The Role of AUV Technology in Seafloor Massive Sulfide Exploration

Proof-of-Concept Trial in Tongan Waters Tests AUV Technique For Seafloor Mapping in Sulfide Exploration

By Dr. Ian Stevenson
Chief Geophysicist
and
Sean Plunkett
Senior Geophysicist
Nautilus Minerals Inc.
Brisbane, Australia

Seafloor massive sulfides (SMS) deposits are typically located in water deeper than 1,000 meters and in close proximity to tectonic plate boundaries and submarine volcanic activity. Commercial exploration of SMS deposits requires mapping the seafloor at various scales, from regional mapping (greater than 10,000 square kilometers) to detailed prospect delineation (1 to 10 square kilometers). Vessel-based multibeam echosounder (MBES) surveys are commonly used at the regional scale of mapping. Follow-up detailed high-resolution mapping has been done with either ROVs or deep-towed geosurvey platforms.

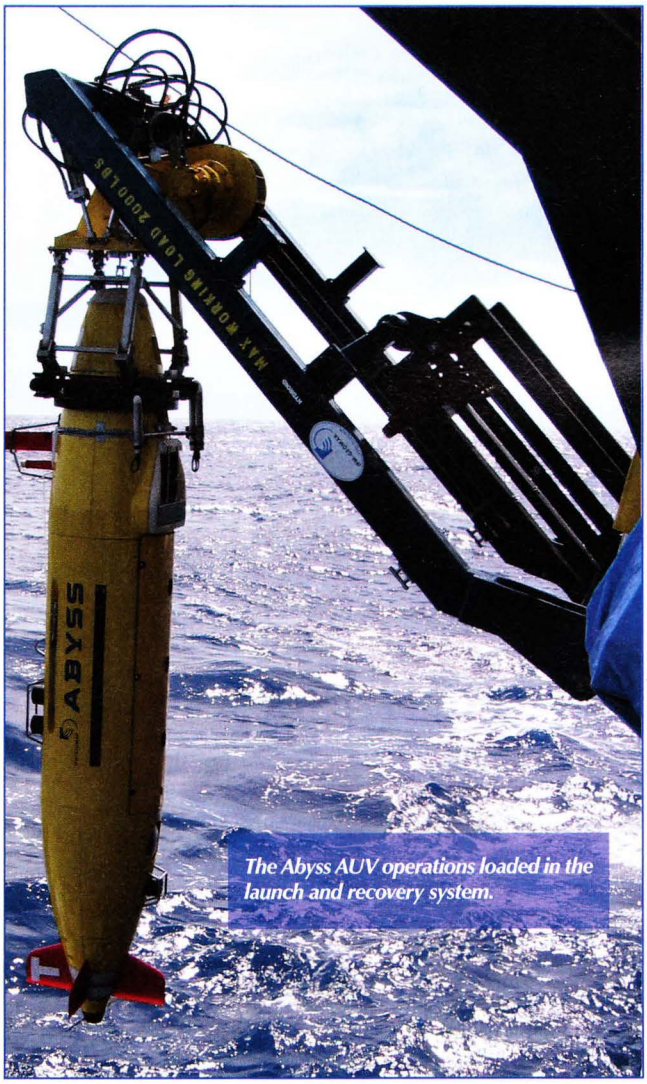
With the SMS exploration and production industry still in its early stages, significant opportunities exist to reapply existing technologies to this new industry. One technology with significant market benefit and growth potential is AUVs. Nautilus Minerals (Brisbane, Australia), which holds almost 600,000 square kilometers of exploration tenements granted or under application, thinks AUV technology can deliver a faster and improved assessment exploration technique to decrease the cost and delivery time of prospective seafloor sampling and drill targets. The company is developing a copper-gold production operation at Solwara 1, located in the territorial waters of Papua New Guinea, and building an exploration pipeline in the western Pacific.

SMS Exploration Techniques

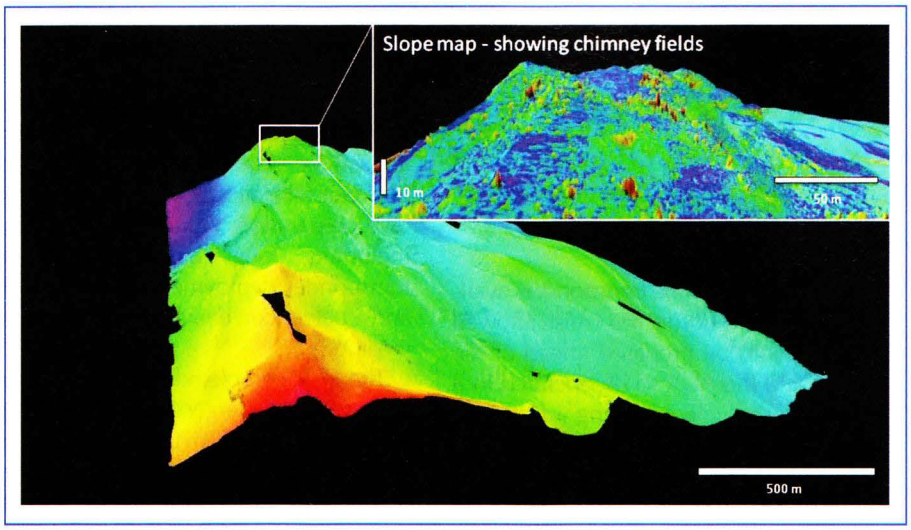
During the early stages of exploration, vessel-based MBES systems are used to map large areas of the seafloor, typically at 25-meter cell size. This enables identification of broad-scale volcanic and tectonic features associated with SMS mineralization. While this technique is rapid and efficient for surveying large areas, it does not provide the resolution needed to confidently discriminate the mound features and chimney structures associated with SMS formation.

In addition to vessel-based MBES operations, CTD sensor tow-yo operations are undertaken to map plume signatures in the water column from active (venting) hydrothermal systems. This technique involves the deployment of a deep-tow sled behind the survey vessel, which is repeatedly winched in and out as the vessel steams along a predefined course, so that the sled acquires a continuous vertical profile of data within the water column, using CTD, Eh and light-scattering sensors.

Once regional targets have been identified, in order to proceed to prospect delineation, high-resolution surveys must be

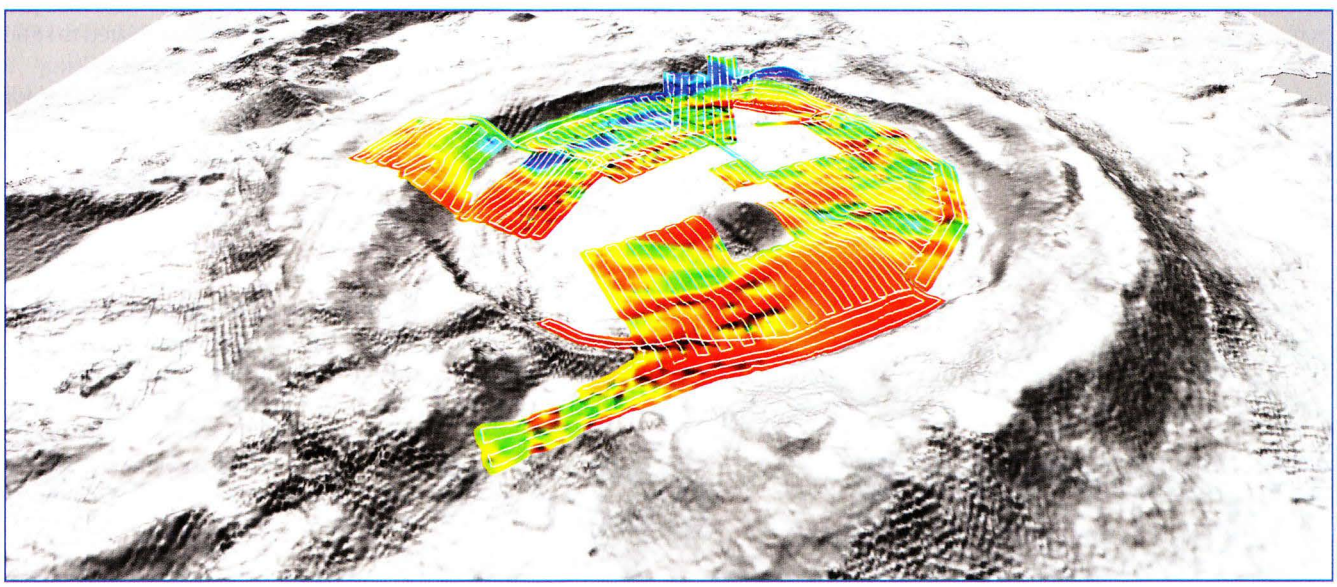


The Abyss AUV operations loaded in the launch and recovery system.



(Left) A RESON SeaBat 7125 MBES data mosaic (50-centimeter resolution) showing SMS chimneys over the Fonualei Spreading Center offshore Tonga.

(Bottom) A 3D drape of AUV magnetometer data showing magnetic anomalies associated with regional structure and possible hydrothermal alteration within a caldera.



conducted closer to the seafloor. Historically, this detailed mapping has included use of deep-tow side scan sonar technology, which is limited by reduced survey speed (maximum 2 knots), poor positional control of the tow-body due to the long length of tow cable behind the survey vessel and limitations of tow altitude (100 to 300 meters above the seafloor) required to avoid collision in predominately rugged volcanic terrain. The result is limited resolution of typically 1-to-2-meter cell size.

Another method for detailed seafloor mapping uses ROV technology. Although ROVs can host numerous geophysical mapping sensors and are well-suited to ground intervention and opportunistic sample recovery (geological rock specimens or hydrothermal chimney fragments), they are an inefficient means of mapping the seafloor and limited to maximum survey speeds of 0.5 to 0.7 knots. In addition, ROVs are not well-suited for continually traversing rugged volcanic terrain, and it is difficult to sustain long periods of productivity and minimize equipment breakdown unless two ROVs are utilized.

Despite their limitations, a combination of these techniques has yielded a high success rate in the discovery of SMS prospects for Nautilus Minerals on its exploration tenements.

AUV Technology

AUVs could bridge the gap between target generation from vessel-based MBES acquisition and detailed, prospect-scale ROV intervention for SMS exploration. AUVs provide the operational flexibility to survey with a variety of sensor payload configurations at different scales of resolution, provide higher-resolution mapping than is possible with conventional deep-tow technology and offer significant operational productivity gains over ROVs.

Conducting high-resolution geophysical surveys by AUV would enable ROVs to be deployed more effectively for other tasks to which they are better suited, such as selective follow-up ground truthing, sampling and electromagnetic surveys.

AUV Proof-of-Concept Survey

In November 2011, Nautilus Minerals sponsored a collaborative marine science research cruise initiative with the University of Hawaii and the Leibniz Institute of Marine Sciences at the Christian-Albrechts Universität zu Kiel (IFM-GEOMAR) over Nautilus Minerals' tenements in the northeast Lau Basin, Tonga. With the RV *Kilo Moana* from the University of Hawaii and Office of Naval Research, and GEOMAR's Abyss AUV, the 21-day cruise provided an opportunity to undertake a proof-of-concept evaluation of AUV technology for SMS mapping applications. The AUV was used for detailed follow-up mapping of hydrothermal plume anomalies discovered during another collaborative cruise initiative with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia, using its research vessel MV *Southern Surveyor* in 2009.

"Conducting high-resolution geophysical surveys by AUV would enable ROVs to be deployed for tasks to which they are better suited."

The GEOMAR Abyss AUV, a Hydroid Inc. (Pocasset, Massachusetts) REMUS 6000 depth-rated to 6,000 meters, included a dedicated launch and recovery system and was contained in two standard 20-foot containers. The primary mapping payload was either a RESON A/S (Slangerup, Denmark) SeaBat 7125 400-kilohertz MBES system or EdgeTech (West Wareham, Massachusetts) 2200 410-kilohertz side scan sonar system. In addition, this marked the maiden cruise for a three-axis flux-gate magnetometer AUV payload built by GEOMAR. Magnetometer data was acquired concurrently with MBES or side scan sonar primary payloads, along with CTD and turbidity data.

The AUV was deployed in fully autonomous mode by laying a two-transponder long baseline array over each dive site. Having additional batteries and long baseline transponders available on board during the cruise allowed dive sites to be prepared ahead of the AUV, and the AUV to be operated in a continuous cycle, enabling a fast turnaround time between dives. The support vessel was able to engage in other activities while the AUV was surveying, including vessel-based MBES and magnetometer survey operations, and camera tow and seafloor sampling activities.

Results

The AUV mapped a total area of 114.71 square kilometers during the cruise, achieving 1,199 line kilometers of survey. Of those 1,199 line kilometers, 1,007 line kilometers of actual data were recovered, due to some data loss encountered on two dives. The AUV undertook surveys 46 percent of the 240.58 hours total dive time during the cruise, with only 5 percent time utilization attributed to equipment failure that caused launch delays. Eighteen percent of operations time was spent on vessel transits between dive sites; 27 percent on AUV dive preparation, launch and recovery, including long baseline acoustic transponder deployment and recovery; and 4 percent on dealing with inclement weather.

The AUV completed surveys of 10 out of a planned 14 target areas, constituting 16 dives in total. From the data acquired, it was possible to map SMS chimney field targets using MBES and side scan sonar. The magnetometer data also provided useful information related to structural trends and anomalies key to understanding SMS mineralization formation processes. CTD and turbidity data provided useful detailed-scale information pertaining to the location and distribution of plumes from active hydrothermal sources.

AUV Versus ROV Survey Efficiency

Comparing AUV and ROV survey efficiencies using historical data from Nautilus Mineral exploration programs over an equivalent cruise duration shows that AUVs are at least 5 to 6 times more efficient; a total of 212.54 line kilometers for ROVs compared to 1,199 line kilometers for AUVs, or 1,007 line kilometers if considering data loss experienced during the *Kilo Moana* cruise.

A comparison of area coverage statistics shows nearly double square kilometers of coverage using AUV technology; an average of 9.4 square kilometers per AUV dive compared to an average of 4.8 square kilometers covered per ROV dive. However, it must be noted that this is a comparison of an AUV traverse line spacing of 120 meters versus an ROV traverse line spacing of 200 to 300 meters.

Future survey efficiency improvements could realistically enable AUV traverse line spacing to be opened up to 200 to 300 meters to gain greater area coverage efficiencies over ROV survey as geological targeting confidence increases with ongoing data set familiarity from mapping sensors onboard the AUV.

The platform stability and payload flexibility afforded by AUVs enables 100 percent seafloor coverage with high-resolution MBES or side scan sonar to a resolution of 50 or 5 centimeters, respectively, which enables much higher

confidence in geological mapping than afforded through the limited field-of-view from ROV camera footage at wider traverse spacings. In addition, AUVs provide a suitable means of addressing the critical resolution gap between target generation (vessel-based regional-scale mapping) and follow-up target-testing mapping (ROV-based operations) in the exploration process.

Conclusions

From the data acquired by the AUV during the proof-of-concept trial, it was possible to map SMS chimney field targets using MBES and side scan sonar. Subsequent ROV selective ground-truth survey is planned for late 2012.

The proof-of-concept trial demonstrated that AUVs are a viable technology for SMS exploration, offering better resolution and productivity than present deep-tow practices and greater efficiency than ROV mapping. AUV technology will enable more selective prospect delineation and ROV follow-up mapping, and provide significant reduction in the amount of ground that needs to be covered by ROV.

The results of this trial are part of the ongoing development of a long-term strategy for a sustainable AUV survey capability to meet the demands of increased global SMS exploration, as well as assessing suitable AUV designs and configurations for SMS exploration needs.

Acknowledgments

Nautilus Minerals wishes to acknowledge the University of Hawaii, particularly Dr. Fernando Martinez, lead scientist for the RV *Kilo Moana* cruise 1129A, and Dr. Colin Devey of IFM-GEOMAR for facilitating the marine science research cruise collaboration.

Thanks to the GEOMAR AUV team, crew and science members on board the *Kilo Moana* for their effort in making the cruise and evaluation of the AUV technology a success. ■

Dr. Ian Stevenson has worked in the marine minerals exploration and mining industry for the past 23 years, specializing in the development and application of high-resolution geophysical techniques and AUV mapping payloads. He has a Ph.D. in geophysics from the University of Reading.

Sean Plunkett is a senior geophysicist for Nautilus Minerals and has been heavily involved in a wide range of seafloor and water-column interrogation techniques utilized in SMS exploration. He holds a bachelor's in geophysics from Curtin University of Technology.