DEPTH OF DISTURBANCE OF SAND IN SURF ZONES

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ABSTRACT

A coring technique employed during wave action allowed accurate measurement of the depth of vertical mixing b_m of fluorescent sand tracer grains within the surf zone of a gently sloping Pacific Ocean beach (beach slope tangent s = 0.012). The depth b_m is the distance from the sediment surface to the lower limit of observed tracer grains within the inner portion of the core. Although this definition is only strictly applicable to a rectangular distribution of tracer concentration with depth, the b_m results were quite similar to those using concentration-weighted depth averages of Crickmore (1967). For one winter regime experiment, vertical cross-sectional contour maps of tracer concentration normalized by the local core maximum were drawn with concentrations computed for each 0.4cm slice. Trends present are (1) in the onshore-offshore direction the maximum concentration is at the bed surface shorewards of the mid-surf position and 0.4 cm to 1.2 cm below the bed seaward of the mid-surf position, and (2) in the longshore direction (at the mid-surf position) the maximum concentration lies 0.4 cm to 1.6 cm below the bed surface. For spilling breaker heights H_b between 75 cm and 150 cm, histograms of b_m were clearly different for spring/summer and fall/winter experiments: the mean and standard deviation (in parenthesis) are 0.5 cm (0.5 cm) and 1.1 cm (0.5 cm), respectively. These results are substantially less than both the 3.0 cm and the 20 cm to 40 cm disturbance depths per 100 cm of H_b reported by King (1951) and by Otvos (1965) and Williams (1970). The discrepancy with Otvos and Williams is due to the much different breaking process; in their experiments small breakers (H_b = 5 cm to 30 cm) plunged directly onto steep beach slopes (s = 0.1) causing large b_m. The tracer grain's longer exposure to bottom stresses of passing surf bores may explain King's greater disturbance depths. Her sampling interval was one semi-diurnal tidal period T versus the span 0.02 T to 0.32 T in this study.

INTRODUCTION

It is well accepted that waves breaking on a beach are the prime mechanism for transporting sand. However, quantitative measurements of the waves and moving sand are scarce

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(e.g., Komar, 1969). Several methods of measuring the volume of moving sand are available (e. g., sand tracers, bedload and suspension traps, periodic surveys). Because of the successes of the sand tracer technique in estimating sand transport in rivers (Crickmore, 1967) and in narrow surf zones (10 m) with large tidal ranges (8 m) (Komar, 1969), the present study investigates its usefulness in wide surf zones (100 m) with moderate tidal ranges (2 m) typical of many Pacific Ocean beaches. A few experiments of this nature were also carried out by Komar (1969).

For non-steady, two-way transport the spatial integration method is to be preferred over both the time integration and steady dilution methods when using sand tracer to calculate sediment transport (Crickmore, 1967); these are essentially the conditions normally present within surf zones. Following Komar (1969) the mean velocity of transport is calculated from the tracer concentration distribution by taking moments of the tracer concentration in the direction of interest. For example, the mean longshore velocity of the tracer centroid is given by

$$V = \sum_{X=0}^{X_b} \sum_{Y=-\infty}^{\infty} y\, C_{(x,y)} \Big/ t \sum_{X=0}^{X_b} \sum_{Y=-\infty}^{\infty} C_{(x,y)} \qquad (1)$$

where $C_{(x,y)}$ is the concentration at a longshore distance y from the injection line and at an offshore distance x, and t is the time between release and sampling. The bulk volume sand transport is then

$$S_1 = b \cdot X_b \cdot V_1 \qquad (2)$$

where b is the depth of disturbance and X_b is the surf zone width. Preliminary field studies of the depth of disturbance are described in this report.

FIELD SITE AND METHODS

Because much of the surf zone remains covered with water at low tide on the beach of interest, a method was devised of obtaining samples under these conditions. It consists of a coring pipe with a transparent sampling tube inserted into the bottom end (Figure 1). This beveled transparent tube is then forced into the sand by leaning on and rotating the coring pipe. The coring pipe is withdrawn slowly, and once the transparent tube holding the sand sample surfaces, it is immediately inspected for sand movement. If there is any, the sample must be retaken. Although the method is not extremely rapid, the cores provide accurate measurements of the depth of disturbance and the tracer concentration.

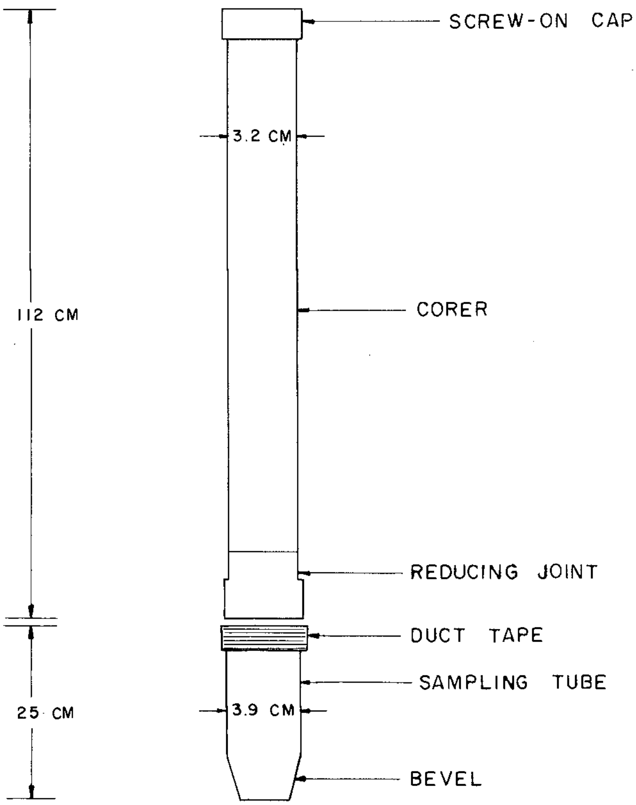


Figure 1.- Sand coring apparatus.

The beach is 15 km long with a lagoon entrance located midway between the rocky headlands at both ends (Figure 2). It is backed by small sand dunes along most of its length. At the site of interest the foreshore sand is relatively fine-grained (Figure 3) with the beach slope tangent s = 0.012. Most of the time the waves form spilling breakers, with the larger waves occuring from fall through spring. Waves from the south are blocked by Punta Banda and Todos Santos Island.

Several sampling intervals and grid sizes were tested to gain familiarity with the surf zone time and length scales. During all nine of the field studies a single point source of tracer sand (20 kg to 50 kg) was injected at an estimated mid-surf position.

RESULTS AND DISCUSSION

A comparison was made of three definitions of the depth of disturbance. (1) b_{max} is the maximum depth below the sand surface of tracer grains observed in the sample. (2) A second disturbance depth b_2 is given by

$$b_2 = h(c_1 + c_2 + c_3 + \cdot\cdot)/c_{max} \qquad (3)$$

where h is the core slice thickness (0.4 cm), c_1, c_2 are the concentrations of core slices, 1,2 where 1 denotes the top slice, c_{max} is the maximum concentration in the core under study. This equation is only directly applicable when the concentration/depth distribution has a continuous negative gradient, with the concentration decreasing sequentially with depth (Crickmore, 1967). The more irregular tracer distributions were first simplified to eliminate any positive gradients and then treated as above (Crickmore, 1967). Figure 4 illustrates this procedure for various forms of concentration distributions (Crickmore, 1967), and it also defines the types of distributions. (3) A third definition of the depth of disturbance b_3 is computed from equation (3) by using the mean concentration (averaged over the number of cores) for each slice where c_{max} is the maximum of these averages. For 60 core samples from the 9DEC experiment the results are

$$\bar{b}_{max} = 1.1 \text{ cm}$$

$$\bar{b}_2 = 1.0 \text{ cm}$$

$$\bar{b}_3 = 1.2 \text{ cm}$$

where - indicates mean value. Since there is less than ten percent difference between b_{max} and the concentration-weighted disturbance depths, b_{max} is used throughout the remainder of this paper.

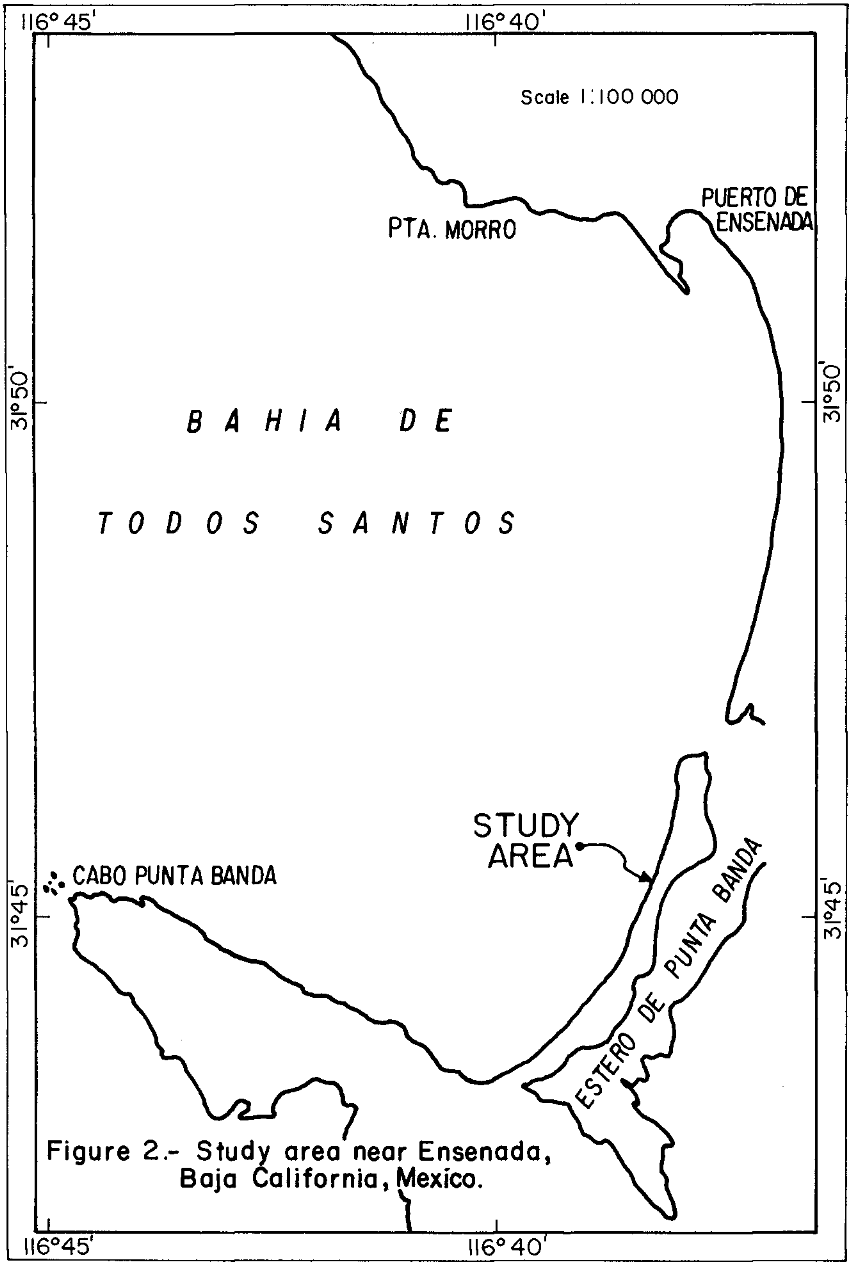


Figure 2.- Study area near Ensenada, Baja California, Mexico.

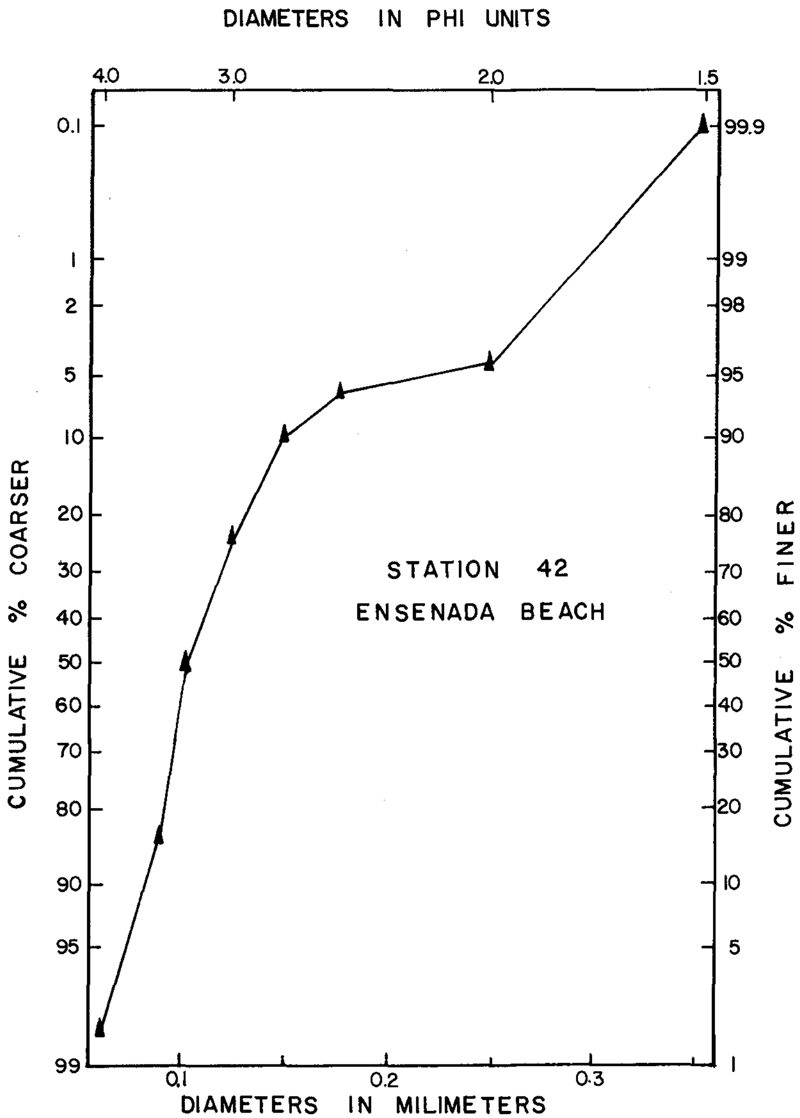


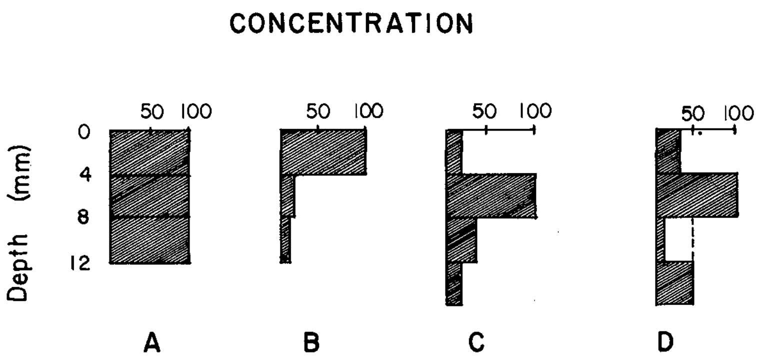
FIGURE 3.– Sand size distribution

$$b_2 = h\,(C_1 + C_2 + C_3 \ldots)\,/C_{max}$$

where

h = core thickness (mm)

c = tracer concentration in number of grains per gram of sand



$\bar{b}_2 = \frac{4(300)}{100}$ $\bar{b}_2 = \frac{4(130)}{100}$ $\bar{b}_2 = 4 + \frac{4(150)}{100}$ $\bar{b}_2 = 4 + \frac{4(100+50+50)}{100}$

$\bar{b}_2 = 12$ mm $\bar{b}_2 = 5.2$ mm $\bar{b}_2 = 10$ mm $\bar{b}_2 = 12$ mm

Figure 4.– Calculation of depth of mixing from core distribution. A. Abrupt decrease, B. Continuous negative gradient. C. One positive gradient. D. Two positive gradients (Crickmore, 1967).

The most frequently occuring concentration distribution type is Type C, which has the maximum concentration in the slice one layer below the surface. It is predominant offshore of the mid-surf position, while Types A and B, which have maxima at the surface slice, occur in nearly half of the samples shoreward of the mid-surf position (Figure 5). The near-to-shore occurrence of Types A and B may be due to sand deposition in the upper swash zone which is continually receding seaward during the ebbing tide. In addition, although the distribution type and b_{max} may be a function of bedform, in this case the vertical scale of the bedforms was very similar. The ripple height of both the usual sand ripples and the backwash ripples was approximately 0.5 cm to 1.0 cm. For the sheet flow-flat bed conditions the depth of the mobile layer was likely less than 0.5 cm, but it is possible some grains mixed to greater depths.

The apparent independence of the disturbance depth on time for wave exposures of 15 min to 240 min is seen in Figure 6. These samples were within 5 m of the mid-surf release site. The 18MAR data have two b_{max} greater than 2.0 cm, and these may be due to sampling within the dyed sand patch before it has had time to disperse; indeed after 80 min the release site still contained much of the tracer sand below a thin moving surface layer (0.3 cm) of undyed sand. The 26MAR samples (b_{max} = 0.8 cm) were cored under very strong current conditions ($H_b \cong 2$ m) resulting in a very rapid dispersion of tracer sand. On this occasion the bed was always flat. Careful measurements of stake heights within 20 m of the release site showed erosion of less than 0.5 cm. Unfortunately the coring technique had not been sufficiently mastered and only 19 cores were acceptable for analysis. The 31MAY data also display very little trend of increasing burial with time.

Figures 7 to 11 are the results of sampling 3 hours after tracer release. Again the tracer sand was exposed to breakers during an ebbing tide. Due to the approximate nature of the mid-surf position, it was considered inappropiate to combine data from separate field studies. Individually some of the measurements do show b_{max} to vary with distance from the injection site; the 25NOV data show a slight tendency to decrease with distance from the injection site.

The disturbance depth seems to show a marked dependence on the incident wave conditions (Figure 12). These histograms represent two classes of field experiments; (1) the spring/summer regime and (2) the fall/winter regime. As yet unprocessed wave measurements may generate a hypothesis attempting to explain these observations.

Vertical cross-sectional contour maps were drawn to study the horizontal variation of the tracer concentration versus depth. Figure 13 demonstrates the effectiveness of this presentation as shorewards of the release site, the maximum con-

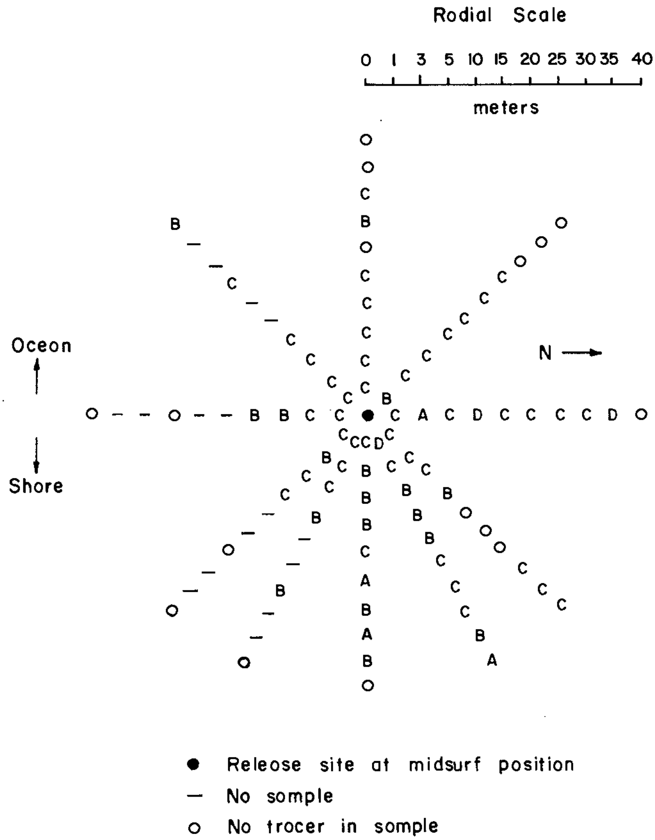


Figure 5.- Map of core concentration distribution types .

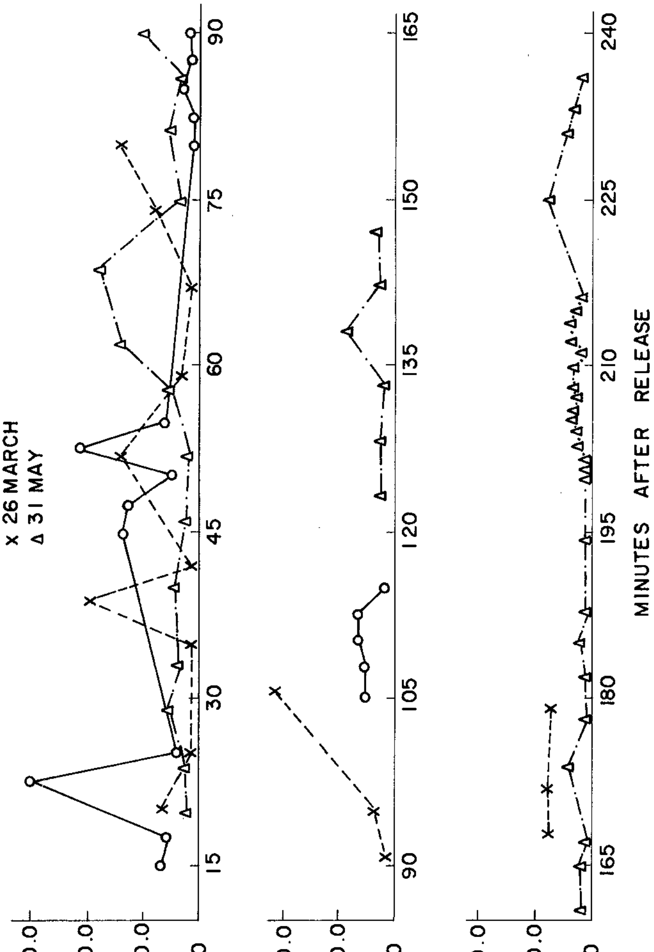


Figure 6.- Depth of disturbance versus time after release within 5 m. of release site at midsurf position.

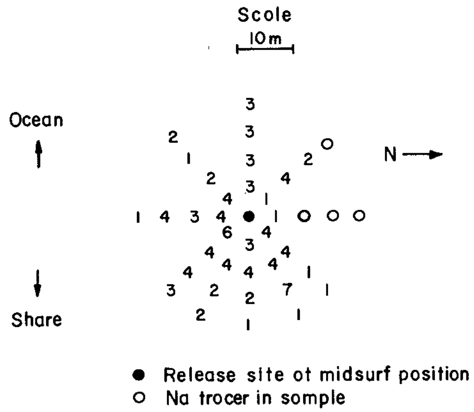


Figure 7.- Map of b_{max} for 13 June (mm)

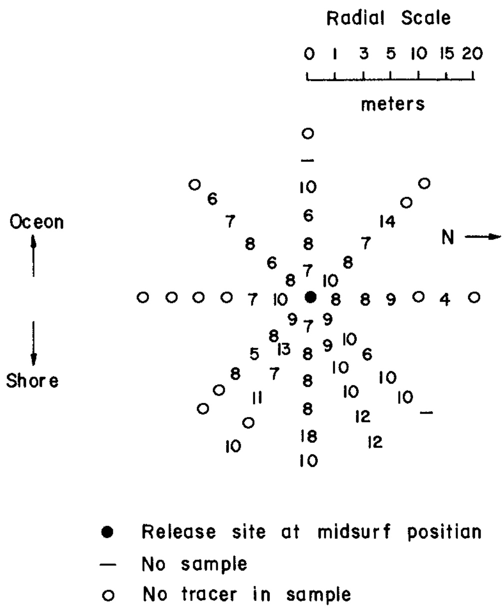


Figure 8 .- Map of b_{max} for 13 Oct. (mm)

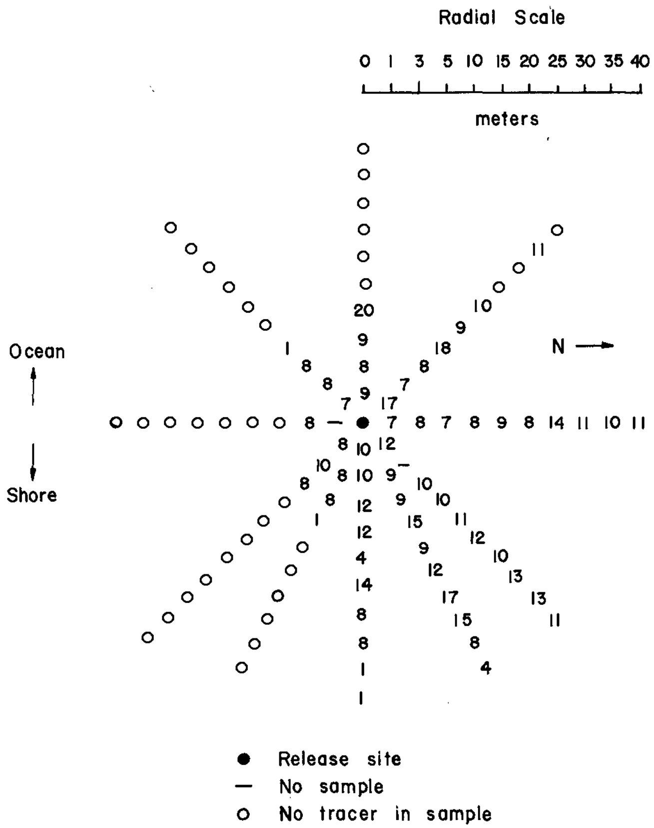
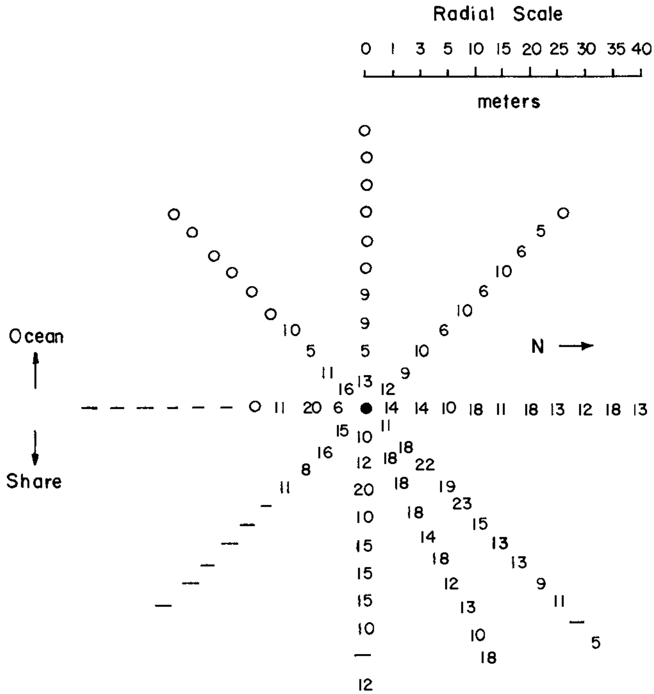


Figure 9.- Map of b_{max} for 10 Nov. (mm) .



● Release site at midsurf position
— No sample
○ No tracer in sample

Figure 10.- Map of b_{max} for 25 Nov. (mm).

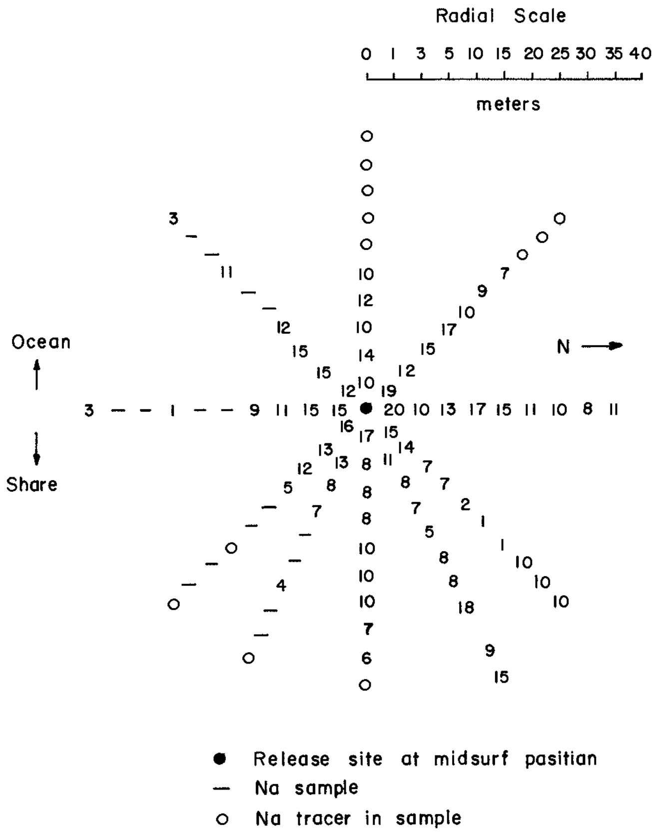


Figure 11 .- Map of b_{max} for 9 Dec. (mm) .

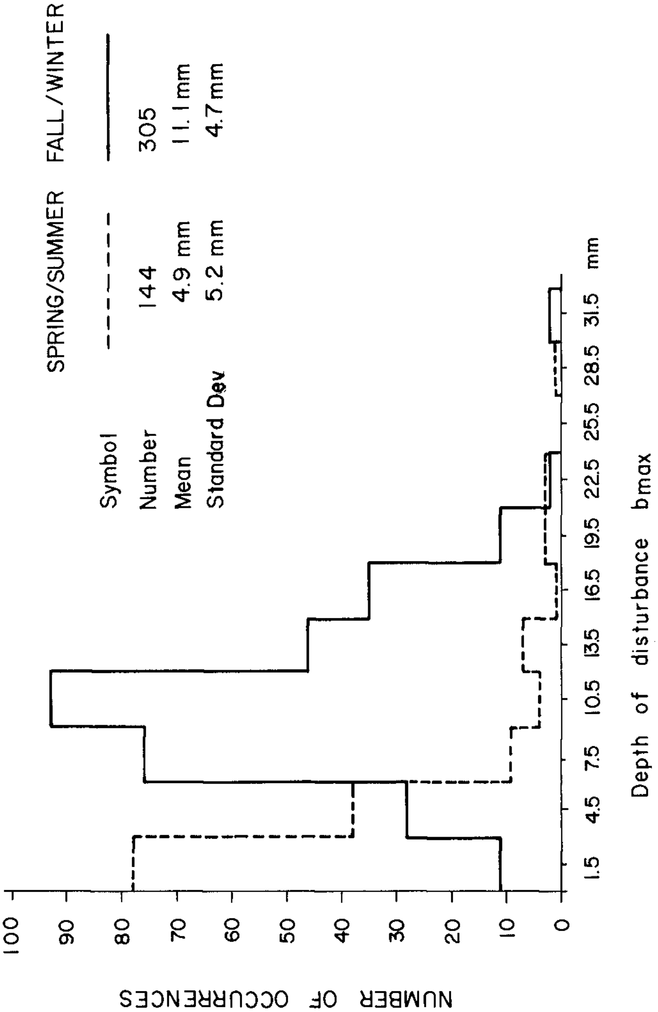


Figure 12 .- Histograms of the depth of disturbance b_{max} for the spring/summer and fall/winter regimes.

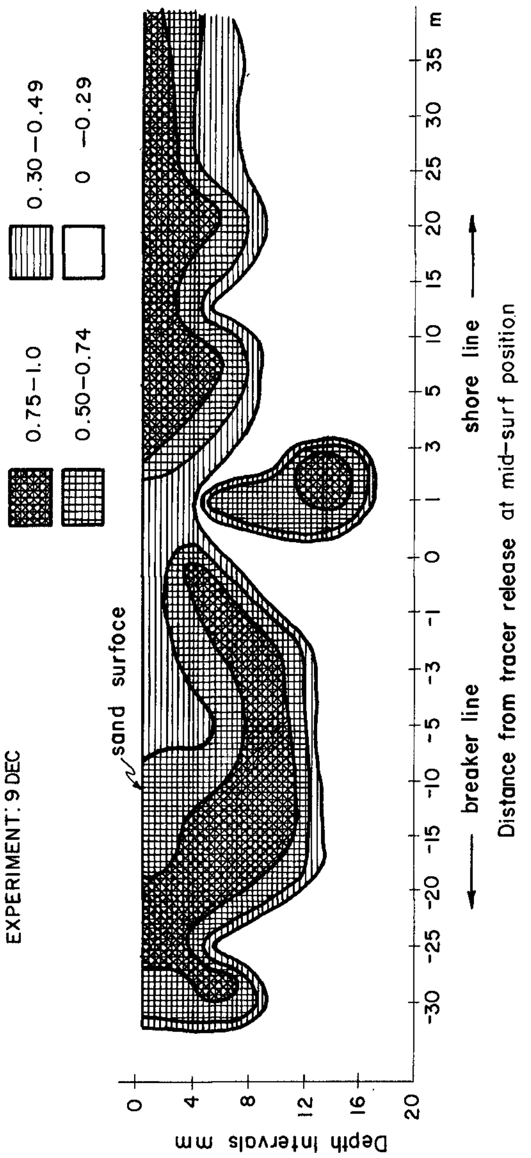


Figure 13.- Cross-sectionol contour mop of tracer concentrotion in the onshore-offshore — direction. Eoch concentration has been divided by the maximum in its core sample.

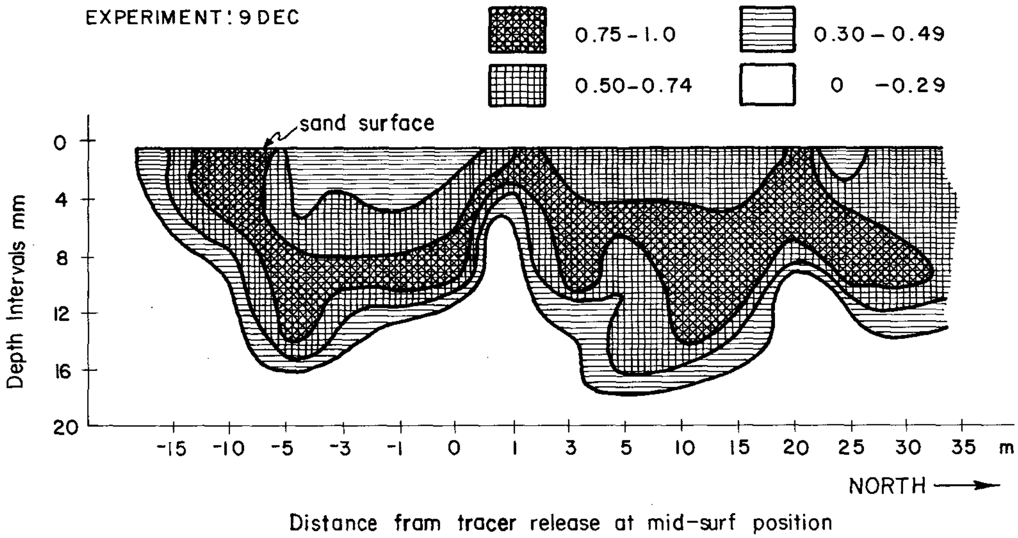


Figure 14.- Cross-sectional contour map of tracer concentration in the alongshore direction. Each concentration has been divided by the maximum in its core sample.

centration is clearly at the bed surface, while seaward of the release site, it is below the surface. The maximum concentration is nearly always below the bed surface along a line parallel to the shoreline located at the mid-surf position (Figure 14).

SUMMARY

All field experiments involved sand tracer exposure to waves in the surf and swash zones during an ebbing tide. For these conditions some important observations are:

1. For breaker heights between 75 cm and 150 cm, the disturbance depth b_{max} averaged much less than in previous experiments of King (1951), Otvos (1965), and Williams (1970).
2. A comparison of b_{max} to concentration-weighted disturbance depths showed less than 10% difference for 60 cores from one field study.
3. Maxima of tracer concentration were located at the bed surface shoreward of the mid-surf release site and just below the bed seawards of the release site. The indication of deposition in the receding upper swash limit leads to hypothesis regarding the calculation of the longshore transport. Obviously, as this tracer sand leaves the longshore transport zone, the longshore transport would be underestimated if these samples were included in the calculation of the moments about the injection line.
4. b_{max} did not show any strong trends either with time near the release site nor with distance from the release site three hours following injection.

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