Using 3D chirp data to identify boulders in the shallow subsurface to further infrastructure design.

Introduction

The identification of buried boulders is critical in the proper planning of sub-seabed infrastructure such as pipeline and cable routes. Coarse sediment such as buried boulders can lead to inadequate depth of burial due to the choice of insufficient trenching or pipeline protection methods. It is therefore fundamental to conduct a proper pre-route survey to increase engineering certainty and associated project costs (Burley et al., 2024) with the initial phase being to identify and quantify that risk (Wetton et al., 2024). In this case study, a replacement water injection pipeline was required to be emplaced between the location of a Floating Production, Storage and Offloading Facility (FPSO) and a wellhead at an associated oil and gas field in an area known to have a complex shallow subsurface.

This study outlines the process to which the Sub-Bottom Imager ™ (SBI) was used to identify the location and characteristics of sub-seabed boulders as well as lithological horizons along the proposed pipeline route, with the aim of further categorising the shallow soil conditions and aiding in the engineering design.

Sub-Bottom Imager and Survey Methodology

The SBI from Kraken Robotics Services is a 3D acoustic system used to image up to 5 m below the seabed. The system uses beamforming synthetic aperture sonar (SAS) to create a 3D volumetric image of the subsurface (Dinn, 2012). Coupled with accurate positioning, it can identify and quantify buried objects to a resolution of 0.1 m. In this case, the SBI was mounted to the base of a Work-Class Remotely Operated Vehicle (WROV), flown at an altitude above seabed of approximately 3.5 m and at a survey speed of 0.5 – 1.0 knots.

An on-site acceptance test was performed using a known section of pipeline to confirm the positioning, precision and repeatability of the SBI data, prior to the survey commencing. After completion, one continuous line of approximately 22 km was surveyed along the entirety of the proposed pipeline route, with the survey completed in less than 24 hours. The SBI data was rendered in real-time in the depth domain to 10 cm^3 voxels using a water and soil velocity derived during the acceptance test.

Survey Area and Geology

The survey area was located in the central North Sea within the United Kingdom Continental Shelf (UKCS). The regional geology can be summarised as follows (BGS, 1972/1973). A Holocene veneer consisting of a fine sand with occasional silt and shells, expected across the entire route to a maximum depth of 0.5 m. This overlies the Forth Formation, present along the majority of the route and comprised of an upper and lower member; the Whitethorn and Fitzroy Members, respectively. The Whitethorn Member is expected to consist of very loose to very dense silt and sand with an erosional surface marking its base. The Fitzroy Member is expected to consist of interbedded sands (very loose to very dense) and sandy clays (very soft to stiff) with a further erosional surface marking both its and the Forth Formations base. The Coal Pit Formation underlies the Forth Formation units and is expected to consist of very hard clay and dense to very dense sand units. These formations were reworked due to or in part by glacial processes and are highly likely to contain boulders and other poorly sorted sediments.

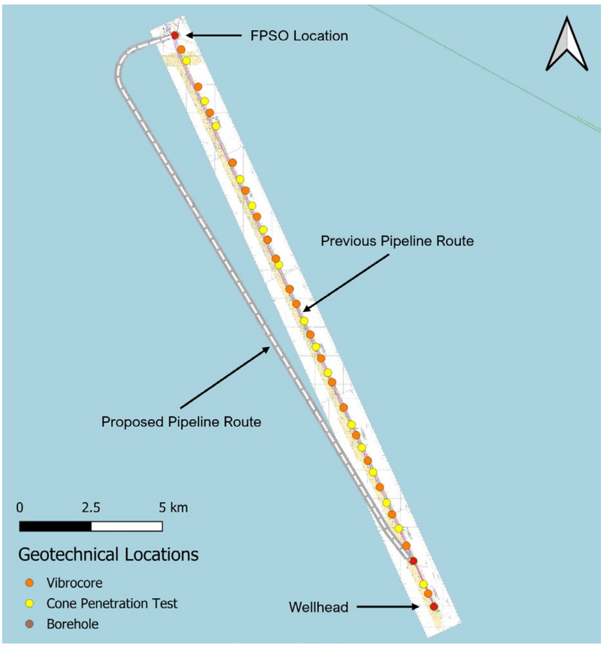

Figure 1 *Image showing the location of the survey corridor and position of supporting geophysical and geotechnical data used to ground-truth the SBI data.*

Data Integration

To properly interpret the SBI data it is highly recommended that it is appropriately ground-truthed. Geotechnical data in the form of borehole, vibrocore and cone-penetration tests (CPT) were made available. The majority of this data, as seen in Figure 1, was not positioned along the survey route. but along the route of a nearby and associated pipeline to the east, therefore in most cases, no direct correlation could be made. Interpretation was therefore started at the northern and southern ends, where a correlation was most certain. Furthermore, geophysical data along this route was made available in the form of alignment charts containing bathymetry, seabed features and shallow soil reflectors . Lastly, bathymetry and side scan sonar data acquired along the proposed pipeline route was also provided. This aided interpretation of when boulder bearing or other coarse deposits were exposed at the seabed.

Sub-seabed Boulder Detection Interpretation

Sub-seabed boulders were interpreted through the identification of discrete anomalies within the SBI data. The 3D volumetric data is sliced through in plan-view to identify discrete anomalies which meet the client reporting criteria, that is with a diameter of >0.3 m and which are usually considered to pose a risk to pipeline installation operations (Burley et al., 2024). The SBI data is also viewed in the profile view to gain an understanding of the relationship between the discrete anomalies identified and associated stratigraphic horizons.

Discrete anomalies are interpreted as sub-seabed boulders due to the fact they are composed of either cemented or crystalline rock. This having a greater density to that of the surrounding water saturated sediment, therefore a greater acoustic impedance. Differentiation between discrete anomalies representing boulders and clusters of relatively finer grained sediment such as cobbles and / or gravel can be made by assessing relative amplitude and shape. Accumulations of cobbles and gravel are assumed as having A) a lower acoustic impedance caused by a water saturated matrix and B) an irregular shape rather than that of a rounded or angular shape that boulders are assumed as having, caused by sedimentary processes.

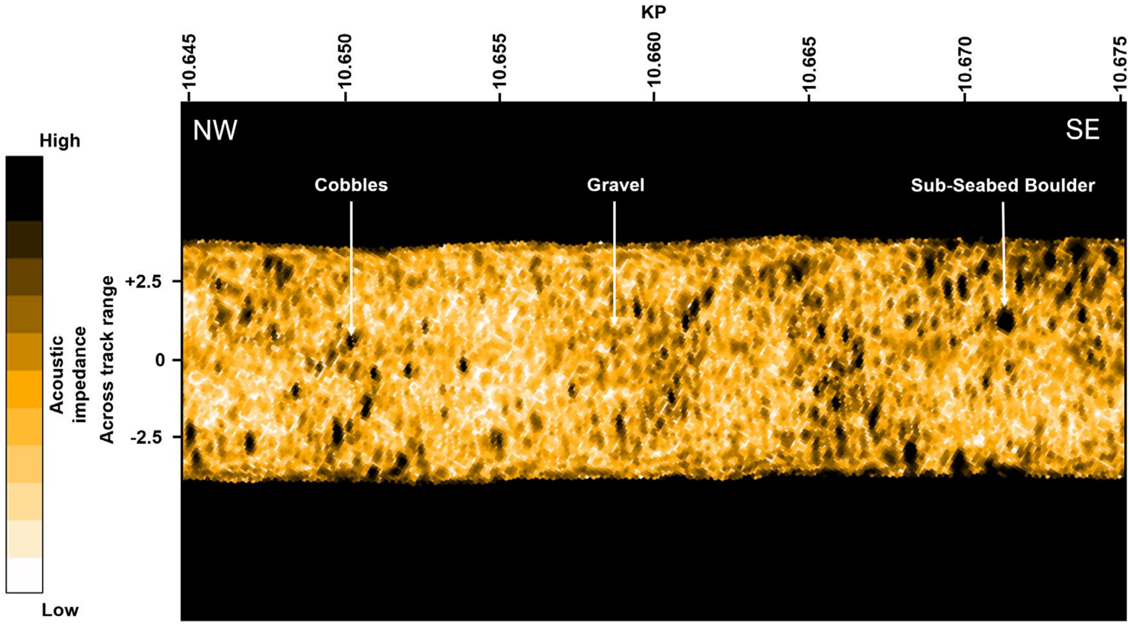

__Figure 2__ SBI data showing accumulations of varying sized coarse-grained sediment, displayed in plan view.

Results

In total 933 discrete anomalies interpreted to be sub-seabed boulders were interpreted throughout the length of the proposed pipeline route. Each of these was given a unique ID and had a measured location, dimensions and burial depth. Of these, the vast majority (750) were located <1.0 m below the seabed. It was found that the majority of buried boulders were associated with the two unconformable erosional surfaces marking the base of the Whitethorn Member (Forth Formation) and top of the Coal Pit Formation, which also showed to contain accumulations of other coarse grained sediments. These two surfaces were interpreted along the length of the survey route with the correlation between their location and that of identified discrete anomalies being shown in Figure 3. It can also be seen that the denser accumulations of cobbles and boulders correlate to bathymetric highs where the Forth Formation sediments thin and the Coal Pit Formation sediments shallow. Lastly, where the Forth Formation was observed to thicken, discrete anomalies were observed to be fewer and located at a greater depth.

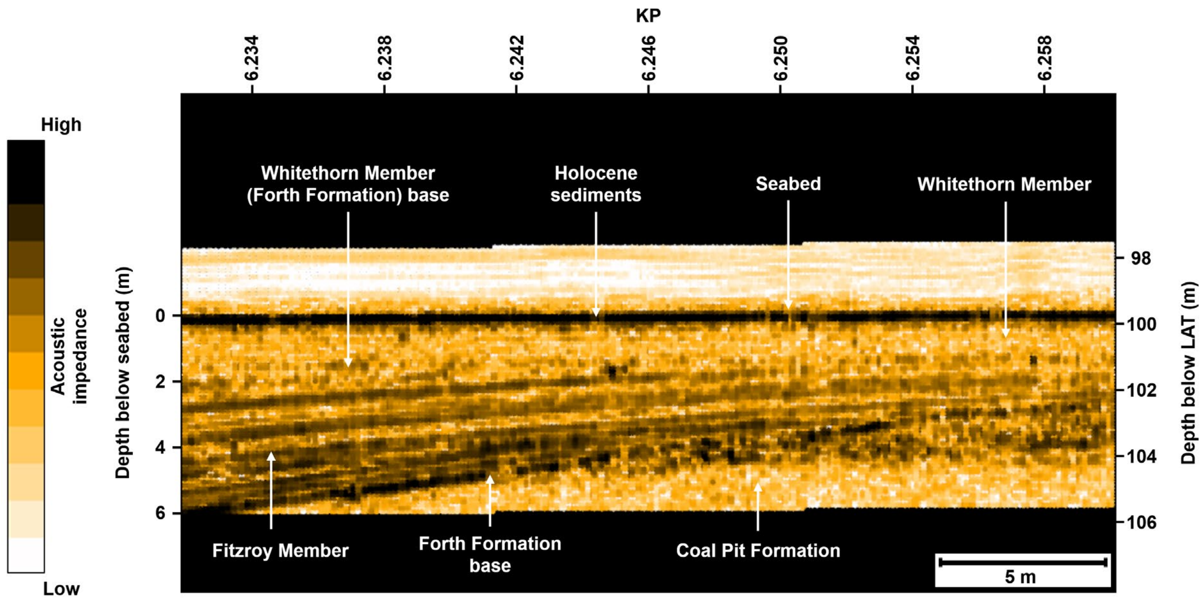

__Figure 3__ SBI data showing interpreted geophysical reflectors, displayed in profile view.

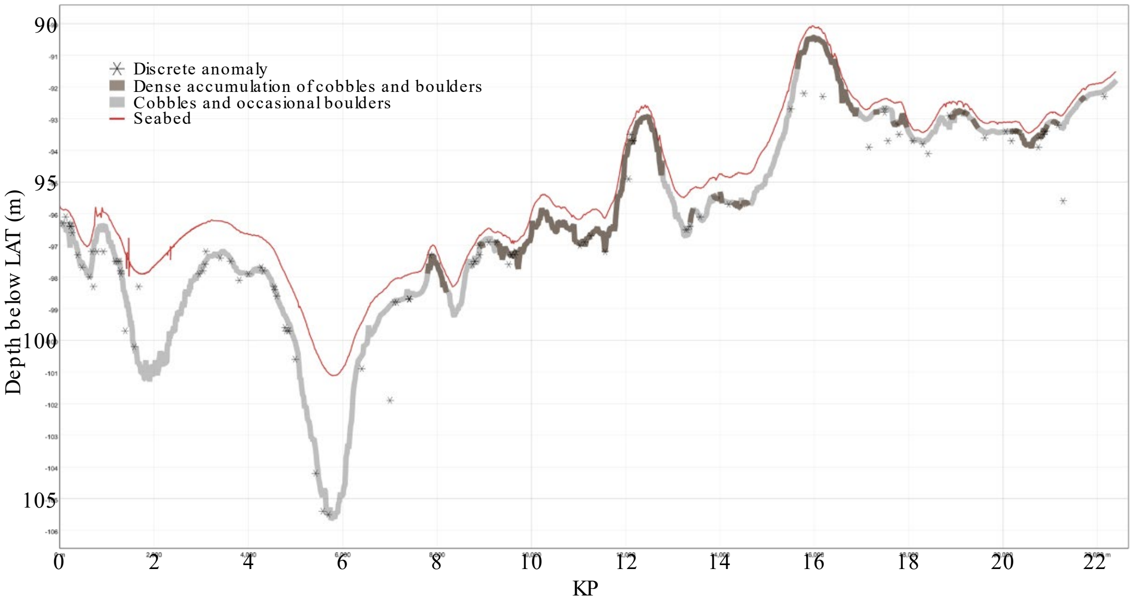

Figure 4 *Profile along the proposed water injection pipeline showing the correlation between the interpreted sub-seabed boulders and interpreted cobble layer.*

Conclusions

In this case the SBI has proved fundamental in identifying the distribution and dimensions of sub-seabed boulders along the proposed route, as well as where further coarse-grained sediments would likely be encountered – through the mapping of unconformable erosional surfaces such as the base Whitethorn Member and top Coal Pit Formation reflectors. This information enables the client to estimate the location and depth to which potentially problematic units or varying boulder densities might be encountered and the impact this would have on trenching operations. Namely which appropriate engineering strategies should be adopted to mitigate potential time and cost overruns.

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