SOME DEVELOPMENTS IN HIGH RESOLUTION SEISMIC REFLECTION PROFILING RELEVANT TO INVESTIGATIONS OF VERY SHALLOW WATER AREAS.

I.R.Richardson (1), P.G.Simpkin (2), A.M.Davis (1), J.D.Bennell (1) and J.A.Butcher (1).

(1) School of Ocean Sciences, University of Wales at Bangor, Menai Bridge, Gwynedd. UK. LL59 5EY.
(2) IKB Technologies Limited. St. John's, Newfoundland. Canada.

ABSTRACT

High resolution seismic profiling of the upper few tens of metres of sediment below the sea floor is a technique which has numerous applications in geological, engineering and environmental studies. Although the current trend in high resolution surveying is towards multi-channel digital data acquisition, single-channel analogue profiling still has an important role to play, particularly when surveying in very shallow water and where the sole requirement is the definition of the sub-bottom reflector configuration.

The Natural Environment Research Council's LOIS Special Topic programme (Land Ocean Interaction Studies) has provided both the impetus and funding for an appraisal of the state of the art with regard to shallow water surveys. This paper aims to highlight some of the problems associated with working in this environment and to make recommendations for improving data quality at the acquisition stage. The majority of problems associated with sub-bottom profiling can be attributed to the various forms of noise encountered; within this paper it will be shown that significant improvements can result from redesign of the receiving hydrophone array, and that resolutions of less than 0.25m metres are attainable based on analogue data alone.

1.0 INTRODUCTION

For many years single channel marine seismic profiling has been employed by geophysists and engineers in routine studies of surficial sediments. In its simplest form a seismic sub-bottom profile may be derived from the conversion of two-way propagation times into equivalent reflection depths. Often overlooked in this type of work is the inter-tidal/shallow water (<10m) region of the coastal zone. This paper will discuss some of the problems encountered whilst surveying in such shallow water conditions and will also outline the ways in which a new profiling instrument, the IKB SEISTEC™ attempts to solve them.

2.0 PROBLEMS ENCOUNTERED IN SHALLOW WATER

Established shallow seismic profiling procedures utilize a seismic source triggered periodically with signals detected by a single receiver, usually in the form of a summed array of hydrophones. It is customary for the source and receiver to be towed behind the survey vessel, usually at a velocity of approximately 2 m/s (4 knots). In shallow water certain aspects of the above configuration lead to degradation in the quality of the recorded data. The major problems encountered in shallow water can be divided into three main categories (Haynes *et al*, [1]) and then further sub-divided (Simpkin, [2]):

(1) Instrumental effects
- Direct interference between source and receiver.
- Source "ringing"
- Source signature variability
- Source directivity
- Receiver response
- Dynamic range of display
- Changes in source/receiver separation

(2) Environmental problems
- Surf and beach noise
- High ship and towing noise

(3) Geological Effects
- Multiples - sea surface/seabed multiples
- Diffractions
- Apparent attenuation - "peg-leg" multiple

Intended improvements to the quality of the recorded data must aim to keep the effect of the above problems to a minimum. To this end an opening existed for new technology and methodologies to tackle the shallow water problem.

A preliminary study was undertaken (Simpkin and Lewis, [3], Simpkin, [2]), in 1986 to determine the ideal configuration for a shallow seismic marine survey. This included a search for the ideal source and receiver partnership for use in the shallow water environment. High resolution sources available at the time included the *Boomer* type (Uniboom etc.) essentially an electrodynamic transducer which produces an impulsive pressure signature which has a wide bandwidth (McGee *et al*, [4]) and is consistently repeatable (Verbeek, [5]).

One of the major weaknesses in conventional systems can be attributed to the traditional type of receivers employed. These receivers (streamer arrays) are usually pressure sensitive elements arranged in oil filled tubes. The output from each hydrophone element are usually summed such that the directional properties of the array are determined by its active length and the separation of each element. Thus, long arrays which can attain a good signal/noise ratio, are commonly preferred.

In the shallow water environment, length of the array becomes a restricting factor. The returning wavefront is usually assumed to arrive at each element of the array simultaneously, and in consequence, the summed voltages are in phase. In very shallow water, however, the length of the array is such that the geometry of the source/receiver can no longer be defined as "zero-offset" and as a result of this, the returned wavefront will sweep past the array (Fig. 1.), resulting in slightly different arrival times at each element within the hydrophone. The summing of these out of phase arrivals will then lead to spatial filtering or "smearing", of the recorded signal (Schott *et al*, [6]). A similar problem arises due to the tendency of the array to sink below the sea surface; the sea surface/air interface acts as a "soft" reflector, returning the energy back to the sea floor (Fig. 1.), and inducing a phase reversal of the returned wavefront. This delayed, phase reversed echo is superimposed upon the response of the array to the primary echo, leading to a reduction in bandwidth of the returned signal and hence a corresponding reduction in the resolution potential of the survey.

SOME DEVELOPMENTS IN HIGH RESOLUTION SEISMIC PROFILING

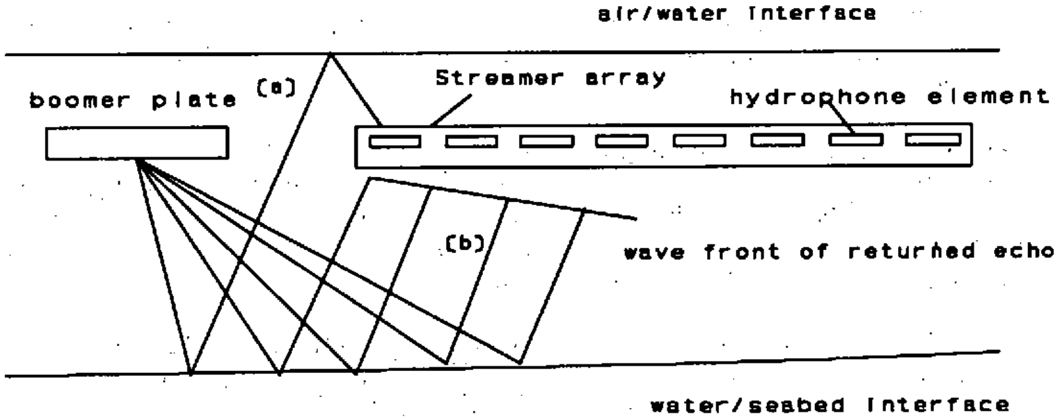

Figure 1 Degradation of the returned echo due to;
(a) Phase reversed reflection from the sea surface
(b) "sweeping" of the streamer array

3.0 THE *LINE IN CONE* RECEIVING SYSTEM

The main disadvantages of the traditional surveying design had therefore been identified as the design of the hydrophone array. Consequently an investigation aimed at improving the receiver configuration resulted in the concept of a *line in cone* configuration which might prove to be more appropriate. To this end a prototype cone was developed which incorporated a short (25 cm) array of single hydrophone elements mounted co-axially in an inverted right circular cone (84 cm diam.). The cone now forms an integral part of the IKB SEISTEC™, the specific which resulted from the system appraisal. The cone itself is inserted in a fairing to reduce drag, and the whole is mounted on a catamaran, along with the source plate. As far as the receiver is concerned, this arrangement offers significant advantages over traditional hydrophone arrays:

- Focusing of the returned echo
- A reduced near-field limit minimizing "smearing" of the received echo
- A shielded receiver free from water flow noise which also reduces the effects of backscattering from the air/water interface

The overall source-receiver configuration also offers several advantages when surveying in very shallow water:

- Fixed geometry between source and receiver
- A minimum of geometric distortion due to the close proximity of the source and receiver
- The ability to tow at reduced speed to improve horizontal resolution

The IKB SEISTEC™ therefore offers a stable platform on which to perform high resolution marine profiling in shallow water, reducing many of the effects usually associated with shallow waters and traditional streamer arrays.

4.0 RECENT SHALLOW WATER DATA ACQUISITION USING THE IKB SEISTEC™

A NERC LOIS (Land Ocean Interactive Studies) contract recently awarded to UCNW presented an ideal opportunity to test the capability of the IKB SEISTEC™ in very shallow water conditions.

One aspect of the research was to map the Holocene sediment distribution in a part of the Tees estuary, including the intertidal area known as Seal Sands. The marine mapping procedure was to be extended on-shore using a land based seismic approach, so that the interpretation could be taken up to and beyond the high water mark. In the area in question the inter-tidal zone had an average water depth of 4 metres at high water.

A schematic diagram of the analogue marine equipment employed for the survey is shown in Fig. 2. The analogue output of the IKB SEISTEC™ was passed to the IKB SEISTEC™ control panel where a linear time varied gain (TVG) was applied (to take account of geometric divergence). It was also possible to apply a second non-linear (x^2) ramp for display purposes. The starting position of the second gain was monitored via an oscilloscope such that the gain could be altered to accommodate changes in water depth.

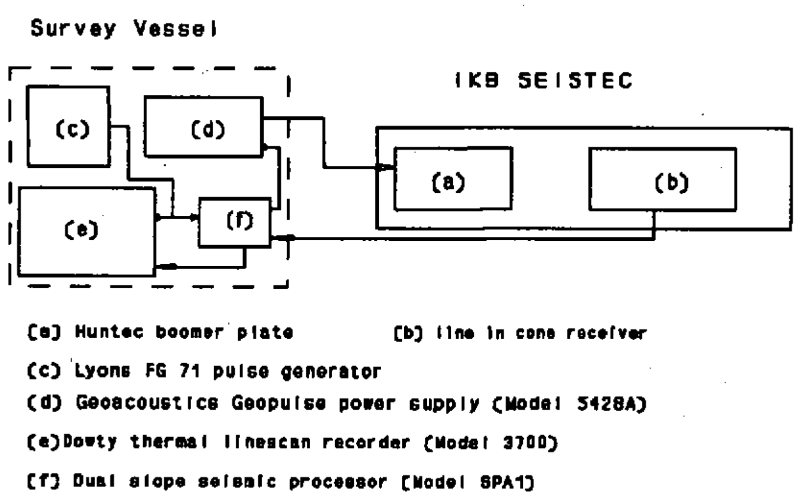

Figure 2 Schematic showing equipment employed for analogue data collection

The acquisition parameters are summarised below:

- 175 Joules power supply
- 4 shots/sec. firing rate
- Survey speed approx. 2 knots (1 m/s)
- Sweep length 50-25 ms. (dependant on water depth)

A major practical limitation relating to data acquisition was the time available for surveying. This was limited to a period of one hour either side of high water due to the draft of the survey vessel (0.75 metre). The seismic data were collected over two periods of high water and positional data were obtained via the logging of GPS data; an example section of analogue record is shown in Fig. 3; the track plot is inset. Also shown in Fig. 3 is the interpreted reflection section, including a tentative geological interpretation based on borehole information (Tooley, [7]).

Using seismic data it is possible to differentiate four distinct layers based on the analogue records, and on the available borehole data. These are:

(1) 1-2m of surficial sediment comprising medium-coarse sand and silt.
(2) 3-4m very soft dark grey to black organic silty clay.
(3) 2-3m soft to firm, becoming firm to stiff dark grey brown laminated silty clay, containing occasional layers of fine-medium gravel.
(4) stiff, becoming very stiff brown sandy clay containing gravel (boulder clay)

It is interesting to note the region described as acoustically turbid in Fig. 3, the abruptness in termination of the horizons appearing artifical. A comparison with records collected on parallel lines also show similar attributes and hence it is considered that the feature is real. It is hypothesised that the presence of gas within layer two may be responsible for masking of the lower horizons.

5.0 DISCUSSION AND CONCLUSIONS

One of the main causes of contamination on seismic records when dealing with shallow waters is the presence of multiples. These multiples can mask many sub-bottom features due to its coincidental arrival time. Although the IKB SEISTEC™ suffers from the same limitations as other systems when dealing with "normal incident" multiples, it does offer the potential to supress "off axis" multiples as well as to remove many of the problems encountered with traditional horizontal arrays, such as "smearing" and phase reversed return echoes, by the focusing of the returned energy onto a shielded, vertically mounted short array. The mounting of the source and receiver within a catamaran provides a stable base from which to perform a survey, while the shielding of the hydrophone offers a reduction in the noise associated with shallow water surveys. Finally, from Fig. 3 it is clear that the improvements cited above have contributed to the excellent resolution shown in the analogue records, in water depths of less than 4m.

6.0 ACKNOWLEDGMENTS

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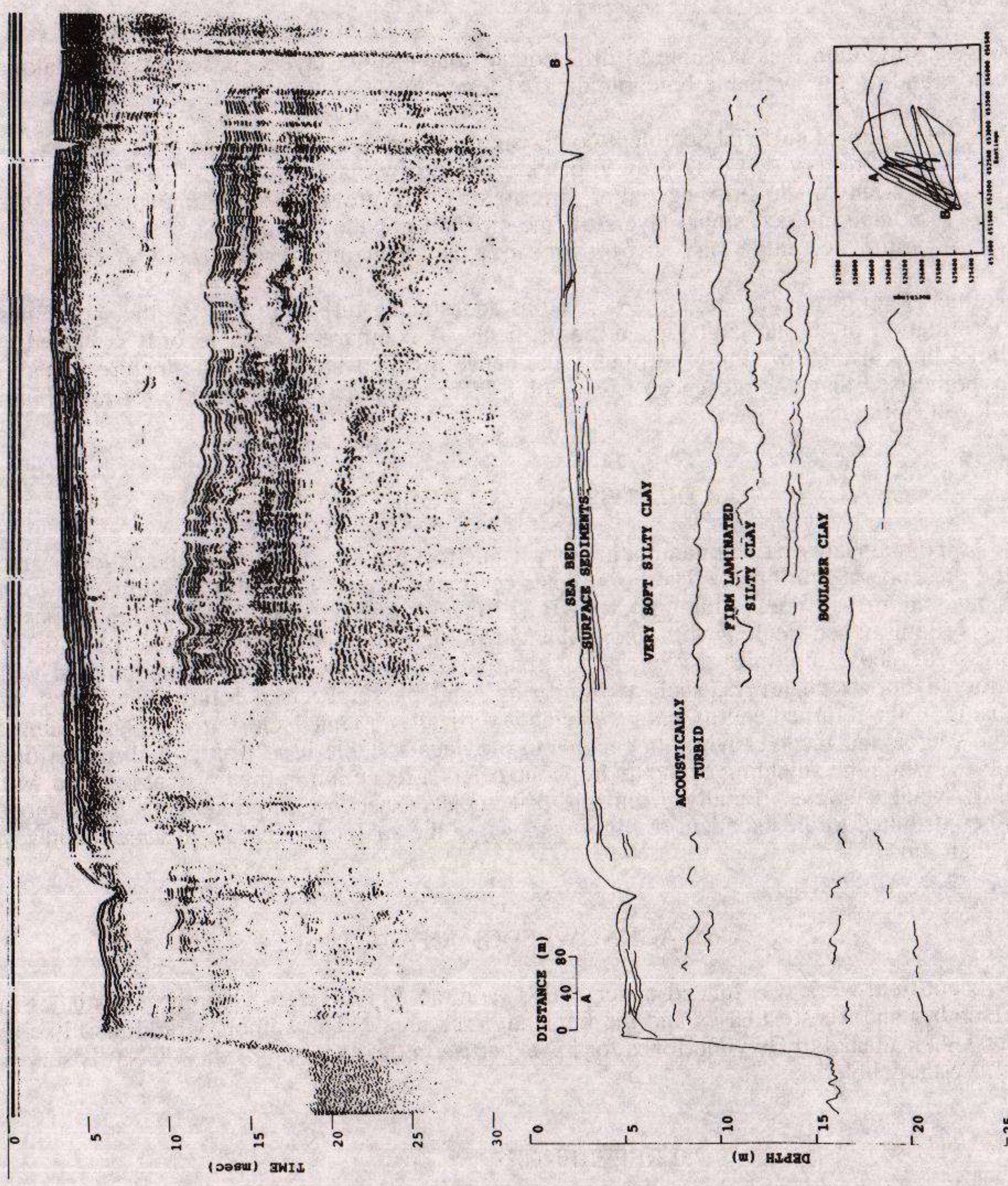

Figure 3 Analogue record and interpreted seismic section (assuming an average velocity of 1650 m/s). See inset for specific location of line AB.

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