The exploration of Eastern Mediterranean deep hypersaline anoxic basins with MODUS: a significant example of technology spin-off from the GEOSTAR program

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Abstract
A significant example of technological spin-off from the GEOSTAR project is the special-purpose instrumented module, based on the deep-sea ROV MODUS, developed in the framework of the EU-sponsored project BIODEEP. The goal to be achieved has been defined as the exploration of the deep hypersaline anoxic basins of the Eastern Mediterranean Sea through real-time video images, measurements and accurate video-guided sampling at water depths well exceeding 3000 m. Due to their peculiar characteristics, these basins are one of the most extreme environments on Earth and represent a site of utmost interest for their geochemical and microbial resources. The paper presents the strategies and the main results achieved during the two cruises carried out within the BIODEEP project.

Key words *deep-sea – anoxic basins – ROV – marine technology – exploration*

1. Introduction

Exploration and long-term observation of the deep-sea environment is one of the last frontiers of marine science and technology. This technology, including marine engineering and underwater acoustics, plays a primary role in the development of equipment which can make possible, and economically feasible, the fulfilment of the challenging goals posed by the scientific community involved in the various disciplines related to the deep-sea environment (such as geophysics, geochemistry, biology, oceanography). Availability of suitable infrastructures, like research vessels, deep-sea ROVs, manned submersibles and seafloor observatories represents another major limitation.

In this scenario, projects built around clear and challenging scientific objectives, as well as sound technological background and innovation perspective, stand for a potential source of spin-offs and exploitation opportunities of the utmost importance. To make this potential become a reality is neither easy nor frequent. In the last decade, in the field of marine research, the EU-sponsored project GEOSTAR (GEophysical and Oceanographic STation for Abyssal Research,

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1996-2001) represented one of the very few cases where successful results were followed by real exploitation. Besides making the first European seafloor observatory available, GEOSTAR developed the special deep-sea ROV, MODUS (Mobile Docker for Underwater Sciences), whose exploitation for the purposes of the EU-sponsored project BIODEEP (BIOtechnologies for the DEEP, 2001-2004) is the object of the present paper.

Together with a brief description of MODUS, this paper will report about its adaptation and successful use for the exploration of a highly peculiar environment in the deep Mediterranean Sea, the Deep Hypersaline Anoxic Basins (DHABs).

2. MODUS: general description

MODUS is a deep-sea Remotely Operated Vehicle (ROV) originally designed for the purpose of GEOSTAR seafloor observatory deployment and recovery (fig. 1, Gerber *et al.*, 2002). Suspended from an electro-mechanical umbilical cable, it is equipped with electrical thrusters ensuring mobility on the horizontal plane, while the dedicated winch onboard the support vessel regulates its ascent/descent. Cable and winch are the infrastructure property of INGV that allow MODUS operation from vessels of opportunity.

MODUS configuration (Clauss *et al.*, 2002) fills the gap between full 6D-space operation and simple hook deployment systems. This means there are no free-swimming capabilities typical for ROVs (especially those equipped with tether management system). However this does not represent a disadvantage, since MO-DUS is not required to carry out close inspection or manipulation tasks like typical ROVs. On the contrary, MODUS can handle heavy loads (up to 30 kN; for comparison, typical payload of a commercial ROVs is less than 1.5 kN), overcoming one of the basic limitations of the existing ROVs. This peculiar characteristic of MODUS is essential for the GEOSTAR concept; its modular design concept opens a wide range of interesting opportunities for its utilisation in different contexts.

Some of these opportunities have already been explored: among these, the possibility to carry out visual and instrumental surveys in

Fig. 1. MODUS and GEOSTAR-stations onboard R/V Urania.

deep waters, and to serve as a carrier of special instrumented packages, ensuring the scientist a virtual presence and operational capabilities in the area of interest. In the short, but already significant, history of GEOSTAR spin-offs, the exploration of the Deep Hypersaline Anoxic Basins in the Eastern Mediterranean Sea is the first of these opportunities.

3. The deep hypersaline anoxic basins of the Eastern Mediterranean and BIODEEP project

The anoxic basins of the Eastern Mediterranean represent a peculiar deep-sea environment having extreme physical and chemical conditions. They are in fact characterised by the presence of hypersaline brines, separated from normal deep-sea water by a sharp physical and chemical interface. They have a variable *pH* and ionic composition, no oxygen and at some places high sulfide concentration, high temperature, and methane seepage (Corselli *et al.*, 1998).

Several DHABs, having diverse morphologies and dimensions, are present in the Eastern Mediterranean in different tectonic settings and at variable depths (3300-3700 m) along the Mediterranean ridge (Jongsma *et al.*, 1983; Scientific Staff of Cruise Bannock 1984-1912, 1985; Medriff Consortium, 1995); their origin is due to the interaction among tectonic processes, fluid migration and dissolution of Messinian evaporitic rocks present in the subsurface at shallow depth (Westbrook and Reston, 2002).

The peculiar physical and chemical characteristics of the DHABs and their location in the deep-sea make such basins an especially interesting site for different fields of research and a new frontier for exploration. In particular, the EU-funded Project BIODEEP was targeted to the investigation of microbial life in such extreme conditions. The challenging goal was to characterise, in four selected DHABs, the physiology and ecology of the extremophiles microbial communities, their cellular components or products and to identify how their features can translate into new biotechnological applications.

Although driven by biotechnological goals, the BIODEEP approach is multidisciplinary, involving geological, geochemical and hydrological tasks besides micro- and macro-biological studies. A fundamental requirement to fulfil the scientific purposes of the project is the execution of accurate sampling at the seawater-brine interface and visual surveys at the surface of the DHABs and at their margins. In particular the latter is intended to obtain a direct, although remotely driven, description of this peculiar environment. In fact the seawater-brine interface has only been detected by geophysical methods (Jongsma *et al.*, 1983; Medriff Consortium, 1985) and directly investigated through CTD measurement and sampling (De Lange *et al.*, 1990): no investigation proved that this transition is visually detectable. Therefore, besides the sampling task, the main questions addressed are related to how the brine interface appears at a visual inspection, which features can be visually detected on it and in particular which features and structures are present at the beach, *i.e.* the line where the brine surface impinges the bottom.

4. MODUS adaptations for BIODEEP

To perform the challenging tasks described above, conventional off-the-shelf equipment is not available. ROVs and manned submersibles have never approached the DHABs close enough to obtain samples at the interface or to make accurate visual surveys, because of the peculiar characteristics of the brines, which can cause damage to the systems. Until recently, sampling in the DHABs has been carried out using tools like CTD/rosettes deployed from the ship. This approach has three basic drawbacks:

a) It is intrinsically inaccurate: the sensors and the sampling devices hang at the end of a very long cable (in the order of 3500 m), so that an accurate regulation of their position for sampling at the brine interface is unlikely.

b) The scientific payload is limited to the essential, and the electro-mechanical cable serving the CTD/rosette has normally no provision for additional telemetry channels (especially high capacity channels imposed by TV cameras).

c) The interaction of the scientists with the phenomena under observation is minimal; there is no possibility to see where the instrumented package is and in which conditions the measuring and sampling operations are performed.

The task the BIODEEP team had to fulfill has therefore been to find a new approach, meeting the challenging scientific requirements and at the same time compatible with the constraints imposed by the project (cost-effectiveness, reduced risks and short development time).

The solution developed by Technische Universität Berlin, TFH Berlin and Tecnomare (the technological partners of BIODEEP project) was based on the adaptation of MODUS to serve as the carrier of a specially developed module (SCIPACK – SCIentific PACKage), the instrumented unit intended to enter the DHABs. In this concept, illustrated in fig. 2, MODUS becomes a powerful and stable platform, capable of being actively positioned and «flown» a few meters over the DHABs surface, moreover providing plenty of telemetry capabilities for the transmission of video images, data and control signals.

To manage SCIPACK, the original idea was to equip MODUS with an underwater deep-sea winch (like those of the ROVs tether management systems). In this way SCIPACK could remain sheltered inside MODUS during the launch/transfer/recovery phases and subsequently lowered into the brines like a «tethered satellite» when MODUS had reached the desired position over the DHAB. This idea was then substituted by the simple low-cost solution where SCIPACK is suspended under MODUS using a fixed length of cable. Although this solution has some impact on the operability of the system (in particular the launch and retrieval procedures are more complicated), it maintains the basic functionalities of the innovative concept.

Fig. 2. MODUS with SCISKID (background) and docking cone (foreground).

MODUS has been adapted for BIODEEP purposes as indicated in fig. 2. The docking cone (visible in the foreground of fig. 2) – not necessary for this operation as no seafloor observatory is involved – has been disassembled and replaced by a frame (SCISKID) housing mechanical and electronic equipment for the SCIPACK operation, an easy procedure because of the modularity of the MODUS design concept. The fully assembled MODUS and the scientific module SCIPACK (equipped with water samplers, CTD, echosounder, a TV camera with light) are shown in fig. 3.

The operational sampling procedure is schematically shown in fig. 4: SCIPACK is deployed from the vessel in a first step; it is followed by MODUS which is constantly communicating with it, allowing control of the procedures to be executed during surveying and sampling. As mentioned above, the deployment and control of the vertical position is performed with the deep-sea winch of the R/V. Horizontal position is controlled by the MODUS pilot. By adopting umbilical cables of different lengths, it is possible to keep SCIPACK more or less close to MODUS, according to the task to be undertaken: for exploration well inside the body of the brines, cables up to 200 m can be used, while for sampling at the interface shorter cables (10-20 m) are preferred, so that MODUS can more accurately manage SCIPACK operations. During these operations it is possible, through the downward-looking TV cameras installed on MODUS, to get visual control of the position of SCIPACK; this was an important innovation in the critical phase of sampling at the seawater-brine interface,

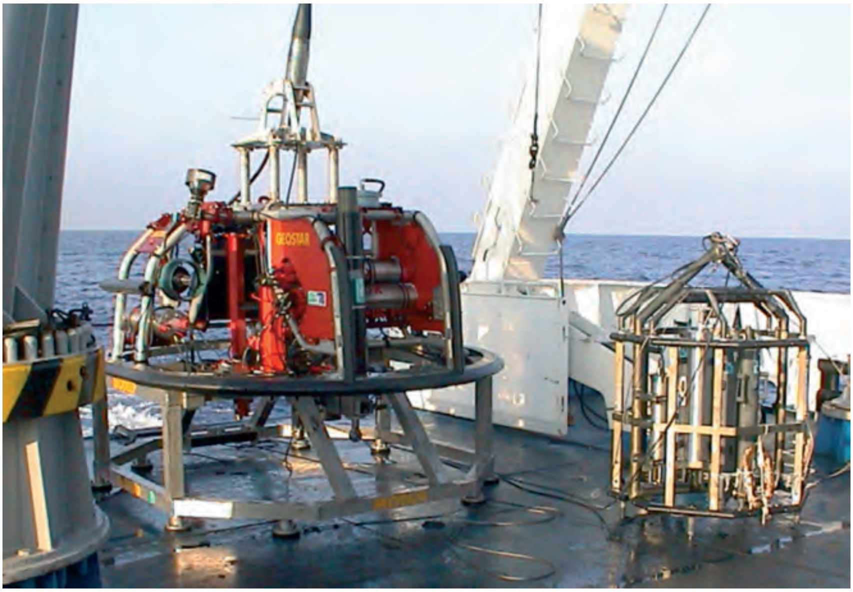

Fig. 3. MODUS with SCISKID (*left*) and SCIPACK (*right*) onboard R/V Urania.

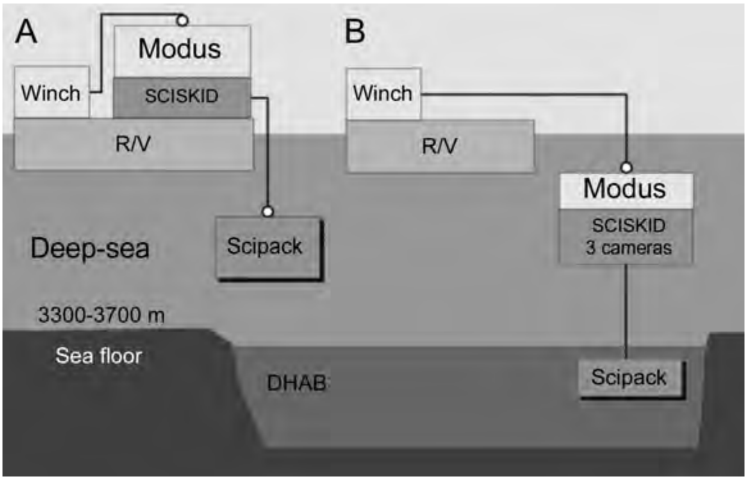

Fig. 4. Operational concept of BIODEEP mission for sampling and surveying: A – deployment of SCIPACK from the ship; B – operation of the MODUS-SCIPACK system at the interface of the DHAB.

providing for the first time the possibility to have a «virtual presence» in this unique environment.

For the execution of visual surveys, the system configuration is modified: SCIPACK and its umbilical cable are removed; all TV cameras are placed onboard MODUS/SCISKID, that can now be flown over the surface of the DHABs.

Two missions were carried within the BIODEEP project using this new technology. During these missions, four DHABs were explored (Urania, Bannock, Discovery, L'Atalante); in all of them sampling tasks were carried out, while three were visually investigated both at the brine surface and at their margins.

5. The missions

The two cruises were performed with the Italian R/V Urania (August 17-September 4, 2001 and November 7-27, 2003) within the framework of the BIODEEP project. The positioning during the cruise was done using dedicated navigation software (NavPro version DOS 5.5 of the Communication Technology), interfaced with a DGPS system. The reference cartographic system used during the Cruise was the ED 50 Ellipsoid, with UTM (Universal Transverse of Mercatore) projection.

A detailed bathymetric survey was performed with two Atlas DESO-25 echosounders – 12 and 33 kHz – at the margins of the basins, based on previous bathymetric maps of the area (Medriff Consortium, 1995), to identify the best sites to lower the MODUS system for the visual survey, *i.e.* areas with gentle slopes and absence of rough topography.

Configuration of the MODUS system for the sampling tasks (sampling at the seawater-brine interface and sampling inside the body of the brines) followed two basic modes, one characterised by a short cable (10 m) and one by a long cable (200 m) connecting MODUS with SCIPACK (fig. 5). Configuration 1 is characterized by a 200 m secondary umbilical with double sided *Y* connection, connecting the SCIPACK during operations in deep zones of the brines. After major difficulties with the telemetry system and a short circuit in a cable, it was decided to leave the deep sampling task out and to shorten the umbilical to 10 m. This yields a detailed view of the sampling activities with cameras. Due to the high number of revolutions of the SCIPACK during descent and ascent, the umbilical situation was changed again to a twin cable configuration: this further prevented the payload from uncontrolled vertical turns (Configuration 2). The final dive configuration was found after placing the DAQ-box from the SCI-

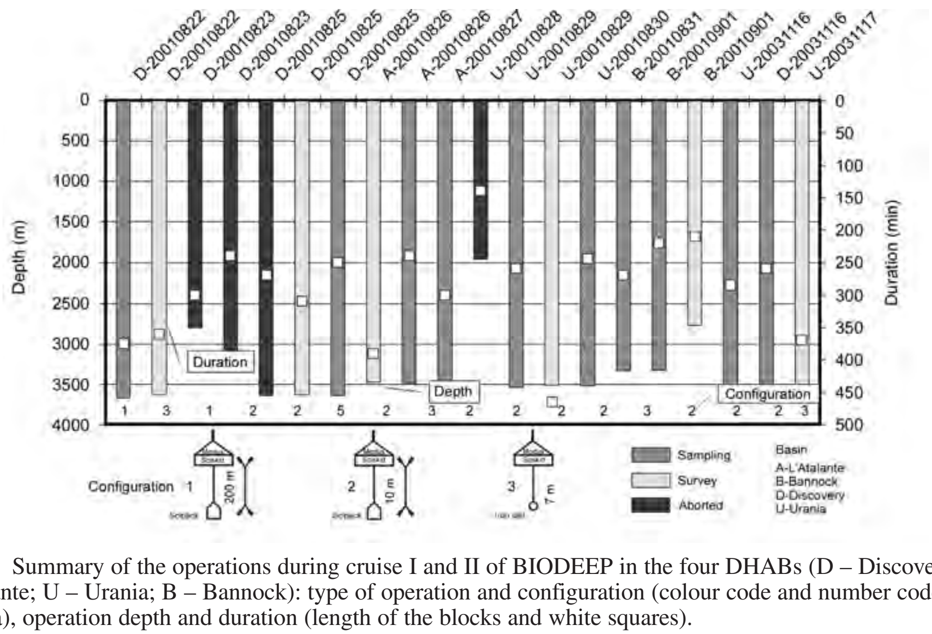

Fig. 5. Summary of the operations during cruise I and II of BIODEEP in the four DHABs (D – Discovery; A – L'Atalante; U – Urania; B – Bannock): type of operation and configuration (colour code and number code in the legenda), operation depth and duration (length of the blocks and white squares).

PACK to the SCISKID frame at MODUS (Configuration 2). The latter allowed us to work with a single secondary umbilical, which significantly improved the quality of data transmission.

Configuration for the visual surveys (Configuration 3, fig. 5) did not include SCIPACK. In this case a simple white-painted iron ball with a white flag was hung at the end of a 7/10 m rope, to create a clear reference and dimension scale during the approach of MODUS to the interface and seabed. The strategy has been to lower the system in an area characterized by regular topography, as near to the beach as possible, thanks to the accurate bathymetric control, and then to move the ship toward the selected target, dragging MODUS along and keeping it straight by using its thrusters. Two different approaches were followed, depending on the morphology of the selected area and on the wind and sea direction, as the ship had always to be directed with the bow against the wind, in order to maintain an accurate positioning at the low speed (1-1.5 knots) needed for the survey.

The first approach is to move from the brine pool toward the normal bottom, *i.e.* upward. This kind of operation is more dangerous, as the bottom can rise quite rapidly, possibly causing MODUS to touch the bottom: the winch operator must be ready at any time to recover the cable. Nevertheless this method allows a better depth control using the sonar and the altimeters. In fact the sonar can «see» the slope while approaching it, while the altimeters, ad hoc developed, can detect the bottom under the brines when these are shallow enough (around 10 m) and therefore disclose in advance when the beach is reached.

The second approach is to move from the normal bottom toward the beach, *i.e.* downward, and then to proceed inside the basin. This operation allows safety conditions for MODUS, but the control on the bottom is less clear: the sonar as well as the altimeters can just see the normal bottom, which is also seen with the TV camera. Therefore the difficulty in this case is that the moment at which the brines are reached remains unknown.

In total seventeen dives were carried out for sampling and surveying during cruise I and three during cruise II; fig. 5 illustrates the diving

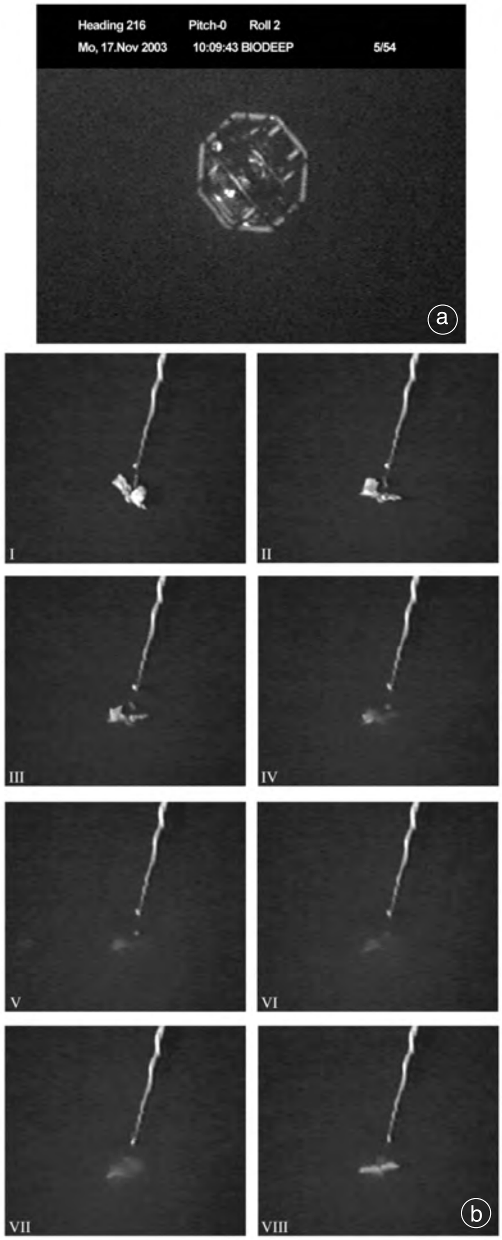

Fig. 6a,b. Images of the interface as seen by MODUS: a) view from MODUS to the suspended SCIPACK (10 m mechanical cable) right before entering the Urania Basin; b) sequence of the survey at the interface of L'Atalante (10 m cable): iron ball and flag approaching the interface (I-III), entering the brines (IV), laying below the interface (V-VII) and coming out (VIII).

depth, the duration of each dive and the dive configuration at the four different anoxic basins.

The operational performance of the system was successful, with up to three dives per day. Only four dives were interrupted for technical reasons during cruise I (all related to failures of single components and not to design faults). The capabilities were confirmed during the recent cruise II where, thanks to the adoption of more sophisticated tools (as a high resolution zoom camera), more accurate sampling within the DHABs and visual observations along the beaches were carried out.

Several samples, dedicated to geochemical and microbiological tasks, were obtained from the four selected DHABs along with data from the sensors mounted on SCIPACK and with an accurate visual control (fig. 6a). Sampling strategies and details are described, among others, in Borin *et al.* (2002).

Three DHABs (Urania, L'Atalante, Discovery) were investigated through visual survey during which their beaches were detected and explored.

The brine interface, observed both during the sampling operations and during the dedicated surveys, appears in all basins as a sharp surface, acting as a «black hole». In fact objects hung under MODUS disappear when crossing the brine surface (fig. 6b). This mechanism can be due to the high light adsorption within the brines or at the boundary itself, due to the high density and optical contrast between the two media.

6. Conclusions

The MODUS system has shown good suitability for deep-sea operations not only for the deployment of stations, as foreseen in the original concept, but also as a surveying and supporting carrier for other scientific packages. The adaptation of this technology, developed during the GEOSTAR project, to the new aims proposed by the BIODEEP project, allowed the execution of sampling and surveying tasks which were up to now not feasible with other conventional equipment, even more sophisticated and expensive, like deep-sea ROVs and manned submersibles.

The BIODEEP project started April 2001, and the cruise where MODUS was used for the first time in the DHABs started mid August of the same year. This means that in four months a new concept for the exploration of the DHABs was developed, fully tested in the laboratory and finally made available fully operative for the first application. This would not have been possible without the availability of a carrier like MODUS.

The application of MODUS technology to the study of the anoxic basins of the Eastern Mediterranean allowed for the first time:

– to observe the seawater/brine interface, which is optically detectable as a light-absorbing surface, as demonstrated by the disappearance of objects when entering the brines;

– to observe the beaches of the selected anoxic basins;

– to accurately sample the brine interface with real-time visual control

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