through-the-depth velocity profiles at Position T10 on 16.2.1984

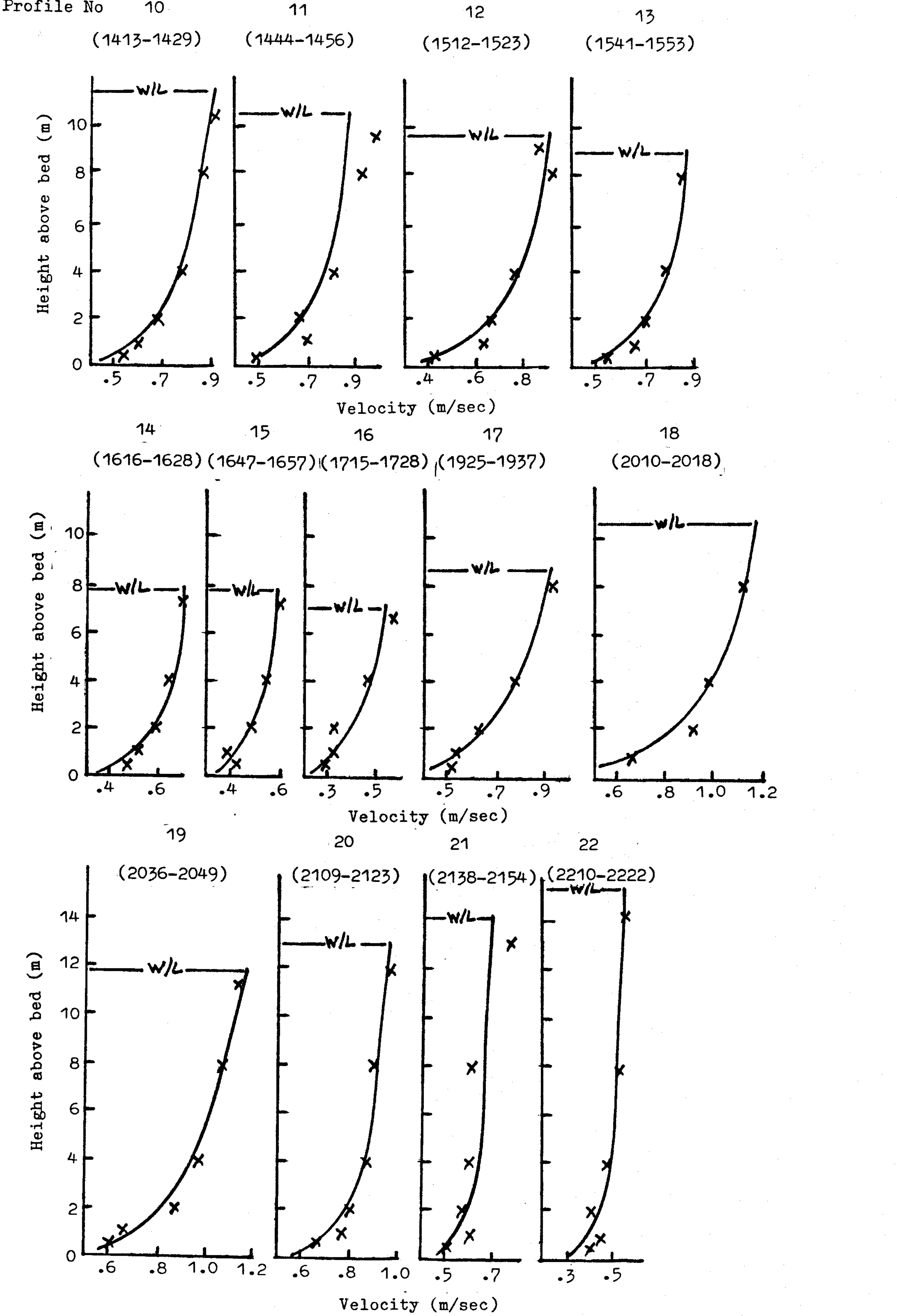

Fig 3 Through-the-depth velocity profiles at Position T10 on 17.2.1984

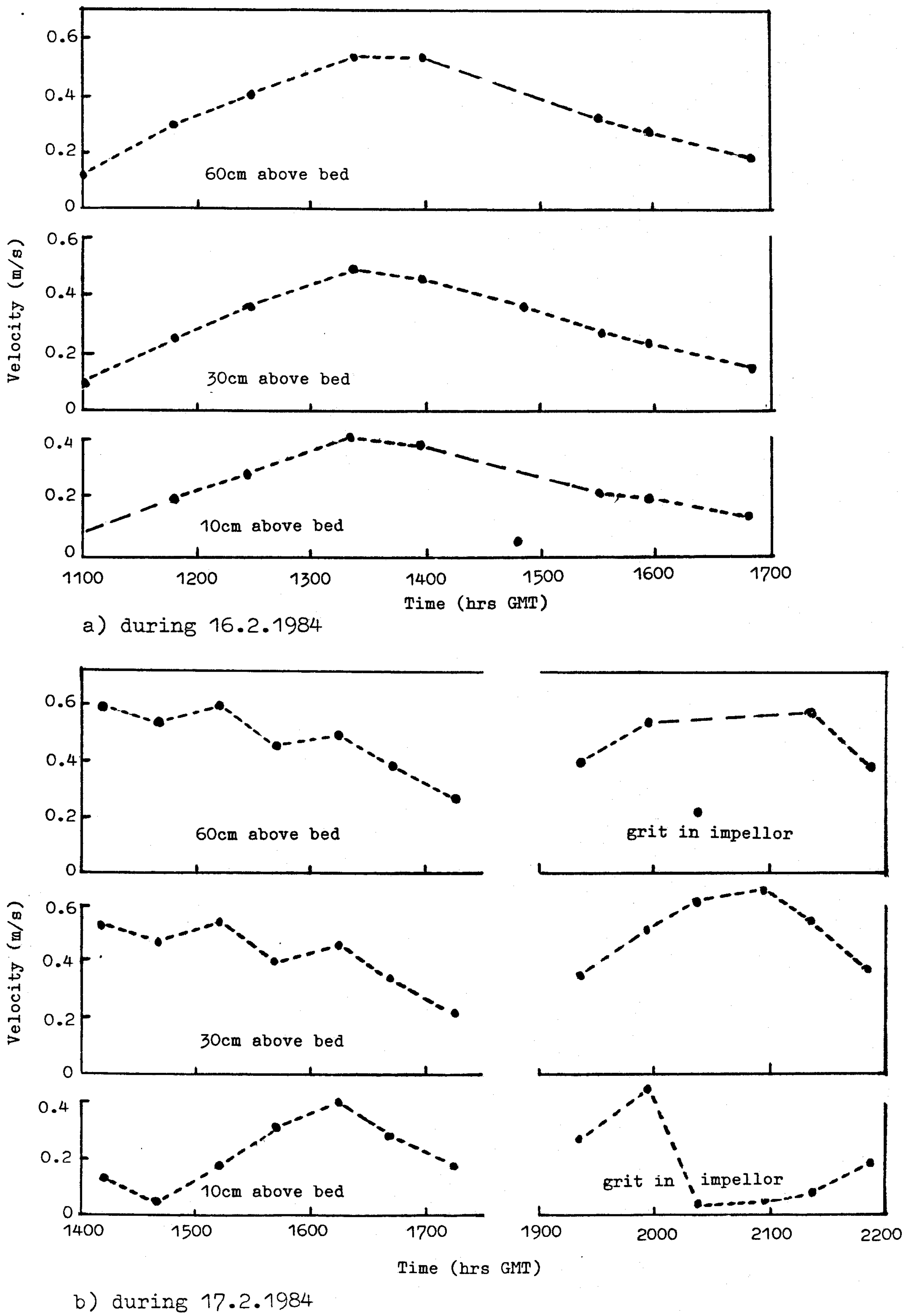

Fig 4 Near-bed velocity variation with time

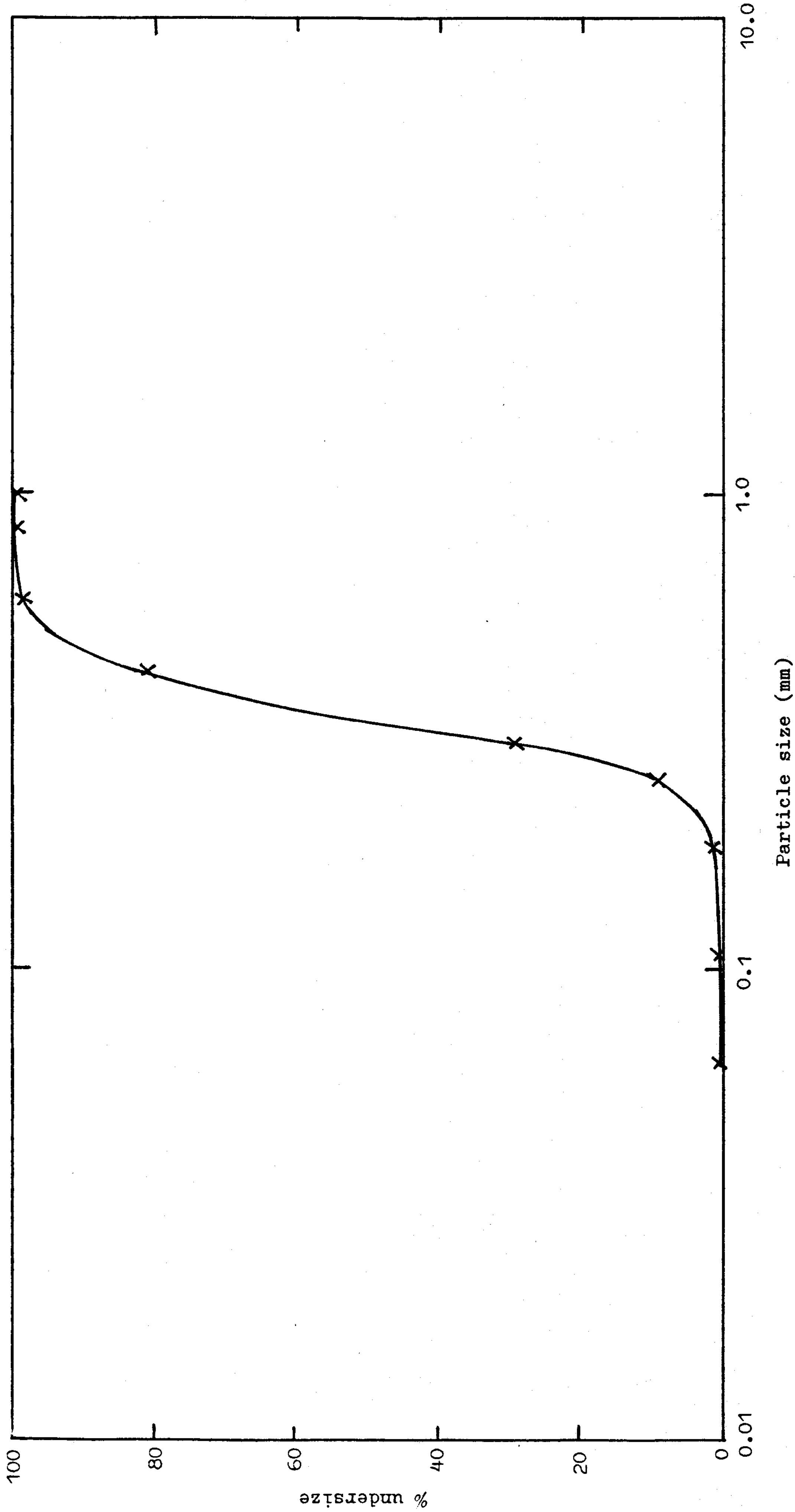

Fig 5 Particle size distribution of grab sample D

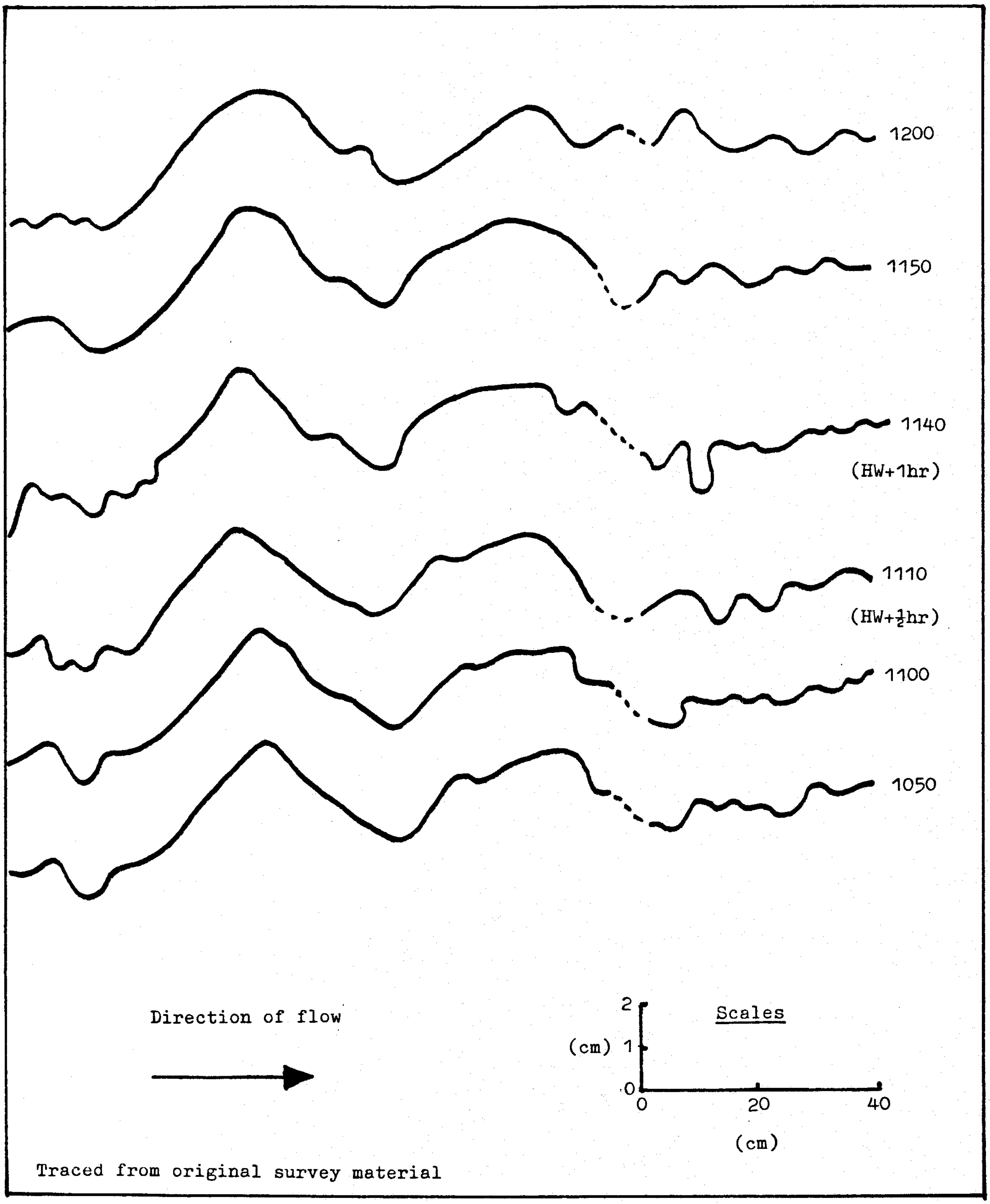

Fig 6 Sand waves at Position T10 on 16.2.1984 : Early ebb tide

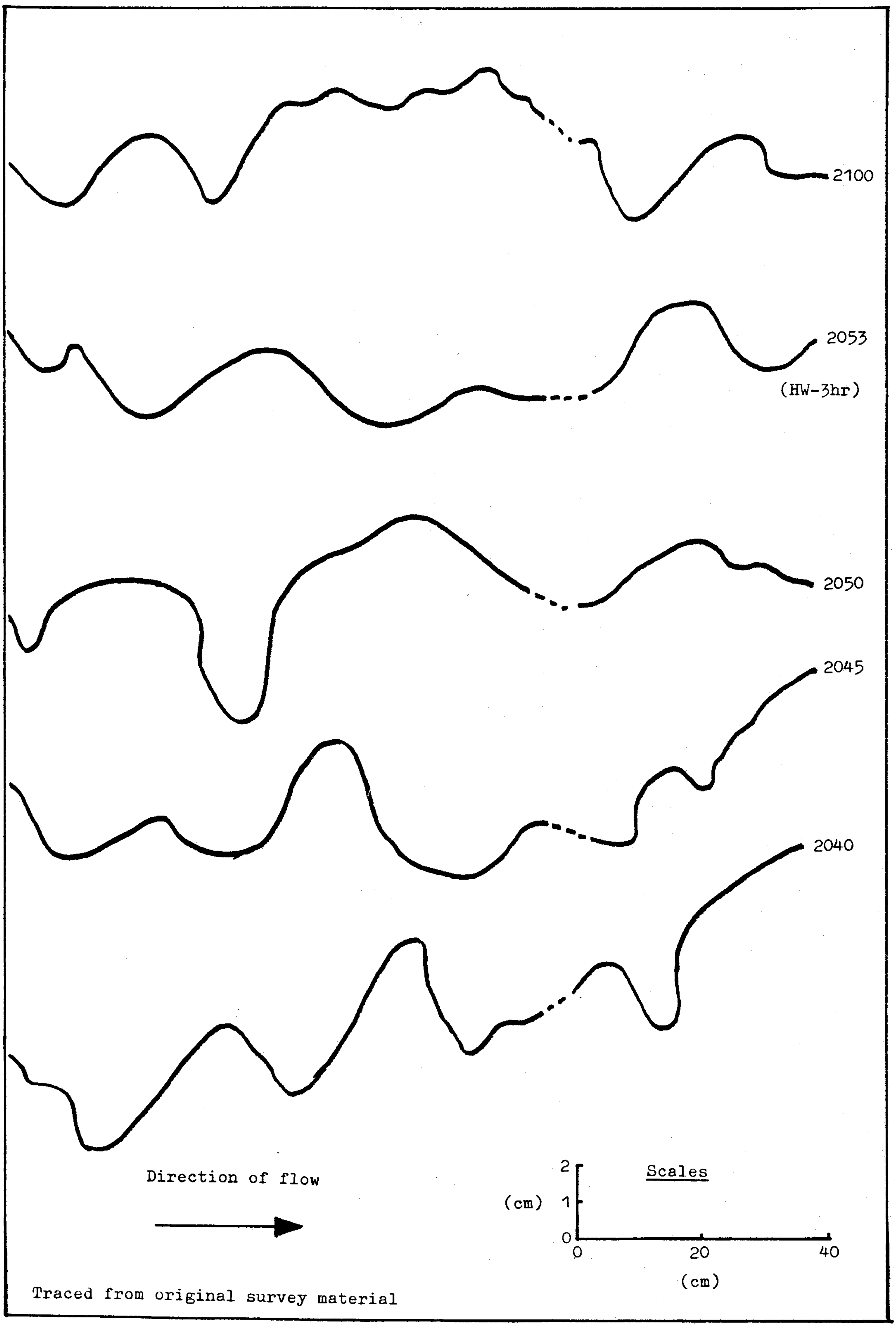

Fig 7 Sand waves at Position T10 on 17.2.1984 : Mid flood tide