Geosurvey Techniques in Offshore Diamond Mining

De Beers Marine routinely acquires ultra high-resolution geophysical data in support of its offshore mining and exploration programmes for diamondiferous placer deposits situated on the continental shelf off the West Coast of southern Africa. Geosurveys are conducted over a wide range of water depths, each with a unique geological seabed terrain and associated survey requirements. Detailed mapping of complex and varied geological terrain demands the use of leading-edge survey technology. To this end, we have for the past four years been routinely operating an AUV (Autonomous Underwater Vehicle) as our principal ultra-high resolution geophysical survey platform.

The continental shelf off the West Coast of southern Africa hosts the worldÃ•s largest known marine diamond placer deposit, with diamond concession areas covering an approximate 1,400km-long stretch of coastline. This coastline is typified by storm-dominated conditions, characterised by high winds and strong swells. The adjacent onshore coastal plain is characterised by an arid to semi-arid climate and is sparsely populated, with few ports. These factors contribute to challenging working conditions for offshore geosurvey, seabed sampling and mining operations.
One of the key factors crucial to success in offshore mining and exploration operations is the ability to improve geological understanding of the targets, thereby reducing the cost per square metre of ground mined. Geophysical imaging constitutes the fundamental framework upon which the entire exploration and mining operation is based. It is used to drive the following key areas: geological mapping and modelling, seabed sample targeting, geostatistical evaluation and mining area delineation, and the provision of geotechnical information used to aid mining tool selection and mining strategies. Geophysical data is also acquired post-mining to audit mining tool effectiveness and potential environmental impact of mining activities.

Terrain and Geosurvey Techniques

The geological terrain of the west-coast continental shelf is highly variable and requires various geosurvey techniques and strategies best suited to the terrain for mapping. The continental shelf commonly surveyed for diamond operations may be divided into three broad terrain types:

Inner Shelf Platform

This region occurs from the present-day coastline to about 2km offshore, from 0-30mbsl (metres below sea level). The seafloor is characterised by rugged topography formed by outcropping crystalline bedrock. Diamondiferous gravels are concentrated in sediment-filled structural depressions and wave-cut gullies eroded in the exposed bedrock (Figure 1), which range from a few hundred metres width down to a few metres width respectively. These gravels are normally extracted by diver-assisted suction hoses operated from small surface-support vessels.
Surveying this sort of terrain requires deployment of geophysical sensors off a small, fast, highly manoeuvrable craft, capable of operating in adverse weather conditions. Surveys are conducted with a pole-mounted Reson 8125 swathe bathymetric system and an in-house customised 1.5-12.5kHz Chirp Sub-Bottom Profiler (SBP), and a cable-towed Klein 3000 Side-Scan Sonar (SSS). The swathe bathymetric (Figure 1) and SSS data are the primary survey sensors in these regions, and are used to delineate gravel trap-site features.

Inner Shelf Slope

This region occurs from approximately 2 to 5km offshore the present-day coastline, from approximately 30-70mbsl. The inner shelf slope is characterised by a 1-20 seaward dip of the crystalline bedrock, which is draped by a thick wedge of unconsolidated sediment attaining a maximum thickness in excess of 40m in places. The diamondiferous gravels are located at the base of this sedimentary sequence. Surveying of this terrain is heavily reliant upon seismic profiling techniques capable of imaging the thick sedimentary sequences and associated gravel units. A Chirp SBP housed in a sub-surface-towed Focus400 ROTV is commonly used to achieve this (Figure 2).

Middle Shelf

This region occurs from approximately 5 to 150km offshore the present-day coastline, approximately 70-200mbsl. It is characterised by a very gentle slope of approximately 0,250. The geological terrain here is characterised by uplifted and eroded interbedded stiff clays, siltstones, sandstones and unconsolidated sands, resulting in a seafloor surface with complex micro-topography draped by a younger veneer of sediment containing diamondiferous gravels, usually no more than 1m in thickness.
The majority of offshore mining activity occurs in this region of the shelf and it is hence the area where the majority of geosurvey work is carried out. Mining and sampling in both inner shelf slope and middle shelf areas is accomplished by remotely operated means, from large mining vessels. Gravel can be mined via a vertical extraction method, using a large-diameter drill (up to approximately 7m diameter) similar to a pile-driving digging-head, that is lowered onto the seabed. An alternative horizontal extraction method uses a remotely operated crawler with a suction/cutting head, which traverses across the seabed forming a cutting lane anywhere between approximately 3 to 17m, depending on the crawler technology used (Figure 3).
In this terrain, geosurvey requirements are for both regional coverage (using the sub-surface-towed Focus400 ROTV and pole-mounted Reson 8101 swathe bathymetric system) and for ultra-high-resolution coverage of small areas of the seafloor (typically 1km2 blocks), with very high-precision positional accuracy. For this latter requirement we have routinely since May 2001 been operating a Maridan 600AUV, Autonomous Underwater Vehicle, (Figure 4). The AUV payload includes an SRD swathe bathymetric system, Klein 2000 SSS and an in-house customised 1.5- 19kHz Chirp SBP. Swathe bathymetry and SSS imagery provides value geological insight into complex seafloor micro-topography governing the distribution of potential diamondiferous gravel concentrations (Figure 3).

Where gravel bodies are obscured by a thin veneer of mud, the ultra-high-resolution of the Chirp sub-bottom coupled with the ability of the AUV to maintain a steady course and very closely spaced survey traverse spacing (down to 2.5m) enables the winning of very detailed information. The spatial distribution, geometry and thickness of these discrete gravel bodies may thus be ascertained.

Operations

De Beers Marine operations for inner shelf slope and middle shelf environments are conducted 24 hours a day. Because of the high occurrence of adverse weather conditions, operations are optimised to maximise the usage of the different survey methods in their respective operational weather-windows. This has enabled operations to cut weather downtime on the West Coast from 35% (1999) to a current 11% (2004). The reliability of the AUV (94% during 2003/4) has enabled other tasks to be completed while the AUV is busy with a dive. Typically, swathe bathymetry and transponder calibrations are carried out during AUV surveys.

The geosurvey team comprises five people: a party chief, section surveyor, geosurvey engineer, electronics technician and a data processor. All data processing is undertaken at sea. Apart from improved data turn-around time, this practise also ensures that data quality control is maintained all the way through to final product at sea. Typically, data from all three geophysical sensors collected during an AUV dive can be turned around within 6 hours of dive completion.

The geosurvey equipment is containerised and a vessel of opportunity is utilised as a survey vessel (Figure 4). Mobilisation of the charter vessel is undertaken in one day, while demobilisation is completed in 6 hours. Geosurvey support for diamond mining operations in the middle shelf region has, in the past, been a full year task. Improvements in survey efficiency, primarily the introduction of AUV technology, have whittled this down to approximately one hundred days. High-resolution targets were surveyed in eight days just three years ago. Today this is surveyed and processed in one day. During a 100-day campaign it is typical to collect approximately 24 square kilometres of AUV data, 200 square kilometres of combined Focus400 SSS, Chirp and pole-mounted swathe bathymetry. An additional 400 square kilometres of pole-mounted swathe bathymetry is also collected.

Geosurvey operations conducted over the inner shelf slope are also undertaken for about thirty days a year, typically with approximately 600 line kilometres of data acquired. Due to the adverse conditions in these very shallow water areas, operations take place only during daylight hours. Survey staff for these operations includes a party chief, surveyor and a technician, and data processing is also carried out on site.

Research and Development

New techniques for offshore mapping are continually being investigated as part of an ongoing geophysical research and development strategy aimed at increasing the confidence in making accurate geological predictions through improvements in data quality, resolution and sensor fusion. Current research involves the development of an AUV-based 3D Chirp sub-bottom profiler system.