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ROXANN SEA BED DISCRIMINATION SYSTEM: *IN SITU* AND LABORATORY VALIDATION

by

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1   INTRODUCTION

An initial attempt to examine the performance of a commercially-available (RoxAnn) sea bed discrimination system has been carried out previously (Voulgaris and Collins, 1990). This investigation compared output from the RoxAnn system with side-scan sonar records, collected during field trials by ARE (Portland) in Bigbury Bay. Water depths ranged from 25 to 34 m and sea bed types examined were: plain sand; sand ripples; sand and rocks; rocks and ripples; rocks and bands of sand; and sand ripples. There was an absence of fine-grained (muddy) deposits in the area in which the trials took place.

The analyses demonstrated high levels of positive correlation between roughness (E1) and hardness (E2) indices of the sea bed. Likewise, negative correlation was established between these indices and water depth. When considering the system's output along a single survey line, to examine the signal response to boundaries (between sediment types), consistent 'peakedness' in the output was identified for the boundary regions.

Other conclusions drawn from the analyses recommended the following areas for future research:

- investigating temporal stability of the discrimination system;

- carrying out 'ground-truth' experiments, over a wide range of particle sizes and involving laboratory and field measurements (for the latter, the use of divers was suggested);

- use of the RoxAnn with echo sounders of different source frequencies;

- modification of the system to record the complete envelope of the return signal, before processing by the RoxAnn ultrasonic processor (USP);

- that more information on the existing signal analysis procedure be made available to investigators;

- laboratory and computer modelling studies should be undertaken;

- intercomparison be carried out between digital side-scan sonar and RoxAnn outputs;

and

- a trial to be undertaken, using the RoxAnn system mounted on a side-can sonar device.

On the basis of these recommendations, it was suggested to ARE that a number of priority areas of research should be undertaken during the course of a two-phase investigation. An initial and modest phase (Phase I) would concentrate upon investigations into: the temporal stability of the RoxAnn system; and some preliminary laboratory and comparative field studies. A more extensive second phase (Phase II) would address other aspects of the requirements and, in particular:

(a)   detailed laboratory and field studies, as a means of 'ground-truthing' the discrimination system - involving different sea bed types and morphology (bedforms);

and

(b)   the development of a high speed data acquisition system, in order to collect the full acoustic signal returning from the sea bed - to examine possible changes to the signal integration 'windows' used presently on the RoxAnn.

The present investigation represents Phase I of the further studies recommended and includes the following:

(*i*)   examination of the temporal stability of the RoxAnn system, through its installation on fixed shoreline structures (*eg* jetties and piers);

(*ii*)   carrying out a feasibility study on the use of the RoxAnn system in a static tank, as a preliminary to Phase II (see above);

and

(iii)   undertaking a comparative field study, examining different sea beds and the 'furrow features' present in the muddy sediments of the East Solent.

For (*i*) above, the RoxAnn system was fixed in position at Bournemouth Pier (over a rippled sand bed) and the jetty of the Department of Oceanography's Shoreside Facility (muddy sea-bed). It was intended originally that measurements would be collected over neap and spring tidal cycles (demonstrating the system's response to change in water levels), during calm and stormy conditions, from these permanent installations. This particular part of the study was modified subsequently, however, on the basis of a preliminary set of observations (see Section 4.2) and in order to avoid duplication of effort with work being undertaken at UCNW, Bangor (see Proceedings, Workshop on 'Seabed Classification Techniques' [4 April 1991]). Consequently, additional field measurements were included in this investigation to incorporate a wider variety of sea bed types.

2   EQUIPMENT USED

The equipment used during the present study consisted of:

(*i*)   a USP RoxAnn system;

(*ii*)   an echo-sounder;

(*iii*)   a navigation system;

and

(*iv*)   other equipment.

Details of each of these instruments are presented below.

(i)   **USP RoxAnn System**

The principle of operation of the RoxAnn system, for sea bed discrimination, has been explained elsewhere (*ie* Burns et al 1985a, b; Voulgaris and Collins, 1991); it detects return signals from the sea bed. The signals are then analysed in such a way that integrals of parts of the first echo (the tail) and the complete second echo, are presented as two variables (E1 and E2 respectively (Figure 1)), for each sounding. A more detailed description of the operation of the system, from the signal processing point of view, is presented below and has been based upon that of Chivers *et al* (1990).

The overall system is shown schematically in Figure 2 and has the following elements:

(a)   a head amplifier which is connected directly across the echo-sounder transducer, in parallel with the echo-sounder transmitter - this is tuned to the transmitter frequency and matched with the transducer power output, such that it has a negligible effect on the transceiver itself;

(b)   a parallel receiver which accepts the echo train from the head amplifier and is designed to have accurate processing facilities, especially of time-varied gain and filtering - the gating of the signal and integration of the first and second echoes is carried out within this unit;

and

(c)   an IBM PC, fitted with a CIL Electronics Ltd Alpha 2 card, to interface the 'parallel' receiver to the computer - the Alpha card is a controller which passes synchronisation pulses through to the central processing unit to calculate depth, while the analogue E1 and E2 voltages are converted into a digital format for processing, storage and display.

The electronic circuitry is shown as a block diagram in Figure 3, with the following general method of operation for E1 and E2 capture:

(d)   the head amplifier (block 1) provides substantial gain, with very low inherent noise, such that it produces two logic level transmit pulses as key gating pulses from the host echo-sounder transmitter - the echo-train is also 'mixed' to produce a 15 Khz intermediate frequency (IF), for subsequent processing in the main parallel receiver;

(e)   the digital board (block 2) provides control pulses and gates, to act on the analogue IF signals;

(f)   the analogue board (block 3) performs TVG, processing and filtering of the echo train, together with detection, gating and 'sample and hold' circuitry - the final processed raw E1 and E2 analogue voltages are then mixed, prior to processing by the Alpha card. [Note: advanced circuitry is also included to ensure that data is only processed when the boat is near to vertical ('gimballing')].

The choice of gating timings for the integration process is crucial. Firstly, the integration process obviously includes the noise on the integral, producing unknown errors. Secondly, and more importantly, the integration period from the first echo must certainly close before the second echo starts to be received. Setting the integration period of the first echo so that the second echo is excluded for shallow depths, may cause the integration to be finished prematurely for the first echo at greater depths, with potential loss of a significant contribution to the integral. In addition, if only the oblique back reflection is to be included in the derivation of E1, then it will be necessary to gate out the initial part of the received first echo (as described above). Automatic calculation of the integration periods is carried out by logic control circuitry (block 2, in Figure 3) determining the gate duration and timings.

(*ii*)   Echo-sounder

The echo-sounder used throughout the trails was a Furuno FCV-262, 2 KW dual frequency colour video sounder, operating at 28 KHz or 200 KHz. The 28 KHz and 200 KHz channel transmit power were both set at 2 KW. Pulse repetition frequency was set to 5 Hz, giving a pulse length of 0.6 ms. For the 28 KHz transducer, the beam angle to the -3dB points was 22 degrees, whilst that for 200 KHz was 5.4 degrees.

For the field trials, both frequencies were used (when available). During the laboratory studies, only the 200 KHz frequency was used, due to failure on the 28 KHz head amplifier.

(*iii*)   Navigation

In order to provide position fixing for the sea trials, a Global Positioning System (GPS) receiver was used. The receiver was a Satnav XR4, operating by tracking the C/A code on the L1 carrier frequency. The navigation information was output as 1200 Baud 5V level RS-232c serial data, using NMEA 0182 protocol - a fixed format representing cross track error and the vessels position in latitude and longitude.

At a later stage in the analysis of the field data collected, the geographical coordinates were converted into Ordnance Survey grid coordinates.

(*iv*)   Other Equipment

A Compac 386 20 PC was used for the storage of the USP RoxAnn data, together with information from the navigation system on the case of the field trials.

The envelope of the return echo was captured during the laboratory experiments, in parallel with the recording of the E1 and E2 values. A high frequency data acquisition system (DATA LAB-MULTI TRAP) was used for this purpose. The data collection was triggered externally using the two (logic) level transmit pulse, generated by the head amplifier of the USP RoxAnn system. The captured return echo was that created by the RoxAnn's head amplifier. The data were recorded on an IBM-compatible PC.

3 EXPERIMENTAL SET-UP AND DATA COLLECTION

3.1 Introduction

The RoxAnn USP ground discrimination system was subjected to a series of trials during March-April 1991 and August 1991. The seaborne trials consisted of two elements: (*i*) static tests at shore sites, namely Bournemouth Pier at Poole Bay and the Southampton University Shoreside Facility on Southampton Water, which were used to assess the temporal stability; and (*ii*) vessels in Southampton Water and, later, Portland Harbour to assess the repeatability of the E1 and E2 values over differing sea bed types. The later (August) trials were carried out using the ISVR (Institute of Sound and Vibration Research) tank facility at Southampton University. This latter series of trials consisted of suspending the transducer in the tank, whilst changing the sediment cover at the base of the tank.

3.2 Field Trials

(a) Static: at Bournemouth Pier and the Shoreside Facility. Two transducers were mounted in a steel frame plate (Plate 1), which was suspended below the low water mark with a system of rigging wire supports. The equipment was left *in situ* for a complete tidal cycle.

A series of data sets, each of one hour duration, was obtained for each of the sites. In each case, the transducer connections in the head amplifier 'break-out' box were swapped after an hour, so that data sets using both frequencies could be collected.

(b) Mobile: on board the Oceanography Department's vessel *Labrax* (Southampton Water) and Dowty Marine's *Sea Searcher* (Portland). The transducers were mounted in the same steel frame as for the static tests, but attached to an 'over the side' pole mount in this particular case.

Three sites were selected for investigation in Southampton Water/The Solent, with different bottom types (for locations see Figure 4). At each site, the transducers were again alternated so that a data set with each frequency was produced. An additional site was selected, to investigate the response of the RoxAnn system to furrows formed in the cohesive estuarine muds. The furrows have been described elsewhere as being up to 4 km in length, 0.5 to 15 m in width, 0.5 to 1 m in depth and spaced about 10-25 m apart (Flood, 1981). The mechanisms suggested for their formation include erosion (Dyer, 1970) or a combination of erosional and depositional processes.

Comparative data were collected then in Portland Harbour (Figure 5).

3.3 Laboratory (tank) Trials

The ISVR tank facility consists of a concrete walled water tank, 5 m deep and 5 m x 5 m in its horizontal extent. In these tests, the 200 KHz transducer was suspended just below the water surface. A wooden tray 1.2 m x 1.2 m square and 150 mm deep was constructed for the study and filled with graded sediment and placed on the floor of the tank (Figure 6). The RoxAnn equipment was allowed then to run for approximately 2000 readings (*ie* 50 mins). Together with these data, a series of envelopes of the returned acoustic signal were recorded.

Various sediment types were used for this particualr part of the investigation: coarse sand; 10 mm (mean grain size) gravel; and 20 mm gravel. The tests were repeated on the concrete floor of the tank and with an empty (marine ply (wooden)) tray in place.

3.4 Sea Bed Sampling and Grain Size Analysis

Seven sea bed samples were collected during the field trials (using a van Veen grab), for comparing their sediment properties with the RoxAnn E1 and E2 output values. 4 samples were collected during the trials at Portland Harbour, whilst 3 samples were collected during the trials in Southampton Water (Table 1)

Table 1: Identification of the seabed samples collected

Sample	Location
P1	Portland
P2	"
P3	"
P4	"
CP	Castle Point
WK	West Knoll
BP	Bird Pile

The samples collected were washed, in the laboratory, with fresh water and then dried. The gravel and sand fractions were separated from the mud, prior to sieve analysis (according to BS 1377, 'Methods of Testing Soils for Civil Engineering Purposes'). The mud fraction was analysed using a Sedigraph. The cumulative frequency of the grain size distribution of the samples is shown on Figure 7. Within Southampton Water (Fig 7a), the Bird Pile sample consists of mud. The West Knoll samples consist of a well-sorted medium to fine grained sand, whilst the Castle Point sample is a sand-mud mixture which is rich (> 50%) in shell fragments. Photographs of the grab samples, taken at the time of their collection, are shown as Plates 2 and 3.

The Portland samples (P1, P2, P3 and P4, Figure 7b) have approximately the same grain size (mud) distributions. The offset in the cumulative curve, to higher percentages, is a reflection of an increase in the shell content contained within the samples.

4 RESULTS - DISCUSSION

4.1 Controlled Laboratory Experiments

Data relating to the response of the RoxAnn system over different sediment types have been collected and collated. The time-variability of the recorded signal is examined here, for each of the test runs. As referred to in Section 3.2, a series of experiments were undertaken (at 200 KHz) with different material forming the artificial sea bed:

i   Concrete (*ie* the base of the tank);

ii   Empty (wooden) tray;

iii   Sand, flattened;

iv   Gravel (10 mm mean diameter);

and

v   Gravel (20 mm mean diameter).

Figures 8 to 11 represent the time-series of the data collected over the different test runs. It should be emphasised that, during these experiments, all the ambient parameters were retained constant (*ie* water depth, artificial sea bed type, water surface roughness and the relative orientation of the transducer to the seabed); therefore, any variation in the recorded signals should be considered as time-variability within the 'total' system (echo sounder and/or USP RoxAnn). General observations which can be derived from the time series are:

i   the outputs show quite considerable time variability, over record lengths ranging from 11 to 73 mins (at 1 record per second);

ii   some of the records appear to show fluctuations about the mean value, throughout the length of the record and particularly for the E2 signal (Figures 8a, 9 and 10);

iii   a gradual increase or decrease is shown in some of the signal outputs, over the total record length, as exemplified by Figures 9 (E2) and 10 (E1), respectively;

and

iv   in some specific cases, there is an abrupt change (mainly in the E2 signal level) - shown as a reduction on Figure 8b (E2) and an increase on Figure 11 (E2).

Mean E1 and E2 values, for each of the sea bed types, are listed in Table 2. Included also are the number of data points and the standard deviation. The mean is derived on the basis of statistical analysis of the full data set.

Table 2: Mean and standard deviation of E1 and E2 values recorded during the laboratory trials

Bed Type	Data Points (Number)	E1		E2	
		Mean	Standard Deviation	Mean	Standard Deviation
Concrete	1500	0.2126	0.0096	3.6908	0.1294
Tray	690	0.2535	0.0170	2.966	0.2404
Sand	4419	0.2526	0.0094	3.4045	0.3002
Gravel 1	3284	0.2584	0.0133	2.5524	0.0795
Gravel 2	3562	0.3145	0.0097	3.5922	0.1299

The relative locations of different types of artificial sea bed material, on an E1/E2 plot, are shown as Figure 12. Table 2 and Figures 8a, 9 and 10 show there to be only a small amount of variation in the E1 values, for the cases of the sand, tray and 10 mm gravel beds.

In order to understand the way in which E1 and E2 values have been calculated and to explain the variation shown in the time-variable plots (Figures 8 to 11), the envelope of the received signal (echo-train) as created by the head amplifier of the RoxAnn system has been captured and analysed. This envelope is the same as that which is utilised by the system, in the derivation of the hardness (E2) and roughness (E1) indices.

Each plot of signal level against time, shown on Figures 13 to 17, shows the mean and standard deviation of 10 individual signal pulses. The pulses were selected, for inclusion in

the analysis, in such a way as to cover the complete period of data collection during a test run (*ie* approximately every $^1/_{10}$ of the total duration of the experiment).

In general, as would be expected, the signal level of the second echo is lower than that of the first. Exceptions occur with the signal return from the sand and the concrete sea beds. Although the inconsistency in the peak height with the results for the concrete bed (Figure 13) could be explained in terms of multiple reflection, there is no apparent explanation available for an increased second echo for the sandy bed (Figure 15).

The pattern in the variation in the signal level, with time, is consistent with the idealised pattern of the returning echoes associated with the RoxAnn system (Figure 1). Nevertheless, some variation in the signal pattern can be observed.

In all cases where the tray was lowered to the bed of the tank, a peak appears at about 0.7 ms following the first echo. This signal return does not appear in the case of the concrete bed, indicating the possible influence of an additional roughness parameter (for example, the 'elevated' tray edge) on the signal return.

The characteristics of the second echo vary between the different data sets, as follows:

1   a distinct echo is associated with the concrete bed (Fig 13), as might be expected;

2   for the sand and empty tray beds (Figures 14 and 15), the echo shows a gradual exponential decrease in the tail;

3   in the case of the 20 mm gravel (Figure 17), a complex echo is present - consisting of a distinctive initial peak, separated from the tail by a marked low;

whilst

4   for the 10 mm gravel (Figure 16), the initial peak of the second echo appears to be depressed or attenuated.

The observed standard deviations in the first echo (Figures 13, 14, 15 and 16), even in the case of a concrete bed, may result from:

(a)   the output and received signal of the echo-sounder;

and/or

(b)   the stability of the head amplifier of the RoxAnn system, responsible for the creation of the recorded echo-train associated with the sea bed features.

Other characteristics of the time-variable outputs, which can be related to the signal level outputs, are the abrupt increase in the mean E2 values. In this particular case, the increase occurs after approximately 2300 records (Figure 11). In an attempt to explain this, a series of envelopes of the received signal have been analysed - 5 associated with the record before the jump (Figure 18b), with 5 after the change (Figure 18a). The data are summarised, in terms of mean values, on Figure 19.

On Figure 19, the increase in the E2 value (see Figure 11) can be seen to be associated directly with an increase in the signal level of the tail of the second echo, for no apparent reason. This pattern means that the change has not been introduced as the result of analyses of the envelope, carried out by the analogue board of the USP RoxAnn system to determine E1 and E2 values, but could be attributable to variability in the output and received signal of the echo-sounder (see above).

It should be noted also that the observed increase in the signal level of the second echo is associated with a decrease in the signal level of the first echo. This 'leakage' of energy may confirm the previous interpretation of the feature.

The mean envelope of this return echo train has been used also for an *independent* calculation of the E1 and E2 values, respectively. The relative hardness and roughness of each material

is compared then below with the relative hardness and roughness, as defined by the E1 and E2 values estimated internally by the RoxAnn system.

The E1 value

The E1 value is the integral of the tail of the first echo and indicates the roughness of the sea bed. The procedure for the calculation of E1 from the mean envelope is shown schematically on Figure 20. The derived E1 values are shown in Table 3:

Table 3: **E1 values for different test-runs as they have been derived by integration of the captured mean return echo envelope (see text)**

Sea Bed Type	E1 (Arbitrary Units Vs
Tray	1.32
Concrete	3.69
Sand	2.97
Gravel (10 mm)	4.29
Gravel (20 mm)	3.53

Using the values presented in Table 3 the relative roughness of the materials, in ascending order is: empty tray - sand - gravel (20 mm) - concrete - gravel (10 mm). Using the E1 values derived, for comparison, by RoxAnn: it is concrete - sand - empty tray - gravel (10 mm) - gravel (20 mm).

The disagreement in the relative order between the two sets of E1 values may be due to the different approaches used, in defining the start and the end of the tail of the signal.

The relative roughness provided by the RoxAnn analysis is in agreement with the simplified hypothesis that the coarser the particles of sediment, the rougher the surface (for flat bed

areas). The empty tray appears, however, to be rougher than sand; this apparent anomaly could be due to the roughness introduced to the signal from the walls (sides) of the tray. When the tray is filled with sand, this particular roughness element becomes less influential on the total signal.

The E2 Value

By definition, the E2 value represents the whole of the area beneath the trace of the second echo in the signal return. For an independent estimation of E2, the integral of the mean envelope of the second echo was calculated. Four different integral limits (times) were used for this estimation: 13.5 ms - 20 ms; 13.5 ms - 18 ms; 13.5 ms - 17 ms; 13.5 ms - 16 ms.

This procedure has permitted the sensitivity of the E2 value to be examined on the basis of the length of the integral of the second echo. The derived E2 values are shown in Table 4

Table 4: Estimated E2 values, for various integration limits, over different sea bed types

'Sea bed' type	INTEGRATION INTERVALS (E2 Values)			
	13.5-20ms	13.5-18ms	13.5-17ms	13.5-16ms
1 Concrete	16.50	15.59	15.01	13.72
2 Empty tray	12.83	12.00	11.51	10.17
3 Gravel (10 mm)	10.89	8.85	7.61	5.17
4 Gravel (20 mm)	17.11	14.79	13.44	10.59
5 Sand	14.99	13.45	12.72	10.72

The relative hardness of the materials used in the trials are listed below for each case, in ascending order.

13.5-20: gravel (10 mm)-empty tray-sand-concrete-gravel (20 mm)

13.5-18: gravel (10 mm)-empty tray-sand-gravel (20 mm)-concrete

13.5-17: gravel (10 mm)-empty tray-sand-gravel (20 mm)-concrete

13.5-16: gravel (10 mm)-empty tray-gravel (20 mm)-sand-concrete

The comparable relative hardness, as estimated by the RoxAnn system is: empty tray - sand - gravel (10 mm) - gravel (20 mm) - concrete.

Disagreement between the relative order, based on the RoxAnn E2 values and those calculated independently from the mean envelopes, must be due to the different approach employed by the RoxAnn software in the calculation of the E2 values. The classification based on the RoxAnn values agrees, however, with the hypothesis that concrete is the harder material. Gravel is also a 'hard' material, but its porosity makes it acoustically 'softer' than concrete. In general, the finer-grained the particles, the greater the porosity; therefore, the acoustic characteristics will be softer.

4.2 Response to Variations in Water Depth

Data relating to the response of the systems to changes in water depth fall into two categories:

(*i*)   qualitative observations, obtained during the use of the system from fixed platforms; and

(*ii*)   quantitative measurements of E1 and E2, collected by lowering the transducer (from a vessel) towards the sea bed.

During the deployment of the RoxAnn system from the fixed platforms at Bournemouth and the Oceanography Department's Shoreside Facility, the minimum and maximum operating water depths were approximately 3 m and 5 m, respectively. On the occasion of these tests, the signal response of the RoxAnn (at both frequencies) was found to be highly variable.

Such shallow depths are consistent with the limits described by the manufacturers; these could represent, therefore, the limit of operation of the system.

A series of measurements (consisting of 114 to 213 data points) were collected and made available to the authors (Murphy, personal communication) at 6 different mean levels above the seabed, representing water depths ranging from 2.7 to 31 m (Table 5). The mean E1 and E2 values, together with their standard deviations, are plotted against depth above the sea bed on Figure 21. Information on the nature of the seabed has not been made available to the authors for this particular experiment. Nevertheless, it is understood that the ship was stationary at the time of the measurements; consequently, no variation in the nature of the sea bed and its characteristics occurred during the course of the experiment.

The results (Figure 21) appear to indicate that there is a depth-dependence in both the E1 and E2 values, down to 15 m and 10 m, respectively. Closer to the seabed, there is an abrupt increase in the E1 values at around 10 m and a more general increase in E2 below this level above the sea bed.

For the particular instrument settings and output considered here, the E1 and E2 values appear to be somewhat stable for various water depths above the bed; they range from 0.040 to 0.032 for 31 m to 10 m and 0.040 to 0.047 for 15 m to 2 m, for E1 and E2 respectively. These results appear to indicate variation in the stability of the E1 and E2 signals, in relation to height above the seabed. The steepness of the gradient of the upper part of the E2 measurements (Figure 21) may give some cause for concern in the subsequent interpretation of field observations (see Section 4.3).

Points	Height (m)	E1		E2	
		Mean	σ	Mean	σ
153	31.00	0.0404	0.0019	0.0716	0.0066
213	20.30	0.0330	0.0046	0.0506	0.0023
199	15.25	0.0317	0.0038	0.0415	0.0035
140	9.91	0.0352	0.0052	0.0404	0.0019
138	5.13	0.0526	0.0044	0.0435	0.0048
114	2.66	0.0633	0.0053	0.0469	0.0046

TABLE 5. Mean and Standard Deviation (σ) of E1 and E2 values, obtained at different heights above the sea bed during an MOD trial.

The results presented above demonstrate some degree of depth-dependence in the System, with temporal fluctuations superimposed (as expressed through the standard deviations of the signal outputs).

4.3 Response to variations in sea bed types

RoxAnn measurements were obtained over various sea bed types in Southampton Water / the East Solent and Portland Harbour. Spatial changes in the ships position, during these surveys, are shown on Figures 4 and 5, respectively.

The bed types covered by the first of these surveys included: mud, well-sorted sands, and a mud-sand admixture with some shell (gravel-sized) material present (Figure 7 and Plates 2 and 3). In addition, an attempt was made to examine the response of the system to the furrows (elongated linear features) present in the cohesive muds of the East Solent.

Within Portland Harbour, the sea bed type consisted essentially of mud, with varying proportions of shell fragments (identified in the grain size analyses, as 'gravel-sized' material).

Mean and standard deviation in the E1 and E2 outputs, together with their intercorrelations for all the experimental sites, are listed in Table 6.

Table 6: Mean and standard deviation of E1 and E2 values for the field trials (the correlation coefficient (R) between the two parameters is also shown)

Low Frequency (28 KHz)

	E1		E2		R
LOCATION	MEAN	SD	MEAN	SD	
Bird Pile (mud)	0.175	0.037	3.237	0.611	-0.21
West Knoll (sand)	0.141	0.009	0.562	0.062	0.58
Castle Point (mixed)	0.168	0.068	1.413	0.511	0.19
Furrows (cohesive mud)	0.228	0.047	1.976	0.853	0.28

High Frequency (200 KHz)

	E1		E2		R
LOCATION	MEAN	SD	MEAN	SD	
Bird Pile (mud)	0.153	0.006	0.213	0.049	0.13
West Knoll (Sand)	0.117	0.021	0.653	0.086	-0.20
Castle Point (mixed)	0.282	0.067	1.110	0.342	0.66
Portland (mixed with shell)	0.085	0.072	0.337	0.098	0.81

Table 7: Correlation coefficient (R) between E1, E2 values and depth, for the field trials

LOW FREQUENCY (28 KHz)

LOCATION	R (E1/Depth)	R (E2/Depth)
Bird Pile (mud)	-0.509	-0.257
West Knoll (Sand	-0.035	0.001
Castle Point (mixed)	-0.282	0.710
Furrows (cohesive mud)	-0.123	-0.586

HIGH FREQUENCY (200 KHz)

LOCATION	R (E1/Depth)	R (E2/Depth)
Bird Pile (mud)	0.024	0.185
West Knoll (sand)	0.303	-0.466
Castle Point (mixed)	0.006	0.386
Portland (mixed with shells)	0.215	0.505

At the Bird Pile (mud) site, the vessel was anchored in shallow waters, as indicated by the constant depth readings (Note: differences in the recorded water depths, at 28 KHz and 200 KHz, can be attributed to variation in the sea bed response to the high and low signal frequencies). For the high frequency recordings, the E1 value ranged from 0.14 to 0.17; comparable E2 values ranged from 0.08 to 0.41 (Figure 22). At low frequency, the corresponding E1 and E2 ranges were 0.13 to 0.58 and 1.76 to 4.86, respectively (Figure 23). In the case of the low frequency transducer, the E2 value appeared to fluctuate with time. Measurements using the high frequency source seemed to take some time to stabilise, then remain relatively constant. In both cases, the E1 values remained relatively constant. Although no explanation is available to explain the temporal fluctuation in E1 and E2, the E2 values may be an indication of sub-bottom penetration. As such, small movements in the

ship's position (see Fig 4) may cause variations in the magnitude of the second echo of the received signal.

High variability in the E2 records, compared to E1, is consistent with the results of the tank test (see Section 4.1). Data interpretation, should be considered however, in relation to the shallow water depths present over the area (see Section 4.2).

Over the West Knoll (sand) site, only small changes in water depth were recorded (Figures 24 and 25). The E1 and E2 values, at low frequency, seem to respond to these changes (Figure 25). The depth dependence is not so clear for the data obtained using the high frequency transducer (Figure 24). For these high frequency recordings, the E1 ranged from 0.10 to 0.21; E2 ranged from 0.40 to 1.03. At low frequency, the corresponding E1 and E2 ranges were 0.12 to 0.17 and 0.37 to 0.71, respectively. There appears to be negative correlation between the indices and water depth; this is in agreement with previous studies (Voulgaris and Collins, 1990), but contrasts to the static tests carried out as part of the present investigation (see Figure 21, Section 4.2). Nevertheless, the analysis of water depth dependence described here is based on the assumption that there is no spatial variability in sea bed type.

For the mixed sediment location at Castle Point, where the sea bed consisted of sand and mud with a high proportion (approximately 50%) of shelly material, the high frequency data were collected over an extended area in comparison to the low frequency observations (Fig 4). The high frequency E1 and E2 values shown a marked peakedness, with E1 varying from 0.2 to 0.5 and E2 from 0.54 to 1.78. On occasions, these coincide with water depth variations; on others, the sets of peaks appear to be displaced (Figure 26).

The corresponding low frequency ranges are 0.07 to 0.3 for E1 and 0.58 to 2.49 for E2. The E2 values are positively correlated with water depth, whereas E1 follows the same general pattern with time inversions (Figure 27).

During the survey carried out over the furrows in the cohesive estuarine muds, only the low frequency source was used. E1 values ranged from 0.13 to 0.36 and E2 from 0.39 to 3.49. In the data presented (Figure 28), it should be noted that the major changes in water depth are associated with the main navigation channel. The influence of the furrows *might* be detectable in the shallow water records (although the speed of the vessel and the data logging rate might preclude their accurate representation by the RoxAnn system). Overall, therefore, the data sets are inconclusive - although abrupt changes in E1 and E2 values can be seen to correlate with changes in water depth.

At Portland Harbour, the sea bed consisted of muds with small proportions of sand (>1% to 10%) and varying amounts of shell fragments (0% to 35%). Ignoring the initial part of the record, where the instrumentation appeared to be stabilising (Figure 29), E1 ranged from 0.02 to 0.2 and E2 from 0.2 to 0.65. Once again, as with the earlier results, it is difficult to associate directly changes in the signal outputs to water depth. Any variations could be due either to depth variations or to different shell fragment contents of the bottom sediments (see Figure 7b).

The mean and standard deviations in E1 and E2, from the different sea bed types and the two frequencies used, are summarised on Figure 30. Unfortunately, these values show little comparison with those obtained from the controlled laboratory investigations (Fig 12). Such differences could be related to a number of factors (*ie* a limited sediment layer thickness in the tank, water depth, multiple reflections *etc*), emphasising the difficulty in obtaining and comparing quantitative output from the RoxAnn system.

5 CONCLUSIONS - RECOMMENDATIONS

This investigation has been concerned with the following aspects of an evaluation of the RoxAnn system for sea bed discrimination:

(*i*)   examination of the temporal stability of the output, through its installation on shoreline structures;

(*ii*)   static tank tests, involving different sizes of sea bed material (a preliminary assessment); and

(*iii*)   comparative field studies, examining various sea bed types and small-scale morphological features.

In addition, data have been made available from an MoD trial - when the transducer, connected to the RoxAnn, was lowered to the sea bed.

On the basis of these laboratory and field measurements, conclusions concerning the use of the system (for sea bed discrimination) can be summarised under the following main headings:

(*a*)   controlled laboratory investigations;

(*b*)   response to variations in water depth;

and

(*c*)   response to variations in sea bed types.

General observations from the laboratory (tank) tests, based on analyses of time-series of E1 and E2 values showed: time variability, over record lengths of 11 to 73 minutes;

fluctuations about a mean value; and either an unexplained gradual increase or decrease, or abrupt changes, in the signal level. The observed abrupt changes could be explained in terms of the use of either: (a) the processor used in the RoxAnn system; and/or (b) instability in the output signal, in terms of its amplitude, of the commercially-available echosounder.

The laboratory data sets have been used also to simulate the derivation of roughness (E1) and hardness (E2) indices, in accordance with the procedure adopted in the USP RoxAnn system, on the basis of the analysis of the captured raw signal. The results demonstrate an inconsistency between the relative ranking of the various sea bed types, in terms of their roughness and hardness, between the two analytical approaches. The relative roughness provided by the RoxAnn analysis is, however, in general agreement with the simplified hypothesis that coarse-grained particles are associated with greater roughness. The effect of modifying the integration time of the raw signal, in the computation of the hardness index, has been examined in terms of values derived using the RoxAnn system. Although results based on the analysis of the raw signal show some degree of consistency, relative hardness values differ from those defined by the RoxAnn analysis. The order presented by the RoxAnn system would appear to be, however, a more realistic approximation. This phase of the investigation, whilst generating a series of relative values, has confirmed our general lack of understanding of the signal processing procedure being used within the RoxAnn unit.

The laboratory tank tests, described above, were carried out in water depths of around 5 m; unfortunately, this is close to the limit of operation of the system, as described by the manufacturers. Other experiments, designed to examine the response of the system to changes in water depth, have demonstrated some degree of depth dependence. Such a depth dependence has been shown in some of the records collected during the field trials, but the relationship between the indices and water depth appear to change for different source frequencies. Interpretation of the data set collected in Southampton Water and the East

Solent is complicated further by the fact that variations in water depth coincide possibly with some spatial variability in sediment type. This factor, combined with the conclusion that the sub-bottom penetration is different for the high and low frequency sources (see, for example, Figure 30), makes this particular data set difficult to explain. Likewise, any attempt to compare the results of these field trials with previous ones from Bigbury Bay is frustrated by the different calibration settings and type of RoxAnn system used. Such changes in the system configuration have led to the derivation of E1 and E2 values of a different order of magnitude, between the two data sets but representative of similar sea bed types (*eg* sand).

The results described above are, regrettably, inconclusive for the following reasons:

- during the field measurement programme, there was insufficient control on water depth or sediment type (it is not clear that this could even be controlled using an anchored vessel);

- in the tank tests, although water depth and sediment type remained constant, the system was operating in a water depth close to its operational limit;

- for both the controlled laboratory and field experiments, a fundamental lack of understanding of the way in which the analytical technique is applied to the signal return imposes severe limitations to the data analysis and interpretation.

Some suggestions for future research programmes, in the use of the USP RoxAnn system for sea bed discrimination, are outlined below. As revealed by the tank tests, temporal variability in the RoxAnn output occurs even when other conditions remain constant; this could be due to instability in the RoxAnn system itself or in the output signal from the echosounder. Hence, the following should be considered:

(a)   RoxAnn instability might be investigated, in the laboratory, through the use of a controlled input signal (*ie* computer simulated);

(b)   Investigations are required into the output stability (signal length and amplitude) of echosounders, used in association with RoxAnn - or the development of a new echosounder could be considered. Commercially-available echosounders have been developed for the accurate measurement of signal return times, which are subsequently converted into water depths. This approach requires signal stability within the time domain, whilst the RoxAnn system requires *also* a stable output in terms of power (signal amplitude).

(c)   Alternatively (to (b)), the RoxAnn system could be developed further such that the pulse emitted from the echosounder should be integrated with into the RoxAnn signal capture facilities. These data could then be used subsequently to 'normalise' the E1 and E2 values, to facilitate comparisons to be made between information collected using different instrumental set-ups and to compensate for any source instability.

Overall, it is recommended that the above research areas should be addressed prior to any further extensive fieldwork, where several interrelated factors combine to complicate the interpretation/discrimination of the sea bed.

6 ACKNOWLEDGEMENTS

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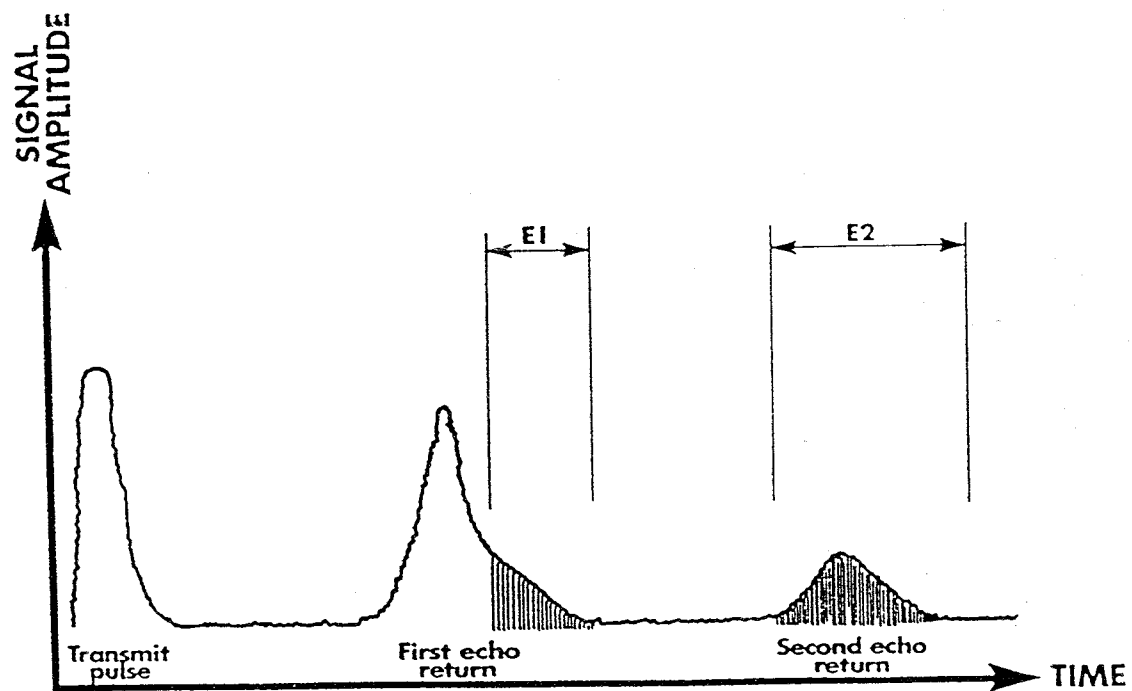
Figure 1   The parts of the return signal integrated by USP (from Emerson et al, 1990)
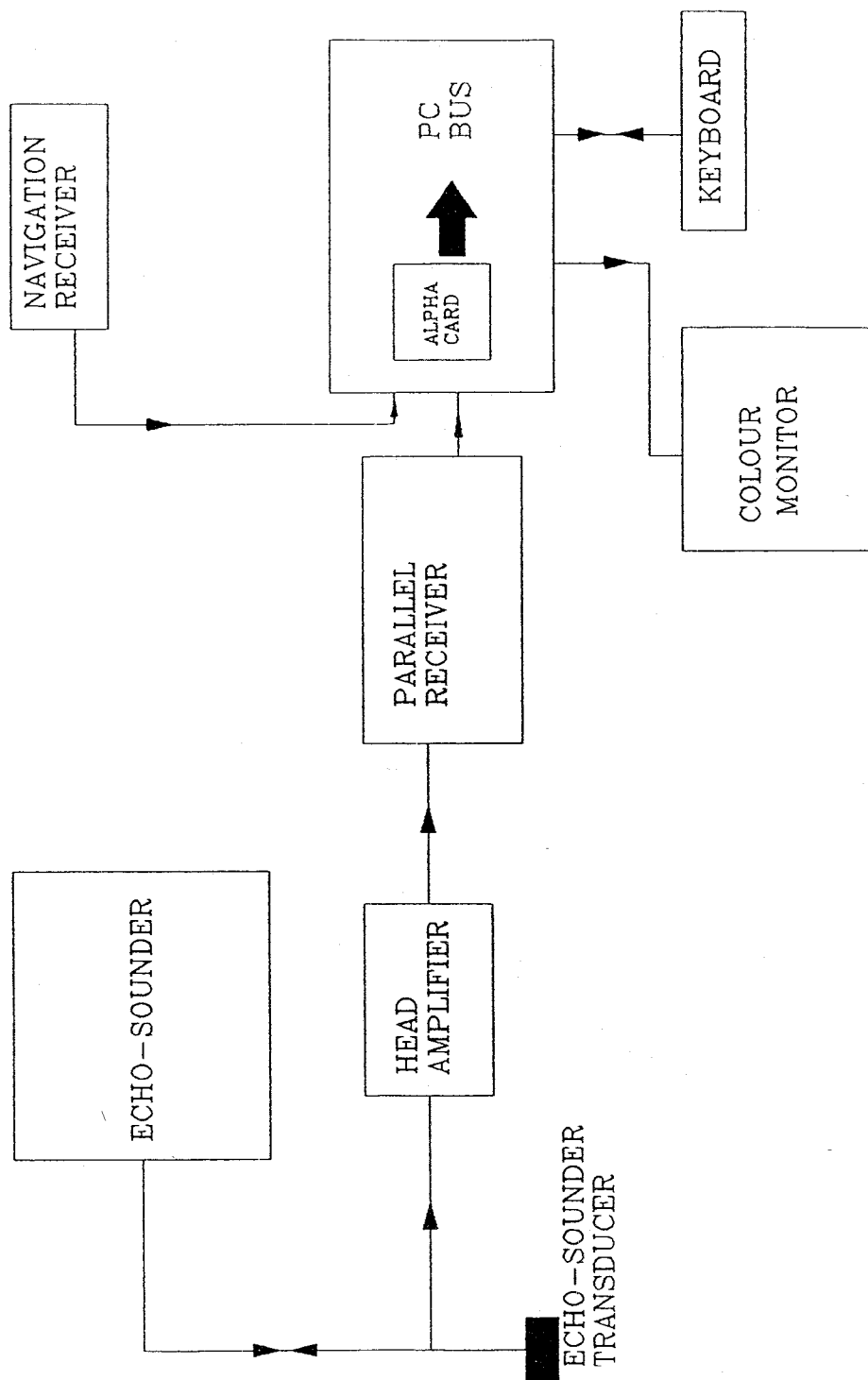
Figure 2   Schematic diagram of the USP RoxAnn seabed discrimination system (from Chivers et al, 1990).
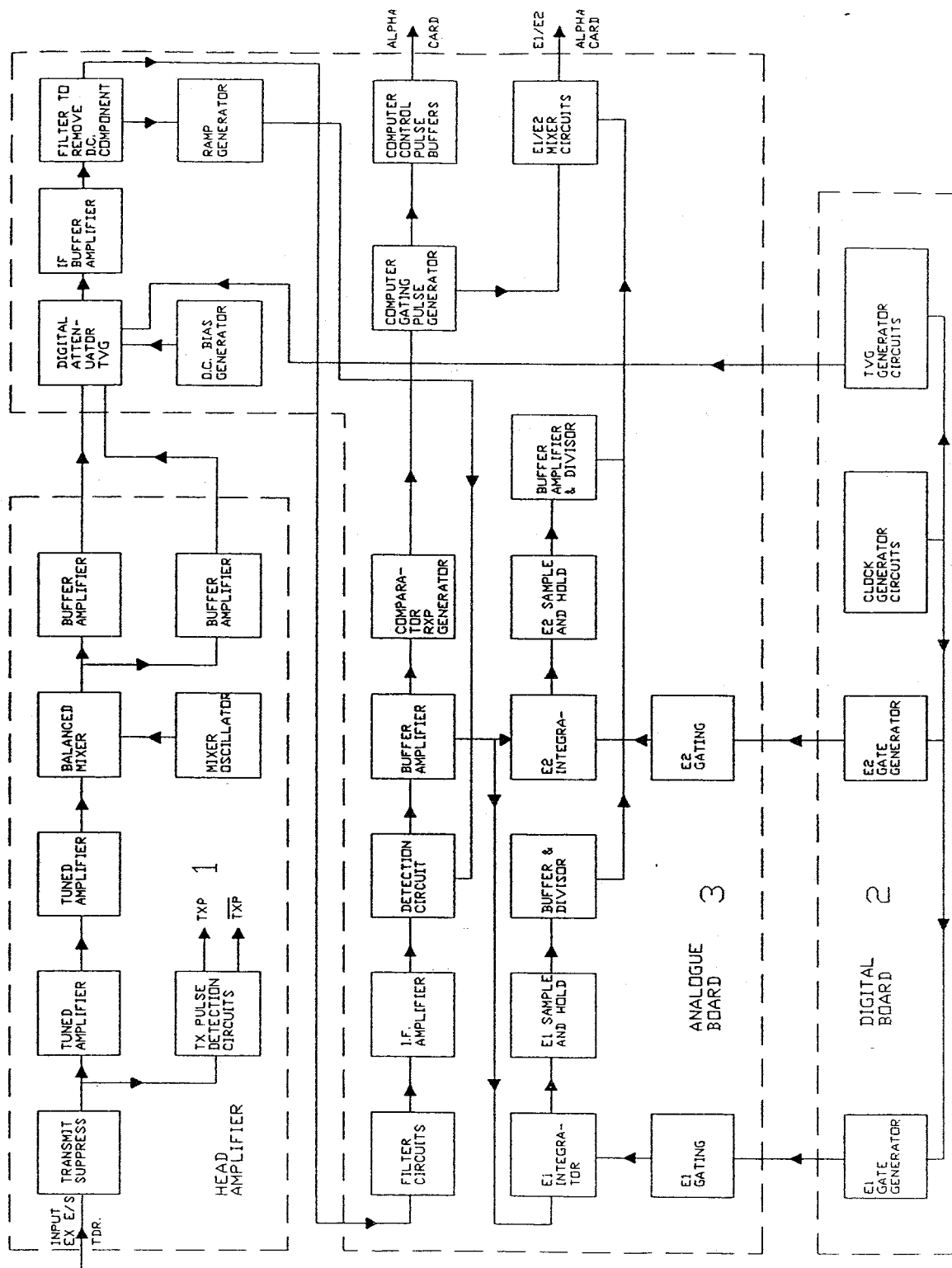
Figure 3   Block diagram of USP RoxAnn electronics circuitry.

FURROW AREA SURVEY (28 kHz)

200m

1 km

BIRD
PILE

SOUTHAMPTON WATER

SITE 2 (--- 200 kHz, — 28 kHz)

100m

SITE 1 (--- 200 kHz, — 28 kHz)

100m

● CASTLE POINT

SITE 3 (--- 200 kHz, — 28 kHz)

100m

● WEST KNOLL
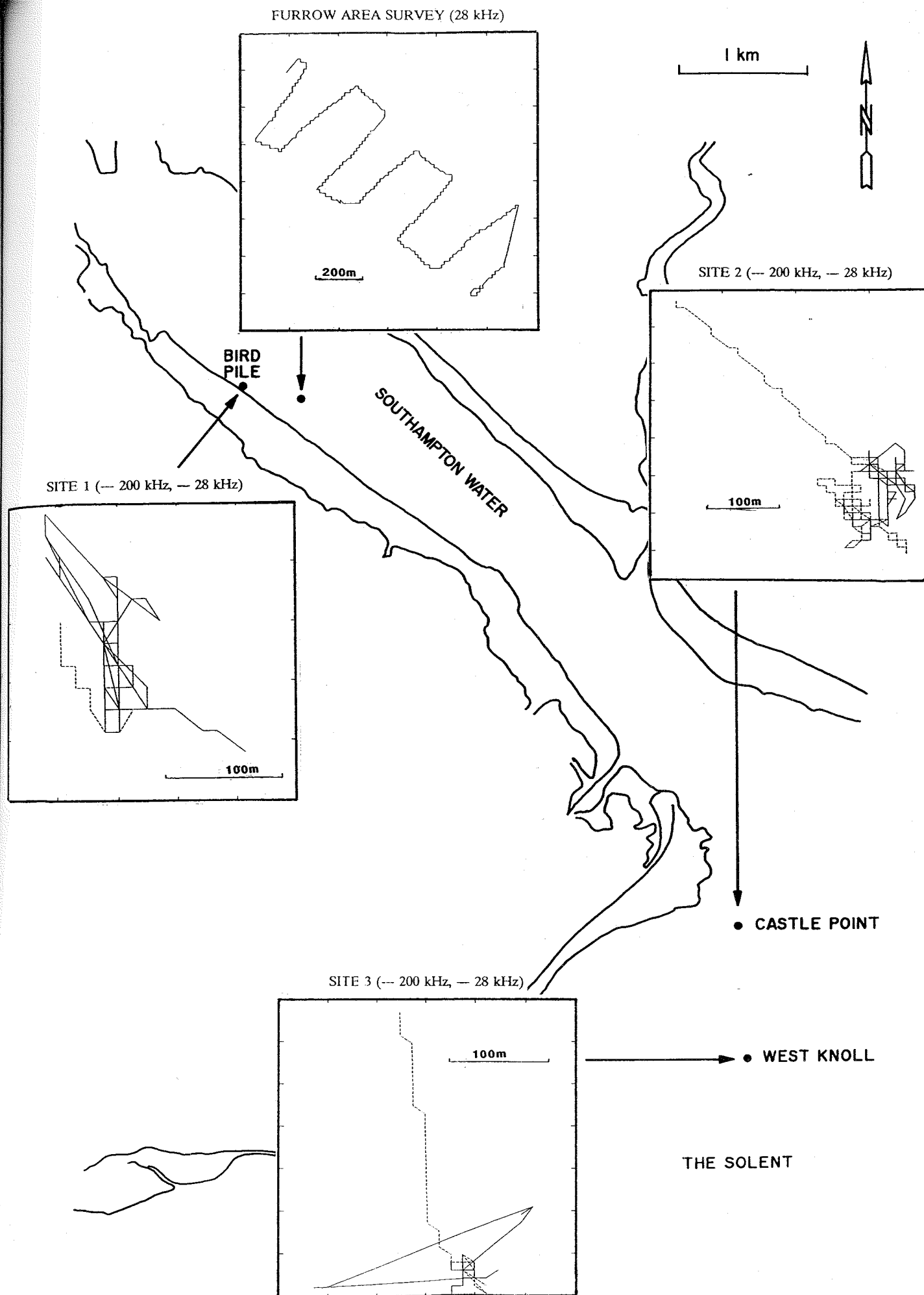
THE SOLENT

Figure 4   Location and ship tracks at the Southampton Water / Solent field
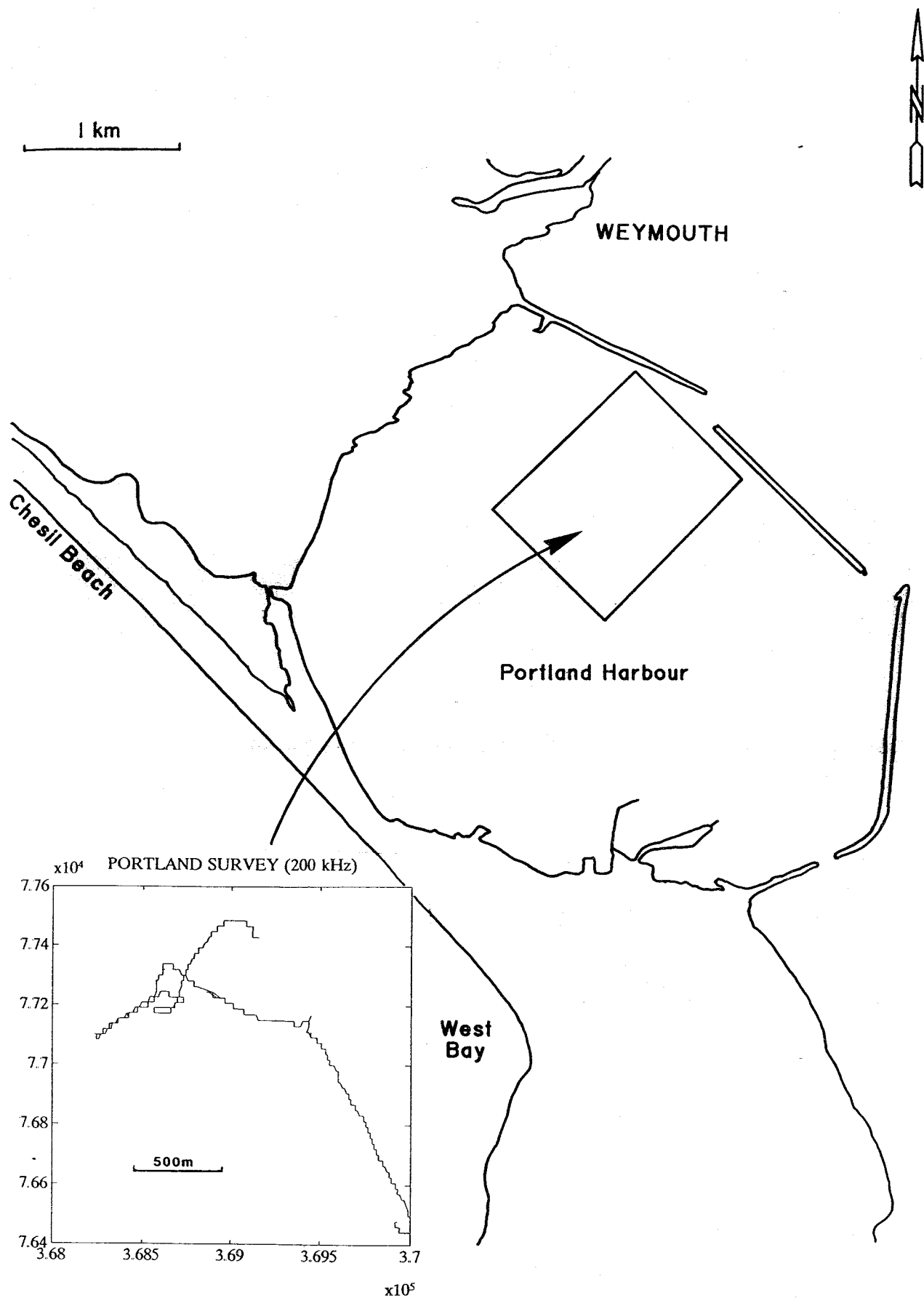
Figure 5   Location and survey track of Portland Harbour field trial.

PC COMPUTER

OSCILLOSCOPE

HEAD
AMPLIFIER

ROXANN

ECHO SOUNDER

DATA COLLECTION SYSTEM

TRANSDUCER

TANK TEST LAYOUT

USP-ROXANN

GROUND DISCRIMINATION SYSTEM
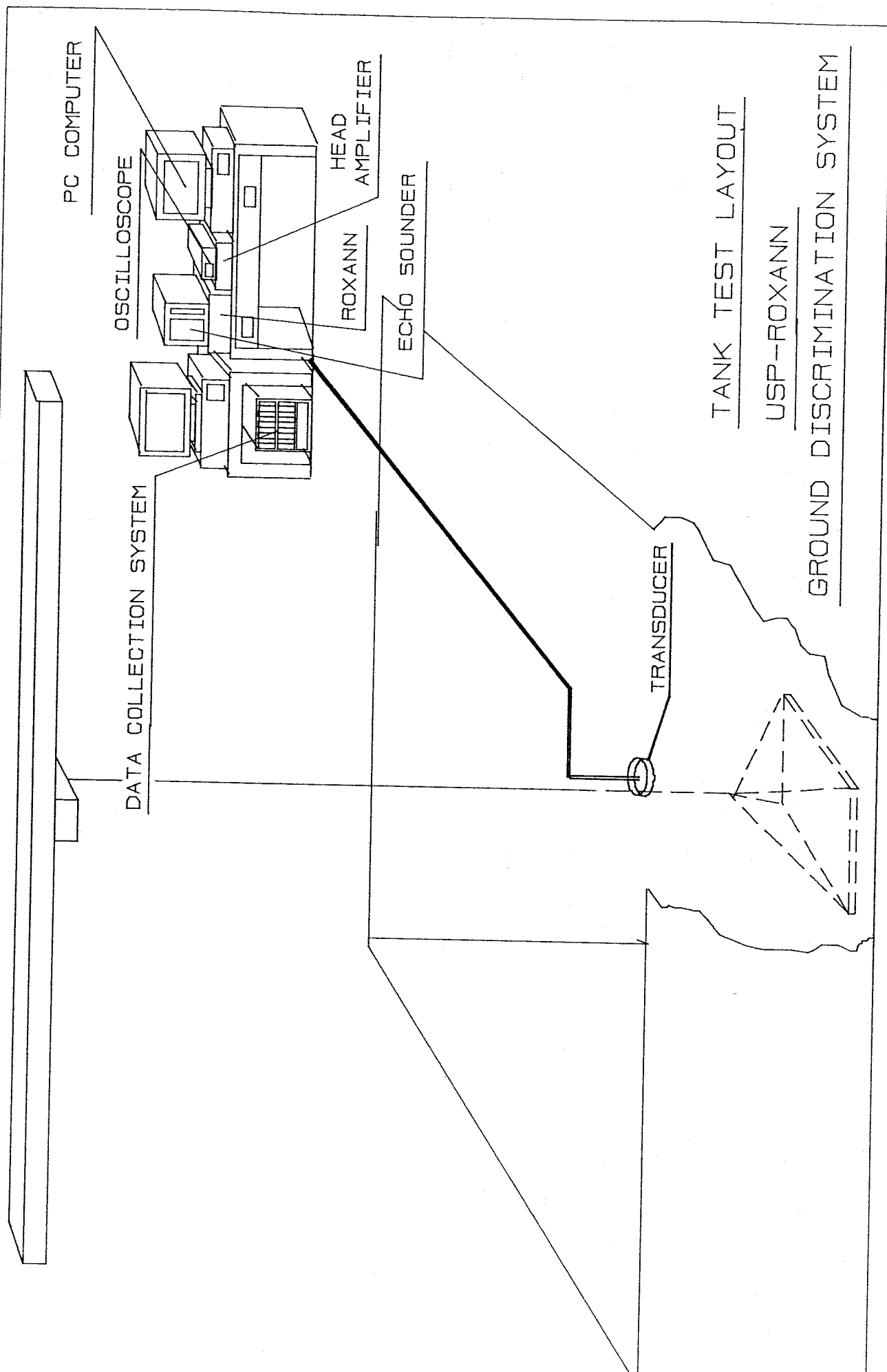
Figure 6   Laboratory (tank) experimental set-up.
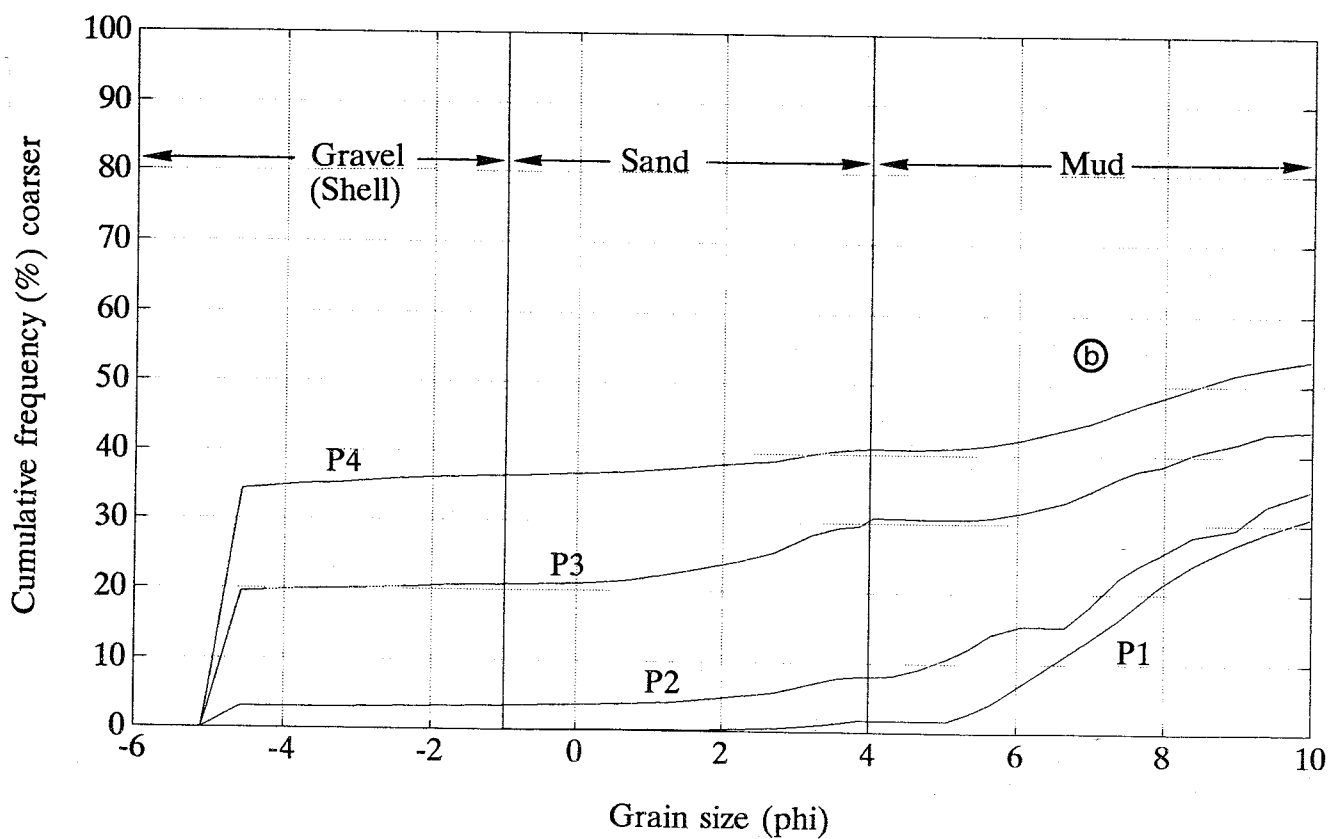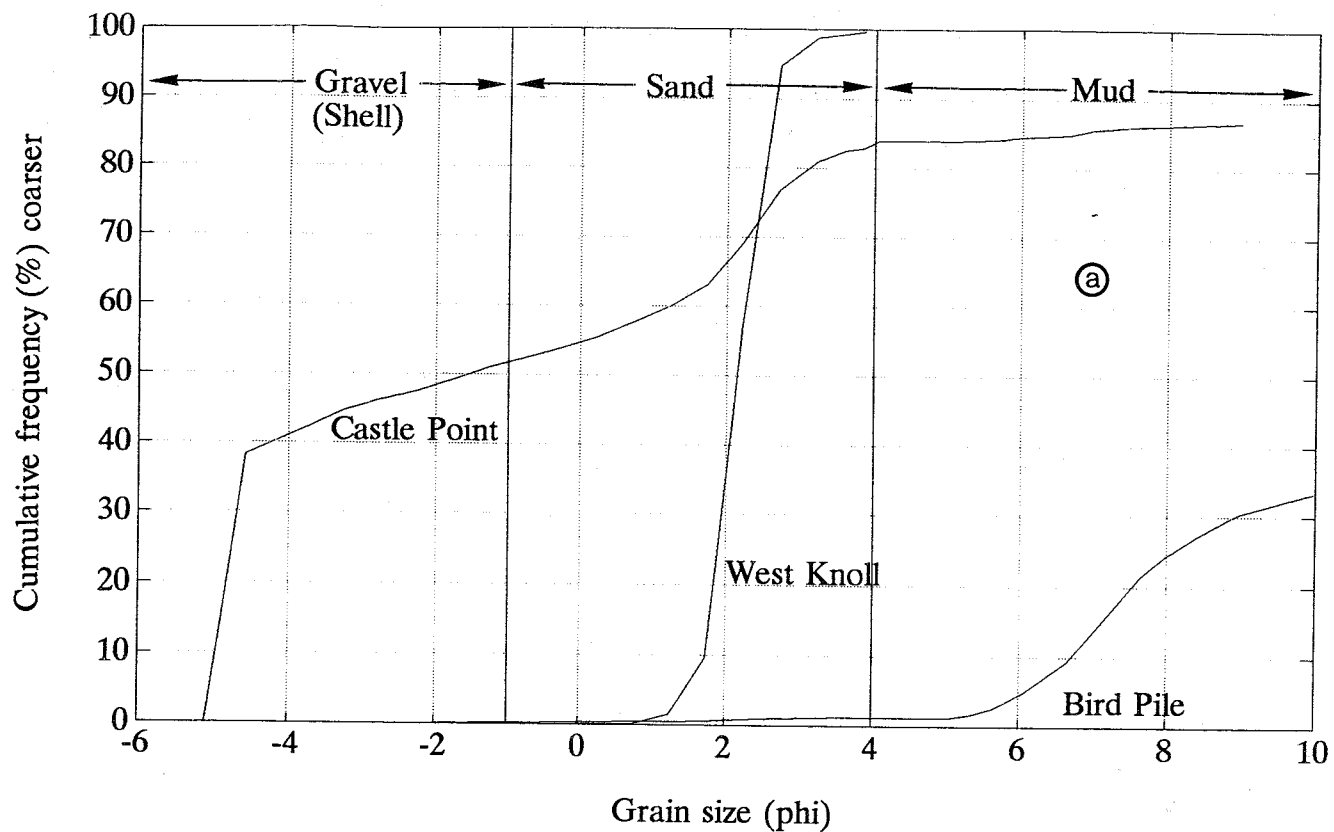
Figure 7   Particle size distribution of the sediment samples from:
(a) Castle Point, West Knoll and Bird Pile; and
(b) Portland Harbour (P1 to P4).
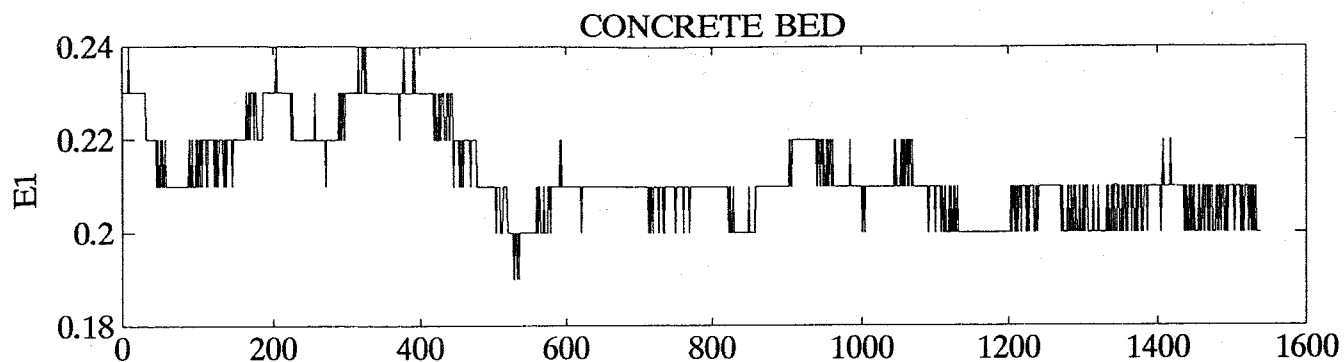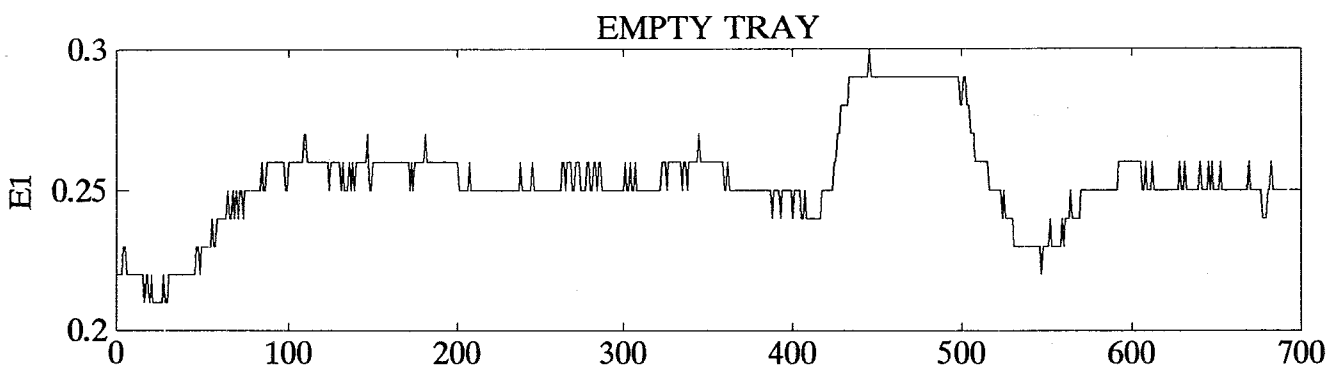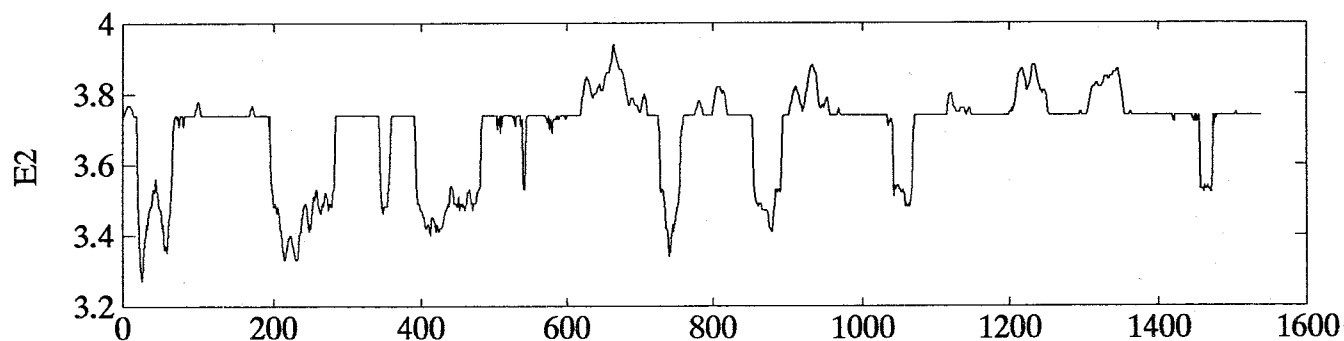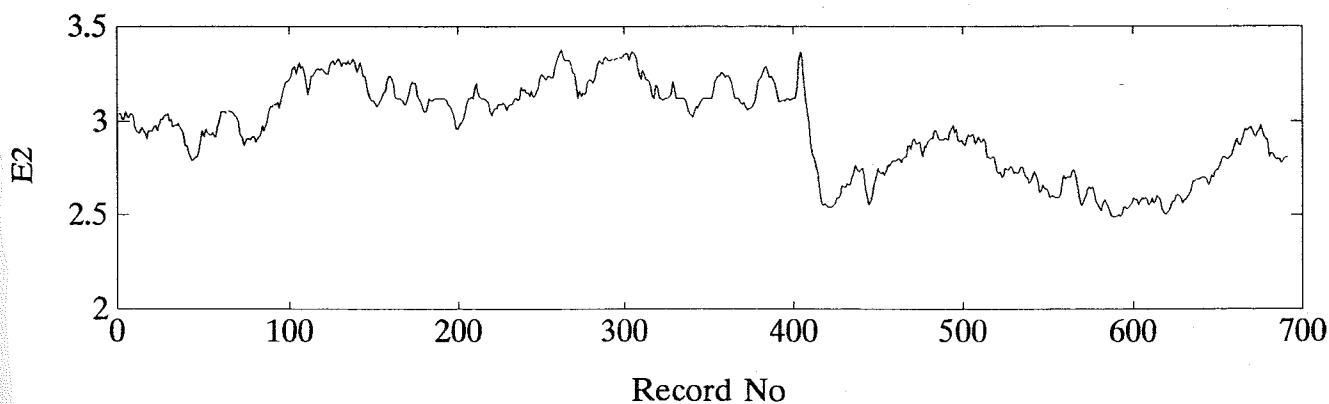
Figure 8   Time-series of E1 and E2 values collected over: (a) the concrete base of the tank; and (b) the empty wooden tray (1 record per second).
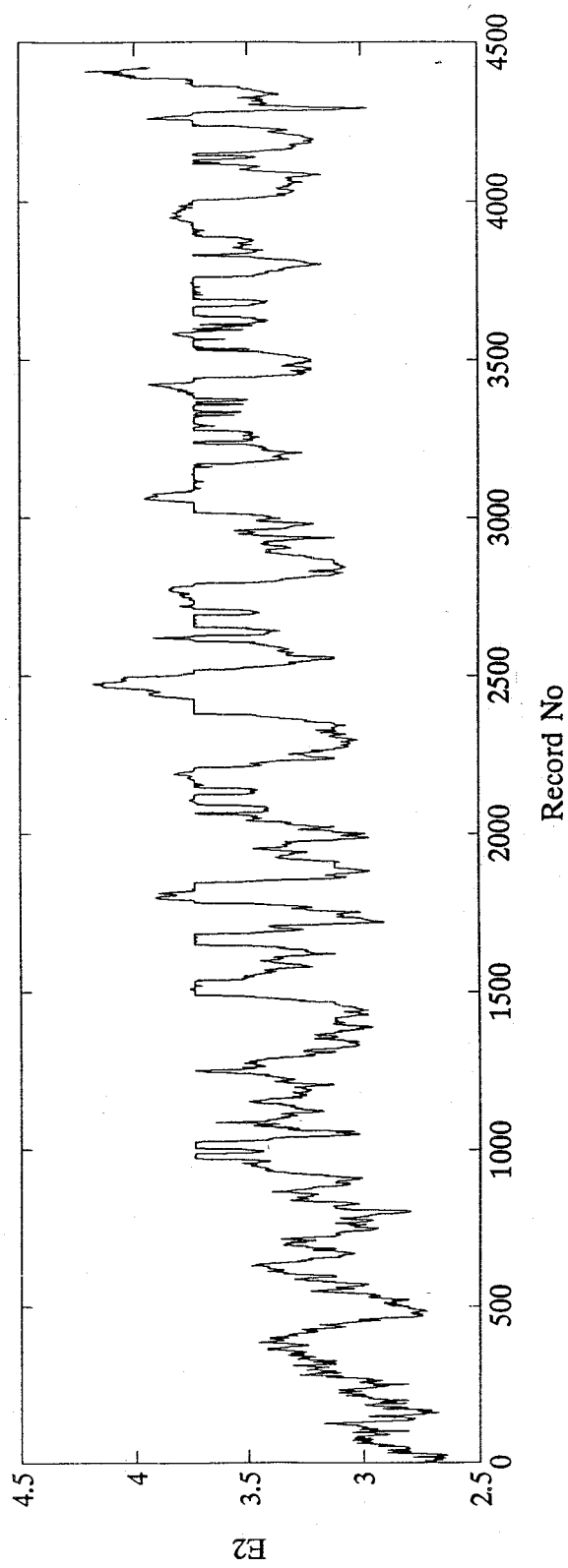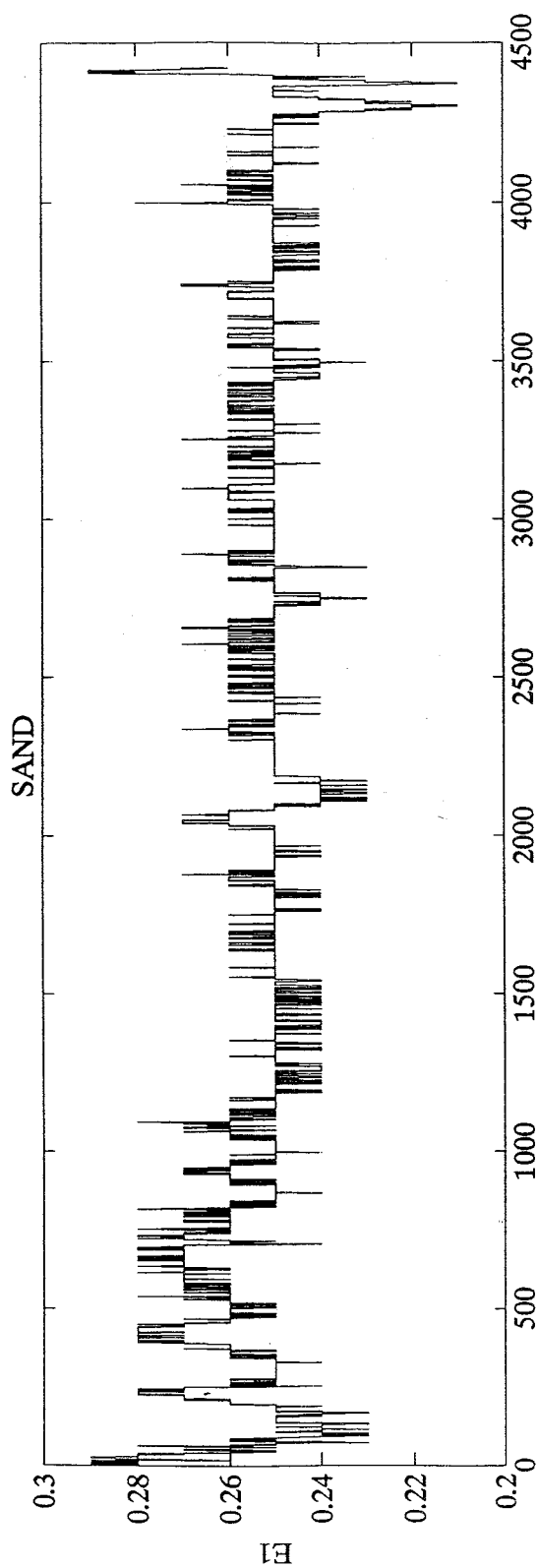
Figure 9   Time-series of E1 and E2 values collected over a flat sandy
artificial bed (1 record per second).
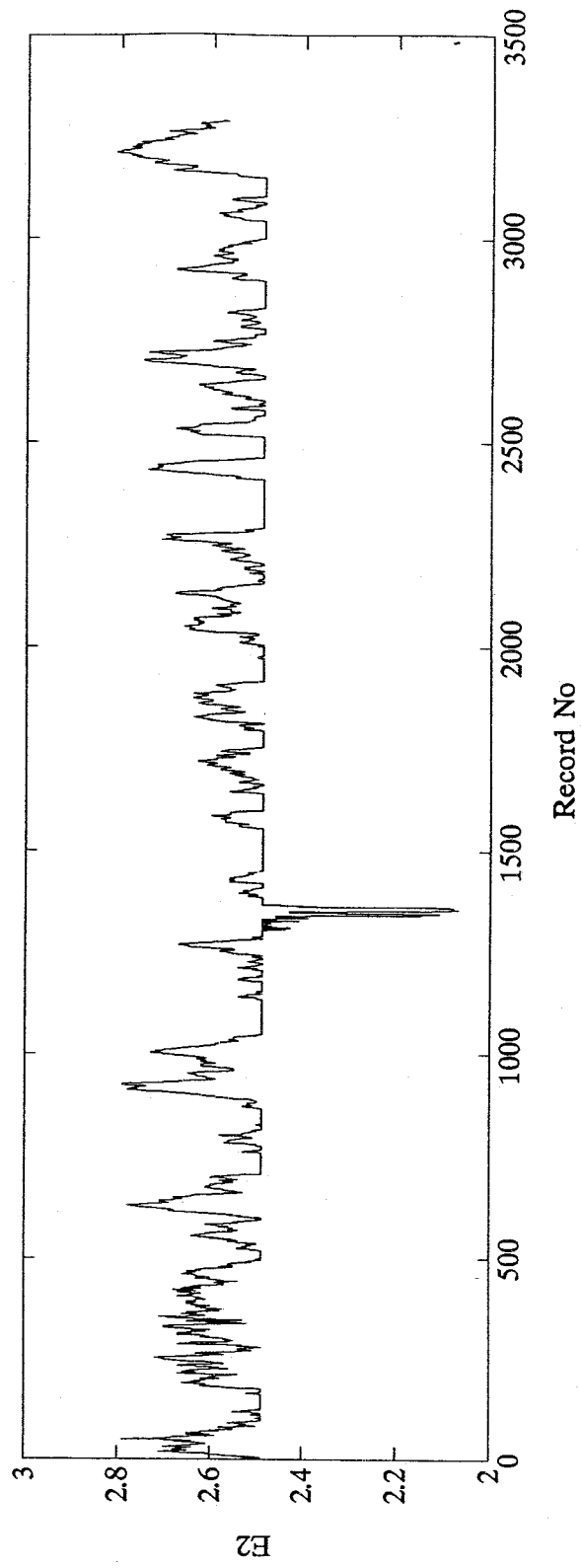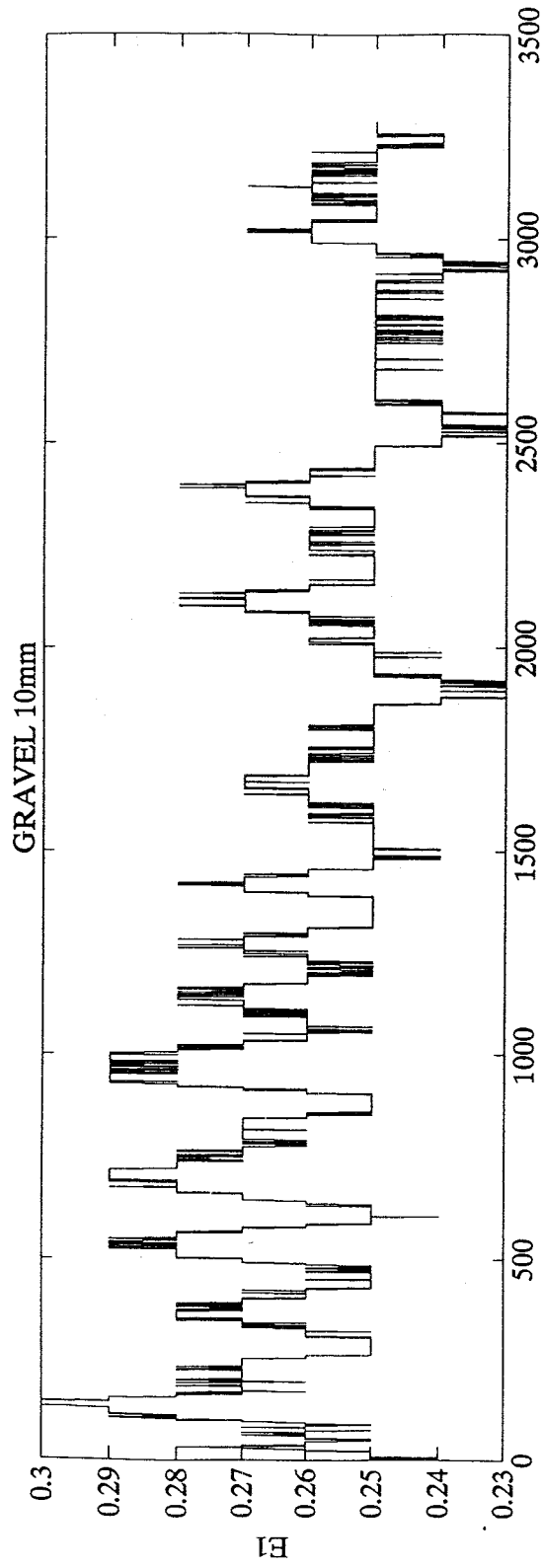
Figure 10   Time-series of E1 and E2 values collected over a gravel (10 mm mean diameter) bed (1 record per second).
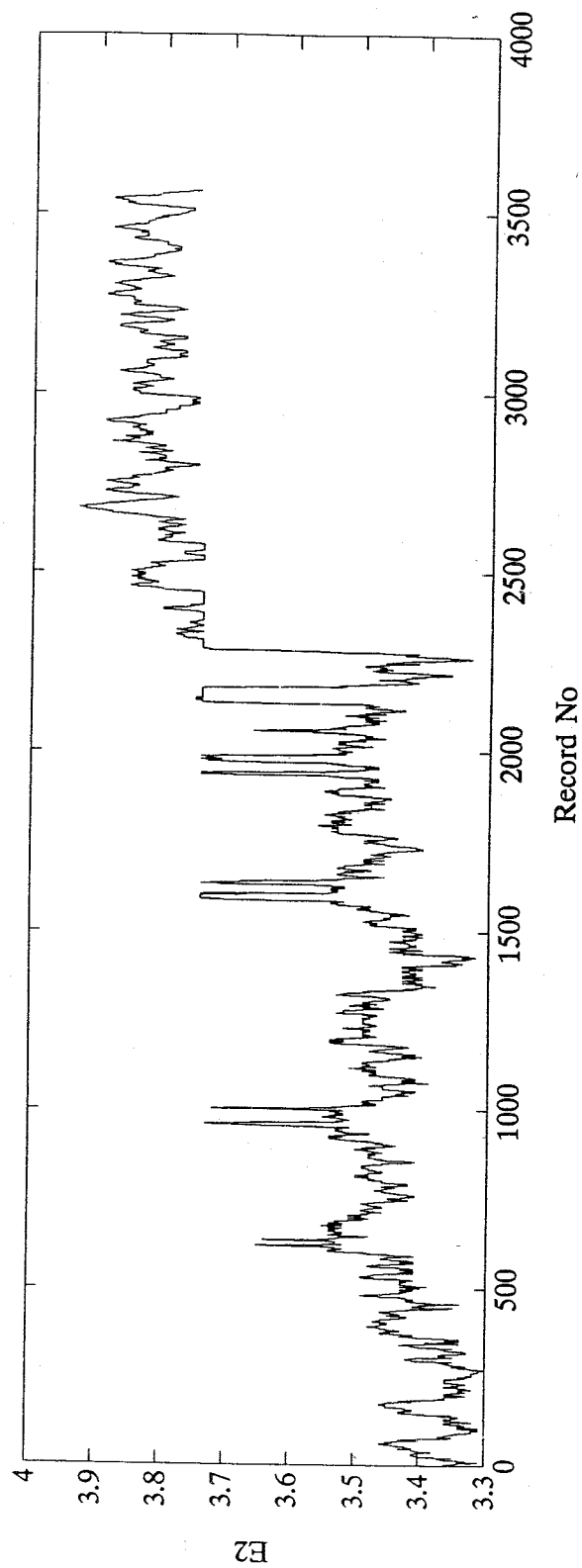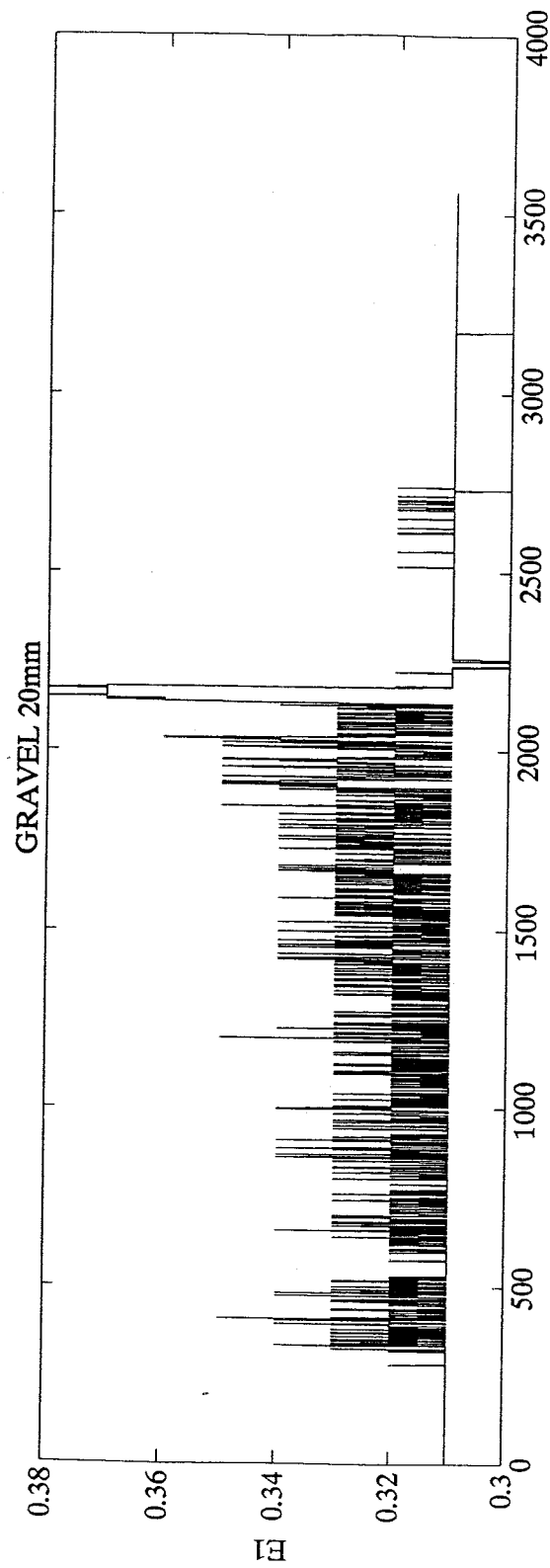
Figure 11   Time-series of E1 and E2 values collected over a gravel (20 mm mean diameter) bed (1 record per second).
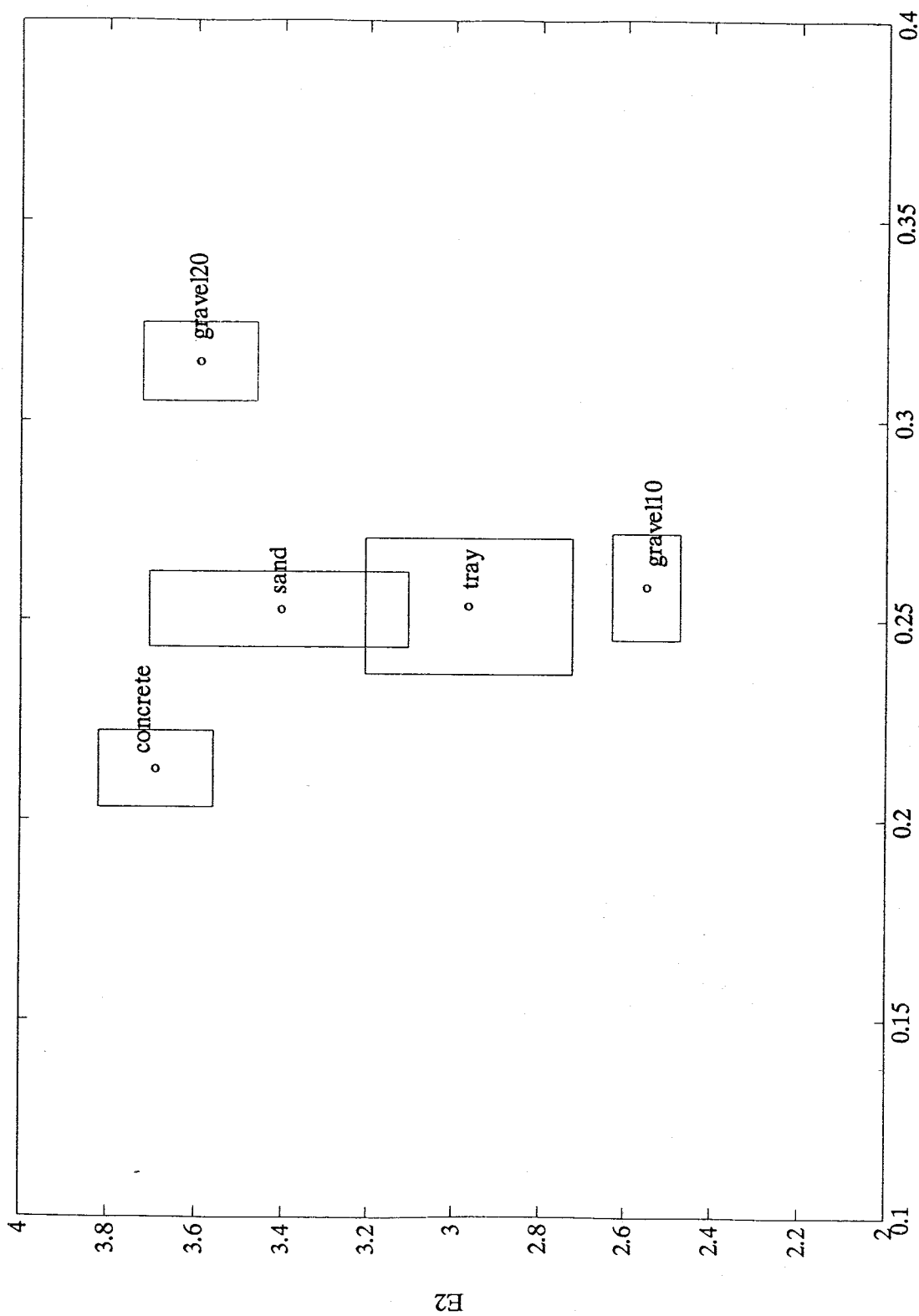
Figure 12   E1/E2 boxes for different artificial beds during tank trials (the sides of the boxes are defined from the mean value ± the standard deviation).
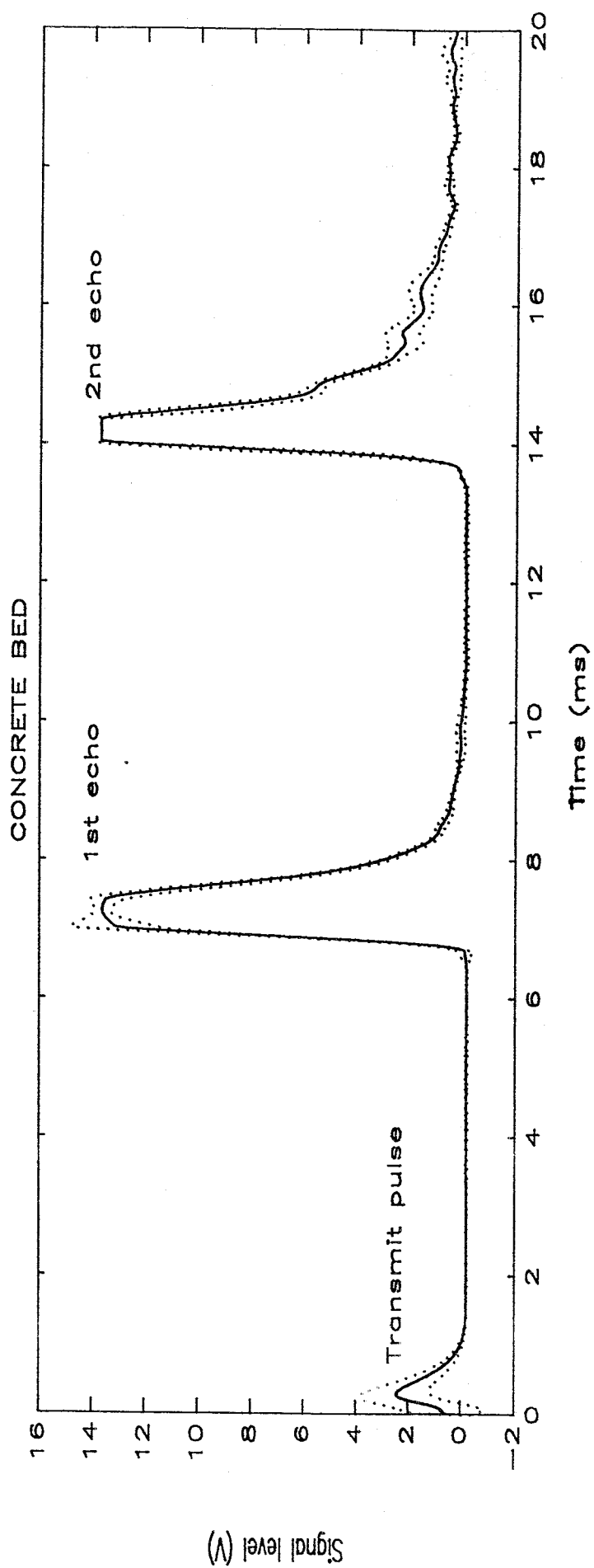
Figure 13   Mean and standard deviation of the envelope of the return echo, during tests over concrete bed (average of 10 signals).
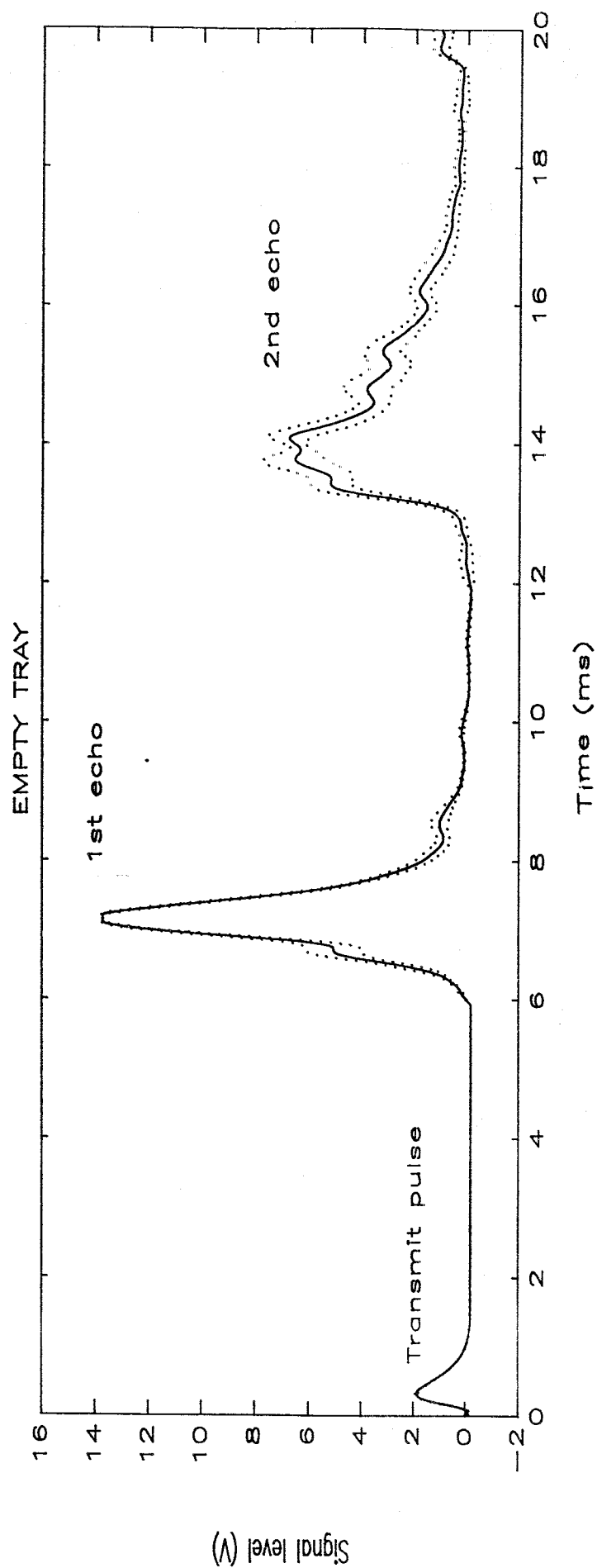
Figure 14   Mean and standard deviation of the envelope of the return echo, during tests over the empty (wooden) tray (average of 10 signals).
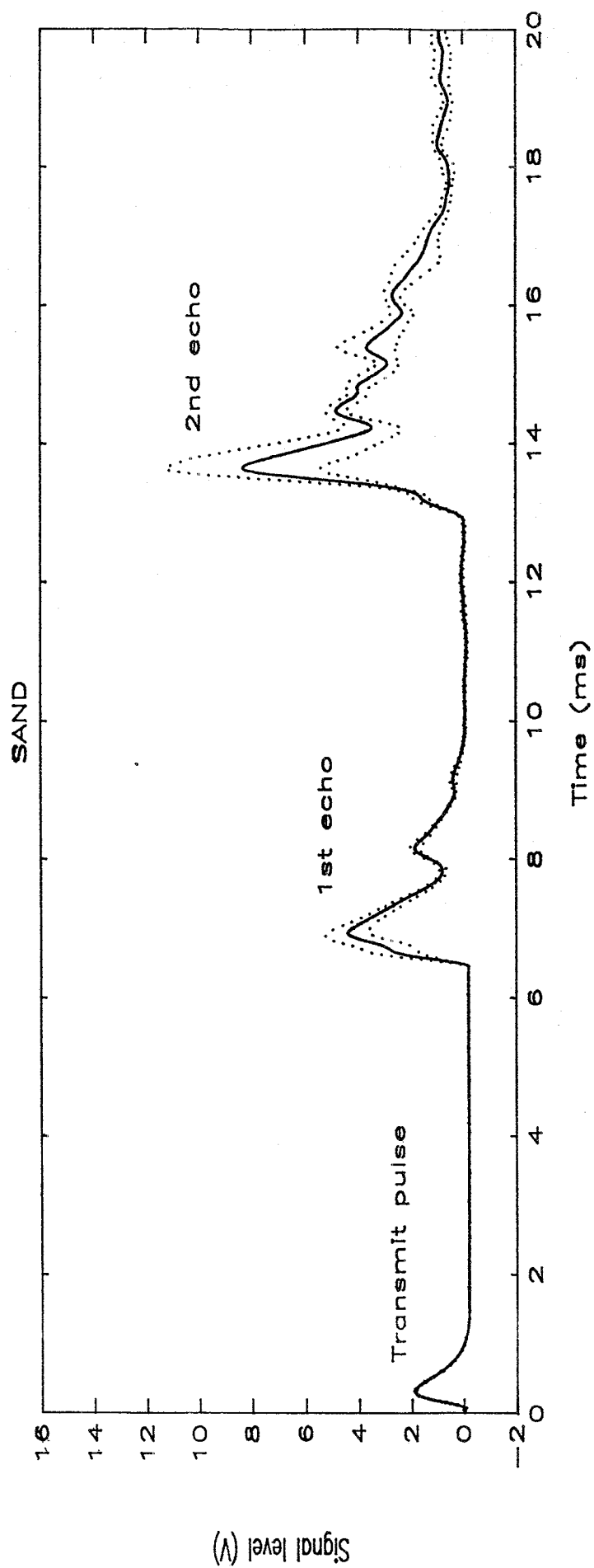
Figure 15   Mean and standard deviation of the envelope of the return echo, during tests over sand (average of 10 signals).
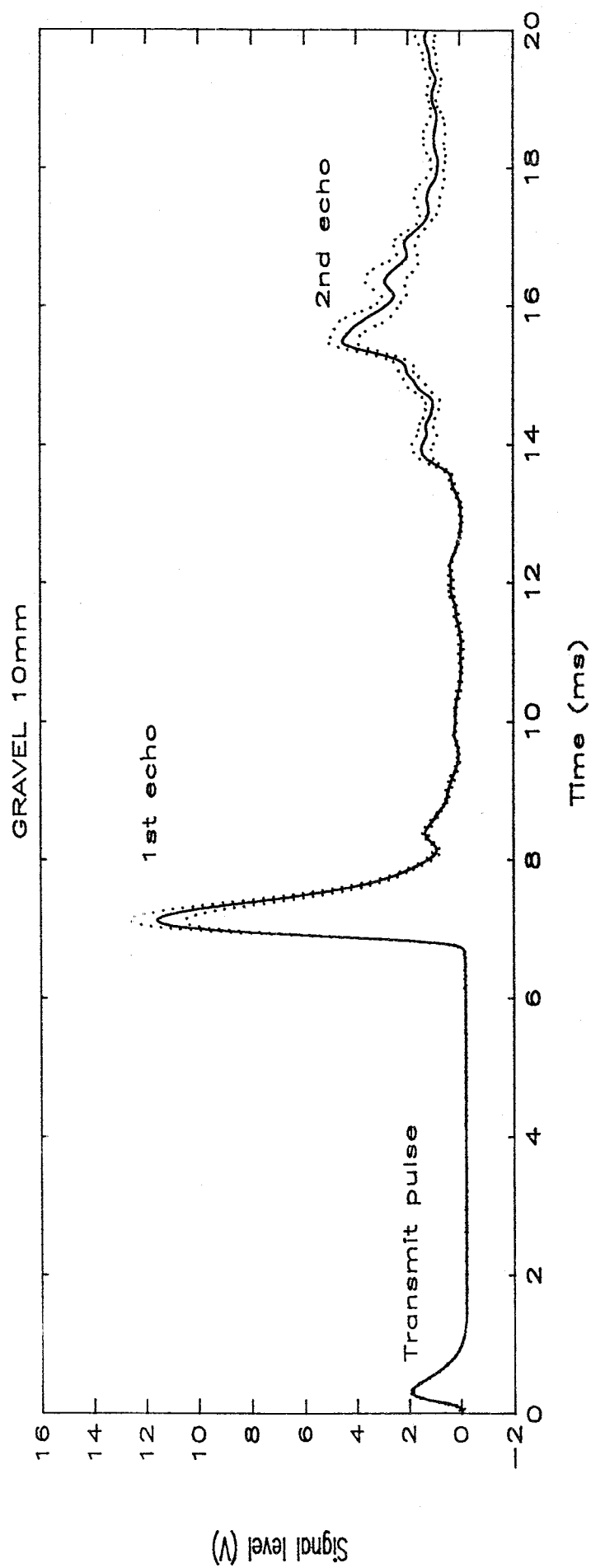
Figure 16   Mean and standard deviation of the envelope of the return echo, during tests over gravel (10 mm mean diameter) (average of 10 signals).
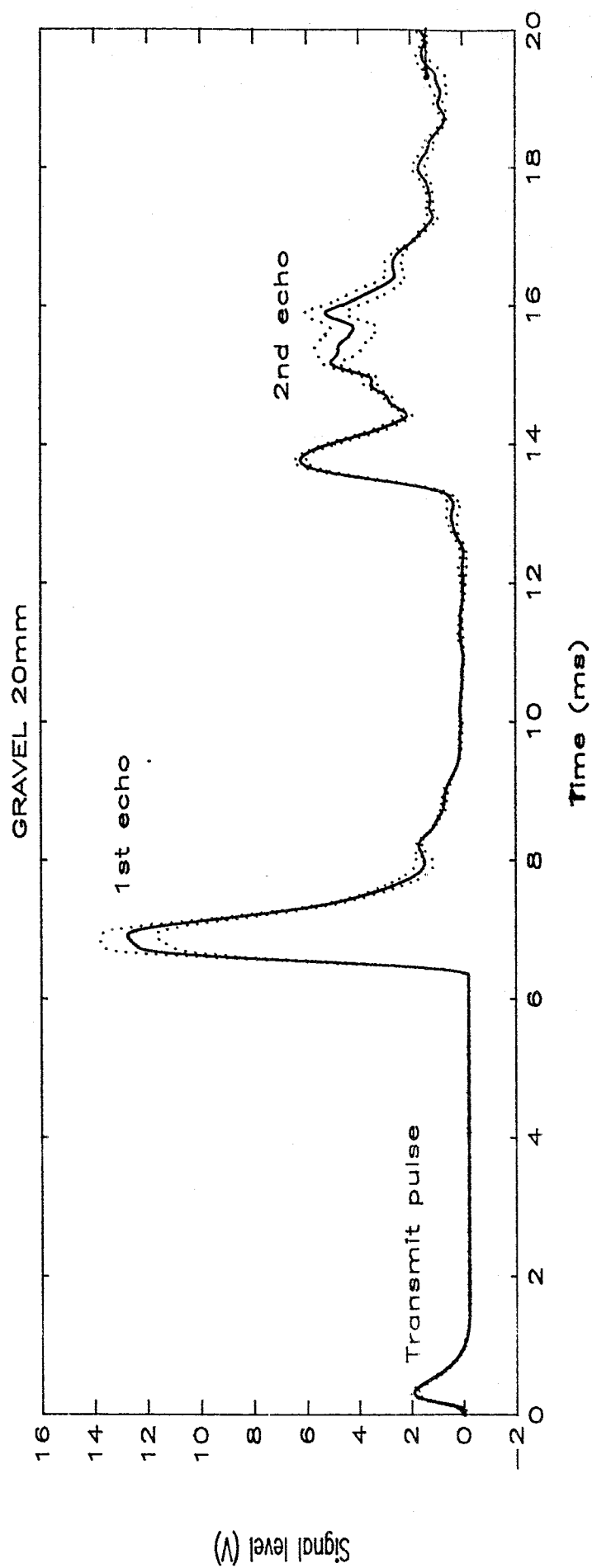
GRAVEL 20mm

Figure 17   Mean and standard deviation of the envelope of the return echo, during tests over gravel (20 mm mean diameter) (average of 10 signals).
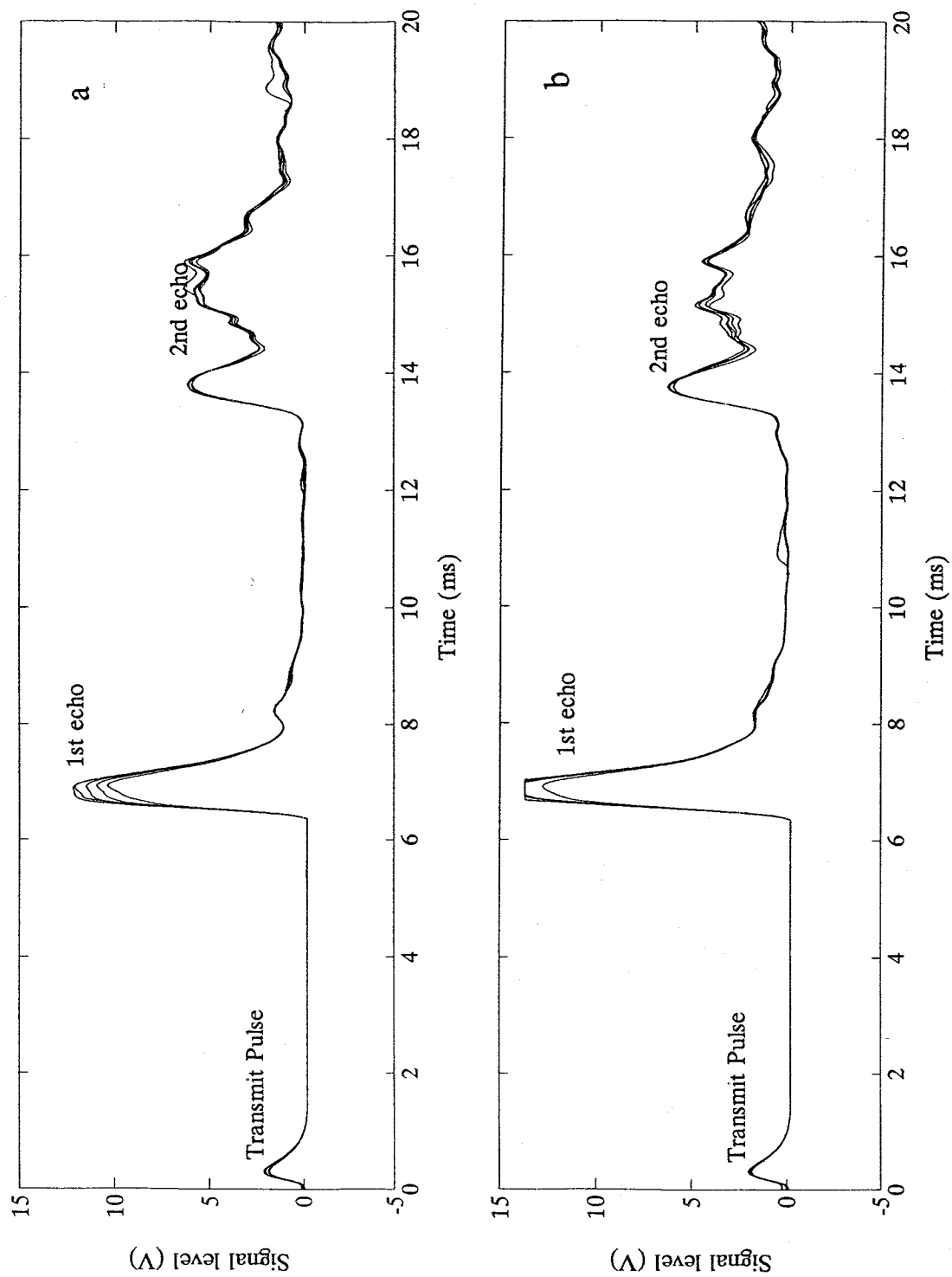
Figure 18   Envelopes of return echo from the tank trial over gravel (20 mm mean diameter). Signals corresponding to the period (a) after and (b) before record No 2300 (see Figure 11).
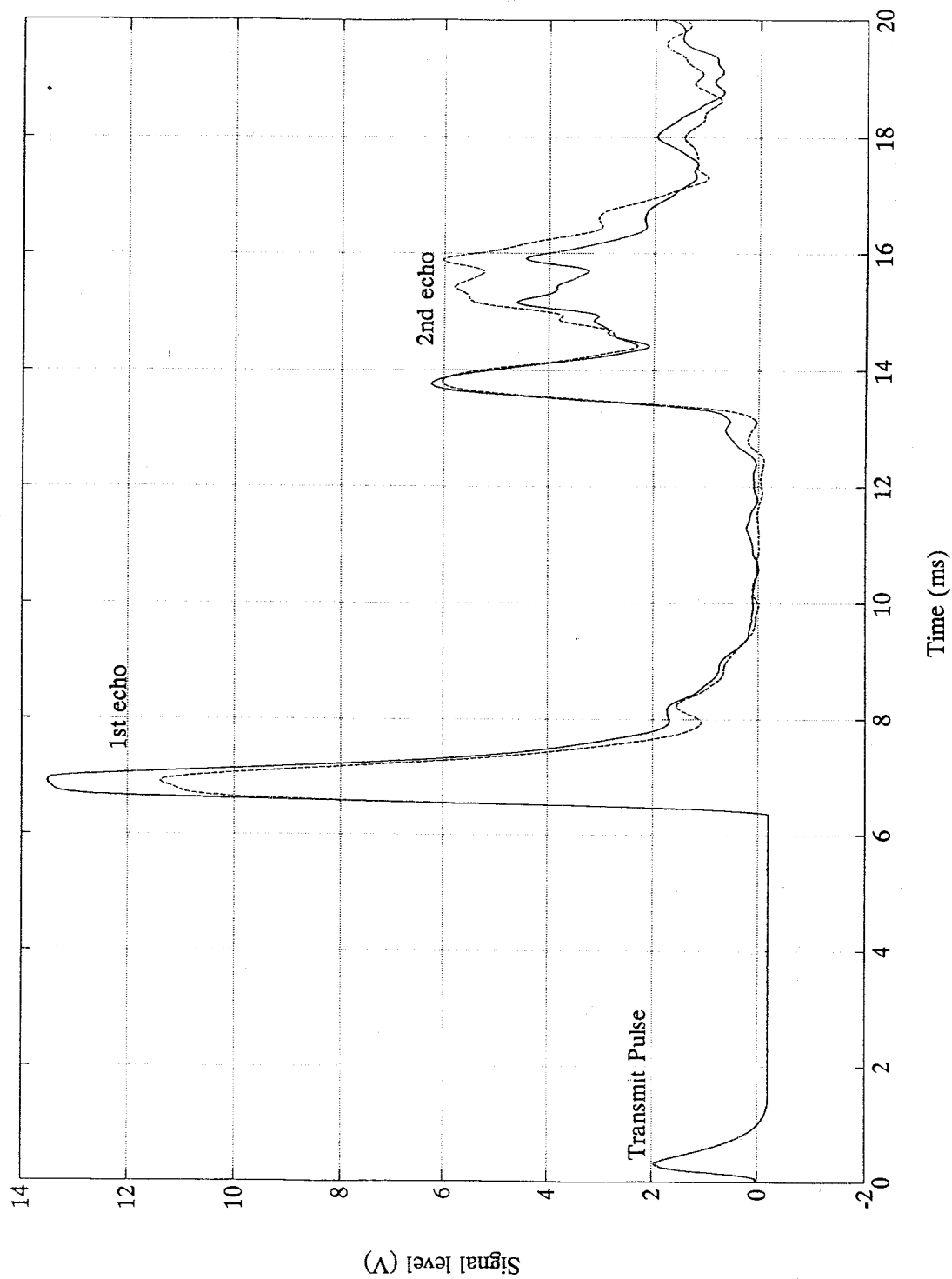
Figure 19   Mean envelopes of return echo for the test trial over gravel (20 mm mean diameter, Figure 11). Solid line corresponds to the period before record No 2300, whilst dashed line coresponds to the period after record No 2300 (see Figure 11).
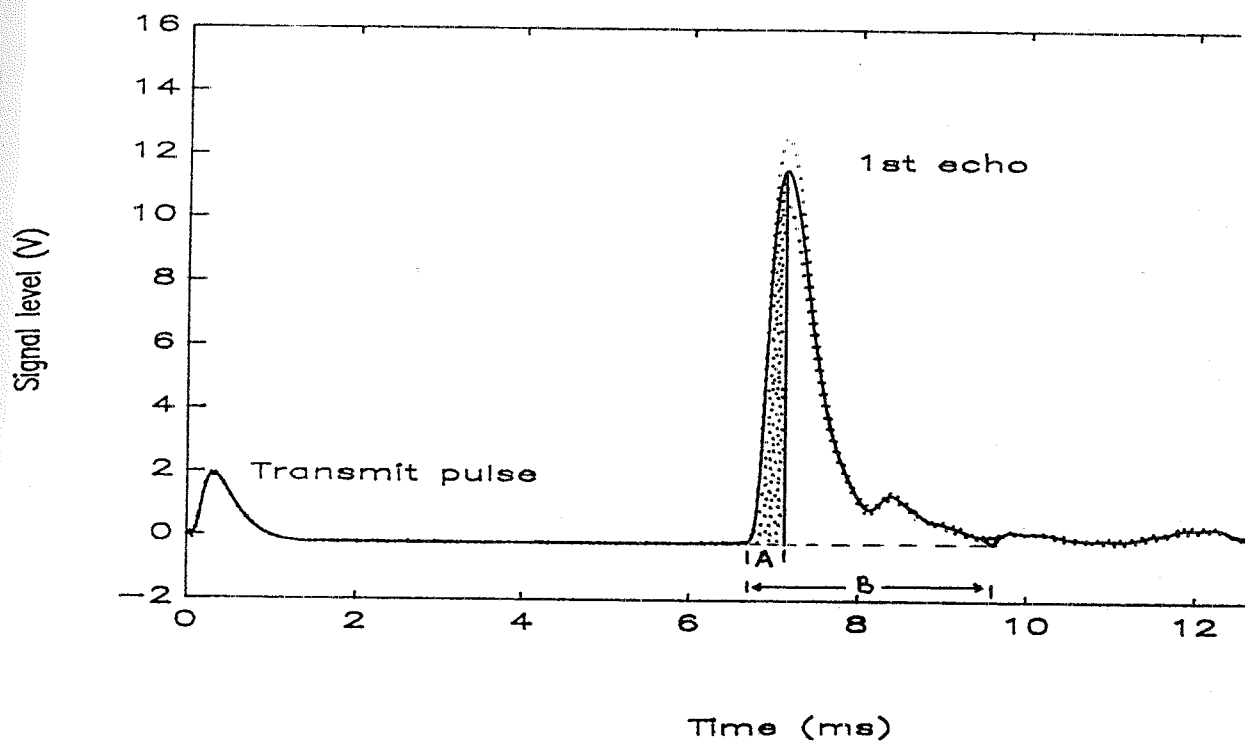
$$E1 = Area(B) - 2\times Area(A) \text{ (Arbitrary Units V·s)}$$

Figure 20   Schematic representation of the procedure for the calculation of the E1 value from the envelope of the return signal.
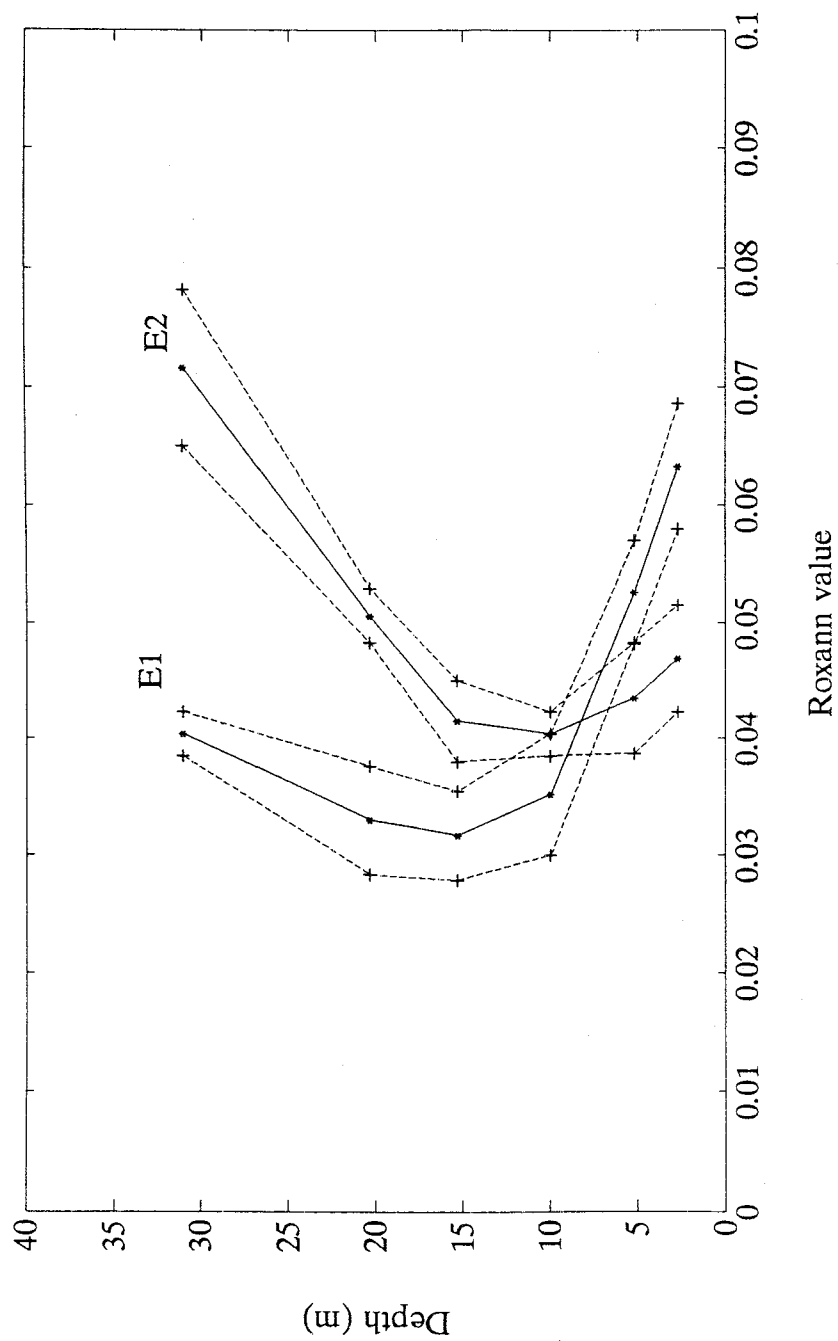
Figure 21   Mean E1 and E2 values (*) against depth (+ represents the standard deviation).
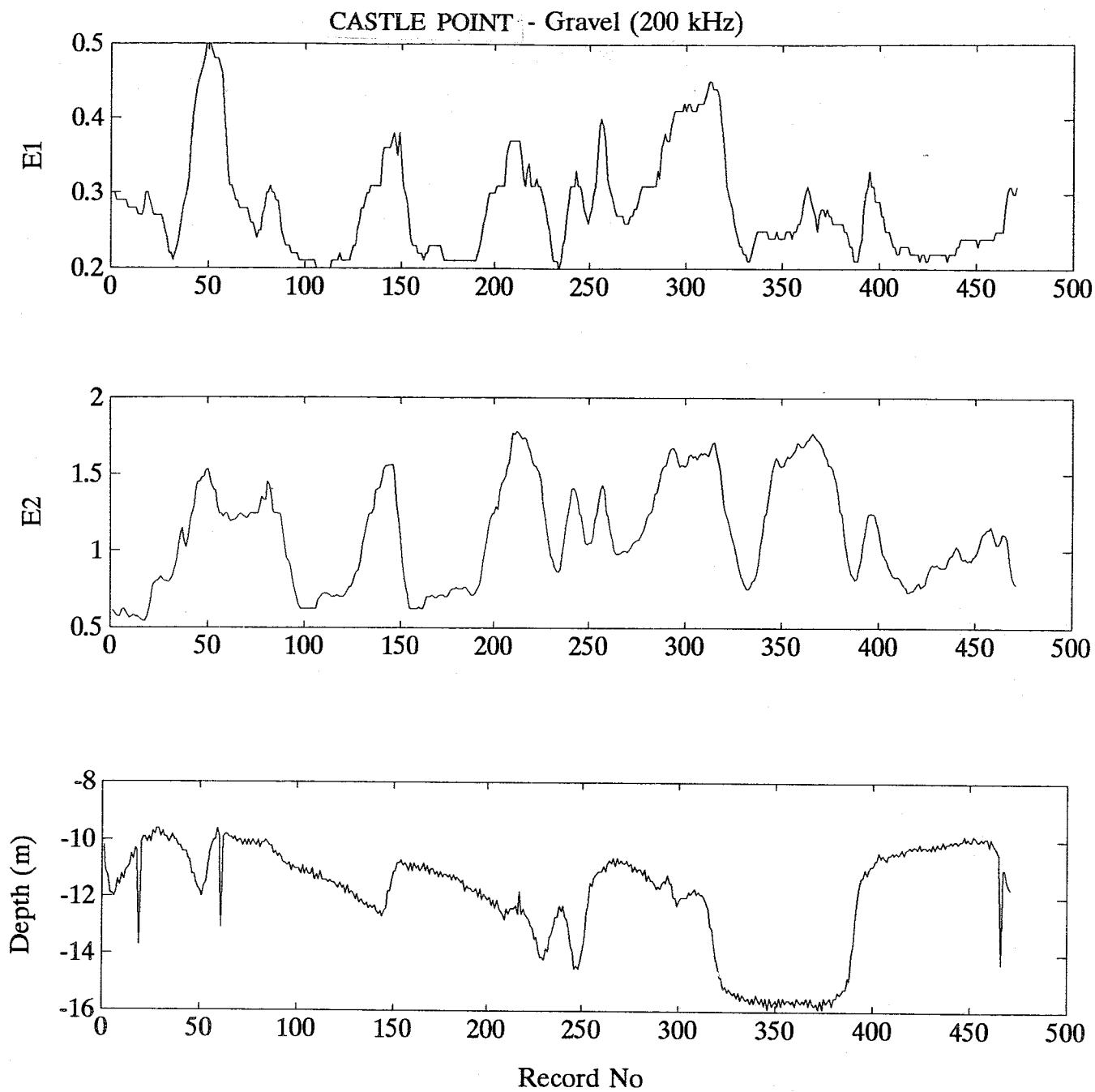
BIRD PILE - Soft Clay/Mud (200 kHz)
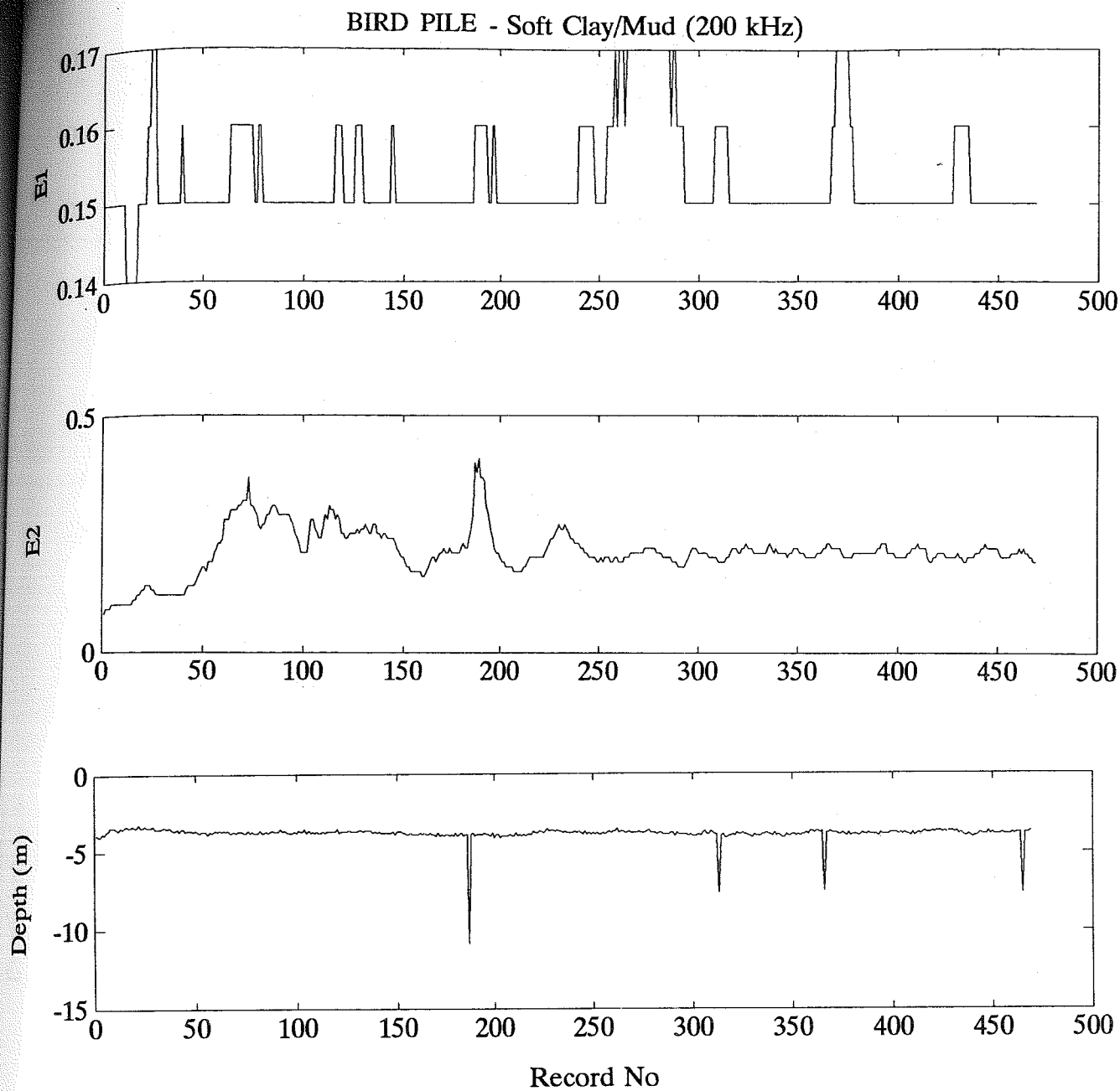
Figure 22   Time-series of data recorded during the field trials at the Bird
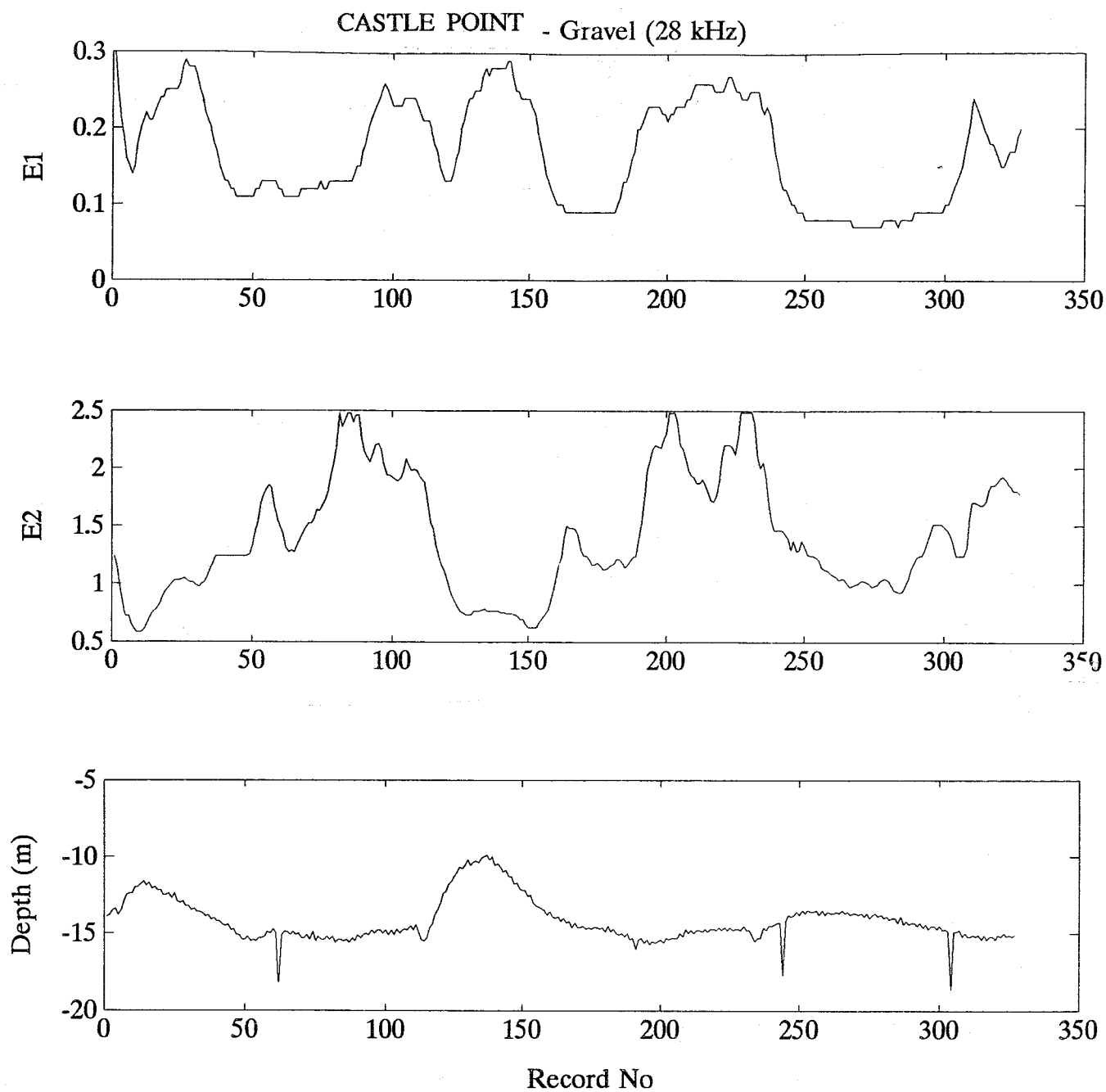   Pile (muddy) site (200 KHz).
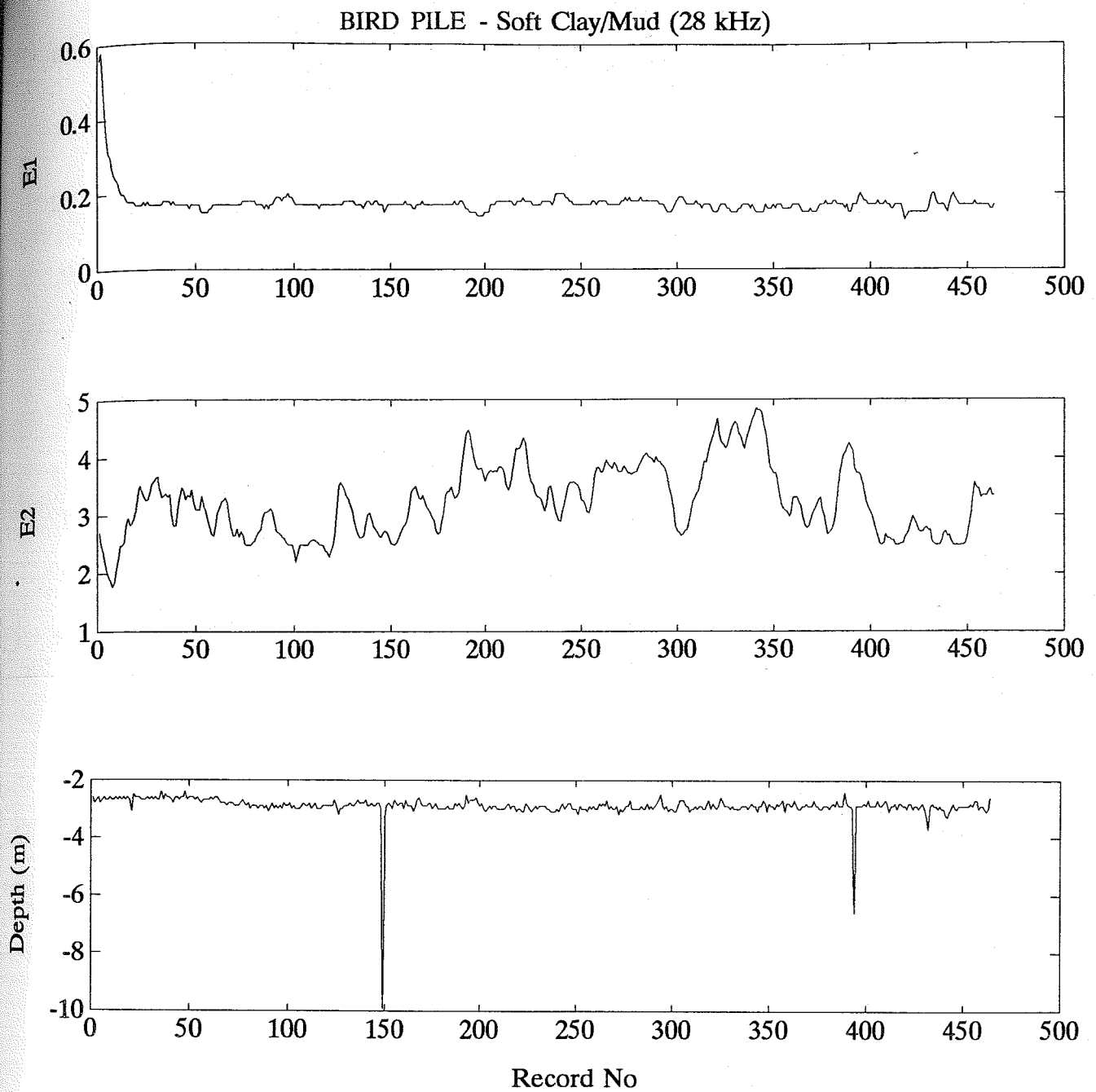
Figure 23   Time-series of data recorded during the field trials at the Bird
            Pile (muddy) site (28 KHz).
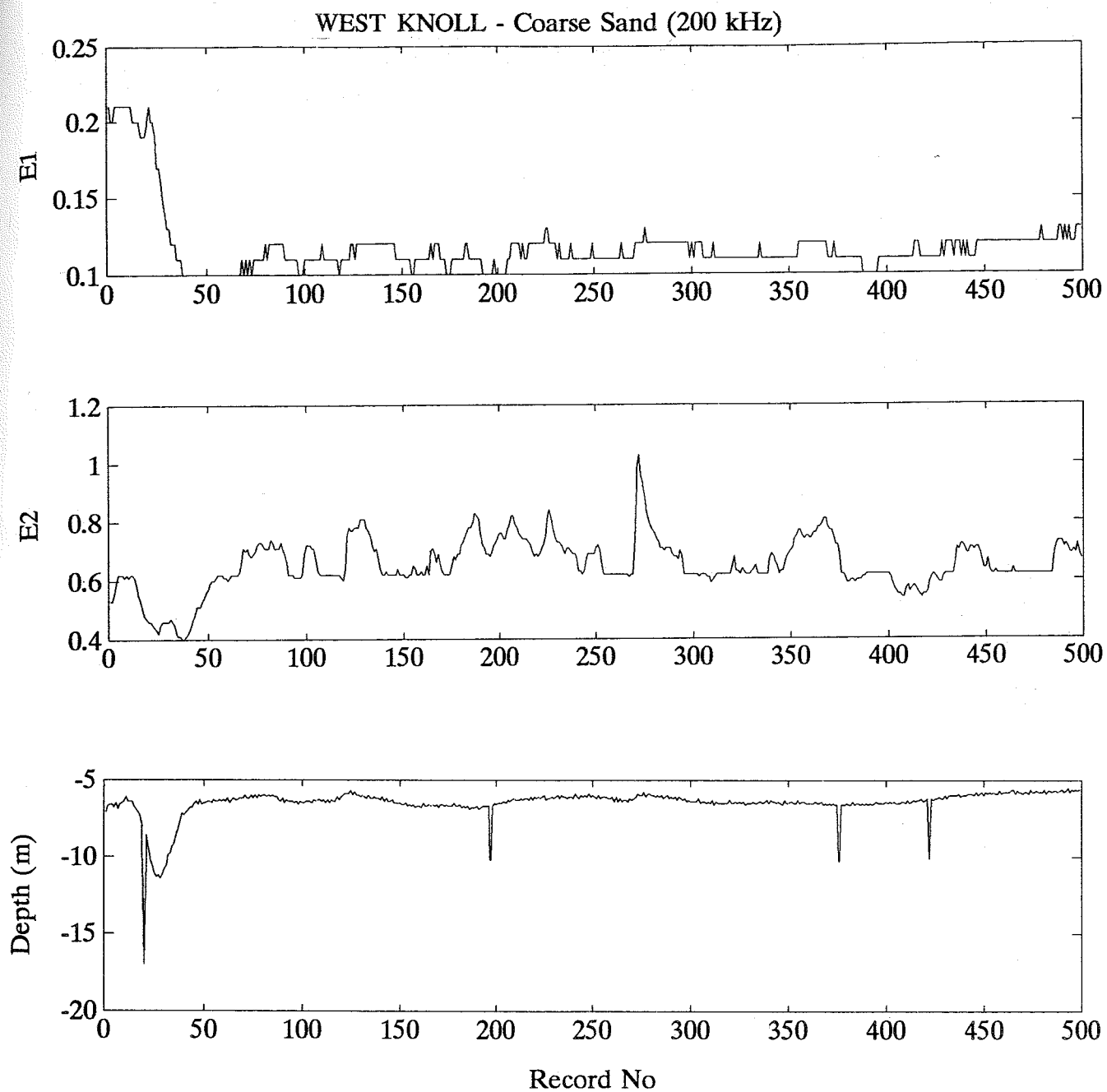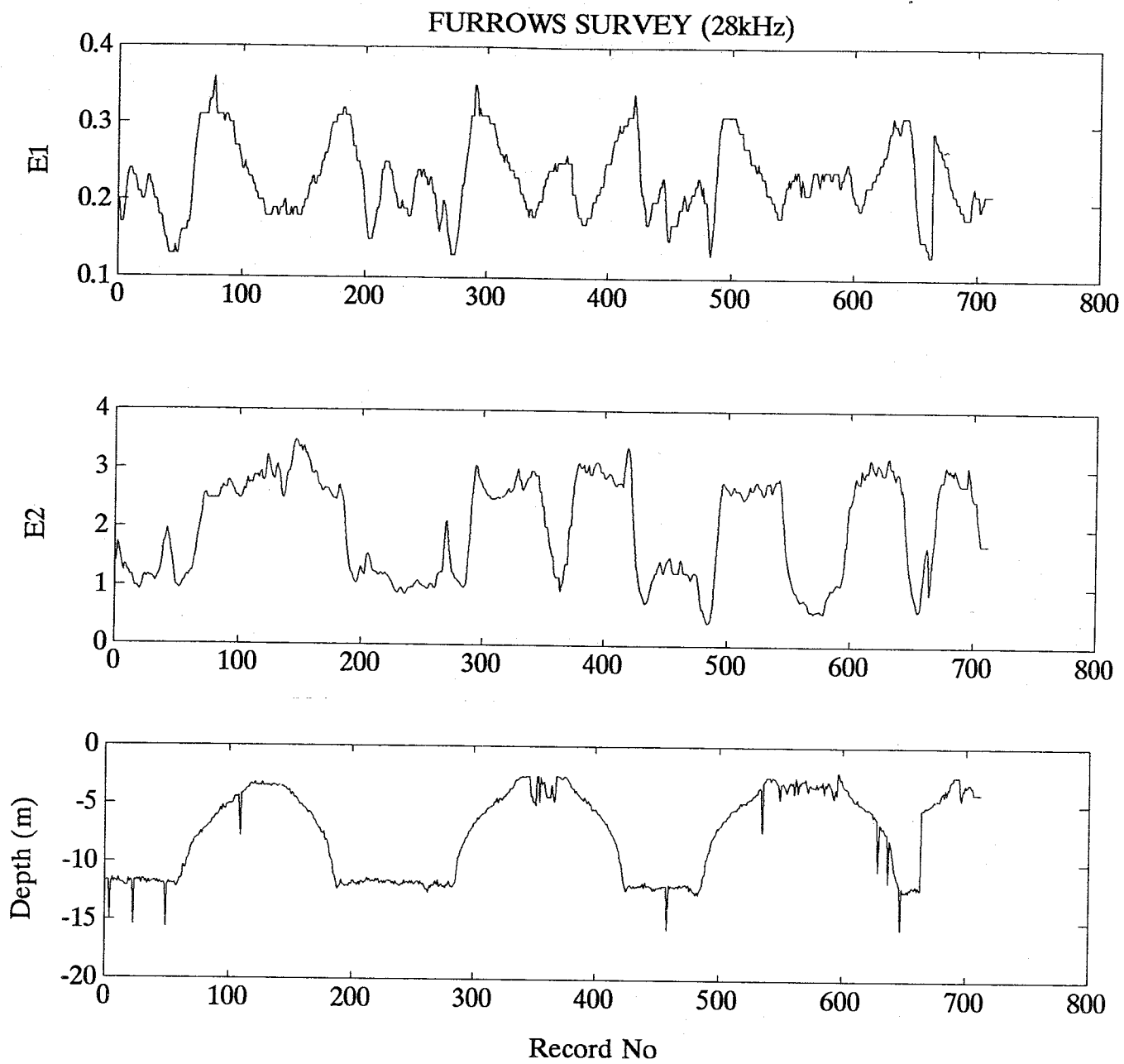
Figure 24   Time-series of data recorded during the field trials at the West
            Knoll (sandy) site (28 KHz).
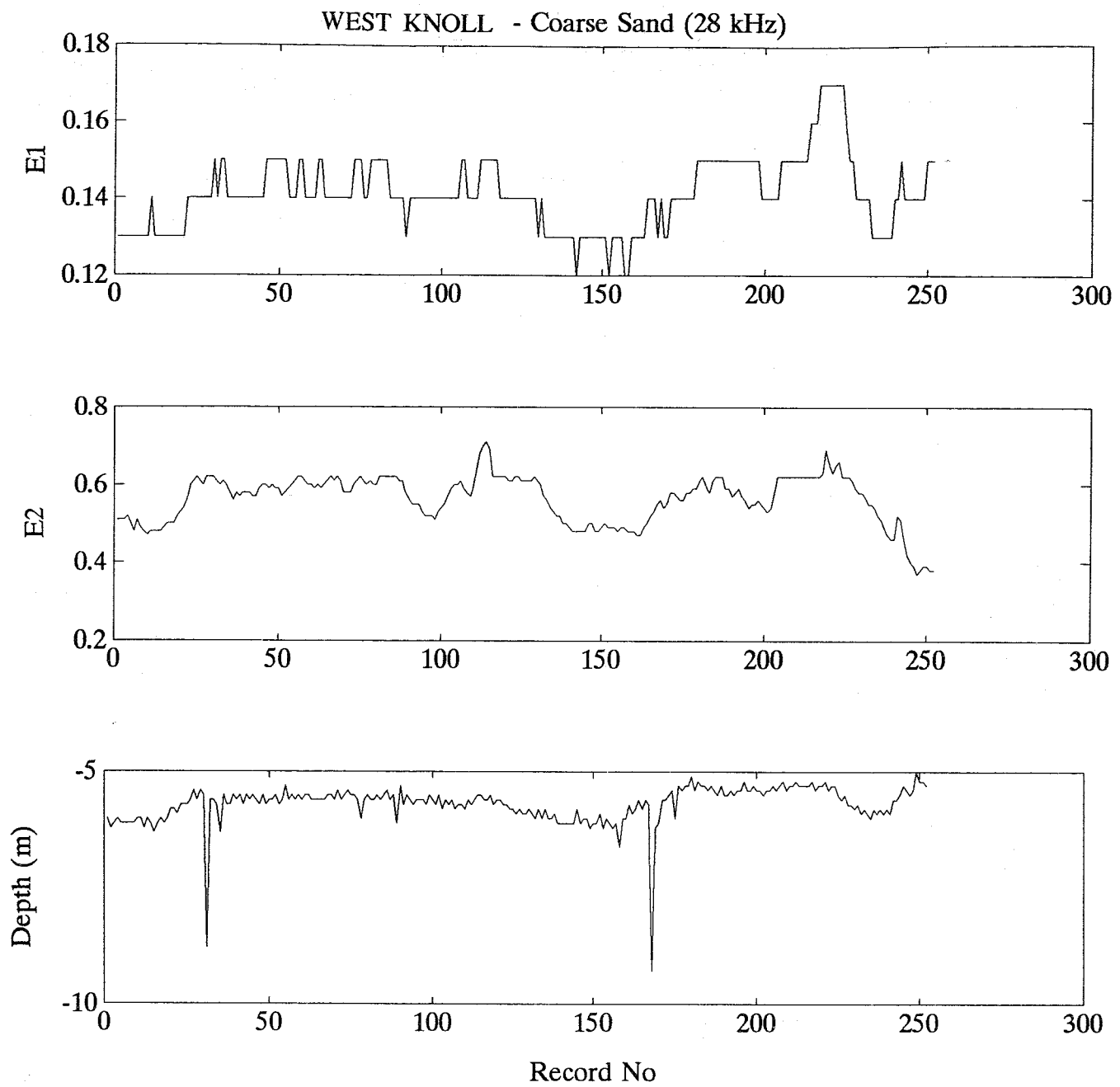
Figure 25   Time-series of data recorded during the field trials at the West Knoll (sandy) site (200 KHz).

Figure 26   Time-series of data recorded during the field trials at the Castle Point (mixed bed) site (200 KHz).

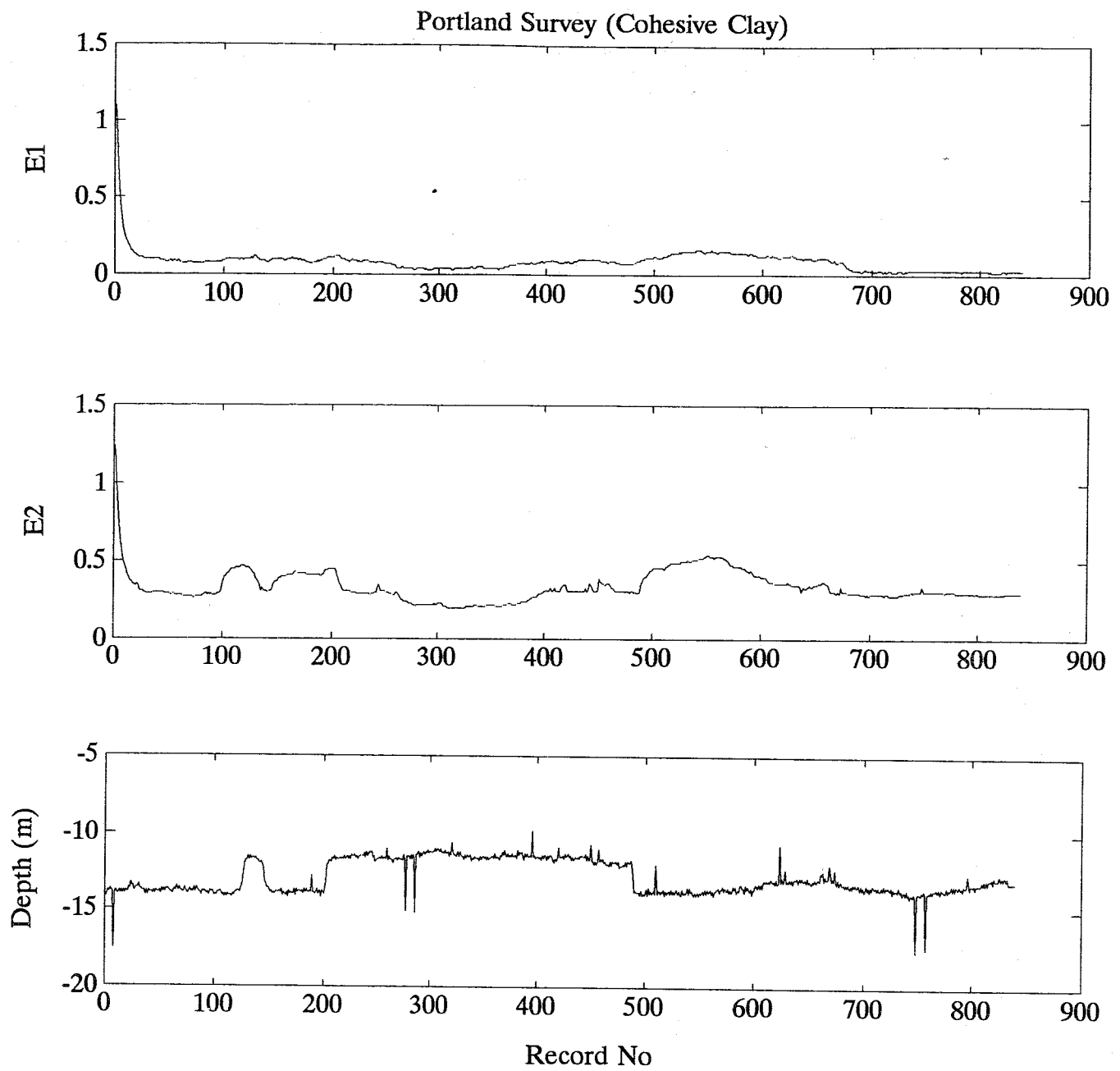Figure 27   Time-series of data recorded during the field trials at the Castle
Point (mixed bed) site (28 KHz).

FURROWS SURVEY (28kHz)

Figure 28   Time-series of data recorded during the field trials at the Furrows area (28 KHz).

Figure 29   Time-series of data recorded during the field trials at the
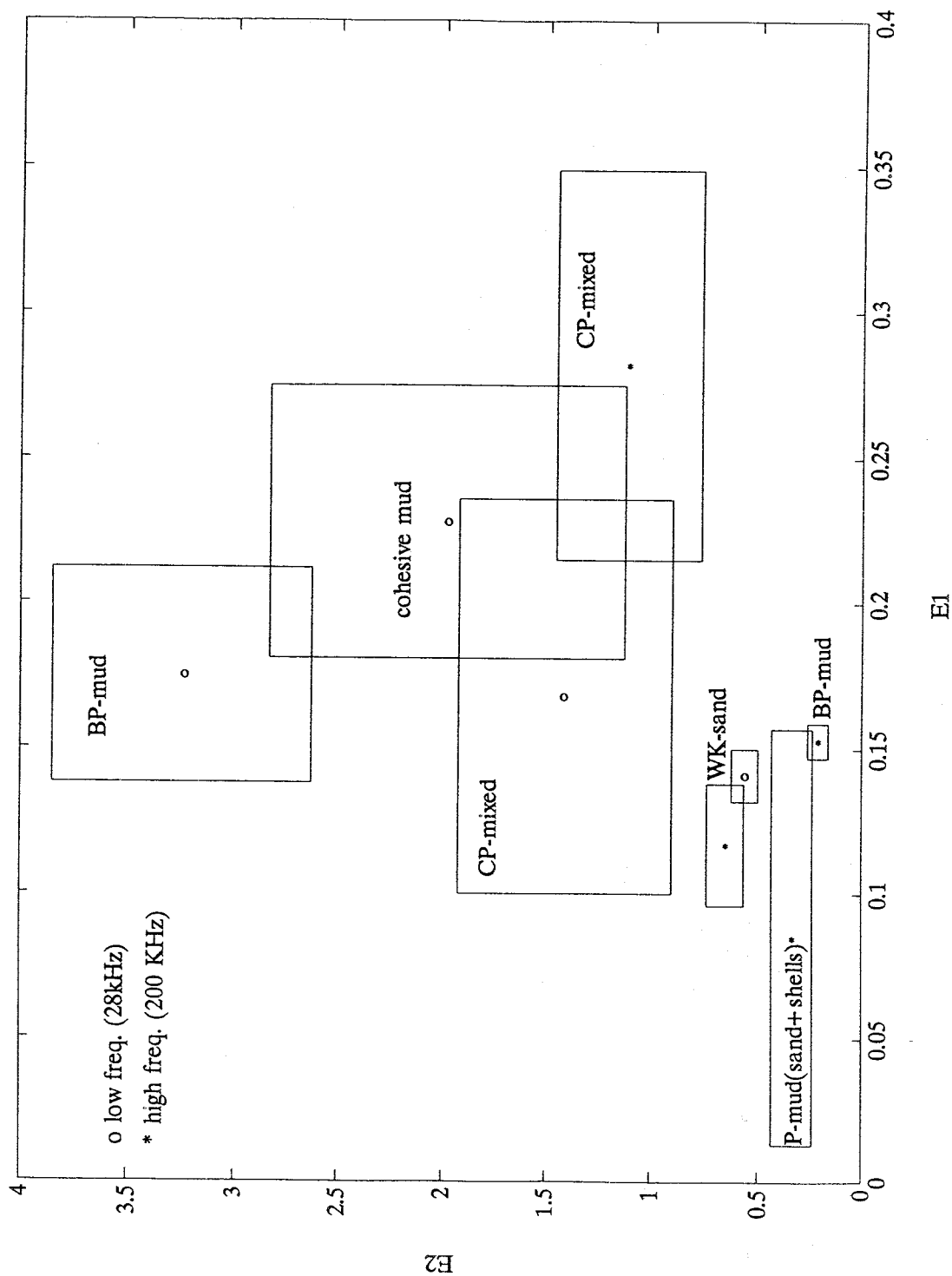Portland Harbour survey (200 KHz).

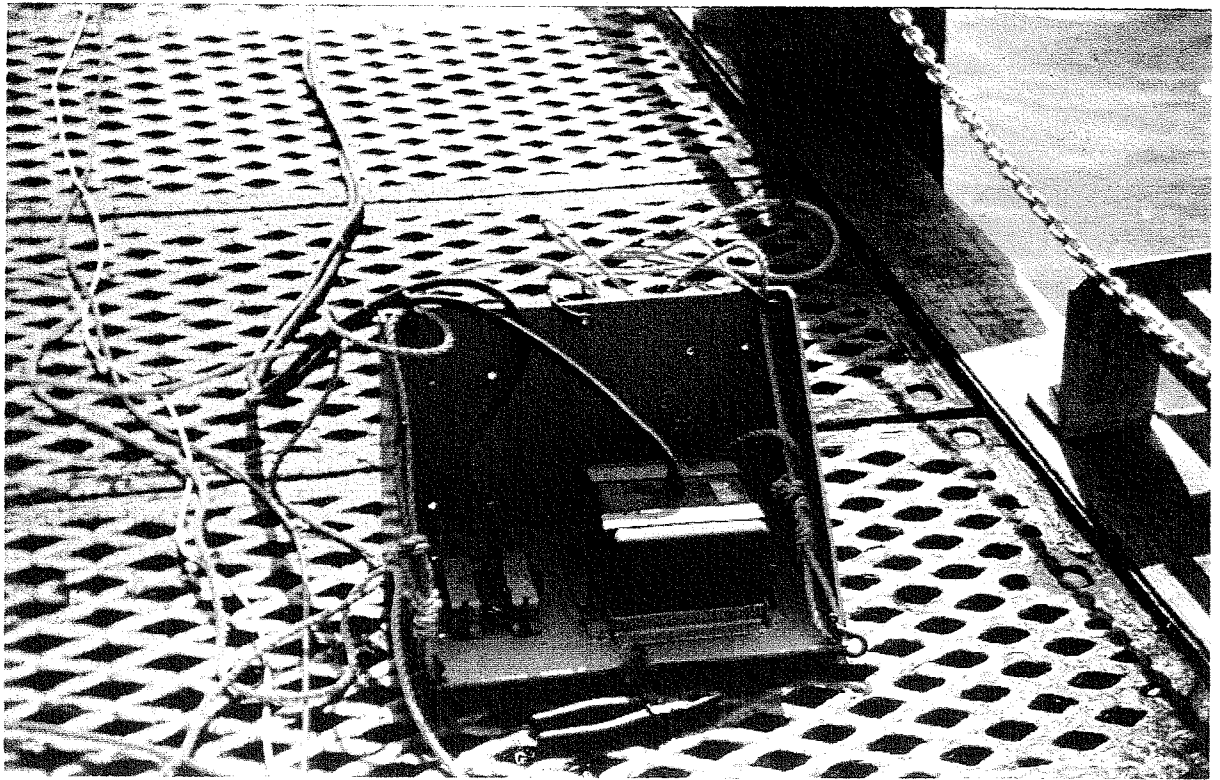Figure 30   E1/E2 boxes for different sea bed types (at two frequencies).

PLATE 1   Steel frame plate used during the field trials, for the installation of the echo-sounder transducers.
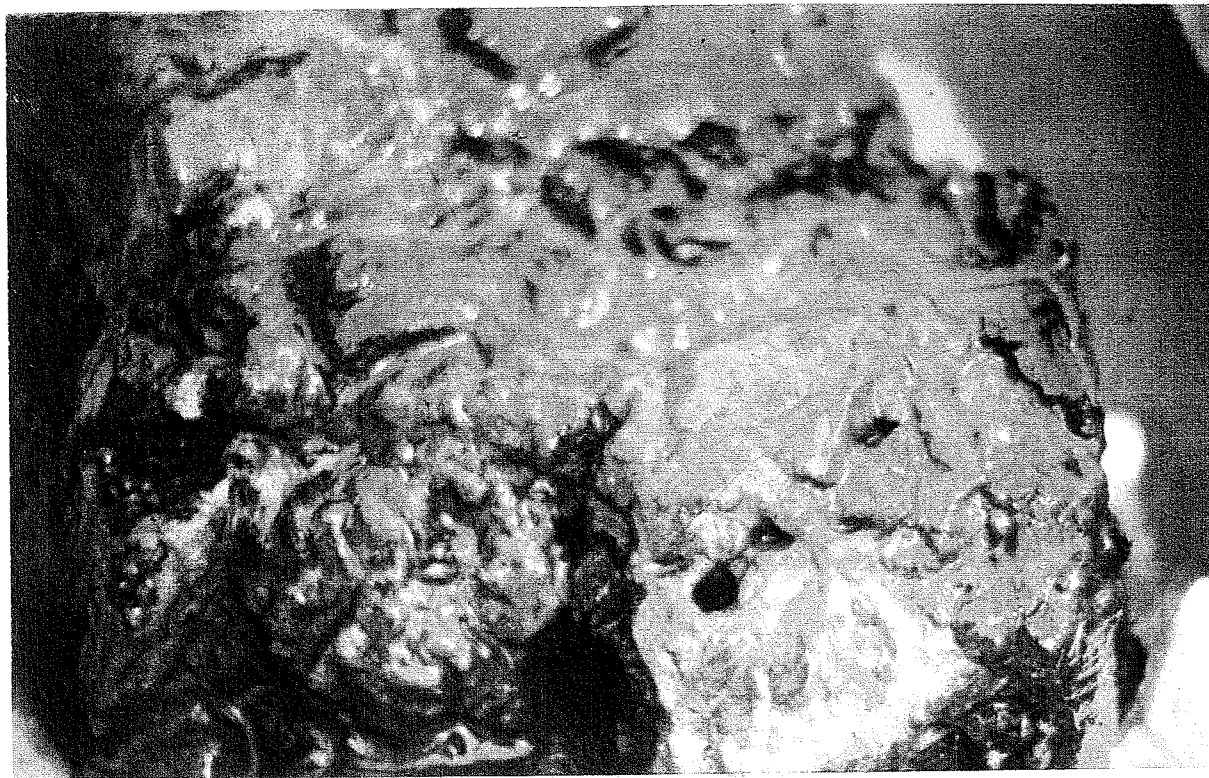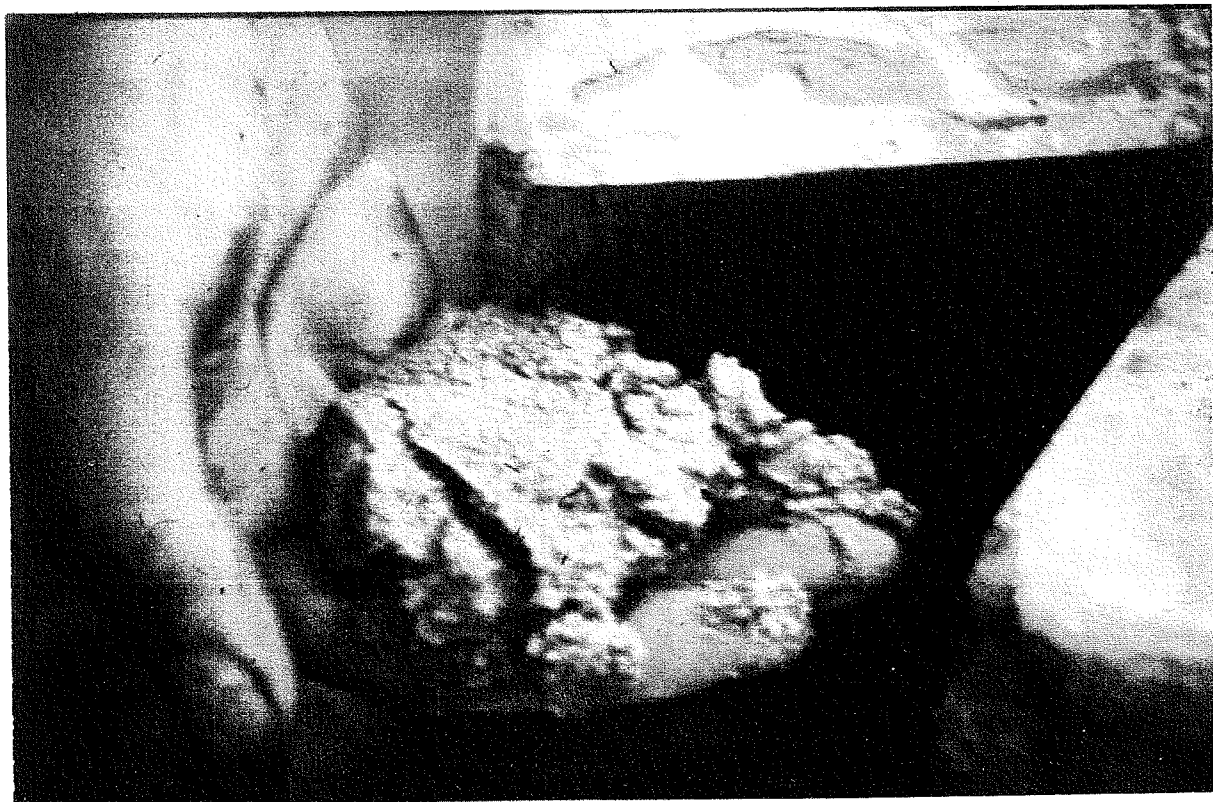
PLATE 2a. Bird Pile (BP) seabed sample.

PLATE 2b. West Knoll (WK) seabed sample.

PLATE 3. Castle Point (CP) seabed sample.