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A PRELIMINARY STUDY OF THE HAISBOROUGH SAND SANDWAVE FIELD AND ITS RELEVANCE TO SUBMARINE PIPELINES

D N LANGHORNE

Report No 100

1980

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF
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This project was supported financially by the Ship and Marine Technology Requirements Board acting on behalf of the Departments of Industry and Energy.

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SUMMARY

A preliminary bathymetric survey was conducted at the Northern end of Haisborough Sand where five submarine pipelines pass through a sandwave field. Echo sounder and sidescan sonar data showed that the main sandwave field is found in a 'lobe' of sand sized sediment which occurs to the north west of the head of the bank. In the deeper water surrounding the sandwave field the sea bed is composed of featureless coarse sediments which are, in some places, overlain by sandribbons. The sandwave asymmetry suggests that net sediment transport is from south east to north west on the south west side of the bank and in the opposite direction off the head of the bank and along the north eastern flank. Between the areas of sandwaves with opposing asymmetry a zone of symmetrical sandwaves was found. Within this zone, dunes orientated at oblique angles to the major sandwave crestlines, indicate that sediment transport occurs between the crests towards the head of the bank.

Hydrographic surveys dating back to 1798 were examined to assess the longer term stability of the bank. It is considered that though the axis of the bank has remained stable since at least 1886, some extension of the bank in a north westerly direction may have occurred since 1932.

Consideration is also given to existing tidal flow and wave data to assess their potential to move different sediment grain sizes in the area.

Annual pipeline surveys were examined to see what changes in pipeline exposure and burial have been detected. It was found on one pipeline that over the period of a year, the percentage exposed within the sandwave field changed from 45% to 81% whilst bed level changes of up to 5.5m occurred between 1967 and 1970.

It is concluded that the sea bed is unstable in the sandwave field. The most pronounced changes are likely to occur during the winter months when wave statistics show that the incidence of storms is greatest. Little information is available about the effects of such changes on the pipelines as annual inspection surveys are not conducted during these periods.

INTRODUCTION

It is a condition, stipulated by the Department of Energy, that submarine pipelines laid on the sea bed, in shallow sediment covered areas, are buried to a depth of at least one metre above the top of the pipe. The reason for this requirement is to protect the pipe from both accidental damage and environmental conditions. The selection of the depth of burial is somewhat arbitrary, but it takes into account the depth of penetration of ship's anchors and trawl boards, as well as possible erosion of the sea bed. In practice, it is generally accepted that though pipes are trenched into the sea bed, little attempt is made to refill the trench as it is assumed that natural processes will fulfil that function. Very sophisticated and expensive equipment has been developed for pipeline trenching and this contributes to the high costs of pipe laying. For example, the approximate cost of the Ninian pipeline was £1½ million/mile in 1977. Economic arguments therefore favour the selection of the shortest routes.

The costs resulting from a break in a pipeline would be considerable in terms of loss of production (with possible penalty clauses), repair and in the case of oil pipes, pollution. Consequently pipeline routes are chosen where possible to pass through easily trenchable and stable areas of the sea bed, but this often conflicts with choice of the shortest route. Despite these requirements, it is thirteen years since the first submarine pipelines were laid in the southern North Sea and little is known about the stability of the sea bed and the conditions under which mobility occurs.

Sediments remain stationary on the sea bed unless the fluid stress is sufficient to move them. On the continental shelf fluid stress may be derived from surface waves and/or tidal flow and potentially it is possible to measure the relevant variables. In the case of the former, wave period, wave amplitude and water depth are important variables, whilst for tidal flow, the flow velocity and flow depth are important. Obviously, the combined effects of waves and tides are of major significance. The erodibility of the sediments themselves is dependent upon such factors as grain size, grain density, compaction, bed roughness, and, in the case of fine grained sediments, cohesion. Numerous attempts have been made to define the threshold velocities at which particular grain sizes become mobile. It can be demonstrated that when the threshold velocity for non-cohesive sediments is exceeded (but remains below a higher critical velocity) the sediment surface will not remain flat, but a rippled surface will form. However, if the initiating flow ceases quiescent ripples will remain.

Ripples (wave heights of a few centimetres); dunes (wave heights of up to approximately 1 metre); and sandwaves (wave heights of up to in excess of 20 metres) occur in combinations on the sea bed with crestlines orientated transverse to the flow direction (Langhorne, 1978). It has long been assumed that it is in the areas of the larger features that the sea bed is particularly unstable. However, as it is not easy to find and study a newly formed sandwave field, it cannot be concluded necessarily that the fluid power available at the present time is the same as that which formed the bed forms initially. Similarly it may be considered that under 'normal' tides and waves,the sandwaves are relatively stable and it is only on occasions of storm generated wave conditions, combined with Spring tides,that significant changes in the form of the sea bed occur.

A study carried out by the Hydrographic Department, Ministry of Defence (Burton, 1977) in which the changes in heights and positions of sandwaves on the Sandettie Bank were examined over a period of three years, showed that a crest position could move by up to 100m and such movement could result in the thickness of sediment in a particular position changing by up to 8m. These conclusions, when considered in relation to the Haisborough Sand pipeline routes, pose the question: does it matter if pipes are not buried in the sea bed? Clearly, if it does then an arbitrary requirement for burial to a depth of 1m is not adequate in some places. If it does not matter, then considerable savings can be made in pipelaying projects.

In 1978 SMTRB acting on behalf of the Departments of Industry and Energy agreed to fund the first of a series of detailed surveys of the sandwave field at North Haisborough Sand. The surveys were to be conducted in association with measurements of tidal flow and wave recording in order to study sandwave mobility and the effect of such mobility on pipeline exposure. Previous research conducted by the Institute of Oceanographic Sciences (Taunton) in Start Bay had shown that it was after periods of storms that the most pronounced changes in sandwave morphology were detected. These changes were sufficient to negate any trends of movement which developed under tidal conditions, (Langhorne, in preparation).

It was after the first of the series of surveys had been conducted that a decision was made to terminate the project. This report presents the results of the analysis of the data obtained in that first survey. It provides a base upon which further research may be undertaken.

HAISBOROUGH SAND

Haisborough Sand lies 8 miles off East Anglia and is orientated approximately parallel to the coast. It is the northernmost bank of a sinuous bank complex which comprises Hearty Knoll in the south, Winterton Ridge, Hammond Knoll, Haisborough Tail and Haisborough Sand. From south to north, each bank is offset successively to the west (Figure 1). Geophysical surveys (Hunting, Geology and Geophysics, 1966) show that the bank, like most of those in the southern North Sea and outer Thames Estuary, has a horizontal base with no underlying rock structure controlling its position. The sediments in the area are probably derived from Pleistocene Crags and reworked glacial deposits. In general, the bank is composed of sand sized sediments (median diameter 0.1 to 1.0mm) which are formed into bed forms ranging in size from ripples to large sandwaves. In contrast, in the deeper water surrounding the bank, coarser sediments predominate. These sediments, typically gravels, are normally featureless. Seismic records show that the strong reflector given by the coarser sediments passes horizontally beneath the bank. In some places the gravels are overlain by longitudinal sand ribbons which suggest sediment transport paths of finer sediment crossing the area. A notable exception to the topographic division of fine and coarse sediments is the occurrence of a lobe of 'bank type' sand deposits to the north and west of the head of the bank. It is in these sediments that the North Haisborough Sand sandwave field occurs. The area of sandwaves is restricted by the surrounding featureless gravels, whilst in the shallower water on the bank, surface wave action prevents sandwave formation. It is probably an over-simplifcation to suggest that this lobe of bank type sediments represents the initial development of yet another bank in the sinuous bank complex.

It is mainly for economic reasons that five submarine gas pipelines, running from the offshore gas fields in the southern North Sea to the shore station at Bacton, pass through the sandwave field at the north end of the Haisborough Sand (Figure 2). The more direct route to the south was not possible because of the shallow water on top of the banks which prevented the passage of the lay-barge. A route to the north of the sandwave field would have necessitated additional distance and hence expenditure.

PROCEDURE

A bathymetric survey of the sandwave field was carried out between 9th and 12th July, 1978. On completion of the main survey sidescan sonar was used to track individual pipelines. This data was analysed in conjunction with preliminary reconnaissance data which was obtained in November 1976. A specification of the equipment used is given in the appendix. The results are

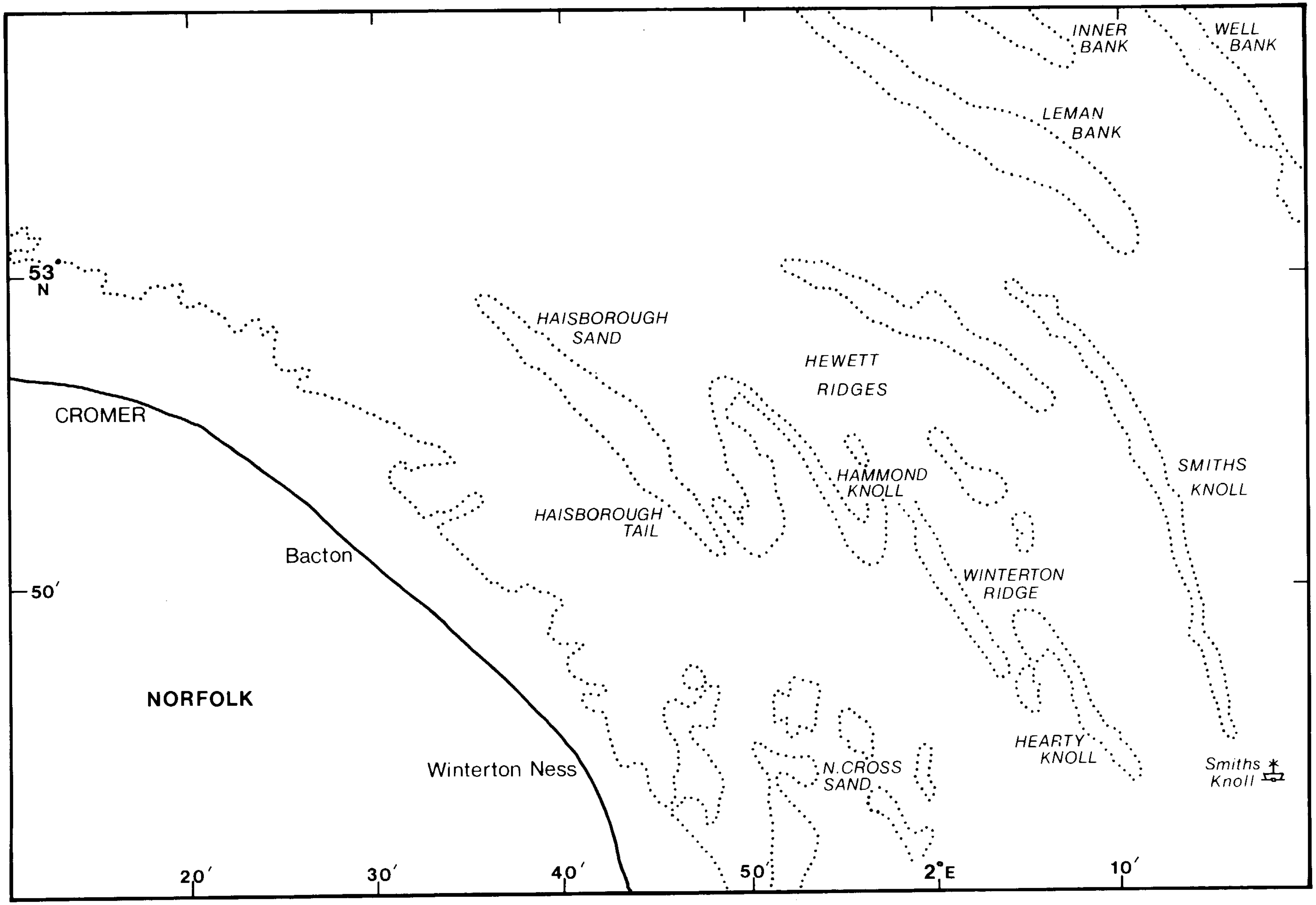

Fig 1 Location diagram: The banks off the East Anglian Coast

considered in relation to oil company pipeline surveys and an analysis carried out by the University of East Anglia (Dr I N McCave) of a survey conducted in 1972.

Diagrams showing the deployment of equipment and the survey track plot are given in Figures 2 and 3. No continuous seismic profiling, flow measurements or sediment sampling were carried out on the first survey as it was intended to conduct such studies at a later date.

RESULTS

(a) The sandwave field

The main sandwave area occurs in a lobe of sand sized sediment which lies to the north west of the head of the bank. To the north east of the bank only small, short-crested sandwaves occur. In this area the coarse sediments extend close to the steep eastern flank of the bank.

Within the sandwave field the mean crestline orientation is 055/235°. This is approximately at right angles to the dominant tidal flow directions as given on Admiralty Chart No 106 for a position to the west of the main axis of the bank. The maximum sandwave height, measured for the 1978 survey data, was 9m and the maximum measured wave length approximately 200m.

Figure 4 shows that symmetrical sandwaves form a zone running east/west from the head of the bank. To the north and east of this zone the sandwaves are asymmetrical with their steeper lee slopes facing to the south east, whilst to the south of the zone the asymmetry is reversed. This suggests that net sediment transport is to the north west on the western side of the bank and south east on the eastern flank. In the case of the former, this inference is supported by tidal stream data on Admiralty Chart No 106 which shows a north west flow residual. A profile across the sandwave field is given in Figure 5.

In all areas where sandwaves occur, sidescan sonar records show that the surface sediments on the flanks of the sandwaves are formed into ripples and dunes. In the area where the steep lee slopes face to the north west the dunes are two dimensional with wave lengths of less than 10m. Their orientation ranges from near parallel to up to 15° to the sandwave crest orientation (Figure 6). In the symmetrical zone much larger dunes are formed. In this area the dune wavelengths reach 15m and their orientation with reference to the sandwave crestlines reaches 65° (Figure 7). A further contrast is to be found in the dunes which occur in the area where the sandwave lee slopes face to the south east. Here the dunes are generally three dimensional exhibiting short

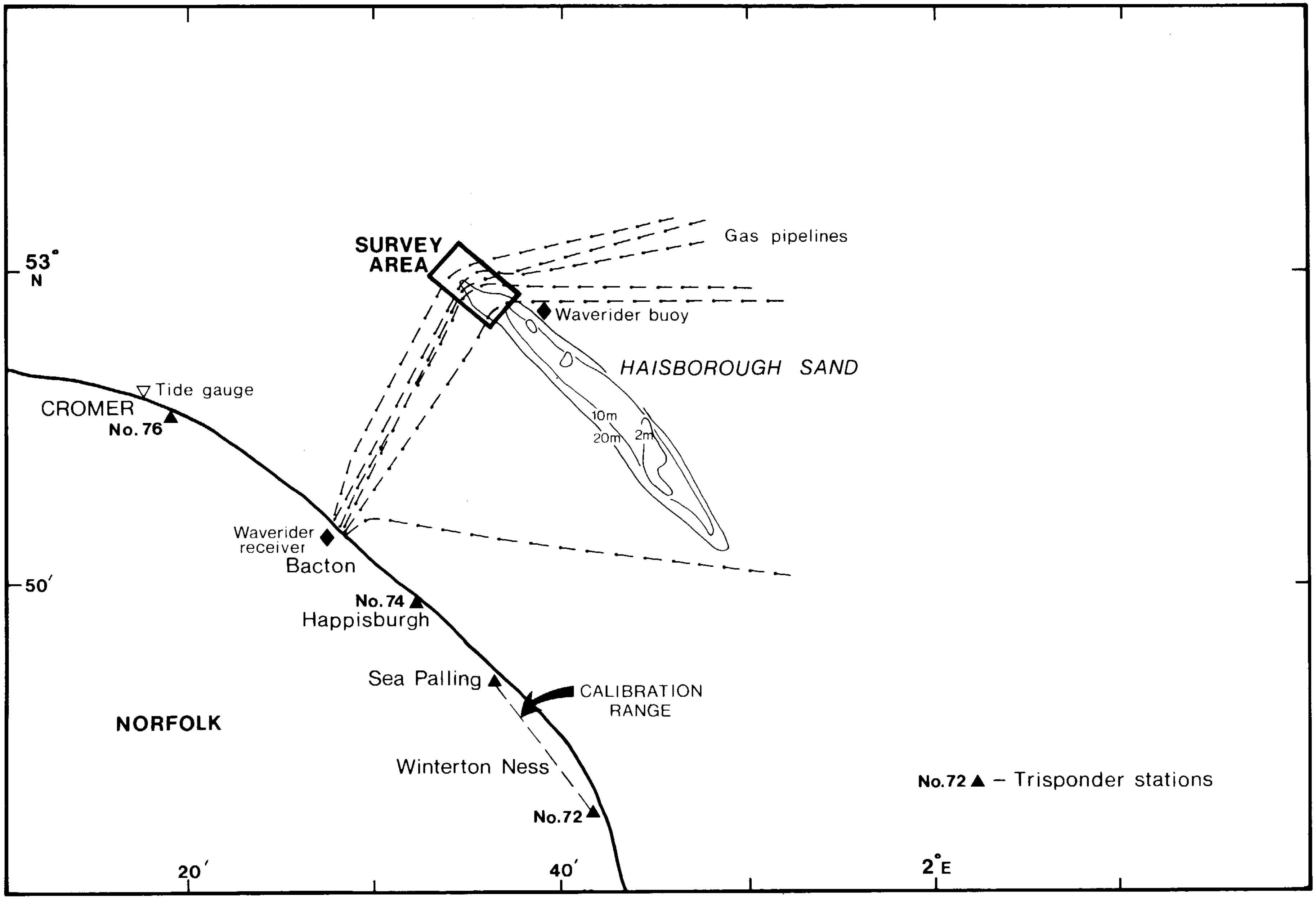

Fig 2 Location diagram: Equipment deployment

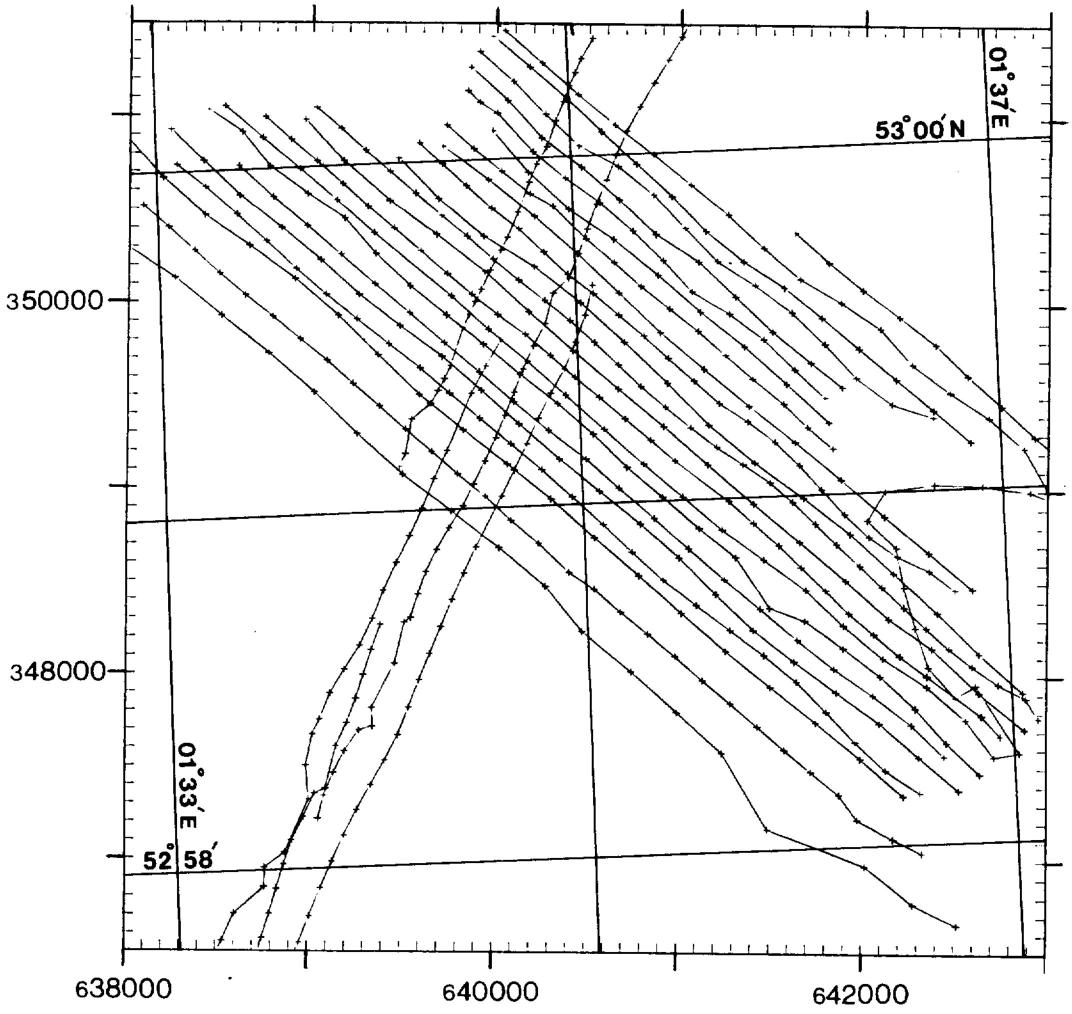

Fig 3 Survey track plot

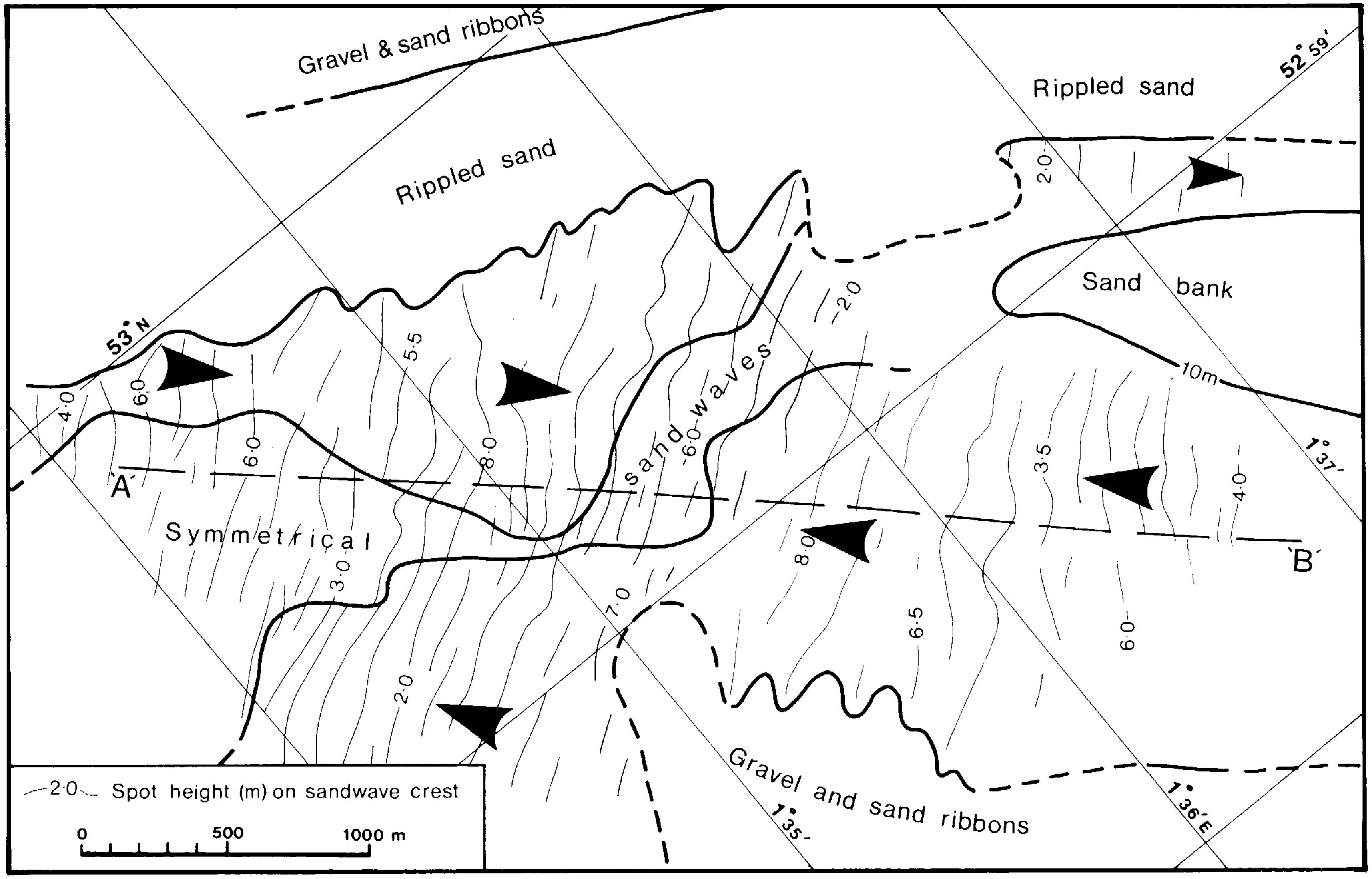

Fig 4 North Haisborough Sand sandwave field

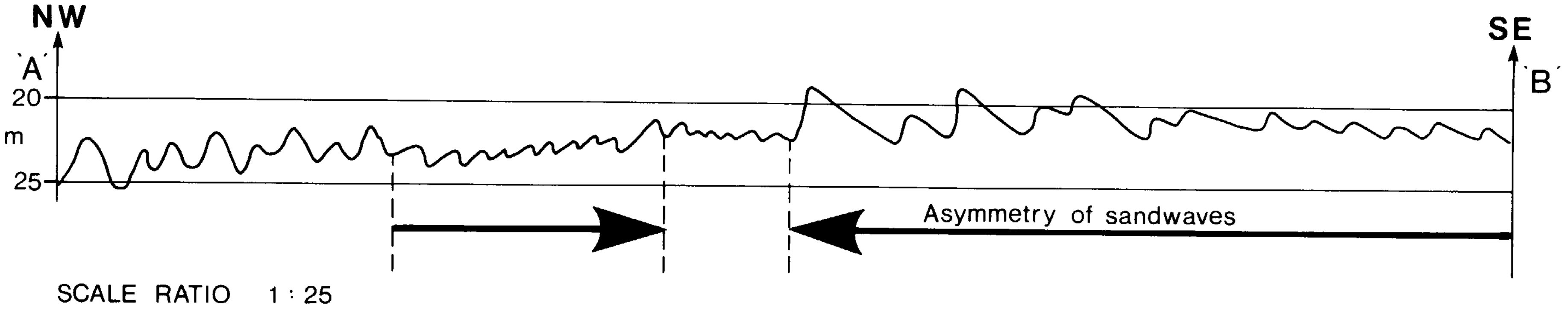

Fig 5 A cross sectional profile across the sandwave field (section A-B on Fig 4)

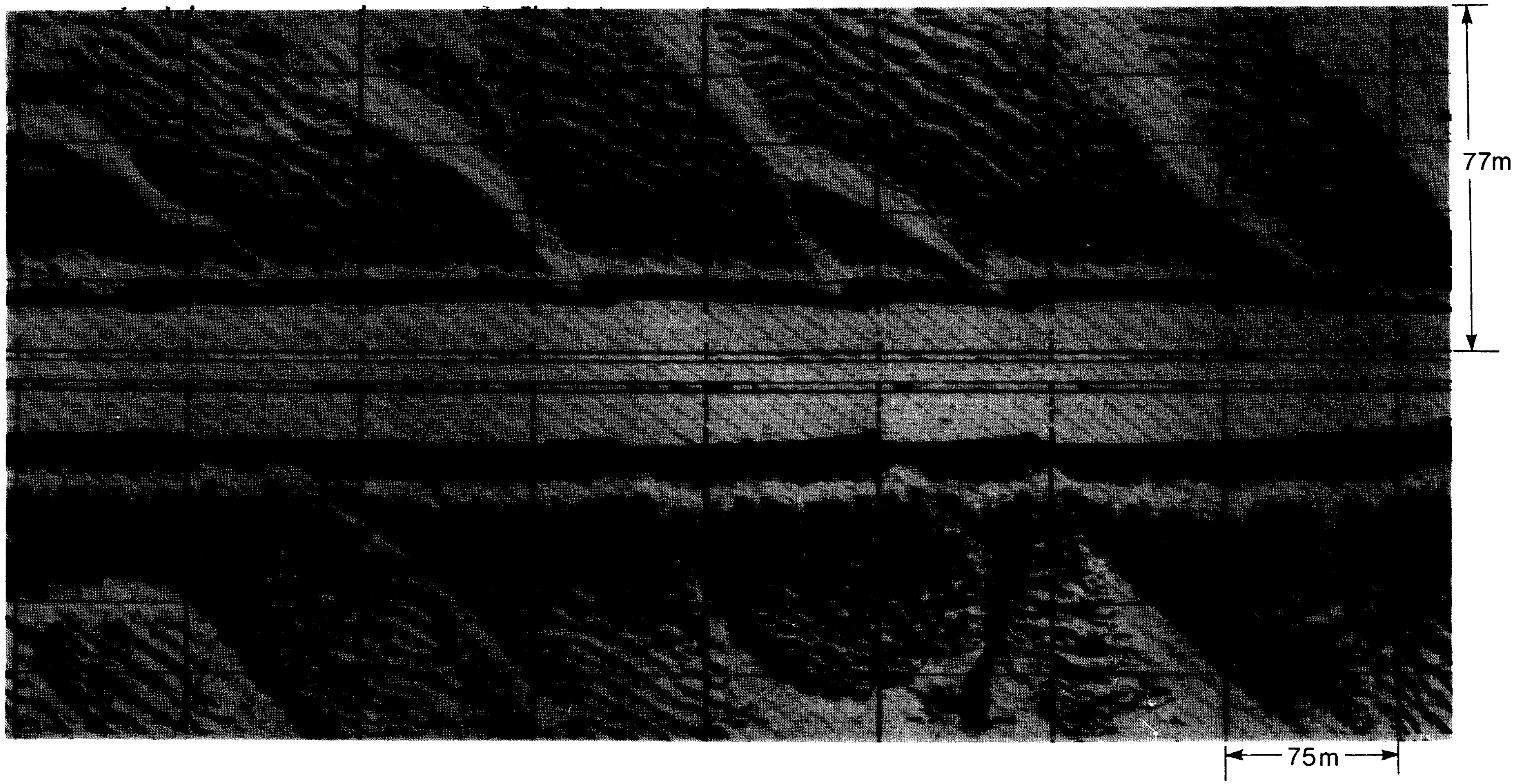

Fig 6 Sidescan sonar record: Sandwaves and near parallel dunes

Fig 7 Sidescan sonar record: Sandwaves and oblique dunes

discontinuous crest lines (Figure 8). It has been shown (Langhorne, 1977) that dunes on the flanks of sandwaves are more ephemeral than the larger features and their orientation and asymmetry are probably more indicative of the short period directions of sediment transport. Consideration of the orientation of the dunes with reference to the major sandwave crests suggests that there is a degree of lateral transport of sediment along the sandwave troughs.

The conclusions based upon this analysis suggest that sediment is transported in a north westerly direction on the south west flank of the bank and in the opposite direction on the north east flank. In the zone of symmetrical sandwaves, between the two major areas of opposing asymmetry, sediment moving between the sandwaves is transported towards the head of the bank in a west to east direction.

A similar conclusion was gained by McCave (Personal communication) from the analysis of an Oil Company survey of 1972. From this data he also identified similar zones of opposing sandwave asymmetry and an intermediate zone of symmetrical sandwaves. Though it is not possible to measure changes in position of individual sandwaves, comparison of the data shows that the orientation of the crestlines, mean wavelengths and wave heights are approximately the same.

The transition from the sand sized sediments, in which the sandwaves are formed, to the surrounding coarser sediments is normally very abrupt (Figures 9 and 17). Close to the boundary a marked reduction in dune wave length occurs associated with the change in bed roughness. Similar reductions in wave length are also often recorded on the flanks of sandribbons crossing gravel areas.

(b) Bank stability

The following bathymetric surveys of the Haisborough Sand area are available from the archives of the Hydrographic Department, MOD.

Reference No	Date
A 45	1798
I 29	1801
E 74	1828
E 824	? Mid-1800's
A 9993	1886
E 3734	1932
E 8865	1949/50

The earlier surveys cannot be used with any confidence to assess the long period trend of the movement of the bank owing to inadequate position control. For these surveys, position control was based upon shore marks, normally church

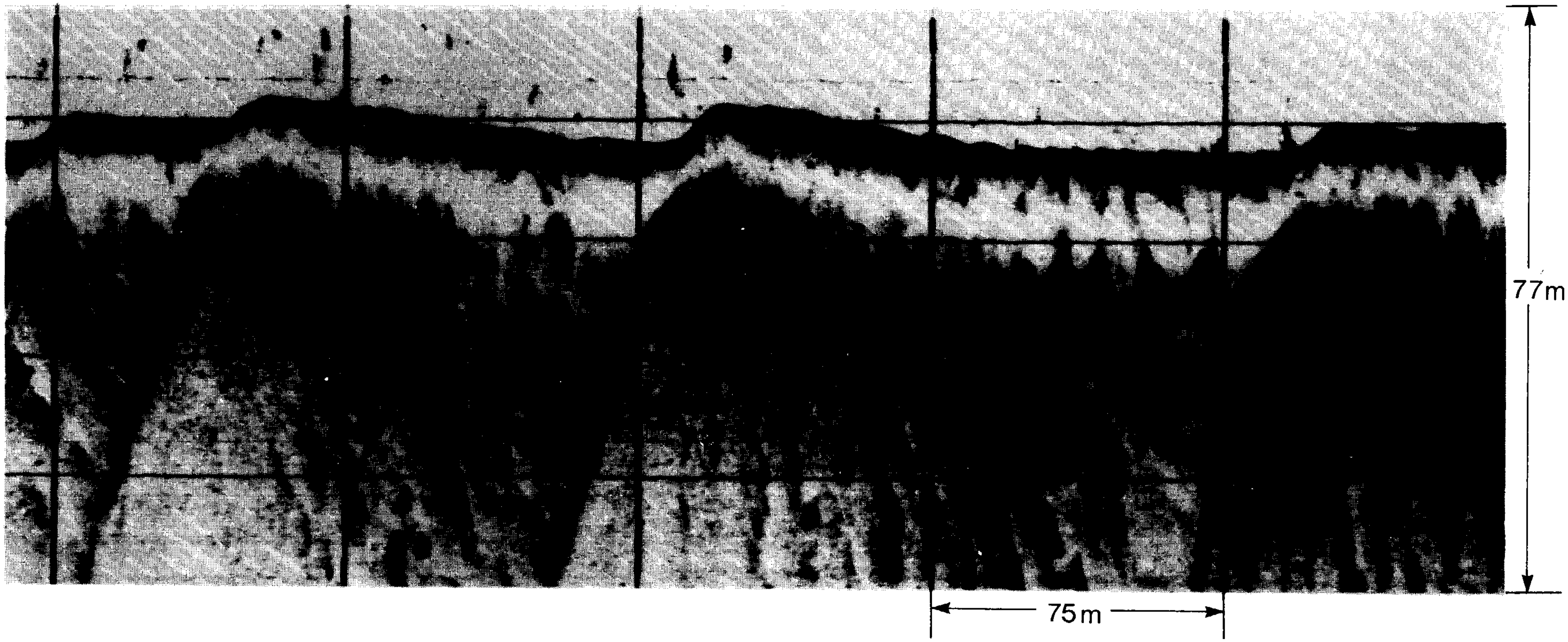

Fig 8 Sidescan sonar record: Sandwaves and three dimensional dunes

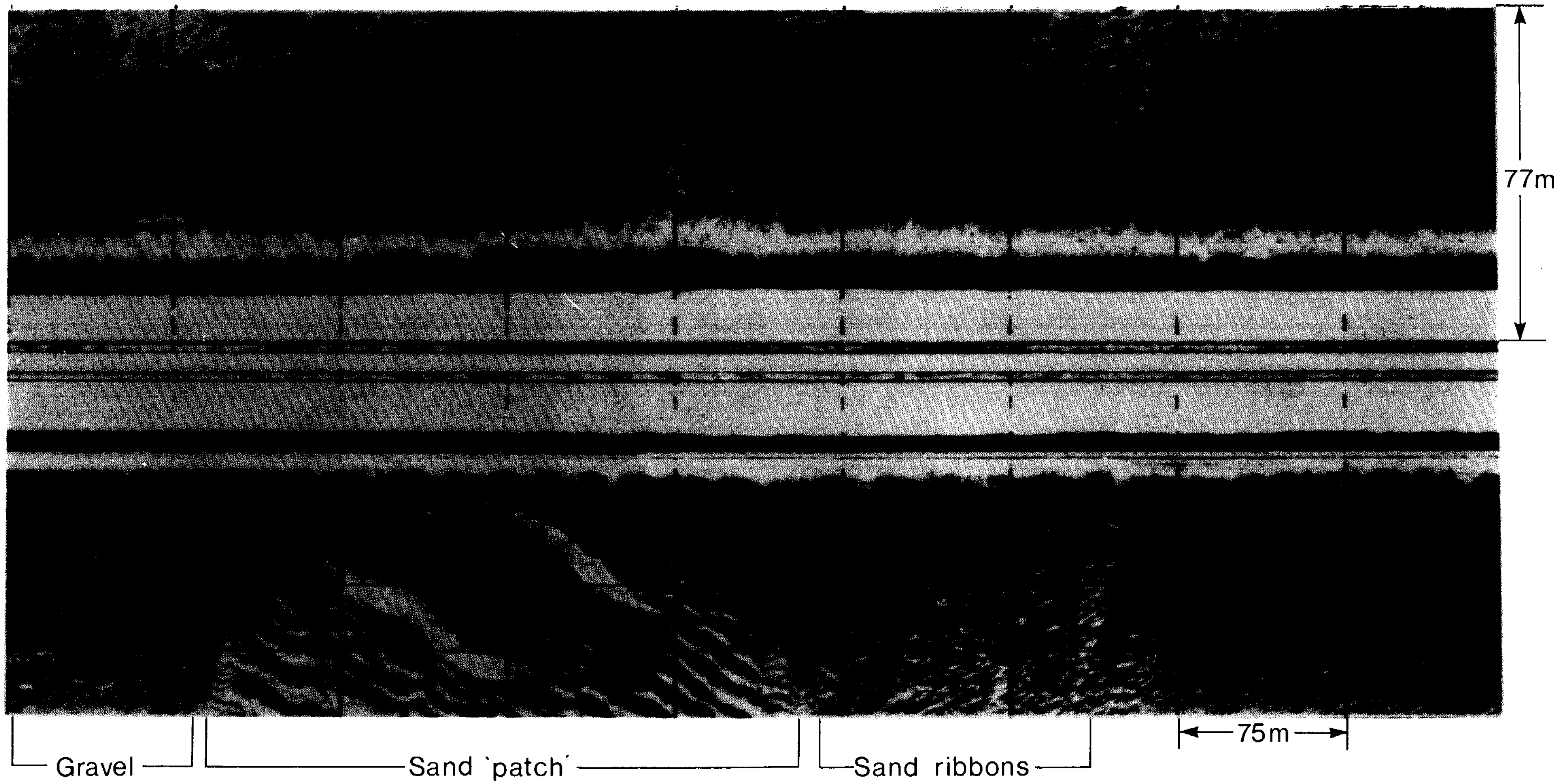

Fig 9 Sidescan sonar record: Sand ribbons and sand 'patches' overlying gravel. Note the marked reduction in dune wavelength at the sand/gravel interface.

towers and these are found to be inaccurately positioned.

Comparison of the three surveys from 1886 to 1949/50 shows that the position of the main north west/south east axis of the bank has remained stable. For all three surveys the survey line spacing was in excess of 450m and line orientation nearly parallel to the sandwave crestlines. With such survey procedures, it cannot be certain that minimum depths were detected and hence the depth contours accurately positioned. Accepting these survey limitations, there is no conclusive evidence of movement of the bank between 1886 and 1932. However, the comparison of the 1932 survey with that of 1949/50 suggests that the head of the bank has extended some 2400m NW at 20m depth. Again, because of the survey procedure this conclusion cannot be accepted without reservation (Figure 10).

(c) Hydrodynamic Regime

(1) Tidal flow

The only tidal flow data currently available from locations close to the head of Haisborough Sand are those given on Admiralty Chart No 106. In this position to the south west of the main bank axis, maximum surface flow velocities reach 140cm s^{-1}. In the absence of other data, an approximate friction velocity, U_* , can be calculated at the sea bed using the equation

$$U_Z = U_* \frac{1}{k} \ln(Z + Z_o)/Z_o$$

This equation is based upon the assumption that the vertical velocity profile is logarithmic and a suitable value of the bed roughness, Z_o , is used. U_Z in this case is the surface flow velocity at height Z above the sea bed and k is von Karman's constant which is taken to be equal to 0.4.

Using a Z_o value of 0.5cm which is considered suitable for rippled sand or gravel (Heathershaw and Hammond, 1979) and the charted depth of 20m, the friction velocity is equal to 6.75cm s^{-1}. Figure 11 (Miller et al, 1977 after Inman, 1949) shows that a U_* value of 6.74 is the threshold friction velocity for the movement of 0.65cm grain sized sediment. Therefore the movement of coarser sediments, or movement at times other than peak tidal flow at Spring tides, would require that the tidal flow velocities at the sea bed are augmented by surface wave energy. No attempt is made to combine the forces acting on the sea bed, generated by tidal flow and waves, in this report.

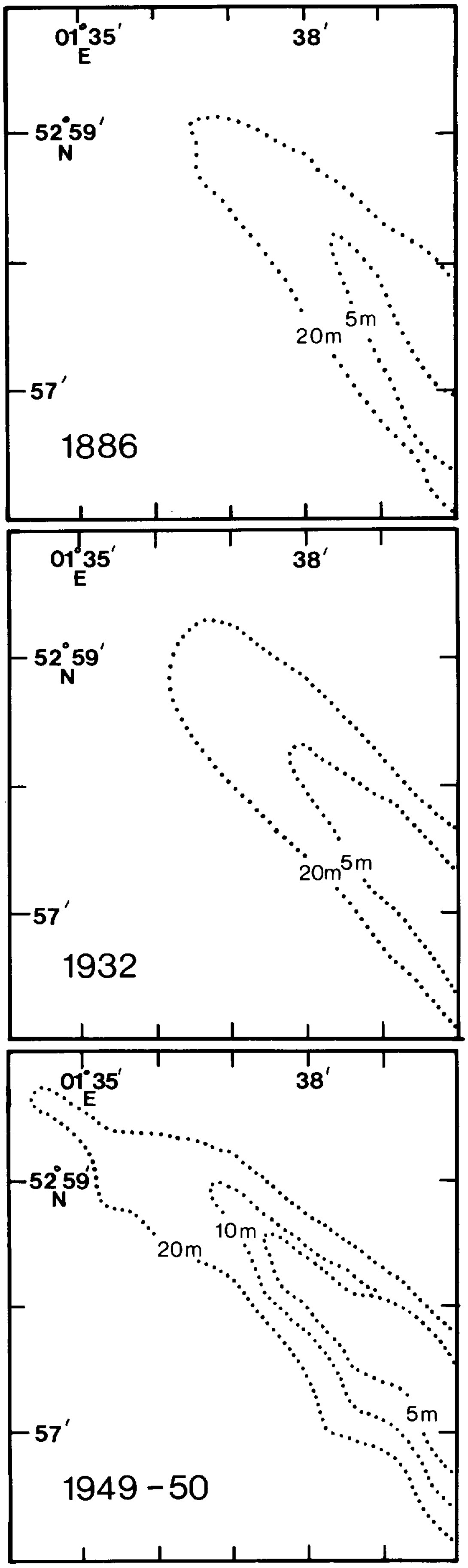

Fig 10 Historical analysis of the position of the head of the bank

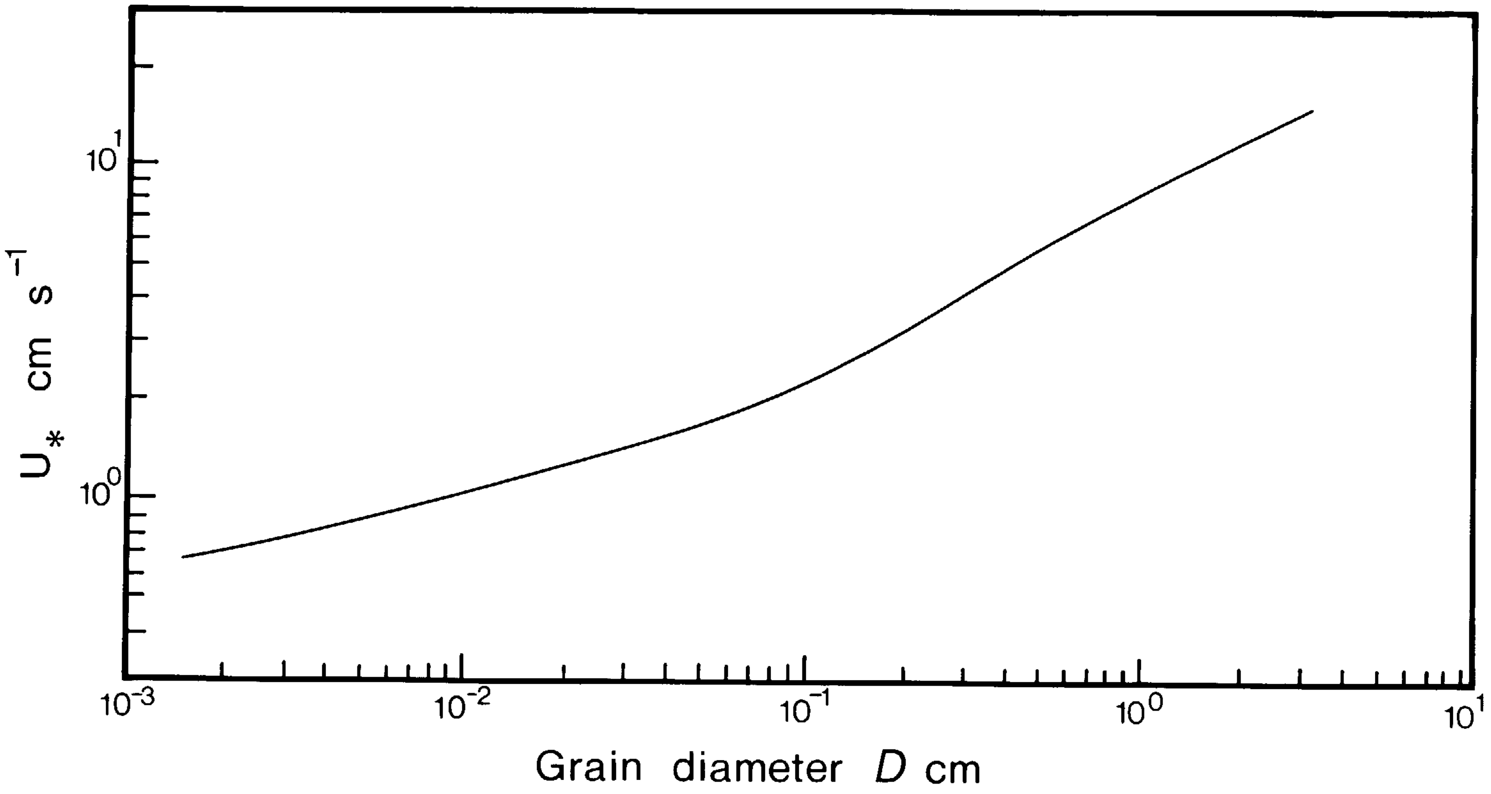

Fig 11 The threshold friction velocity for the movement of sediment grain sizes. (after Miller, McCave and Komar, 1977)

(2) Surface waves

The approximate particle orbital velocity amplitude, U_m, close to the sea bed, generated by waves, can be calculated from the equations:

$$U_m = \frac{gak}{\sigma \cosh (kh)} \qquad \text{where} \quad \sigma = \frac{2\pi}{T}$$

and in which a is the wave amplitude and T the wave period.

The wave number k, wave frequency σ, and the water depth h, are related by the dispersion relation:

$$\sigma^2 = gk \tanh kh$$

It is also possible to calculate the approximate threshold velocity, $U_{m(crit)}$ for the movement of sediment of a known grain size,, D, using the equation (after Komar, 1974 and Heathershaw and Carr, 1977):

$$U_{m(crit)} = \left(0 \cdot 21 g \frac{\rho_s - \rho}{\rho}\right)^{2/3} \times \left(\frac{DT}{\pi}\right)^{1/3}$$

In which ρ_s is the density of sediment (2.65gm cm^{-3}) and ρ the density of sea water (1.025gm cm^{-3}).

National Institute of Oceanography Report No 33 (Draper, 1968) gives the analysis of a year of wave data (March 1959 to 1960) obtained at Smith's Knoll Lightvessel. This position lies approximately 56km to the south east of the sandwave field. Owing to the complex bank topography it cannot be concluded necessarily that the same wave conditions occurred in both areas, but these results are considered to give a good approximation.

The annual summary of wave data is given in Figure 12. Figure 13 gives the calculated orbital velocity amplitude at a depth of 10m for typical wave heights and periods together with the actual recorded data given in Figure 12($\geqslant$ 5 occurrences per 1000). Included in this diagram are the calculated threshold velocities for the movement of particular grain sizes.

Pipeline surveys in this area are normally carried out during the summer months when better sea conditions are to be expected. The conclusions gained on pipeline exposure and spanning are therefore based upon sediment movement which occurs at these times of the year. Little information is obtained upon the short period changes which could occur as a result of extreme wave conditions generated by winter storms. The seasonal differences in wave conditions recorded at Smith's Knoll Lightvessel are given in Figure 14.

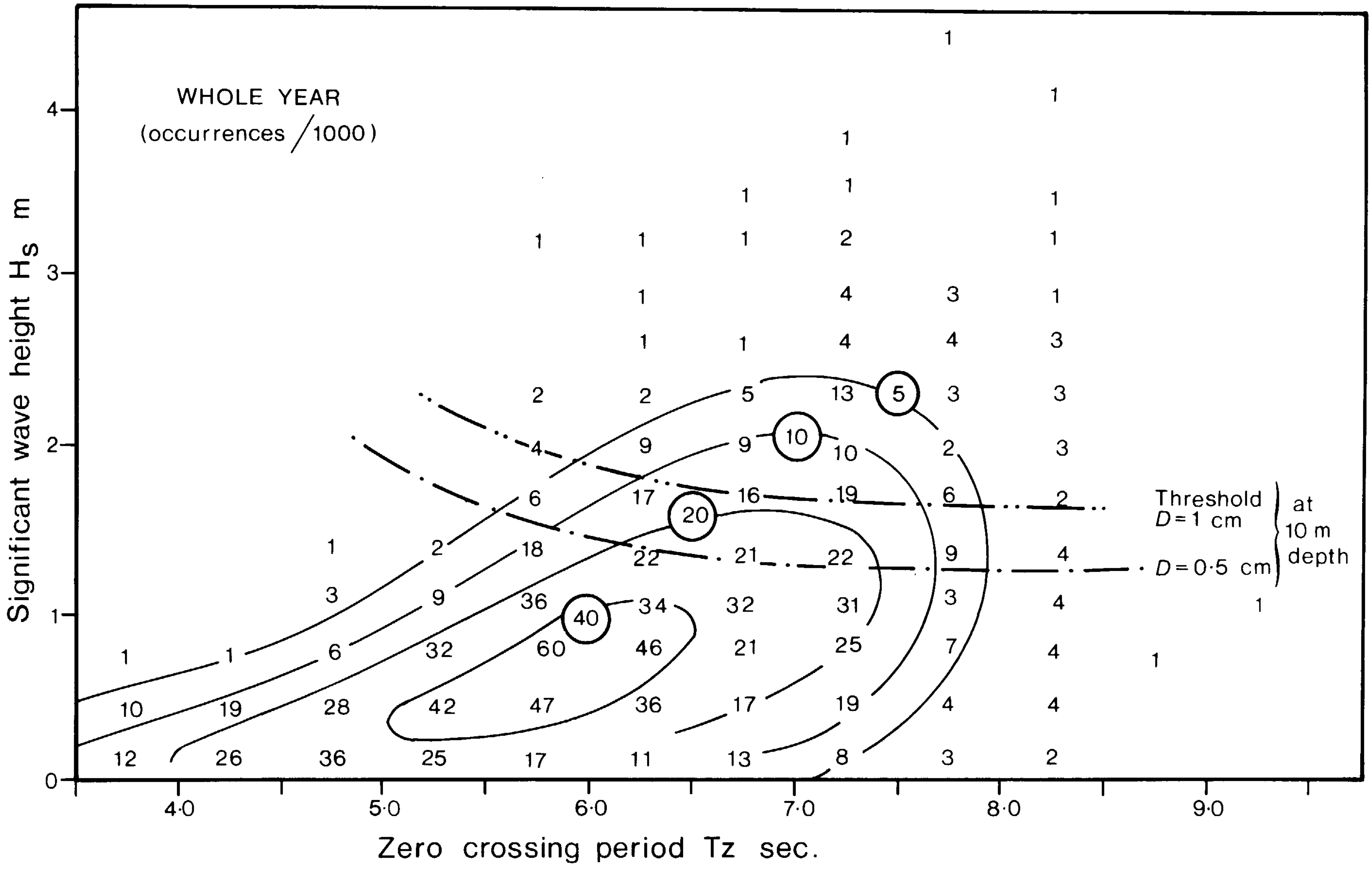

Fig 12 Wave statistics: Smith's Knoll Light Vessel (1959-1960)

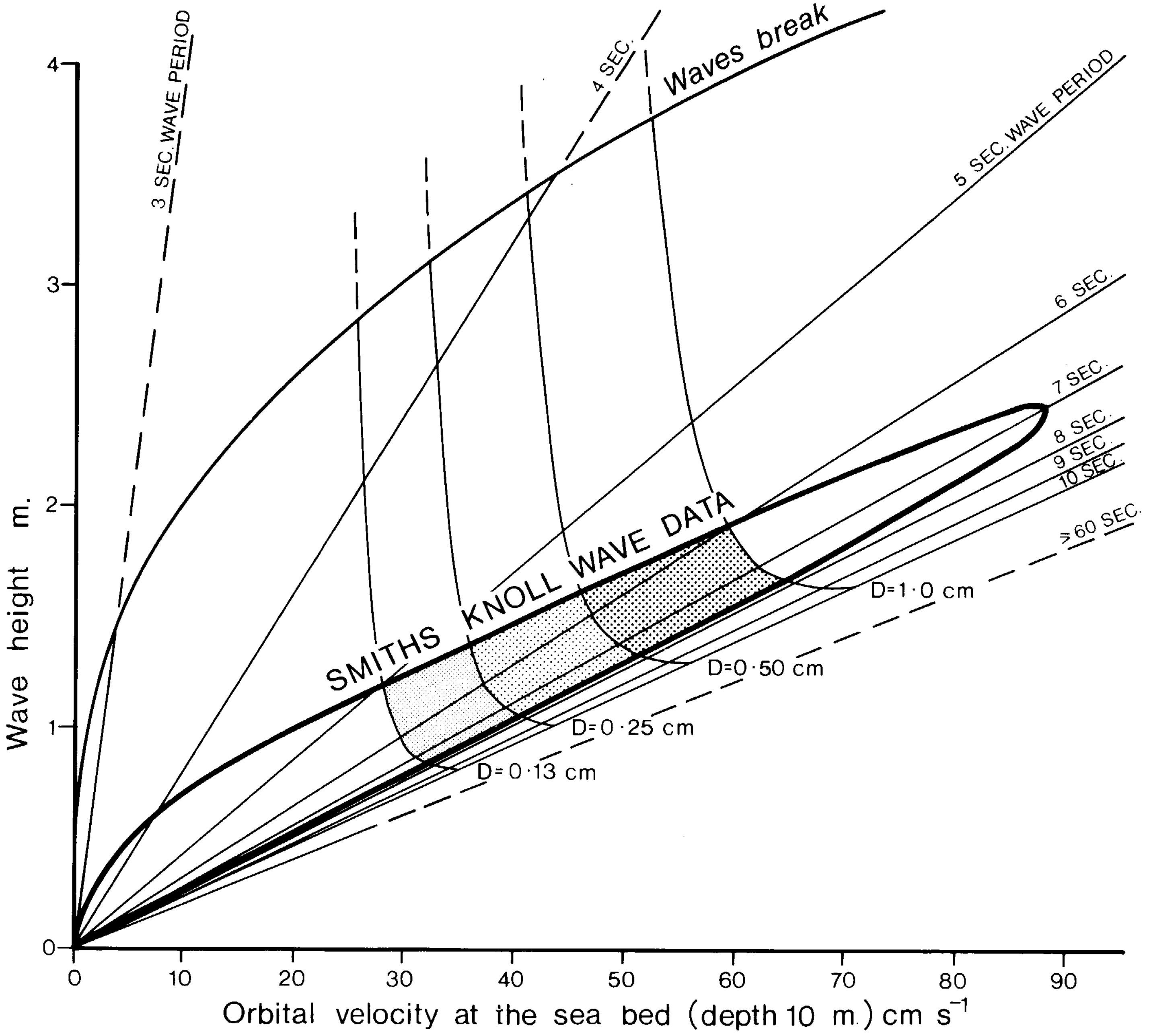

Fig 13 Calculated orbital velocity amplitude at a depth of 10m, and the threshold velocity for the movement of sediment grain sizes. (Smith's Knoll wave data from Fig 12 is included)

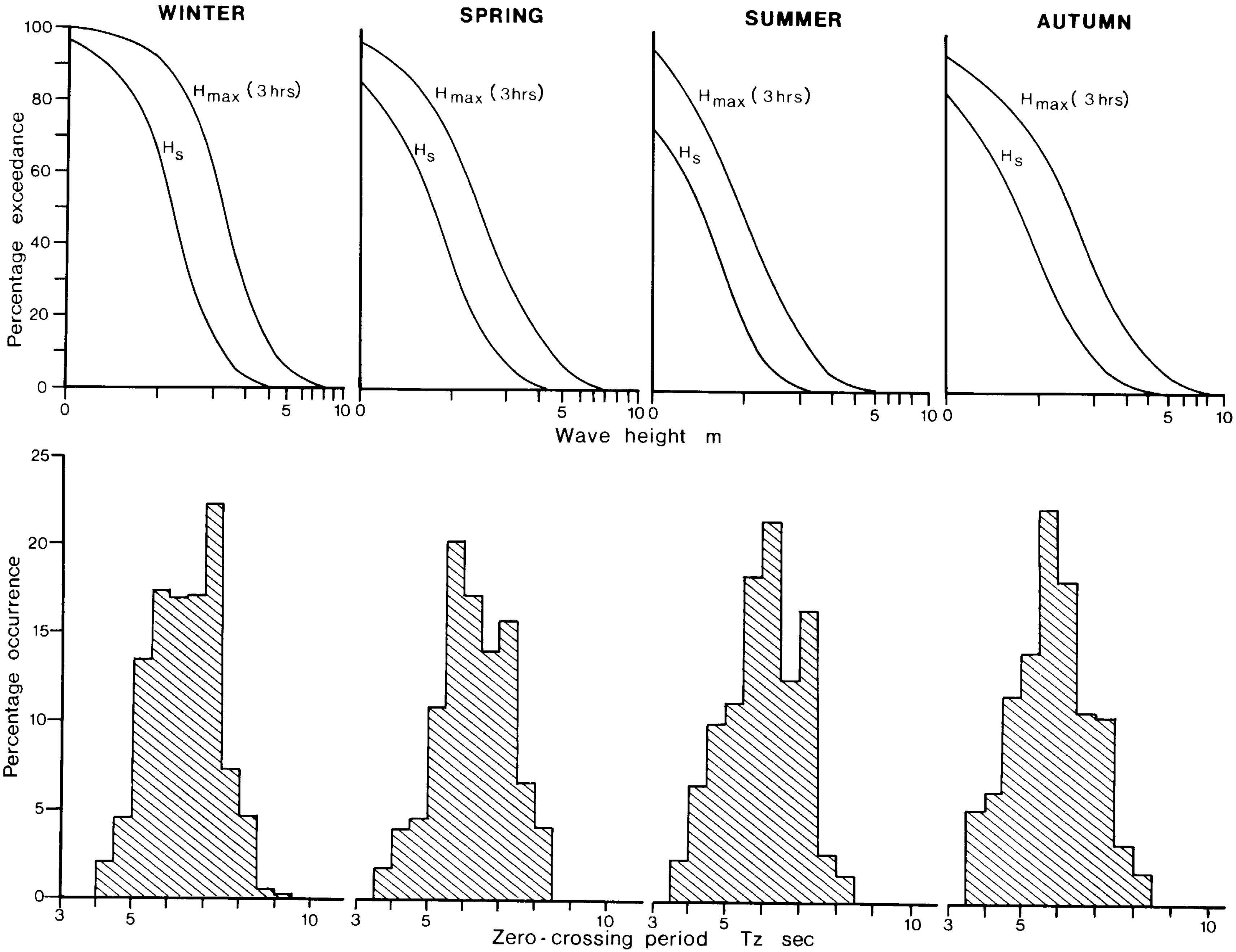

Fig 14 Wave statistics: Seasonal wave data from Smith's Knoll Light Vessel

(d) Submarine pipelines

An analysis was carried out on the survey data on the 30 inch Shell gas pipeline (AP) to Bacton. These surveys were conducted by subcontractors for the Oil Company. Sidescan sonar and ORE sub-bottom profilers were used to establish pipe exposure or burial. In some cases the depth of burial was also given. The comparison of annual surveys between 1975 and 1979 is shown in Figure 15. A 2000m length of pipeline was considered which covered the area where the pipeline passed through the sandwave field. From the diagram it is apparent that during this period maximum exposure of the pipeline occurred in 1976 when approximately 81% of the length considered was exposed. This compares with the preceding year when only 45% was apparently exposed. In one position, over this period the pipeline changed from being 3.4m above the sea bed (?spanning) to 0.6m buried. Over the four year period only 8% of the length considered remained constantly buried whilst 7% remained constantly exposed.

A second analysis carried out by the Oil Company showed that, over the period 1967-1970, the sea bed level along the pipeline route changed by up to 5.5m. In this case, the bed level change was accretionary and therefore of benefit to the safety of this particular pipeline. Accepting the validity of the survey data, these results indicate the high degree of sea bed mobility within the sandwave field.

Examination of the sidescan sonar data obtained by IOS shows that, in the area of coarse sediments surrounding the sandwave field, the pipeline route can almost always be detected. This suggests that there is little movement of the coarse sediments in this area. The only evidence of sediment transport is given by sandribbons which have reformed to fill the trench and obliterate the track. In other cases the sandribbons remain truncated indicating that even in the sediment transport paths of finer sediments, the rates are often relatively low (Figure 16 (a, b, c)).

Within the sandwave field sonar evidence of the pipeline trench was generally missing. This suggests that sufficient sediment transport has taken place since pipeline laying to obliterate the trench. It must also be accepted that in sonar shadow areas behind large of steep sandwaves information may be missed. Though the pipeline trench and general disturbance of the sea bed may have been obliterated by sediment movement, the pipeline itself if exposed, is as a result often easier to detect. Examples are shown in Figure 17 (a, b). Calculations based upon the height of the sonar transducer above the bed, the range of the pipeline and the length of the shadow would suggest that the top of the

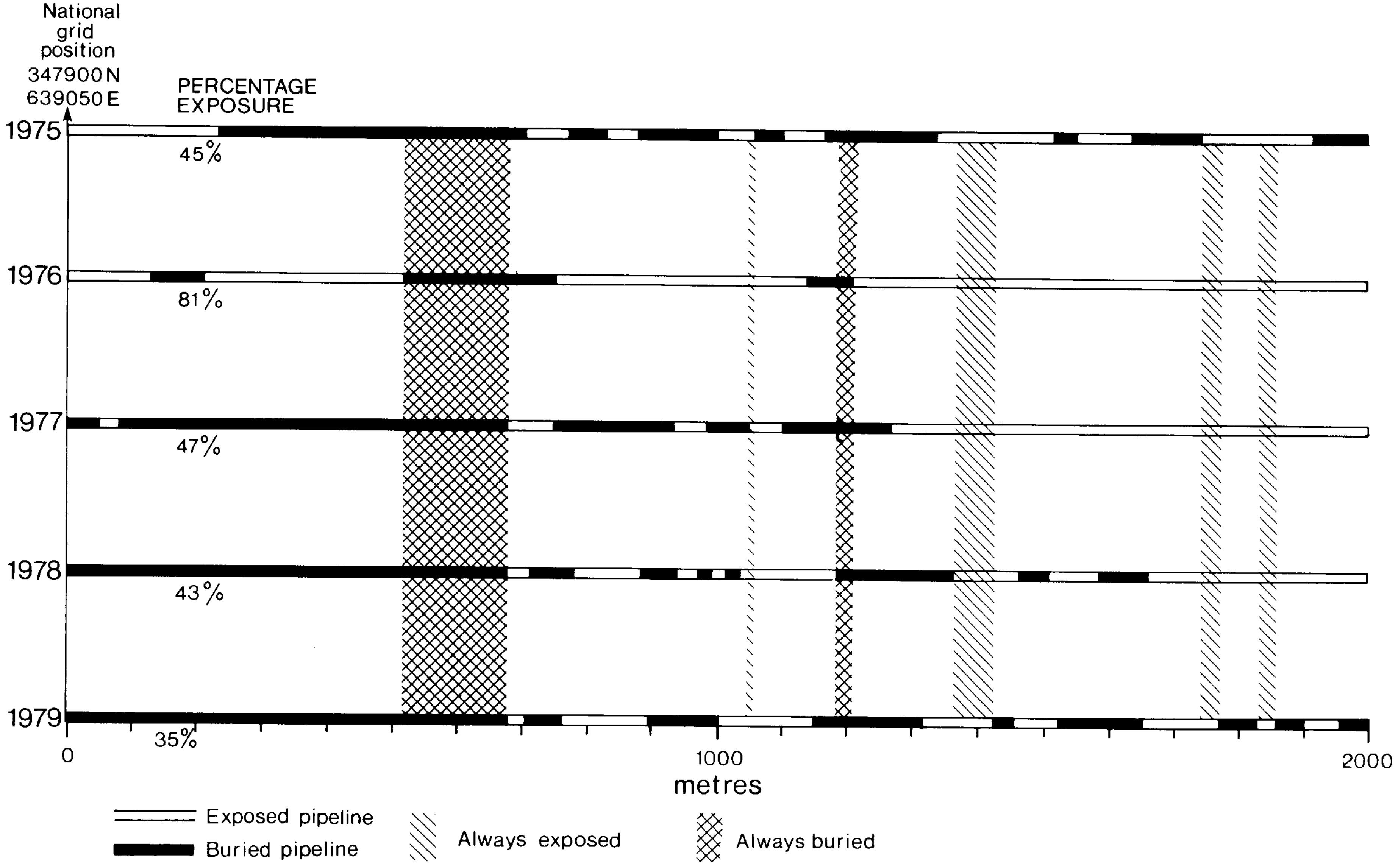

Fig 15 Analysis of pipeline survey data, 1975-1979
(Shell 30 inch pipeline, AP to Bacton)

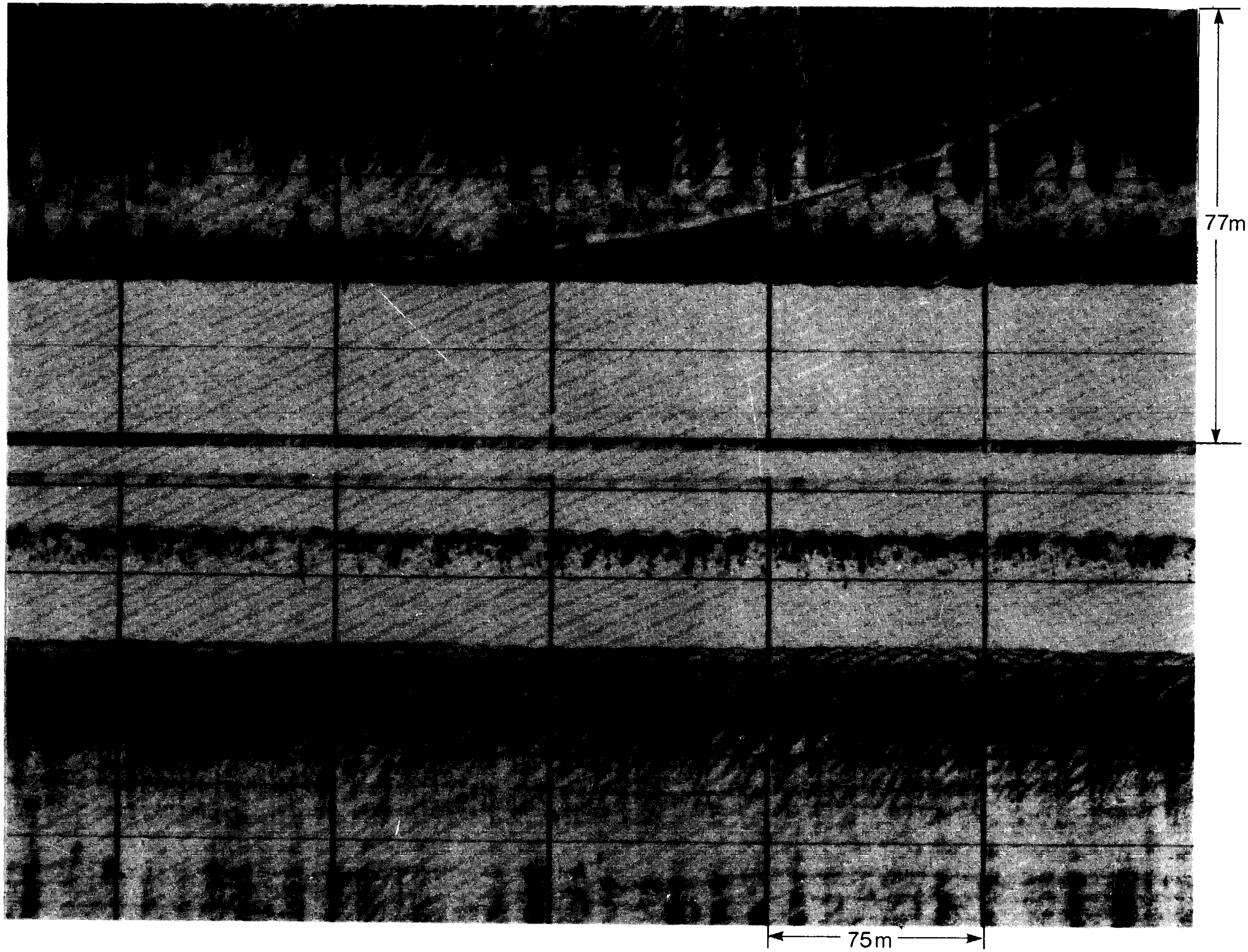

Fig 16A Sidescan sonar record: Exposed pipeline in a gravel and sandribbon area.

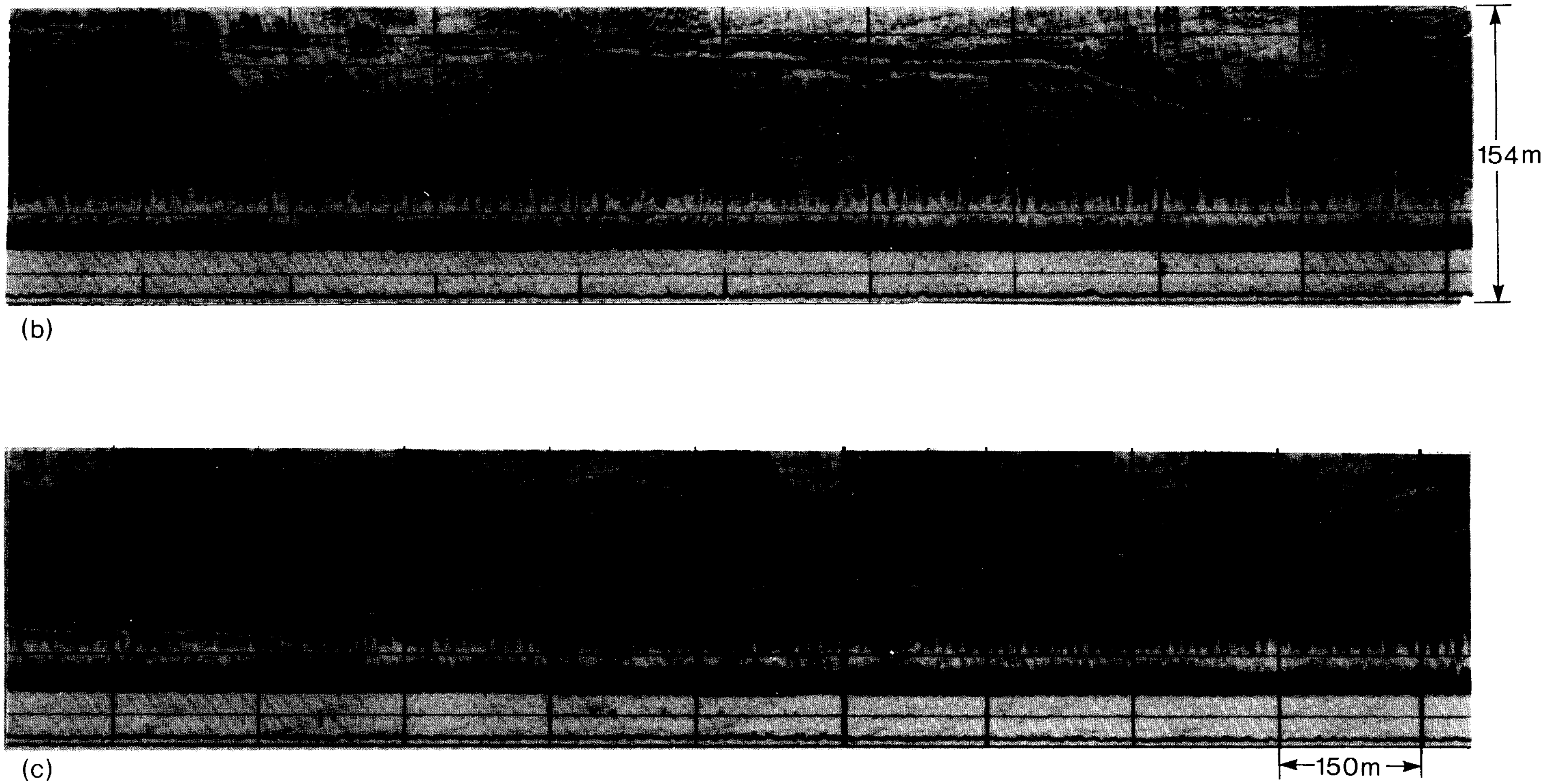

Fig 16B and C Sidescan sonar records: Pipeline trench in a gravel and sandribbon area. Note the partial infilling by sandribbons.

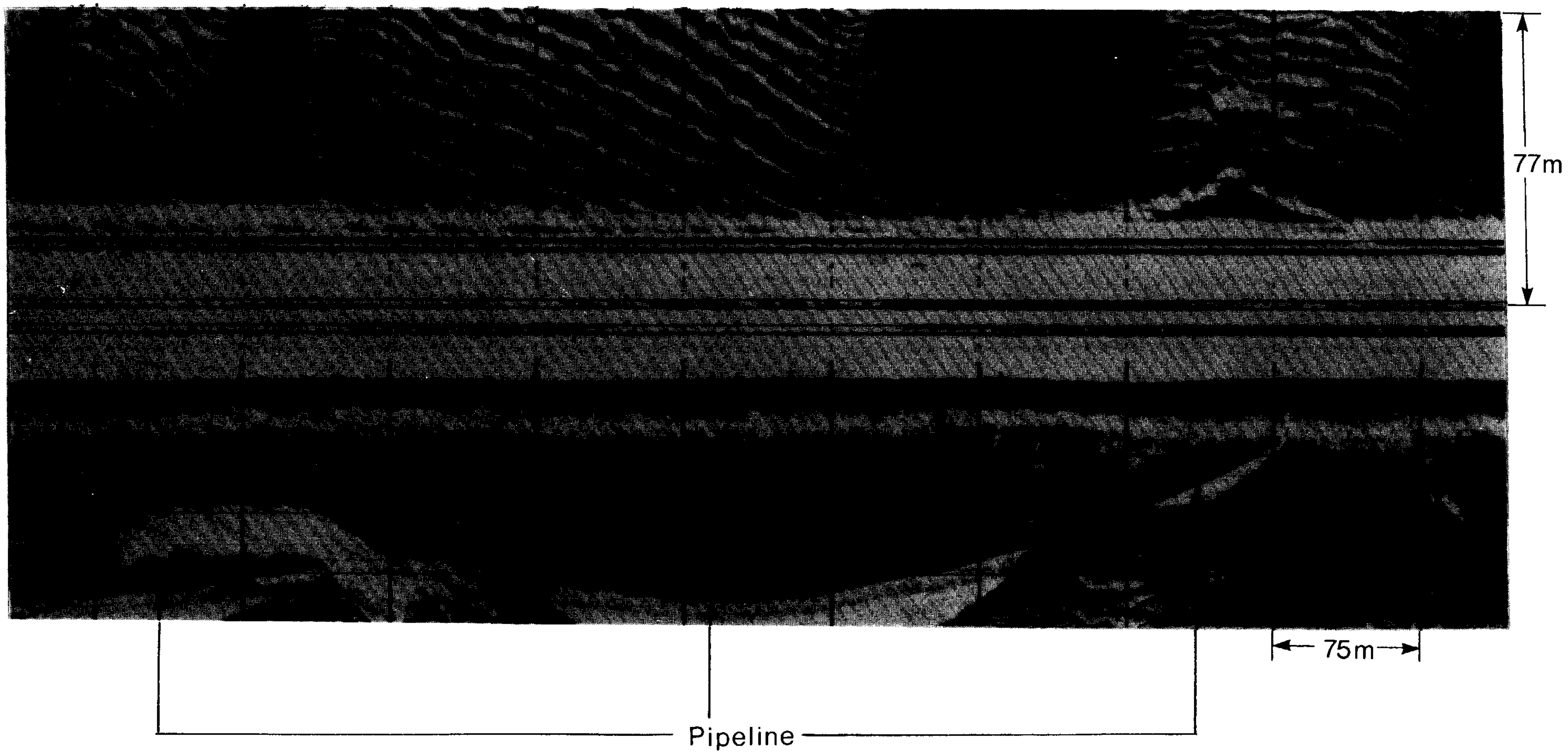

Fig 17A Sidescan sonar record: Pipeline exposure in the sandwave area. Note, no evidence of the pipeline trench, wide shadows behind the pipe but no evidence of spanning.

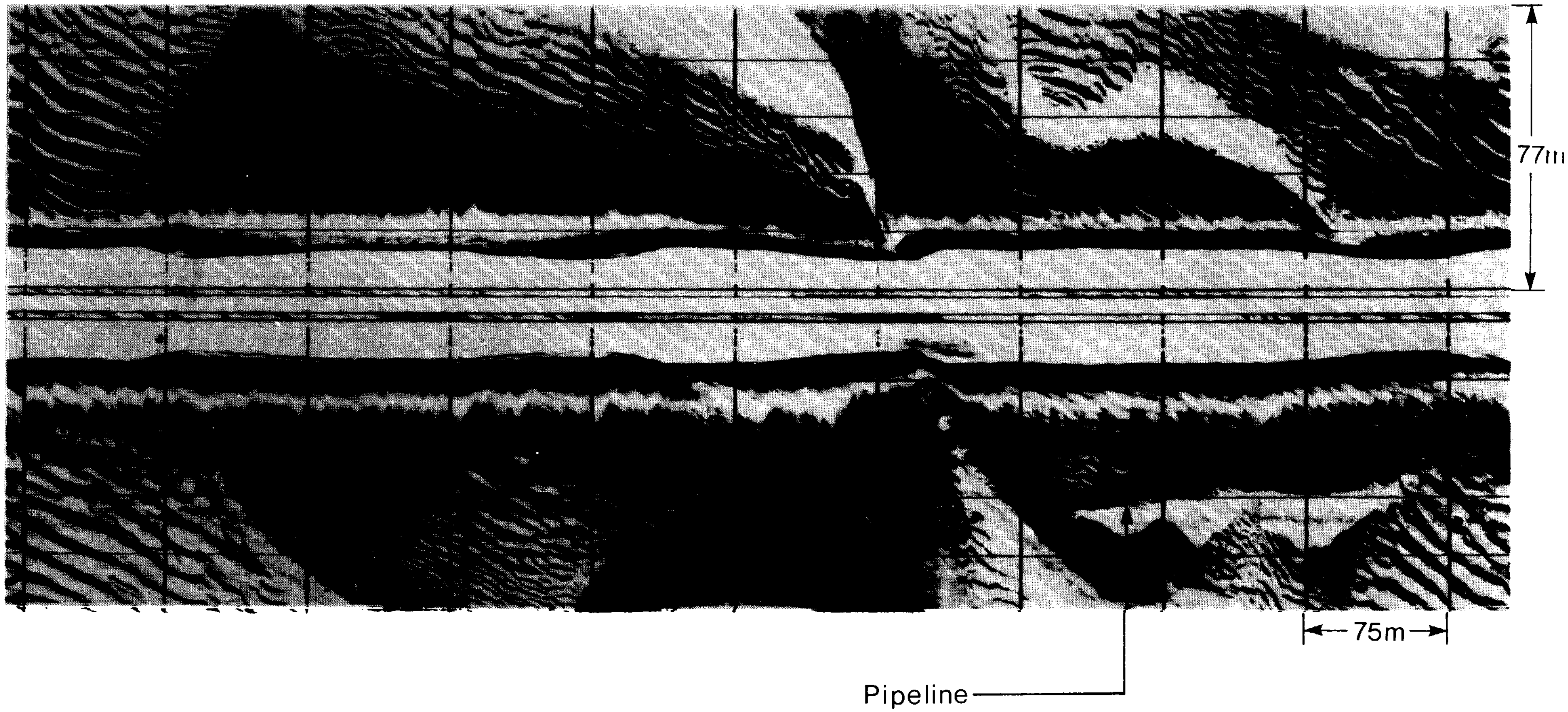

Fig 17B Sidescan sonar record: Pipeline exposure in the sandwave area.

pipe is up to 3m above the bed. This assumes a horizontal sea bed in the direction of the sonar transmission. If this was the case, then some evidence of pipelines spanning would be expected. No such evidence exists which suggests that the pipeline is either supported by sediments, or that the sea bed is sloping away from the transducer at an angle of approximately 6°.

CONCLUSION

The survey data obtained at the northern end of Haisborough Sand confirms the presence of a complex sandwave field. The differing orientation and asymmetry of the bed forms suggest different sediment transport paths around the head of the bank. The bathymetric data, when considered with routine pipeline survey data and with sandwave studies conducted elsewhere, indicate that the sea bed is unstable and this has a marked effect upon the pipelines. Annual surveys conducted during the summer months show that over the period of one year the exposure changed from 45% to 81%. With such information any necessary remedial action may be taken if the pipelines are considered to be endangered. No such information is available during the winter months when the incidence of storms is greater and it is these storms which are likely to produce more rapid and pronounced changes of the sea bed.

ACKNOWLEDGEMENTS

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REFERENCES

BURTON, B.W., 1977. An Investigation of a sandwave field at the South Western end of Sandettie Bank, Dover Strait. International Hydrographic Review, 54, (2), 45-59.

DRAPER, L., 1968. Waves at Smith's Knoll Light Vessel, North Sea. National Institute of Oceanography Internal Report No A33, 15 pp.

HEATHERSHAW, A.D. and CARR, A.P., 1977. Measurements of sediment transport rates using radioactive tracers. Coastal Sediments '77: Proceedings of the Fifth Symposium of the Waterway, Port, Coastal Engineering Division of the American Society of Civil Engineers, Charleston, South Carolina, 399-416.

HEATHERSHAW, A.D. and HAMMOND, F.D.C., 1979. Swansea Bay (Sker) Project; Offshore Sediment Movement and its Relation to Observed Tidal Current and Wave Data. Institute of Oceanographic Sciences Report No 93, 119 pp.

INMAN, D.L., 1949. Sorting of sediments in the light of fluid mechanics. Journal of Sedimentary Petrology, 19, 51-70.

KOMAR, P.D., 1974. Sediment threshold under oscillatory waves. Proceedings of the Fourteenth Coastal Engineering Conference, 756-775.

LANGHORNE, D.N., 1977. Consideration of Meteorological Conditions when determining the Navigational Water Depth over a Sandwave Field. International Hydrographic Review, 54(1), 17-38.

LANGHORNE, D.N., 1979. Offshore Engineering and Navigational Problems, the relevance of sandwave research. Society for Underwater Technology in conjunction with the Institute of Oceanographic Sciences. 21 pp.

MILLER, M.C., McCAVE, I.N. and KOMAR, P.D., 1977. Threshold of sediment motion under unidirectional currents. Sedimentology, 24, 507-527.

APPENDIX

EQUIPMENT

(a) Echo-Sounding: Raytheon DE-719 Echo-sounder. Operating frequency 200KHz. Over-the-side mounted transducer, 8° beam width at half power points.

Bar checked within the survey area using a variable depth vertical reflector.

Comment - For the bathymetric survey a line spacing of approximately 100m and line orientation of $310^{\circ}/130^{\circ}$ was adopted. The orientation was planned in order to cut the sandwave crestlines at right angles. During the survey poor sea conditions resulting in ship motion distorted the echo-sounding records.

(b) Sidescan Sonar: EG & G Dual channel sidescan sonar. Operating frequency 100KHz. Range scales used: 0 - 77m and 0 - 154m on either side of the ship's track.

Comment - Sidescan sonar was used in conjunction with the echo sounder to study sandwave morphology and pipeline exposure. In the areas where the pipe track was detectable it proved possible to 'con' the ship along the track using the sonar.

(c) Tidal Reduction: A Bubbler Tide Gauge (IOS(B)) was installed on Cromer Lifeboat Pier. The height of the gauge was levelled to an Ordnance Survey bench mark close to the end of the pier.

Comment - Some considerable difficulty was experienced in installing the outlet tube below low water sea level beneath Cromer Pier because of poor sea conditions.

(d) Horizontal Position Control: Decca Trisponder microwave position fixing system (range/range). An initial calibration was carried out between Sea Palling Church tower and Winterton Church tower (range 9576.01m, corrected for scale factor). Remote stations were installed at:

Winterton church tower (No 72) Height 50m.
National Grid coordinates: 649107E 319460N.
Happisburgh Coastguard station (No 74) Height 22m.
National Grid coordinates: 637590E 331672N.
Cromer Coastguard station (No 76) Height 50m.
National Grid coordinates: 662692E 341902N.

Comment - The Trisponder system performed well and ranges of up to 35km were obtained for remote station No 72. During the survey remote station No 76 failed. This was found to be the result of power supply failure. Some transmission interference tended to occur in the proximity of the Haisborough Bank Lightvessel.

(e) Data Logging: Decca Data Logger (Maglog) interfaced to Trisponder and Decca Mark 21.

(f) Wave Recording: Datawell Waverider Buoy laid in position 53°58.8'N, 01°38.5'E. Shore receiver installed at Bacton Gas Terminal. Wave data were recorded for 12 minutes every 3 hours.

Comment - It was intended to carry out wave recording for the duration of the project so that bed form changes detected on subsequent surveys could be related to preceding wave conditions.