A Search for UXO in Papua New Guinea

Mapping small magnetic anomalies under difficult conditions

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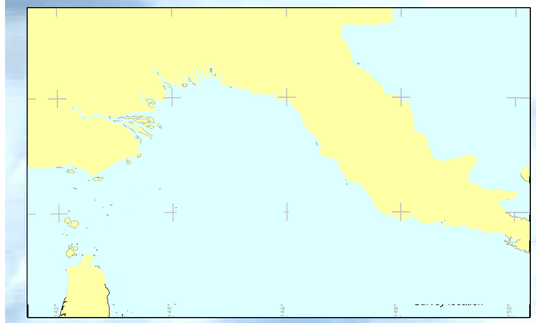
The PNG LNG Project proposes to develop gas fields in the Southern Highlands and Western Province of PNG and transport the gas via pipeline to an LNG facility in Caution Bay, near Port Moresby, for shipment to markets overseas. The processing facility site, and the last few kilometers of the proposed pipeline, are located in the vicinity of a World War II artillery testing range. The potential for unexploded ordnance (UXO) represents an ongoing hazard for the proposed development.



25 Pounder rounds (High Explosive (left) and Smoke (right)

Fugro Survey Pty Ltd were contracted by ESSO Highlands Ltd to provide marine survey services to locate any potential WWII-era UXO along the proposed pipeline routes and within the berthing and jetty areas in Caution Bay. The UXO are 25 Pounder Artillery shells, and measure 35cm long with a diameter of 9cm. Given the size and the sixty year age of the objects, they are impossible to detect with conventional magnetometers. In order to detect them, Fugro used a SeaQuest four-sensor magnetic gradiometer supplied by Marine Magnetics.

Scope of Survey

Caution Bay is fringed by mangrove trees, and has an intertidal reef platform extending approximately 1 km from the edge of the trees, with a water depth of 1 m to 2 m at the reef edge. The reef slopes steeply to a depth of 7 m approximately 50 m from the reef edge. From the base of this steep reef slope, the seabed is smooth silty sand which slopes gently to the west, reaching 17 m water depth at the end of the survey area 2 km from the reef edge.

The survey was conducted in two phases. The first, which covered water depths between the 17 m WD contour up to the reef edge (7 m WD contour) was carried out from the *MV Blue Angel*. For the areas above the reef edge, the water was too shallow for the *Blue Angel*, and a 3 m tender vessel was used to survey the remaining area up to the 0 m WD contour.

Operational Difficulties

The survey encountered numerous difficulties, including trouble with the vessel, and operational difficulties with the gradiometer.

Strong currents and high winds made line-keeping difficult, and deployment and recovery of the gradiometer dangerous. Given the predominant trade winds in the region, the wind often exceeded 20 knots in the early afternoon, and operations were frequently suspended.

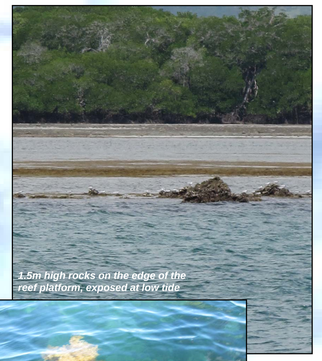
The seabed near the reef edge has numerous isolated coral and rock pinnacles and bomboras, which posed a risk to equipment.

In places the reef platform was fringed with up to 1.5m high rocks. Survey operations were limited to daylight hours, and high tides.

The reef platform is covered in 2m high seaweeds. These seaweeds frequently tangled around the frame of the gradiometer causing "weed strike" artifacts in the data. These artifacts appear similar to intense short-wavelength magnetic anomalies, and care had to be taken to identify these false readings.

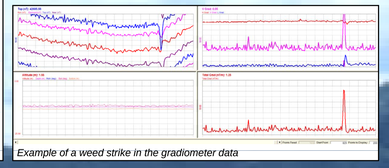
During the shallow water survey, a large foam block was affixed to the gradiometer in order to prevent it from impacting the reef platform and to keep the DGPS antenna above water. This had the additional effect of increasing noise in the data due to the increased movement of the gradiometer in small seas. Although magnetic anomalies could still be identified in these data, the shallow water data and deep water data are incompatible due to the relative background noise and intensity levels.

Despite these difficulties the survey was completed, and full coverage of the survey area was achieved. Given the limited range of the system a survey line spacing of 8m was required, meaning the total survey distance was approximately 250 line km.

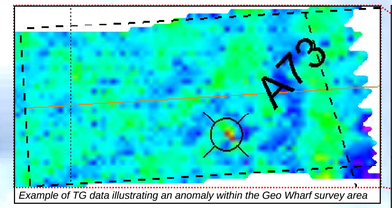


1.5m high rocks on the edge of the reef platform, exposed at low tide

Seaweed on the intertidal reef platform



Example of a weed strike in the gradiometer data



Example of TG data illustrating an anomaly within the Geo Wharf survey area

Results - Total Gradient

The Total Gradient (TG) accentuates magnetic anomalies relative to the background magnetic level.

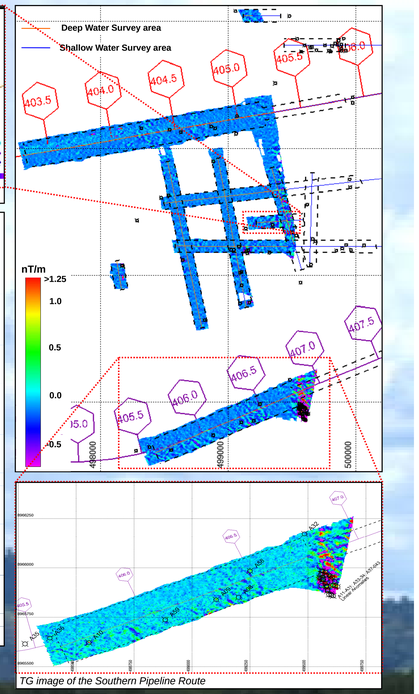
The advantage of the TG image (right) is that the locations of anomalies which are detected on adjacent lines can be compared, and the peak of the anomaly can be accurately determined.

A number of high intensity, short wavelength anomalies describing NNW/SSW linear features were identified at the eastern end of the Southern Pipeline Route. These anomalies were interpreted as metallic debris such as cable or pipe. Later investigation by ROV discovered that the anomalies were the result of sections of metallic cable protection on or buried just below the seabed.

The survey detected 103 separate magnetic anomalies, 63 of which were within the magnitude range expected for 25 Pounder UXO. The anomaly locations have an accuracy of ± 2-3 m.

The survey identifies potentially hazardous locations which can then be further inspected or avoided. If necessary, the potential hazards can then be removed by UXO specialists.

The results of this survey show that with the correct equipment it is possible to detect very small magnetic targets in very difficult conditions.



TG image of the Southern Pipeline Route

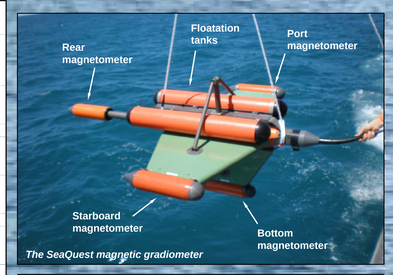
Remnants of metal cable protection in the eastern Southern Pipeline Route interpreted as the cause of the cluster of linear anomalies (above)

Gradiometer Theory

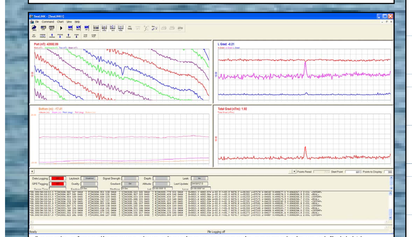
The SeaQuest magnetic gradiometer comprises an array of four magnetometers, which take total field readings at each sample location. The difference between the observed magnetic field value at each sensor can be use to calculate the magnetic field gradients in the X (horizontal), Y (longitudinal) and Z (vertical) directions. From these three gradients the Total Gradient can be derived according to the formula:

$$TG = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$

Where ΔX, ΔY and ΔZ are the horizontal, longitudinal and vertical gradients. Since the total gradient is a squared operation, the resulting anomalies are always positive. This removes the bi-polar effect of magnetic anomalies, and locates them directly over their source bodies, improving the accuracy of the survey.



The SeaQuest magnetic gradiometer



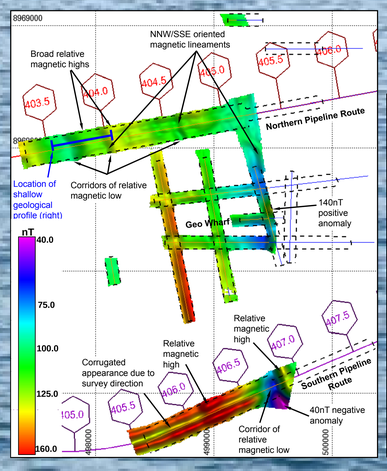
Sample of gradiometer data showing a magnetic anomaly in total field (A), vertical gradient (B), and total gradient (C) data.

Positioning

The gradiometer was positioned using a Sonardyne SeaScout USBL system. In order to avoid interference noise from the survey vessel engines, the gradiometer was towed at a distance of 75m. In the shallow water survey over the reef platform, the towfish was positioned with DGPS.

Pre-survey Trials

Testing with a shell found on the SP152 site showed that UXO were detectable at a maximum distance of 6 m from the gradiometer towfish, at a towing height between 2 m and 4 m above the seabed. The gradiometer was operated at a cycle speed of 2 Hz. The survey vessel was operated at a speed of 4 knots, which results in an along-track sample rate of 1 sample per metre.

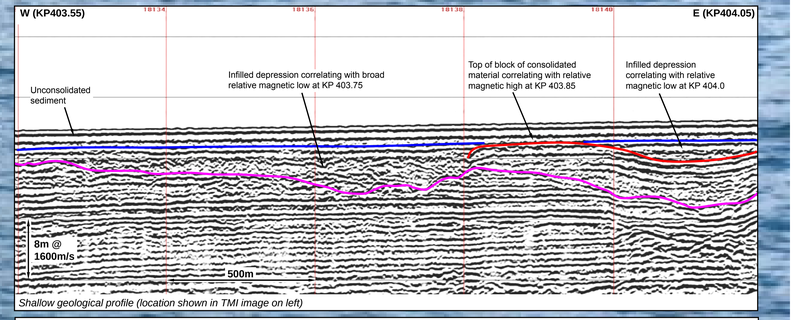


Results - Total Magnetic Intensity

The Total Magnetic Intensity (TMI) is the average of the total magnetic field measurements from each sensor, with the geomagnetic field value removed. No other corrections were made to these data. Only the data for water depths greater than 7m (i.e. the *Blue Angel* data) is shown, as the data above the reef platform are particularly noisy and unsuitable for analysis.

Several features were identified on the TMI image (left):

- A series on NNW/SSE oriented magnetic lineaments, particularly along the northern pipeline route. Comparison with previously acquired sub-bottom profiler data shows that these highs and lows correlate with shallow buried geological features.
- A relative magnetic high north of the Geo Wharf survey area, interpreted as a body of highly magnetic basalt or andesitic tuff.
- A NNW/SSE relative magnetic low trough near the eastern end of the Southern Pipeline Route located parallel to a relative magnetic high.



Shallow geological profile (location shown in TMI image on left)

Acknowledgements

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