3D Chirp is a surface-towed sub-bottom profiling system capable of imaging the upper tens of metres of the subsurface in three dimensions with decimetric resolution. This article describes the concept of high-resolution 3D sub-bottom profiling, outlines the design and application of the 3D Chirp system, and demonstrates its capabilities using a data set imaging a buried coffer-dam in the Port of Southampton, UK.

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3D High-resolution Sub-bottom Profiling

3D Chirp

The hydrocarbon exploration industry has routinely used marine 3D seismic reflection methods for over 30 years to image geological structures down to kilometres depth with resolution capabilities of some tens of metres with the aim of detecting hydrocarbon traps. However, near-surface high-resolution sub-bottom profiling currently still relies mainly on single-channel 2D methods.

In contrast to the 2D methods, which produce individual vertical cross-sections of the subsurface, 3D methods produce data volumes that can be processed coherently across a site, and then visualised and interpreted using advanced software revealing the 3D geometry of the subsurface. By respecting the 3D wave propagation during data processing, 3D seismic reflection data has higher data quality and resolution than 2D data, making it possible to detect small objects and reveal complex geometries.

When downscaling the method from typical source frequency ranges of tens of hertz in conventional 3D seismic survey to the kHz range used here, it is essential that the reflected wavefield is fully sampled. In particular, it is important that the receiver spacing is adapted to the frequency range to avoid spatial aliasing and to adequately record the absolute positions of the source and receiver elements during data acquisition. To achieve this, the design concept used in the 3D Chirp profiler described here is to place all source and receiver elements on a rigid structure that is positioned using Real-Time Kinematic (RTK)-GPS technology.

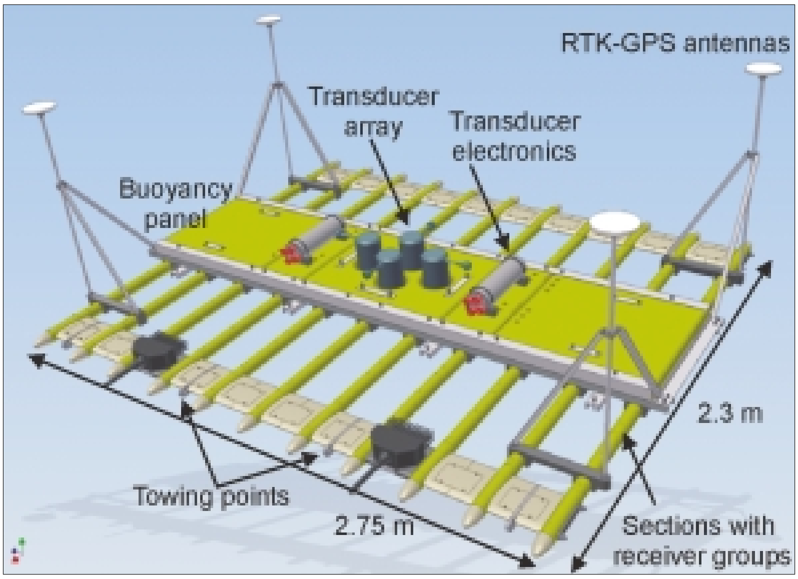

Figure 1: 3D Chirp high-resolution sub-bottom profiling system. The surface-towed, rigid, 2.75m wide by 2.3m long frame holds 60 receiver groups in the longitudinal sections and a four-transducer source array on a central buoyancy panel that operates with a bandwidth of 1.5 to 13kHz. It is positioned using RTK-GPS and attitude systems with four GPS antennas attached to the frame.

System Design

The 3D Chirp system, shown in Figure 1, consists of a surface-towed array made up of longitudinal sections holding a total of 60 receiver groups, which are separated by 25cm in both horizontal directions. The source array, consisting of four Chirp transducers operating with a bandwidth of 1.5 to 13kHz, is positioned on buoyancy panels in the centre of the array. The construction concept makes it

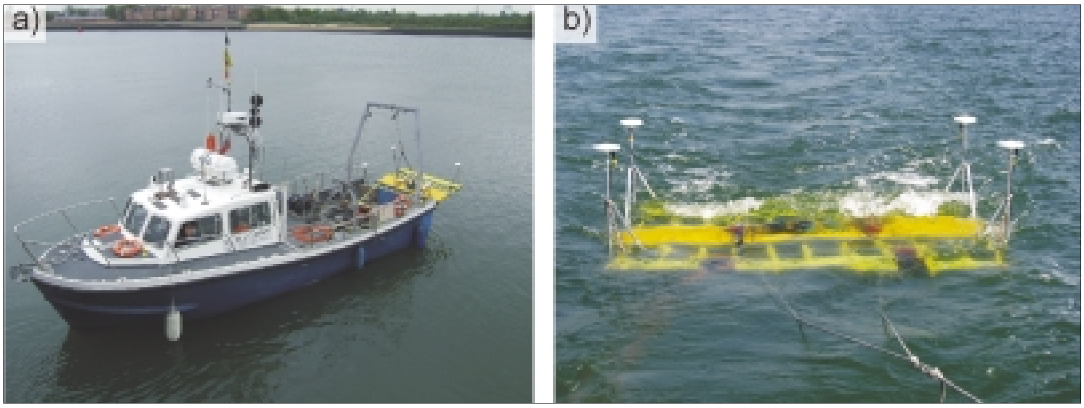

Figure 2a: The 3D Chirp system is deployed from the A-frame of the 12m long R/V Bill Conway.
Figure 2b: Its lightweight open and rugged construction results in neutral buoyancy and assures a stable towing behaviour. The GPS antennas stay clear of the surface during the survey.

easy to expand the presently 2.75-metre-wide and 2.3-metre-long array by adding sections with additional receiver groups. It is constructed from glass-reinforced plastic and PVC foams making it a rugged, lightweight, overall neutrally buoyant system that is easily deployed and shows stable towing behaviour. The array is positioned using RTK-GPS positioning technology (Sagitta, Thales Navigation, CA, USA) together with a GPS-based attitude system (ADU5, Thales Navigation), making it possible to determine the absolute position of the source and receiver elements with sufficient accuracy for 3D seismic data processing. The four GPS antennas are placed on the system and stay above the water surface during deployment. The seismic data is recorded with a custom-built seismograph allowing high shot rates and sample rates.

Data Acquisition and Processing

The 3D Chirp system is deployed from small survey vessels as shown in Figure 2. The survey area is covered by sailing along closely spaced lines with a typical survey speed of 4 knots. The data coverage is monitored online, together with the quality of the recorded seismic data. The first processing step is to assign the geometry by calculating the positions of the source and receiver elements from the RTK-GPS position and attitude system, and determining the reflection midpoints, which are then associated with the recorded seismic traces. After performing standard trace-by-trace seismic processing steps, such as filtering and source sweep correlation (a necessity when using a Chirp source), the data are combined into a 3D data volume by assigning and stacking the positioned traces to a regular bin grid with bin sizes as small as 12.5cm. The resulting data volume can then be visualised and interpreted. An alternative to this last processing step, 3D pre-stack Kirchhoff migration, based on 3D wave-propagation theory, can be applied. This technique repositions reflection energy to the correct subsurface position and enhances data quality and resolution. The output is a regularly sampled data volume as shown in the case study presented below.

Data Example

In the 1970s the Prince Charles Container Terminal was constructed in the Port of Southampton. Prior to the construction of the quay walls a coffer-dam, formed with steel sheet piles, was constructed. This was subsequently toppled into a pre-formed trench and buried. In association with Associated British Ports (ABP) Southampton, a survey was completed to locate and image the buried coffer-dam.
The area was surveyed in 6 hours and a migrated seismic data volume was produced for an area of 200 by 25 metres within the survey (Figure 3). Sections of the data can be viewed in any orientation, independent of the original survey direction. In this figure, vertical inlines and cross-line sections are highlighted together with a horizontal time slice, representing the

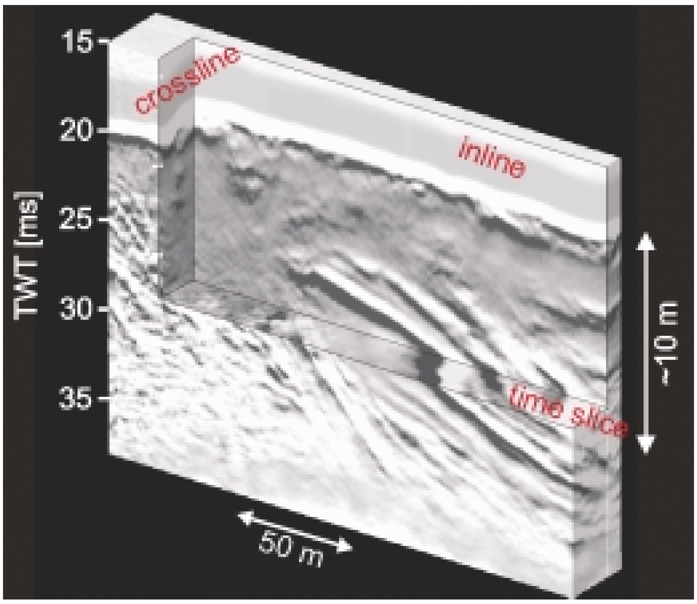

Figure 3: 3D Chirp data volume over the coffer-dam area. The data volume is a 200m long by 25m wide area and images structures down to 15 metres below the seafloor. Note the vertical inline and cross-line sections together with the horizontal time slice. Dipping bedrock reflectors are apparent that are overlain by sediments and interrupted by a trench containing the buried coffer-dam. See Figure 4 for detailed interpretation.

reflection amplitudes at a constant Two-Way-Travel-time (TWT). The sea floor is at 20 metres TWT, which equals approximately 15-metre water-depth and the sub-surface penetration is equally approximately 15 metres. The bedrock, which underlies

> » 3D Chirp is a valuable tool «

a sedimentary cover, shows dipping reflectors of which the true dip and strike can be easily deduced from their 3D representation. A disturbed zone that represents the infilled trench containing the reflection of the coffer-dam interrupts the sedimentary cover and the bedrock reflectors. Figure 4 shows an inline section together with two time slices at marked depths, in which the described features are highlighted. The reflection associated with the coffer-dam is believed to originate from the top of the structure. Its width of 6 metres and length of 17.5 metres matches the dimensions of the coffer-dam revealed in technical drawings.

Conclusions

The 3D Chirp system provides 3D imaging of the subsurface for the shallow survey market. It three-dimensionally images complex geometries and small objects in the subsurface with high resolution, making it a valuable tool for marine engineering, defence and marine archaeology, as well as general marine geology and geophysics applications. It is commercially available from GeoAcoustics Ltd.

Acknowledgements

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Biography

Dr Martin Gutowski is a marine geophysicist who has specialised in high-resolution seismic techniques. He has worked as a Research Fellow at the National Oceanography Centre, Southampton on the development and application of the 3D Chirp system for the last 4 years. ■

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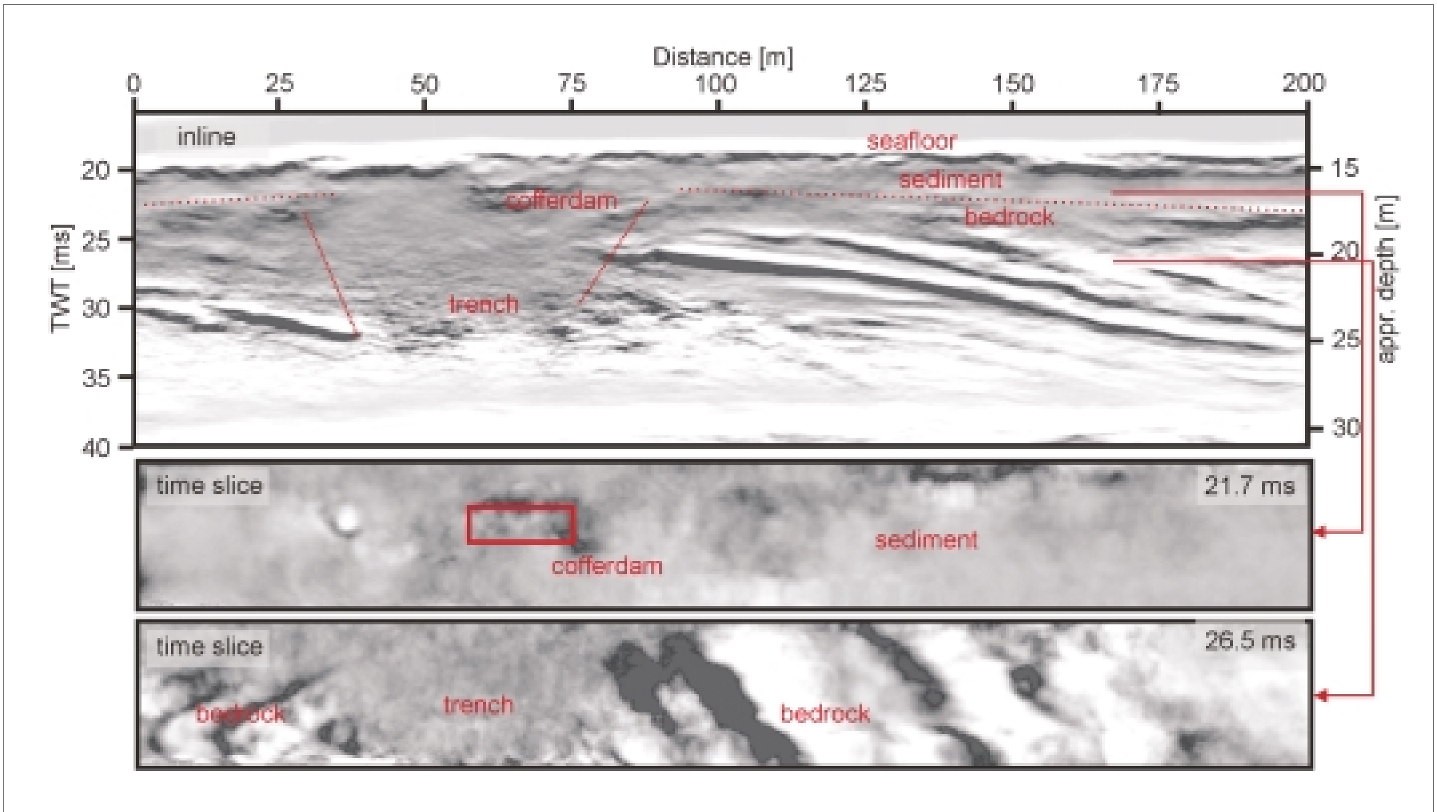

Figure 4: A vertical inline section and two horizontal time slices from the 3D Chirp data volume of 200m length and 25m width (Figure 3). The seafloor is at about 15m depth and the maximum penetration is equally 15 metres. The sections show dipping reflectors in the bedrock that are overlain by sediments. Between 25 and 85 metres, a disturbed area is apparent that is interpreted as the trench that was dredged to hold the toppled coffer-dam and then later infilled. Within the trench the reflection from the top of the coffer-dam with a length of 17.5 metres and a width of 6 metres is apparent, which corresponds to the dimensions recorded in detailed construction drawings of the structure. Note that the true strikes of the bedrock reflectors are apparent from the time slice at 26.5ms TWT. The time slice at 21.7ms TWT images the coffer-dam within soft surficial sediments (above bedrock).