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Supporting Alternative Energy Projects Using High Resolution Hydrographic & Geophysical Techniques — Garden Island, Western Australia

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INTRODUCTION

Wave energy is likely to become increasingly important as the global economies look to adjust to alternative energies that can be produced without any consequences to the environment. Marine geophysical surveys can play an important role in defining suitable environments for the establishment of power generation infrastructure and also for making significant contributions towards the more detailed geotechnical investigations required for site investigations and cable routing options. In April 2015, Marine GeoSolutions was contracted by Carnegie Wave Energy to undertake a detailed geophysical investigation of a selected site offshore of Garden Island to assess the area's suitability for the establishment of a wave power generation array (CETO6) and to investigate cable routing and installation site options for this infrastructure. The aims of the investigations were to map the seafloor and sub-bottom geology within the survey area and highlight any potential geohazards or unstable ground conditions which might have an effect on the installation of the wave generation array and the power cable connecting it to the shore.

SURVEY METHODS

The survey area comprised of a 13.1 km by 1.5 km corridor and three 1 km by 1 km individual site surveys were surveyed with the simultaneous acquisition of multibeam echosounder, side scan sonar, marine magnetometer and two different sub-bottom profiling systems (Figure 1).

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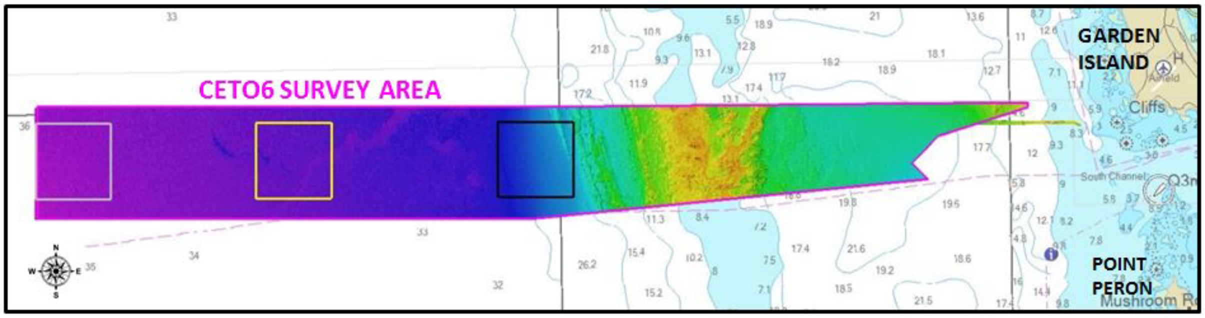
FIGURE 1. A shaded bathymetry chart showing the survey area and the site survey areas covered during the CETO6 geophysical survey campaign.



The survey line plans consisted of longer shore normal primary survey lines, a set of shorter subordinate coast parallel cross-lines and three sets of survey grids located at each of the site locations. Primary lines were spaced with a 50 m line separation, with MBES infill required over the shallow reef areas of Five Fathom Bank. Two tide gauges (RBR TGR-2050) were deployed near the survey area at Point Peron to record tidal elevations during the course of the survey. The elevations of the tide gauge pressure sensors were also accurately surveyed.

The survey instrumentation used for the project included:

- C-Nav 3050 GNSS & POS MV 320 inertial navigation system
- Reson SeaBat 7101ER-SV multibeam echosounder & Reson SVP’s
- Klein 3000 side scan sonar
- SeaSPY2 magnetometer
- GeoAcoustics pinger sub-bottom profiler
- Design Projects/AAE 500 J boomer sub-bottom profiler system
- Bolt 1500LL 5 cubic inch mini-airgun
- AAE Nexus EasyTrak USBL system & T-Count cable counter
- AGO Environmental sonar winch
- RBR 2050 tide gauges
- Van Veen grab sampler

The survey instrumentation sensors were either mounted on rigid, over-the-side poles or towed astern of the vessel. The magnetometer was interfaced into the side scan sonar in a tandem tow configuration whereby the magnetometer was towed on a fixed layback behind the side scan sonar. This tandem tow configuration was necessary to screen the magnetometer from all potential magnetic disturbances associated with the survey vessel, side scan sonar & boomer sub-bottom profiling electronics. Positioning of the towed arrays was made using a cable counter and the HYPACK® layback algorithms, and USBL beacon tracking. The medium penetration sub-bottom profiling was initially acquired using the 5 cubic inch airgun but this was changed to the 500 J boomer system due to the improved penetration (>40 m) and resolution of the boomer system. Various modules in HYPACK® were used to acquire all of the navigation, hydrographic and geophysical datasets. A custom-designed seismic acquisition system, developed in collaboration between Marine GeoSolutions and HYPACK, was used to acquire the dual channel sub-bottom profiling data.

On completion of the data acquisition phase of the survey, side scan sonar & multibeam backscatter mosaics were produced in order to design a sediment sampling programme to adequately ground truth the geophysical survey data.

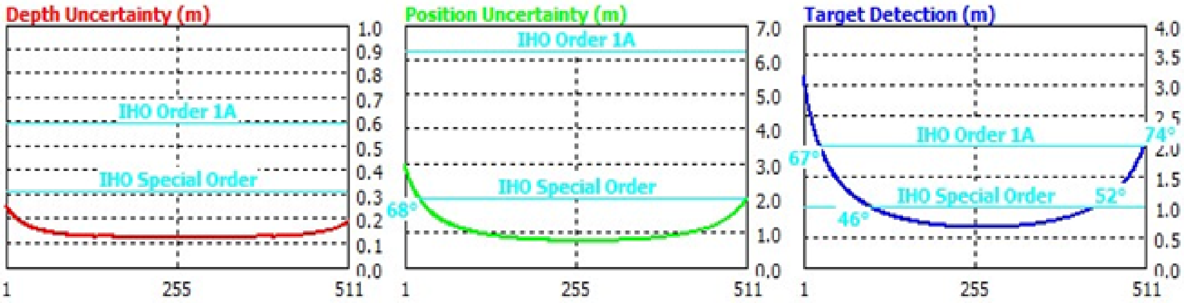
DATA PROCESSING

A total of 251 Gb of raw hydrographic and geophysical data were acquired during the course of the survey and were processed to produce the final survey products for the project. All bathymetric and sub-bottom profiling elevations are referenced to Low Water Mark Fremantle (LWMF), with the bathymetry data also being referenced to lowest astronomical Tide (LAT) and Australian Height Datum (AHD).

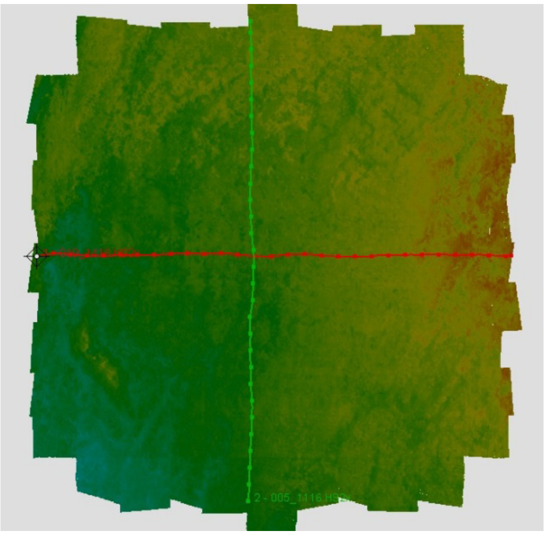
The tidal variation for the tide gauge deployment period fluctuated between 0.41 m and 1.64 m with respect to LWMF, with a range of 1.23 m, and a mean elevation of 0.80 m above LWMF.

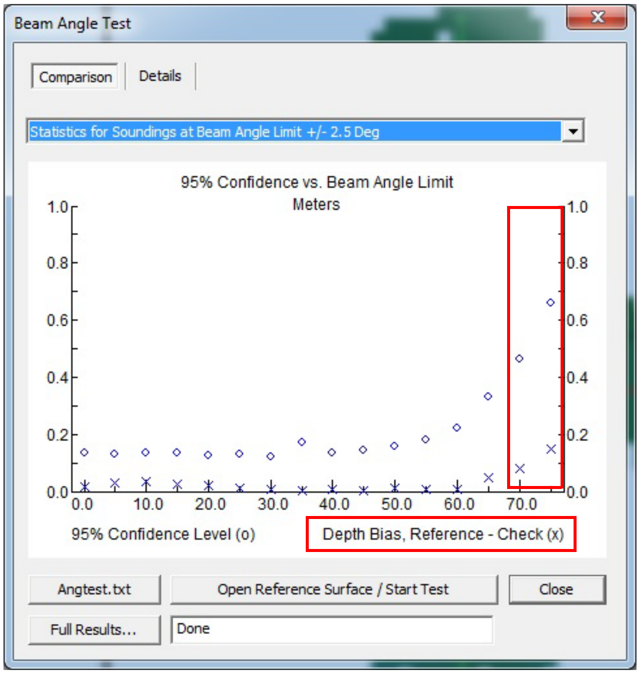
The multibeam echosounder data were processed using HYPACK® MBMAX64 (64-bit HYSWEEP® EDITOR). Data processing routines used included applying the tidal and sound velocity data collected during the survey; replacing real-time heave with post processed *True Heave* data; applying depth, spike and quality filters to remove spurious data; and, finally, using the *CUBE* statistical filters within the QPS Fledermaus software to clean and bin the data into suitable data density cells for map production. The average multibeam bathymetry sounding density consisted of 30 soundings per 1 m² in depths of -4 m to -36 m. A complex statistical assessment of the accuracy, performance and error budget of the multibeam bathymetry data was undertaken based on the criteria set out by the International Hydrographic Organisation. (IHO S44 5th Edition, 2008) using the HYPACK® total propagated uncertainty (TPU) editor. The calculated total reduced depth error for the average survey water depth (-25 m) was determined to be 0.12 m for the beams used (Figure 2). In addition to the statistical error budget assessment, a reference surface test area was surveyed in the deepest part of the survey area to compare the actual sounding uncertainty between a reference surface and two cross-lines (Figure left). This assessment was undertaken using the Beam Angle Test program in *HYPACK®* using the 0.5 m average BIN data. The results of this direct test yielded a depth bias of only 0.01 m to 0.05 m for all beams out to 68° from nadir and a depth uncertainty of between 0.12 m to 0.33 m at the 95% confidence level, which agreed well with the statistical analysis (Figure right).

FIGURE 2. *Statistical graphs showing the total propagated uncertainty (TPU) of the reduced depth, position and target detection based on IHO Special Order and Order 1A standards.*



Bathymetry reference surface sounding grid with beam angle test cross-lines superimposed. (left) HYPACK beam angle test graph showing the correlation of depth uncertainty verse beam angle from nadir. (right)





Statistics for Soundings at Beam Angle Limit +/- 2.5 Deg

Done

In addition to providing seafloor bathymetry data, the multibeam echosounder was also used to record the backscatter data. The multibeam echosounder backscatter data were processed using the Geocoder algorithm, which was developed at CCOM-JHC at the University of New Hampshire in the USA. The Geocoder engine applies a suite of accurately modeled backscatter radiometric and geometric correction algorithms to the data. For this project, a high-resolution (0.25 m) backscatter mosaic of the entire survey area was produced from the 240 kHz multibeam echosounder data.

The side scan sonar data were acquired directly within HYPACK®; therefore, no conversion was required to the data format. HYPACK® HYSCAN (SIDE SCAN TARGETING AND MOSAICKING) was then used to process the side scan sonar data into a 0.1 m resolution GEOTIFF mosaic and the final image processing was accomplished in ERMapper software.

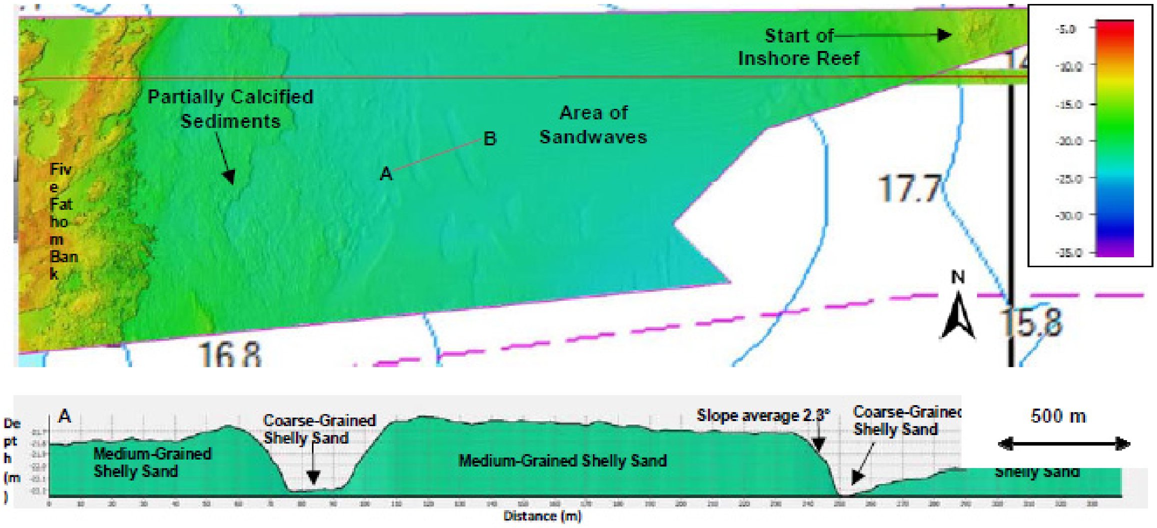
Basic processing of the magnetometer data was undertaken in the HYPACK® MAGNETOMETER EDITOR with the advanced data processing, including micro-tieline levelling and FFT (Fast Fourier Transform) processing, being accomplished within the INTREPID software suite.

The sub-bottom profiling data were processed using the HYPACK® SUB-BOTTOM PROFILER. This software is designed to process raw data (SEGY format), through the application of bottom tracking, TVG (time varied gain), band-pass filtering and contrast enhancement. The sub-bottom manual picking routine was used to digitize sub-bottom reflectors and correct for water column and saturated sediment velocity changes. The sub-bottom profiling data were separated into a number of discrete seismic units, by identifying well developed, acoustically reflective unconformities (erosional surfaces or surfaces which represent significant periods of non-deposition) within the penetrative range of the sub-bottom profiling equipment. In this way, the sub-surface succession was divided into discrete seismic units of similar degrees of consolidation and sedimentary character, based on the acoustic properties of each unit.

SURVEY RESULTS

The bathymetry data acquired during the CETO6 geophysical survey revealed isolated examples of low profile inshore reefs in the shallow inshore areas of the survey corridor, which gave way to a wide expanse of relatively flat seafloor dominated by medium–grained unconsolidated sediment cover. This broad area of unconsolidated sediment cover occurs inshore of the high profile calcarenite reef complex of Five Fathom Bank and is characterised by numerous bedforms indicating an east-northeast sediment transport direction. This area of flat seafloor gives way to a more lithified substrate along the eastern flank of Five Fathom Bank where subtle scarps indicate the presence of low relief calcarenite ledges (Figure 3). The seafloor in this area is believed to be composed of a broad expanse of partially calcified sediments that have accumulated along the eastern flank of the high profile Five Fathom Bank reef complex.

FIGURE 3. Inshore CETO6 survey area bathymetry and SW-NE trending bathymetric profile through coarse-grained sediment accumulations. Vertical exaggeration of profile is x36.



The Five Fathom Bank is composed of calcarenite outcrop that rises from a water depth of -20 m along the inshore reef margin, to a minimum water depth of -4.0 m along the reef crest. The Five Fathom Bank reef crest is defined by a highly variable topography comprising numerous rounded to sinuous calcarenite pinnacles that are dissected by sinuous and bifurcating inter-reef gullies that are infilled with a thin veneer of unconsolidated sandy sediment (Figure 4). The more rounded nature of the Five Fathom Bank reef crest is replaced by a series of well-defined linear calcarenite ridges along the western flank of the reef. These low-relief, linear calcarenite outcrops dominate the western flank of the reef and are eventually replaced by an extensive area of flat, featureless seafloor that dips gently towards the west. The flat and featureless area of the continental shelf is very extensive and extends to the western limit of the survey area. Relict features preserved on this part of the continental shelf include a lithified barchan dune and a palaeochannel that has been incised into a calcarenite substrate (Figure 5).

FIGURE 4. Five Fathom Bank Shaded Relief Bathymetry

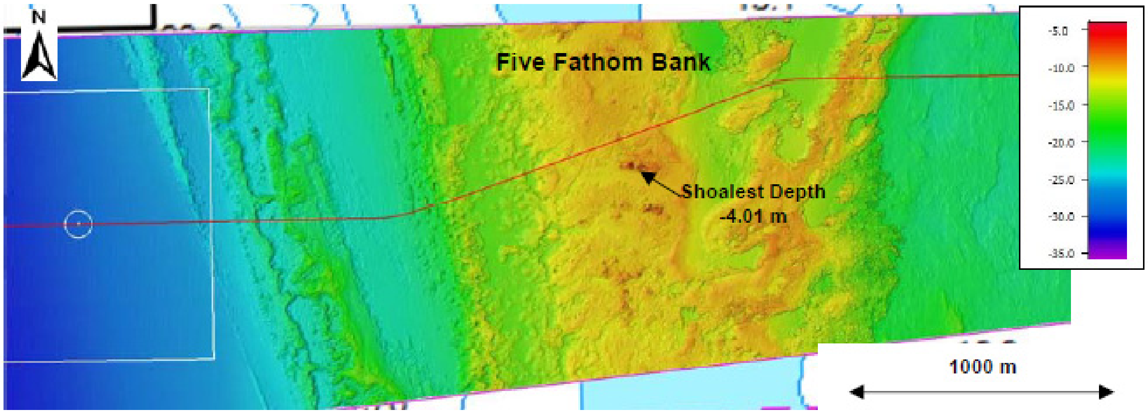
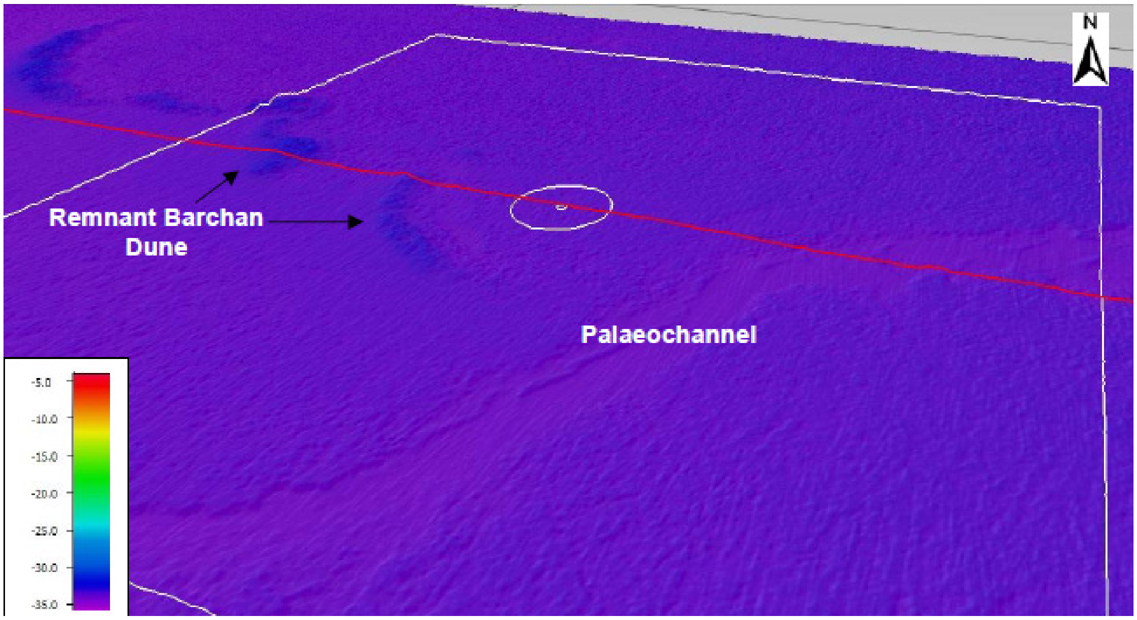


FIGURE 5. 3D Bathymetric Image Showing the Paleaochannel and Remnant Barchan Dune



The surficial seafloor geology was defined from a combination of the 500 kHz side scan sonar mosaic and the 240 kHz backscatter mosaic (Figure 6) which were digitised to produce a seafloor geology map (Figure 7 & Figure 8). Four different acoustic facies were identified within the unconsolidated sediments and ranged from medium-grained shelly sand to very coarse-grained shelly sand. Acoustic facies identified over lithified substrates included partially calcified sediments, a calcarenite boulder field, as well as low relief, medium relief and high relief calcarenite reef outcrop. Bedforms identified from the side scan sonar data included medium and large sandwaves. The large sandwaves appear to be storm-generated features which transport sediment shoreward in an east-northeast direction, whereas the medium sandwaves appear to have formed due to the development of a northerly flowing current between Garden Island and the Five Fathom Bank.

Angular Range Analysis (ARA) was undertaken on the backscatter data to model sediment grain-size based on the acoustic reflectance of the seafloor. A high degree of correlation was achieved between the predicted grain-size achieved with the ARA processing and 25 grab samples that were collected during the course of the survey to ground truth the side scan sonar data.

FIGURE 6. Multibeam Backscatter Mosaic Image Example of Medium-grained Shelly Sand Showing More Reflective Coarser Grained Shelly Sand Entrapped in the Medium Sandwave Troughs.

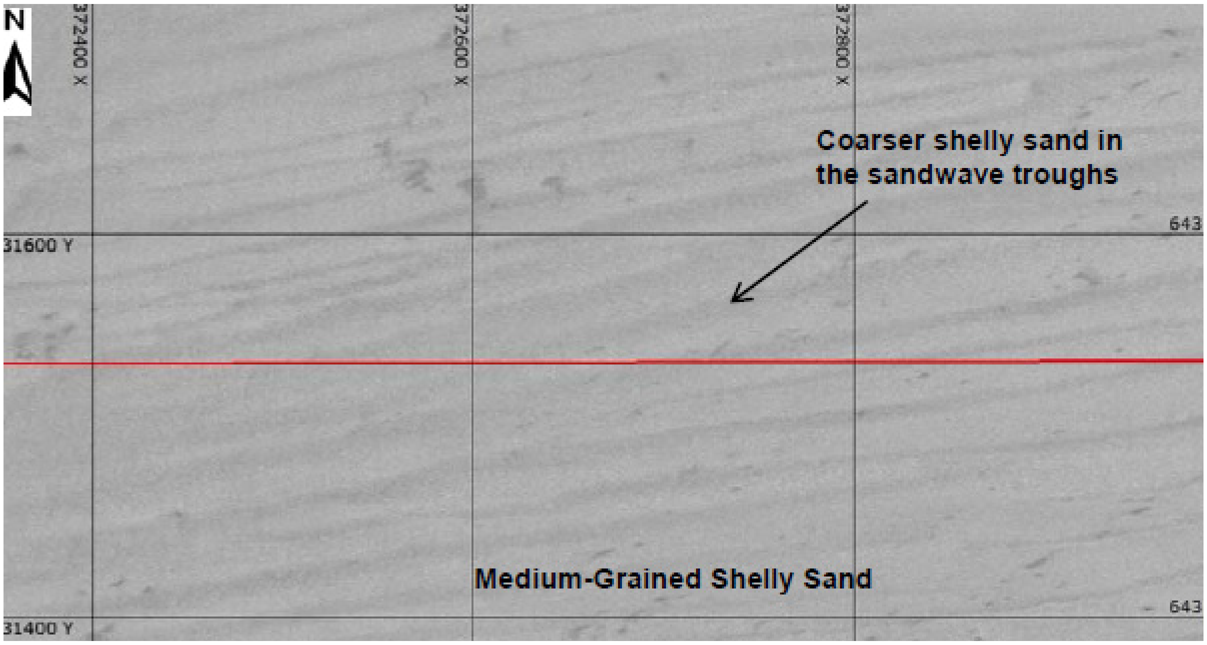


FIGURE 7. A Small Area of the Surficial Seafloor Geology Map, with Superimposed Sediment Thickness Isopachs, Showing the Complexity of the Survey Area.

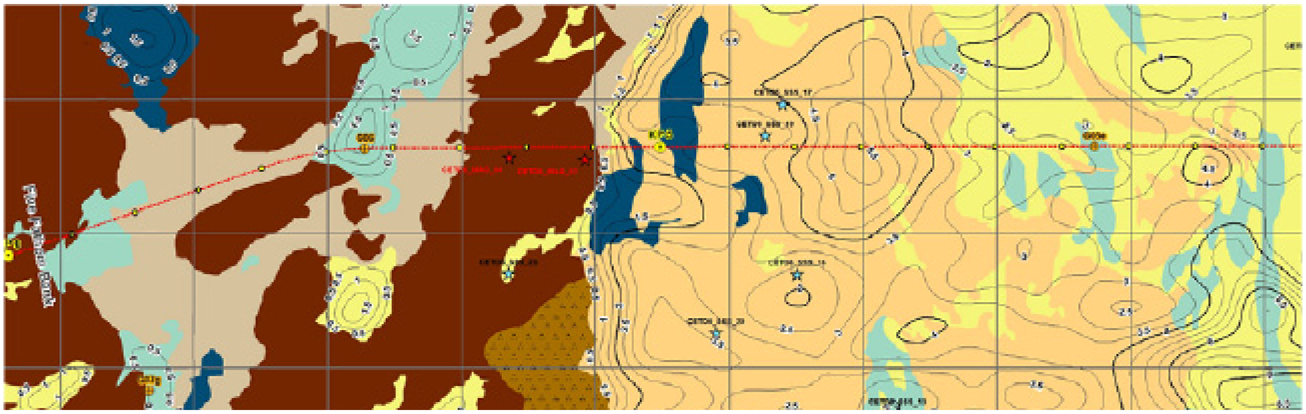
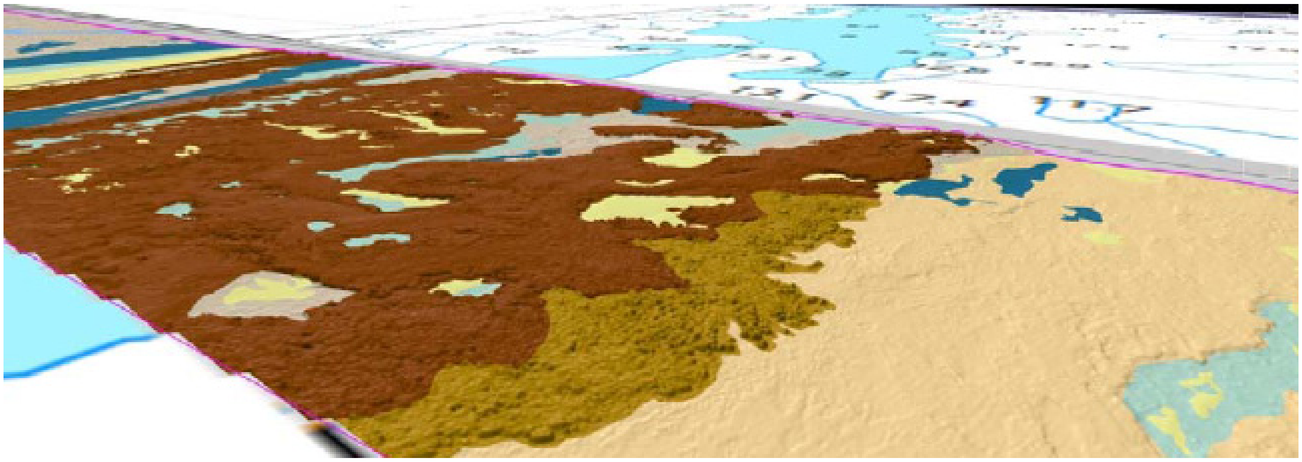
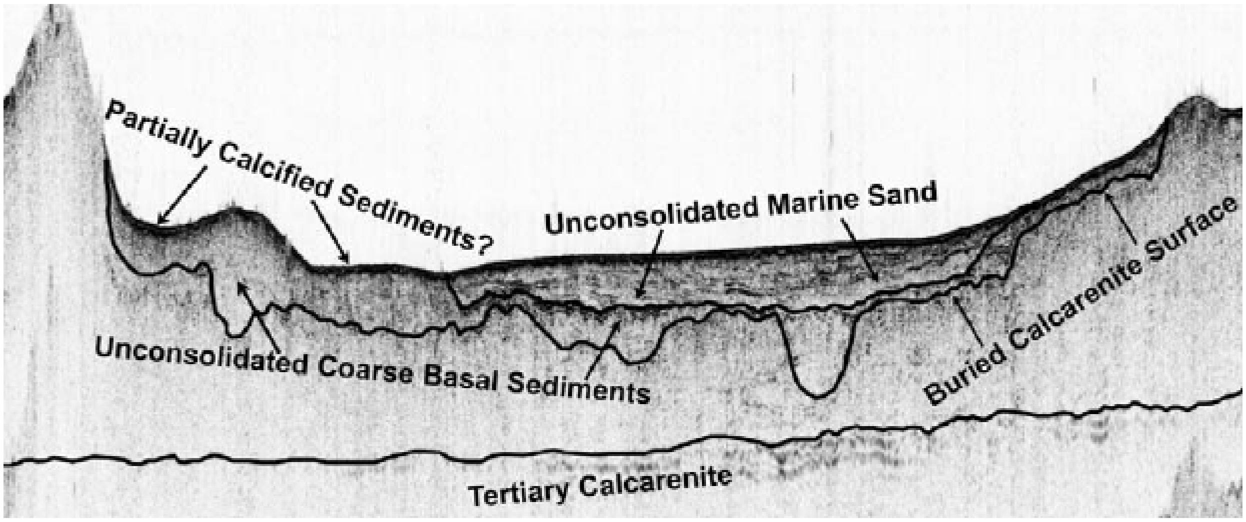


FIGURE 8. *Seafloor Geology Interpretation Merged with the Multibeam Bathymetry Data to Produce a 3d Model.*



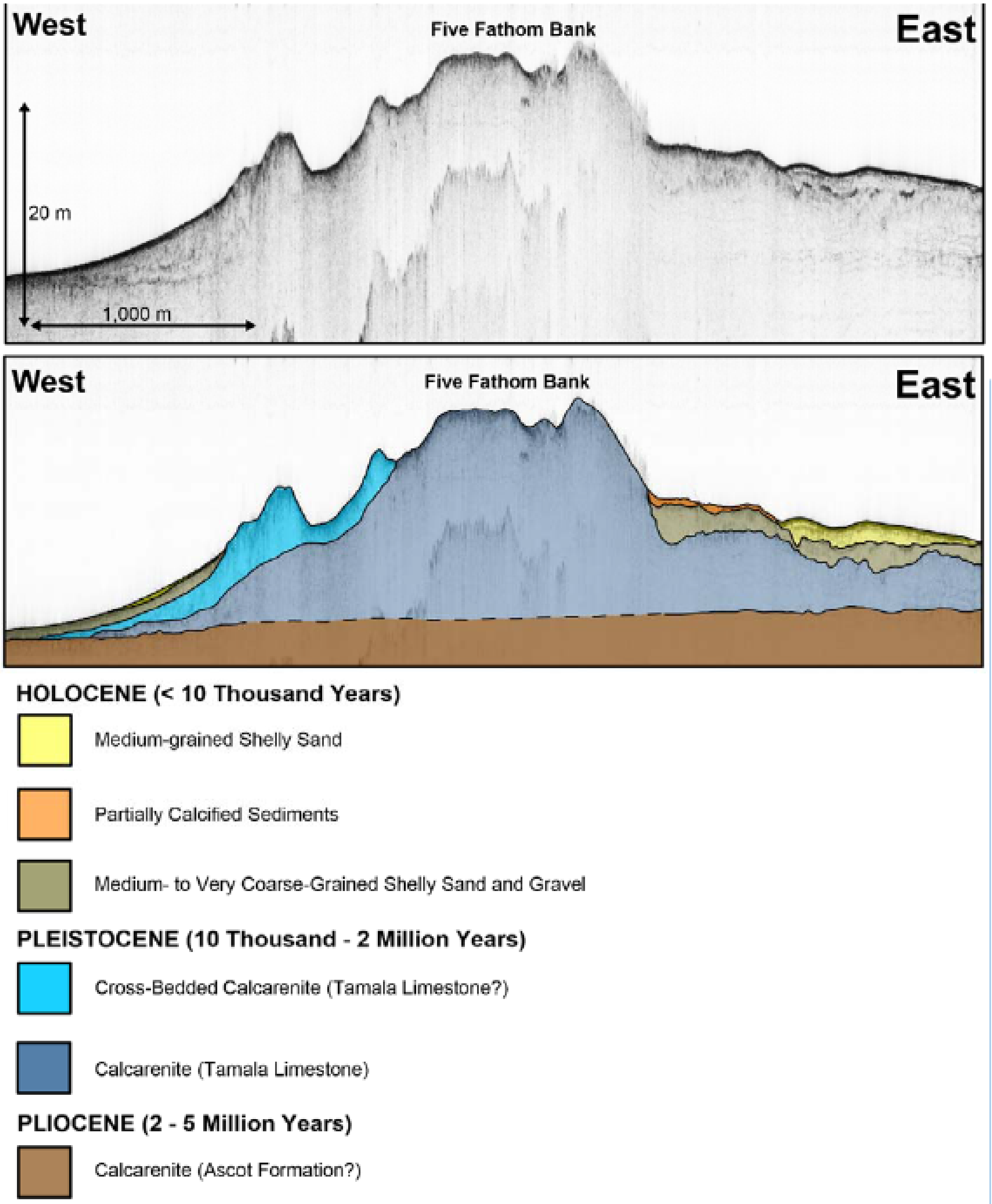
Several unconformities were detected within the penetrative range of the sub-bottom profiling equipment, including the Holocene unconformity that separates the unconsolidated marine sediments from underlying older calcarenites and a marine planation surface that underlies the high-profile Pleistocene calcarenites that form the Five Fathom Bank. The top of the sedimentary succession comprises relatively thin (0 m – 8.5 m) lenses of unconsolidated sediments, that consists of an upper unit of acoustically transparent sediments (0 m – 4 m) interpreted as medium-grained sands, and a thin (0 m – 7.5 m) basal unit of moderately reflective sediments interpreted as coarse-grained shelly sands and gravels. Together these sediments represent the Holocene unconsolidated sediments that occur in a broad trough inshore of the Five Fathom Bank (Figure 9).

FIGURE 9. *A filtered boomer sub-bottom profile illustrating unconsolidated marine sand and coarse unconsolidated coarse basal sediments overlying highly undulating buried calcarenite topography in the broad depression inshore of Five Fathom Bank. A deeper planar calcarenite surface of probable early Pleistocene age is also evident at the base of the sub-bottom profile.*



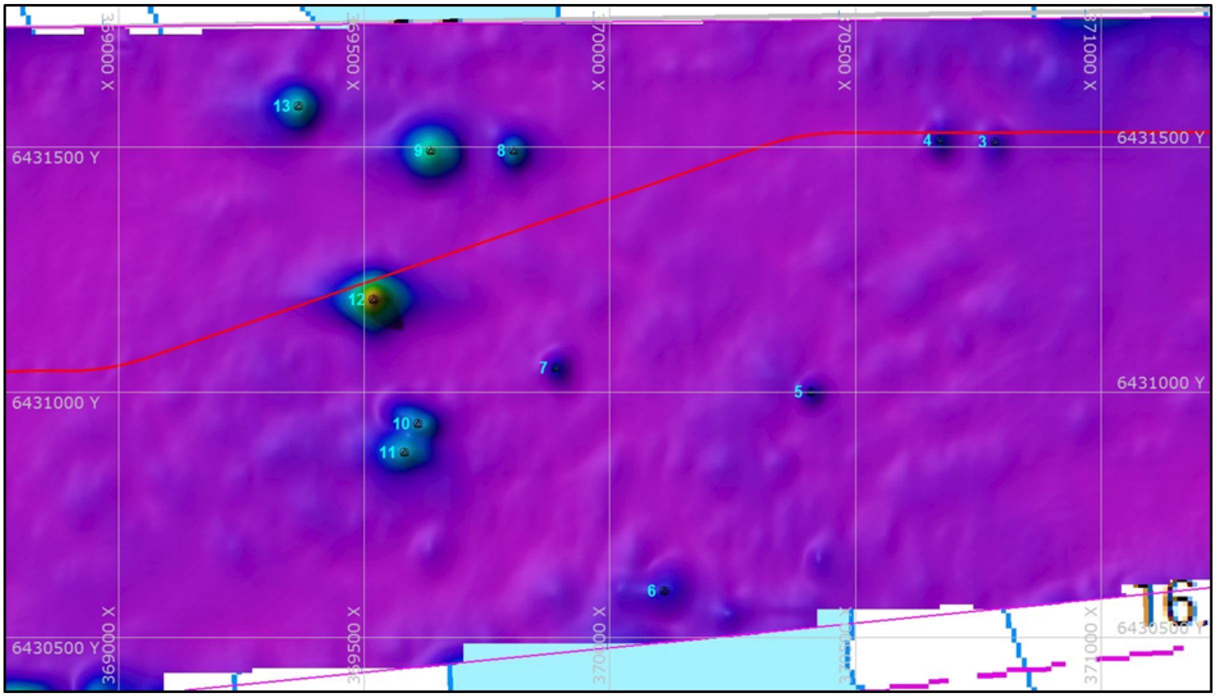
The relatively thin unconsolidated Holocene marine sediments in the survey area are underlain by a variety of calcarenite lithologies that are believed to vary significantly in age of deposition. The calcarenites are generally characterised by a highly acoustically reflective upper surface and a chaotic to saturated internal reflection configuration. The sub-bottom profiling data suggests at least three calcarenites, of different age and character, are evident below the CETO6 survey area. These are set apart one from the other on the basis of the surface morphology, discernible internal structure of the calcarenite units, and evidence of post depositional erosion features that are preserved within the calcarenites. The calcarenites identified beneath the CETO6 survey area include a strongly cross-bedded calcarenite of probable late Pleistocene age that has accumulated against the western flank of the more massive calcarenite that forms the higher profile reef of the Five Fathom Bank. The high relief calcarenite of the Five Fathom Bank reef crest is believed to be of a slightly older age and is assigned to the calcarenites of the Tamala Limestones, which are of Pleistocene age. Both the late Pleistocene and Pleistocene calcarenites rest unconformably on a well-developed planation surface that is underlain by older calcarenites of probably Pliocene age (Figure 10).

FIGURE 10. *Interpreted Seismic Stratigraphy for the Sediments Encountered Below the CETO6 Survey Area.*



The magnetometer data was processed to produce a Total Magnetic Intensity map and an Analytic Signal magnetic map. The Total Magnetic Intensity data is most useful in providing information regarding the deeper sub-surface geology and sedimentary basin characteristics whereas the Analytic Signal data is more useful in discriminating anthropogenic (man-made) targets lying on the seafloor or shallow-buried in unconsolidated sediment. The analytic signal survey product was of greater significance in the CETO6 geophysical survey and was used to accurately map twenty three high frequency magnetic anomalies (Figure 11). Most of these anomalies were associated with crayfish pots that had been deployed over the Five Fathom Bank reef crest and as such were interpreted as ferruginous ballast weights that were added to the crayfish pots to keep them stationary on the seafloor.

FIGURE 11. *Analytic Signal Magnetic Image Showing Anomalies Associated with Crayfish Pots and Fishing Debris on Five Fathom Bank.*



CONCLUSIONS

The CETO6 geophysical survey was a complex, multi-sensor geophysical survey which resulted in the acquisition of 2,325 line km of high resolution data. The survey can be considered a resounding success in light of the precision achieved during the survey, the high resolution data products delivered to the client and the value adding to the survey products that was provided by Marine GeoSolutions.