OFFSHORE DIAMOND MINING APPLICATIONS

AUV-based 3D Chirp Sub-bottom Profiling

During the 1990s De Beers Marine identified a major business opportunity in radically improving its geological modelling capability. It set up a project to deliver the necessary geophysical systems and the team soon saw potential in integrating the companyâ€™s future development ideas for Chirp sub-bottom profiling sonar and sediment characterisation with the stability and accuracy of AUVs. The result was an ultra-high-resolution, 3D-volume imaging sub-bottom profiling system capable of low-cost, large-scale, deep-water (600m) mapping from a low-specification survey support vessel.

Since 2001 De Beers Marine (DBM) has been routinely operating an Autonomous Underwater Vehicle (AUV) as its principle, ultra-high-resolution geosurvey platform in support of marine diamond mining activities off the west coast of southern Africa. The key technological driver for adoption of this technology was the need to greatly improve the resolving capabilities of seabed mapping through the adoption of ultra-high-resolution, 3D, seafloor characterisation. By the late 1990s DBM had reached the technical limits of conventional vessel-towed, sub-bottom profiler (SBP) technology. Mine-support geophysical surveys were conducted with a MacArtney A/S Focus steered ROTV. Surface-vessel steering constraints meant that line holding was limited at best to 25m survey-line spacing for 2D-SBP acquisition. Added to this were limitations in ROTV motion stability in terms of heave, pitch, roll which impeded efforts to implement robust and repeatable, remote, sediment classification techniques on SBP data.

Perspective

To put the requirement for improving seabed characterisation into perspective, offshore mining operations employ two different methodologies to liberate diamondiferous gravels from the seafloor. The vertical seabed extraction method uses a large-diameter, pile-driver-like drill, up to approximately 7m diameter. The second method employs a horizontal-attack method whereby gravel is removed using a remotely operated crawler with suction/cutting head that traverses the seabed with a swathe of between 3-17m. Various seabed-mapping pilot studies had shown that the degree of variability in distribution, thickness and geological character of seafloor diamondiferous gravels were of a scale at least comparable to the size of the mining tools used. This is considerably smaller than the 2D-SBP-line coverage afforded by survey technology at the time.

The adoption of AUV technology offered both the platform stability and the line-holding capability to fully realise 3D-SBP potential. Between 2001 and 2004 AUV operations were geared towards improving operational efficiency of mine-support geosurvey activities and resolution and data quality of the geophysical payloads, which included a 2D Chirp SBP, Klein 2000 side-scan sonar and SVS swathe bathymetry system. Current mining-license areas held by DBM off the west coast of southern Africa (offshore Namibia and South Africa) approximate 15,000km2 area of seabed, over which a thin, patchy, gravel body is distributed with an average thickness of 0.5m. Little more than 8% of this area is characterised by gravel exposed at the seafloor. In these areas, side-scan sonar and swathe bathymetric data collected by the AUV has leveraged unprecedented improvements in geological characterisation of the seafloor, resulting in â€˜facies-scaleâ€™ geological models that have ultimately enabled selective mining and sampling activities in several areas. However, in the majority of the mining lease areas the gravel is overlain by a thin veneer of modern-day sediment. The current challenge is to map obscured gravel bodies in these remaining areas to the same level of detail using SBP mapping technology.

Data to Date

During February 2005 DBM commissioned a prototype 3D Chirp SBP system on its Maridan M600 AUV. To date, seven 3D datasets have been collected over various complex geological terrain, with 3D-coverage of the seabed of some 0.7km2 in over 100m water depth. The 3D data volumes acquired are binned to 30cm voxel size in X and Y and 3.75cm in Z, with an average depth of penetration into the seafloor of 5m.

3D System Specs

The 3D system is comprised of a transmit array of four inline transducers which transmit a 1.5-12.5 kHz Chirp signal. The array focuses the acoustic energy onto the seabed in an across-track direction from the AUV flight path. Echoes of the chirp signal from the seabed are received on the 3D-receive array, a 3m wing attached to the underside of the AUV containing 28 hydrophone elements (Figure 1). The signals received by each hydrophone are digitised and stored by the SBP acquisition system. The data is downloaded once the AUV is docked on the mother vessel and is processed offline using pulse-compression and beam-forming techniques that produce angular-swath data. This data is then binned to produce the final seismic volume. The seismic volumes produced to date are typically 450m by 400m in X and Y extents. During a typical survey the AUV â€˜fliesâ€™ at 5m altitude and 2.5m line spacing. Current battery technology allows us to collect approximately 20km of 3D data per dive.

Positioning

At the outset of the AUV project in 1999 positioning was seen as a huge challenge. The AUV needed to perform multiple dives on the same site in a robust and reliable manner and no system existed on the market that satisfied this need. Consequently, a state-of-the-art positioning system was specified and co-developed by DBM and Maridan. This formed a parallel development to the 3D project and was fully commissioned in 2003. In essence, a single transponder is placed on the seabed and calibrated to the GPS constellation. Before the start of each survey the AUV â€˜checks inâ€™ with this transponder. In this way the dive phase error is eliminated at the start. At the end of the dive the AUV checks in with the transponder again to measure drift while surveying. This drift error, which is usually no greater than 1m, is removed during processing.

3D Value-add

Acquisition of 3D datasets over some fairly complex geological terrain has begun to highlight the value-adding benefits, in terms of improved geological understanding, of 3D seismic data acquisition over conventional 2D data for mine support geosurvey work. For the first time it is possible to map out the full geometry and spatial extent of diamondiferous gravels (Figure 2). Areas of gravel accumulation versus areas devoid of gravel can be easily assessed. It has also been possible to map complex stratigraphic relationships within the gravel sequence through observation of superimposition of depositional features seen in the 3D datasets. Subtle geological and geomorphological features are also being mapped for the first time (Figures 2, 3 and 4).

Further benefits of 3D-data acquisition include the ability to assess sampling and mining effectiveness through the adoption of a strategy of pre-mine 3D seismic surveys followed by post-mine swathe bathymetric surveys to assess the clean-up effectiveness of the mining operation. One of the main downstream benefits of 3D data acquisition is the ability to visualise and understand complex real-world environments in a fully immersing and collaborative manner. It enables all downstream multidisciplinary technical experts and decision-makers to be involved and to interact with the data co-operatively. To this end, DBM is currently setting up a 3D-stereo immersing visualisation capability for interacting with the 3D seismic datasets.

Future Vision

During 2006 DBM will be commissioning a second AUV to cope with the increased survey requirements demanded by 3D data acquisition, as the implementation of this technology is rolled in as standard practise for offshore mine-support geosurvey. In addition, a more robust, production-orientated 3D-acquisition system is currently being developed in-house. Coupled with this, we are also pursuing optimisation of 3D surveys, experimenting with different flight heights and line spacing. Ongoing research and development of the system will also address derivation of velocity data from the system, with a view to correcting the 3D seismic volumes from depth-in-time to true depth. Currently, depth correction of volume is performed using estimated velocity-correction factors aided by a regional geo-acoustic database of the mine area. Another area of current research is mining tool control, location and visualisation, with the future vision being a mining tool for optimal extraction of diamondiferous gravel from the seafloor by selectively mining to a 3D-model.

We are also developing a broader-band, higher-frequency 3D chirp system with the aim of improving the angular and vertical resolution of the current system to open up opportunities for exploring potential MCM applications in buried mine detection.