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A STUDY OF PROPOSED SITES FOR WAVE/CURRENT/SEDIMENT INTERACTION EXPERIMENTS

BY

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INTRODUCTION

Previous work at IOS Taunton on the water motion near the sea bed in coastal waters and its interaction with the sediments has dealt with the action of waves and currents separately. After several years study of these admittedly rather artificial conditions, the time is ripe to study the more realistic situation of waves and currents acting simultaneously. The purpose of this short investigation has been to identify locations where the near bed mean and fluctuating velocties and pressures resulting from the interaction of waves and tidal currents may be measured as they interact both with a mobile and immobile sea bed. This document contains the findings of a desk top study and short cruise to confirm the magnitude and direction of the tidal flows and the type and mobility of sediment.

SITE SELECTION CRITERIA

Considerations of the requirements for such a site resulted in the criteria set out in Table 1. The reasons for each requirement are as follows:

i) The tidal currents must be capable of mobilizing sand on their own in order to study one extreme of the wave-current conditions - ie "small" waves. Similar currents are required over mobile and immobile beds to study the effect of sediment mobility.

ii) Again, in order to obtain the extreme conditions of waves moving sediment in the absence of currents, wave induced velocities up to 100 cm/sec are desirable. These must occur "reasonably" frequently, and hence the depth must not be too great.

iii) A one-dimensional model of the flow in the wave-current boundary layer is being developed as part of this project. Comparison of field data with this model will be easier if the experimental site is "not too close" to the shore. It was arbitrarily decided that a distance >10 km offshore would be desirable

iv a & b) The flow will be complicated by any topography present, and so the sea bed should preferably be flat with no banks or sand waves present.

c & d) For the comparison of flows over mobile and immobile beds, two sites composed of sand and gravel respectively were thought appropriate.

v) The water should be well mixed to avoid complexities of stratification and contain little weed etc that might foul the instruments. The absence of fine material (mud) would facilitate any photography that might be required and enable optical sensors to be used to monitor the suspended sand if required.

vi) It is intended that the instrumentation module should be of a type that can be deployed remotely for up to 3 months. It would be difficult to make the module "trawler proof", and so areas of high fishing activity should be avoided. Similarly, busy shipping areas are not desirable. The presence of submarine cables could hinder laying and recovery.

Several of the above requirements tend to be contradictory, and hence any one site will be a compromise.

CHOICE OF SITES

The problem was approached by examining the bottom sediments on Hydrographic charts together with consideration of bathymetry, configuration of coastline and general knowledge of wave conditions and tidal currents. It is known that wave conditions moderate as one proceeds further from the continental shelf edge and up the English Channel or Bristol Channel; tidal currents are larger in certain areas (eg Bristol Channel or centre of the English Channel,) whilst being locally modified by bays and headlands. Deeper water results in less bottom activity for a given wave height. These considerations result in conflicting factors. Shallower regions tend to be further from the edge of the continental shelf and have a less severe wave climate. But what wave activity there is, is less attenuated at the sea bed. Near the coast, shallower regions tend to be in bays, which are sheltered from the main tidal stream, even though they may be exposed to regular wave action/activity. Proximity of a possible site to Plymouth or Barry was considered desirable, as this may make deployment or recovery of the instrument module by a "research ship of convenience" possible.

IMMOBILE BED SITE

The above considerations suggest that a possible site for wave-current interaction experiments over an immobile (gravel) bed is off the south west coast of the Isle of Wight, see Figure 1. This material may be mobile at higher tidal velocities, when the rate of the tidal stream can be in excess of 100 cm/sec (Admiralty Tidal Stream Atlas). Field observations have been made in this area by Langhorne and Heathershaw in their studies of the mobility of gravel. The bed was found to consist of gravel with only a few isolated topographic features. These were gravel "waves" up to 5 m high, and were thought to be controlled by the underlying geology rather than being the result of active sediment movement. In fact, little sediment motion was observed during a cruise just before spring tides (5.11.83) in conditions of low wave activity. A string of current meters was deployed (at 10, 5 and 2 m above the bed) for 5 days in 1982 at the site marked in Figure 1, and this confirmed the magnitude of the currents (up to 100 cm/sec) predicted from the Admiralty Tidal Stream Atlas with a direction of 90° and 270° magnetic for flood and ebb respectively. The details of this data are available if required.

The underwater visibility encountered in this area was good, with little evidence of weed. The fishing tends to be for lobsters etc rather than trawling. Two areas must be avoided, however, those marked on Figure 1 as "the spoil ground" and "the dredging area". Despite being close to Southampton, the area is surprisingly free from shipping; on leaving the Needles Channel, ships tend to either head west down Channel or steer a straight course to round St Catherines Point. There are no submarine cables in this area.

The wave activity in this area was assumed to be similar to that at the Shambles Light Vessel. The H_s - T_z scatter plot at the Shambles is reproduced in Figure 2, upon which is also drawn the line which represents those waves that cause a bottom orbital velocity of 10 cm/sec in 30 m of water. Estimates of percentage exceedance of certain nearbed orbital velocities are shown in Table 2. Seasonal data is not available. These estimates will tend to be conservative as the method used is based on H_s - T_z and not the spectral content of the waves. It will be advisable to perform the experiment during the winter in order to obtain wave orbital velocities closer to those desired.

MOBILE BED SITES

Two sites in the Bristol Channel were considered for investigation:-

1. The North West Bank on the western side of Lundy Island. About 1.6 km from the island.
2. The Helwick Channel, south west of the Gower Peninsular in South Wales, 5 km from Worms Head.

These sites were selected on the basis that they had a depth between 20-30 m in a fairly energetic wave environment, where wave action would reach the seabed not too infrequently, but were as far as possible from the coast. Both these sites were expected to have well mixed water and a sandy bottom. No submarine cables obstruct the sites and neither are within main shipping routes.

At each site measurements were attempted over one flood tide using the following instrumentation:-

1. An NBT82 suspended solids sampler was deployed for the whole period of the flood at 50 cm above the bed.
2. Direct reading current meter measurements were taken every half hour giving the speed and direction of the current. The depth of the current meter was deduced from the length and angle of the rope from which it was suspended.
3. One van Veen grab sample of the bed material was taken at each site.
4. A Raytheon echo sounder was deployed at intervals during the flood to determine the depth of water.
5. An underwater television camera was used to observe sediment motion near the bed.
6. EG and G sidescan sonar traces were recorded over the area of the site.
7. Decca position fixing was used in the sidescan survey and to fix the position of the sediment sampler and where the ship was anchored.

Tidal Currents

Lundy

The ship was anchored at the northern end of the bank just below the 30 m depth contour (chart survey 1879) where the bank shelves steeply, see Figure 3, although the depths recorded indicate an average of 20 m depth over the tide. The current meter was deployed about 1 hr 20 mins after low water at a depth of 15 m and later at 20 m which was within 2 or 3 m of the bed. Interpretation of the tidal atlas shows the tide to be a standing wave in this region, and so slack water is expected to occur at high and low water. However, velocities just below 100 cm/sec were observed in the first reading, see Figure 4a. It is possible that the high velocities measured soon after low water were associated with flows over the bank. At 2-3 m above the bed the velocity peaked at just over 60 cm/sec. Figure 4b shows the depth of the current meter which was measured by marking the rope from which it was suspended in 5 m intervals. The angle of the rope varied with the current velocity between about 5-30°, thus varying the depth of the current meter. The direction of the current stayed fairly constant at 40°, varying 10° either side in lighter currents.

Helwick

The ship was anchored in about 25 m of water in the Helwick Channel, see Figure 5. The current meter was deployed at 15 m below the surface at the start of the flood tide, 6-8 m above the bed. It was later dropped to 20 m, about 5 m above the bed, see Figure 6b. It was kept at this depth, so towards the end of the tide was about 10 m above the bed. Velocities of up to just under 100 cm/sec were recorded (Figure 6a). The angle of the current meter rope varied between 5°-30°. The direction of the current was 110°.

Sediment Observations

Lundy

Two television observations of the bed were made, both after the maximum flow (Figure 4a). The first showed fine sand with not much evidence of ripples. The visibility was reasonable and there was a lot of material in suspension, though it was not clear whether this was organic or sediment. The second observation was made just before high water and showed ripples of approximately 20 cm wavelength. There was still material in suspension but as no bottom movement was visible it was suspected that the material was organic. Both the bottom sample and the suspended sediment sample showed well sorted sand where over 75% of the samples were between 212 and 300 microns (see Figure 7). Very little silt and clay was observed in the bottom sample although there was a little more in the suspended sediment sample. Most of the coarser material was organic.

The suspended sediment was sampled for three periods of 80 minutes over the flood tide (see Figure 4a) and the sample of 1.072 gm gave an average concentration over the deployment time of 207 mg/l.

Helwick

Television observations were made before and just after the peak flood (see Figure 6a). The first observations in poor visibility showed poorly defined ripples of about 20 cm wavelength. Material observed in suspension was thought to be organic but some bedload and ripple movement was developing. The second observation showed vigorous bedload and suspended load and the ripples appeared smaller and more regular. The bottom sample and the suspended sediment sample both showed a wider, less well sorted distribution of grain sizes than at Lundy (see Figure 8) although a similar median grain size. The coarser fractions contained some shell with some sand grains larger than 710 microns. There was a high silt and clay content in the suspended sediment sample, but not in the bottom sample. However, the sample obtained in suspension was very small, 0.073 gm, compared with the observed motion and it was suspected that the sampler was not functioning correctly. From the sample obtained the suspended concentration was calculated at 14 mg/l.

Sidescan Survey

Lundy

The survey was obtained at low water, see Figure 3, and showed the bank shallowing from South East to North West with no distinguishable dunes or sandwaves.

Helwick

Two surveys were obtained, positions 1 to 12 in Figure 5 at low water and positions 13 to 28 at high water. At the start of position 1, between positions 4 and 5 and between positions 7 and 12 there are dunes of approximately 3 m wavelength running 90° to the measured direction of flow. Between positions 5 and 12 the depth is uniform. Similarly between positions 17 and 25 the depth is uniform, but shallowing between positions 25 and 28, with no evidence of bedforms.

Wave conditions

The wave climate in the Bristol Channel has been measured in several places, including St Gowan, Helwick and Scarweather light vessels. St Gowan, off the South Pembrokeshire coast, has very similar exposure to waves as Lundy, and so was taken to have a similar wave climate to North West Bank. The Helwick data did not have a seasonal breakdown, and so the Scarweather Bank data was used to estimate the seasonal variation. The percentage of time that the waves are of a sufficient size, as evaluated by the method in the Appendix, are shown in Table 3. It can be seen that it is better to deploy the instrument module in the winter, especially if the depth of deployment is 30 m.

CONCLUSIONS

The area off the south west coast of the Isle of Wight should provide a suitable place for a wave-current information study over an immobile bed. The actual position of deployment of the instrument module will have to be deduced following a sidescan sonar survey, avoiding the spoil ground and dredging area and the isolated topographical features.

The Lundy site would be more suitable for the purposes of wave-current interaction experiments over a mobile bed. However, the velocity and sidescan information obtained here is rather sparce; it may be possible to do some further survey work "economically" if considered necessary.

In general, some of the criteria listed in Table 1 were too stringent, in particular (ii) and (iii). At either site (Lundy or IOW) during a long winter deployment, orbital velicities of 100 cm sec^{-1} may be obtained, but they will be very unusual. This is especially true if (iii) has been accomplished, ie the site is more than 10 km from the coast. It is more likely that the site will be within 5 km of the coast. Whereas wave-current-sediment interaction will occur at distances from the coast greater than this, the infrequency of occurence of these events (which will be associated with severe storms) will be such that data will not be easily obtained.

ACKNOWLEDGEMENTS

The criteria for site selection evolved as a result of discussions with R L Soulsby. The field information about the Isle of Wight site was obtained during research cruises led by A D Heathershaw and D N Langhorne. R Gleason was most helpful in directing us to the relevant wave climate information.

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APPENDIX

Estimation of wave activity at sea bed

The orbital velocities at the sea bed induced by surface waves have been studied by Hadley, Draper and Ewing. However, the shallow areas required for the wave current interaction experiment are not covered in this previous work. Whereas evidence of sediment motion by waves is found over all the continental shelf, the percentage of time that threshold is exceeded in deeper water is very small. We require a good chance of significant bottom activity during the period of deployment of the instruments. Thus the crucial orbital velocity was taken as 50 and 100 cm s^{-1} for the "immobile" bed (gravel) and as the oscillatory threshold under waves above for a given size (d_{50}) of sand for the mobile bed. The latter were interpolated from Komar and Miller 1974, see Table A1.

The heights of waves of a given period in a given depth of water that cause these velocities were then estimated using first order (Airey) wave theory from

$$\hat{u} = \frac{\dot{w}H/2}{\sinh k h} \qquad \text{A1}$$

This was solved for wave height (H) for given values of orbital velocity ($\hat{u}$), water depth (h) and wave frequency ($\dot{w}$). The wave number (k) of wave of frequency w in water depth h was found from

$$w^2 = g k \tanh k h \qquad \text{A2}$$

(The graphical solution of the latter given in le Mehauté 1976 was used.) The resultant wave heights are plotted in Table A2.

The values of wave height and period for incipient motion of a given grain size of sand (or those that produce an orbital velocity of 50 or 100 cm/sec) in a given depth of water are then plotted on an Hs - Tz scatter plot of the wave climate in the appropriate area. An example is given in Figure A1. The parts per thousand above the line can then be summed to estimate the proportion of the time that the crucial bottom velocities are exceeded.

OSCILLATORY THRESHOLD VELOCITIES FOR SAND
AFTER KOMAR AND MILLER 1974 (CM/SEC)

	Wave Period (SECS)				
d_{50}	5	7.5	10	12.5	15
1000μ	32	35	37	39.5	41
500μ	23	26	28	30	31
250μ	16	19	21	23	24
125μ	12.5	15	17	19	20
63μ	9.5	11.5	13	15	16

(Interpolated and smoothed)

TABLE A1

WAVE HEIGHTS THAT GIVE A THRESHOLD ORBITAL VELOCITY FOR A GIVEN GRAIN SIZE (m.)

depth = 10 m — Wave Period (secs)

d_{50} μ	5	7.5	10	12.5	15
1000	1.4	0.9	0.9	0.9	0.9
500	1.0	0.7	0.7	0.7	0.7
250	0.7	0.5	0.5	0.5	0.5
125	0.6	0.4	0.4	0.4	0.4
63	0.4	0.3	0.3	0.3	0.3

depth = 20 m

d_{50}	5	7.5	10	12.5	15
= 1000μ	6.4	1.9	1.4	1.3	1.3
500μ	4.6	1.4	1.1	1.0	1.0
250μ	3.2	1.0	0.8	0.8	0.8
125μ	2.5	0.8	0.7	0.6	0.6
63μ	1.9	0.6	0.5	0.5	0.5

depth = 30 m

d_{50}	5	7.5	10	12.5	15
= 1000μ		3.8	2.1	1.8	1.7
500μ		2.8	1.6	1.4	1.3
250μ		2.1	1.2	1.1	1.0
125μ		1.6	1.0	0.9	0.9
63μ		1.2	0.8	0.	0.7

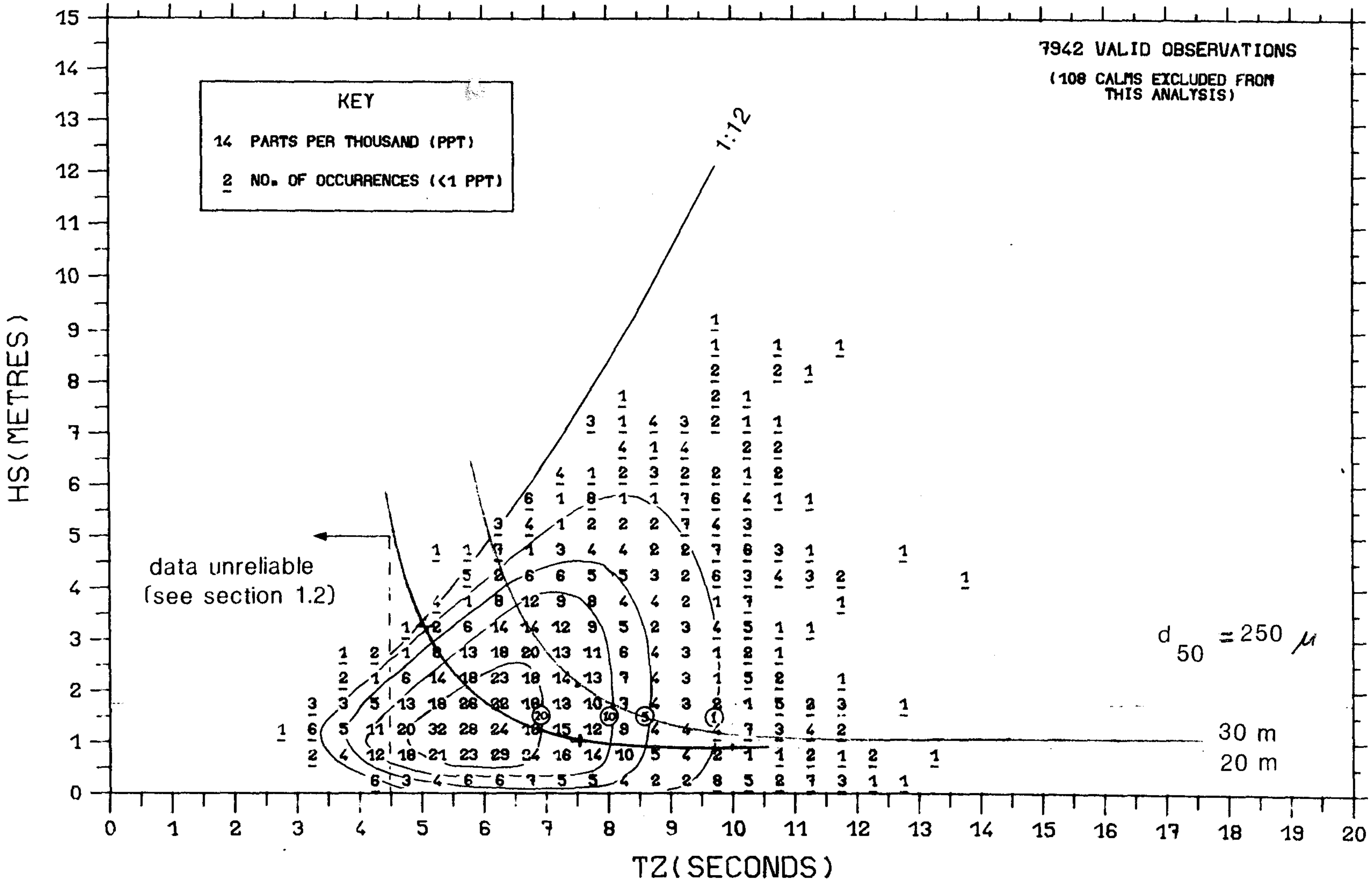
depth = 40 m

d_{50}	5	7.5	10	12.5	15
= 1000μ			3.2	2.4	2.2
500μ			2.4	1.8	1.6
250μ			1.8	1.4	1.3
125μ			1.5	1.2	1.0
63μ			1.1	0.9	0.8

depth = 70 m

d_{50}	5	7.5	10	12.5	15
= 1000μ			9.8	5.1	3.8
500μ			7.4	3.9	2.8
250μ			5.6	3.0	2.2
125μ			4.5	2.4	1.8
63μ			3.4	1.9	1.5

TABLE A2



SCATTER PLOT OF HS AND TZ

ST. GOWAN LV 1975/6, 1977, 1978

Figure 1A

WAVE/CURRENT SITE SELECTION

i)	Tidal currents	-	50-100 cm/sec
ii)	Waves	-	up to 100 cm/sec orbital velocity; so for an 8-12 sec wave in 20 to 30 m of water this needs a wave height of 4 to 6 m.

iii) Away from coasts (> 10 km) for simpler application of results to numerical model.

iv) Bed characteristics
a. Flat - no obstructions for up to 30 x depth.
b. Preferably no banks or sand waves.
c. Initially, immobile sediment (perhaps gravel best for this).
d. Mobile sand required later in programme.

v) Water characteristics
a. Little or no weed.
b. No stratification.
c. Clearish water (avoid mud?).

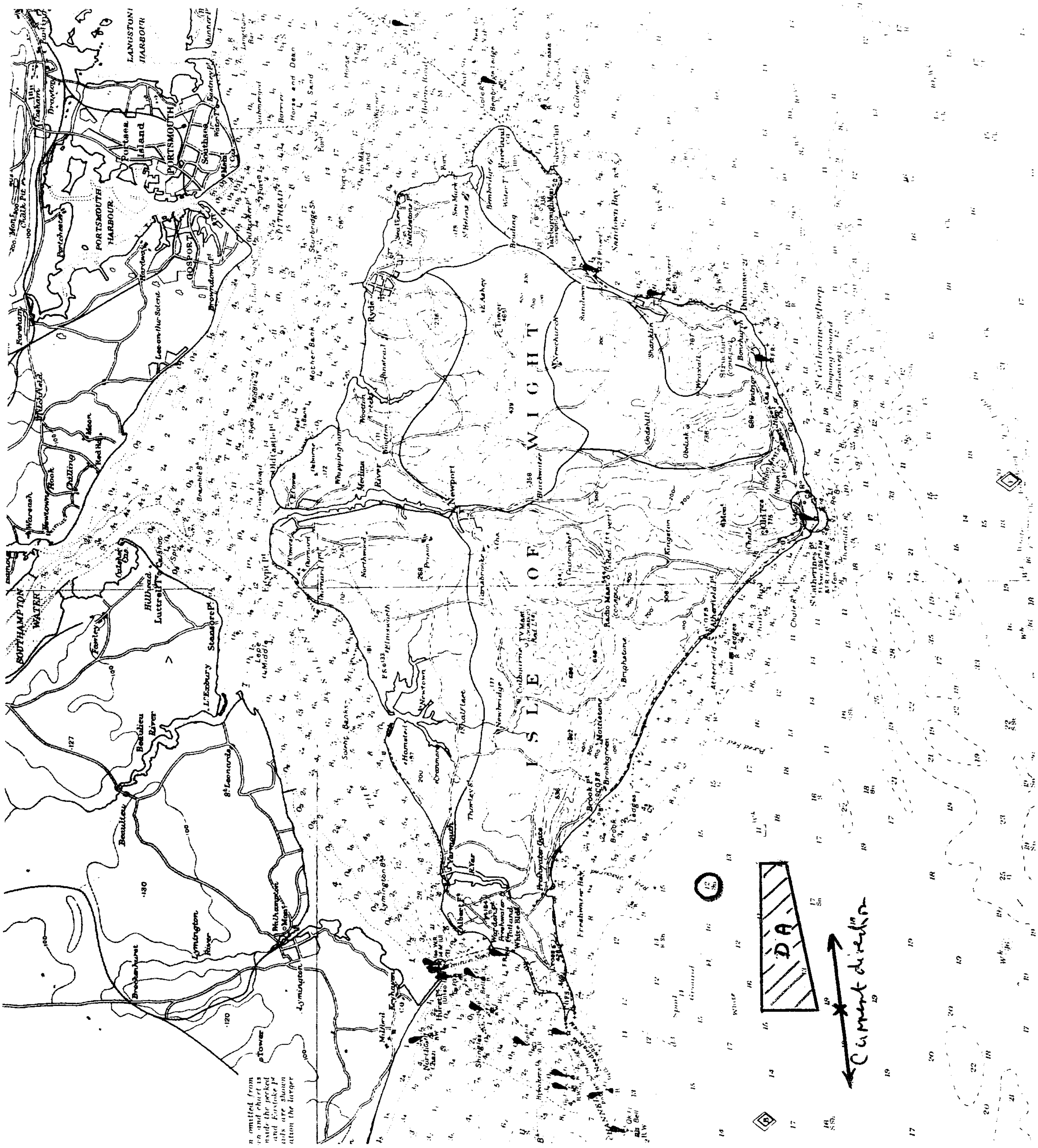
vi) Mooring/Saftey
a. Low trawl activity.
b. Low shipping activity.
c. Clear of submarine cables.

Table 1

RLS/RHW

Approx. scale (km)

0 1 10

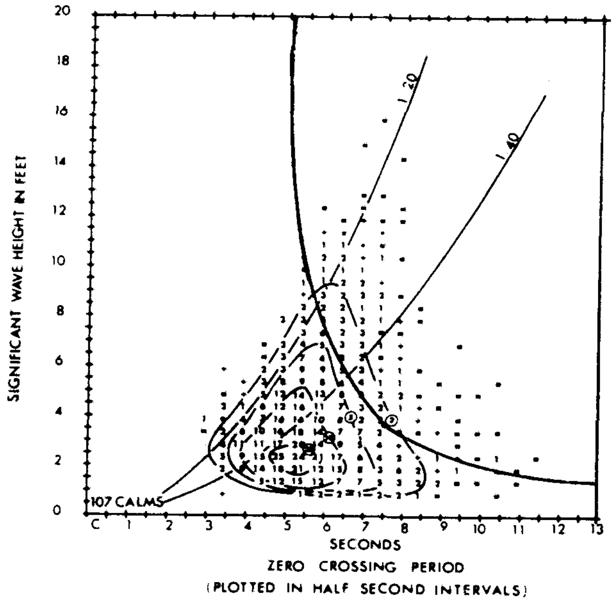


O Suggested site D A Dredging Area

× Current meter station

Figure 1

Shambles Light Vessel



h = 30 m

$\hat{U}$ = 10 cm/sec

COUNT = 77 ppt

Scatter diagram for the significant wave height and zero-crossing period in parts per thousand for 1968.

FIGURE 2

DEPTH OF WATER m

ORBITAL VELOCITY (cm/s)	20	30
10	20.5	7.7
25	4.8	0

TABLE 2 Estimate of percentage of time that wave orbital velocities exceed given magnitude

Data from Shambles light vessel - similar to IOW site

ST GOWAN

DEPTH OF WATER	20m	30m
WHOLE YEAR	46	25
SPRING	44	23
SUMMER	23	5
AUTUMN	58	25
WINTER	64	41

HELWICK

DEPTH OF WATER	20m	30m
WHOLE YEAR	47	24
SPRING	45	26
SUMMER	18	4
AUTUMN	58	30
WINTER	65	42

Seasonal data not available: seasonal variation interpolated from St Gowan and Scarweather Bank

SCARWEATHER BANK

DEPTH OF WATER	20m	30m
WHOLE YEAR	42	16
SPRING	40	20
SUMMER	11	1
AUTUMN	51	22
WINTER	57	27

Table 3 Estmated percentage exceedence of threshold of motion of 250μ sand by bottom orbital wave velocity.

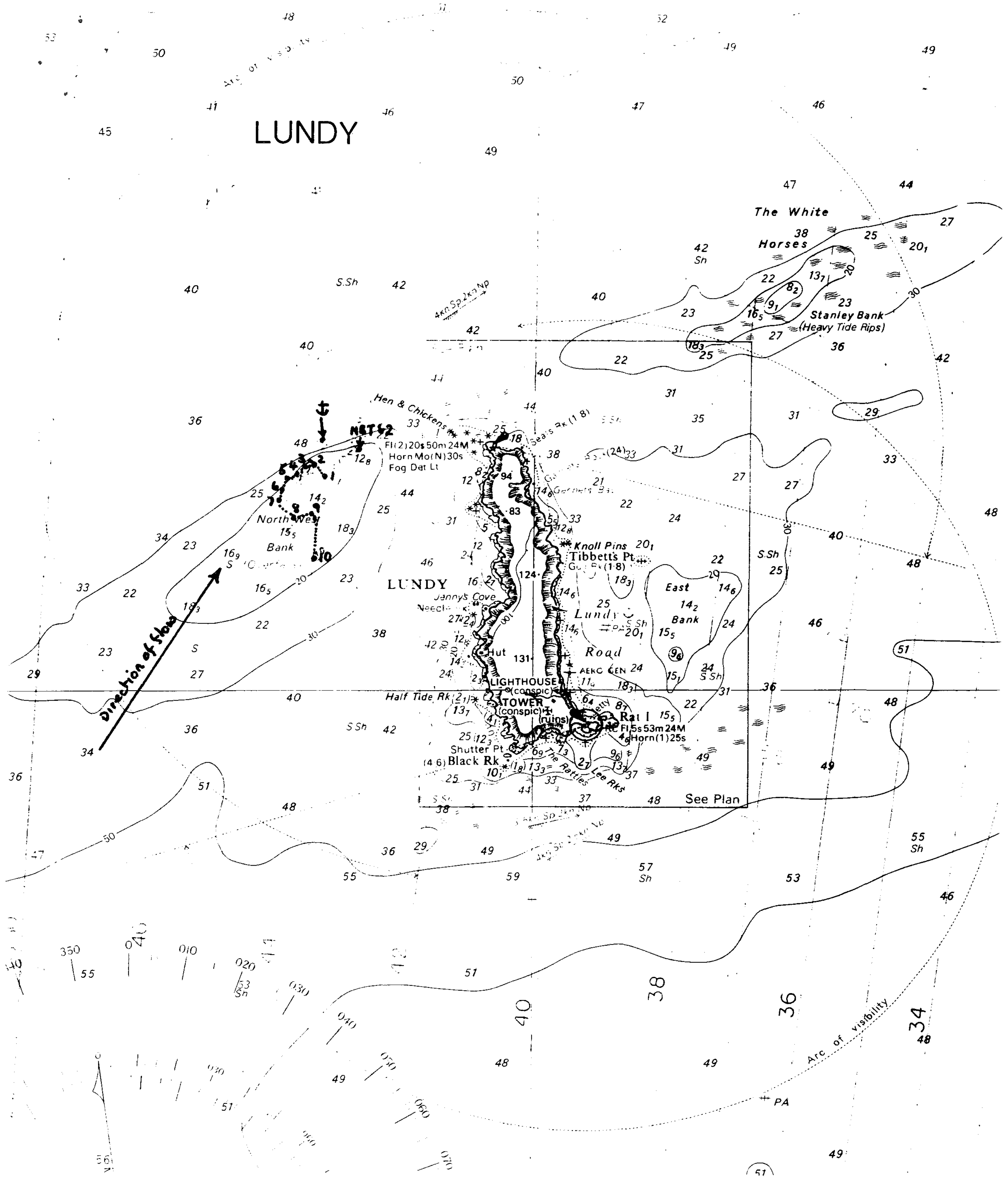


Figure 3 Section of chart showing the sidescan survey track, the anchor and sediment sampler positions and the direction of flow of the flood tide.

LUNDY

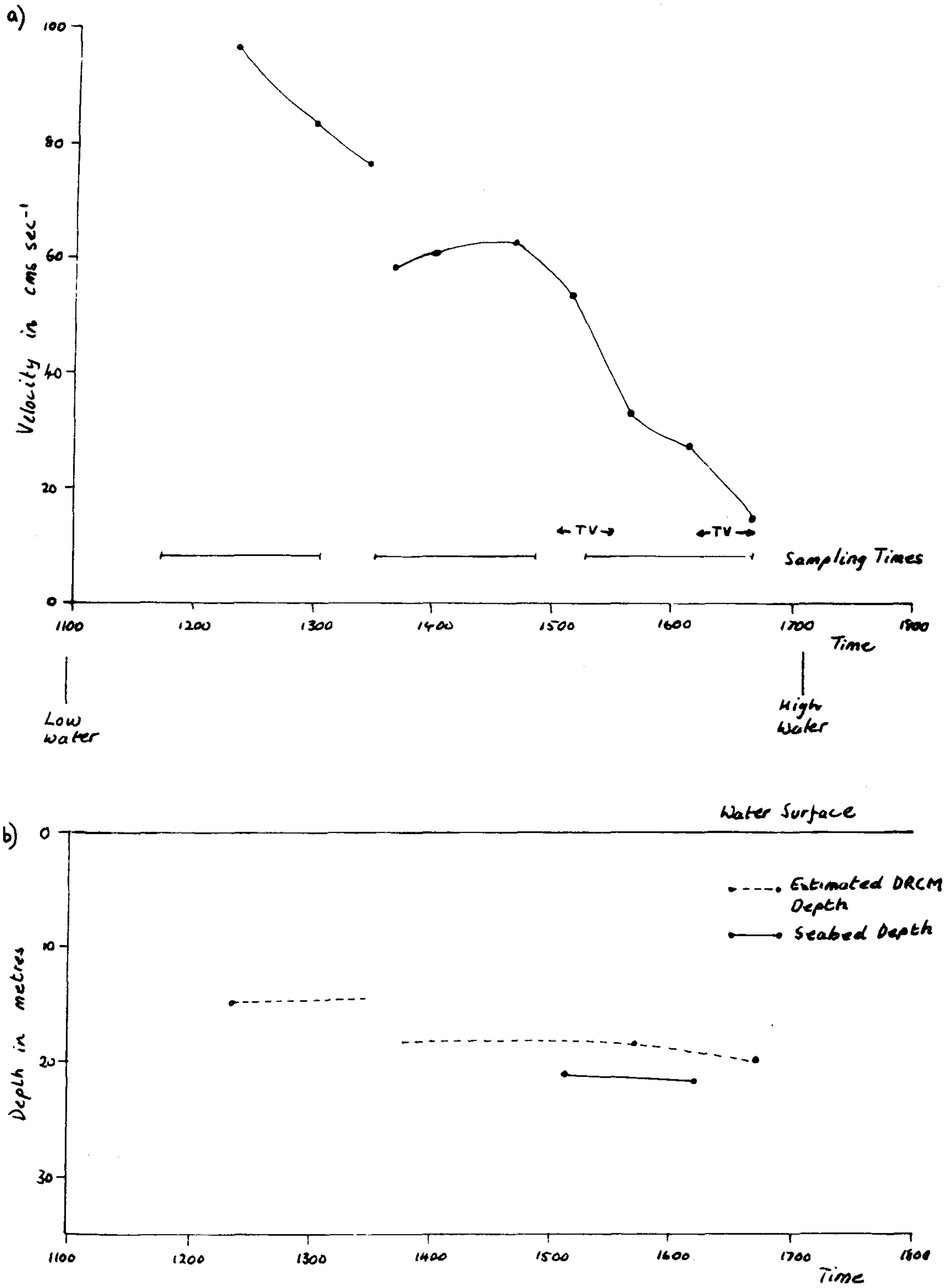


Figure 4 a) Direct reading velocity measurement over the flood tide.
b) Depth of current meter and seabed during the flood tide.

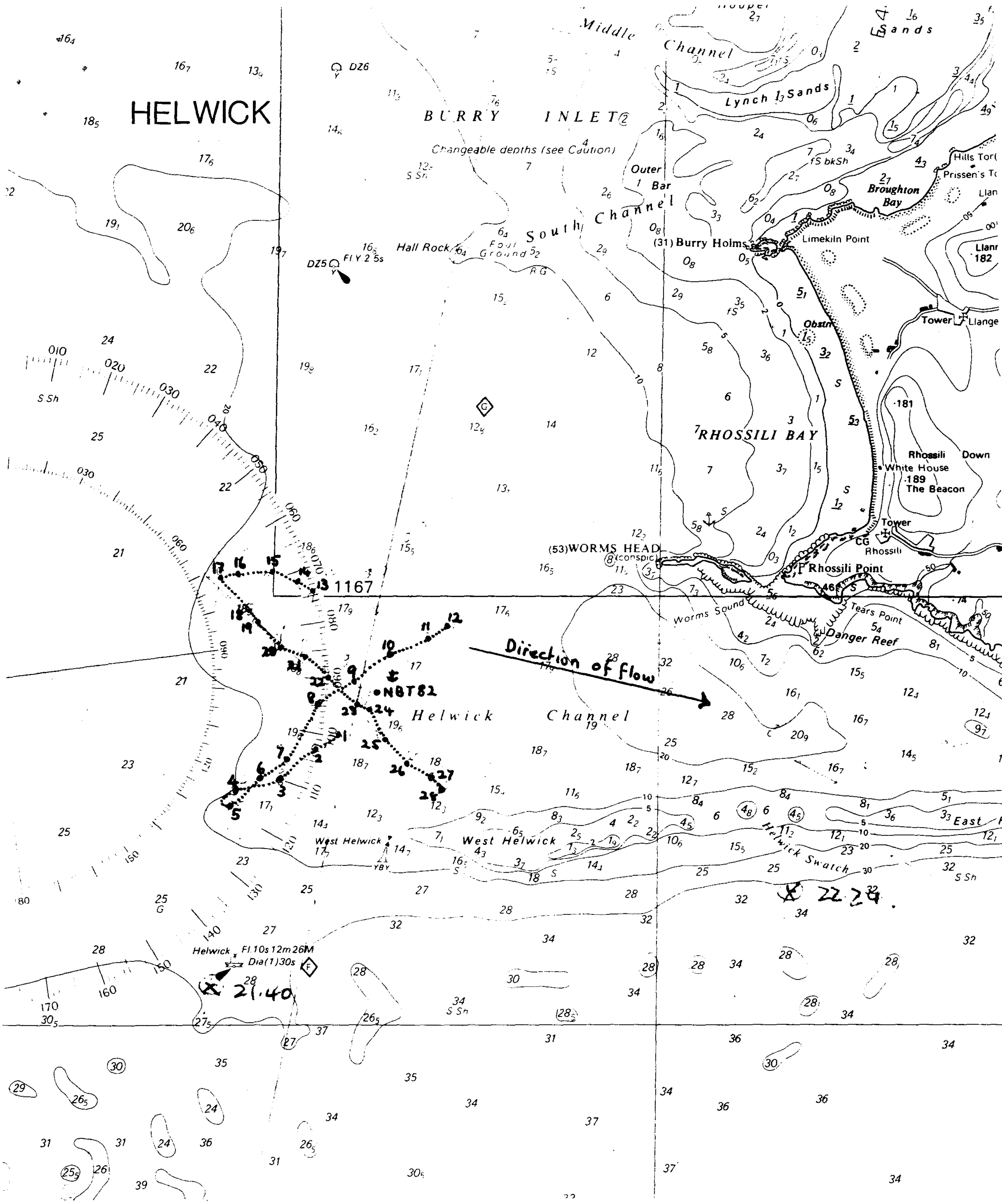


Figure 5 Section of chart showing the sidescan survey track, the anchor and sediment sampler positions and the direction of flow of the flood tide.

HELWICK

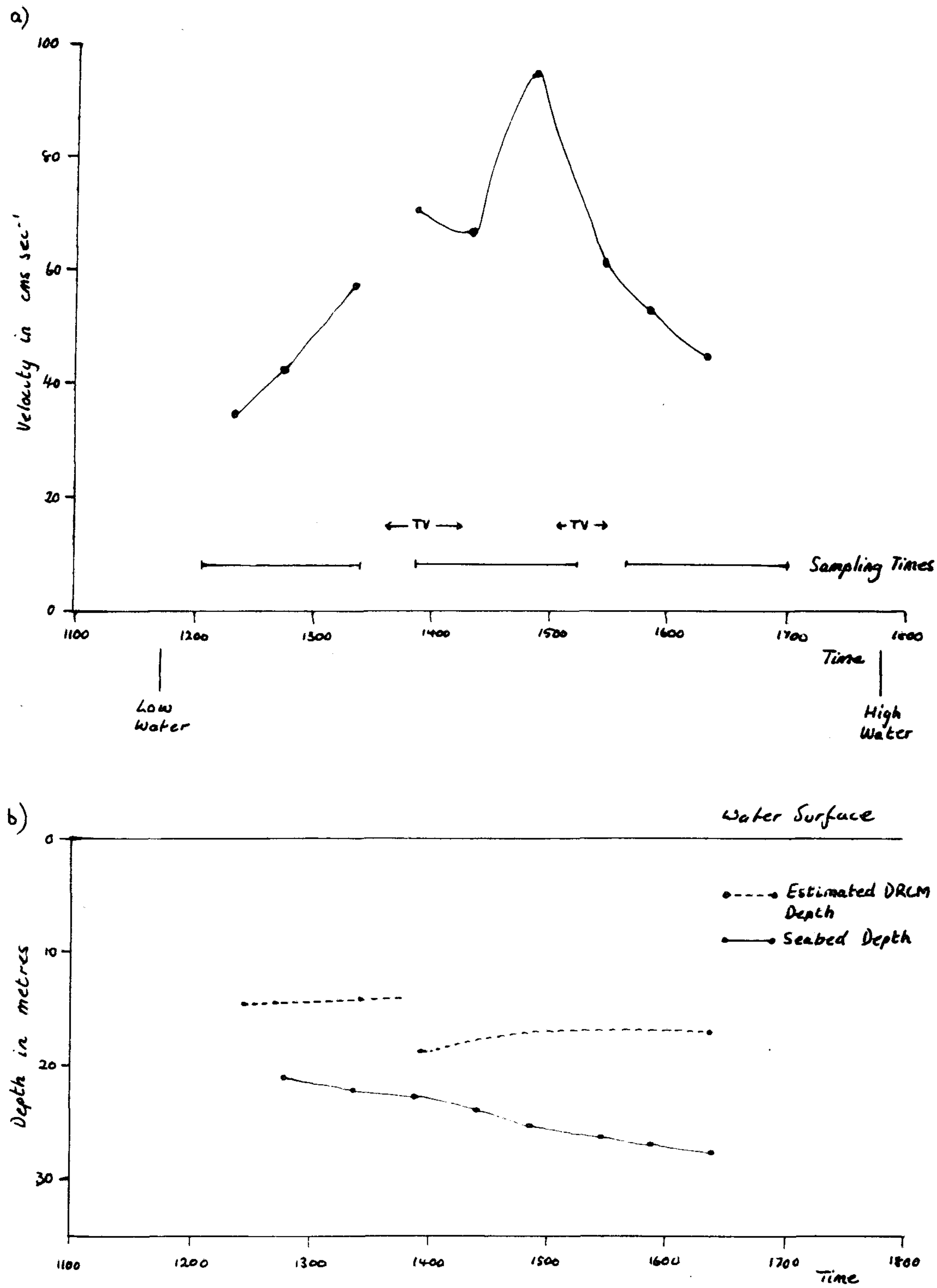
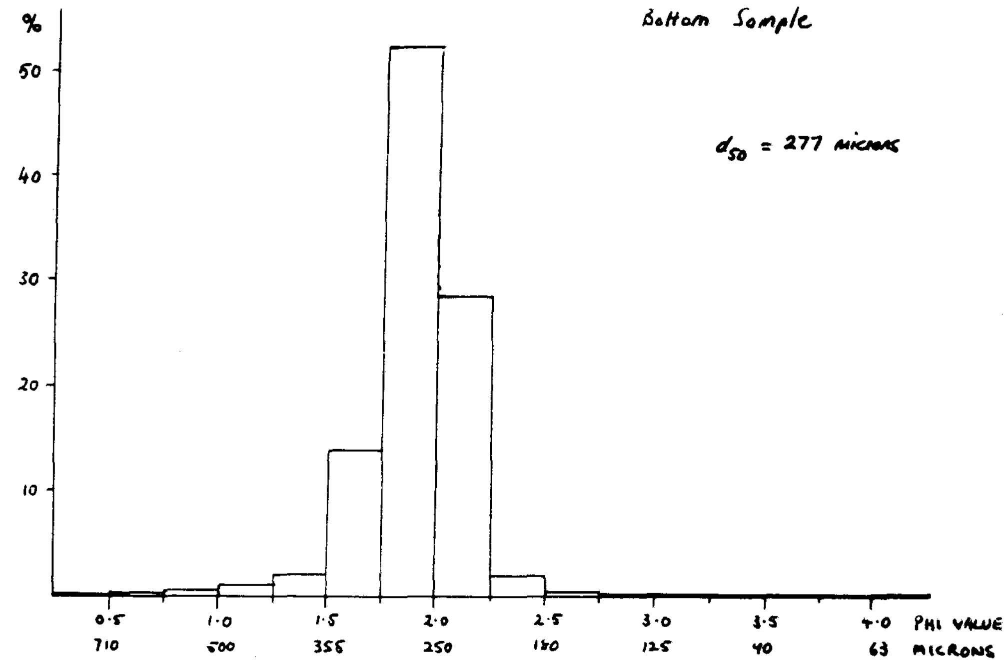


Figure 6 a) Direct reading velocity measurement over the flood tide.

b) Depth of current meter and seabed during the flood tide.

LUNDY

a)



b)

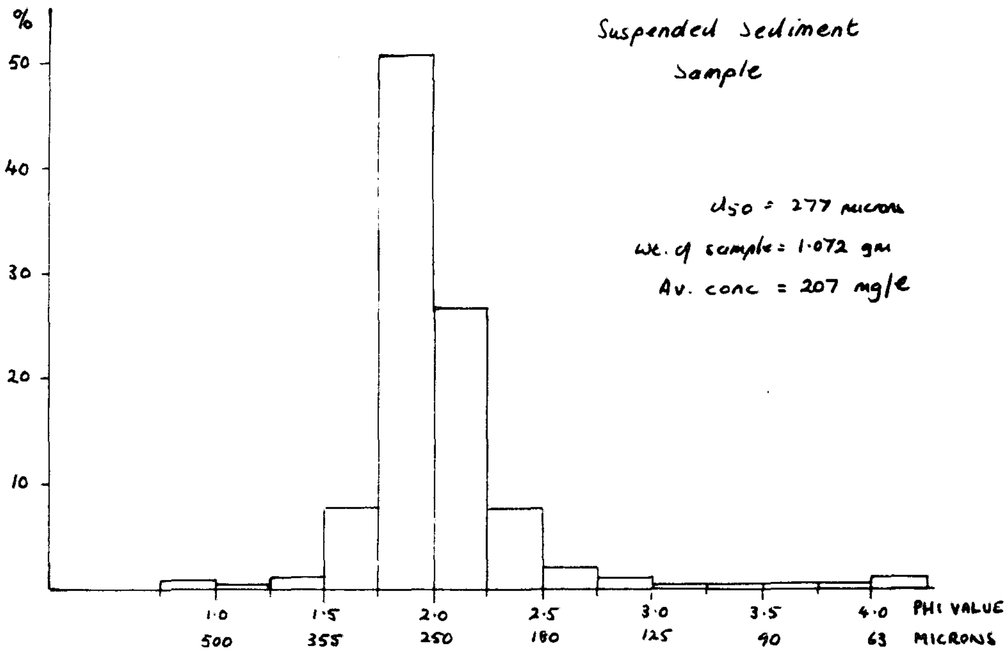


Figure 7 a) Percentage distribution of grab sample grain sizes.

b) Percentage distribution of suspended sediment grain sizes.

HELWICK

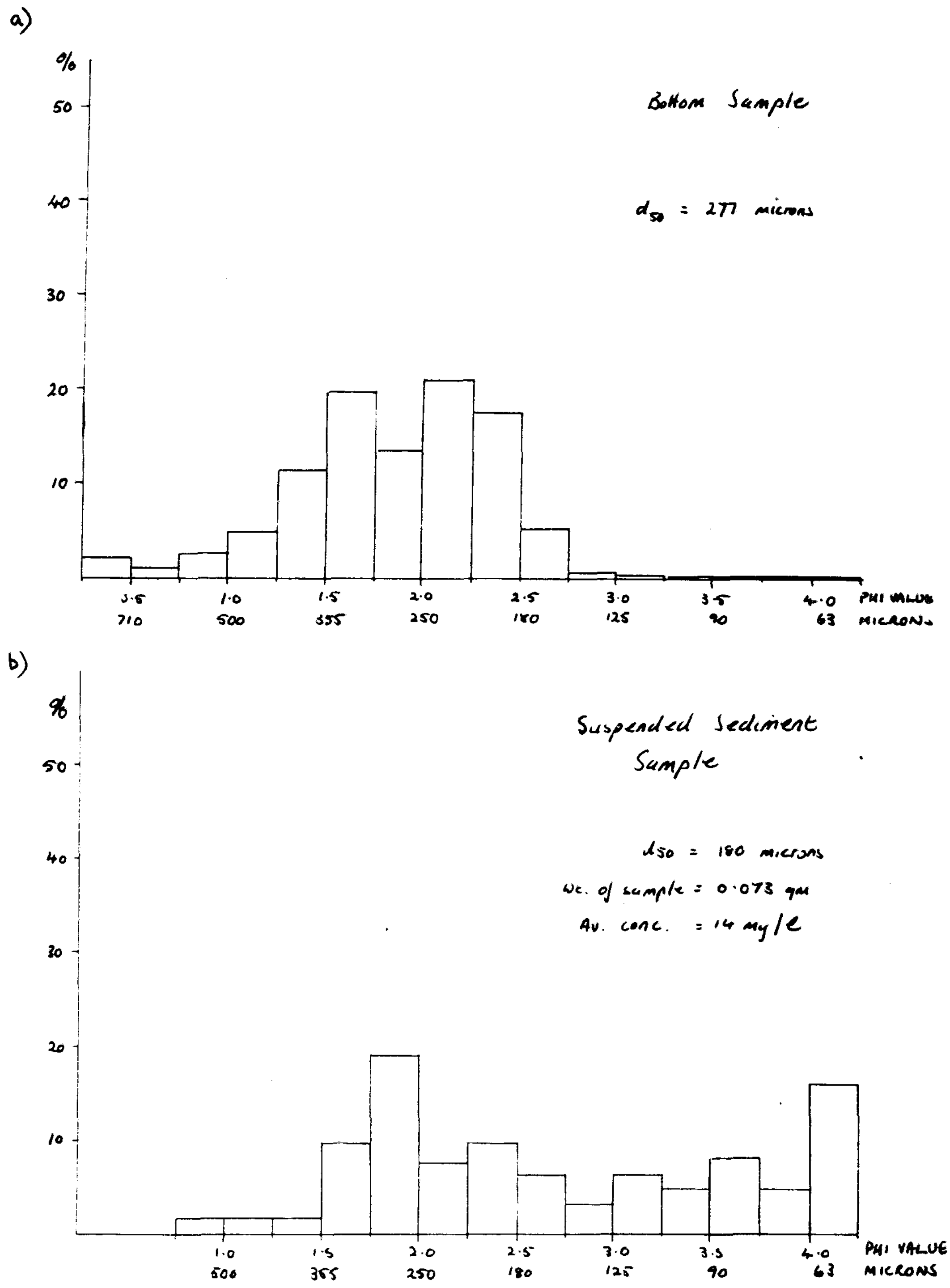


Figure 8 a) Percentage distribution of grab sample grain sizes.

b) Percentage distribution of suspended sediment grain sizes.