SEISMIC PROFILING IN SHALLOW WATER - A NOVEL APPROACH

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1.0 INTRODUCTION

Marine seismic profiling is made possible by an attribute common to all natural materials; sound propagates with little loss due to elastic behavior. In addition, changes in acoustic properties of the material, such as bulk density and sound speed, will partition propagating seismic energy. Boundaries between layers of different acoustic properties will reflect a portion of the incident energy back towards a source. If this reflected energy is detected (as a pressure wave at the sea surface), then its time history will relate to the geological structure beneath the seafloor. A seismic section is produced by the juxtaposition and alignment of successive signatures along a track on the Earth's surface .

While the basic principles of seismic profiling are scale independent, a variety of source and receiver configurations are required to adequately cover the wide range of conditions and water depths that exist in the oceans. Low frequency sound (20 Hz - 200 Hz) is utilized for targets occurring kilometres below the surface. However, for shallow seismic profiling, where target depths are a maximum of hundreds of metres, smaller sources producing energy with spectral content in the 100 Hz to 10 kHz range, and compatible receiving arrays are best suited[1]. The need to focus upon particular geologic and natural environments has, over the years, prompted the development of a variety of seismic sources, receivers and their respective configurations.

Seismic profiling in water depths less than 10 m is subject to unique problems because of the need to maintain the receiver in close proximity to the source. With traditional systems, this invariably results in target masking due to direct acoustic contamination between the source and receiver which may last for many milliseconds after source firing.

IKB Technologies Limited has recently introduced a new system for seismic mapping of sediments within embayments, lakes, river estuaries, canals and the near shore marine environment. This novel shallow water profiling system is designed to meet the requirements of both industry and others who are involved in sub-sea geological mapping, engineering foundation studies, environmental studies, cable route and pipeline surveys and resource inventories, requiring high resolution profiles in water depths from 1m to 100m.

2.0 THE SHALLOW WATER PROBLEM

Traditional shallow seismic profiling uses one of several types of underwater sound source to produce a pressure impulse near the water surface at regular intervals (0.1 - 1.0 second). Echoes resulting from these outgoing impulses are detected by a pressure sensitive receiving array, conditioned, and then printed to a graphic recorder or stored for further analysis. The seismic source and receiver, traditionally separate entities, are generally towed behind the survey vessel at speeds up to 4 knots (2 m/s) along a pre-determined track. The resulting seismic sections, when related to navigation, are interpreted to allow a sub-bottom geological map to be compiled. This relatively simple configuration has certain limitations in shallow water which, in this context, is regarded as 10 metres or less. The major problem areas which affect the quality of the seismic echo in shallow water are:

- Direct interference from source to receiver
- Closely spaced seabed multiples
- High ambient sea noise levels
- Surf and beach noise
- Vessel and towing noise
- Source and system "ringing"
- Source variability
- Vertical receiver motion

Another major problem area, spatial filtering, causes geometrical distortions of the seismic section. These distortions are due to:

- Excessive receiving array length
- Relative motion between source and receiver (horizontal)
- Changes in source/receiver separation
- Excessive source/receiver separation.

Most, if not all, of these limitations must be addressed if we are to improve the quality of shallow water seismic data. Signal processing, recording and display techniques must also be addressed since, in attempting to improve both horizontal and vertical resolution, higher firing rates and wideband echoes with greater dynamic range will be produced. Optimizing data quality requires the selection of compatible system components, primarily the source, receiver and recording equipment to produce reliable, low-noise seismic echoes where variations due to effects other than the target geology are reduced to a minimum. In a dynamic, noisy environment such as a moving vessel on open water, this is not a trivial task.

3.0 AN ALTERNATIVE APPROACH

In 1985 IKB Technologies Limited reviewed existing techniques to identify possible methods of improving the quality of shallow water seismic data. A short study[2] was undertaken using geology typical of an area of the Beaufort Sea as a model target area. The study addressed various seismic sources, several receiving systems and geometrical configurations.

It was immediately apparent that high resolution seismic sources such as the *Boomer* were readily available and were well suited to the task at hand. These electrodynamic transducers[3] are reliable and rugged and produce a near ideal, consistent, impulsive pressure signature that can theoretically resolve target layers spaced 12 cm apart. *Boomers* have other advantages; they are directional with a high front-to-back ratio, the pressure signatures are very stable over extended time periods and they can be used in fresh water. Supporting equipment such as energy storage/discharge units and signal processing and recording systems were, at that time, adequate.

Numerous weaknesses, however, were identified in the use of traditional receivers in the near shore environment. These receivers, often termed *eels* or *streamer arrays,* typically consist of a number of pressure sensitive elements arranged in an oil-filled neoprene or plastic tube. They are usually towed behind the vessel some distance away from the source. Their active length determines their directional properties; long arrays being preferred if good noise rejection is desired. In calm, relatively deep water conditions, providing the eel array is correctly ballasted, consistent echoes can be obtained. However, in less than ideal conditions, many sources of contaminating noise, both natural and man-made persist at the sea surface. Towing and flow noise, turbulence, bubbles and wave generated noise due to both the *eel* itself and towing vessel become dominant above a certain speed. A major problem with *eels* is that a stable towing geometry cannot be guaranteed; there is no reliable method of maintaining a consistent towing depth. This is important particularly when high resolution data is required since the sea surface acts as a *soft* reflector. Thus the response of the *eel* to an echo is modified by the superposition of a delayed, phase-reversed echo which has the effect of reducing the bandwidth and hence the resolution potential of the receiving system. The *eel's* response is also non-stationary in a statistical sense since it is affected by externally varying conditions such as wave regime, speed, swell and water density variations.

Wide band sources such as the *Boomer* emit acoustic energy in all directions resulting in a pressure wave front that sweeps past the *eel* array. In deep water this is not usually a problem since the wave front will have passed the array before any target surface is encountered. In shallow water, problems occur as a result of the overall geometry. If the source/receiver separation is too great, scale distortion will occur such that time/distance relationships are not linear. Also, further bandwidth reduction can occur due to spatial filtering of the echoes. In essence, the target zones are in the near field region of the array. This causes an additional reduction in echo resolution. A trade off is necessary between the need to reduce this type of source contamination and maintaining a reasonable geometry.

The Beaufort Sea study ultimately concluded that the techniques traditionally used for receiving the echoes in shallow water exacerbated most of the problems listed above. In addition to the reduction in resolution expected in the near field zone, it was estimated that signal to noise ratio would have to be improved by up to 16 dB if some of the deeper layering in the Mackenzie Delta model were to be observed. The question then arose:

Is there an alternative receiver configuration that can address some of these weaknesses and give improved performance in shallow water?

4.0 THE *LINE IN CONE* RECEIVING SYSTEM

A receiving system based on the *Line in Cone* concept appeared as an possible alternative to the traditional seismic eel receiver. Although the *Line in Cone* configuration had been used in sonar[4] transducer design for many years, it had not, to our knowledge, been applied to the relatively low frequency, broadband seismic sector. Thus in 1987, IKB Technologies Limited developed a prototype *Line in Cone* receiver consisting of a short, 25 cm array of sensitive elements mounted co-axially in an inverted right circular cone. The cone, which acted as a fixed reflector of acoustic energy, had a base diameter of 84 cm. It was mounted in a faring and incorporated in a towed catamaran flotation system. From an acoustic viewpoint, this configuration offered certain interesting features:

- A circular aperture and circular directional characteristics resulting in a bounded target zone
- A reduced near-field limit, thus minimizing echo smear at close ranges
- A cosine directivity function which reduces off-axis response due to surface scattering
- A shielded receiver, free from flow noise, which reduces ambient noise from all horizontal directions
- A high front-to-back ratio which reduces the effect of surface reflected energy
- Relatively stable and fixed geometry which is important for high resolution profiling.

In 1987, trials undertaken in the Canadian Arctic proved conclusively that the *Line in Cone* receiver was effective in shallow water. In several areas of the Mackenzie Delta, continuous and detailed geological data down to 60 m below the seafloor were obtained in water depths less than 20 m. Results also suggested that the data could be further improved if the source and receiver were combined in the same catamaran. This led to the prototype development of the IKB-SEISTEC™ profiler.

5.0 THE IKB-SEISTEC™ HIGH RESOLUTION PROFILER

Combining the *Boomer* source and *Line in Cone* receiver into one catamaran offers several advantages particularly in very shallow water. These are:

- Reduced geometric distortion due to the close proximity of the source to the receiver
- Fixed geometry between source and receiver
- Fixed geometry between the source/receiver and a known datum (water surface)
- The ability to tow at reduced speed to improve horizontal resolution.

However, in designing such a combined system, reducing the effects of the direct source/receiver transmission path through the water and vibration induced effects through the supporting frame to a tolerable level becomes the critical acoustical problem. Addressing these concerns has led to the development of the latest version of IKB-SEISTEC™ profiling system, shown in Figures 1a and 1b. Several new design features improve the acoustic isolation between the source and receiver and optimize the towing performance. In addition, the signal conditioning aspect was addressed with the introduction of an analog conditioning unit specifically designed to match the attributes of the system when used in shallow water. In a recent surveys[5], exceptional quality shallow water seismic data were collected in water depths less than 2 m. Figure 2 is a seismic section from the Menai Straits (North Wales). Near-surface layers in this high energy environment can be resolved to better than 25 cm. This example also shows that direct interference by the outgoing acoustic pulse and acoustic coupling between the source and receiver has been effectively eliminated from the record. Similarly, ambient noise levels are found to be very low, given that the catamaran was less than 5 metres from the propeller of a 100 tonne research vessel. Figure 3 is a seismic section over a sand bank in the Tees Estuary which is normally dry at high water. Here, the water depth is about 1.5 m.

6.0 CONCLUSIONS

The IKB-SEISTEC™ profiling system is fully operational in water depths less than 2 m. Layering less than 25 cm can be resolved with the same equipment package that can, provided the geology co-operated, delineate sediments over 60 m beneath the seafloor.

However, in multifaceted problem areas such as seismic profiling, improvements made in one sector mean that the limitations in another sector become dominant. These must be addressed if further advances are to be made. Recently, we have observed that wave and swell induced motion of 2 cm could be detected in the seismic records. Vertical motion (in excess of 10 cm), and not acoustic noise, is now considered to be the dominant cause of data degradation. This can be minimized by adding motion compensation. Motion compensation also increases the working weather windows making surveys more cost effective.

Digital recording and signal processing has made great advances in recent years and computer based systems are readily available to further enhance shallow seismic profiles both off and on-line. Because of the stable geometry and acoustic configuration, the IKB-SEISTEC™ system is ideal for parameter extraction as changes in echo characteristics are more likely to relate to actual acoustic parameters of the seafloor sediments rather than to variations in the sensing technique. This is a fundamental requirement for any quantitative analysis technique. Remote identification and characterization of bottom sediments may now be viable with this system since strong relationships exist between their acoustic and geotechnical properties. The directional characteristics and stability of both the *Boomer* source and the *Line in Cone* receiver in this configuration are also positive attributes in this respect.

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[1] Echo sounders and sidescan sonars, which are generally non-penetrating, operate at higher frequencies in the range from 50 kHz to 1 MHz.

[2] For the Atlantic Geoscience Centre, Dartmouth, Nova Scotia. Canada.

[3] The *Boomer* is a term commonly used to describe an electrodynamic transducer comprising a pancake coil approximately 50 cm in diameter which is in close proximity to an aluminum piston approximately 6 mm thick. When stored electrical energy, typically several hundred Joules, is discharged in the coil in approximately 100 μs, the piston rapidly accelerates due to opposing forces acting between the coil and the piston. The pressure signature measured on axis and in the far field mirrors the acceleration history of the piston.

[4] In this context, sonar systems are defined as those that employ **reversible**, narrow-band transducers with a relatively high Q; seismic systems use impulsive, **non-reversible** sources and separate receivers, both of which are usually broad-band.

[5] I. Richardson, A.Davis, J. Bennell and P.G.Simpkin, "Some developments in high resolution seismic reflection profiling relevant to investigations of very shallow water areas". Proceedings of the International Conference - " Acoustic Classification and Mapping of the Seabed", University of Bath, U.K. 14 - 16 April 1993.

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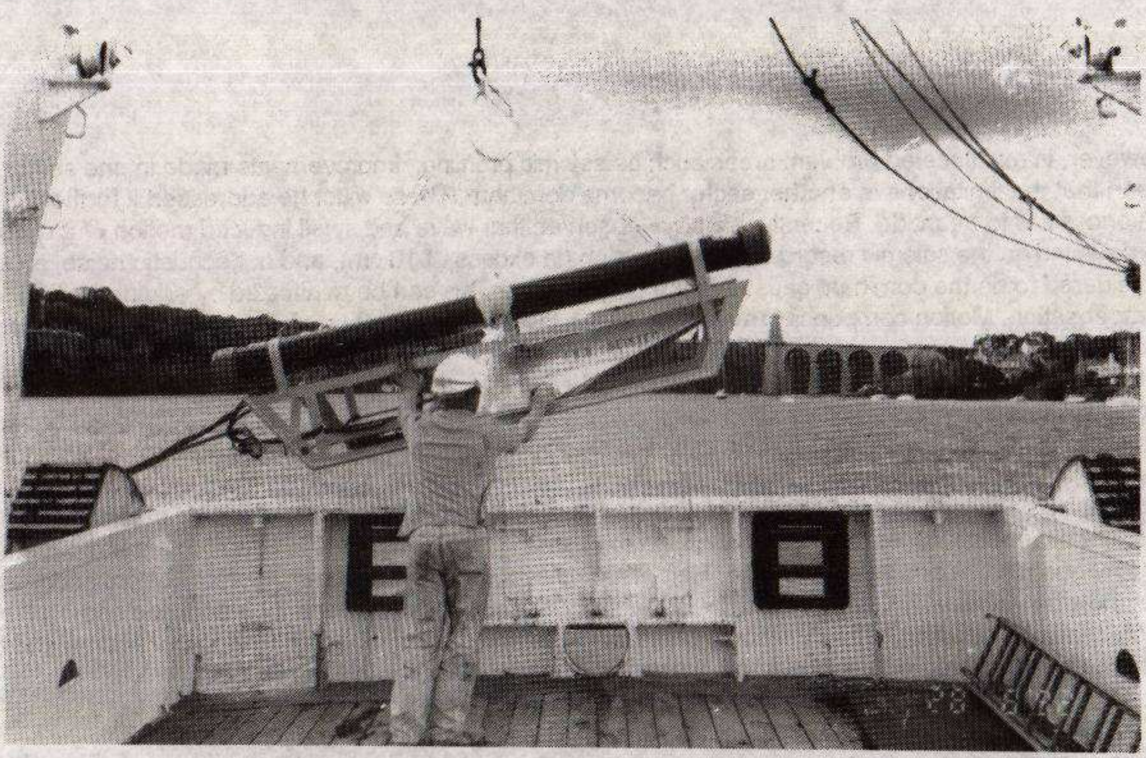

Figure 1a The IKB-SEISTEC™ Profiling System

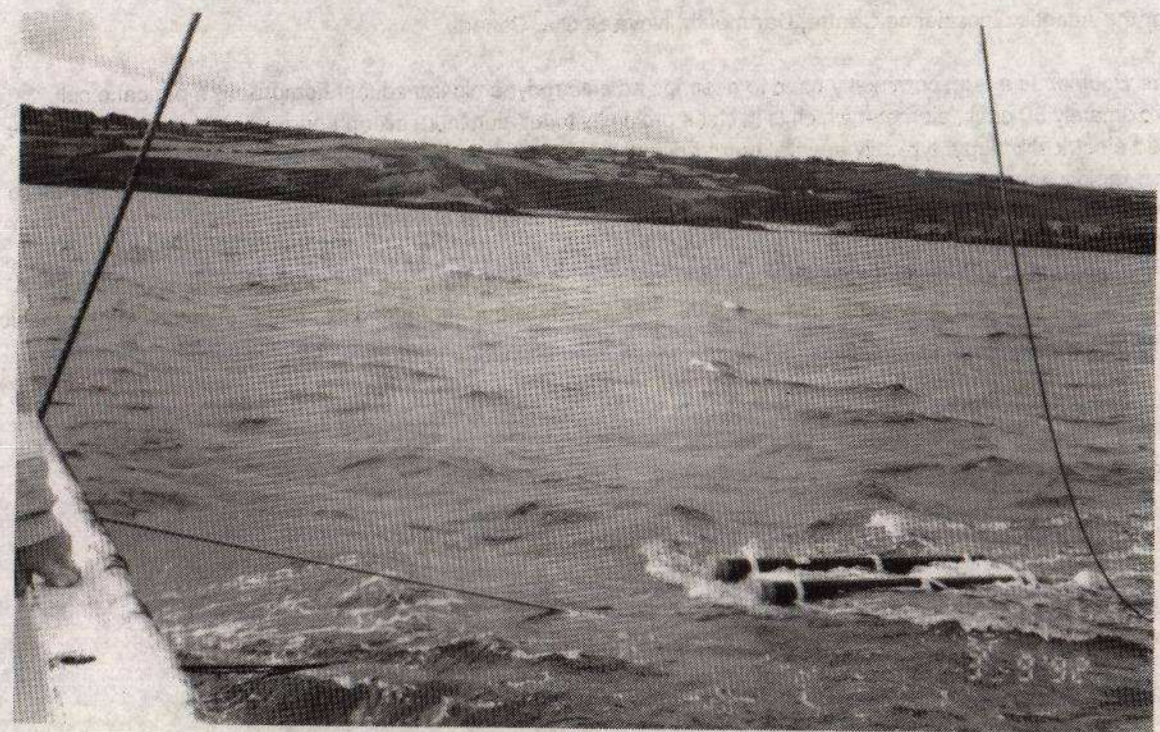

Figure 1b Catamaran under tow, Menai Straits, U.K. September 1992.

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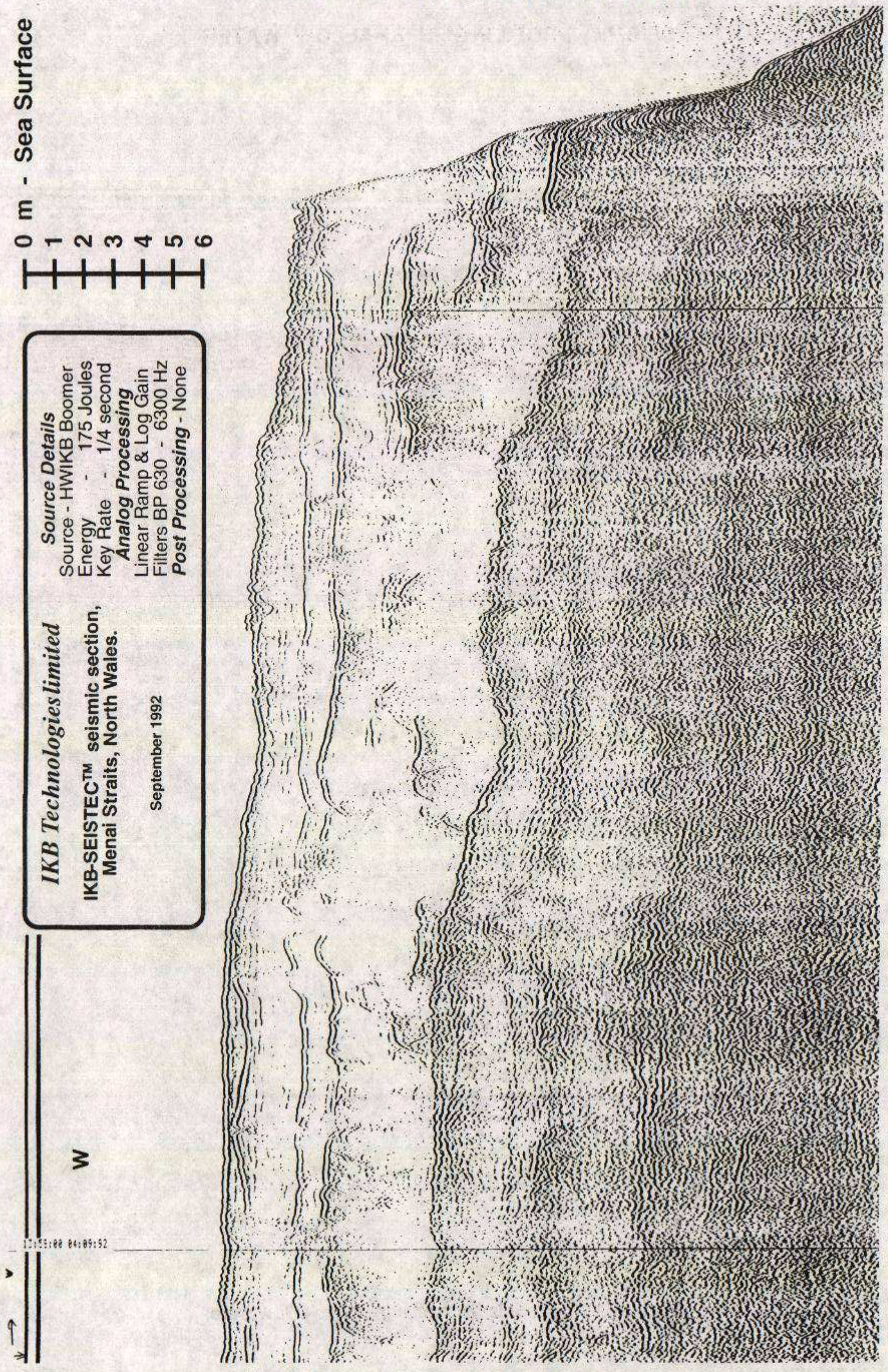

Figure 2 Seismic profile in shallow water

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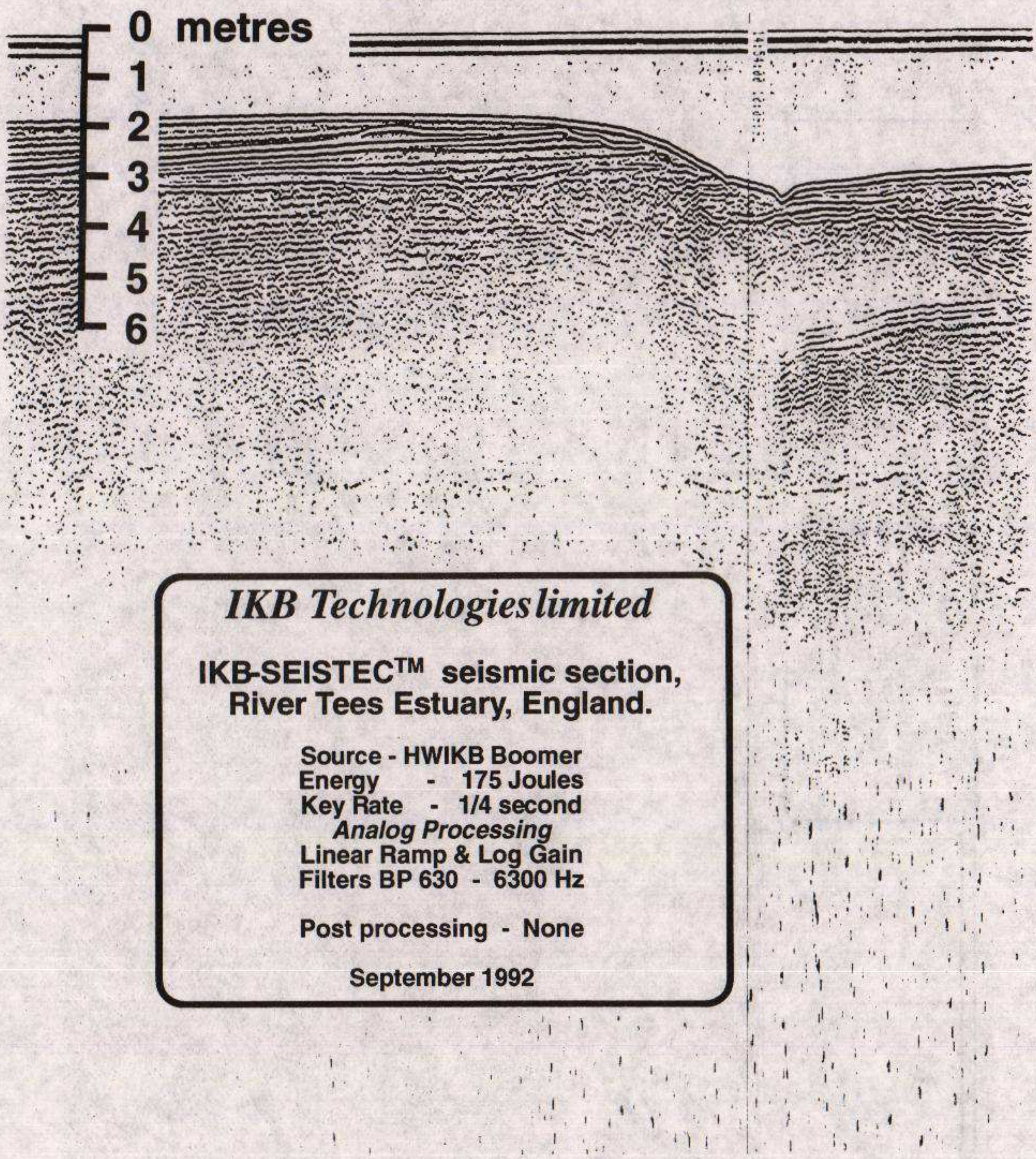

Figure 3 Seismic profile in very shallow water