I.O.S.

SWANSEA BAY (SKER) PROJECT
TOPIC REPORT 7A

M W L BLACKLEY

Beach Fluorescent Tracer Experiments

Report No 105

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF
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SCIENCES

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This report is one of the Topic Report series concerning Swansea Bay and describes the use of fluorescent tracers in determining sediment transport on the E foreshore of the Bay. Although the trend of movement of the tracer centroids for the two experiments was in opposite directions, the rate of movement away from the injection site fell in each case as the experiments progressed, suggesting an approach towards equilibration of the tracer with the indigenous sediment towards the end of the experiment.

Additional information indicating that there was little net longshore transport on the beach was obtained from a background survey carried out prior to Experiment 2. After nearly 6 months the centroid of the tracer remaining from the previous experiment was found to have moved only 50 m south of the injection line giving an average drift rate of 0.21 m per tide.

Calculations on the tracer budget showed that between 50-100% of the injected tracer could be accounted for at the end of each experiment. Cores taken in the injection area revealed discrete layers of buried tracer that in some cases remained throughout the experiment.

From work on the selective transport rates of different grain size fractions it would appear that the coarser material moves preferentially as bed load. As the grains decrease in size, the effect of grain suspension may play a more important role.

1 INTRODUCTION

1.1 Preface

The use of radioactive tracer offshore in Swansea Bay had proved most useful in determining sediment transport rates and direction of movement (Heathershaw and Carr 1979). A similar type of experiment was designed to assess the direction and rate of longshore transport of sand on the Morfa Mawr beach. To facilitate handling and on the grounds of health/safety the use of a radioactive tracer was ruled out and a sand fluorescently coated was used instead.

The first experiment was undertaken in November and involved searches on both spring and neap tides but due to an instrument fault little hydraulic data was gathered. A second similar experiment took place in the following April/May. The fluorescent tracer work for both these experiments is dealt with here but the analysis and interpretation of the associated hydraulic data can be found in Wilkinson (1980).

1.2 Description

The experiments were carried out at a site (Figure 1) 3.1 km south of the tidal harbour at Port Talbot, midway between the harbour and the River Kenfig. This stretch of beach is comparatively simple in form with a uniform slope of approximately 1:50 except near the dune face at the rear of the beach, where it steepens rapidly. This latter area corresponds to that above High Water Mean spring tides, the uniform fine sand of most of the beach surface being replaced there by a narrow steep pebble and cobble storm beach. The broad sand zone represents more than 95% of the inter-tidal zone at Low Water spring tides, the other 5% comprising lag deposits and larger areas of peat and clay. The Morfa Mawr part of the beach was chosen for the tracer work because it was largely free from these exposures, the nearest clay outcrop being 350 m north of the tracer injection site. Figure 2 shows the beach section at the tracer injection site and Figure 3 indicates the variability of beach surface elevation over the same section during the period November 1976 to May 1977. As can be seen the range in the surveyed profiles was of the order of 0.15 to 0.63 m, the variations being greatest at the high and low water levels.

2. METHOD

2.1 Experimental design

On each of 5 occasions during the two experiments 500 kg of sand labelled with a fluorescent coating was placed at zero Ordnance Datum (Newlyn) (ODN) which is virtually mid-tide level. Three colours were used: red(twice), blue (twice) and green (once). The tracer was prepared by Feslente Ltd, Kings Lynn, UK, and was a washed and graded 99.1% silica sand of mean grain size 2.07 (240μM) ± 0.44 φ which matched reasonably well the mean grain size of the sand found at mid-tide level in the experimental area (2.16 (226μ M) ± 0.48 φ) Figure 4.

Instrumentation for measuring wave induced and tidal currents was placed 50 m further seaward at a height of 1 m above the beach face. As the gradient was 1:50 the equipment on the rig became submerged at the same time as the tracer material.

Tracer was placed flush with the beach face in a shallow depression some 2.5 cm deep and 3.5 metres square for most of the injections. King (1951) has, shown that the depth of disturbance of sand on the foreshore is closely related to the breaker height. For beaches with similar grain size material and tidal range but with slopes of 1:80 the depth of disturbance was found to be 1 cm for every 30 cm of wave height. Work by Fortnum and Hardcastle (1979) has shown that at Port Talbot, for the autumn months, waves greater than 1 m occur for about 50% of the time. For waves of this height, and bearing in mind that the beach slope in Swansea Bay is somewhat greater than 1:80, depths of disturbance of the order of 3 cm per tidal cycle are predicted (Table 1). In order to assess the effect of exposure, one batch of tracer (green) was placed directly on the beach surface. During the second injection the April-May 1977 experiment tracer was placed on the beach to a depth of 1.5 cm only, to ensure that all the tracer was released on the first tide.

To reduce the surface tension of the tracer and to avoid atypical rates of travel due to aggregation a wetting agent, which consisted of a concentrated mixture of detergent and water, was used. On all occasions except Phase 1, Experiment 2, this was applied to the tracer in-situ. On the one odd occasion when the wind was sufficiently strong to permit aeolian transport the detergent mixture was added directly to the sacks just prior to injection.

In order to ensure rapid and systematic sampling, a 50 x 50 m grid of metal rods was laid out long axis parallel to the beach over a length of 1.2 km and a width of 450 m (Figure 5). Samples were collected at grid points as well as intermediate locations at 12.5 x 12.5 m intervals around the injection site (Figure 5). The samples were collected using a specially designed trowel which when just full gave a consistently sized sample measuring 10 x 10 cm and 2 cm thick. As the area to be covered was large, sampling was carried out from a vehicle. At night it was sometimes possible to use a portable generator and UV lamp in the field in order to determine the spread of the tracer and hence reduce the sampling area. Unfortunately, a combination of the beach being naturally very wet; incidence of rain; and much stray light at night, made this task difficult and time consuming and eventually it was found to be quicker to sample the whole grid although some on the spot assessments were made. The number of samples collected during each low tide search varied between 170 and 270.

Additionally, within and immediately around the dump site, between 5 and 12 4 cm diameter cores (Figure 6) were taken during each search. These penetrated the beach to about 20 cm. In addition to the beach searches, during the 1976 experiment sampling was carried out offshore by the University College of Swansea's launch RV Nicola. Because tracer was not found in any of these offshore samples during Experiment 1 surveys were limited to the exposed beach and the immediate nearshore zone during the second experiment in 1977. Further comments on experimental techniques are included in Appendix I.

The first phase of each experiment closely coincided with neap tides (range approximately 4.4 m and 3.8 m for November 1976 and April 1977 respectively) and the second phase with the maximum spring tides (range approximately 9.7 m on each occasion). After each injection searches of the beach were carried out on the next four successive low waters. Prior to the start of Experiment 2 limited sampling was carried out to discover if any of the tracer remained from Experiment 1. It had been anticipated that following a 5 month gap between the 2 experiments that the tracer levels would be low and fairly uniform. This later proved not to be the case and provided complications in the interpretation of the tracer concentrations for Experiment 2.

Before any transport calculations, measurements were made to see what proportion if any of the tracer was not covered by the fluorescent coating and therefore was undetectable by the ultraviolet light source. The amount untreated varied between 1.5 and 11.0%. This examination also revealed that some of the larger fluorescent grains were in fact composed of smaller particles adhering to each other. An examination of the specific gravity of the tracer material was also made in order to determine what effect the coating had on the weight of the grain. It was found that the tracer coating contributed between 5.6 and 11.49% of the tracer sand by weight.

Calculations of the volume of tracer assumed that the tracer was initially dry and loosely compacted and that subsequently, like the indigenous beach sand, it became wet and densely compacted. Several density values exist for these conditions but those of Terzaghi and Peck (1968) have been used here.

Uniform loose sand dry = 1.44 gms/cm^3
Uniform dense sand dry = 1.74 gms/cm^2
Uniform loose sand saturated = 1.89 gms/cm^3
Uniform dense sand saturated = 2.08 gms/cm^3

2.2 Number of grains of tracer sand per injection

In order to validate the results from the tracer experiments it is necessary to know the percentage of the injected tracer accounted for in each search. For this to be calculated the number of grains in each 500 kg batch of tracer sand (Table 2) has to be known and this has been estimated in 2 ways:

(i) Calculation of the number of particles based on mean and frequency within classes at $\frac{1}{4}\phi$ intervals between 1.0 and 4.0ϕ (where ϕ (phi)) $= -\log_2$ diam (mm)).

(ii) Physical counting of grains in a 1% mixture of tracer in 99% sand.

2.2.1 Frequency method

Samples of fluorescent tracer were taken from the red, blue and green material used in each experiment in Swansea Bay and also from similar red tracer material used in an offshore study on the East Coast during 1978-79. These samples were sieved and the weights retained on each sieve recorded. For a particle count to be obtained assumptions had to be made that the grain size for each $\frac{1}{4}\phi$ was intermediate between the sieve mesh sizes and that the sand particles were spherical and had a density of 2.65. The weight retained on each sieve was then transformed into an equivalent number of particles and then summed together. The figure was then scaled up to represent the weight of tracer used in each injection.

2.2.2 Dilution method

A series of sub-samples were taken from the various tracer sand samples. These sub-samples were then mixed on the basis of 1% tracer and 99% indigenous beach sand, by weight. A series of aliquots were next taken from the mixture and the number of tracer grains counted per aliquot. These values were averaged andthe whole scaled up to represent the particle numbers in 500 kg as before. In general values obtained by dilution method were somewhat lower than those based on frequency. It was interesting to note that in one instance where the tracer was decoagulated in the laboratory with a detergent prior to counting the value was 12% higher than the comparable result from frequency calculation. Even so decoagulation of the samples still produced a value somewhat less than the average particle number obtained by the frequency method (3.4128×10^{10} as against 3.5690×10^{10} per 500 kg).

It was clear that many factors influenced the frequency figure. However, the mean of figures derived from Experiments 1 and 2 and similar work on the East Coast (Lees, 1980) 3.5690×10^{10} particles in 500 kg of tracer was used in all subsequent calculations.

2.3 Laboratory Procedures:

The bagged and labelled surface samples were returned to the laboratory. In order to increase the speed of analyses the samples were first spread out on trays and then viewed under UV light. In this way samples not containing any fluorescent sand could be discarded, whilst the rest were dried. A proportion of each sample containing the tracer was then spread very finely over the bottom of a non-reflective tray and viewed under UV light. The number of fluorescent grains of each colour of tracer was recorded and the amount of sample examined was weighed. The particle count was scaled up to the amount assumed to occur in a standard mass of 1 kg.

The cores were sliced longitudinally. One half of the core was then sliced horizontally into 2 cm thick segments and these were treated in the same way as the surface beach samples. Some cores contained undisturbed bands of tracer and these band thicknesses together with the depths below the beach surface were recorded.

3. ADDITIONAL DATA

3.1 Wind data

Wind roses covering the 2 periods of the experiments, 14-25 November 1976 and 25 April - 5 May 1977, are shown in Figure 7a and 7b. For 27% of the time during Experiment 1 winds were mainly light, 8.2 m/s (16 kn) and for the most part offshore or alongshore. During Experiment 2, the winds were stronger, exceeding 10.8 m/s (21 kn) on occasions, and mainly from a south westerly direction.

3.2 Wave data

Wave data was collected from an offshore wave recorder cabled in at Port Talbot. The records showed (Figure 8 and Table 3) that the mean significant height Hs value for the 2 phases of each experiment and the intervening period followed a similar pattern. Each experiment started with waves of the order of 1 m high, the conditions then became calmer as the work progressed.

The mean wave period (Tz) did show a difference between the two experiments having a mean value of Tz = 10.4 sec during Experiment 1 and 8.2 sec during Experiment 2.

Some information on wave direction was obtained from radar equipment mounted on the end of the southern breakwater of Port Talbot (Heathershaw, Blackley and Hardcastle 1980). Unfortunately it was non-operational during Experiment 1, but during Experiment 2, where the waves were sufficiently large to be detected on the radar, directions between 225° and 235° from true north were obtained. This would result in the typical nearly normal approach to the beach.

4. ANALYSIS OF DATA

The injection point of the tracer was taken as the centre of an coordinate with the x axis running along the longshore direction (+ towards Port Talbot) and the y axis at right angles to it (+ towards Low Water). Using results from Crickmore and Lean (1962) the x, y coordinate of the centroids for each search was calculated from

$$\bar{x} = \frac{\sum_{i=1}^{M} c_i x_i}{\sum_{i=1}^{M} c_i} \qquad \& \qquad \bar{y} = \frac{\sum_{i=1}^{M} c_i y_i}{\sum_{i=1}^{M} c_i}$$

where x_i and y_i are the x and y coordinate of each sample having a tracer concentration c_i (in grains per kg) and M is the total number of samples containing tracer.

Recovery rates and tracer budget were also calculated. The recovery rates refer only to the amount of tracer that could be accounted for in the top 2 cm of the beach (the depth of the scoop samples).

Less reliable results were obtained for the amount of tracer remaining (tracer budget) at depth within the search area. This assumed that the concentration of tracer found in the top 2 cm at a grid point extended down to the maximum depth to which tracer was found in the appropriate cores.

The cores also showed that layers of concentrated tracer existed at depth many tides after the injection had taken place. Attempts were therefore made to calculate the amount of tracer remaining within the dump area at a depth based on the concentration values obtained from a single central core.

4.1 Experiment 1

The analysis of data from Experiment 1 was reasonably straightforward. For each completed search the number of grains per kg for each sample together with its appropriate grid position were recorded. A computer programme was then used that took all the surface concentration data both at the 50 m grid interval and at the closer sampling interval around the injection site and produced point values based on a smaller evenly spaced grid. The displacement of the tracer centroid after each tide (Figure 9) and the contoured plots of the tracer dispersion cloud (Figure 10a-h) were calculated from data based on this grid. The sum of the number of grains occurring in the top 2 cm of the beach surface for each contour plot was also recorded.

4.2 Experiment 2

As mentioned earlier it had been assumed that any tracer left over from the first experiment would be of low value and evenly spread over the beach. For this reason only a limited pre-injection search was carried out over the grid before the introduction of the new red tracer (Experiment 2). Blue tracer found on the beach during the first 4 red searches of Experiment 2 was also recorded and contributed towards the background information on the blue tracer.

The background values for the red tracer were so varied that a mean value was calculated and this was subtracted from all the values obtained during Experiment 2. For the blue tracer there were more background values per grid point. The means and standard deviation for each sampling point were found and the various sampling points aggregated until such a time as the standard deviation began to increase again. The sample for any survey site during Phase 2 of Experiment 2 (Figure 11a-d) was only considered above background if it exceeded the 1 sd value for the aggregated area. Although the coverage could not extend far enough seawards to reach 'zero' background, this method appeared to produce sensible results and avoided the 'holes' (negative values) appearing on the contoured plot. The movement of the centre of gravity of tracer clouds (Figure 12) and the contoured plots for the red tracer (Figure 13a-h) were then produced as before.

5. RESULTS

5.1 Experiment 1

5.1.1 Centroids

Red tracer: Table 4 summarises the tracer centroid movements. After 2 searches the centroid had moved approximately 50 m in a northerly direction and slightly up the beach. By search 3 the tracer had moved seawards and slightly back towards the injection point. For the remaining searches the tracer centroids were found shorewards of the injection site and continuing the former northerly movement. The limited coring around the injection site showed that after search 1, a proportion of the tracer became buried in a discrete band. Even at the end of search 8 a concentrated layer of tracer and sand 5 cm thick and 8 cm from the surface could still be seen in the central core. Further examination of the upper 8 cm of the core by UV light showed very little tracer material present.

Blue and Green tracer: The burial of the red tracer by the beginning of Phase 2 enabled the blue tracer to be placed in an excavation above it. The green tracer was placed on the beach surface in a low mound 5.0 cm high over an area of 6.25 sq m immediately to the south of the blue tracer. Despite an initial divergence of movement of the 2 centroids, after 4 tides the blue and green tracer centroids were respectively 30 m and 43 m up the beach but with little alongshore displacement.

5.1.2 Recovery rate (top 2 cm)

Estimates were made of the amount of tracer found in the top 2 cm of the beach (ie the thickness of the scoop), (see Table 5). The pattern of sampling used excluded any scoop samples being collected from inside the injection site which was only cored. This resulted in the apparent recovery rates being low when there was little or no dispersion of tracer. As the experiments progressed and tracer moved away from the central area this problem was reduced. At the end of each phase of the experiments the value of tracer occurring in the top 2 cm of the central core was included in the computer data. This led to increased recovery rates in some cases. The recovery rates for the red tracer in Experiment 1 fell from 18% after search 1 to 10.5% after search 8.

The data gathered for the green tracer was somewhat limited as it was not as easily distinguishable as the blue. The cores showed that most of the blue tracer stayed in the top 2 or 3 cm of the beach and this was supported by the fact that by the end of phase 2, 74% of the blue and 83% of the green could be accounted for in the top 2 cm.

5.2 Experiment 2

5.2.1 Centroids

Red tracer: For searches 1 and 2 the centroid movement was larger and in a southerly direction, ie opposite to that encountered in Experiment 1. By

Search 4 this direction was reversed, the centroid for search 4 falling north of the injection site. The cores showed that for the first 2 searches the red tracer became progressively buried. By search 2 a discrete layer 4.5-6.5 cm below the surface was observed. By the next search the depth of disturbance was such that this discrete layer had been dispersed. At the beginning of phase 2 no more discrete bands of red tracer were detected and the centroids continued a more even movement southwards, but in a slightly seaward direction.

The blue tracer also showed a southerly movement during this time except during the last search when an apparent movement back towards the injection site was detected.

5.2.2 Recovery rates (top 2 cm)

The amount of tracer accounted for in the top 2 cm showed a marked increase from 11% to 32% about the time the discrete layer was destroyed. By the end of phase 2, 20% of red tracer was still in the top 2 cm of the beach. By this time the maximum depth at which tracer was detected was 14 cm. One core showed approximately uniform concentrations of tracer down to 20 cm but this core may have suffered some disturbance on transport back to the laboratory.

At the end of phase 2, 24.3% of the blue tracer was accounted for in the top 2 cm of the beach.

5.3 Rate of movement of centroids: (Experiment 1 and 2)

The average drift per tide since injection for tracer remaining in the upper 2 cm of beach can be seen in Figure 14. The blue tracer (Experiment 1, Phase 2, Experiment 2, Phase 2) was influenced by only 4 tides whilst the red tracer Experiment 1 and Experiment 2 had 19 and 16 tides respectively. In spite of the fact that the movement of material was in different directions during the 2 experiments and that some searches were carried out on spring tides whilst others were on neaps the average amount of movement was very similar in magnitude showing a progressive decline over time from between 33 to 47 m/tide to less than 1 m/tide at the end of the experiment.

5.4 Total Tracer Budget

Table 5 shows amount of tracer accounted for in the surface 2 cm of the beach and also that remaining at depth within the original dump area. Using the former value and assuming that this concentration continued to the maximum depth at which tracer was found in that search, some estimate of the percentage of tracer on the beach can be made.

By the last search (8) of Experiment 1 52% red, 100% blue and 83% green can be accounted for in this way. (As no core information was obtained for the green tracer, this is in the top 2 cm only.) Similarly for Experiment 2 100% red and 73% blue could be accounted for in a similar fashion.

These estimates must be regarded with extreme caution because, obviously, uniform distribution of tracer does not occur when discrete bands of tracer are still visible.

Komar (1969) has suggested that the depths at which tracer is found is likely to decrease away from the injection point towards the periphery of the tracer cloud. Unfortunately all the cores collected were taken close to the injection site so if Komar is correct Swansea Bay values will be unduly high.

In fact some loss of tracer must have taken place outside the sampling area. The contoured plots of the tracer show open seaward boundaries for the red tracer in Experiment 1, Searches 2 and 4, and Experiment 2, Searches 1, 2, 3 and 4, although the latter group may be due to residual background values. Other plots also show a movement of some tracer above the landward limit of sampling.

An estimate was made of the amount of tracer remaining at depth within the dump site area assuming that the central area core(s) was representative of the rest of the dump site. For the red tracer in Experiment 1 the percentage of tracer remaining fell from 13.5% to 2.8%. For the blue tracer the value was 12% after search 8 (ie the last).

For the red tracer of Experiment 2, the tracer was well mixed by the end of search 8 and only 0.5% was accounted for in the dump area. 5.5% of the blue tracer remained.

5.5 Background Survey

Figure 15 shows the distribution of blue tracer remaining on the beach face some five months after injection. Grid concentration values were obtained as for the previous searches. A mean concentration value plus standard deviation for each sampling line at right angles to the longshore direction was then calculated. Figure 15 also emphasises high variability near the injection point due to large across beach concentration gradients, and variation from survey to survey. The peaked form of the graph suggests that even after nearly 6 months what tracer remained is concentrated near the injection site and had not reached equilibrium with the rest of the beach. In fact it is distributed almost symmetrically north and south of line 9 ie approximately 50 m south of the original injection line.

Between November 1976 and May 1977 the average depth of disturbance of the beach surface was 20 cm. This figure together with the number of blue tracer grains accounted for during the background searches, suggests a recovery rate of 15.5%. To account for all the initially injected tracer and assuming uniform mixing, the disturbance would have to extend down to a depth of 1.29 m. This is very unlikely, considering the depth of sand cover and variability of beach level encountered during beach profiling. The conclusion must be that the bulk of the blue fluorescent tracer material from Experiment 1 is most likely to have moved seawards, although the possibility of a loss of fluorescent coating on grains must be considered as a partial cause.

5.6 Selective transport rates of different grain-size fractions within the beach

The opportunity was taken to examine certain beach samples taken during one of the searches and investigate the relationship between the transport rates of the various size fractions. Komar (1977) had carried out similar work on El Moreno (New Mexico) beach. The beach there was coarser (mean grain size 0.76 ϕ (600 μm)) steeper (slope 8°) and narrower (width 30 m) but with a tidal range of 8.6 m. His 5 samples were collected 2-4 hours after injection and in a line 7.6 m, 30.5 m, 45.7 m, 61.0 m and 91.4 m from the injection line and all within the top 5 cm of the beach. He found that the coarsest grain size -0.25 ϕ (1.18 mm) had the highest longshore transport velocity, 0.31 cm s^{-1}. The velocity decreased fairly constantly with grain size reaching a minimum 0.063 cm s^{-1} for grain size 1.75ϕ(300 μm). Material finer than this appeared to be transported at a slightly faster rate than the minimum.

Komar interpreted these results as showing that the coarser material was moved principally as bed load, the larger grains moving alongshore faster than the finer sizes. As the grains decreased in size, the effect of grain suspension played a more important role, increasing the transport rates for the finer material, the maximum longshore current velocity being the limiting value.

Search 3 of Experiment 1 was selected and samples collected on line G (25 m shoreward of injection site) were analysed. This provided 9 samples ranging from 50 m south of the injection site to 350 m north of it. About 20 gms of each sample was sieved at $\frac{1}{4}$ ϕ intervals and the number of red fluorescent grains occurring in each fraction recorded. Only grain sizes falling between 1.50-3.25 ϕ (355-106 μm) were used (about 90% of the sample) as fluorescent grains smaller than this were difficult to count accurately whilst grains larger than 1.50 ϕ (355 μm) were usually made up of aggregates of smaller grains.

A transport velocity in m/tide for each phi size was calculated and plotted against the appropriate phi size. A comparison of Komar's results and those obtained on the Swansea Beach can be seen in Figure 16a. The graphs broadly show the same trend, the velocity first decreasing and then increasing as the material becomes finer. The minima are very similar in position with regard to phi size. The difference in slope of the graphs is most likely due to the Swansea Bay material being influenced by 3 tides whilst Komar's samples were collected 2-4 hours after injection.

The same analysis was then repeated on samples taken from a line (line 10) in an across-beach direction passing through the injection site (Figure 16b). A similar pattern to the alongshore movements was observed with the transport velocity increasing with decreasing grain size. The general trend was for the coarser material to move in an offshore direction whilst the finer material moved up the beach. Ingle (1966) suggested that this differential movement lends support to the idea that the coarser grains in the mobile bed beneath the surf zone tend to move offshore to the higher energy breaker zone under the multiple influence of backwash, seaward return flow and gravity (slope).

6. CONCLUSIONS

The movement of the red tracer centroids during Experiment 1 was mainly northward whilst that for Experiment 2 was southward. In neither experiment was the movements of the individual centroids progressively in one direction. This indicated the effect of exhumation of tracer at or near the dump site on occasions. After 4 tides (Experiment 1) the blue and green tracer centroids were very similarly placed in spite of the fact that the blue tracer was placed in an excavation 2.5 cm deep and the green tracer in a pile 5 cms high on the beach surface. The blue tracer Experiment 2, Phase 2 was laid in the shallowest excavation (1.5 cm) and showed large centroid movements, of the order of over 100 m after 3 tides. All tracer injections that were placed in excavations suffered from burial to some degree.

The average drift rate per tide for the centroids after injection, fell off rapidly for both experiments from 33 m/tide and 47 m/tide respectively for experiments 1 and 2 to less than 1 m/tide after 17 tides for both experiments.

Data obtained from the background survey prior to Experiment 2 indicated that even after 300 tides the blue tracer centroid was still only approximately 50 m south of the injection line giving an average drift rate of 0.21 m/tide.

The symmetrical distribution of the tracer about this line implied that even after a lapse of nearly 6 months there had been little net longshore transport. Only about 15% of the blue tracer was accounted for, assuming uniform disturbance down to a depth of 20 cms. As noted above, this and the open boundary conditions along the seaward edge, suggest that some of the tracer must have gone seaward over this period.

Recovery rates, relating to the amount of tracer found in the top 2 cms. of the surface ranged from 2.4% to 83.0% of the introduced tracer, but some of the lower values may have been a result of the sampling technique used.

Figures for the percentage recovery of tracer occurring at depth within the search area (tracer budget) should be treated with caution as calculations assumed a uniform concentration of tracer with depth whilst the cores showed discrete layering.

Calculations of along-beach selective transportation for different grain sizes show decreasing mobility of the coarser fractions indicating movement preferentially as bed-load for this material. As the material became finer grain suspension plays a more important role, the maximum transport rate depending on the maximum longshore current velocity. The data showed that a minimum mobility occurred in the range 2 ϕ - 2.25 ϕ (250-212 μ m). These results are consistent with Komar (1977).

Similar calculations for across beach movements showed a tendency for material coarser than 2 ϕ (250 μ m) to move offshore whilst finer material moved onshore.

REFERENCES

CRICKMORE, M.J. and LEAN, G.H., 1962. The measurement of sand transport by means of radioactive tracers. Proceedings Royal Society A, 266 402-421.

FORTNUM, B.C.H. and HARDCASTLE, P.J., 1979. Waves recorded at Port Talbot on the South Wales coast. Institute of Oceanographic Sciences Report No 78.

HEATHERSHAW, A.D., BLACKLEY, M.W.L. and HARDCASTLE, P.J., 1980. Wave direction estimates in coastal water using radar Coastal Engineering 3 249-267.

HEATHERSHAW, A.D. and CARR, A.P., 1977. Measurements of sediment transport rates using radioactive tracers. ASCE Proceedings Coastal Sediments '77 Charleston South Carolina W.S.A. pp 20.

INGLE, J.C., 1966. The movement of Beach Sand, Amsterdam Elservier pp 221.

KING, C.A.M., 1972. Chapter 9 Beaches and Coasts Second Edition, London, Edward Arnold 570 pp.

KOMAR, P.D., 1969. The Longshore transport of sand on beaches, University of California, San Diego Ph.D.

KOMAR, P.D., 1977. Selective longshore Transport rates of different grain-size fractions within a beach. Journal of Sedimentary Petrology 47 (4) 1444-1453.

LEES, B.J., 1980. Sediment transport measurements in the Sizewell-Dunwich Banks area. East Anglia, U.K. Holocene Marine Sedimentation in the North Sea Basin I.A.S. Special Publication No. 5.

TERZAGHI, K. and PECK, R.B., 1968. Soil Mechanics in Engineering practice 2nd edition New York Wiley 729 pp.

WILKINSON, R.H., 1980. Foreshore Sediment movement and its relation to observed tidal currents and wave climate Institute of Oceanographic Sciences Report No. 98.

TABLE 1 DETAILS OF FLUORESCENT TRACER INJECTIONS

	Injection		Colour of tracer	Area of injection m^2	Thickness of injected tracer (cm)	State of tide at injection	Injection area
	Date	Time					
Experiment 1							
Phase 1	14.11.76	0530	Red	12.25	2.5	Neap	Shallow excavation
Phase 2	22.11.76	0030	Blue	12.25	2.5	Spring	Shallow excavation
	22.11.76	0030	Green	6.25	5.5	Spring	Shallow mound (just N of above)
Experiment 2							
Phase 1	26.4.76	0540	Red	12.25	2.5	Neap	Shallow excavation
Phase 2	2.5.77	1500	Blue	25.0	1.5	Spring	Excavation just N of previous sites as red tracer still near surface

All injections consisted of 0.5 tonnes of tracer

TABLE 2 NUMBER OF GRAINS IN 500 Kg OF TRACER AS DETERMINED BY THE FREQUENCY AND DILUTION METHODS FOR THE DIFFERENT COLOURED TRACERS

Method	Experiment	Location	Particle Size ϕ	Red Tracer grains/500 kg	Blue Tracer grains/500 kg	Green Tracer grains/500 kg
Frequency	Experiment 1	Swansea Bay	0.5 - 4.0	3.5698×10^{10}	3.1818×10^{10}	3.8454×10^{10}
Frequency	Experiment 2	Swansea Bay	0.5 - 4.0	3.0352×10^{10}	3.9647×10^{10}	—
Frequency	Offshore tracer	E Coast	0.5 - 4.0	$\left.\begin{array}{l}3.9642 \times 10^{10}\\3.8700 \times 10^{10}\end{array}\right\}*$	—	—
Dilution Method	Experiment 1	Swansea Bay	0.5 - 3.5	3.4128×10^{10}	3.0149×10^{10}	—

* Two subsamples from same sample

TABLE 3 MEAN SIGNIFICANT WAVEHEIGHT Hs(m) AND WAVE PERIOD Tz (sec) DURING AND BETWEEN THE 2 PHASES OF EXPERIMENT 1 AND 2

		Phase 1 ($S1-S_4$)	Between Phases (S_4-S_5)	Phase 2 (S_5-S_8)
Experiment 1	Hs	0.90 ± 0.2 m	0.58 ± 0.3 m	0.49 ± 0.17 m
	Tz	10.2 ± 0.92 sec	10.3 ± 0.92 sec	10.8 ± 1.26 sec
Experiment 2	Hs	1.11 ± 0.16 m	0.70 ± 0.38 m	0.27 ± 0.06 m
	Tz	8.19 ± 0.75 sec	8.16 ± 0.77 sec	8.07 ± 0.76 sec

TABLE 4 POSITION OF TRACER CENTROIDS

		Colour of tracer	Search No	x	y
Experiment 1 Nov 1976	Phase 1	Red	1	11.5	1.0
		Red	2	51.0	-10.0
		Red	3	46.5	5.0
		Red	4	49.5	1.0
	Phase 2	Red	5	60.0	-48
		Red	6	72.0	-42
		Red	7	69.5	-47.5
		Red	8	59.5	-43.5
		Blue	5	8.5	-35.5
		Blue	6	15.0	-28.5
		Blue	7	9.5	-34.0
		Blue	8	5.0	-30.5
		Green	5	-18.0	-27.5
		Green	6	-3.5	-39.5
		Green	7	8.0	-34.5
		Green	8	4.0	-43.0
Experiment 2 April/May 1977	Phase 1	Red	1	-31.5	29.5
		Red	2	-84.0	-8.5
		Red	3	-83.5	-23.5
		Red	4	15.0	-1.5
	Phase 2	Red	5	-88.0	-5.0
		Red	6	-83.5	-3.5
		Red	7	-88.0	1.5
		Red	8	-85.0	2.0
		Blue	5	-41.5	-29.5
		Blue	6	-63.5	-29.5
		Blue	7	-103	3.0
		Blue	8	-33.5	-0.5

Co-ordinates of centroid positions obtained for all tracer colours and searches during Experiment 1 and 2.

TABLE 5 DEPTH INFORMATION AND RECOVERY RATES OF TRACER FOUND DURING EXPERIMENT 1 AND 2

( ) value obtained using surface core data * Estimated value

				Surface Samples	Core Samples		
		Tracer Colour	Search No	% of tracer in top 2 cms	Max Depth of tracer cms	depth at which discrete tracer found cms	% of tracer at dump site
Experiment 1 Nov 1976	Phase 1	Red	1	17.9	2.0	0-2.0	13.5
		Red	2	10.9	8.0	2.5-5.0	*16.6
		Red	3	12.8	6.0	No data	6.2
		Red	4	11.4	8.0	5.0-6.5	*10.0
	Phase 2	Red	5	9.5	10.0	No data	No data
		Red	6	8.9	8.0	7.5-8.5	*7.1
		Red	7	9.1	12.0	8.0-11.0	*16.7
		Red	8	10.5	10.0	8.0-8.5	2.8
		Blue	5	23.8	2.0	No data	No data
		Blue	6	28.6	6.0	1.2-3.0	*14.7
		Blue	7	37.3	6.0	2.0-4.0	*21.5
		Blue	8	55.7 (74.0)	8.0	2.0-3.0	11.7
		Green	5	2.4	No data	No data	No data
		Green	6	4.4	No data	No data	No data
		Green	7	16.8	No data	No data	No data
		Green	8	83.0	No data	No data	No data
Experiment 2	Phase 1	Red	1	16.3	10.0	1.5-4.0	10.9
		Red	2	21.2	8.0	4.5-6.5	9.5
		Red	3	11.2	10.0	mixed	3.6
		Red	4	31.8 (31.9)	12.0	mixed	2.1
	Phase 2	Red	5	24.4	12.0	mixed	0.6
		Red	6	23.8	12.0	mixed	0.6
		Red	7	19.1	12.0	mixed	2.4
		Red	8	20.8 (21.8)	14.0	mixed	0.5
		Blue	5	3.2	8.0	0-3.5	11.6
		Blue	6	6.5	8.0	0-2.5	7.7
		Blue	7	7.4	6.0	0-4.0	7.3
		Blue	8	8.7 (24.3)	6.0	0-3.0	5.5

APPENDIX Comments on Experimental Techniques

The method used for injecting tracer into a beach depends to some extent upon tidal range and beach slope. In this work a mid-beach position was chosen for Swansea Bay partly because of the large tidal range (approximately 9.7 m spring tides) and gentle slope (1:50) and partly because this position was thought to best represent the movement of beach material as a whole. The tracer was placed in shallow square pits excavated to depths of 1.5 cm or 2.5 cm deep depending on the likely wave conditions to be encountered during the experiment. At these depths it was hoped that the tracer would become rapidly mixed with the beach sand. Komar favoured digging a shallow trench 4 cm deep, about 25 cm wide and between 200-800 cm long when working on El Moreno beach, Mexico. Although the tidal ranges of the two beaches are similar, El Moreno beach is much steeper with low water exposing a coarse sand beach only about 30 m wide as opposed to over 400 m in Swansea Bay.

Results from data collected at the same time as the tracer experiments and repeated 2 years later (Heathershaw et al, 1980) suggest that changes in beach elevation are a minimum in the mid-tide position. This is partly due to the fact that on beaches with large tidal ranges and low slopes, erosion and deposition is likely to be greatest in the upper and lower beach regions where exposure to wave activity is longest. It would have been interesting to note what effect this would have had if 3 simultaneous injections of different coloured tracer had been made in the lower, mid and upper regions of the beach. If repeated sampling is to be carried out a marked out grid is a necessity as it ensures accurate and rapid sampling. The grid interval chosen should reflect the likely movement of the tracer and in the vicinity of the injection site sampling should be at smaller grid intervals to accurately resolve the large concentration gradients in this area. If, as in this experiment, the grid is marked out with rods these could be graduated to provide useful information on changes in the beach surface elevation occurring during each search.

The depth and amount of each sample is again a matter of choice. For this work a sampler was designed to collect a sample 2 cm deep and about 225 cm^3, this depth of sand was thought to adequately represent the layer of sand likely to be moved by each tide. Komar collected samples 5 cm deep. If the results obtained from tracer experiments are to be meaningful the amount of tracer on the beach during each search needs to be estimated. This can only be done by collecting cores that penetrate the beach to a depth below that at which the tracer is found. The importance of coring was shown in Swansea Bay as for most of the time concentrated layers of tracer remained in the injection area. When this occurs accurate coring and subsequent investigation of the cores has to be carried out in order to determine how much tracer is contained within these layers. Cores should also be collected at intervals over the rest of the grid in order to discover depths of burial.

The question of how soon to sample after injection is more difficult to answer. If sampling takes place too soon (which seems to be the case in some tracer studies) the answer may be of limited value. Over a short period it is unlikely that the tracer will have had time to come into equilibrium with the beach sand and therefore the results will reflect the movement of the tracer but not necessarily that of the indigenous sand. This happened in Swansea Bay where initial centroid movements were 30 to 50 times greater than those recorded later in the experiment. If too long a time elapses, the tracer may be lost altogether. It was possible to sample the exposed beach in Swansea Bay and this was done on four successive neap tides immediately after injection. The same procedure was repeated for spring tides some days later. Sufficient tracer remained on the beach after nearly 6 months to be detected and analysed. The physical number of samples collected may also restrict the number of searches undertaken.

Once the samples have been analysed the data can be interpreted. Difficulties arise however if data from different grid spacing are used together as is the case in calculating the centroids of movement of the tracer clouds. These difficulties were overcome by using a computer program that takes tracer concentration values at any grid interval and provides values at regular grid intervals which may be real or interpolated. This way the bias towards the close grouped values near the injection area is removed.

Movement of the centroids must also be interpreted carefully. Tracer can become buried in discrete layers at depth. If the beach is not cored they may go undetected, with the result that later in the experiment these layers may be re-exhumed and so act as new injections of tracer material. If the concentration in these layers is large this will cause an apparent movement of the centroid towards the newly exposed tracer.

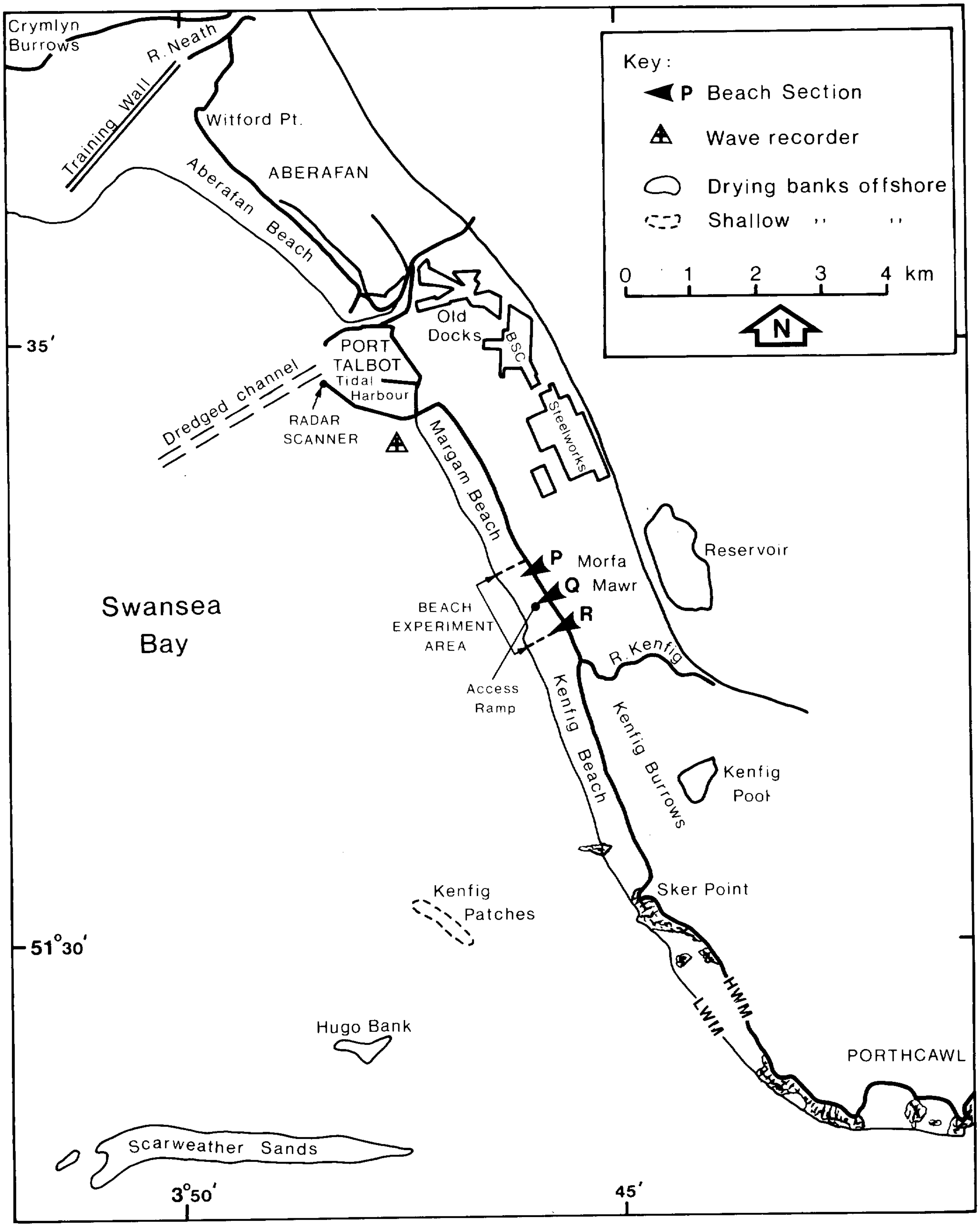


FIGURE 1 Site map

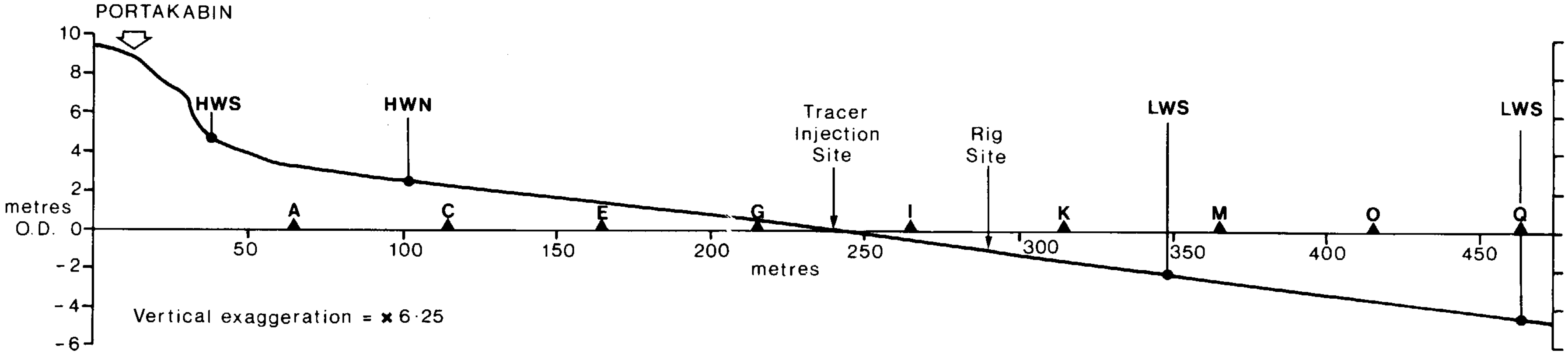


FIGURE 2 Section through injection line showing rig and tracer injection site

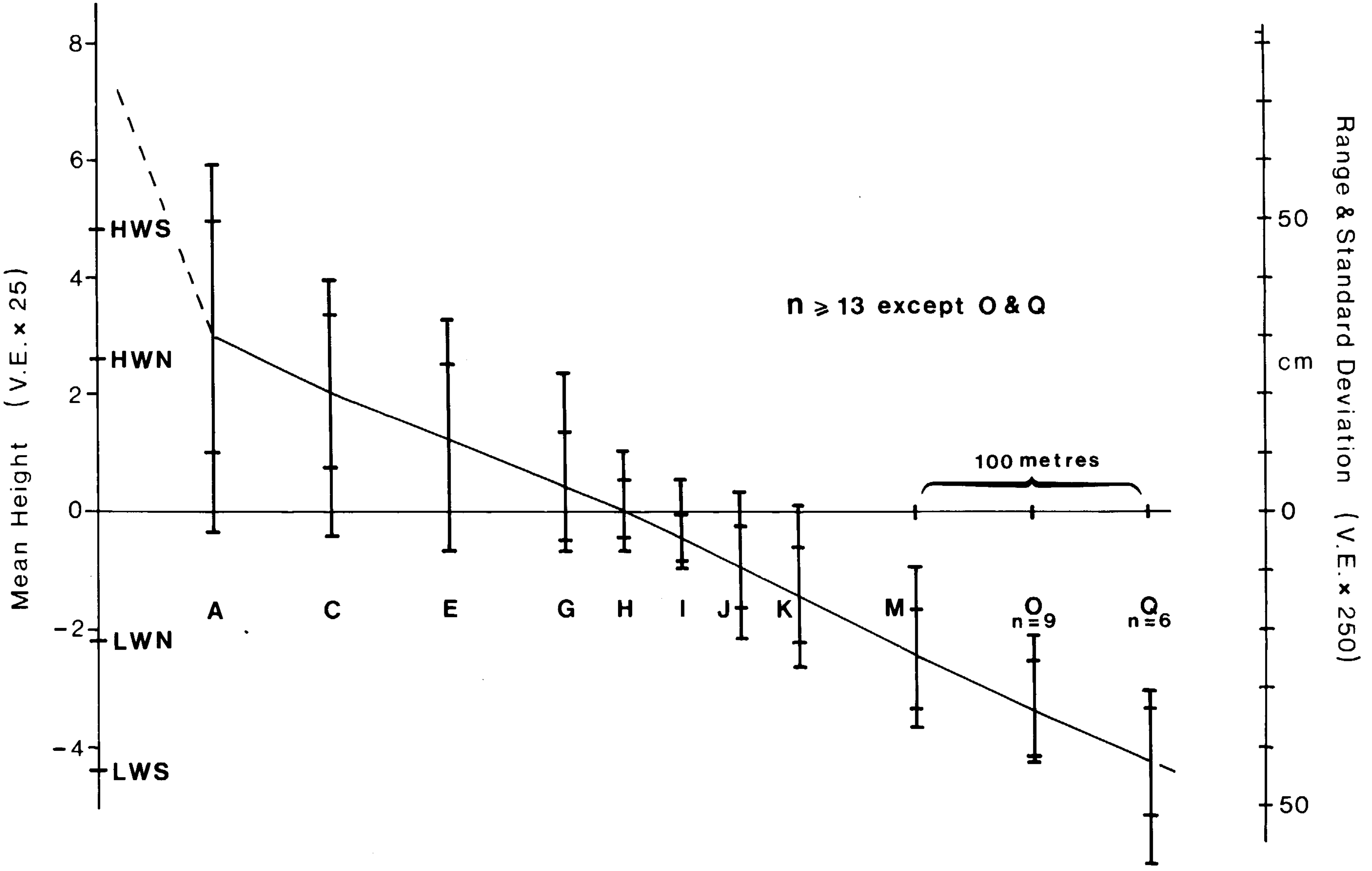


FIGURE 3 Beach elevational changes on tracer injection line (Section Q) November 1976 - May 1977

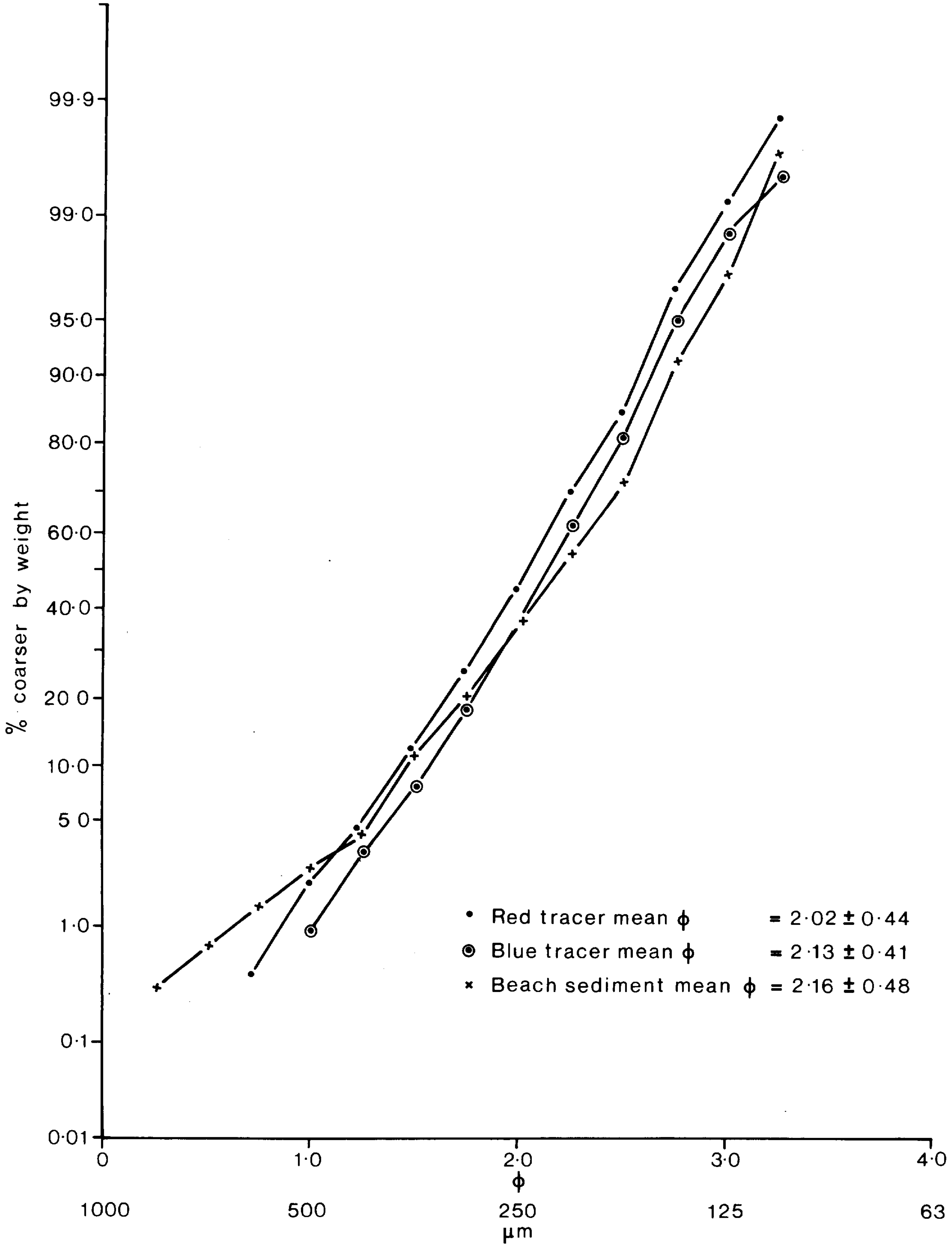


FIGURE 4 Grain size distribution of red and blue tracer and beach material

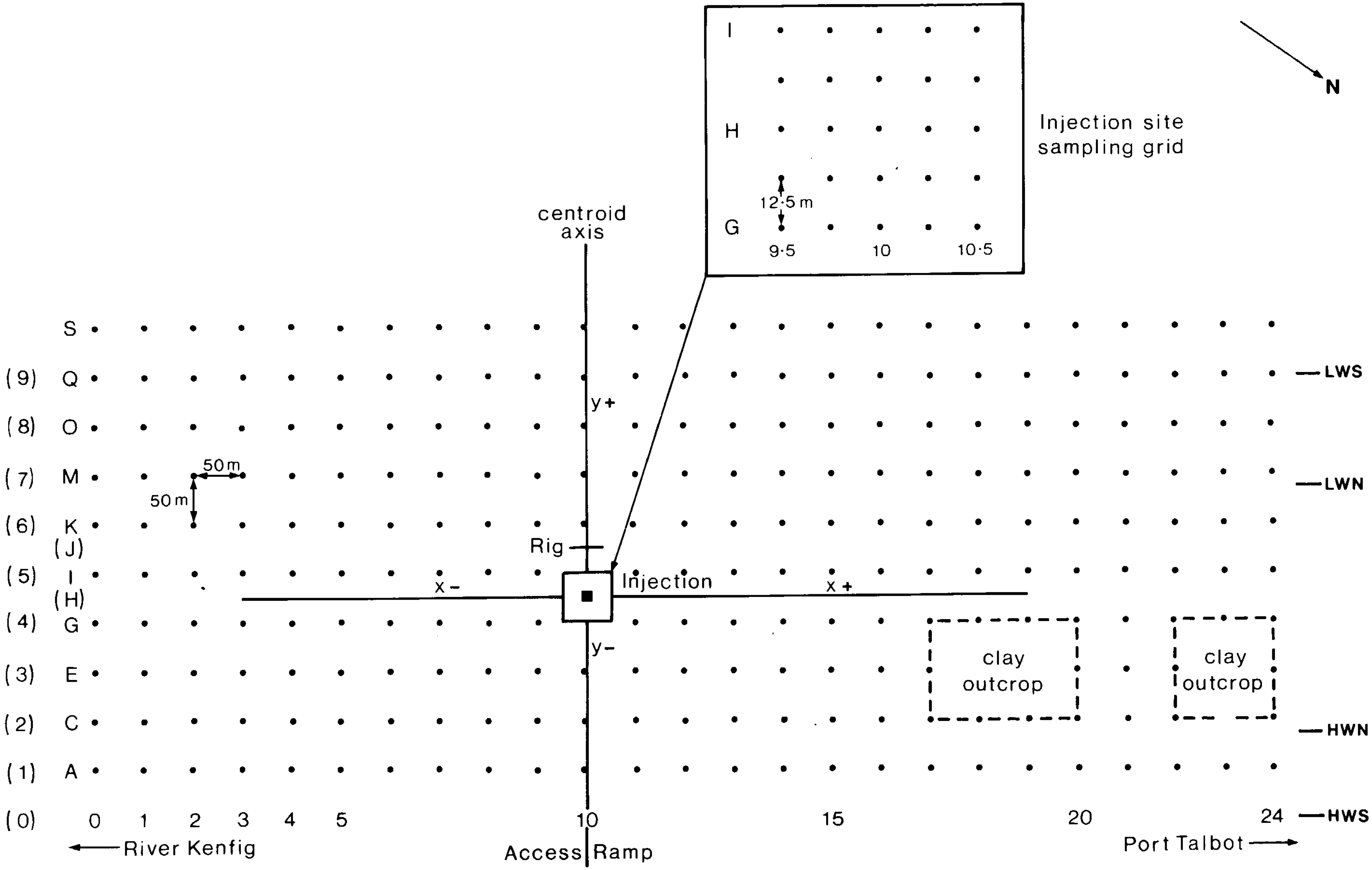


FIGURE 5 Beach tracer sampling grid

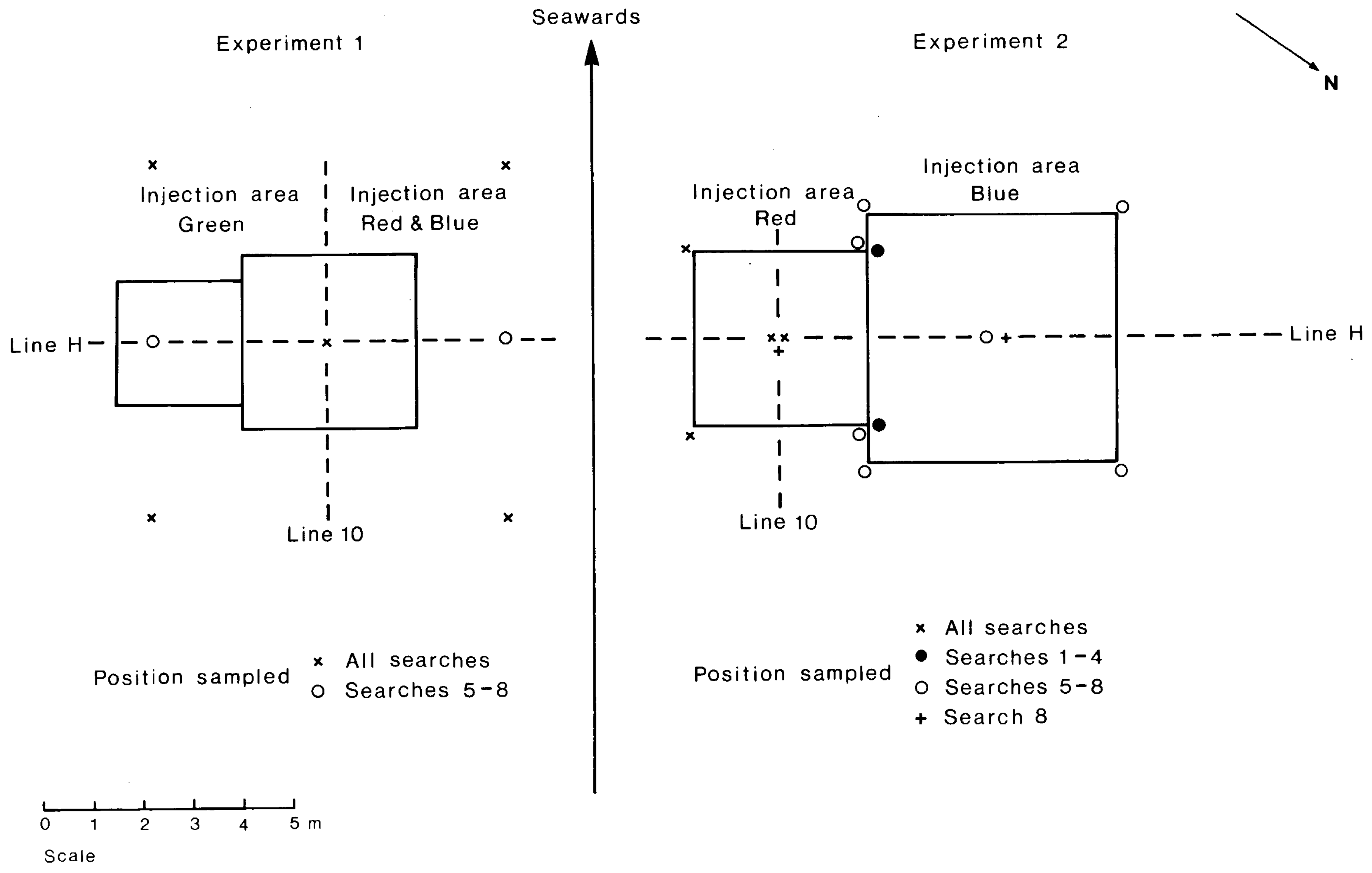


FIGURE 6 Beach core sampling grid

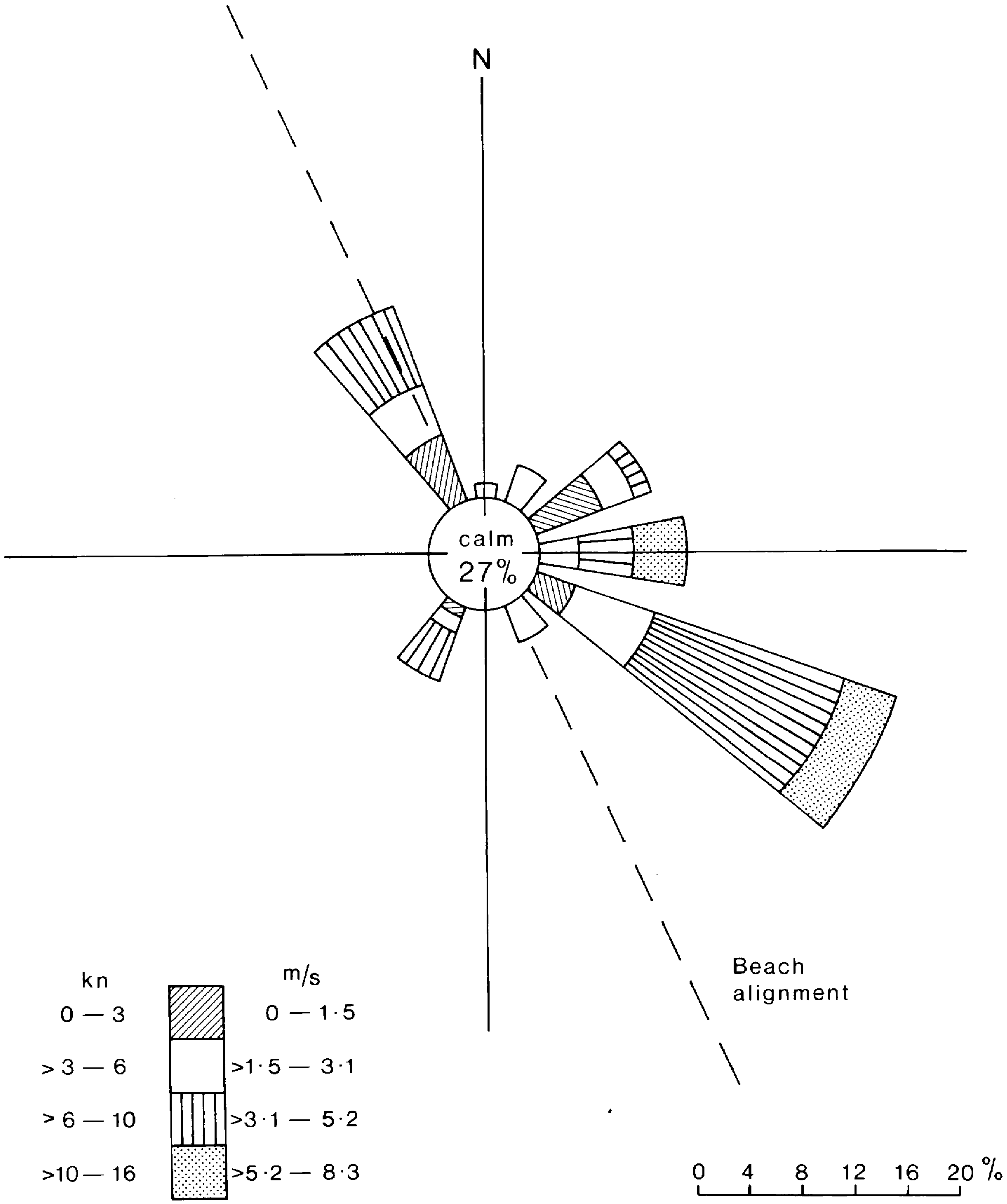


FIGURE 7a Wind rose for period November 14-25, Experiment 1

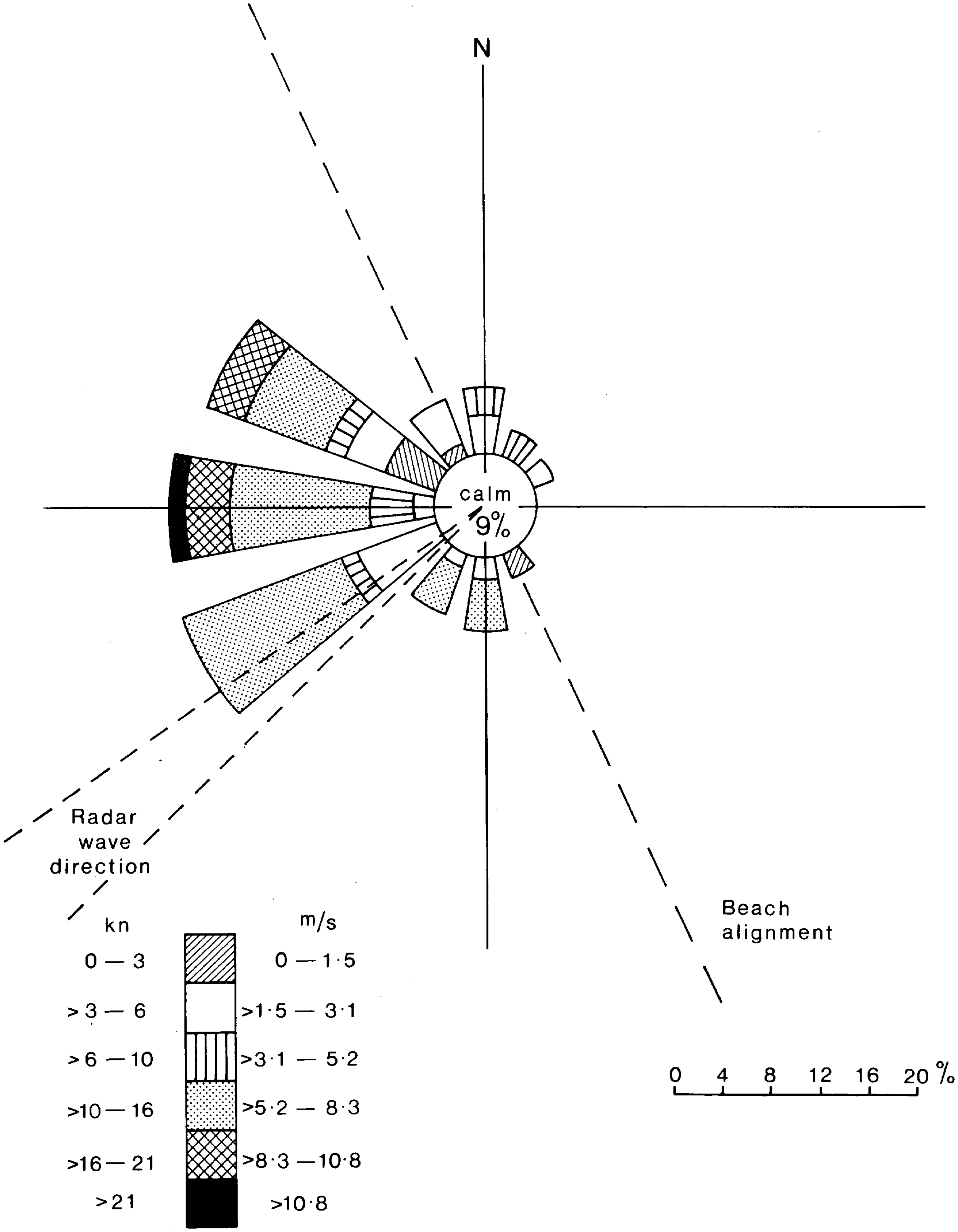


FIGURE 7b Wind rose for period April 25 - May 5, Experiment 2

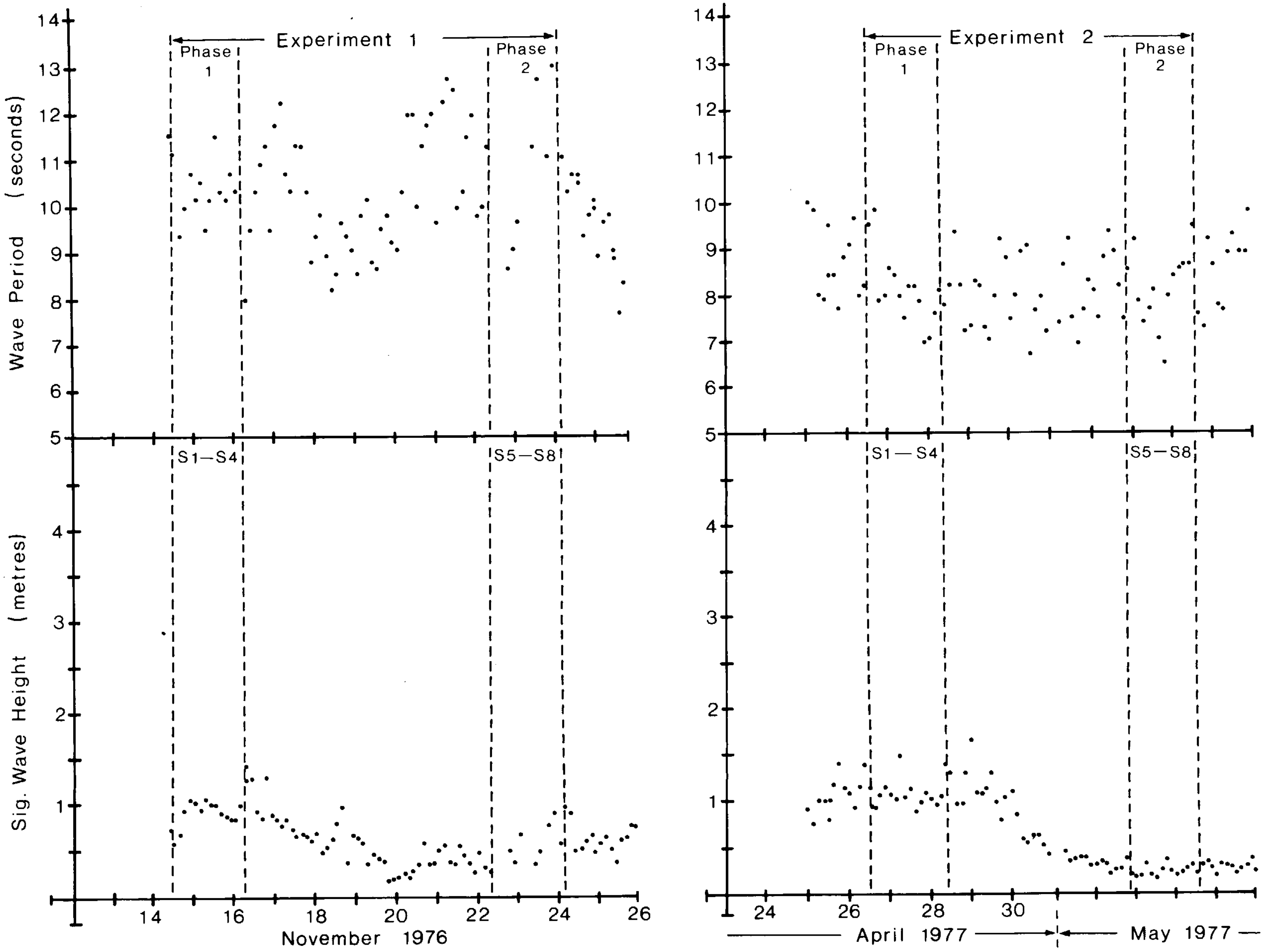


FIGURE 8 Significant wave height (m) and wave period (sec) during Experiment 1 and 2

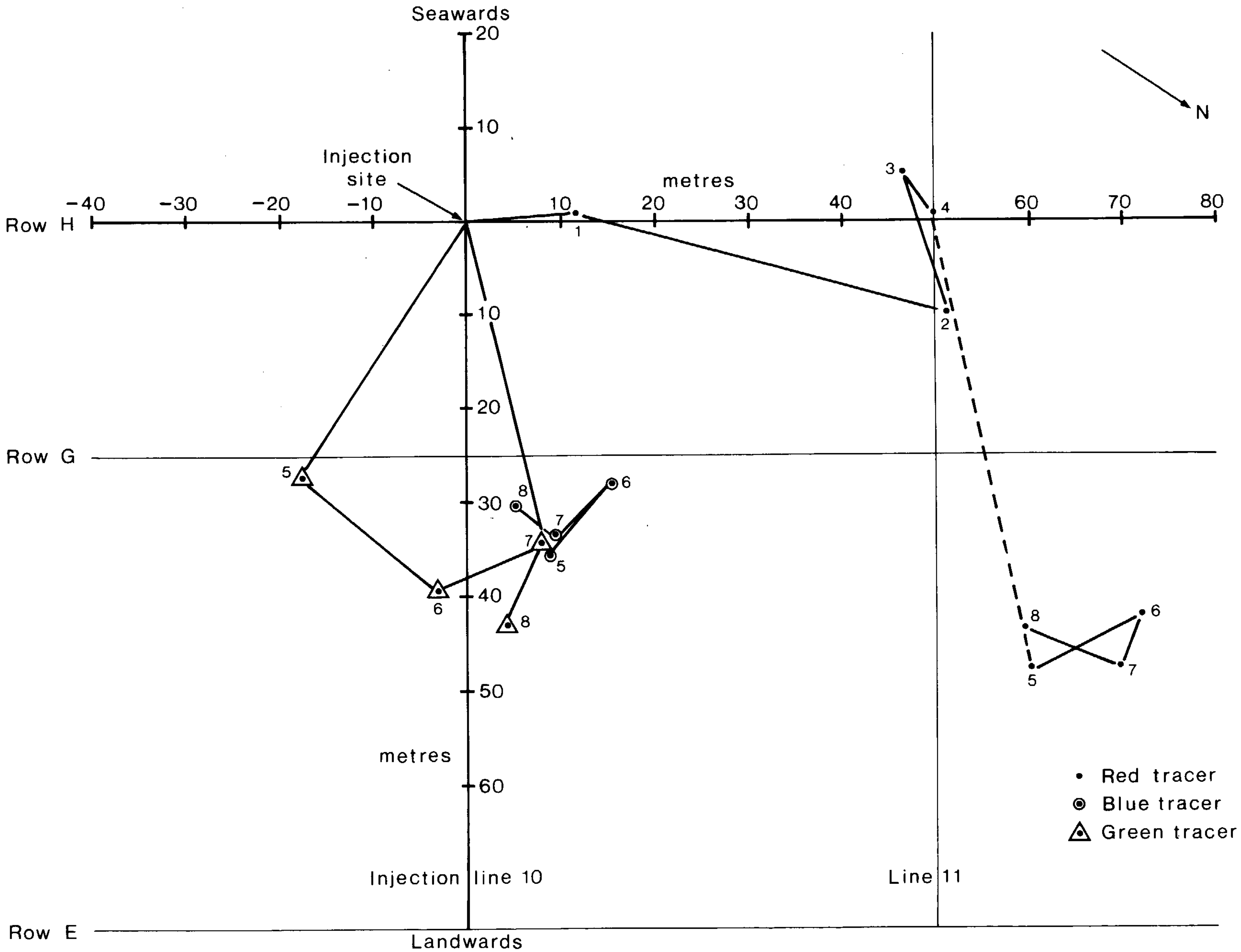
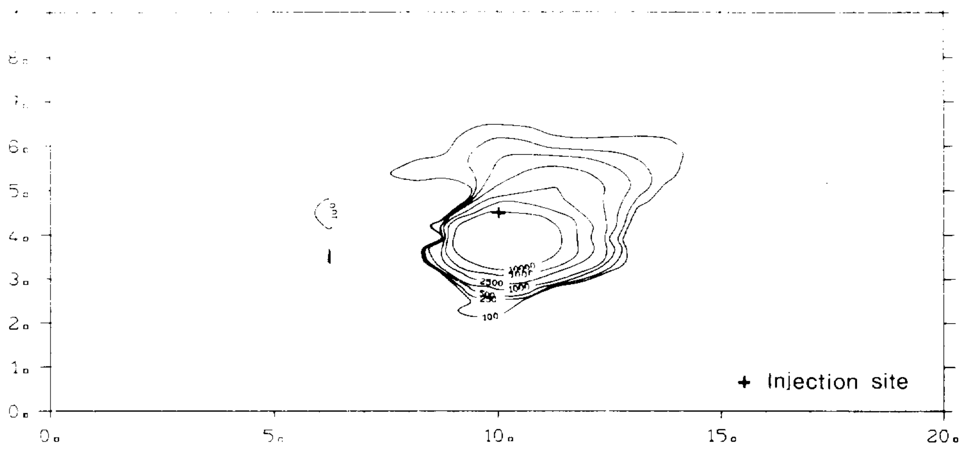
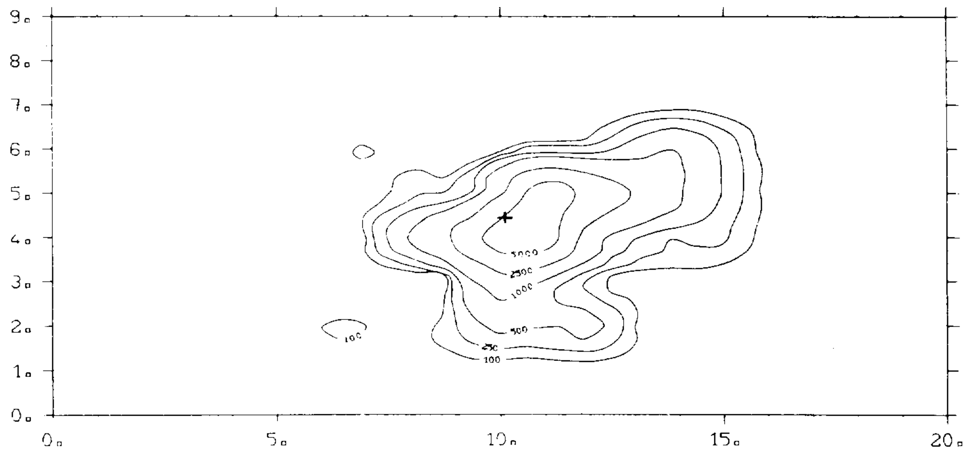


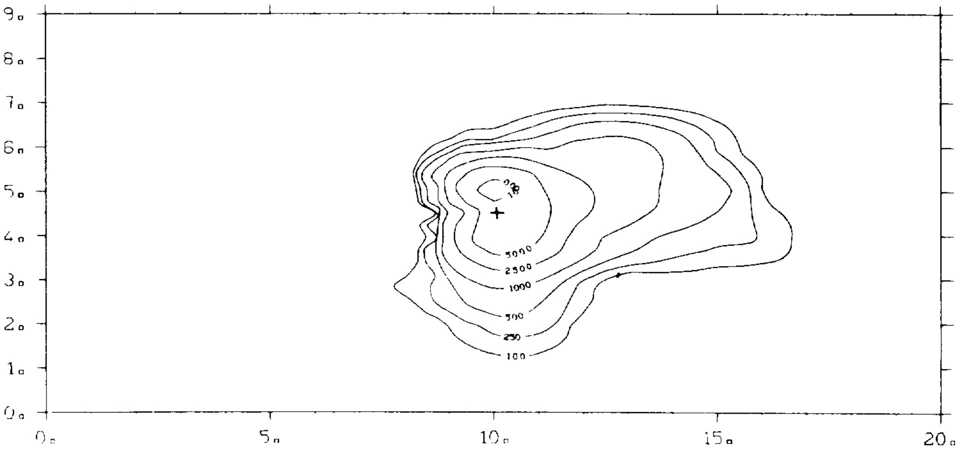
FIGURE 9 Centroid movement for red, blue and green tracer, Experiment 1



10 a SEARCH 1 1976 RED TRACER Contours show number of grains of tracer per kg

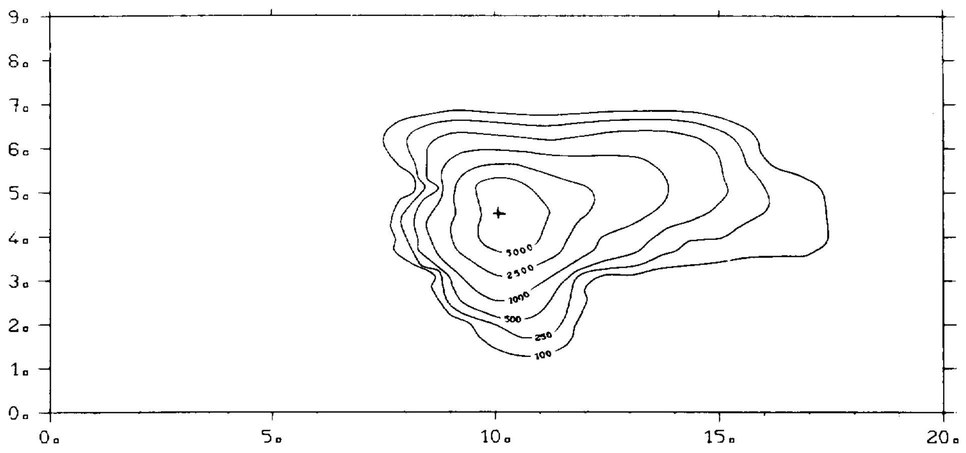


10 b SEARCH 2 1976 RED TRACER

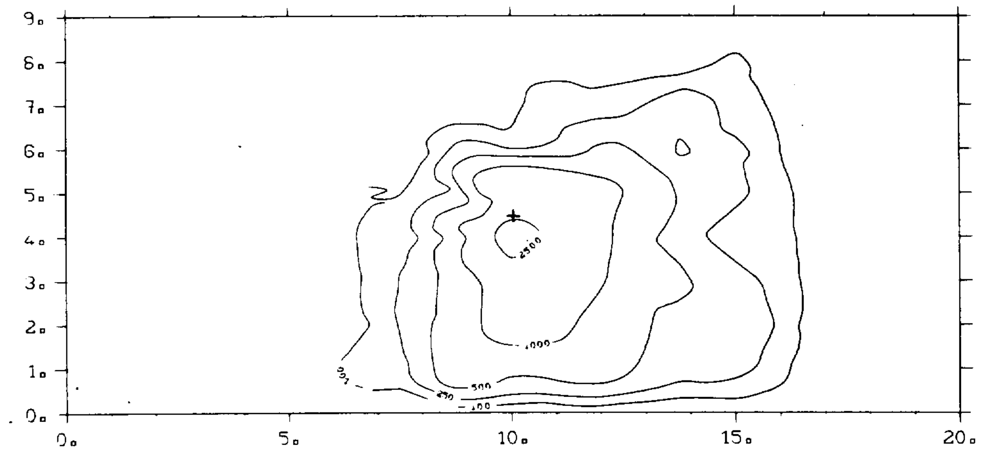


10 c SEARCH 3 1976 RED TRACER

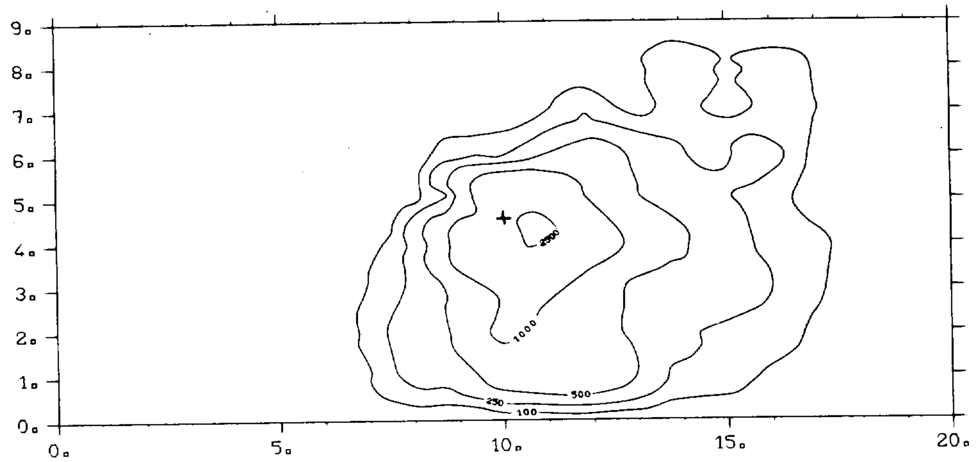
FIGURE 10a-c Contour plots of red tracer from searches 1-3 Experiment 1



10 d SEARCH 4 1976 RED TRACER

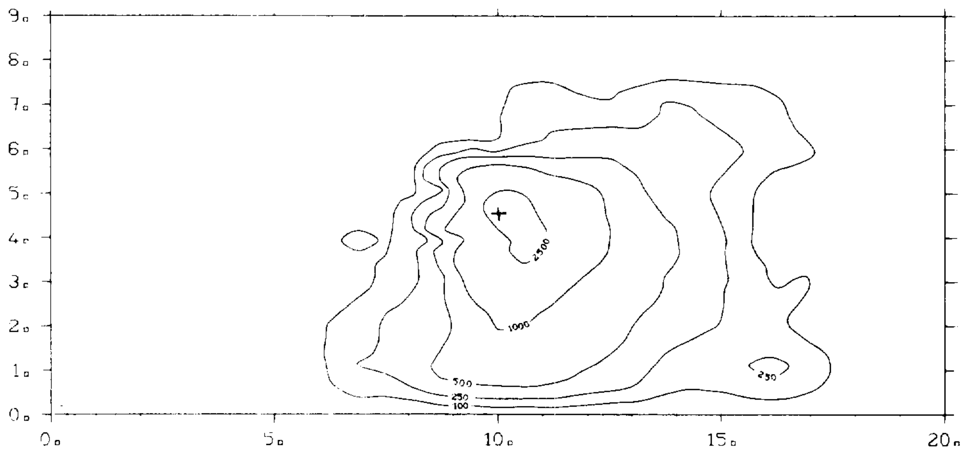


10 e SEARCH 5 1976 RED TRACER

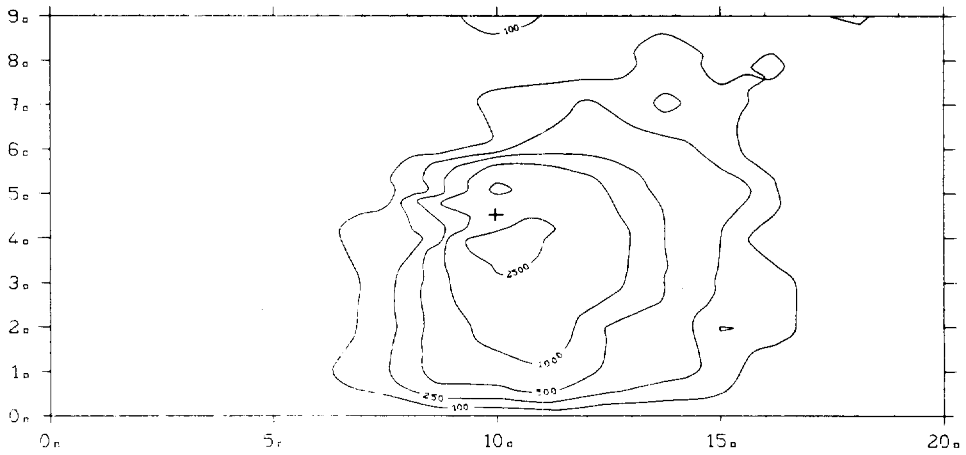


10 f SEARCH 6 1976 RED TRACER

FIGURE 10d-f Contour plots of red tracer from searches 4-6 Experiment 1

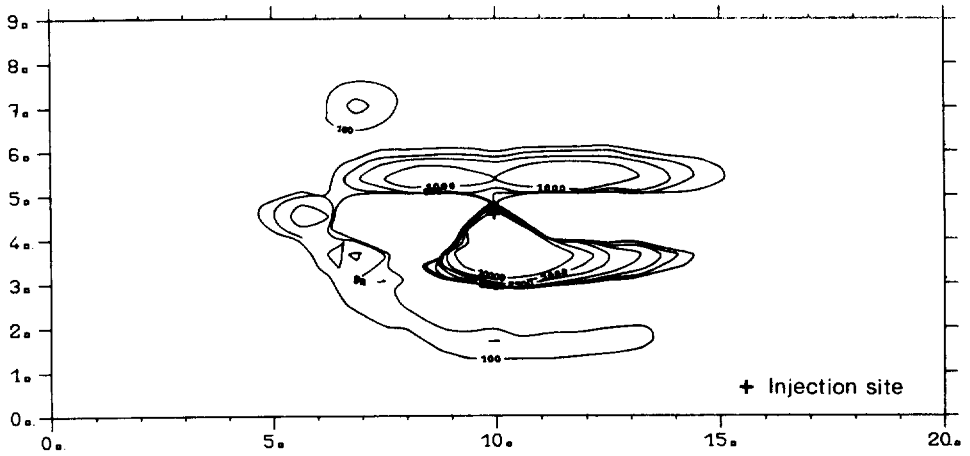


10g SEARCH 7 1976 RED TRACER

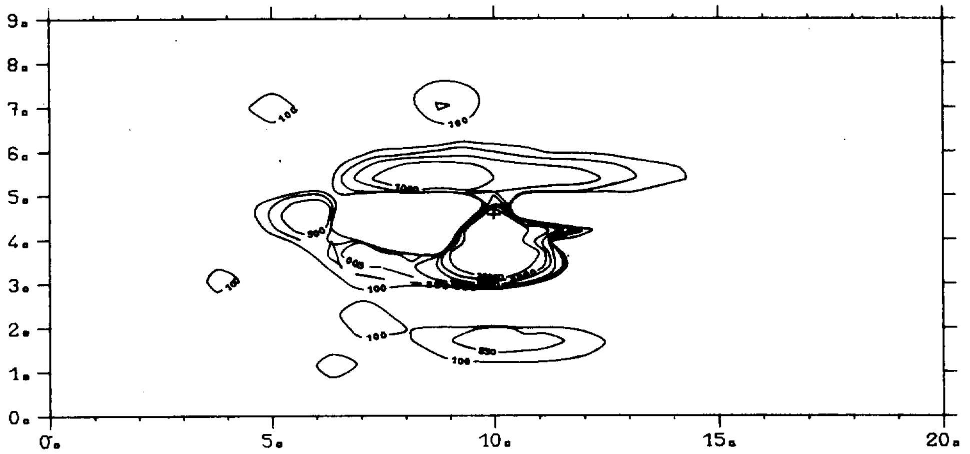


10h SEARCH 8 1976 RED TRACER

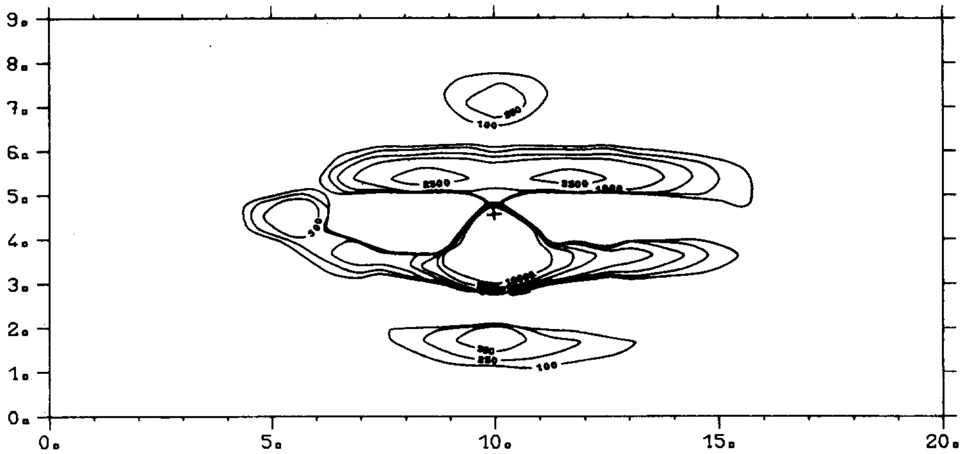
FIGURE 10g-h Contour plots of red tracer from searches 7-8 Experiment 1



11 a SEARCH 5 1976 BLUE TRACER Contours show number of grains of tracer per kg

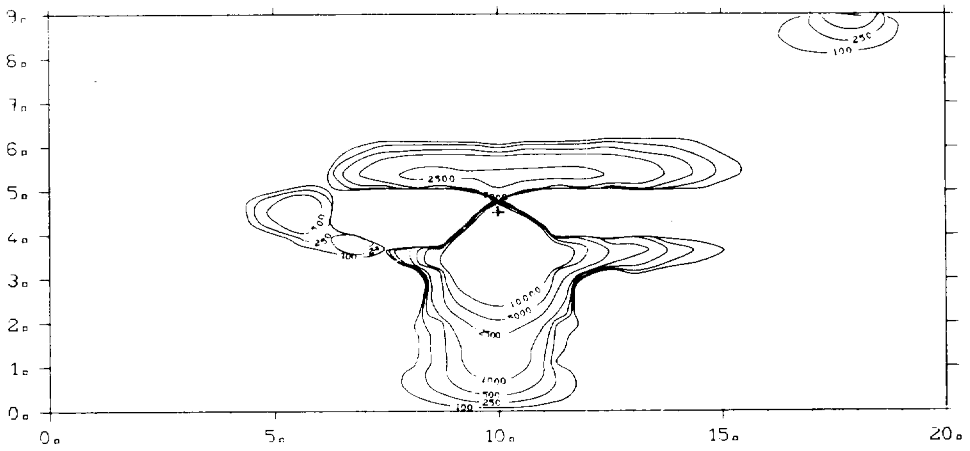


11 b SEARCH 6 1976 BLUE TRACER



11 c SEARCH 7 1976 BLUE TRACER

FIGURE 11a-c Contour plots of blue tracer from searches 5-7 Experiment 2



11d SEARCH 8 1976 BLUE TRACER

FIGURE 11d Contour plots of blue tracer from search 8 Experiment 2

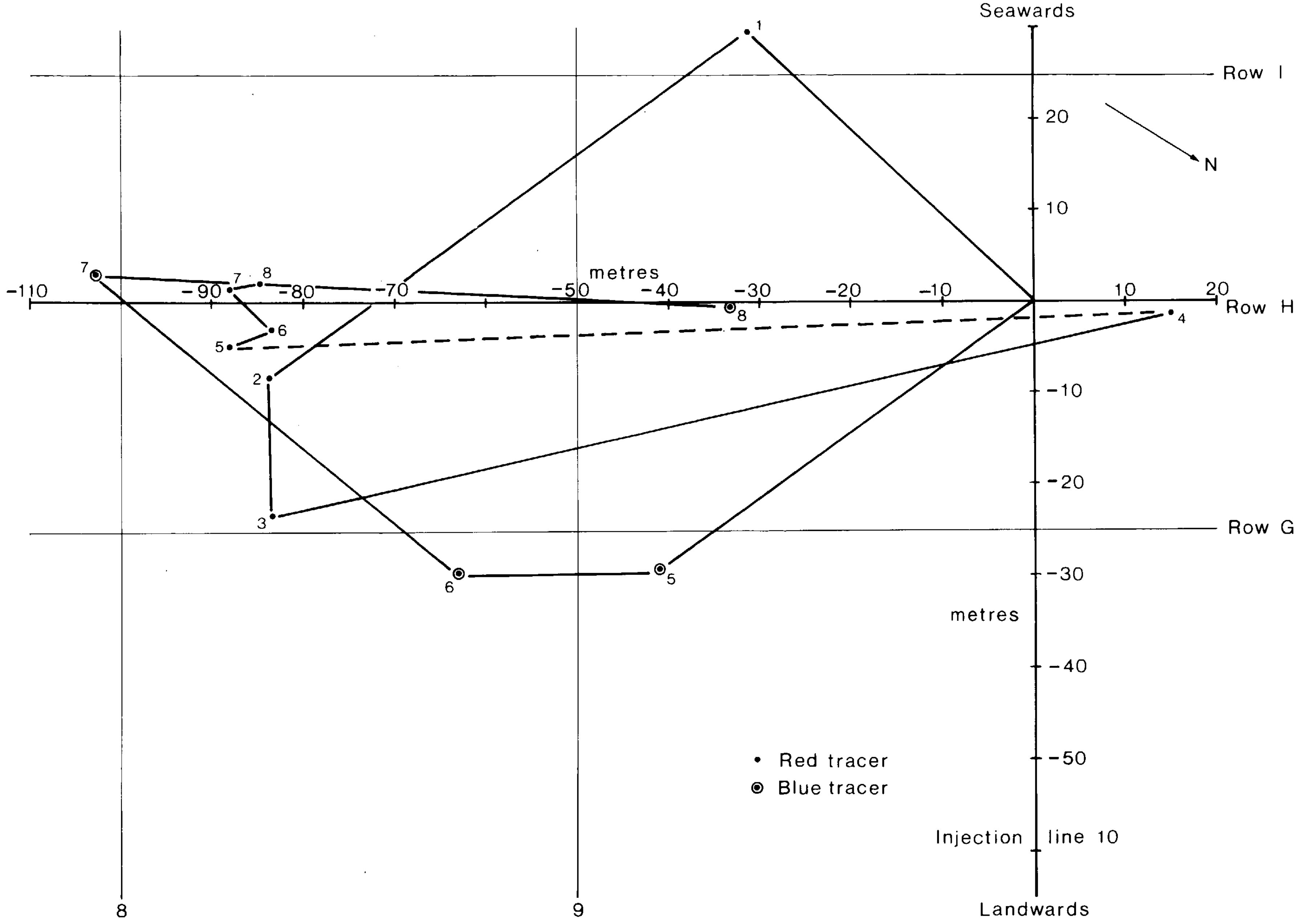
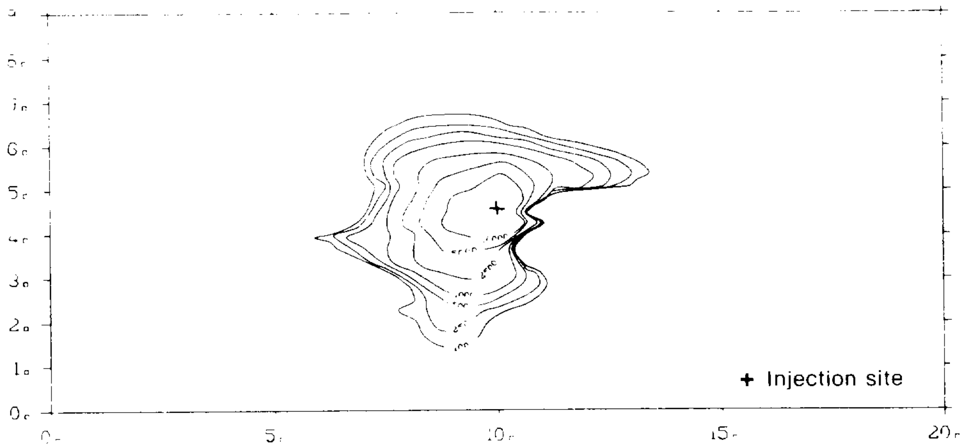
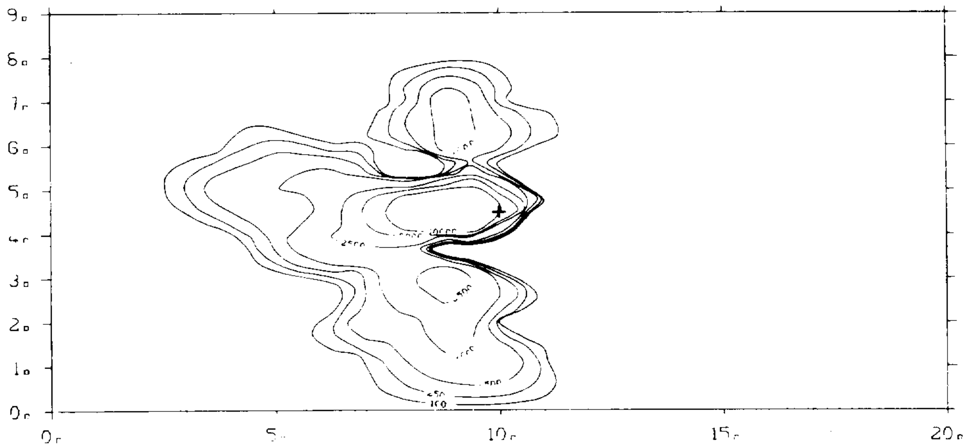


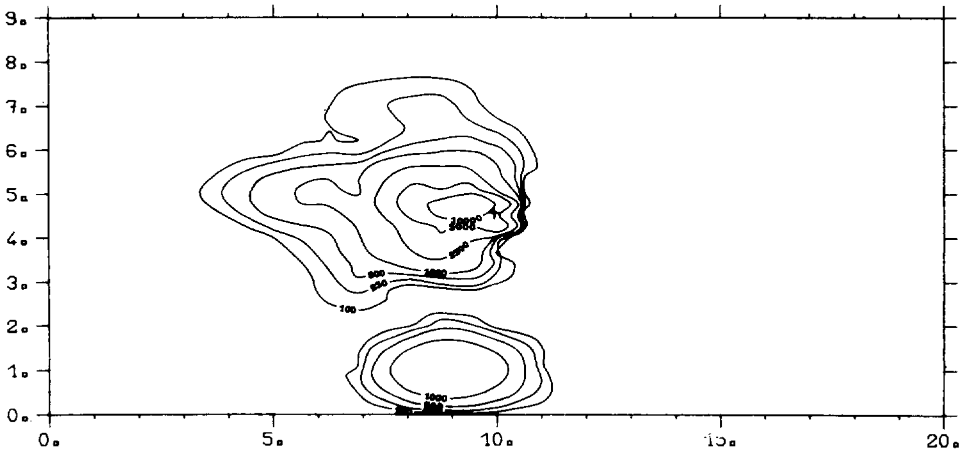
FIGURE 12 Centroid movement for red and blue tracer, Experiment 2



13 a SEARCH 1 1977 RED TRACER Contours show number of grains of tracer per kg

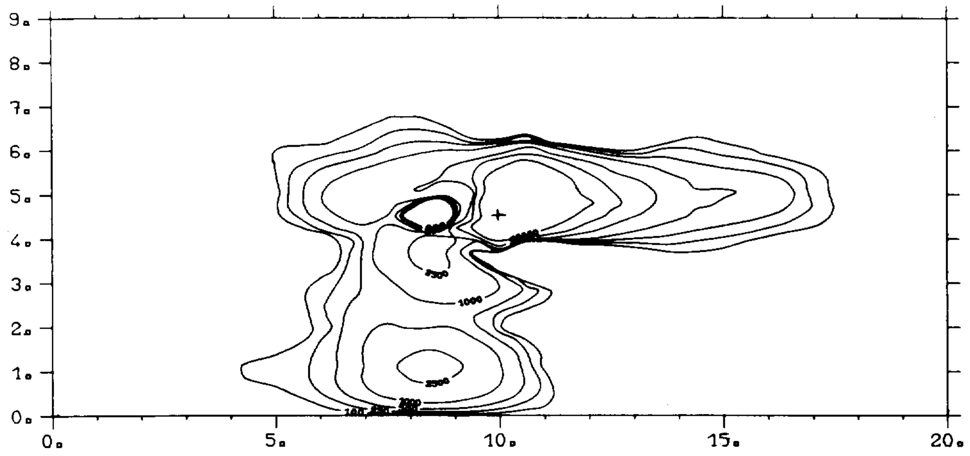


13 b SEARCH 2 1977 RED TRACER

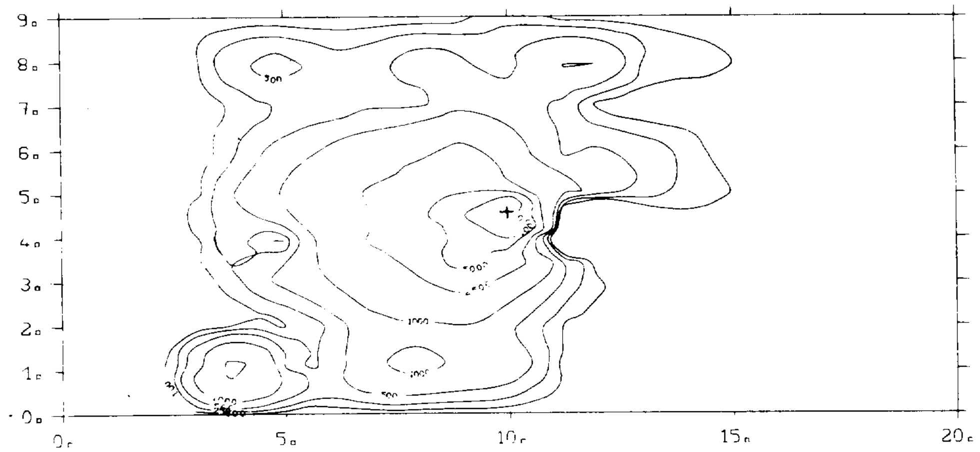


13 C SEARCH 3 1977 RED TRACER

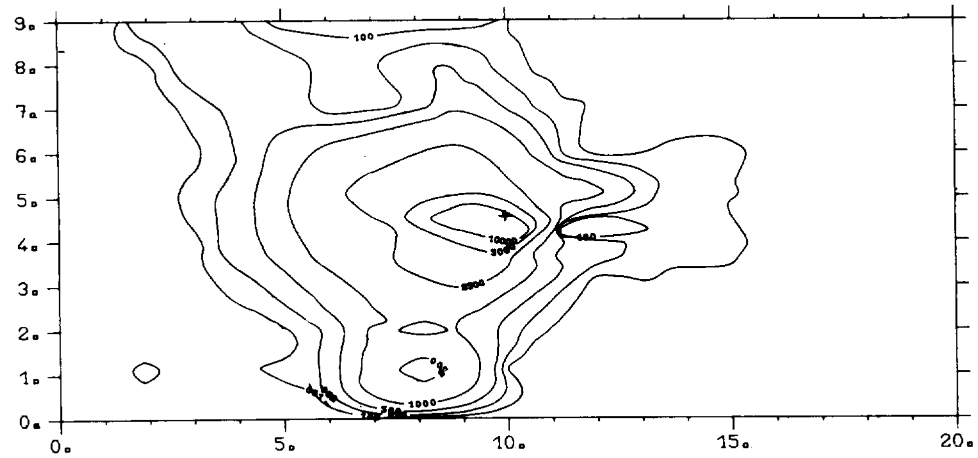
FIGURE 13a-c Contour plots of red tracer from searches 1-3 Experiment 2



13 d SEARCH 4 1977 RED TRACER

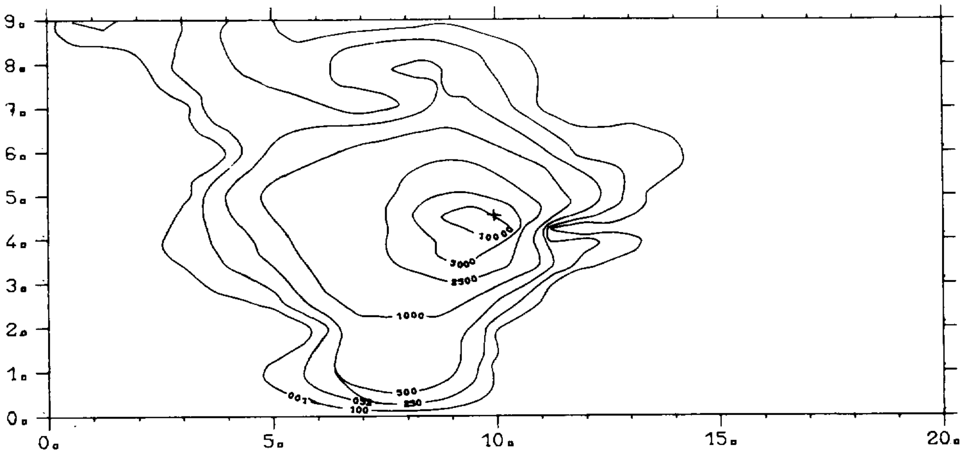


13 e SEARCH 5 1977 RED TRACER

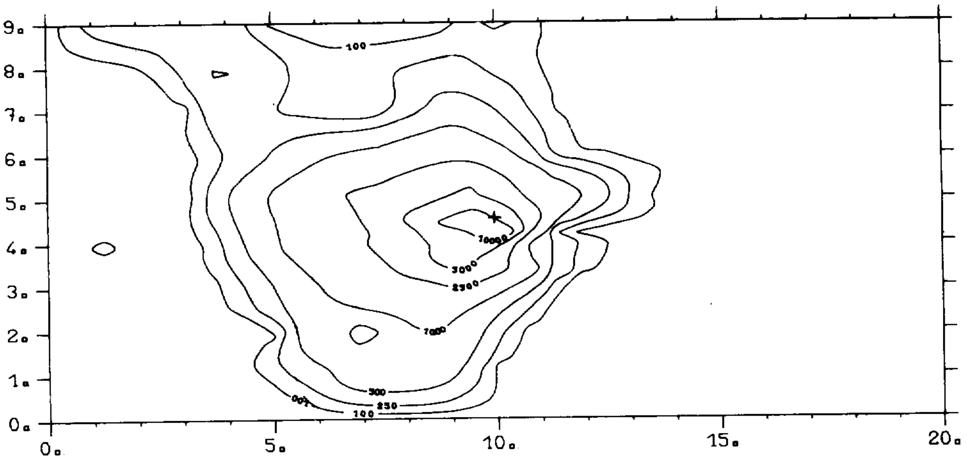


13 f SEARCH 6 1977 RED TRACER

FIGURE 13d-f Contour plots of red tracer from searches 4-6 Experiment 2



13 g SEARCH 7 1977 RED TRACER



13 h SEARCH 8 1977 RED TRACER

FIGURE 13g-h Contour plots of red tracer from searches 7-8 Experiment 2

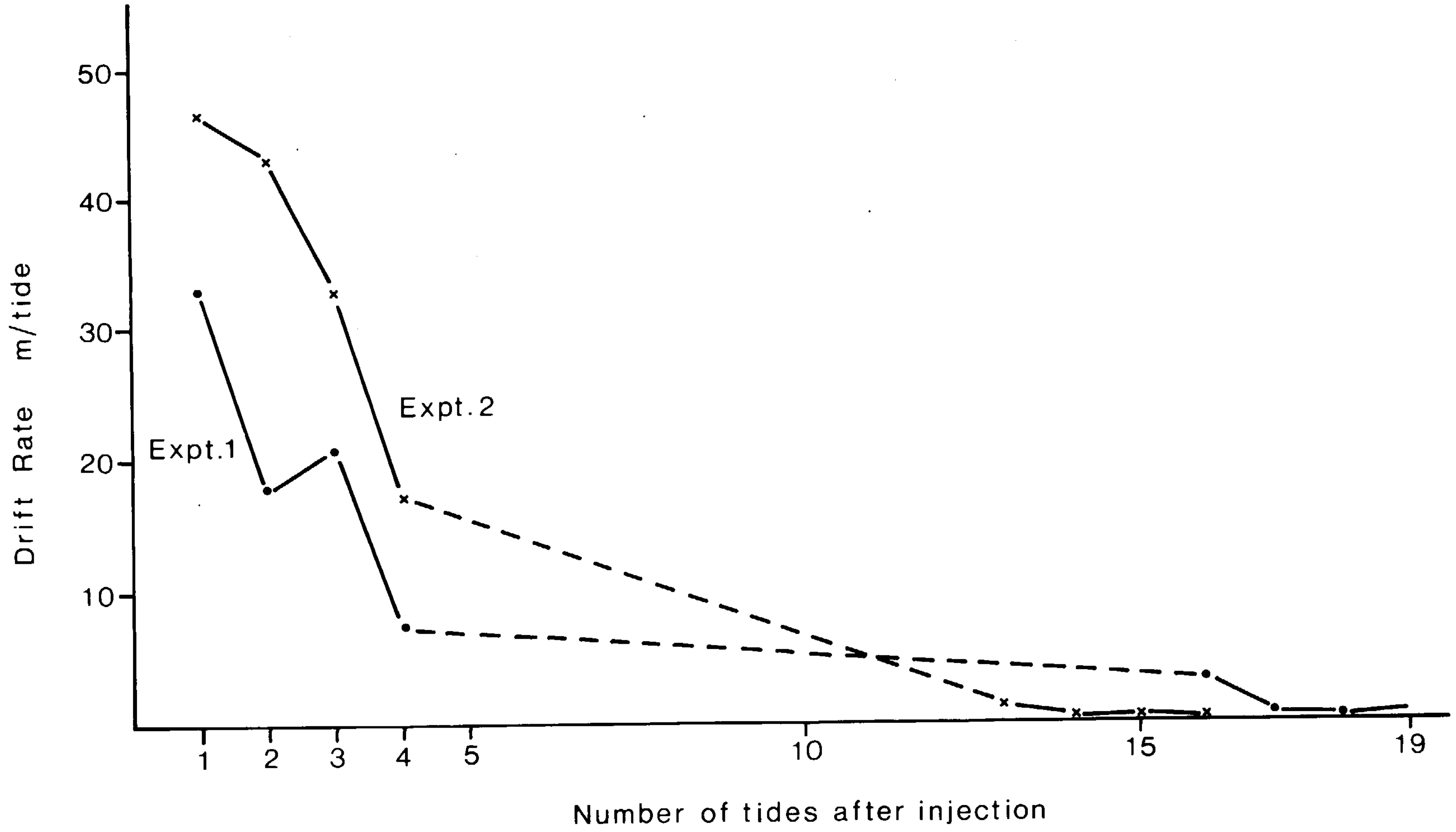


FIGURE 14 Mean drift rate (m) per tide since injection of tracer, Experiments 1 and 2

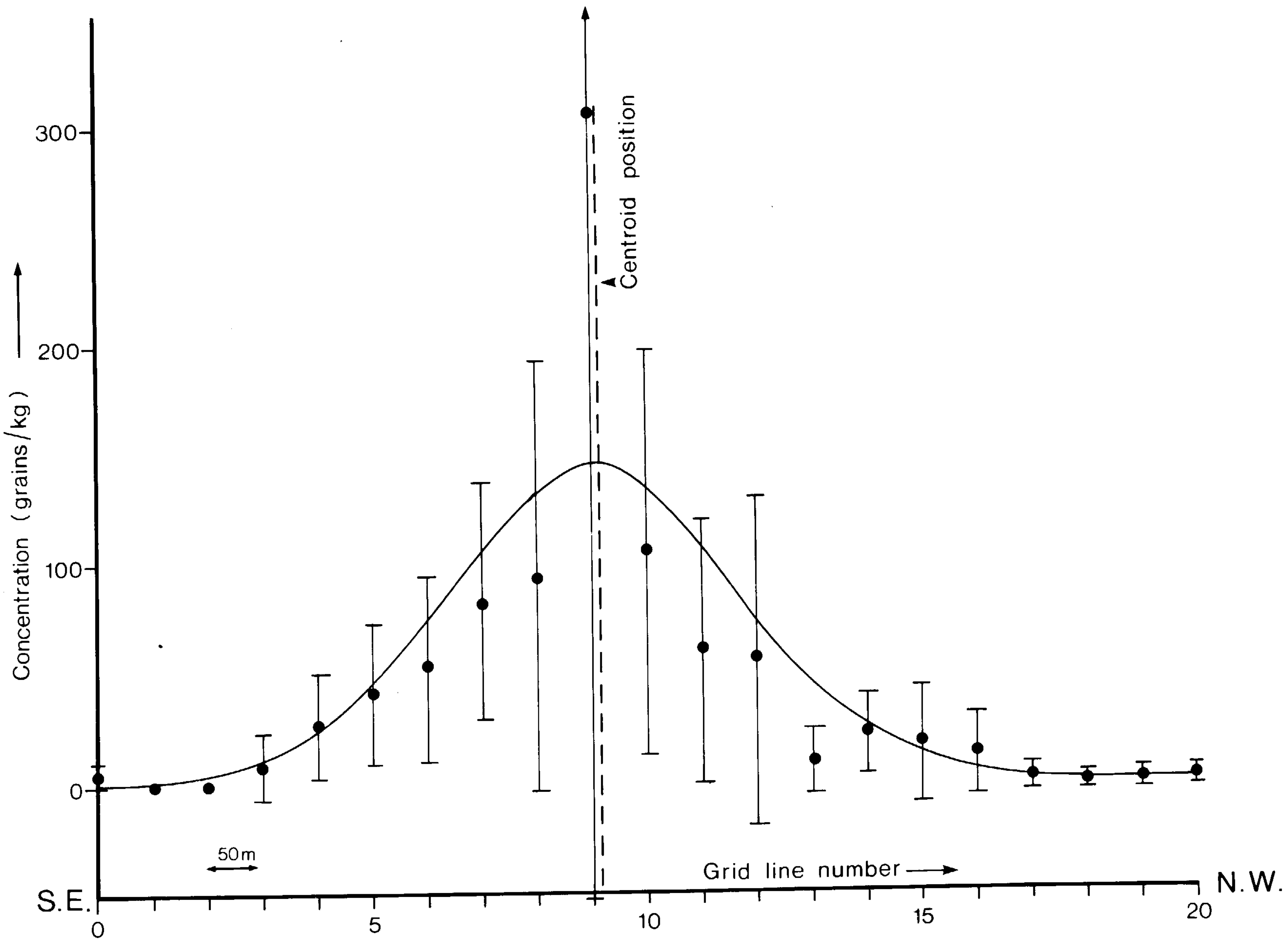


FIGURE 15 Distribution of blue background material on beach (approximately 6 months after injection)

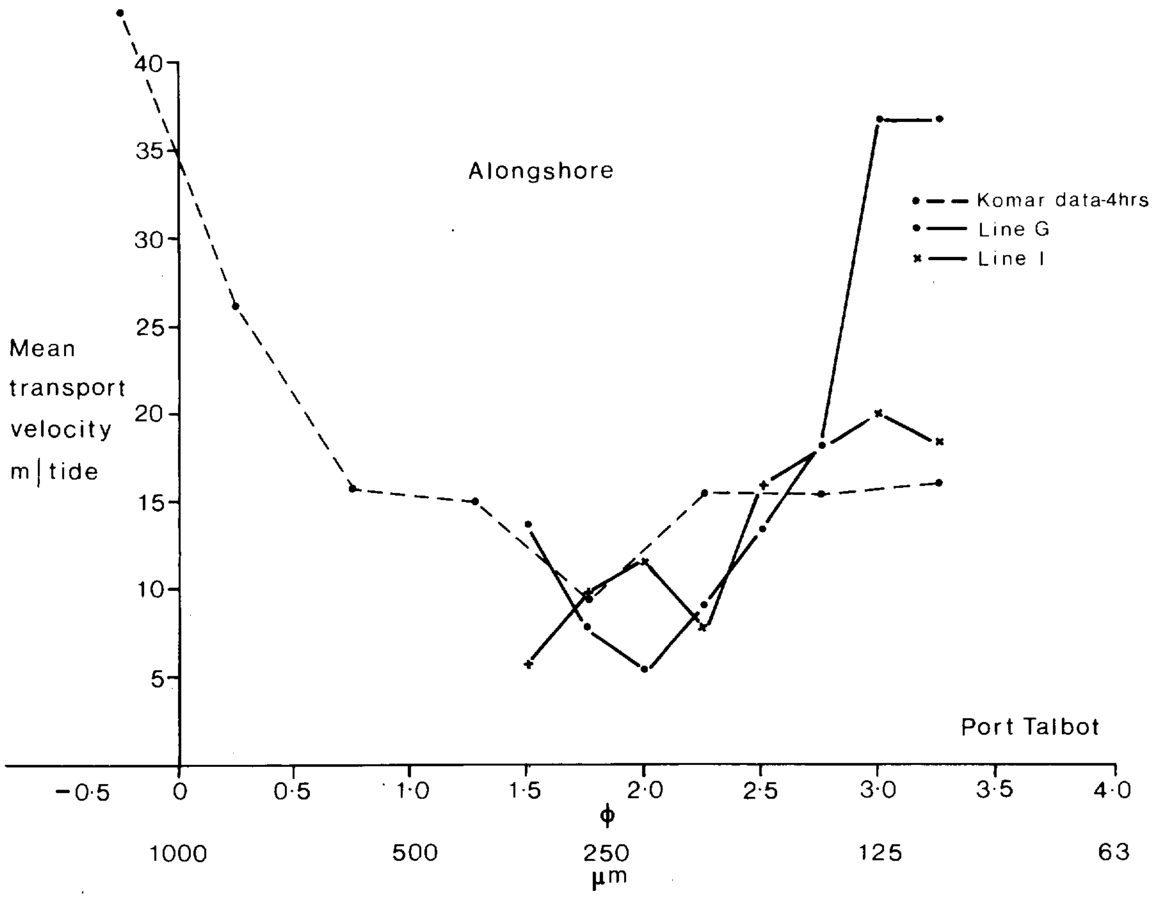


FIGURE 16a Comparison of transport velocities m/tide for different Ø sizes of material along beach after 3 tides

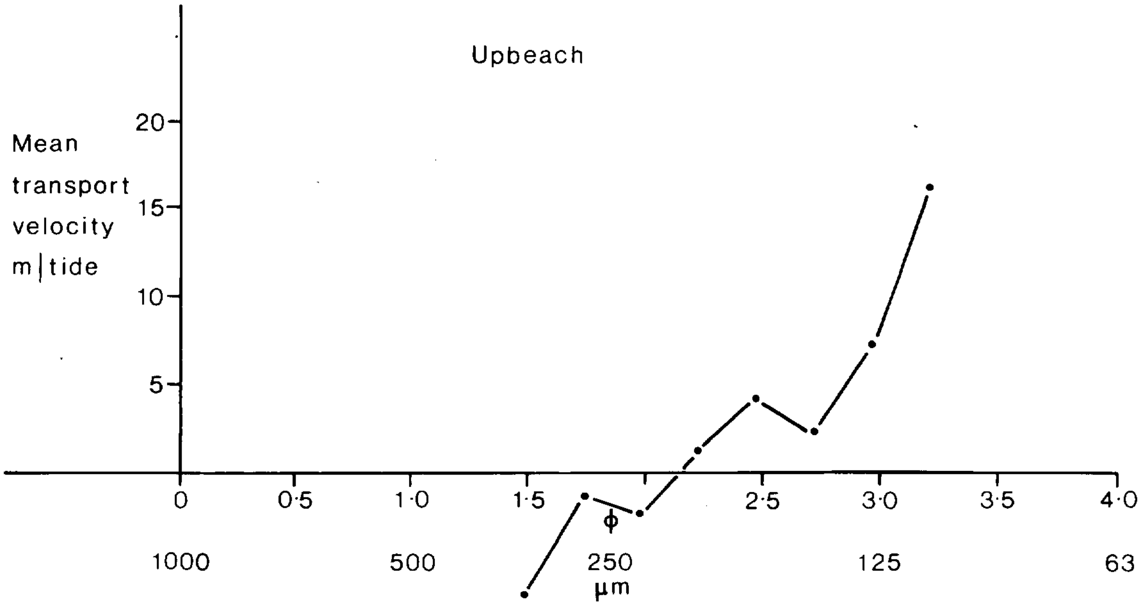


FIGURE 16b Comparison of transport velocities m/tide for different Ø sizes of material up the beach after 3 tides