Fig. 4 is poor in all copies of this report.

I.O.S.

SWANSEA BAY (SKER) REPORT

A D Heathershaw, A P Carr, M W L Blackley and
F D C Hammond

PROGRESS REPORT
for the period
August 1977 to July 1978

Report No 74

1978

NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF OCEANOGRAPHIC SCIENCES

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Institute of Oceanographic Sciences
Crossway
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Somerset

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SWANSEA BAY (SKER): FOURTH PROGRESS REPORT

1. INTRODUCTION

Three previous Progress Reports (IOS Reports 20/75, 26/76 and 48/77) described the work carried out to the end of July 1977. This, the Fourth and final report in this series, describes work undertaken during the period 1 August 1977 to 31 July 1978: it is intended that all future developments in the study will be described in the individual Topic Reports (see Appendix 1) which will be completed before another annual Progress Report becomes due.

The format of this Report is similar to previous Progress Reports and consists of 3 main sections, as follows:

1. Report of progress in the 12 months up to 31 July 1978
2. Summary
3. Plans for the future

Three Topic Reports (IOS Reports 42/77, 51/77 and 60/78)have now been produced which may be considered as dealing with the historical, geological and geophysical background to the main physical study. Because of the varying rates at which different types of data have been processed the sequence and timing of Topic Reports outlined in the Third Progress Report has been amended. Thus the latest Topic Report 'Geophysical interpretation and sediment characteristics of the offshore and foreshore areas' appears ahead of those dealing with waves and tidal currents. The numbering now corresponds with the order in which Topic Reports will appear and the revised schedule is shown in Appendix I.

During the period covered by this report effort has been devoted almost entirely to the processing and analysis of data. These tasks are now well in hand and the project has been aided recently by the availability of additional manpower.

2. PROGRESS ON THE SWANSEA BAY PROJECT TO 31 JULY 1978

A brief summary is given here of Topic Reports 2 and 3. Topic Report 1 was summarised in the last Progress Report.

2.1 Topic Report 2: Evidence for Beach Stability: Photogrammetric and Topographic measurements.

2.1.1 Evidence from photogrammetry (1968–1975)

A comparison of the beach contours between 1968–1970 showed only a marked landward displacement along the lower part of Kenfig Beach (Fig 1). Between 1970–1975 erosion was concentrated higher up the beach face not only on Kenfig Beach but also on Margam Beach.

The 1968 aerial photographs showed 32,000 m^2 of peat and clay exposed on Margam Beach but no such exposures on Kenfig Beach. By 1970, however, 3500 m^2 were visible just north of Sker Point. The 1975 survey showed 44,500 m^2 and 28,000 m^2 of peat and clay on Margam and Kenfig Beaches respectively. Cobble spreads also became more extensive over the period, particularly on Kenfig Beach. All these trends were essentially long-term, not seasonal. Figure 2 shows some of the recorded changes in diagrammatic form.

2.1.2 Evidence from beach profiles (September/October 1975 to April/May 1977)

The extremes of range of height on the sections occurred mainly during the winter months when short periods of stormy weather removed large quantities of material from the beach. In general the whole inter-tidal profile moved in the same sense (ie it all showed erosion or accretion) but there was little consistency between neighbouring sections in any one month. The maximum height range was just over 1 m. This variation in range increased from N to S indicating that the beaches became less stable in this direction.

Figure 3 shows the changes on Section Q during the winter 1976/77: they are small and reach a minimum at mid-tide level.

2.1.3 Calculation of changes in volume of beach material

Although monthly changes in erosion and accretion were appreciable the net imbalance of material was quite small. Only Section Z, nearest Sker Point, showed persistent erosion. Sections L, N and P (Margam Beach) also showed a net loss of material while the intervening area covered by Sections R, T and V showed gains, especially R. This may be explained by the addition of sand from the eroding dune system, the effect of the R Kenfig on sand transport, and the attempt of the area to regain equilibrium following the end of commercial sand extraction.

Taking a two-year period up to October 1977, and assuming the intervening area of beach behaves in a similar manner to the nearest profile, would imply overall changes in height of +1, –4 and less than +1 cm for Aberafan, Margam and Kenfig Beaches, respectively. This compares with a calculated fall in level of 25 cm for Margam and Kenfig Beaches attributable to sand-winning up to the end of 1973.

2.2 Topic Report 3: Geophysical Interpretation and Sediment Characteristics of the Offshore and Foreshore areas

Samples were obtained by means of vibrocoring, box-coring and grab sampling. Geophysical data were acquired by side-scan sonar and continuous seismic profiling.

Although the bedrock was mantled with a substantial thickness of superficial material, the CSP records indicated a surface with a gentle slope to the south-west. Upon this surface glacial drift of varying thickness has been deposited. Some of the present day topographic features, such as the North Kenfig Patches and the Outer Green Grounds, largely owe their existence to the surface expression of these deposits.

Channels cut in the drift surface and bedrock appear to have been infilled, probably with outwash material. This is shown locally as successive layers, 2 to 3 metres thick. The rise in sea level associated with the Flandrian transgression followed and resulted in the deposition of a wide variety of sediments in the mantle up to 10 m thick.

Later, conditions similar to those which exist today were established and resulted in the formation of South Kenfig Patches, Hugo Bank and Scarweather Sands. All three are resting on a flat Pleistocene or Flandrian surface. The first two banks are approximately 8 m thick whilst Scarweather Sands is in the region of 12 m (Figure 4). Their present-day position seems to be a response to the hydrodynamics acting on the sediments in this area, although existence of a Boulder Clay outcrop to the north of the South Kenfig Patches may have some effect on that bank's position. The banks themselves are composed of, and in general surrounded by, fine to medium sands mostly between 2 to 2.5ϕ (Figures 5 and 6). However, the channels between the banks are floored with a much coarser material, reminiscent of the cobble lag deposits found on parts of Kenfig Beach. Brown shelly sand was also found in the vicinity of the Outer Green Grounds overlying Boulder Clay and thickening away from the Grounds in a northerly and southerly direction.

A large central area of very fine sediment up to 80 cm thick occurs in a natural depression lying between the North Kenfig Patches and the Outer Green Grounds. In many of the vibrocores the junction between the fine silts and clay, and the underlying sand, was very distinctive being shown as a layer of fragmented shells and sand and clay pellets up to 30 cm thick. The boundary of the mud mapped by Commander Alldridge in 1859 is very similar to the area occupied by the present day fine sediment, but its thickness is thought to be greater now due to the deposition of dredging spoil. It is hoped to determine the age and rate of deposition of this material by using a radioactive isotope of Pb^{210}.

Over the remaining areas where the Pleistocene tills were at or near the surface the sediment is much coarser.

Sand waves were detected on the limbs of the South Kenfig Patches, east and west of Hugo Bank, east of Scarweather Sands and southwest of Hutchwns Point. Where the waves were asymmetrical, those on the north flank of South Kenfig Patches and those off Hutchwns Point indicated movement of material in a southeasterly direction whilst those on the southern limb of South Kenfig Patches indicated transport in a northwesterly direction.

The sands of Aberafan, Margam and Kenfig beaches were sampled at HW, MW and LW on a number of occasions along the lines of the topographical survey sections. Normal to the beach the finest material was always found at LW whilst alongshore the material tended to become finer towards the centre of Aberafan Beach, towards the River Kenfig and again towards Sker Point. However, these changes in sediment size were only minor (over two thirds of the data points falling within a range of $< 0.5\phi$ (approx 200-260 μm)) and thus not very conclusive.

Other aspects considered in Topic Report 3 are the results of a series of six boreholes in the Kenfig Dunes area. These are shown as Figure 7 of the present report.

2.3 Current measurements, sediment transport rates and meteorological forcing

During the period covered by this Report the preliminary analysis of all the recording current meter data collected in Swansea Bay has been completed. These data are to be described in a separate IOS Data Report (additional to the Topic Report series).

From the results obtained so far it has been possible to deduce certain features of the mean water circulation in the Bay: these results are summarised in Figure 8a. However further work remains to be done to establish the mean sediment circulation (see later). Recent work by Pingree (1977) suggests that the effect shown in Figure 8a might be associated with the formation of large eddies or gyres in the mean circulation off headlands and promontories. The occurrence of such a feature in the Swansea Bay area has now been confirmed experimentally in this work and in theoretical studies (R Uncles, personal communication) as shown in Figure 8b.

An unusual feature to emerge from the residual circulation studies so far completed is the pronounced reversal in the mean flow at Station A (see Figure 9) with increasing height above the sea bed. This feature has been observed consistently over a period of 2 years with different instruments and is therefore considered to be a genuine feature of the flow. Its appearance has important consequences in any attempt at modelling the circulation using 2D depth averaged models.

Another interesting feature to emerge in the mean circulation is the area of divergence (see Figure 8a), which occurs between Port Talbot and Sker Point. The area immediately due N of this divergence is an area of low tidal and residual currents and coincides with the central silty area off Port Talbot, shown in Figure 5.

More recently work has commenced on examining the response of the circulation to meteorological forcing. For this purpose wind speed and direction data from Port Talbot and atmospheric pressure data from Rhoose (see Figure 10) are being used. Additionally atmospheric pressure gradient data based on pressure readings at Hartland Point, Rhoose and Aberporth are utilised (see Figure 10). Multiregression analysis using the 24 hr 50 minute residual currents and winds, atmospheric pressure and pressure gradient terms has been carried out, using the current meter data from shallow locations in the bay where the forcing effects are likely to be greatest. In these preliminary analyses no attempt has been made to separate the tidal and meteorological residuals, the tidal currents in any case being low. However techniques are now being developed which will enable the meteorological residuals to be isolated. This will involve harmonic analysis of the records for the S_2, M_2, M_4 and M_6 components and removal of the purely tidal signal from the current meter data.

The results of a typical multiregression analysis, using current meter data from Station B (Figure 1) are summarised in Table 1. At this location the tidal flow is constrained to lie along the coast and we have examined the response of the alongshore component of the residual flow ($\overline{u}_y$), at a height of 2 m above the sea bed, to the various forcing terms. The relative effectiveness of these terms is best determined from the standardized partial regression coefficients given in Table 1.

This shows that winds from the SE are most effective in forcing the mean current along the coast to the North whereas SW winds being about a reversal in the residual circulation causing a flow to the SE. This result suggests that SE winds tend to enhance the mean circulation in the area, which at Station B is to the North or North East, whereas SW winds can, in fact, reverse it. The latter effect may occur as a result of SW winds driving water up into the head of the Bay and producing a compensatory return flow at the sea bed. Such effects will of course influence the direction of movement of sediment and therefore need to be considered in the overall sediment circulation pattern of the area.

It is hoped to examine this and other features of the mean circulation in future studies.

Work is also in hand to compare measured and predicted sediment transport rates in the offshore area using the available hydraulic data and the results of radioactive tracer experiments (Heathershaw and Carr, 1977). Six sediment transport formulae have been provisionally chosen for analysis (see Table 2); these are either bedload or total load formulae. Suspended load estimates have been based on measured concentration profiles and the Rouse relationship (5) together with values of the friction velocity derived from measured near bottom velocity profiles.

On the basis of these comparisons it is intended to use one of the above formulae, in conjunction with the current meter data, to determine the mean sediment circulation pattern in the area.

However, some preliminary comparisons of measured and predicted rates of transport have already been carried out for peak transport rates at spring and neap situations. For example bed load transport has been estimated using Bagnold's (1963) formula but in a form modified by Gadd et al (1978). Bagnold's original formula expressed the bed load transport rate q_{sb} in terms of the stream power (ω) and an efficiency factor k, that is

$$q_{sb} = \frac{\rho_s}{(\rho_s - \rho).g} \cdot k\omega \tag{1}$$

where ρ_s is the sediment density, ρ is the density of sea water and ω is the stream power given by the product of the bed shear stress and the friction velocity u_*. The application of this formula requires specification of the efficiency factor k which has been shown to be a function not only of grain size but also of the bed form amplitude. This dependence has been removed by Gadd et al (1978), who, using the flume data of Guy et al (1966), expressed (1) in terms of the current at 100 cm above the sea bed ($\overline{u}_{100}$) and a threshold velocity (u_{th}) so obtaining

$$q_{sb} = \beta \left(\overline{u}_{100} - u_{th} \right)^3 \tag{2}$$

where β is a constant obtained from flume data.

In this study we have taken current measurements at 200 cm above the seabed ($\overline{u}_{200}$) and by assuming that the near bed velocity distribution is logarithmic, that is

$$\overline{u}(z) = \frac{u_*}{\chi} \ln \frac{z}{z_0} \tag{3}$$

where χ is von-Karman's constant, u_* is the friction velocity $\left(u_*^2 = \frac{\tau_0}{\varrho}\right)$, z is the height above the sea bed and z_0 is the measured roughness length, have expressed (2) in terms of measurements at 200 cm. This assumption is to some extent justified by the near-bottom velocity profile measurements which have been carried out in this study and which are described later. Comparisons of measured and predicted bed load transport rates are shown in Tables 3 and 4 together with the results of suspended load calculations described in 2.4. These results show that for material coarser than 40μm the suspended load transport rate is unlikely to exceed that due to bed load transport. Furthermore the figures shown in Table 4 indicate suprisingly good agreement between measured and predicted net transport rates and suggest that the radioactive tracer has in this case moved mostly as bed load.

Bagnold's (1963) formula is one of the simplest expressions currently in use by oceanographers and engineers, and is based on the physics of the stream power concept.

As an example of a more sophisticated expression, which is to be used in this study, Ackers and White's (1973) formula is based largely on the techniques of dimensional analysis and has been calibrated against a large number of laboratory and field experiments. This formula is generally considered to be the best of those currently available (eg Swart, 1976; Flemming and Hunt, 1976) although it does have a number of limitations when applied to sediment transport in the sea. In particular it expresses the sediment transport in terms of a depth mean flow requiring that the velocity distribution over the entire flow depth be known or that some assumptions be made regarding it.

The current measurements in Swansea Bay are also being used to study the potential erosion characteristics of the sea bed. For example. Figure 11 shows current exceedance curves from four locations which illustrate well the increasing competence of the currents to transport sediment as one moves offshore from a low to a high tidal energy regime and as one moves along the coast in a SE direction towards Sker Point (see Figure 1).

2.4 Beach Experiment Data

2.4.1 Fluorescent tracer studies

2.4.1.1 The design of the tracer experiments undertaken in November 1976 and May 1977 was described in detail in the Third Progress Report. However brief details are included here for completeness.

In each of the two series of experiments fluorescent labelled sand, closely corresponding in size range to that of the actual beach, was used. In the first series 3 colours, red, blue and green, were injected, each injection being of 0.5 tonnes. The initial injection corresponded to neap tides. An excavation 2 cm deep was made into the beach surface over an area 3.5 m^2 and the tracer was placed in this, and levelled so that the surface was comparable with the adjacent beach. The tracer was then thoroughly wetted with a solution of detergent in sea water to reduce its surface tension. At spring tides the other 2 colours were deployed, one batch in a similar fashion to the neap's injection; the other as a thin veneer on the beach surface. In the 1977 experiments injections again corresponded to neaps and spring tides, and were similar in design but only 2 colours (red and blue) of fluorescent sand were sand.

In all cases systematic sampling was employed. Close to the injection site cores were taken but elsewhere surface sampling was used, between 170 and 270 samples being taken at each low water for a total of 16 tides. During periods of darkness maximum travel was determined by an ultra-violet lamp powered by a generator mounted on the back of a Land-Rover. Because tracer did not appear to go offshore in the November experiment, only the exposed beach was sampled in the spring 1977 experiments.

During the period of the current Progress Report the laboratory counting of the tracer in the samples has been completed and much of the detailed analysis and computation has been carried out. The latter includes computer graphics output of the tracer distribution on the beach such as that shown in Figure 12.

2.4.1.2 There are several interesting aspects of the results. These include:

(a) the very shallow depth of disturbance of the beach surface, and hence of the tracer during the period of the experiments. For example, in the first series of experiments, after 18 tides, less than 6 per cent of the red fluorescent tracer was subject to beach processes, virtually all the rest remaining in situ below the thin surficial mobile layer. This trend was even more marked in the May 1977 experiments. As a result centroid calculations have been made with both the uniform grid pattern and with closer detail near the injection site; and on the basis of either incorporating the whole mass of tracer in the computation or considering only the proportion actually subject to movement. An example of the latter is shown as Figure 13.

(b) Figure 13 indicates that, because the surface of the tracer is not in equilibrium with the, albeit thin, mobile sand of the actual beach, initial transport is relatively high compared with that shown in subsequent search periods. This feature has also been observed in the radioactive tracer experiments undertaken offshore in Swansea Bay (Heathershaw and Carr, 1977). The similar pattern of movement for both the blue and green beach tracer is also noteworthy.

(c) During the first experiment in November 1976, no tracer was detected as far seaward as low water mark spring tides, let alone offshore, although some material did go seawards during the 1976–77 winter period thereafter.

(d) Before the second series of experiments in May 1977 a background search was undertaken to determine the level of tracer still present on the beach from the first series. It had been anticipated that after 6 months, including winter storm activity, that the background values would be relatively low and uniform. In the event they were sufficiently high that it was possible to compute a centroid for the blue background tracer. This position was less than 50 m S of the original injection site. Furthermore, subsequent background searches showed that the tracer left over from November 1976 was still subject to beach processes and could not be regarded as having reached equilibrium with the indigenous material.

2.4.2 Wave and tidal flow measurements

The objectives of these measurements were outlined briefly in the previous Progress Report. During the period under review considerable progress has been made towards achieving these objectives.

The overall requirement of these measurements has been to relate the observed alongshore component of wave-energy to the sediment transport rates obtained from the fluorescent tracer experiments (see Figure 14). The foremost requirement has therefore been to obtain estimates of the direction of wave approach at the beach. To this end, a suite of computer programs has been developed to process flow measurements from the beach experiments and in particular to compute smoothed estimates of the directional wave spectrum $F'(\sigma, \theta)$ where σ is the angular frequency of the waves and θ their direction of propagation, using the methods developed by Cartwright (1962) and Longuet-Higgins et al (1963).

The equipment and recording system were described in a previous report (IOS Report 48/77) and are not discussed here.

The first stage of the analysis of these data is to produce cleaned up and calibrated signals, examples of which are shown in Figure 15. The spectra, co- and quadrature spectra, are then calculated (see Figures 16–17) and from these the coefficients A_0, A_1, A_2, B_1 and B_2 obtained for computation of $F'(\sigma, \theta)$ where

$$F'(\sigma, \theta) = \frac{1}{H^2(\sigma)} \cdot \left(\frac{1}{2} A_0 + \frac{2}{3}\left[A_1 \cos\theta + B_1 \sin\theta\right] + \frac{1}{6}\left[A_2 \cos 2\theta + B_2 \sin 2\theta\right]\right) \quad (4)$$

Here $H(\sigma)$ is the depth attenuation function, which together with the coefficients A_0, A_1, B_1, A_2 and B_2 is defined in Appendix 3. A plot of mean direction $\bar{\theta}$ is shown in Figure 19.

Only a limited quantity of data has been analysed so far, largely for the purposes of validating the computer programs. However spectra of the velocity components u, v and w and the pressure p, show that the bulk of the energy arriving on the beach is centred on a wave period of 5 s. The bulk of this energy was contained in the onshore–offshore component of velocity, u (see Figure 16). Less energy is found in the alongshore fluctuation v, although an interesting feature of the v spectra is the energy occurring at low frequencies ($<$ .1 Hz) which is not associated with waves and may be due to the presence of longshore and/or tidal currents flowing over the beach face.

The uw co-and quadrature spectra (see Figure 17) show considerably more energy in the cospectrum than would be expected if linear wave theory were applicable, under which circumstances the bulk of the energy should be in the quadrature spectrum. This effect may be due to the waves being near to breaking although the symmetry of the velocity fluctuations shown in Figure 16 and their quasi-Gaussian probability distributions shown in Figure 18 would suggest that this was not the case. A more likely cause for the finite energy cospectra is a misalignment of the flow sensors with the inclined flow over the beach face; locally this is of the order of 1:50.

Insufficient data were analysed to draw any general conclusions regarding the directional characteristics of waves arriving on the beach. However, it is already apparent from the single data set described here, that the bulk of the energy-containing wave motions are aligned normally to the beach, ie wave rays normal to the beach. Departures from normal incidence do occur at low frequencies ($<$ .1 Hz) and high frequencies ($>$ .3 Hz) but these motions do not contain significant amounts of energy. For the period in which these measurements were made wind speeds of 5 m s^{-1} from the NW were recorded and it might have been expected that there would be some contribution to the directional spectrum by waves from this sector. Such seas would be locally generated, however, and it is possible therefore that they may not have influenced the velocity measurements at the depth (about 4.5 m) at which these measurements were made. Other measurements made in shallower water may reveal some effect of this nature.

The analysis of all the data from the 1976 and 1977 beach experiments is now in progress.

2.5 Suspended sediment and near bottom velocity profile measurements

The analysis of suspended sediment samples and velocity profile measurements, which was described in previous Progress Reports (IOS Reports 26/78 and 48/77) has now been completed. Concentration determinations have been carried out on a total of 692 samples and particle size analyses on 34 of these. A typical concentration profile is shown in Figure 20. A striking feature of all the Swansea Bay measurements is the extent to which fine particulate matter ($< 40 \mu m$) completely dominates the suspended load characteristics; the present of this 'washload', which is typically 1–2 orders of magnitude larger than the concentration of material $> 40 \mu m$ while having important environmental implications, is not considered lkkely to complicate the interpretation of the results of this study which is concerned mainly with the coarse fraction have a mean grain size of the order of 200 μm .

In order to compare peak suspended sediment transport rates (q_{ss}) with the previously calculated bed load transport rates (q_{sb}) we have combined the Rouse profile

$$\frac{C(z)}{C(a)} = \left(\frac{h-z}{h-a} \cdot \frac{a}{z}\right)^{\frac{W_s}{\kappa u_*}} \qquad (5)$$

where $C(z)$ is the concentration at a height z above the sea bed, $C(a)$ is the reference concentration at height a , h is the total flow depth and W_s is the settling velocity, with the logarithmic velocity profile (3), to obtain the suspended sediment flux q_{ss} . That is

$$q_{ss} = \int_{z_0}^{h} u(z) . C(z) \, dz \qquad (6)$$

where h has been taken as 20 m and z_0 as 0.5 cm.(6) has been integrated numerically using values of $C(a)$ derived from the suspended sediment measurements in the bottom 2 m of the flow.

This method of course assumes that the logarithmic velocity distribution extends to the free surface. Whereas, in practice, it may only hold in the lower regions of the flow. However, it is unlikely that departures from this behaviour will introduce large errors into the estimates. This follows since the bulk of the material coarser than 40 μm will in any case be concentrated near the sea-bed. In fact using (6) and measured values of $C(z)$ it can be shown that about 50% is concentrated in the lower 10% of the flow. The calculated suspended sediment transport rates (q_{ss}) are shown in Table 3.

2.6 Wave Data

The preliminary analysis of wave data from Swansea Bay has now been completed. Monthly summaries of significant wave height, zero crossing period, percentage occurrence of wave period and percentage exceedance of wave height have been produced. The periods covered by these records are as follows:

Scarweather Light Vessel (Waverider), 8/74 - 2/78

Port Talbot (sea-bed pressure wave recorder), 5/75 - 11/77

These data together with a limited amount of data from two other recorders in the Bay, will be used as input to the main wave climate studies of the area and in particular for the wave refraction analyses described in 2.7.

2.7 Wave Refraction studies

Some preliminary wave refraction analyses were described in a previous Progress Report (IOS Report 20/75) and these were useful in illustrating the focussing effects due to the offshore Banks. However the area covered by these computations was not considered entirely representative of the offshore bathymetry and did not include the whole of the Swansea Bay coastline. This latter point is important when considering the equilibrium response of the Bay to the prevailing wave climate. New bathymetry has therefore been produced which meets these requirements and is represented on a 25 x 25 km grid having 2500 500 x 500 m elements. The orientation of this grid (see Figure 21) was chosen to minimise the amount of land and to include as much of the coastline as possible. Two sets of bathymetry with nominal datings of 1859 and 1974 are again being used to study the effects of long term changes in the positions of the Banks.

2.8 Wave direction from Radar

Between October 1976 and November 1977 the 3.2 cm X-Band radar continued to function satisfactorily on its new site at the end of the southern breakwater at

Port Talbot. However on 11 November particularly severe weather caused waves to overtop the end of the breakwater. The hut housing the display unit was badly damaged and the radar equipment in the hut damaged beyond repair. Examination of wave records from a nearby recorder showed a significant wave height (H_s) of 4.63 m during this period. Further offshore at the Scarweather Light Vessel an H_s of 5.68 m was recorded.

During the period 25/10/76–11/11/77 183 days of radar data were collected consisting of 1460 frames of the sea-surface (see Figure 22). Just under a half of these contained wave direction information.

From these data 3 periods were chosen which represented the main fetch characteristics of the Bay (see Figure 10). In particular the measured wave direction obtained from each radar image was compared with the mean wind direction in the 3 hourly period prior to the picture being taken. It has been found that out of nearly 300 frames showing wave direction 99% of these gave a wave direction falling between 220 and 240°, this narrow band corresponding to the open fetch of the Atlantic (see Figure 10).

Further analysis of the radar data has been carried out. In particular the wave period has been calculated from the observed wave spacing, taking the depth of water at the time the image was recorded. Figure 23 shows wave period measurements from the radar and those from a nearby bottom-pressure wave recorder. Despite some scatter there is reasonable agreement between the two estimates and this suggests that the radar provides a reasonably accurate 2-D representation of the sea-surface.

3. SUMMARY

During the period under review effort has been devoted almost entirely to the analysis of data collected in the preceding 3 years of field work.

In the offshore areas certain features of the mean water circulation and observed sediment distribution can be related. Comparisons of measured and predicted sediment transport rates suggest that for coarse material, of the type found on the beach, transport as bed load is likely to be the dominant mode of transport. This result is to some extent supported by the results of radioactive tracer experiments.

On the foreshore fluorescent tracer experiments indicate a weak and variable transport along the beach to the NW or SE. Preliminary wave direction estimates suggest that waves are for much of the time normally incident on the beach, this finding being supported by wave direction estimates from the radar at Port Talbot.

The large body of historical, photogrammetric and beach profile data described in Topic Reports 1 and 2 point to the reduction in beach levels on Margam Beach as having been brought about by sand extraction on the foreshore. However it is only now towards the end of the period under review that preliminary results are beginning to emerge which relate to the physical processes which might be capable of replenishing the beach.

4. FUTURE WORK

As indicated in the Introduction, this project has now passed into its final phase with the analysis and interpretation of results. No further field work is planned.

Some preliminary results have been indicated here. However future work will entail considerable development of these and additional techniques and it is intended to utilise as much as possible of the existing IOS expertise. In particular extensive use of IOS Bidston computer programs is envisaged.

5. ASSESSMENT OF PROGRESS TOWARDS THE OVERALL OBJECTIVES OF THE PROJECT

The main objectives of this study include the identification and quantification of these processes responsible for the erosion of the foreshore on the East side of Swansea Bay.

Progress towards these objectives is conveniently thought of in two stages:

(1) completion of the largely historical and geophysical background to the problem;

(2) completion of the physical aspects of the study including identification and quantification of sediment transport processes.

The first stage is now complete and described in three Topic Reports (see Appendix 1). Historical records point to the long term variability of the area although there is little evidence to suggest that coastal erosion has been a widespread problem in the past. A more important clue to the recent problems on the East side of the Bay may be found in figures for the landings of dredged sand and gravel at Swansea and Briton Ferry. These show that extraction of sand from the foreshore in period 1970–73 was of the same order as that of sand and gravel for the offshore Banks (mostly Nash Bank). Foreshore extraction can be shown to have brought about an average lowering of the inter-tidal beach surface of the order of .25 m. Photogrammetric measurements and, in particular, beach profile measurements indicate that the naturally occurring fluctuations in beach levels are often less than this figure and that there has been no net accretion of this order to replace that material which has been lost.

Geophysical observations in the offshore areas have delineated those areas of potentially mobile material, comparable in size with that which is found on the foreshore. This work has also identified an important sedimentological feature of the area; that is the occurrence of a large area of muddy sand immediately offshore of Port Talbot and the beach being studied. This feature has an important relation to the mean tidal circulation, which is described later, and the possibility of former dredging activity in contributing to the material in this area cannot be ignored. The offshore banks have been found to be major repositories of foreshore size material.

Due largely to delays in field work and the preliminary analysis of data, the second stage of the study has lagged the first considerably. However, the analysis of these data is now well in hand and some important features are already becoming clear.

Observations suggest that movement of material by tidal currents towards or away from the study area is likely to be minimal. Additionally, the observed mean circulation indicates an area of divergency immediately offshore of Port Talbot with an associated stagnation point (ie, no net flow) near the study area. These features to some extent explain the occurrence of the central silty area previously described. A large eddy or gyre in the mean circulation has been observed situated over the Scarweather Sands.

Work is now in hand to compare various sediment transport formulae in order to estimate the mean sediment circulation pattern for the area and to quantify the sediment budget. Preliminary calculations, using near bed concentration and velocity profiles, have already shown that, for material coarser than 40 μm movement as bed load is likely to be more important than suspended load transport. Reasonable agreement has been obtained between measured (from radioactive tracer experiments) and predicted bed load transport rates. However measurements have also demonstrated the importance of fine particulate material in the sediment budget. The role of waves in the offshore processes has yet to be evaluated.

Preliminary results suggest that meteorological forcing of the mean circulation, particularly in the shallow areas of the Bay, may have some influence on the sediment circulation patterns.

The analysis of data from two beach experiments is now well in hand and attempts are being made to relate the observed alongshore component of wave energy to the measured sediment transport rates (from fluorescent tracer studies). The directional characteristics of waves in the foreshore area are being studied using wave velocity and pressure measurements, and radar observations. Preliminary observations suggest that the direction of wave approach to the beach is mostly normal with measured alongshore sediment transport rates being low and variable in direction to NW or SE. This suggests that longshore replenishment processes are likely to be weak.

The analysis of wave data from the offshore and foreshore areas is now largely complete and will be used as input for further wave refraction studies. Earlier work has already indicated the importance of wave energy focussing by the offshore Banks and a resultant alongshore variation in wave energy. This may have important implications for sediment transport on the foreshore.

The main conclusions which may be drawn from the work carried out to date are that the deterioration in the foreshore on the E side of the Bay has been brought about largely by sand extraction. Preliminary analyses suggest that any replenishment processes are likely to be weak. Onshore—offshore exchanges of material appear to be an unlikely mechanism and a weak but variable alongshore transport of material is indicated. In this context, the presence of the breakwaters at Port Talbot is likely to have some effect.

Progress towards the immediate objectives of this study is now well in hand and it is anticipated that the remaining Topic Reports, including the Final Report, will be completed in the first half of 1979. Beyond this it is intended that the main scientific conclusions of the study will be reported in the open literature.

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TABLE 1

STANDARDISED PARTIAL REGRESSION COEFFICIENTS AND TOTAL CORRELATION COEFFICIENTS FROM A MULTIREGRESSION ANALYSIS OF RESIDUAL CURRENTS AND METEOROLOGICAL DATA IN SWANSEA BAY AT STATION B (See Fig 1).

Partial regression coefficients		Total correlation coefficient
components	$\bar{u}_y$	
$\bar{W}_x$	- .3176	.7882 (accounting for about 62% of the variance)
$\bar{W}_y$	.6689	
P_R	.1293	
$P_H - P_R$	- .2632	
$P_R - P_A$	.2320	

Note that the tidal residual has not been removed.

$\bar{u}_y$ = mean current in NW direction
$\bar{W}_x$ = mean wind from SW
$\bar{W}_y$ = mean wind from SE
P_R = atmospheric pressure
$P_H - P_R$ = atmospheric pressure difference in x direction
$P_R - P_A$ = atmospheric pressure difference in y direction

See Figure 10 for further explanation of terms.

Measurements at Stn B were made at a height of 2m above the sea bed in a mean depth of about 10m.

TABLE 2

PROVISIONAL LIST OF SEDIMENT TRANSPORT FORMULAE BEING USED FOR PREDICTION OF SEDIMENT TRANSPORT RATES

Originators	Date	Type	Load
Bagnold [a]	1963	Deterministic	Bed
Yalin [a]	1963	Deterministic	Bed
Einstein [a]	1950	Stochastic	Bed
Ackers and White [b,d]	1972	Deterministic	Total
Frijlink [b c]	1952	Deterministic	Bed
Engelund and Hansen [b,d]	1967	Deterministic	Total

(a) Used recently by Gadd et al, 1978
(b) " " Swart, 1976
(c) " " Barber, 1977
(d) " " Flemming and Hunt, 1976

TABLE 3

COMPARISON OF SUSPENDED LOAD AND BED-LOAD TRANSPORT RATES IN SWANSEA BAY

	Transport rates g $cm^{-1} s^{-1}$	
	$u_* = 2.18$ cm s^{-1} (Neaps)	$u_* = 4.37$ cm s^{-1} (Springs)
Bed-load[a]	.093	4.63
Suspended load[b] ($d > 40 \mu m$)	.0073	.69

a using Bagnold's (1963) equation

b using Rouse-Einstein profile

TABLE 4

COMPARISON OF MEASURED AND PREDICTED NET TRANSPORT RATES

	Transport rates g $cm^{-1} s^{-1}$		
	Location	Min	Max
Measured (R/A tracer)	T1	.039	.14
	T2	.031	.097
Predicted[a] (bed-load)	C	.12	.20
	A	.0096	.10

a-using Bagnold's (1963) equation

Locations in Table 4 are shown on Figure 1

APPENDIX 1

SWANSEA BAY PROJECT : REPORTS COMPLETED AND THOSE DUE FOR COMPLETION

Progress Reports			IOS Report No/Date
1.	Progress Report for the period to	March 1975 and subsequent developments	No 20, 1975
2.	" "	August 1975 to July 1976	No 26, 1975
3.	" "	August 1976 to July 1977	No 48, 1977

Topic Reports			
1.	Swansea Bay:	(a) Introduction (b) Long-term changes of the coastline	No 42, 1977
2.	Swansea Bay:	Evidence for beach stability: Protogrammetric and topographic measurements	No 51, 1977
3.	Swansea Bay:	Geophysical interpretation and sediment characteristics of the offshore and foreshore areas	No 60, 1978
4.	Swansea Bay:	Tidal currents: observed tidal and residual circulations and their response to meteorological conditions	December 1978 *
5.	Swansea Bay:	Wave data: observed and computed wave climate	December 1978 *
6.	Swansea Bay:	Offshore sediment movement and its relation to observed tidal current and wave data	February 1979 *
7.	Swansea Bay:	Foreshore sediment movement and its relation to observed tidal currents and wave climate	April 1979 *
8.	Swansea Bay:	Final Report: a study of foreshore and offshore sedimentation processes	June 1979 *

* Provisional completion dates

Note: See attached Appendix 2 for related reports and papers arising from the work in Swansea Bay

APPENDIX 2

REPORTS AND PAPERS RELATED TO THE WORK IN SWANSEA BAY BUT NOT INCLUDED IN APPENDIX 1

(1) Water Circulation in Swansea Bay by A D Heathershaw
A Report submitted to the Welsh Office and the Welsh National Water Development Authority. IOS Internal Document No 18, 1977.

(2) Measurements of sediment transport rates using radioactive tracers, by A D Heathershaw and A P Carr
Proceedings of ASCE Coastal Sediments Conference, Charleston, South Carolina/Nov 2 - 4 1977.

(3) Waves recorded at Port Talbot on the South Wales Coast by B C H Fortnum and P J Hardcastle. IOS Report (in preparation).

(4) Waves recorded at the Scarweather Light Vessel by B C H Fortnum and P J Hardcastle. IOS Report (in preparation).

APPENDIX 3

DEFINITION OF THE TERMS USED IN CALCULATING THE DIRECTIONAL WAVE SPECTRUM

Best estimates of the directional spectrum are given (Cartwright, 1962) by:

$$F'(\sigma,\theta) = \frac{1}{H^2(\sigma)}\left(\tfrac{1}{2}A_0 + \tfrac{2}{3}\left[A_1\cos\theta + B_1\sin\theta\right] + \tfrac{1}{6}\left[A_2\cos 2\theta + B_2\sin 2\theta\right]\right) \qquad (A3.1)$$

where σ is the angular frequency of the waves, θ the direction of propagation.

The harmonic coefficients A_0, A_1, A_2, B_1 and B_2 are obtained from

$$\left.\begin{aligned}
A_0 &= \frac{S_{pp}(\sigma)}{\pi} \\
A_1 &= \frac{C_{up}(\sigma)}{\pi}\cdot\frac{\sigma}{gk} \;;\quad B_1 = \frac{C_{vp}(\sigma)}{\pi}\cdot\frac{\sigma}{gk} \\
A_2 &= \frac{S_{uu}(\sigma) - S_{vv}(\sigma)}{\pi}\cdot\left(\frac{\sigma}{gk}\right)^2 ;\quad B_2 = \frac{2C_{uv}(\sigma)}{\pi}\cdot\left(\frac{\sigma}{gk}\right)^2
\end{aligned}\right\} \qquad (A3.2)$$

where S_{uu}, S_{vv}, S_{pp}, C_{up}, C_{vp} and C_{uv} are the spectra (S) and cospectra (C) of the wave induced velocity and pressure fluctuations.

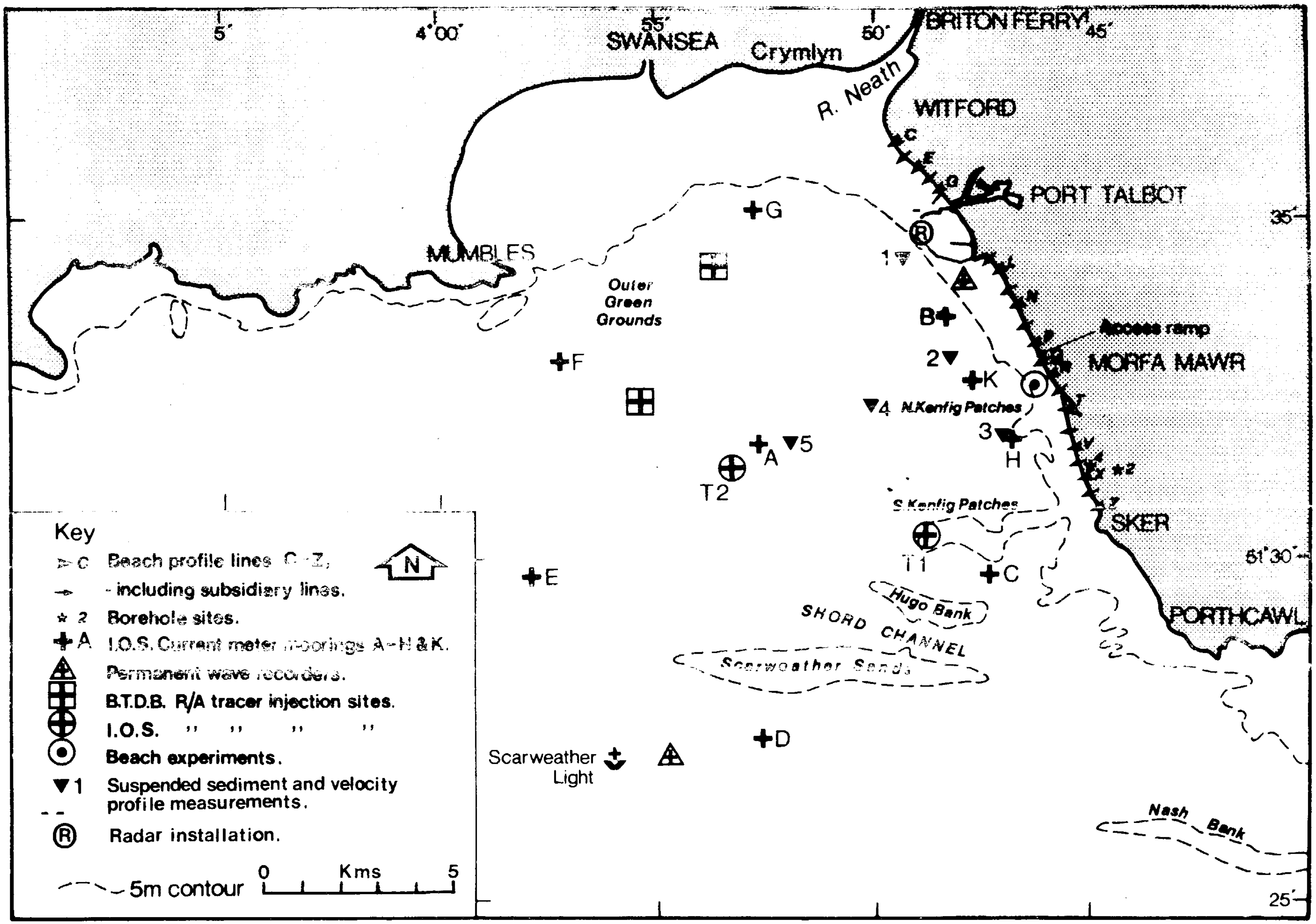
$H(\sigma)$ is the depth attenuation function which in terms of the wavenumber k is

$$H(k) = \frac{\cosh k(z+h)}{\cosh kh} \qquad (A3.3)$$

where $k = \frac{2\pi}{L}$ where L is the wavelength given by

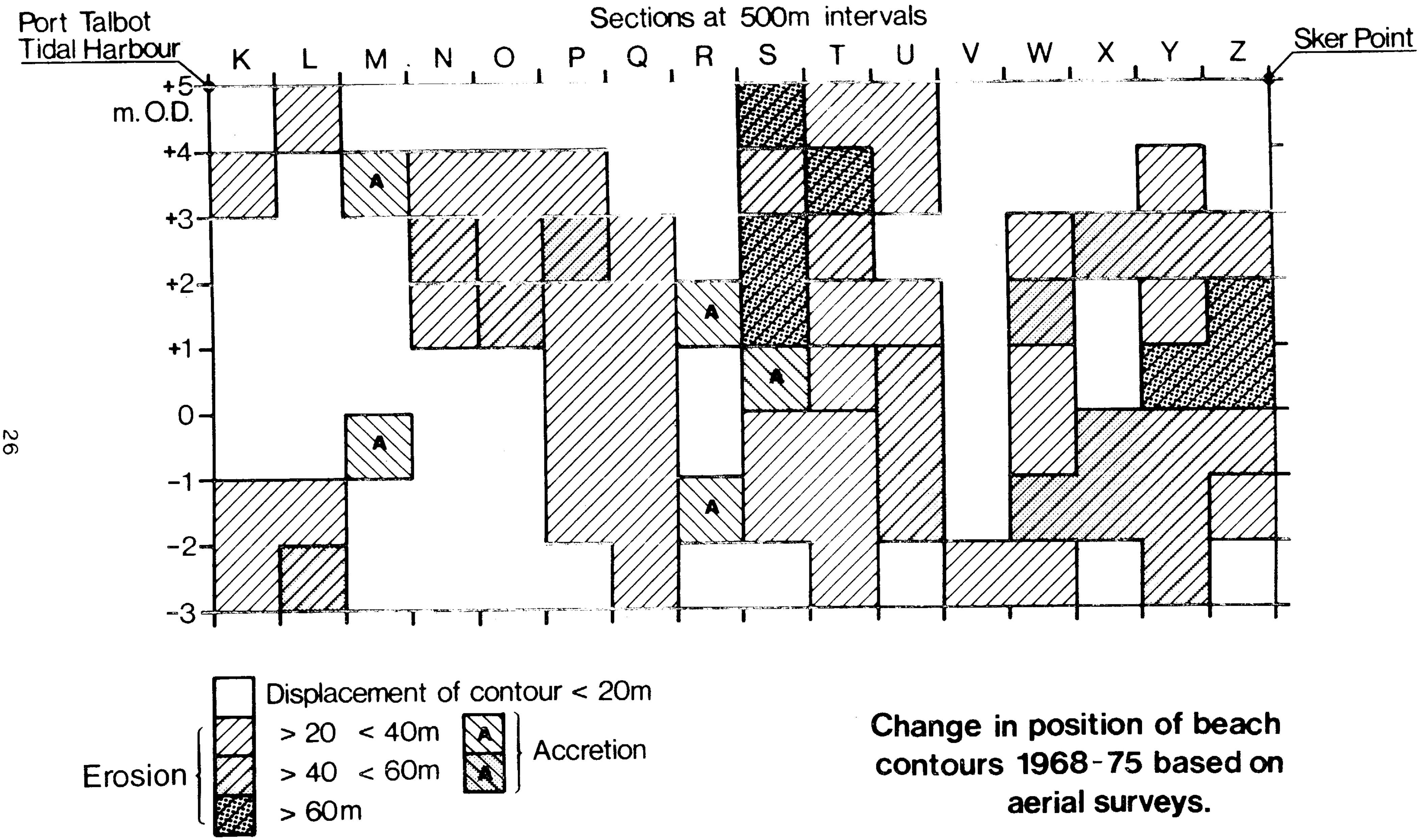
$$L = \frac{gT^2}{2\pi}\tanh\frac{2\pi h}{L} \qquad (A3.4)$$

In (A3.3) and (A3.4), h is the water depth, z is the distance of the u, v and p sensors from the mean sea surface and T the wave period.



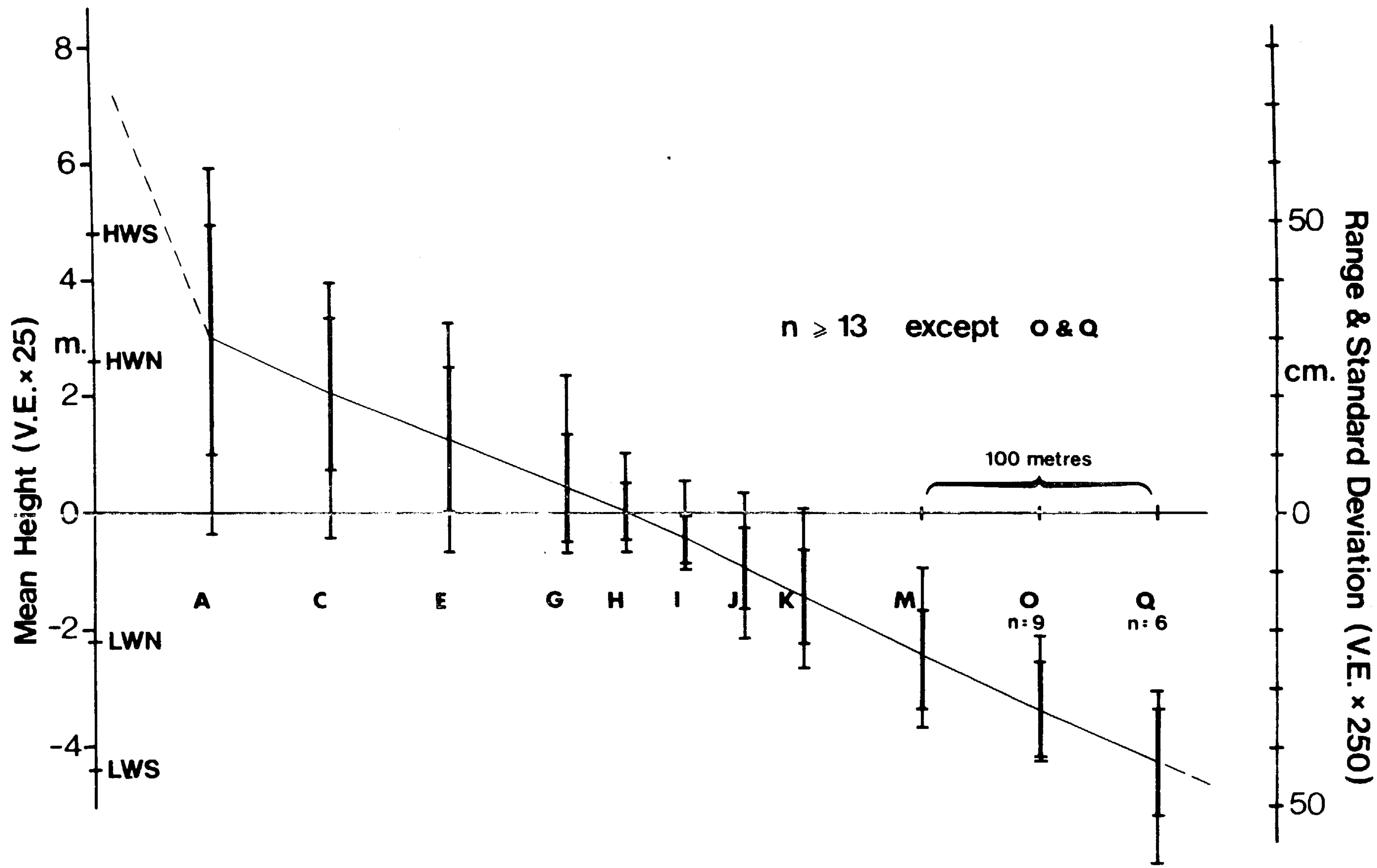
5'
4°00'
55'
50'
45'
35'
51°30'
25'
SWANSEA
Crymlyn
R. Neath
BRITON FERRY
WITFORD
PORT TALBOT
MUMBLES
Outer Green Grounds
Access ramp
MORFA MAWR
N.Kenfig Patches
S.Kenfig Patches
SKER
PORTHCAWL
Hugo Bank
SHORD CHANNEL
Scarweather Sands
Scarweather Light
Nash Bank
G
F
E
D
C
B
A
K
H
T1
T2
1
2
3
4
5
Key
Beach profile lines C - Z,
- including subsidiary lines.
Borehole sites.
I.O.S. Current meter moorings A - H & K.
Permanent wave recorders.
B.T.D.B. R/A tracer injection sites.
I.O.S. " " " "
Beach experiments.
Suspended sediment and velocity profile measurements.
Radar installation.
5m contour
0 Kms 5
N

Fig.1

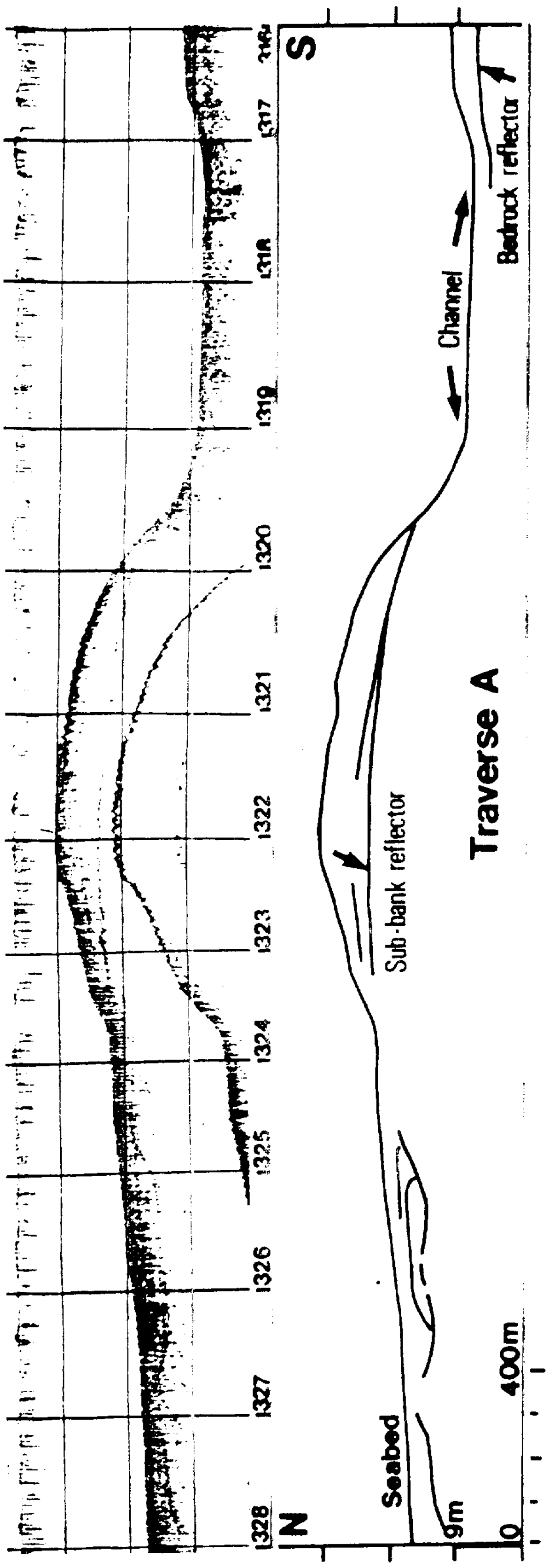


Change in position of beach contours 1968-75 based on aerial surveys.

Fig. 2



SECTION Q. Changes Nov 1976 to May 1977.
Fig. 3



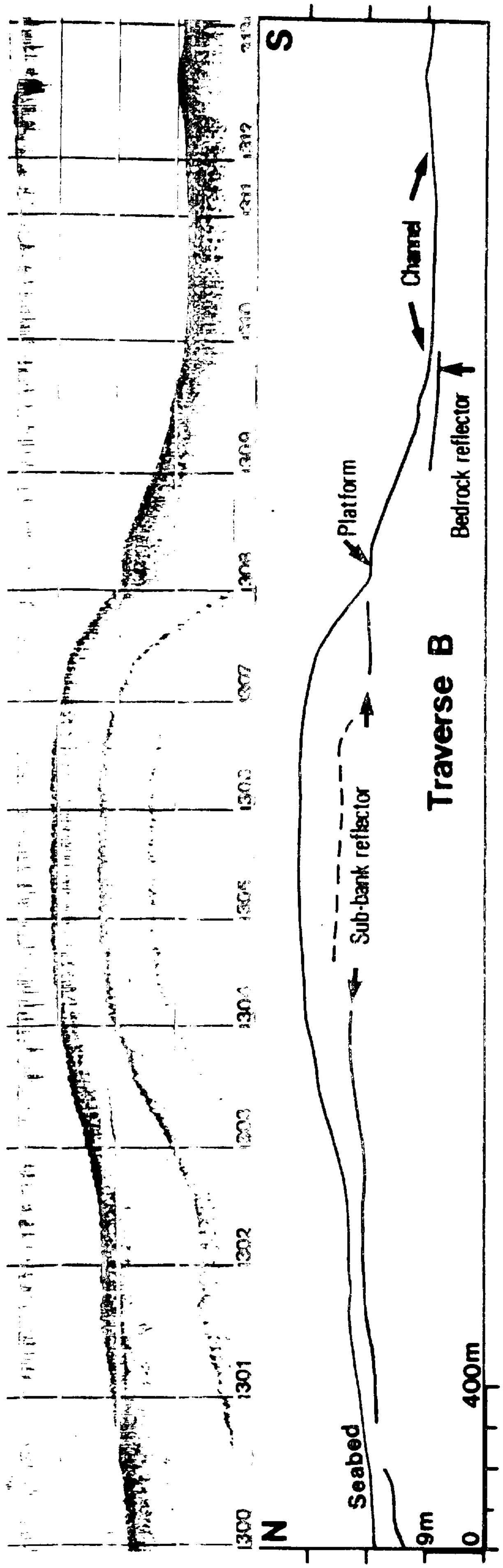
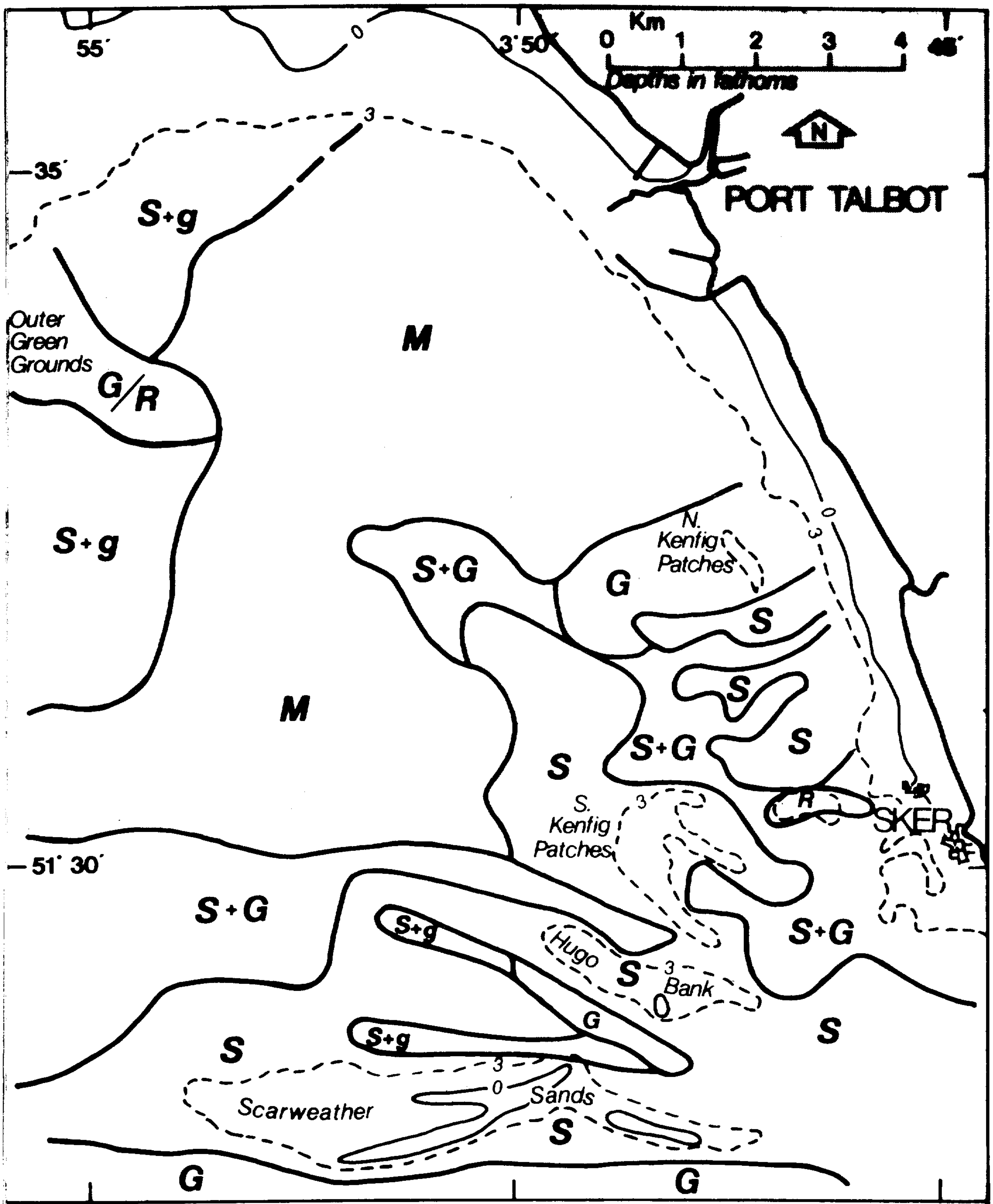


Fig.4 CSP traverses on Scarweather Sands

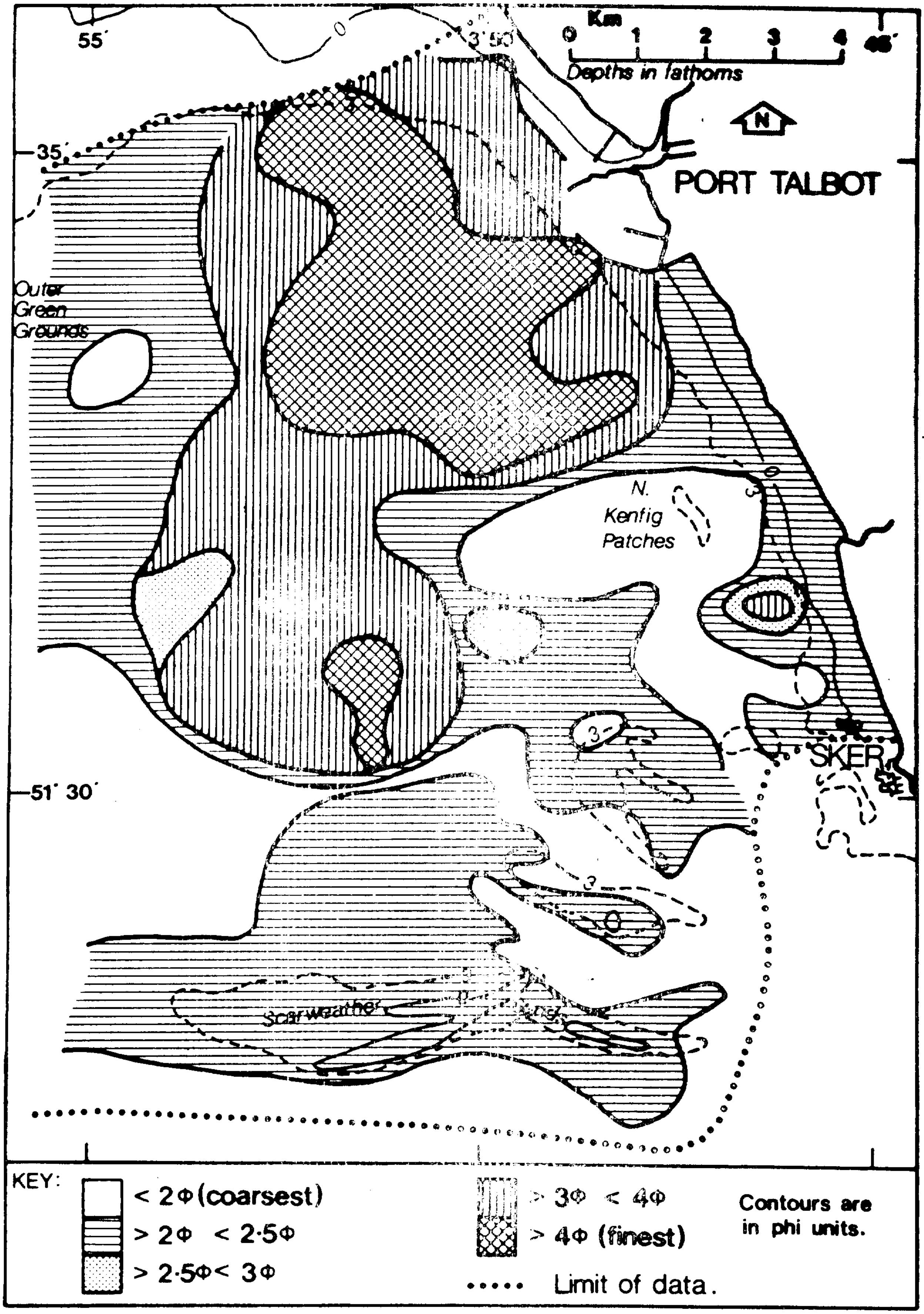


KEY:

R - Bedrock. ***G / g*** - Gravels. ***S*** - Mainly sands. ***M*** - Mainly very fine sands and mud.

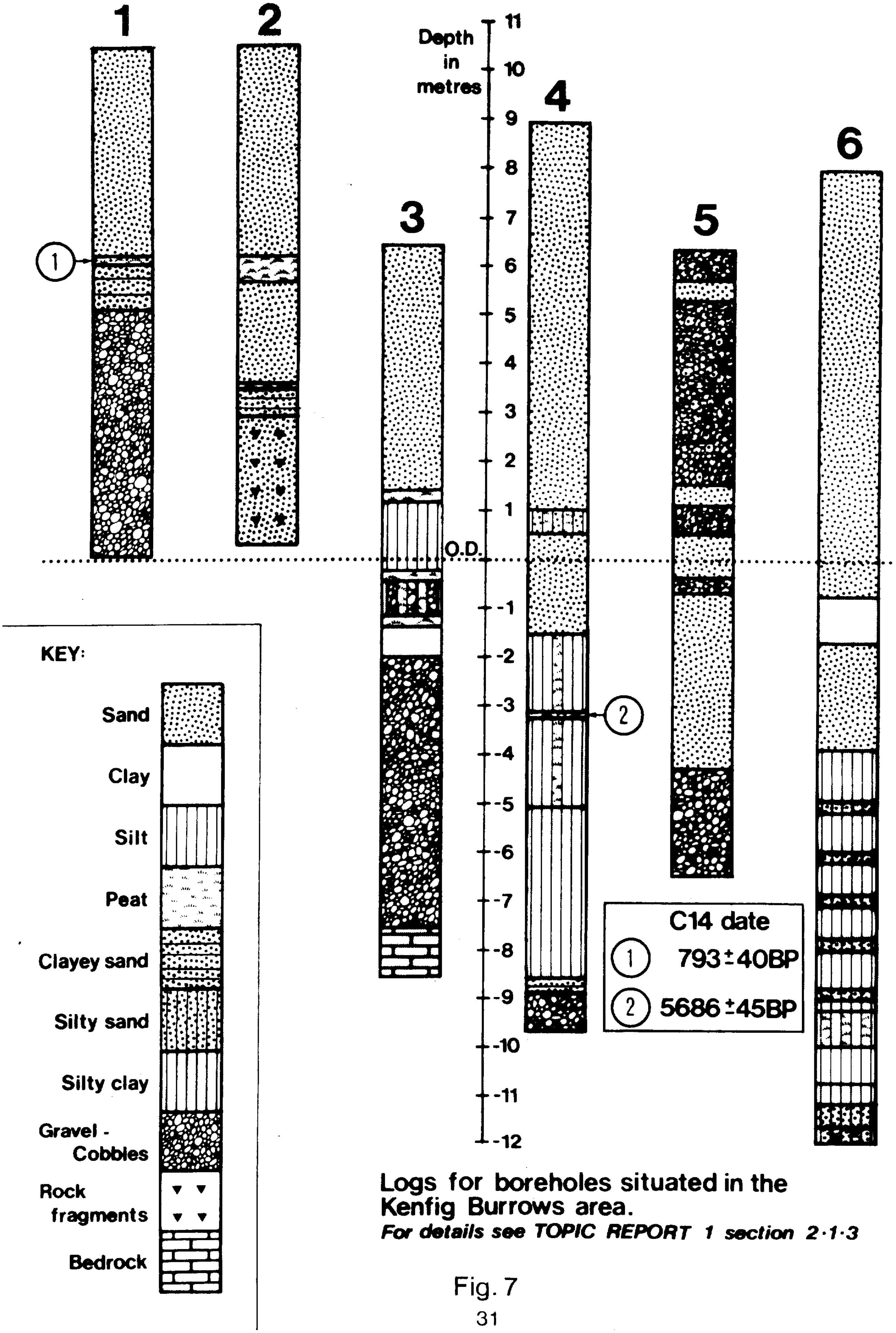
Surface sediment distribution map of research area as determined from Box core, Grab and Vibrocore samples, also from Side scan sonar and Continuous seismic profiling records.

Fig. 5



Mean grain size distribution.

Fig. 6



Logs for boreholes situated in the Kenfig Burrows area.
For details see TOPIC REPORT 1 section 2·1·3

Fig. 7

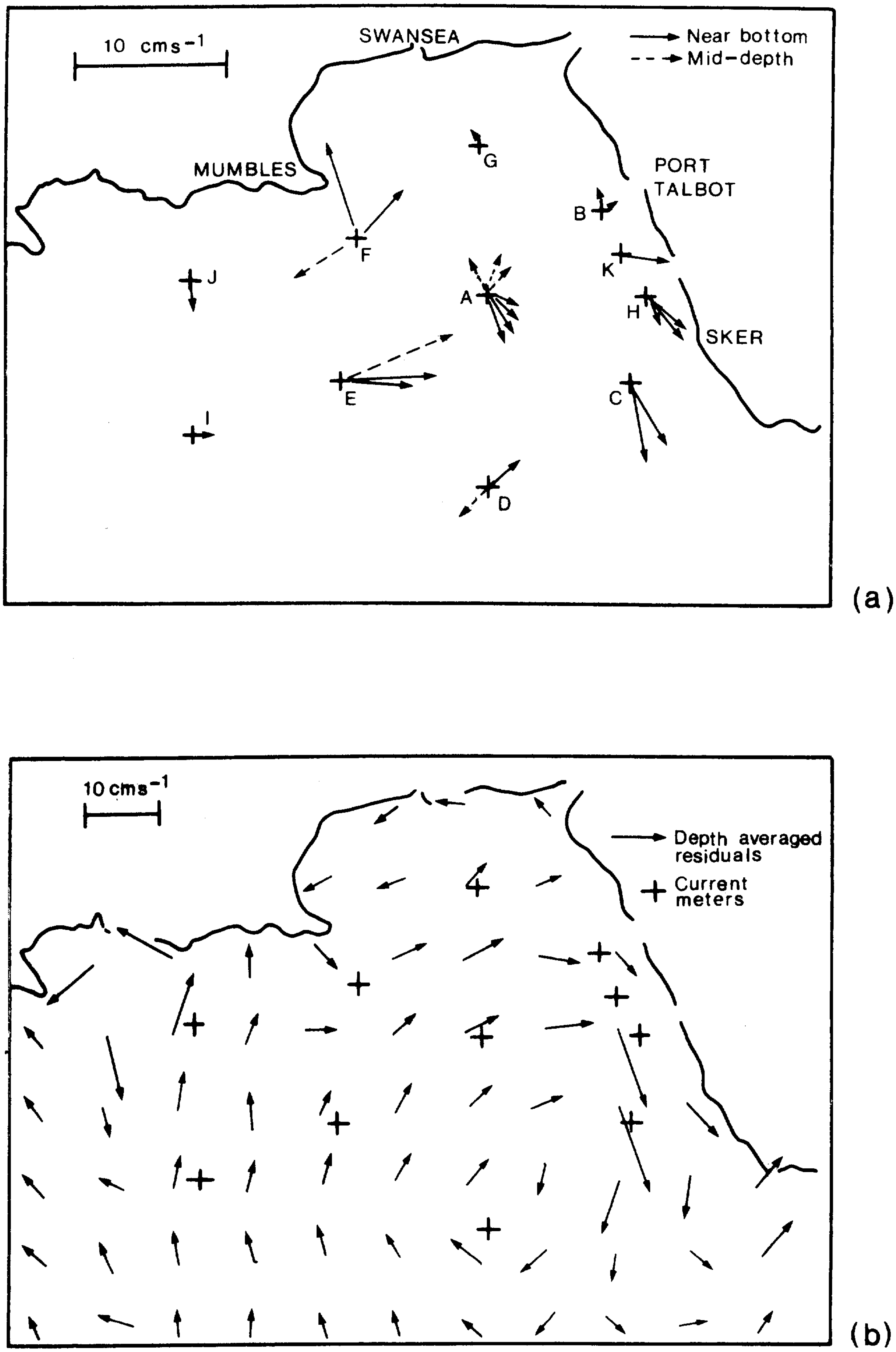


Fig. 8 Observed (a) and predicted (b) mean circulations in Swansea Bay. Predicted values have been taken from Uncles' (1977) numerical model (note the difference in the scale of the residuals).

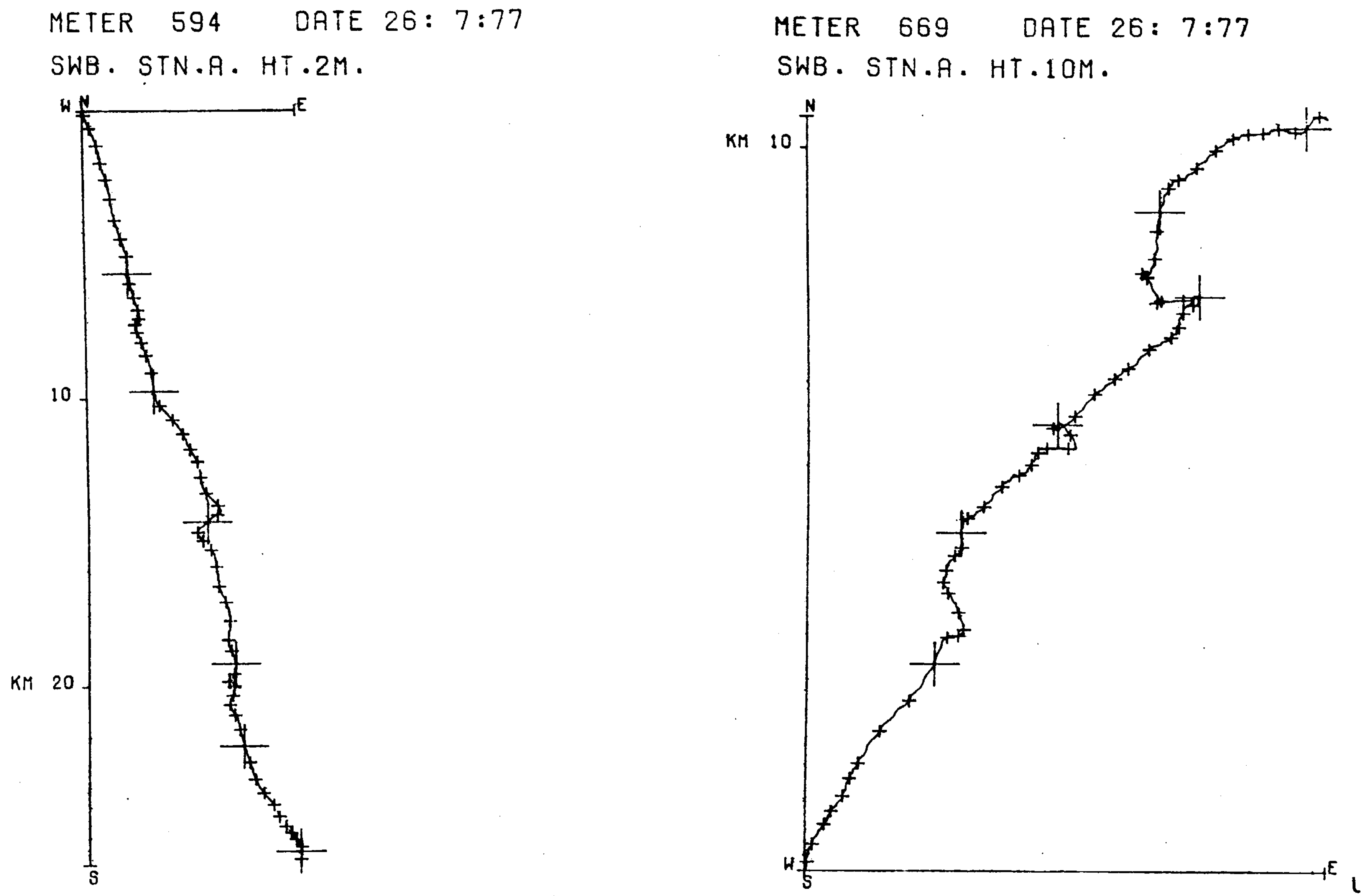
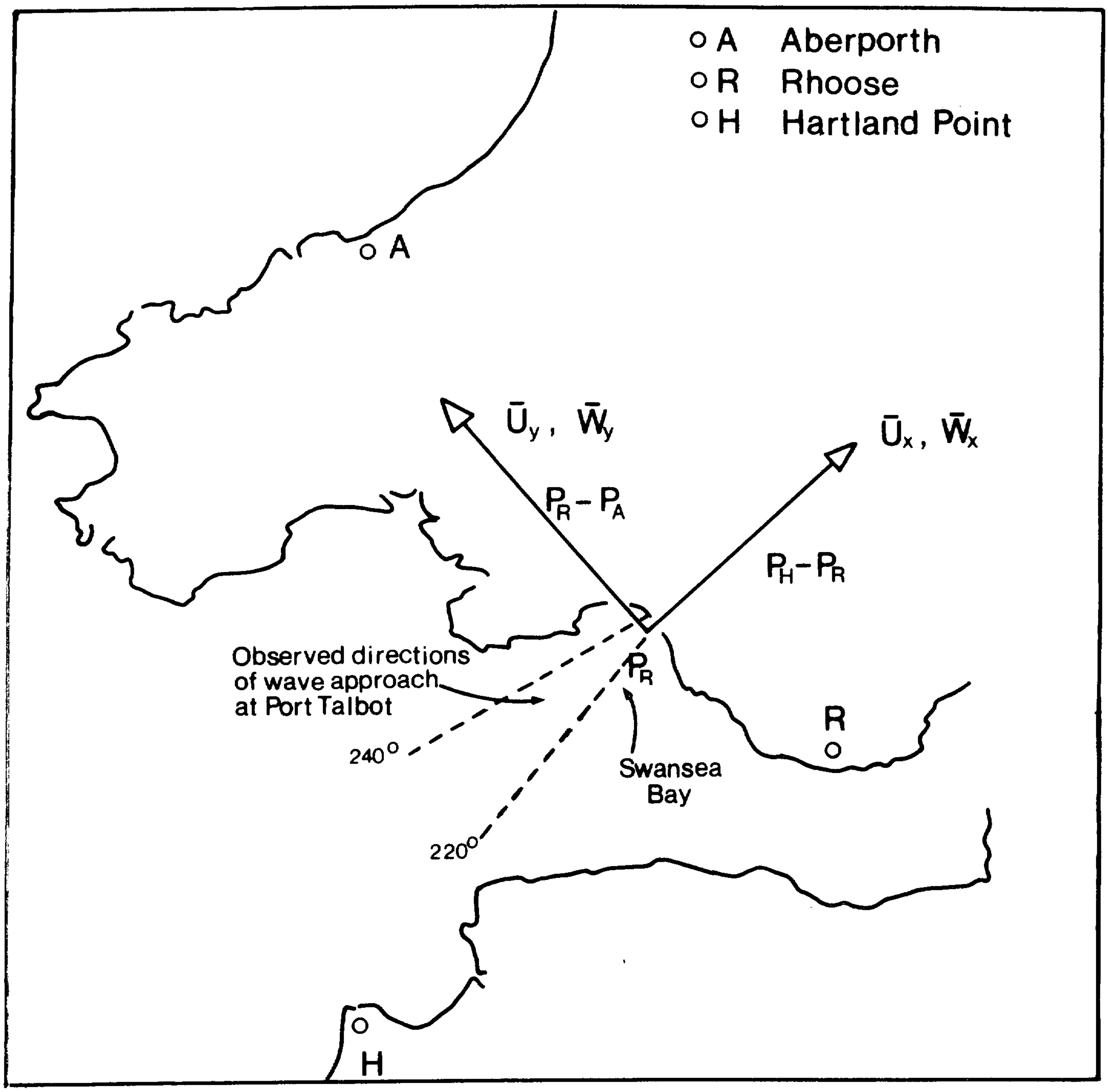


Fig. 9 Observed residual flows at Stn. A (See Figure 1)



$\bar{U}_y$, $\bar{W}_y$	longshore component of mean current and mean wind
$\bar{U}_x$, $\bar{W}_x$	onshore component of mean current and mean wind
P_R	atmospheric pressure at Rhoose
$P_H - P_R$	atmospheric pressure difference Hartland - Rhoose
$P_R - P_A$	atmospheric pressure difference Rhoose - Aberporth

Fig.10 Definition of terms used in meteorological forcing and wave direction studies

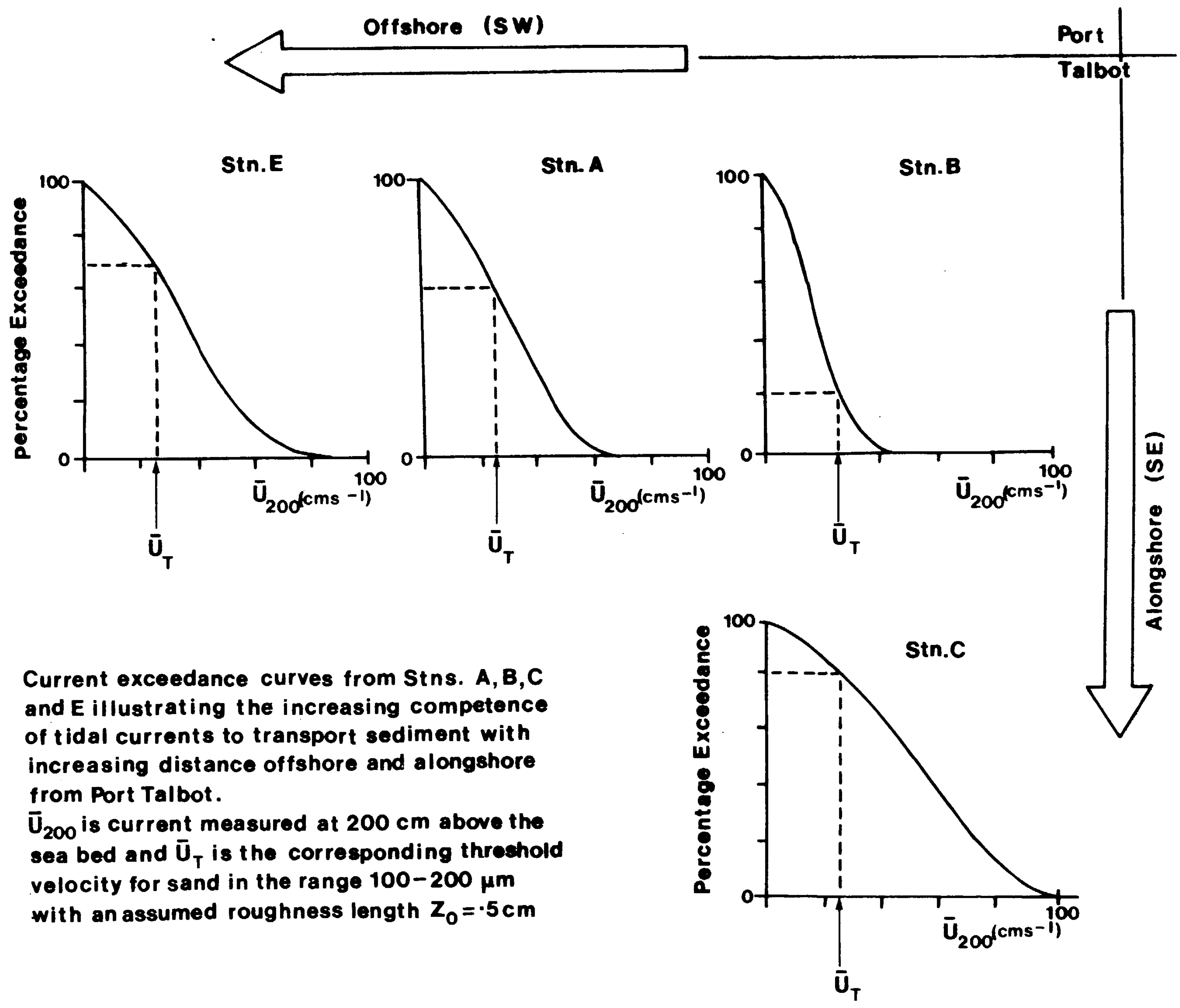


Fig.11 Current exceedance curves from Stns. A, B, C and E illustrating the increasing competence of tidal currents to transport sediment with increasing distance offshore and alongshore from Port Talbot.
$\bar{U}_{200}$ is current measured at 200 cm above the sea bed and $\bar{U}_T$ is the corresponding threshold velocity for sand in the range 100–200 µm with an assumed roughness length $Z_0 = \cdot 5$ cm

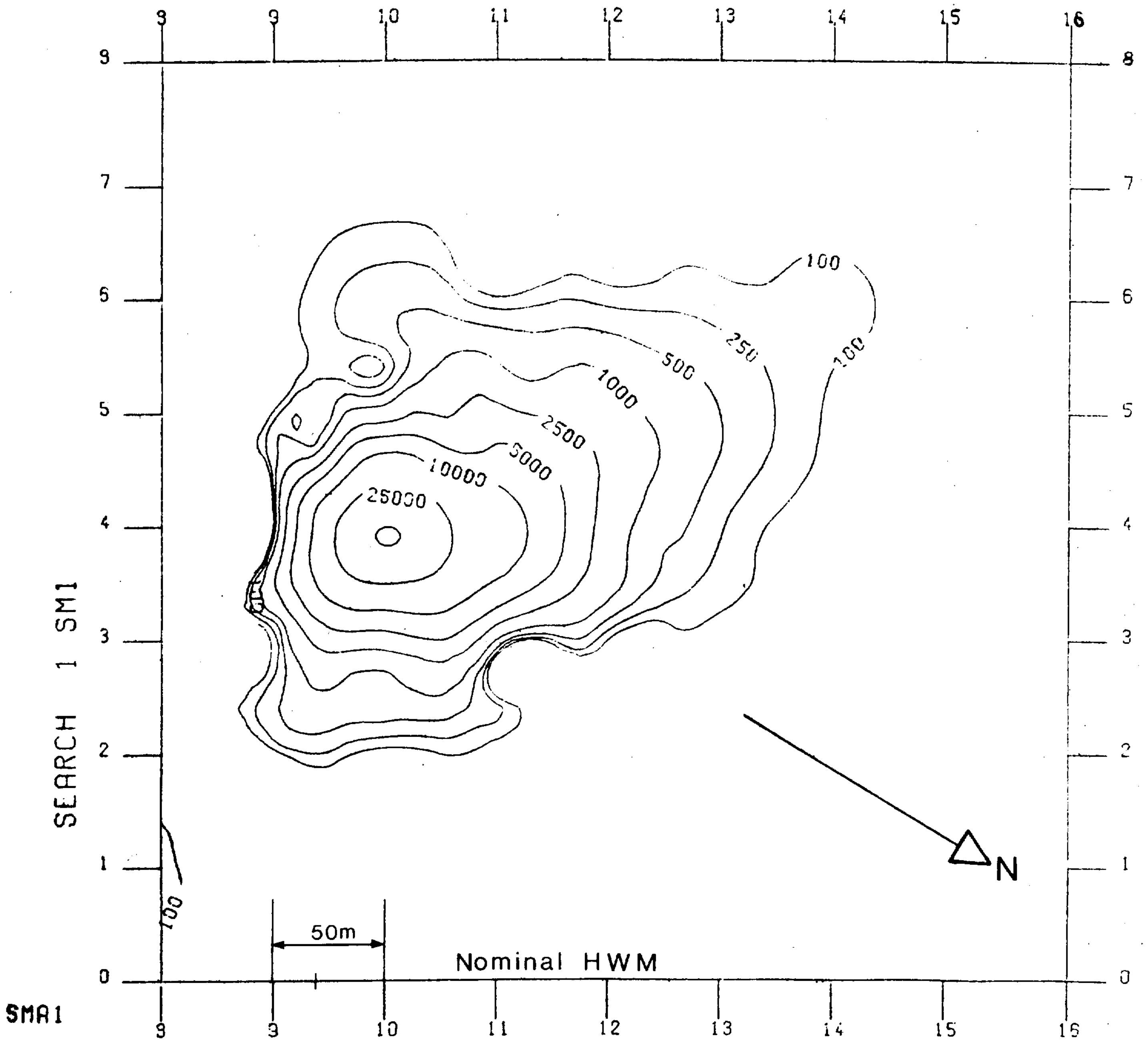


Fig. 12 1976 Beach Experiment: Fluorescent Tracer Dispersion Pattern after 1 Tide See Figure 1 for location.

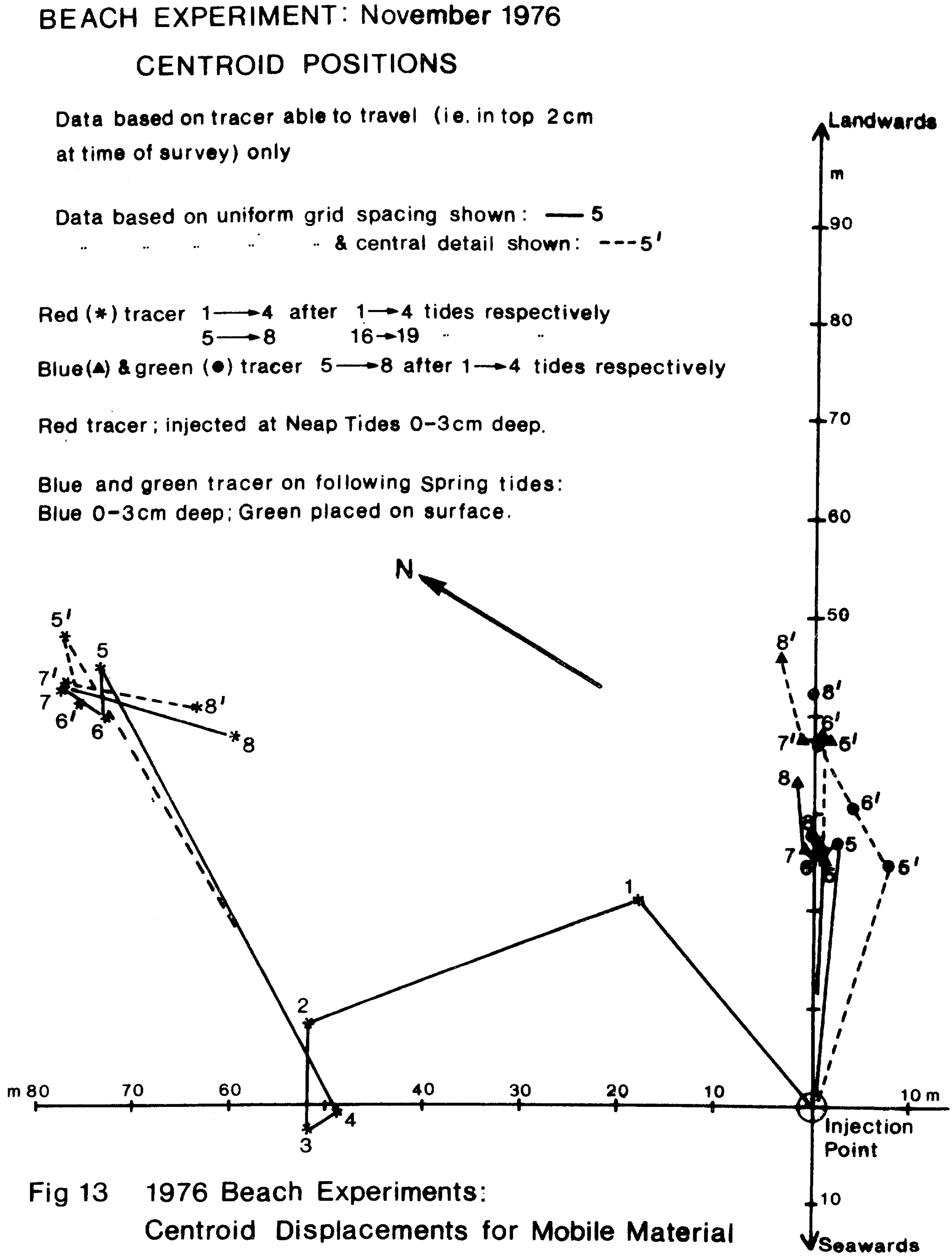


Fig 13 1976 Beach Experiments: Centroid Displacements for Mobile Material

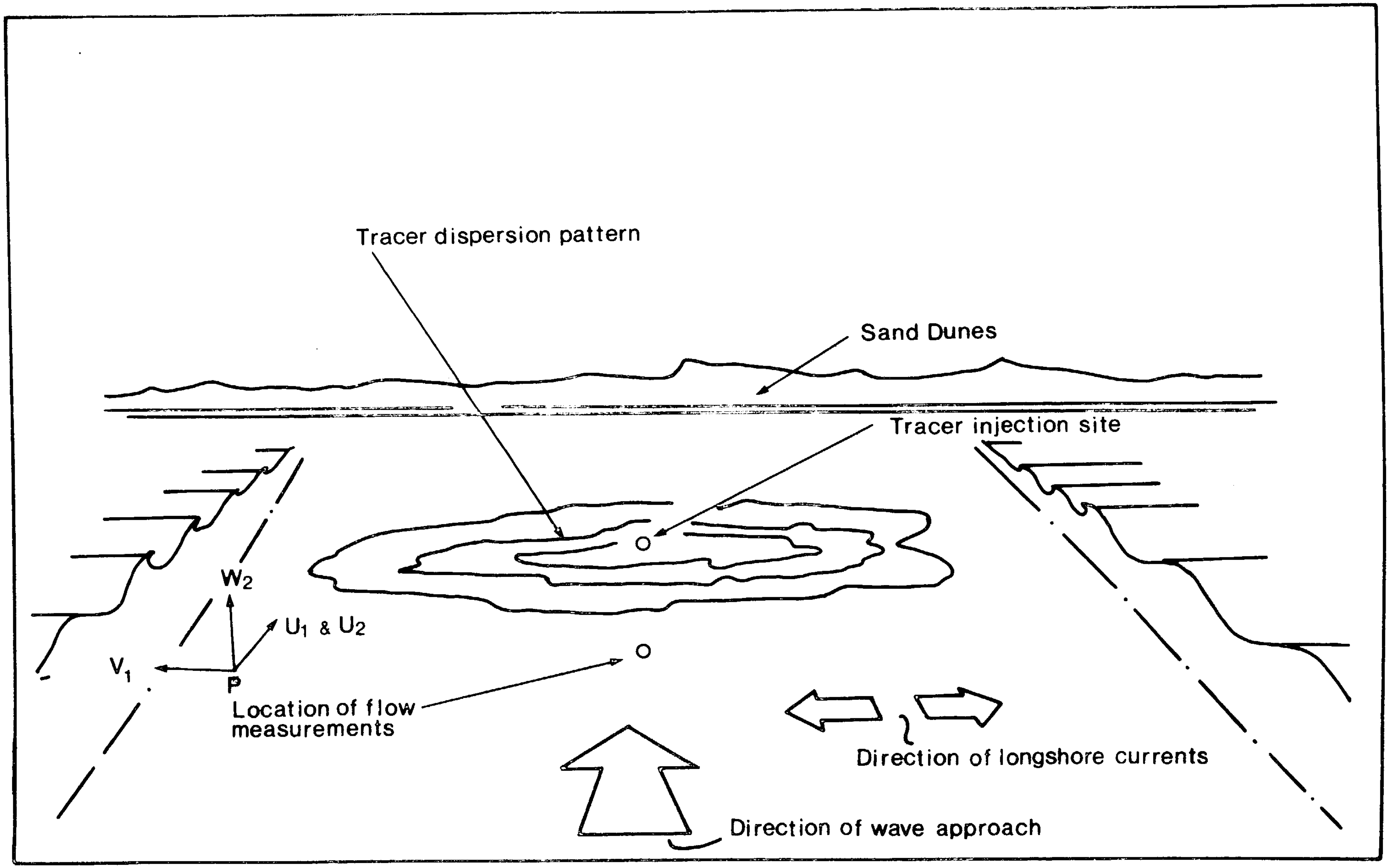


Fig.14 1976/77 Beach Experiments: Schematic diagram of flow and tracer measurements

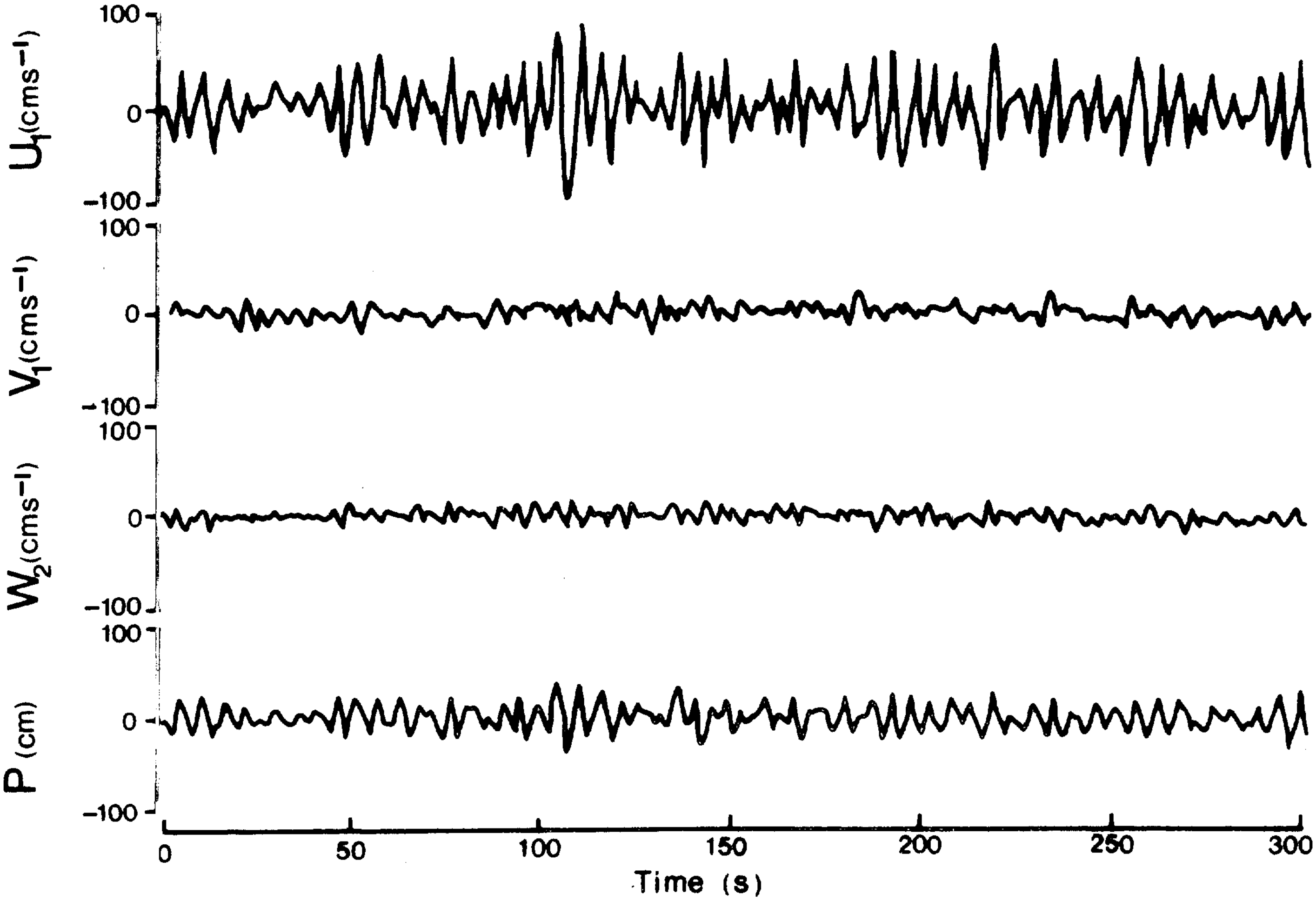


Fig. 15 1977 Beach Experiment: U,V,W and P records
U is the onshore/offshore velocity component;
V is the alongshore velocity component,
W is the vertical velocity component and
P is the pressure (see Figure 14)

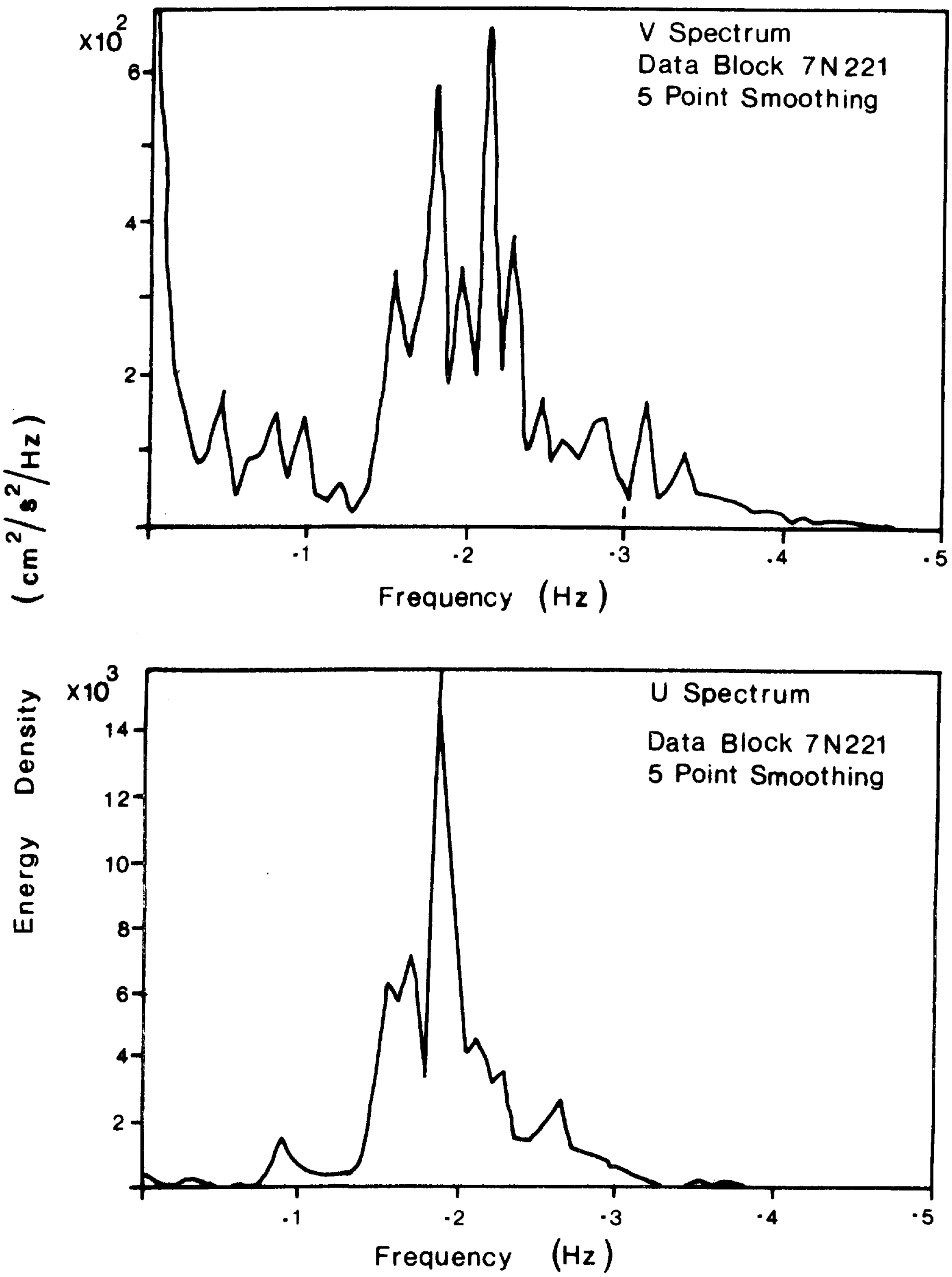


Fig. 16 1977 Beach Experiment: U and V Spectra
(Note difference in energy scales)

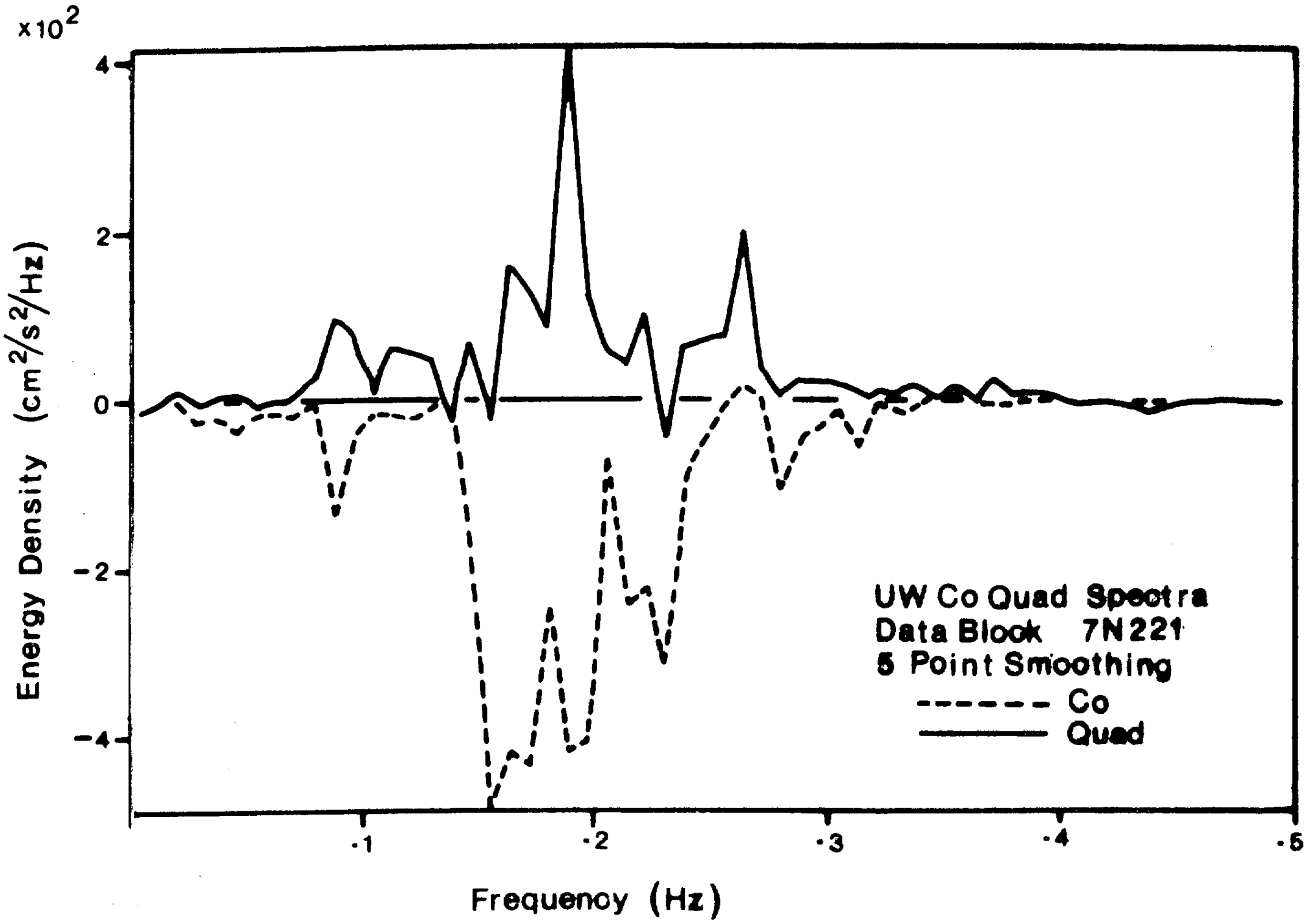


Fig.17 1977 Beach Experiment:
Co- and Quadrature Spectra

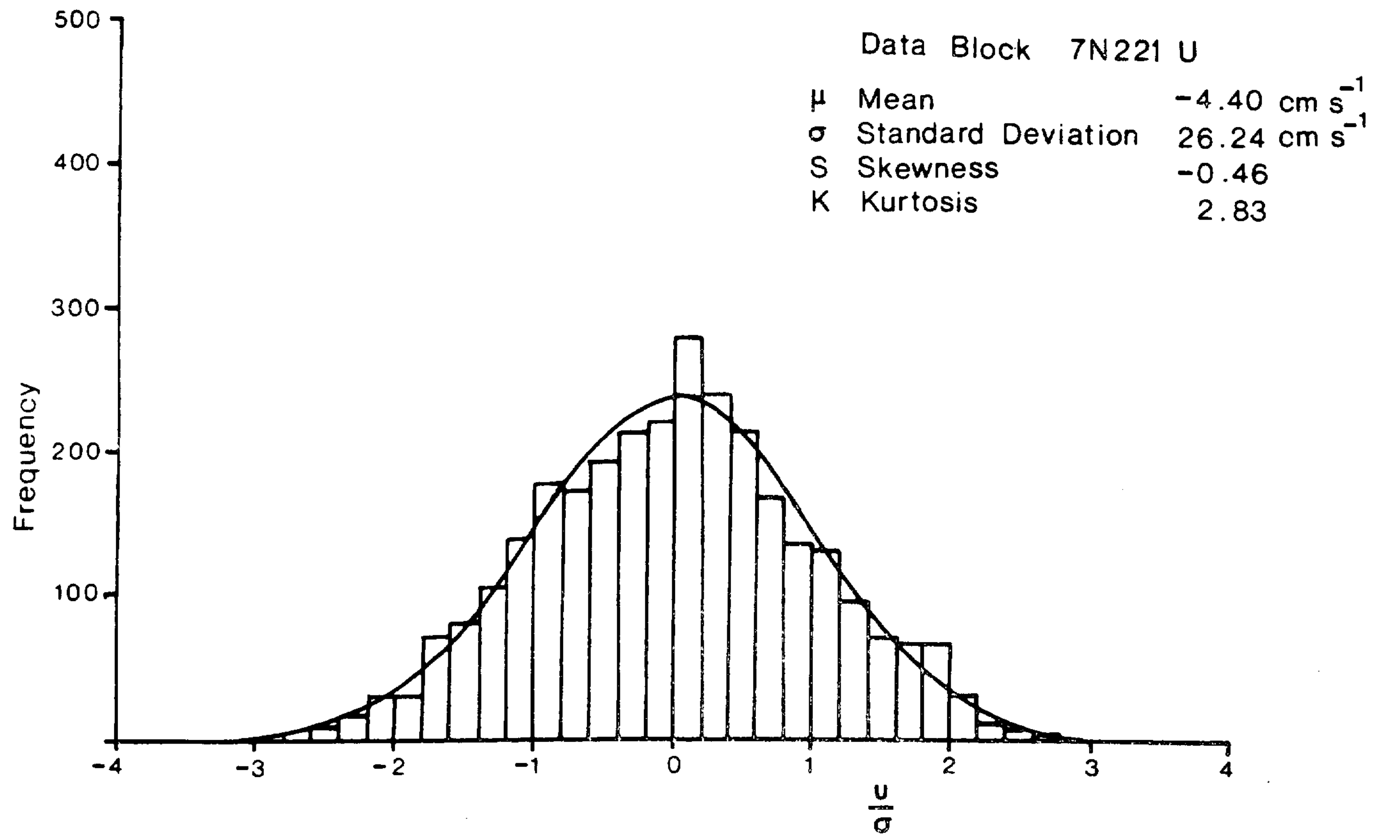
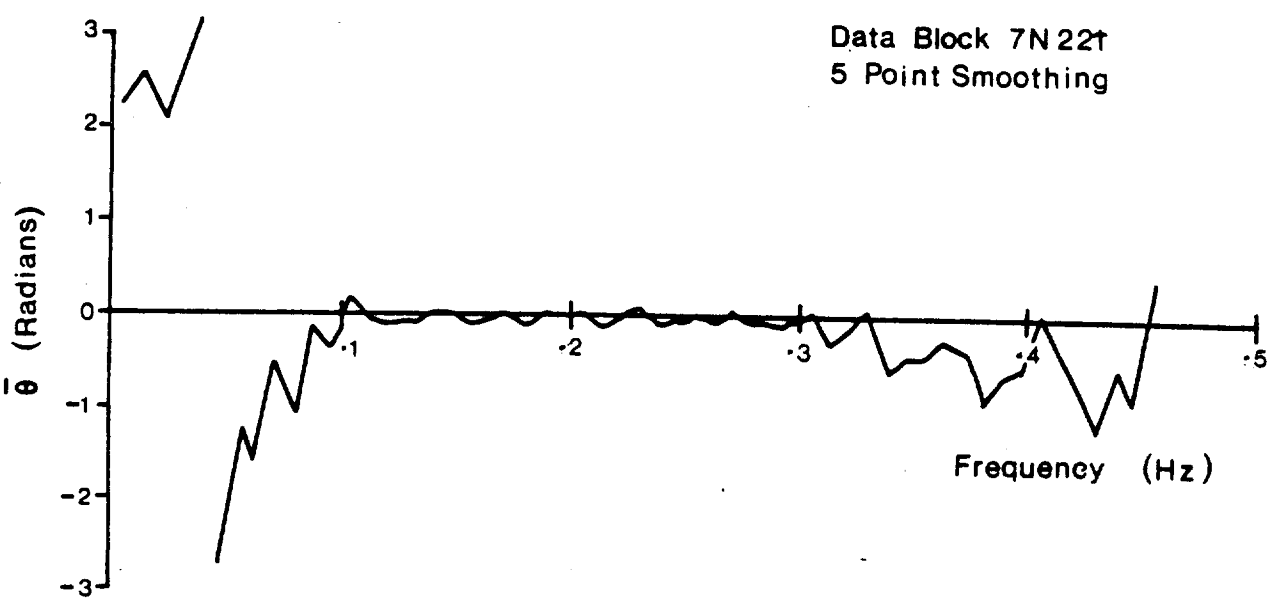
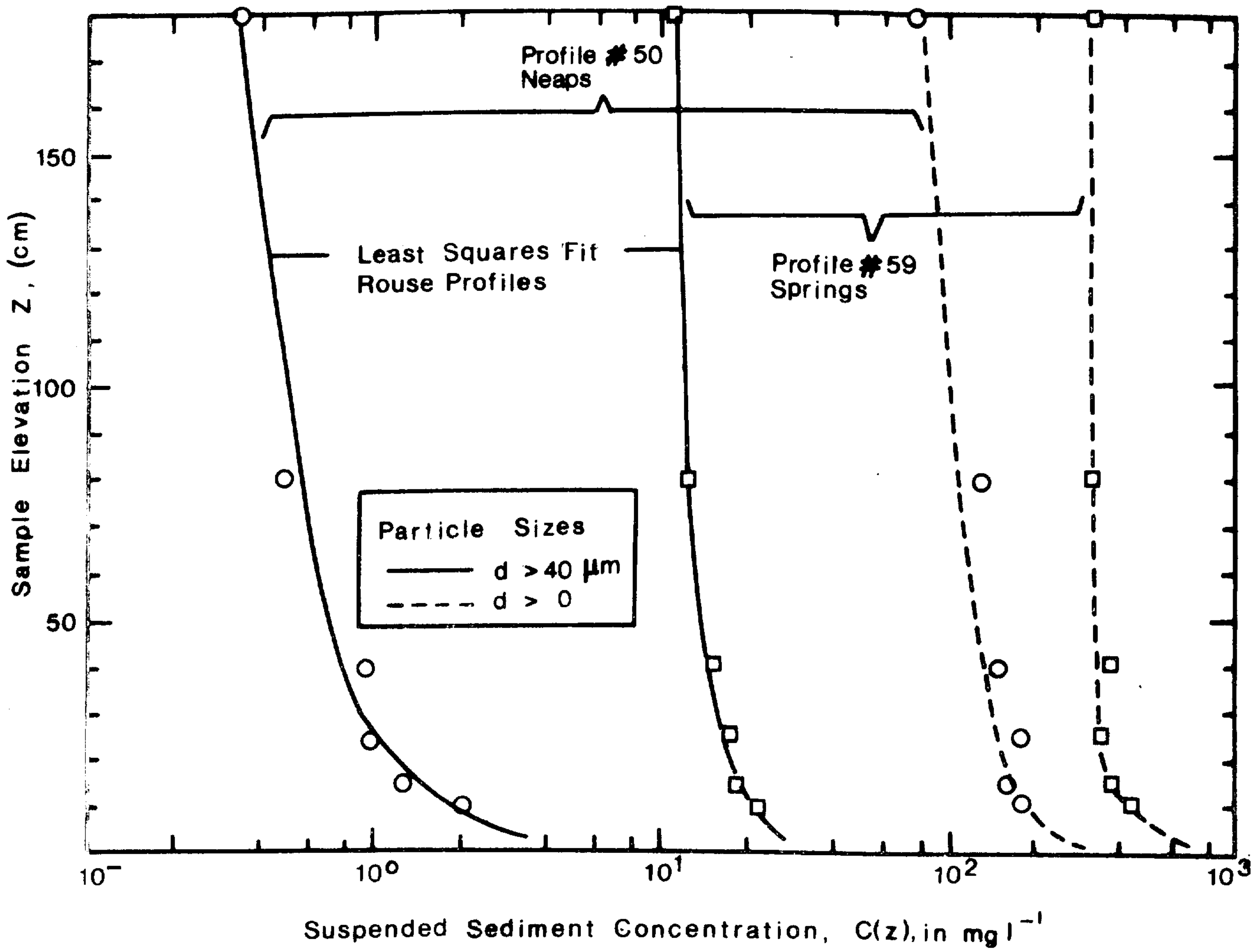


Fig.18 1977 Beach Experiment: Frequency distribution of U. Solid curve is a Gaussian distribution for the same mean (μ) and standard deviation (σ).



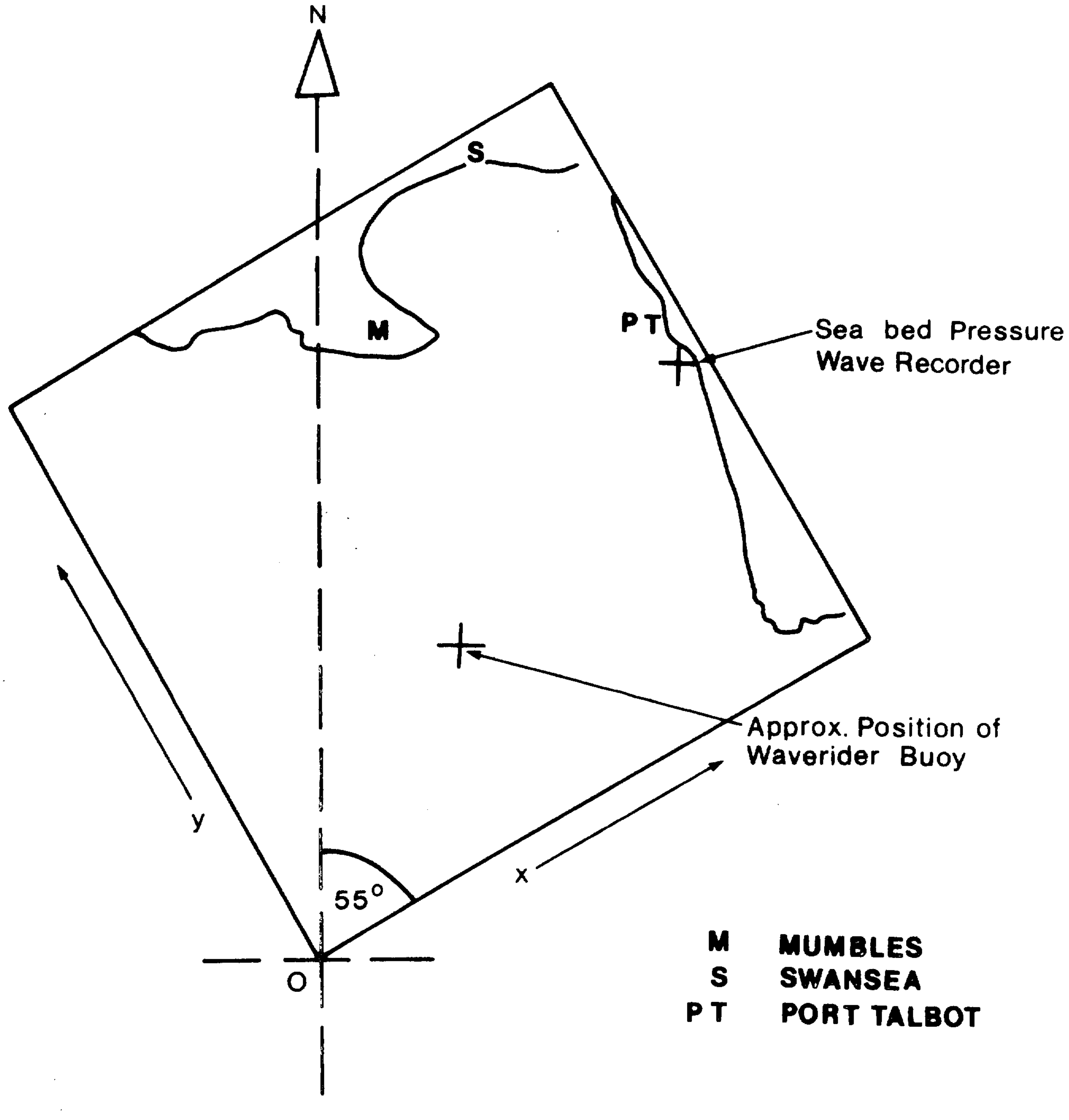
Mean direction ($\bar{\theta}$) of waves approaching Beach measured in radians anti-clockwise from normal to Beach in a shoreward direction

Fig.19 1977 Beach Experiment:
Plot of mean direction ($\bar{\theta}$) of wave approach



Profile No. 50 (Neaps)	$U_* = 2{\cdot}18\ cms^{-1}$ $C(a) = {\cdot}47\ mg\,l^{-1}$ at $Z = 100cm$ For $d > 40\ \mu m$
Profile No. 59 (Springs)	$U_* = 4{\cdot}37\ cms^{-1}$ $C(a) = 12{\cdot}21\ mg\,l^{-1}$ at $Z = 100cm$ For $d > 40\ \mu m$

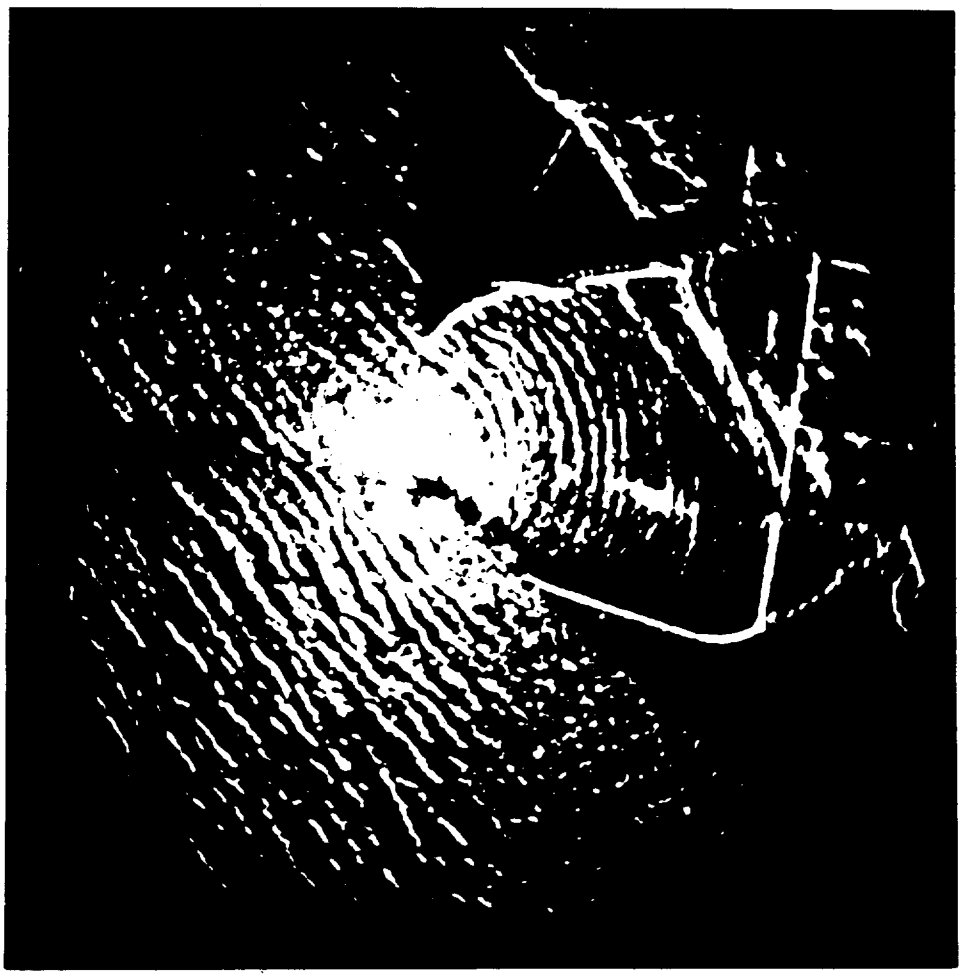
Fig. 20 Typical suspended sediment concentration profiles measured at Stn.5 (see Fig.1) illustrating the effects of the spring-neap variation and the effects of fine particulate material



Origin (O) at: 3° 58.00′ W; 51° 21.00 N

Overall dimensions of grid are 25x25 Km. made up of 50x50 elements having dimensions 500x500 m.

Fig. 21 New IOS Wave Refraction Grid



Wind Speed $20\ m s^{-1}$
Wind Direction 260° (T)
Wave Direction 235° (T)
Significant Wave Height (H_S): 4.63 m.
Zero Crossing Period (T_Z): 10.3 s.

Fig. 22 Typical Radar image of the Sea Surface at Port Talbot

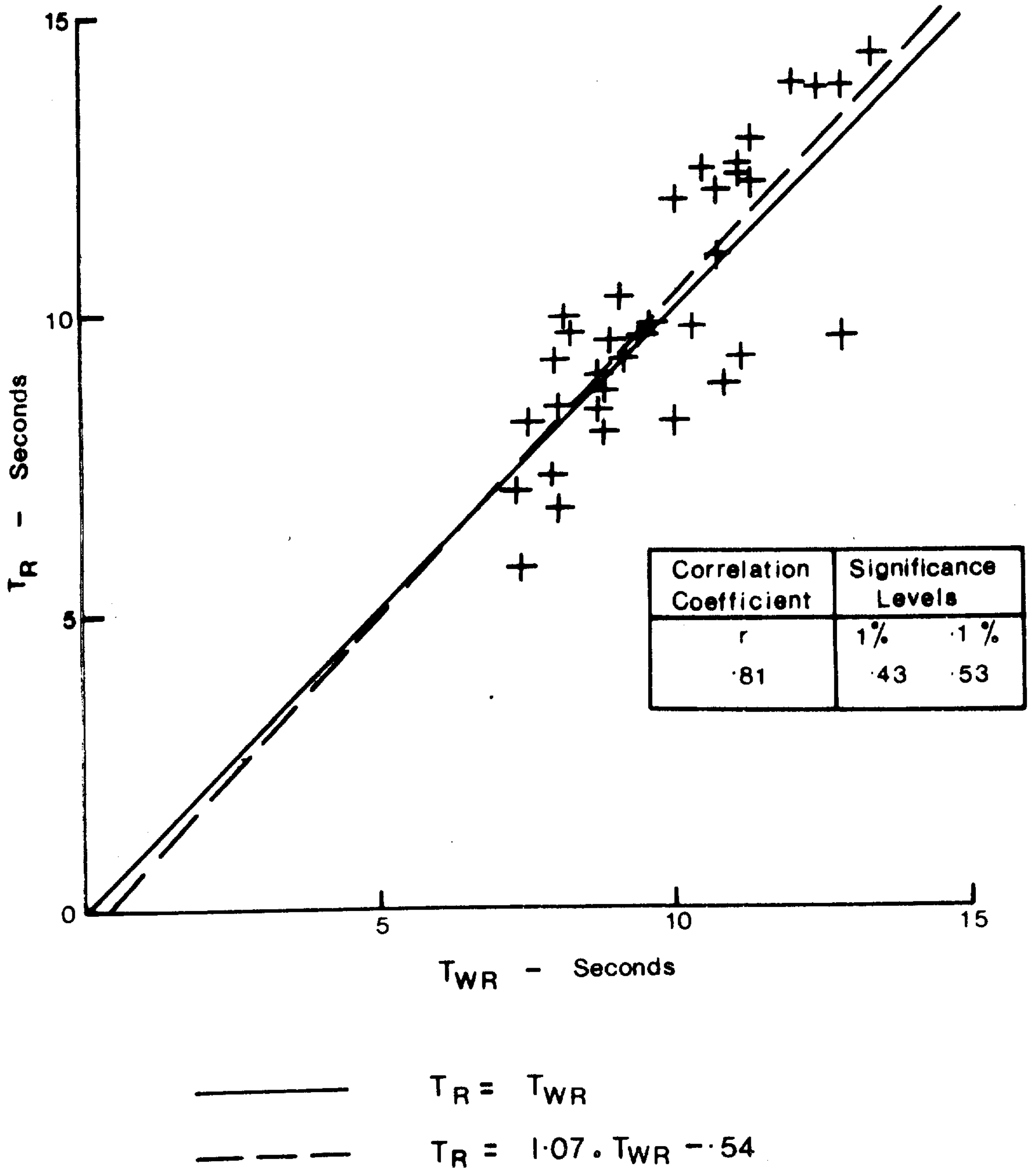


Fig. 23 Wave period from the Radar (T_R) plotted against wave period from the Wave Recorder (T_{WR}). T_R and T_{WR} are significantly correlated with a correlation coeffient of r = ·81