



Evaluating the Applications and the Growing Importance of Autonomous Underwater Vehicles (AUVs) in Marine Geophysical Survey

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DOI: <https://doi.org/10.70382/ajsitr.v7i9.032>

Abstract

Autonomous Underwater Vehicles (AUVs) serve a broad spectrum of purposes in marine geoscience and oceanography, and are increasingly utilized across scientific, military, commercial, and policy domains. Their capacity to function independently of support vessels makes them ideal for exploring challenging environments, such as the deepest hydrothermal vents and areas beneath polar ice. Beyond their autonomy, AUVs are highly efficient at collecting vast amounts of high-resolution, precise, and accurate data in a very short period, making them powerful tools in underwater exploration. AUVs have significantly advanced our ability to image the seafloor, offering seafloor mapping data of higher resolution than what surface vessels can achieve—especially in deep-sea settings. This review highlights the role of AUVs in acquiring electric and magnetic field data for geophysical surveys and subsea structure inspections. It underscores how AUV-based technologies are transforming deep-sea robotic exploration, particularly under Arctic ice cover, and evaluates their growing utility in gathering geophysical information. Research has shown that AUVs are effective tools for scientific investigations beneath permanent ice sheets. However, the use of electromagnetic methods in AUV surveys remains relatively rare. The integration of self-compensating magnetometers with electric field sensors allows for the

collection of comprehensive electromagnetic vector data. These data are valuable for a variety of applications, including subsea infrastructure inspection, self-potential studies, and controlled-source electromagnetic surveys. Looking ahead, advancements in AUV technology that could enhance marine geophysical monitoring include vehicles with improved hovering capabilities, extended endurance, deeper operational limits, and rapid deployment features. Additionally, the development of novel sensors will broaden the spectrum of geophysical properties that AUVs can measure, as demonstrated in the context of deep-sea robotic exploration in the ice-covered Arctic Ocean.

Keywords: Marine Geophysical, Autonomous Underwater Vehicles, Remotely Operated Vehicles, Control Source Electro-Magnetism, Subsurface Sea Structures, Ocean Technology.

Introduction

Marine autonomous systems like streamers, submarine gliders, and AUVs are revolutionizing ocean mapping and observation by collecting data independently, without physical tethering or real-time human control, even though they are typically deployed from research vessels (Yoerger et al., 1998, 2007; Caress et al., 2008; German et al., 2008b; Griffiths, 2003). Their independence allows marine autonomous systems to collect data in otherwise inaccessible ocean regions, such as beneath polar ice sheets or in extreme environments like hydrothermal vents, which feature high temperatures and constant seismic activity (Bellingham et al., 2000; Brierley et al., 2002; Nicholls et al., 2006; Wadhams et al., 2006; Dowdeswell et al., 2008; Jenkins et al., 2010; Graham et al., 2013). Additionally, these systems are

enhancing the detail and frequency with which a wide range of marine parameters can be measured.

Equipped with advanced sensors and imaging tools, Autonomous Underwater Vehicles (AUVs) can collect detailed data and high-resolution images of the ocean floor. Their ability to reach depths beyond human access makes them valuable for exploring uncharted regions, studying marine habitats, mapping underwater geology, and locating submerged artifacts. The advancement and use of AUVs have greatly expanded our knowledge of the ocean, opening new avenues for scientific discovery, environmental assessment, resource exploration, and marine archaeology. Thanks to their ability to operate independently over long durations, AUVs have become essential tools for collecting

vital information and conducting research in remote and demanding underwater environments (Ahmed, E. et al., 2017).

Advanced seabed image processing methods have greatly improved AUV capabilities, enabling efficient analysis of vast visual data through modern algorithms and computer vision technologies (Wölfl et al., 2019). They support a wide range of applications, from recognizing marine life and habitats to identifying geological structures and submerged objects, offering critical insights into the marine environment.

Additionally, recent economic factors—such as the sharp rise in vessel fuel costs—have made autonomous systems an appealing option for organizations engaged in large-scale, cost-efficient marine data collection efforts (Wynn et al., 2012). Marine autonomous systems are also finding broader applications across defense, industry, and policy sectors, including in geohazard assessments related to oil and gas infrastructure (Eddy Lee and George, 2004).

This paper will examine the current status of Autonomous Underwater Vehicles, explore their role in marine geophysical surveys, and highlight potential future uses along with emerging technological advancements.

LIMITATIONS TO THE USE OF CONVENTIONAL RESEARCH VESSELS

Throughout 20th century, Research Vessels (RVs) served as the primary platforms for collecting marine scientific data at sea. However, in the latter part of the century, several alternative platforms emerged, offering in some cases more effective means for acquiring specific types of data. Satellites, for example, have been utilized to gather large-scale, high-resolution data across the visible, infrared, and microwave regions of the electromagnetic spectrum (Johannessen et al., 2000). These satellites provide valuable information such as ocean color (indicative of phytoplankton and suspended particles), sea surface temperature, and altimetry data related to sea level, wave roughness, wind patterns, and ocean currents. Additionally, ships of opportunity contribute various datasets, including long-term records from Continuous Plankton Recorder surveys (Reid et al., 1998; Rossby, 2001). Fishing vessels can also support data collection, either through direct charter or by equipping them with the necessary instruments and training (Melvin et al., 2002). Drifting and stationary buoys collect a wide range of hydrographic and biological data, as demonstrated by projects like Smart Buoys (Mills et al., 2002) and studies by Holliday et al. (1998). While these alternative platforms offer extended spatial and temporal data to supplement RV-based research, none—either individually or in combination—can fully replace the comprehensive capabilities of research vessels. They have undergone significant

advancements over the past century. Contemporary vessels are now built to be more powerful and acoustically quiet, equipped with integrated electric systems, dynamic positioning capabilities, and a wide range of deck machinery such as winches, cranes, and A-frames, along with specialized cables (Graf von Spee and Ollier, 2001), the crew-to-scientist ratio has markedly decreased over time (Currie, 1983).

However, despite these enhancements, ocean-going research vessels still face inherent limitations. These ships are generally large (over 50 meters in length), requiring substantial initial capital to construct and ongoing annual maintenance costs. Even with improvements in staffing efficiency, they still demand a considerable crew—including watch-keepers, engineers, deck crew, and support personnel—in addition to the scientific team. As a result, research vessels remain costly to operate.

Regardless of how they are built, research vessels are inherently limited to operating on the ocean surface and are often affected by unfavorable weather, which can lead to the loss of scheduled cruise days. In certain regions and seasons, using research vessels may even be entirely unfeasible due to extreme weather conditions.

Another challenge that can restrict survey time is the limitation on working hours. This issue can force research institutions to either hire additional personnel to maximize operational time or to reduce the overall working hours. For instance, the Dutch research vessel *Tridens* is required to return to port on weekends (Couperus, RIVO, Netherlands, personal communication). In both scenarios, survey efficiency is reduced—resulting in less productive ship time for each unit of cost. Ironically, this undermines the progress made in lowering the crew-to-scientist ratio.

Due to these high operational costs, available time aboard research vessels remains limited and highly competitive. Consequently, marine scientists are often unable to fully leverage advancements in computing, information technology, and sensor innovation that could otherwise facilitate the processing of large datasets for building more accurate scientific models.

One key limitation of research vessels (RVs) is their confinement to surface operations, which necessitates remote methods for collecting data from deeper waters. For hydrographic surveys, this mainly results in time-consuming deployment and retrieval of instruments. However, in environments like the deep sea—where interest is rapidly increasing—RVs face significant challenges in collecting dependable data, especially regarding active marine life. Other difficult areas for RVs include regions beneath sea ice and even the ocean surface under certain conditions.

Moreover, due to the high demand and operational costs of research cruises, scheduling RV use typically requires months of advance planning. Except in cases of major national emergencies, such as oil spills, it is usually difficult or impossible to

respond to spontaneous or unplanned events of scientific significance because of rigid cruise timetables.

A promising alternative for some of these challenges is the Autonomous Underwater Vehicle (AUV). AUVs offer potential solutions to many of the constraints linked with traditional RV-based sampling. Once seen as mere experimental tools, AUVs have now evolved—thanks to technological progress—into reliable platforms capable of independent operation, precise mission control, and safe recovery (Millard et al. 1998).



Fig 1: A typical research vessel

Source: <https://images.app.goo.gl/qLpM4Hf9XAUx8SVo9>

Expedition and Limitations to the Use of Remotely Operated Vehicle (ROVs) for Underwater Surveillance

Seabed exploration has long relied on Remotely Operated Vehicles (ROVs) to support surveys from research vessels, offering real-time visuals and access to depths unreachable by scuba divers. The active Sicilian volcanoes—Etna, Stromboli, Vulcano, Lipari, Panarea, Pantelleria, and Banco Graham—are either partially submerged (Etna), largely submerged (Stromboli, Vulcano, Lipari, Panarea, Pantelleria), or completely submerged (Banco Graham). These volcanoes, located in key Mediterranean areas, have been occupied since the Bronze Age. Historically, they played significant roles in maritime traffic control, with important harbors serving military and trading functions, though some remains have been lost over time. Numerous ancient ships, often carrying amphoras, lie at the bottom of the sea. In recent years, the submerged parts of these volcanoes have undergone various investigations, often using medium or large research vessels to survey vast submerged areas, frequently far from shore. However, the large size of these vessels made operations in

shallow waters challenging, limiting the study of underwater structures essential for understanding the eruptive history of each volcano and its effect on the surrounding marine environment. Many of these areas have great environmental, historical, and archaeological significance, and should be protected due to the high biodiversity, especially on offshore volcanic banks and the slopes of submerged volcanic islands. Due to their size and weight, standard ROVs have operational limitations, as their launch and recovery require large vessels with specialized cranes. The use of such large vessels entails significant economic costs, which can be difficult to justify, particularly for repeated research campaigns.



Fig. 2. A picture of a Remotely Operated Vehicle

Source: <https://images.app.goo.gl/NwRCG1Tj4RyM4znY6>

Description of an Autonomous Underwater Vehicle (AUV)

Autonomous Underwater Vehicles (AUVs) are untethered, unmanned submersibles designed for precise, high-resolution remote sensing. They carry instruments like sonars, cameras, and hydrocarbon detectors, and navigate using inertial guidance supported by depth, salinity, and velocity sensors. Communication is managed via acoustic systems such as HiPAP, ACL, and ADL. Powered by an aluminum-oxygen fuel cell, AUVs can operate for up to 55 hours and are equipped with emergency ascent systems and location aids like GPS, radio beacons, and pingers.



Fig 3: A typical AUV ready to be deployed

Source: <https://images.app.goo.gl/gSNyYdbdxj98n32i6>

Historical Development of AUVs

The development of Autonomous Underwater Vehicles (AUVs) began in the 1960s. Only a limited number of AUVs were constructed during this period, primarily designed for specific tasks or data collection purposes. There is a relatively small number of published studies documenting these early initiatives.

In the 1970s, various experimental platforms were created. Several institutions developed AUVs for specialized research: the University of Washington's Applied Physics Laboratory created the UARS and SPURV for Arctic data collection; the University of New Hampshire's Marine Systems Engineering Lab (now the Autonomous Undersea Systems Institute), in partnership with the U.S. Navy, developed the EAVE vehicle; and Russia's IMTP, RAS introduced the SKAT series and deep-diving models L1 and L2. Many other prototypes emerged during this period. It was a period marked by technological experimentation aimed at exploring the potential capabilities of autonomous underwater systems. Although there were notable achievements alongside numerous setbacks, the aspirations of the research community often surpassed the technological limitations of the time. Nevertheless, the era saw meaningful progress in the evolution of AUV technology.

In the 1980s, advances in compact, low-power computers, expanded memory, and improved software engineering greatly boosted AUV development by enabling sophisticated guidance systems and complex software integration. Despite these advancements, it became evident that numerous technical challenges still needed to be addressed before AUVs could become fully operational systems. One of the most well-documented initiatives of the decade was the Draper Labs program, which developed two large AUVs to serve as test platforms for various Navy research efforts. This period marked a pivotal point in AUV development—it was increasingly evident that

the technology would mature into functional systems, though the exact nature of their applications remained uncertain.

Between 1990 and 2000, AUVs transitioned from experimental testbeds into the first generation of operational systems capable of performing specific missions. Numerous organizations worldwide began developing AUVs tailored to particular operational goals. The emergence of potential users helped shape AUV mission requirements and system design to align with data collection goals. This period also saw innovative concepts like the Autonomous Oceanographic Sampling Network (AOSN) and increased support that advanced AUVs toward commercial viability.

Between 2000 and 2010, AUV commercialization took off, with initiatives focused on design, deployment, and revenue generation. During this period, target markets were identified, and AUV technology transitioned from academic research to the broader commercial ocean industry. However, despite the progress, certain technical challenges still persisted, and the economic sustainability of AUV technology had yet to be fully demonstrated. To gain widespread industry adoption, AUVs needed to prove their reliability and effectiveness in real-world operational settings.

Over time, the direction of technological development has shifted in response to emerging ideas aimed at overcoming persistent challenges. While some issues have been successfully resolved, others continue to demand attention, and new, previously unforeseen problems have also emerged. Creating a definitive list of required technologies for AUV systems is difficult, as any such list would inevitably be incomplete. Nevertheless, it is possible to highlight a range of key technologies that have been the focus of development efforts over the past thirty years.

- Autonomy
- Energy
- Navigation
- Sensors
- Communications

What's notable about this list is that, despite considerable advancements in many of these technical fields, several of these technologies remain the key limitations—or "bottlenecks"—in AUV development. The limitations within these essential technologies continue to constrain the full potential of AUV systems.

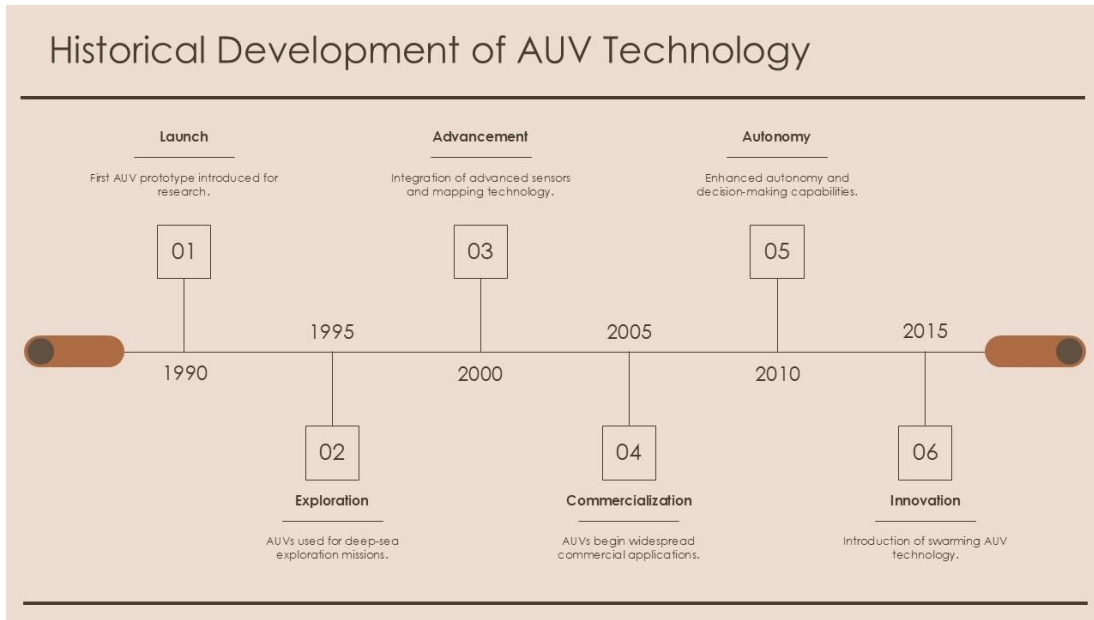


Fig 4: Developmental stage of an AUV

Source: <https://images.app.goo.gl/8yyijauUbBhyUbnc7>

Components of an AUV

The embedded systems in AUV can be classified according to their functionality:

Propulsion or Drive System: Various propulsion systems, such as steering rotors and propellers, are used for AUVs, with a variety of shapes and materials available [T.-H. Joung et al., 2012; M. A. H. Ramli et al., 2018]. The choice of propulsion system depends on the vehicle's design and intended purpose [B. Allotta et al., 2015]. Experts in aerodynamics and fluid mechanics study the hull shape, which is critical for efficiency [A. Alvarez et al., 2009]. Research also focuses on optimizing trajectory control and propulsion, utilizing mathematical and algorithmic advances to improve AUV mission autonomy [I. Masmitja et al., 2018; M. M. Hammad, 2017]. AUVSIPRO, a simulation software, has been developed to predict performance with different propulsion configurations, offering an effective method for studying hull hydrodynamics [M. Tran et al., 2018].

Power Sources: Common methods for energy storage in AUV systems include commercial batteries like magnesium-seawater batteries [O. Hasvold, 1993], pressure-tolerant Li-ion batteries [O. Hasvold, T. C. Johannessen, 2006], and aluminum-hydrogen peroxide semi-fuel cells [O. Hasvold and K. H. Johansen, 2002]. Battery selection, such as alkaline cells or fuel cells, depends on factors like buoyancy, system

simplicity, and depth requirements [R. d'Amore-Domenech, M. A. Raso, 2018]. Research is also exploring new energy sources like hydrogen fuel cells and hybrid systems combining existing technologies, with a focus on renewable energy solutions [A. Mendez, T. J. Leo, and M. A. Herreros, 2014; H. Weydahl et al., 2016].

Navigation and Positioning Systems: AUVs operating in vast offshore areas require effective navigation and positioning systems for underwater surveys. These techniques are categorized into three types: Acoustic transponders and modems [S. Sendra et al., 2019], Inertial/dead reckoning [B. Allotta et al.], and Geophysical methods. These approaches integrate both hardware and software systems, including the Extended Kalman Filter [X. Shao et al., 2017], range-only localization, and algorithmic combinations of light beacons.

Mapping and Sampling Systems: AUVs monitor seabed areas by creating 2-D and 3-D maps, useful in applications like sonar technologies. Primary sensors for this purpose include optical cameras, which use LED illumination to handle underwater darkness and provide varied lighting conditions. The collected data can be converted into audiovisual formats for real-time exploration, utilizing techniques like image de-scattering, high-definition analysis, and color restoration. The growing number of studies on optical capture and camera systems highlights their importance in graphical documentation for maintenance tasks [R. Pino Díez et al., 2019].

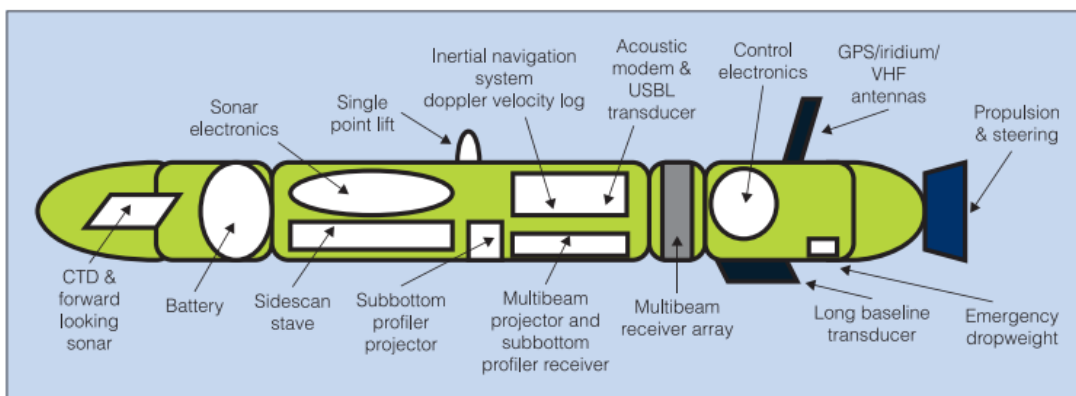


Fig 5: A picture highlighting the basic components of an AUV

Source: <https://images.app.goo.gl/csh7iVZuaLyxZrpV6>

The Evolution and Significance of AUVs for Underwater Exploration

Underwater exploration has advanced significantly, especially with the development of Autonomous Underwater Vehicles (AUVs), which have revolutionized the field [M. Jamshidi, 2008]. These autonomous robotic vehicles, crucial for marine scientists and explorers, can operate without human control, enabling complex missions in remote and challenging underwater environments [Jamshed Iqbal et al., 2017]. Initially, exploration relied on remote-controlled vehicles (ROVs) that required human oversight and control, but their limitations became evident as the need for more efficient, autonomous operations grew [Christopher R. German et al., 2016]. AUVs can dive to great depths, navigate underwater terrains, and perform tasks with high precision, providing valuable data for the study of marine life, ecosystems, and geological formations. They can also be programmed for specific tasks and deployed in groups for extensive exploration [Laughlin et al., 2016]. Research groups have explored lakes and cenotes as analogs for polar regions [A. Forrest et al., 2007; N. Fairfield et al., 2007].

The transition to AUVs marked a major advancement, as these vehicles, equipped with sensors, navigation systems, and AI algorithms, can operate autonomously, performing complex tasks and adapting to changing underwater conditions [M. Racault et al., 2014; Hidenori Kumagai et al., 2010]. The AGAVE expedition led to significant discoveries, including deep explosive volcanism and undersea volcanoes [R. Sohn et al., 2008], demonstrating the effectiveness of AUVs for seafloor exploration [Clayton Kunz, et al., 2015].

Furthermore, AUVs have been used to measure marine self-potential, with studies such as those by Steven Constable et al. [2017] confirming the viability of AUV-mounted electric field sensors for prospecting seafloor mineralization and hydrothermal activity, the advancement in AUV technology have enhanced seabed image processing enabling researchers to gain valuable insights into the underwater environment [Andrew D. Bowen et al., 2008].

Samuel R. Qualls 2015 also demonstrated that an AUV could be equipped with a UEP sensor. In his work “Underwater Electric Potential Measurements Using AUVs” he showed that a moving UEP equipped AUV is capable of detecting an ac electric field at frequencies of 5, 10, and 20 Hz on a moving surface vessel.

Case Studies of the Applications of AUVs in Marine Geophysical Survey

AUVs have been widely used in marine geoscience, initially for seafloor mapping and later expanding to water column geochemical and oceanographic measurements. The IFREMER L'Epaulard AUV, deployed in the early 1980s for mapping deep-sea

manganese nodule fields, is considered the first AUV used specifically for marine geoscience [Galerie, 1983]. By the early 1990s, over 56 different AUVs were documented, though many were demonstration models [Bellingham and Rajan, 2007]. By 2007, 92 REMUS AUVs were in operation, with a majority used for military purposes, while 10 were dedicated to scientific research [Moline et al., 2007]. The increasing importance of AUVs in marine research is reflected in the growing number of peer-reviewed publications and the vast amount of information available online, with Google searches for terms like "AUV marine geoscience" returning significant results [July 2020].

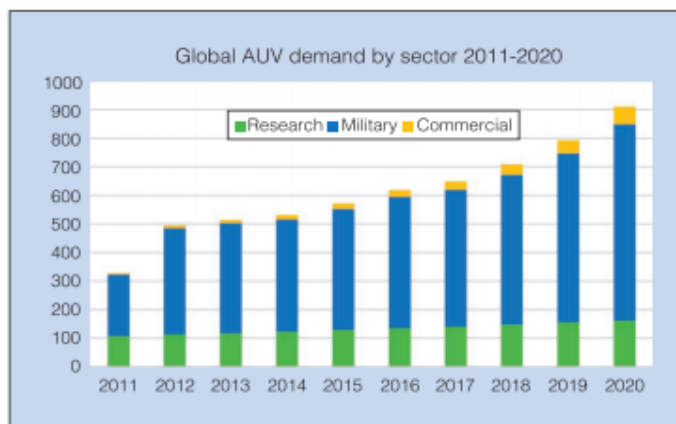


Fig 6: A chart showing the adoption of AUV rate from 2011 to 2020

Source: <https://images.app.goo.gl/LHLdmj5wVrsTk1HY6>

Several AUVs have been extensively used in marine geoscience researches, including the 6000m depth-rated NERC Autosub6000 [McPhail, 2009], the 6000 m-depth-rated MBARI D. Allan B. [Kirkwood, 2007; Caress et al., 2008], the 6000 m-depth-rated WHOI Autonomous Benthic Explorer ABE [Yoerger et al., 2007], the 5000 m-depth-rated MARUM Seal 5000 [Römer et al., 2012; Marcon et al., 2013], and the 6000 m-depth-rated IFM-GEOMAR ABYSS [Haase et al., 2009]. Other notable AUVs include the 3000 m-depth-rated Ifremer AsterX [Dupré et al., 2008], the 3500 m-depth-rated JAMSTEC AUV Urashima [Kumagai et al., 2010; Nakamura et al., 2013], and the 700 m-depth-rated ACFR AUV Sirius [Williams et al., 2010; Lucieer et al., 2013]. New AUVs are also entering service in the scientific sector, alongside established providers in the commercial sector, such as Kongsberg REMUS and Hugin. The broad scientific applications of AUVs are discussed in this report.

The Application of AUVs in Detecting Submarine Volcanism and Hydrothermal Vents

AUVs are frequently employed in marine geoscience, particularly in the study of submarine volcanism and hydrothermal vents. They are used to: i) create high-resolution bathymetric and magnetic field maps of the seafloor, ii) detect active hydrothermal plumes using sensors like temperature, optical backscatter, electrochemical redox (Eh), vertical velocity, and SSS imagery, and iii) generate detailed geo-referenced photomosaics of areas of interest (Yoerger et al., 2007a; German et al., 2008b; Nakamura et al., 2013). Early studies with the WHOI AUV ABE, deployed over the Juan de Fuca Ridge in 1995-1996, demonstrated the value of high-resolution magnetic data in detecting new lava flows and mapping hydrothermal plumes (Tivey et al., 1997, 1998; Yoerger et al., 1998). Subsequent studies used ABE's data to explore mid-ocean ridge crest environments, revealing magmatic subsidence, episodic dike swarms, and relationships between hydrothermal vents and volcanic features (Carbotte et al., 2003; Shah et al., 2003; Cormier et al., 2003; Fornari et al., 2004; Ferrini et al., 2007).

On the Mid-Atlantic Ridge (MAR), ABE mapped the Lost City hydrothermal vent field at depths of 750–900m, using high-resolution MBES data, video, and sample data from an ROV (Kelley et al., 2005). ABE also surveyed the southern MAR to locate active hydrothermal venting sites, leading to the discovery of the Beebe Vent Field, where follow-up missions with the NERC ROV Isis successfully navigated challenging terrain to avoid vent fluids at temperatures around 400°C (German et al., 2008a).

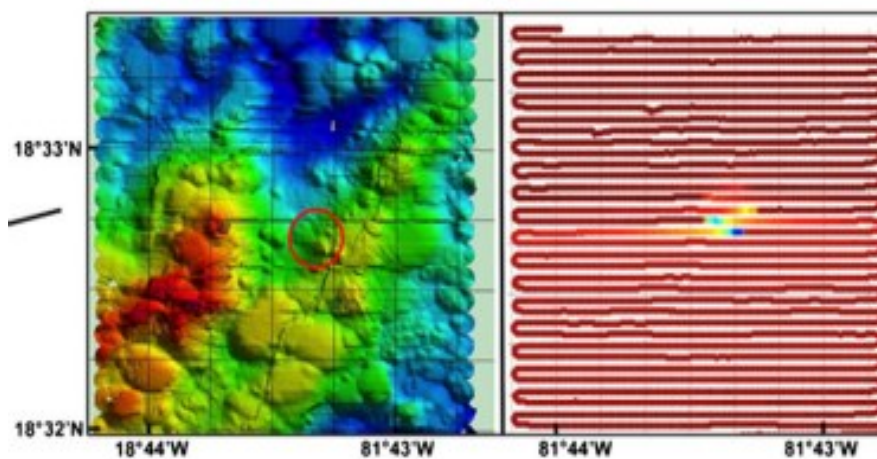


Fig 7: Showing the high resolution of the mapped Lost City hydrothermal vent field at depths of 750–900m.by the ABE

The Application of AUVs' Detection of Fluid-Escape Features and Chemosynthetic Ecosystems

AUVs have played a critical role in exploring low-temperature fluid escape features and deep-water hydrothermal processes. Paull et al. (2008) used the MBARI D. Allan B. AUV to collect high-resolution data over fluid escape mounds in the Santa Monica Basin, revealing gas hydrate accumulation beneath the seafloor and supporting the "submarine pingo" hypothesis. Newman et al. (2008) employed the WHOI SeaBED AUV to study methane venting in pockmarks off the east coast of the U.S., offering new insights into methane concentration variations. In the Mediterranean, Dupré et al. (2008) mapped active mud volcanoes offshore Egypt with the Ifremer AsterX AUV, uncovering features not seen in ship-mounted data and providing new understanding of mud volcano formation. Moss et al. (2012) mapped pockmarks in the Rosetta Channel, while Macelloni et al. (2012) used AUV data to explore hydrocarbon fluid flow linked to the Woolsey Mound in the northern Gulf of Mexico, revealing new fault details and targeting future monitoring of hydrocarbon leakage.

Wagner et al. (2013) used the WHOI SENTRY AUV to investigate geochemical and biological interactions at cold seep communities on the Blake Ridge Diapir off South Carolina, USA. The AUV collected high-resolution MBES, SSS, and digital photo data over seafloor pockmarks, including 5,568 georeferenced images. This data revealed new seep communities and provided insights into the distribution of mussels and clams, showing how chemical gradients influence mega-fauna distribution.

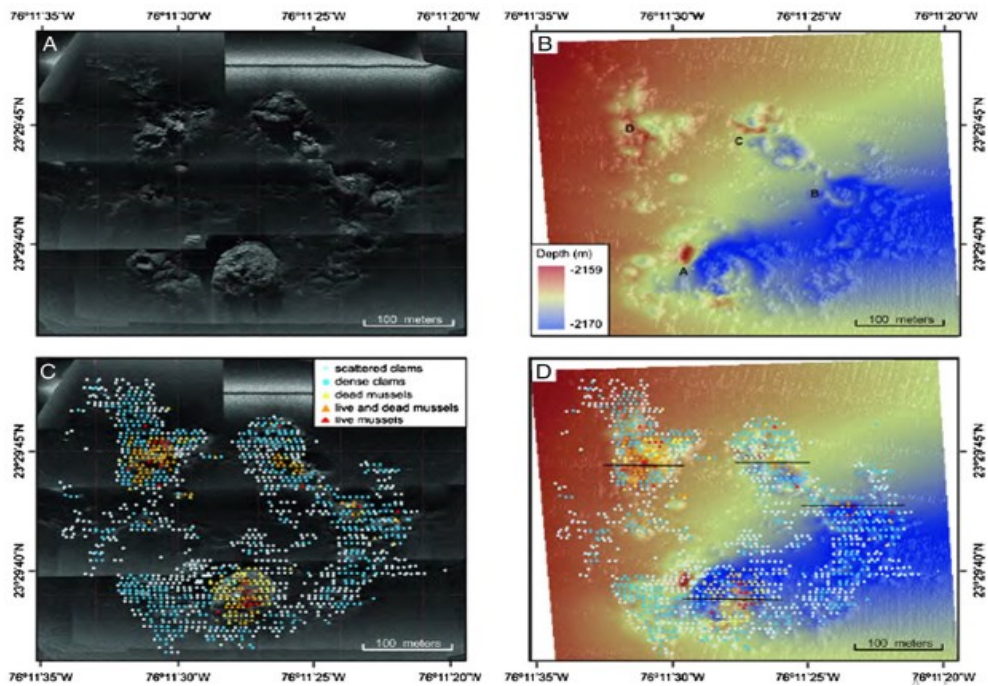


Fig 5: B EM200 (1 m resolution) MBES derived from Autosub6000 showing a NE–SW alignment of volcanic domes (each ranging between 200 and 600 m in diameter); the red circle indicates the position of the Beebe Vent Field at 5000 m WD (legend: red = 4760 m, dark blue = 5260 m). (C) Signal strength from an Eh sensor on Autosub6000 (legend: blue = low Eh, red = high Eh) acquired at the same time as the EM200 MBES; the negative Eh signal is indicative of reduced fluids entering the water column from an active hydrothermal source located on the seafloor

The Role of AUVs in Mapping Seafloor Morphology Associated with Bedforms, Scours and Scarps

AUVs have been used to map various seafloor features, including beneath ice sheets and in deformation studies. Jenkins et al. (2010) used the NERC Autosub3 AUV to study the retreat of Pine Island Glacier in West Antarctica, providing key data on processes driving ice loss and global sea level impacts. Graham et al. (2013) further analyzed seafloor features using the same data. Dowdeswell et al. (2008, 2010) mapped glacial bedforms in Greenland’s Kangerlussuaq Fjord, contributing to ice shelf reconstruction.

Larroque et al. (2011) used an AUV to study tectonic and gravitational deformation on the Ligurian margin, revealing a previously unseen fault scarp. Eddy Lee and George (2004) mapped the Sigsbee Escarpment using an AUV, linking seafloor features to salt tectonics and gravity-driven mass failure. Huvenne et al. (2009) and

Macdonald et al. (2011) deployed the NERC Autosub6000 AUV to survey deep-water erosional scour zones along the northeast Atlantic margin, providing insights into scour formation and facilitating future coring plans.

AUVs' Application in Oil & Gas industry

Survey AUVs have become popular in the oil and gas industry due to the high costs of traditional surveying technology in deep-water blocks off the Americas and Africa. While some have suggested using reprocessed 3D seismic data for seafloor imaging, many professionals argue that proper survey tools and quality procedures are essential. AUVs offer a cost-effective solution, providing high-quality surveys comparable to those in shallower waters. Additionally, AUVs are being adapted for shallow water applications, making them a promising alternative for inshore surveys, especially in hard-to-reach or hazardous areas.

For the oil & gas industry, AUVs are suitable alternatives for:

- a) Geo-hazard and clearance surveys
- b) Rig site surveys
- c) Acoustic inspection of pipelines and sub-sea installations.
- d) Pipeline route surveys
- e) Construction site surveys

New AUVs entering the market are often large, measuring up to five or six meters in length, which presents challenges in handling and requires specialized launch and recovery systems. As a result, only larger vessels can typically operate these AUVs. The hybrid vehicle is seen as a significant advancement in AUV design, particularly in the oil and gas industry. AUVs are advantageous in pipeline route surveys, utilizing sensors like multibeam echo sounders and side-scan sonars, allowing the mother vessel to focus on more complex tasks. AUVs also offer a new role in environmental data collection, especially in deep-water regions, where they can monitor environmental conditions, observe water flows, and detect protected seafloor populations.

Minerals and Mining

AUVs have been introduced in the search for seafloor minerals, with companies like De Beers acquiring Maridan vehicles to expand their operational coverage in the hunt for precious stones. The subsea mining industry is expected to grow, and AUVs are seen as practical tools for mapping, such as identifying manganese nodule fields. Hybrid-class vehicles may also be used for both mining and monitoring activities.

Limitations in the Use of Autonomous Underwater Vehicle for Marine Geophysical Survey

The list of AUVs which have been used to search for marine geophysical survey in the deep oceans is short and have considerable limitations in the field of marine geophysical surveillance. Studies have addressed the challenges of operating AUVs through ice holes [R. Bono et al., 1998].

1. **Limited Payload Capacity:** Imagine an AUV designed for high-resolution seabed mapping. It might be equipped with a sophisticated multibeam sonar system, but lack the space for a sub-bottom profiler to investigate deeper subsurface layers. AUVs have finite internal space and weight restrictions. This limits the number and size of sensors they can carry. For example, a high-resolution seismic survey might require a large array of hydrophones, which may exceed the AUV's payload capacity. This limitation can restrict the scope and complexity of geophysical surveys, potentially preventing the simultaneous collection of multiple datasets.

2. **Battery Life Constraints:** An AUV deployed for a long-range survey of a deep-sea trench runs out of battery power before completing its mission, resulting in lost data and potential damage to the vehicle. Battery technology, while constantly improving, still limits the endurance of AUVs. This restricts the duration and distance of missions, impacting the survey area coverage. Long-range surveys or operations in challenging environments with strong currents can significantly drain battery power, potentially forcing premature mission termination and compromising data collection.

3. **Navigational Uncertainties:** An AUV operating in a region with strong tidal currents experiences significant drift, leading to inaccurate positioning and causing gaps or overlaps in survey lines. Ocean currents, tides, and magnetic disturbances can significantly impact an AUV's position and heading. These factors can introduce errors in navigation, leading to inaccurate data collection. For example, in seismic surveys, precise positioning is crucial to ensure accurate source-receiver geometries and avoid distortions in the recorded data.

4. **Data Processing and Analysis Challenges:** An AUV collects terabytes of raw data during a long-duration survey. Processing and analyzing this massive dataset requires specialized software, significant computational power, and experienced personnel, potentially delaying the interpretation of results. AUVs generate large volumes of data at high sampling rates. Processing this data requires sophisticated algorithms and high-performance computing resources.

5. **Limited Maneuverability:** An AUV attempting to survey a complex underwater topography, such as a steep slope or a narrow canyon, may experience difficulties in maintaining a stable altitude and following the desired survey lines. AUVs have

inherent limitations in their maneuverability, especially in confined spaces or in the presence of strong currents. This can restrict their ability to operate in complex underwater environments and collect data from challenging locations.

6. **Communication Challenges:** An AUV operating in deep water or in remote locations experiences difficulties maintaining a reliable communication link with the surface, hindering real-time monitoring and control of the vehicle. Maintaining reliable communication between the AUV and the surface can be challenging, especially in deep water or in areas with high levels of background noise. Communication disruptions can hinder real-time monitoring of the vehicle's status, prevent mission adjustments, and potentially lead to data loss.

7. **Vulnerability to Hazards:** An AUV encounters an unforeseen obstacle, such as a fishing net or debris, resulting in damage to the vehicle and mission failure. AUVs are susceptible to various hazards in the marine environment, including collisions with underwater objects, entanglement in fishing gear, and damage from marine life. These hazards can cause physical damage to the vehicle, disrupt operations, and compromise data quality.

8. **High Initial Investment Costs:** The acquisition and deployment of a high-end AUV system, including the vehicle itself, associated sensors, and support equipment, requires a substantial financial investment. AUVs represent a significant capital investment, requiring substantial upfront costs for acquisition, maintenance, and operation. This can limit the accessibility of AUV technology for smaller research institutions or companies with limited budgets.

Recent Upgrades in the Development of AUVs for Research Work and Analysis

While the field of Autonomous Underwater Vehicle (AUV) research has witnessed considerable progress over recent decades, several fundamental challenges continue to demand attention. A primary contemporary issue lies in the attainment of true autonomy, a complex objective for which the integration of intelligent systems offers a promising, albeit partial, resolution.

The provision of adequate and sustainable energy has also long constituted a significant concern in AUV development, with technological evolution marked by a transition from traditional Silver-Zinc and Lead-Acid batteries to more energy-dense commercial Nickel-Metal Hydride (NiMH) alternatives. Furthermore, the strategic incorporation of solar photovoltaic technology as a supplementary power source presents a compelling avenue for extending the operational endurance of these autonomous platforms.

Ensuring robust and precise navigation along predetermined trajectories represents another active domain of ongoing research and development. Acoustic transponder-based navigation systems offer a relatively economically viable approach to this challenge, with the potential for enhanced accuracy through the synergistic application of Global Positioning System (GPS) data where available. The inherent limitations associated with employing non-specialized sensor arrays across diverse AUV platforms, particularly concerning the effective decision-making range in critical operational scenarios, are being progressively mitigated through the adoption of integrated, high-range sensor suites specifically engineered for the unique demands of AUV applications.

The establishment of dependable communication links with and between AUVs constitutes a particularly intricate undertaking, stemming from the inherent complexities of underwater signal propagation. These challenges encompass phenomena such as multipath propagation, constrained bandwidth availability, temporal unpredictability in the transmission channel characteristics, and substantial signal attenuation within the aquatic medium. Despite the theoretical potential of short-range optical (laser) and long-range radio frequency (RF) communication methods, their practical limitations in the underwater environment have led to the prevalent adoption of acoustic signaling, notwithstanding its inherent constraints in terms of data transmission rates when compared to terrestrial communication paradigms. To facilitate coordinated behavior and maintain situational awareness, the deployment of a localized wireless network enabling inter-vehicle information exchange is a fundamental requirement for networked AUV operations.

Conclusion and Recommendations

AUVs are highly effective for collecting spatial velocity data in depths greater than 100 m, essential for studying sediment transport and deposit formation. They provide a stable measurement platform, and advancements in technology are enhancing their ability to analyze various flow types in deep oceans. Over the past 15 years, AUVs have become crucial for marine geoscientists, particularly in seafloor mapping and monitoring, offering higher resolution data than surface vessels. AUVs also assist in detecting hydrothermal or cold seep fluids in the water column. With ongoing technological improvements and advancements in artificial intelligence, AUVs are becoming more reliable and adaptable, capable of avoiding obstacles and adjusting surveys based on environmental changes. As demand for marine applications grows, AUVs are expected to play a larger role in ocean exploration and monitoring, including for Marine Protected Areas and offshore renewable energy projects.

Recommendations

1. There are issues associated with the basic system design. the system design must result from an understanding of the mission to be undertaken by the system, the general design for AUVs needs to be adjusted and improved upon.
2. The initial cost for acquiring AUV technology is high for light researchers a programme should be put in place to assist and encourage its adoptability for feedback and possibly improvement in its technology and its sensors.
3. More room should be given in the AUV to carry more sensors for multiple data collection.
4. The computing system need to improve for effective handling of vast data gotten from an AUV.
5. More study should be conducted to investigate the incorporation control source electromagnetic survey (CSEM) and it's limitation in AUVs technology.

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