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THE UNIVERSITY OF BATH SWATHE SOUNDING SYSTEM

R.L. Cloet (1), C.R. Edwards (2) and A.J. Duncan (3)

(1) School of Physics, University of Bath, Bath, Avon
(2) School of Electrical Engineering, University of Bath, Bath, Avon
(3) School of Physics and Geosciences, W. Australia, Institute of Technology

ABSTRACT

An interferometric depth swathe sounding system has been developed, in the course of the last few years, funded by the Science and Engineering Research Council. It is based on the production of two interferometers, generated by means of three 300 kHz sidescan transducers. These are each spaced several wavelengths apart, one pair having a slightly different spacing from the other. The resulting "vernier", produced by the phase differences between the two pairs provide the means of resolving the phase ambiguities, while the spacing of several wavelengths yields a higher resolution than would otherwise be the case.

The transducers are mounted on a pressure vessel which contains a full set of attitude sensors.

Sea trials have been carried out from a 37 ft catamaran vessel of the Plymouth Polytechnic. These have culminated in the execution of a hydrographic survey of an area in Plymouth Harbour which has both reasonably level, and steep terrain as well as a range of sea-bed textures. The area had previously been bench-marked in detail by means of duplicate echo sounding surveys.

The results show that depth accuracies of 25 cm should normally be obtained where errors induced by the positioning system is not a factor.

A matrix, consisting of depths spaced every 5 m on a rectangular grid, has been adopted as being adequate to record the dimensions of most features which exceed in height the resolution of which the swathe sounder is capable at present. Access to such data matrices permits sensitive monitoring of sea-bed areas which are liable to movement.

A significant contribution swathe sounding can make is that it helps materially in overcoming the sometimes misleading information yielded by aspect dependent sidescan sonars.

INTRODUCTION

In the course of the last two decades the demand for greater precision in mapping the sea-bed has become more pressing. Largely because the sea areas, in which the data became needed had not previously presented any hazard to shipping, and sea room had been readily available, underkeel clearance had been no problem (refs 1,2). Wherever repeat surveys were carried out, after an interval of time, the depth differences were assumed to be caused by the instability of the sea-bed. However closer examination has recently shown that the causes were as likely to have been aliased sampling, positioning system instability, or undetected, or uncorrected, positioning errors (refs 4,5,6).

There is thus a threefold need to be satisfied in mapping the sea-bed:

(1) the density of depth samples needs to be commensurate with the complexity of sea-bed features:

(2) it is necessary to have a means of establishing the tolerances of the depth measurements made;
(3) it must be possible to complete a survey in a reasonably short period, both to avoid the complication of sea-bed movement in the course of the survey, and for straightforward economic reasons.

Because the system operates at 300 kHz, it is possible to achieve a high pulse repetition rate, of 5 per second. Hence, at a ship's speed of 2.5 m/second, the acoustic interferometer is capable of producing uninterrupted coverage, and the redundancy in the data can produce a measure of the measurement tolerances. Because of the coverage it achieves, it can also be a single pass system, using a line spacing which is wide enough to result in significant time saving.

REMOVING AMBIGUITIES FROM THE INTERFEROMETER

In order to remove ambiguities from a phasemeter, attempts have been made, using a pair of receiving transducers, to put them as closely together as is physically possible, and to use baffles to shade the transducers from the sea surface (ref 7).

The University of Bath solution has been the introduction of a third transducer by means of which a second interferometer is generated. The separation between the latter transducers differs by 1λ from that of the first. Thus the difference phase is merely used to resolve the phase ramp ambiguity, and either, or both, of the faster phase ramps form the basis for the computation of the angle between the transducer plate and a point on the sea-bed.

A sliding averager is used to obtain a depth value approximately every 0.5 m down ping, although the averaging window may be as long as 4 m at about 100 m abeam. However its length can be varied in areas of rough terrain when a second post processing pass is made to recover more of the data. Normally, when the purpose of the survey is measuring natural features which exceed 0.5 m in height, the spatial resolution is amply adequate without such enhancement. The processing method is reasonably simple and inexpensive to realise.

It is evident that the attainable resolution in a single scan is affected by the ground length of the averager. That dimension is different at near from far ranges, whether an upslope or downslope profile is being scanned, and also depends on the mean depth below the fish. The question of attainable accuracy and resolution is considered in another paper being presented at this conference (ref 3).

THE ATTITUDE SENSORS

A depth profile becomes a meaningful set of measurements only when it is correctly referenced to a depth datum, and to a geographical position line. With these requirements in mind, a full package of attitude sensors was placed in a pressure housing to which the plate, on which the acoustic transducers are mounted, was attached. Two gyroscopes were used. One, to record heading and yaw, which had an accuracy of 0.3^{o}, and a drift rate of 1^{o} per hour. The other was capable of recording roll and pitch to 0.1^{o}. In addition three accelerometers were housed, but because the trials were carried out in sheltered conditions, no significant displacement effect was recorded from these. The position of the vessel was determined by the use of a TRISPONDER 540 microwave system. The offset to the fish was measured directly because the trial survey was carried out with a tow fish depth of 2 m.

THE BENCHMARK SURVEY

In order to test the operational value of the swathe sounding system a small area of Plymouth Harbour was chosen, which was known to contain both fairtly flat and steep surfaces, and around which a well conditioned set of positioning reference stations could be erected (ref 8). However no large scale survey, retaining sufficient detail, existed of the area, and it proved necessary to carry out such a survey in order, eventually to demonstrate the potential of swathe sounding.

Because of limitations of positioning systems, and the practical limitations of steering a vessel, even in a sheltered area along very closely spaced tracks, a series of lines spaced, on average, at 5 m intervals was run, both in the W-E and the S-N direction. Each set of data was used to interpolate into a rectangular matrix.

A measure of repeatability was then obtained from a comparison of the two surfaces. When considering the average differences between the two depth matrices as a function of bed slope, they were found to range from 5 cm to 20 cm, and the standard deviations less than 10 cm, for nearly flat surfaces, to 30 cm, for slopes exceeding 25%. It was evident that most of the latter could be accounted for by the positioning errors which amounted to ±2 m.

THE SWATHE SOUNDING SURVEY

In October 1983 a swathe sounding survey was carried out in the same area as the bench mark echo sounding survey. Although there was previous adequate evidence that ranges in excess of 100 m could be obtained, the line spacing adopted was 50 m in order to ensure, as far as possible, that total coverage was achieved.

The data recorded consisted of the phase data from the two interferometers, and the analogue, sidescan amplitude, signals from one of the transducers.

The survey was duplicated, so that both a W-E and a S-N set of runs were carried out. Both the swathe and the echo sounder surveys were made at an average speed of 5 knots with the Plymouth Polytechnic 12 m catamaran.

Figures 1 and 2 display the position plots of the profiles for alternate lines. The latter have been separated in order to illustrate the accepted profile lengths and their relative positions. The short lengths of the profiles, in the western parts of lines A6 and B2, in figure 1 and A8, in figure 2, are due to the occurrence of a steep cliff section, which produced a shadow zone. Also in figure 2, the eastern section of line C3 suffered a significant loss of profiles, in one case, over a distance of 30 m. This was caused by a logic condition in the software which rejects data whenever roll exceeds 10°/sec. The condition is arbitrary and has been inserted because the attitude sensors, were only interrogated at the beginning of each transmission, i.e. every 0.2 seconds. Therefore the depth reference surface could only be interpolated linearly, with acceptable confidence, within those narrow limits. Much can be recovered by increasing the attitude sensor asmpling rate, or further processing of the existing data.

A sizable bight is seen in the section 6000 E to 6250 E in line C1 of figure 2. Only half range was achieved, and bottom sampling, by Plymouth Polytechnic, has established that the nature of the sea-bed is silty peat. Here again more of the data can now be recovered by further modification of the software.

GRIDDING OF THE DEPTH DATA

In order to combine the profile data into a depth map, an arbitary decision first has to be made about the spacing of the depth values to be retained. Largely for the sake of economy of storage of data, a 5 m spacing was adopted which also provides sufficient detail for most natural features which can be resolved to about 0.5 m in depth. The profile data was therefore "binned" in 25 m^2 areas from which the depth of each point was computed. Figure 3 provides an indication of the population of each grid point bin, for the W-E survey, and figure 4 illustrates a similar coverage plot for the S-N survey.

It will be seen, particularly in figure 4 that there was a tendency for the populations to be lower in the shallower depths.

Figure 5 is an isometric display of the gridded data. There remain some errors, which show as distinctive ridges parallel to the ship's tracks, and which on occasion reach almost 0.5 m in height. Investigations since then indicate that the roll gyro had been tuned for aircraft use, in which the permitted wander was nearer 0.5^{o} rather than the 0.1^{o} normal for ships.

REPEATABILITY OF THE SURVEYS

It is desirable that, at some stage, an attempt should be made to determine the summary accuracy of a bathymetric survey. This is affected by factors which are not purely instrumental, such as the swathe sounder and the positioning system. It is, for instance, limited by the rate of data acquisition and the size of the grid mesh chosen to record the survey. It is also influenced by the roughness scale of the sea-bed. In this case we were primarily interested in obtaining a measure of confidence in the depth values obtained in either of two independent surveys of the same area. The two surveys were examined by comparing mean differences and standard deviations for a range of sea-bed gradient conditions. The slope dependence of both (see figure 6) may, as in the case of echo sounding again be largely ascribed to limitations in the positioning system. However, in the areas with minimal gradient, although the mean differences are less than 10 cm, standard deviations attain values of 25 cm. It is probable that at least some of this is due to the calibration of the roll gyro.

SIDESCAN IMAGING OF A CLIFF

In position 6075 E, 2725, see figure 5, lies a 5 m high cliff. The area was boxed by the east-west running tracks of one survey, and the south-north tracks of the other. Figures 7a and 7b show the cliff seen respectively from northward and southward. Although well capable of displaying small, detail features, those looking towards the cliff face, in particular figure 7b, produce a quite unimpressive record of a major feature.

It is appropriate to emphasise that the swathe sounder is not aspect dependent, as is the case with ordinary side-scan sonar. This is particularly useful, when surveying in an area where mobile linear features occur which tend to be transverse to the tidal flow. When navigating down tide sidescan images are then frequently disappointing. On the other hand any other course which improves the sidescan can also result in data loss in the sometimes large shadow areas.

CONCLUSION

It is now practical to obtain spatially continuous depth coverage of the sea-bed with a reasonably simple, portable swathe sounding system, with a spatial resolution, even at far range, of the same order as can be achieved with standard surveying echo sounders. Although the depth resolution, at present, falls slightly short of what can be achieved by means of an excessively densely sounded survey, it produces a much closer approximation to the bedforms than any normally sounded survey.

Because it is possible, using a swathe sounder, to map areas of the sea-bed closely, it will now also be practicable to carry out short term synoptic studies of unstable sea-bed areas.

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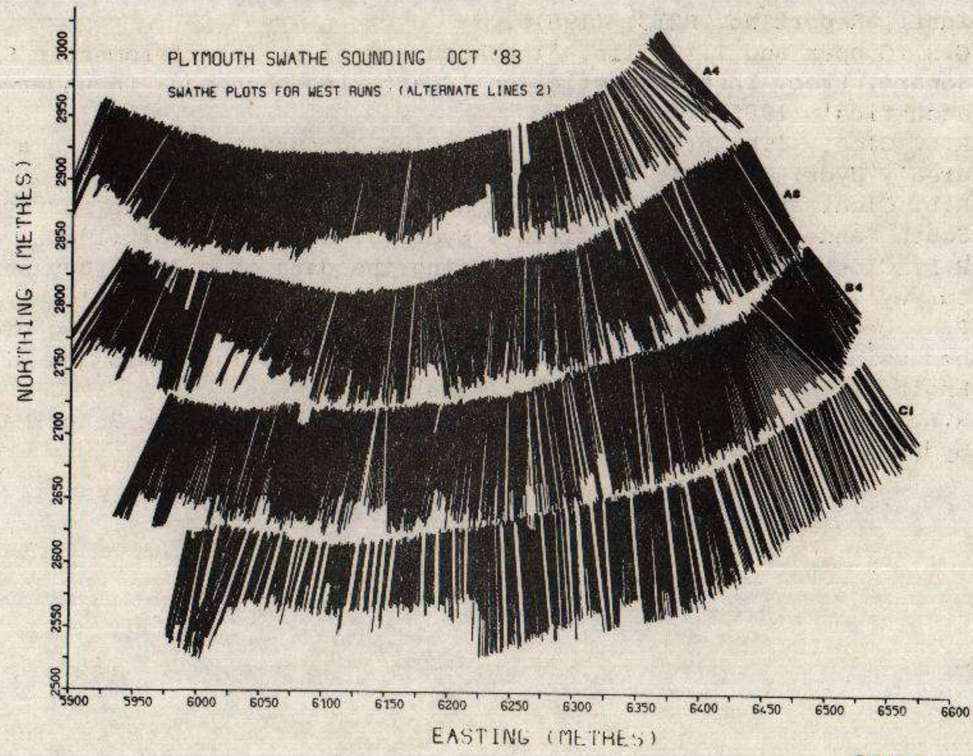
PLYMOUTH SWATHE SOUNDING OCT '83
SWATHE PLOTS FOR WEST RUNS (ALTERNATE LINES 2)
NORTHING (METRES)
EASTING (METRES)
A4
A8
B4
C1

FIG. 1

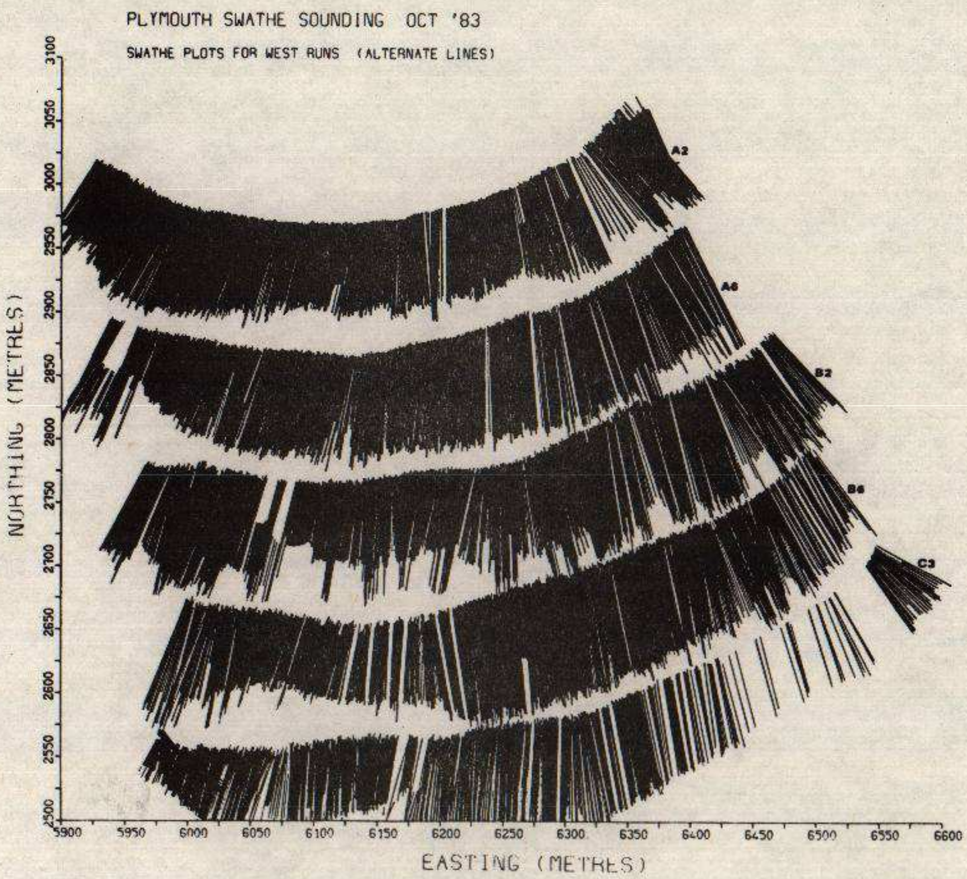
PLYMOUTH SWATHE SOUNDING OCT '83
SWATHE PLOTS FOR WEST RUNS (ALTERNATE LINES)
NORTHING (METRES)
EASTING (METRES)
A2
A6
B2
B6
C3

FIG. 2

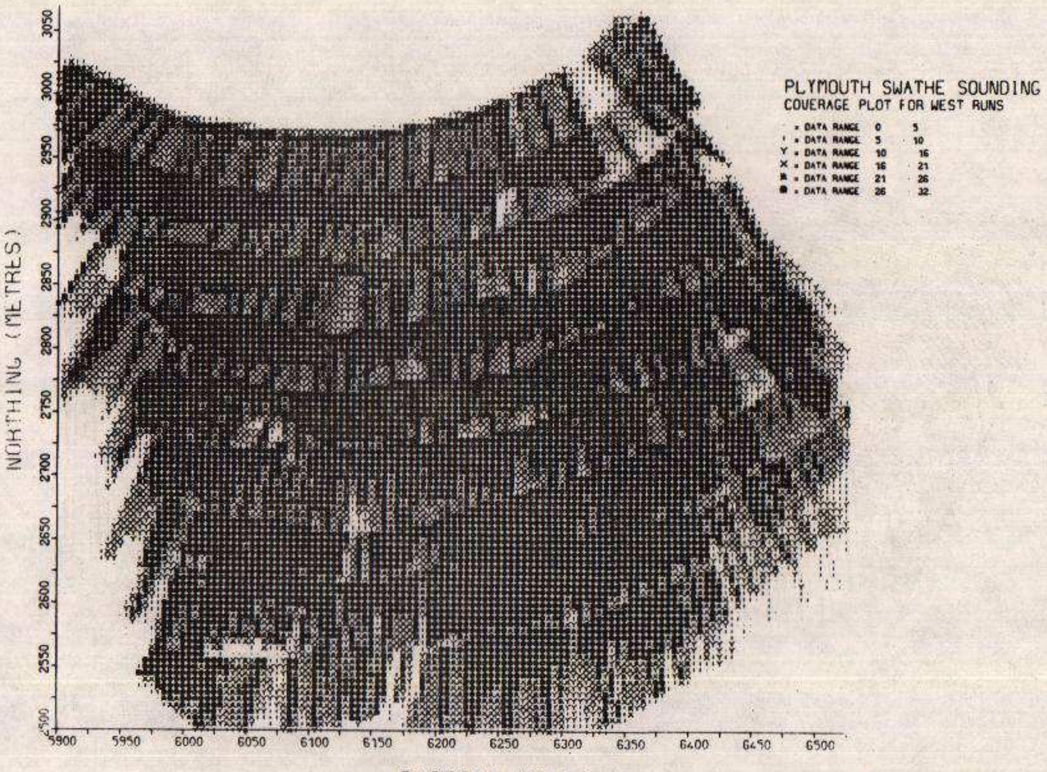
PLYMOUTH SWATHE SOUNDING
COVERAGE PLOT FOR WEST RUNS
= DATA RANGE 0 5
' = DATA RANGE 5 10
Y = DATA RANGE 10 16
X = DATA RANGE 16 21
= DATA RANGE 21 26
= DATA RANGE 26 32
NORTHING (METRES)
3050
3000
2950
2900
2850
2800
2750
2700
2650
2600
2550
2500
5900
5950
6000
6050
6100
6150
6200
6250
6300
6350
6400
6450
6500
EASTING (METRES)

FIG. 3

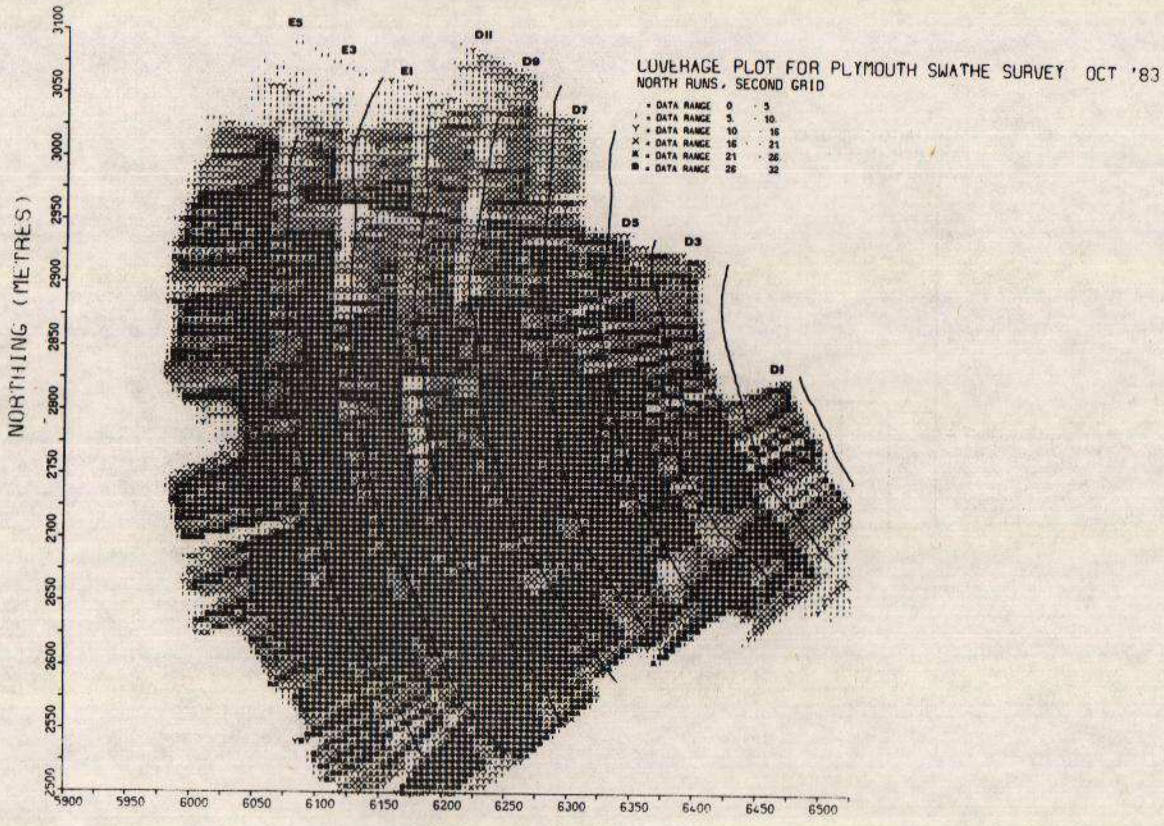
COVERAGE PLOT FOR PLYMOUTH SWATHE SURVEY OCT '83
NORTH RUNS, SECOND GRID
= DATA RANGE 0 5
' = DATA RANGE 5. 10.
Y = DATA RANGE 10 16
X = DATA RANGE 16 21
= DATA RANGE 21 26.
= DATA RANGE 26 32
E5
E3
E1
D11
D9
D7
D5
D3
D1
NORTHING (METRES)
3100
3050
3000
2950
2900
2850
2800
2750
2700
2650
2600
2550
2500
5900
5950
6000
6050
6100
6150
6200
6250
6300
6350
6400
6450
6500
EASTING (METRES)

FIG. 4

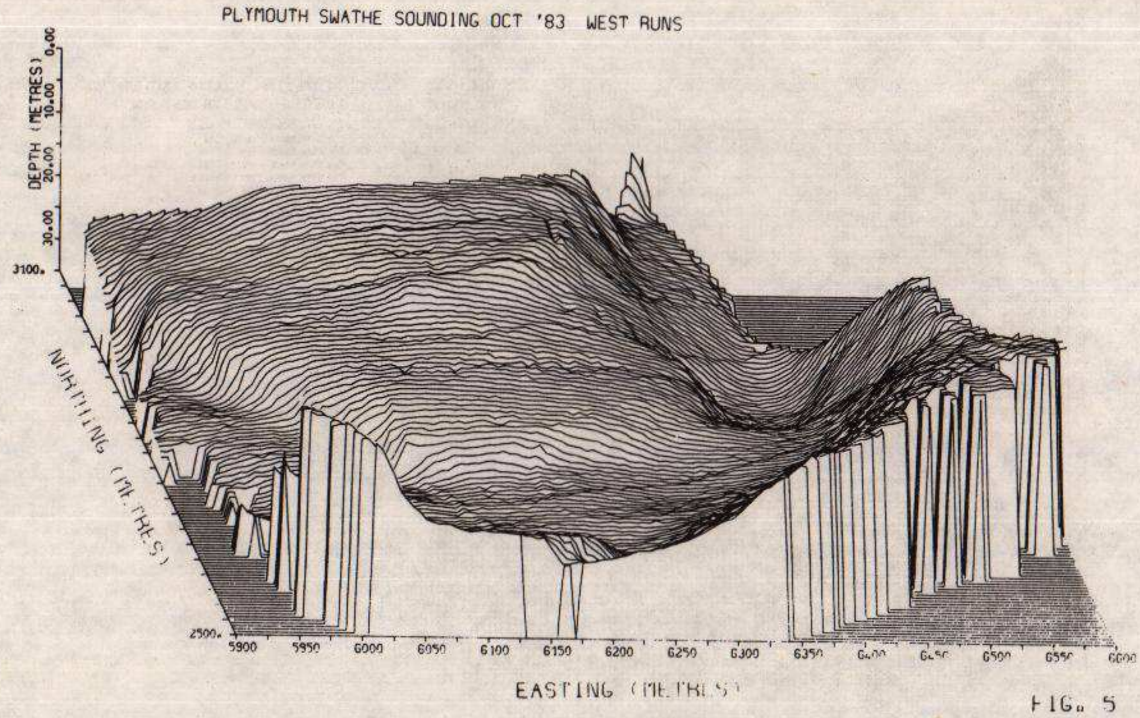
PLYMOUTH SWATHE SOUNDING OCT '83 WEST RUNS
DEPTH (METRES)
0.00
10.00
20.00
30.00
3100.
NORTHING (METRES)
2500.
5900
5950
6000
6050
6100
6150
6200
6250
6300
6350
6400
6450
6500
6550
6600
EASTING (METRES)

FIG. 5

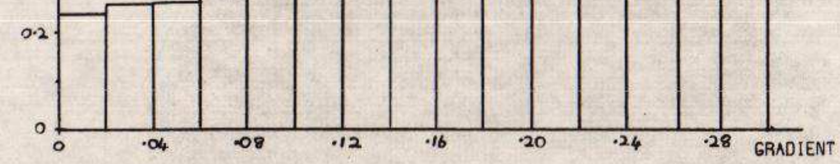
STANDARD DEVIATION OF
DEPTH DIFFERENCES
(METRES)
0·6
0·4
0·2
0
0
·04
·08
·12
·16
·20
·24
·28
GRADIENT

FIG. 6

A

B

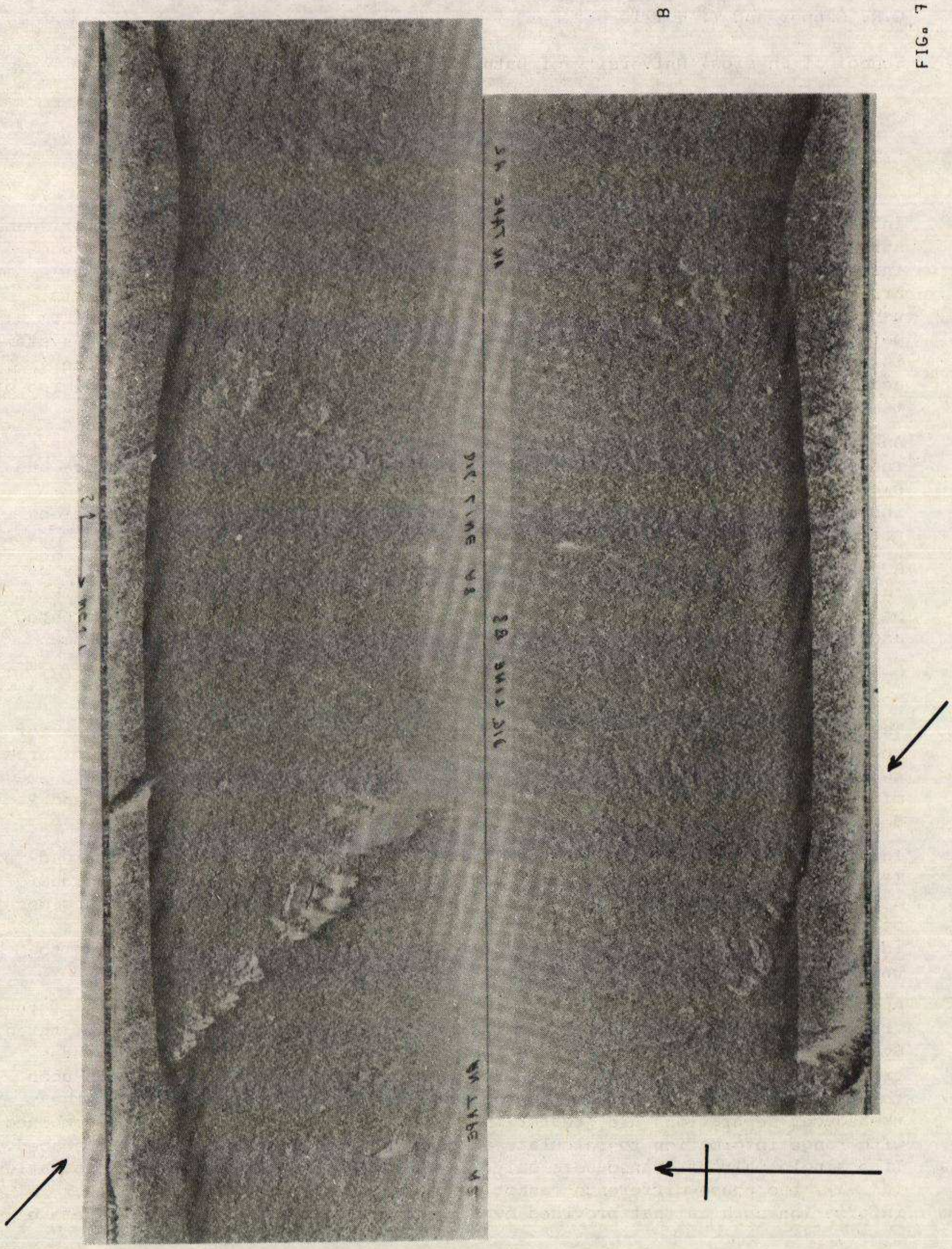

FIG. 7