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► **To cite this version:**

Paul Chapman, Giuseppe Conte, Pierre Drap, Pamela Gambogi, Frédéric Gauch, et al.. VENUS, Virtual ExploratiON of Underwater Sites. 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST 2006), Oct 2006, Nicosia, Cyprus. hal-00339481

HAL Id: hal-00339481

<https://hal.science/hal-00339481>

Submitted on 9 Oct 2022

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VENUS, Virtual Exploration of Underwater Sites

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Abstract

The VENUS project aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeology sites. Underwater archaeological sites, for example shipwrecks, offer extraordinary opportunities for archaeologists due to factors such as darkness, low temperatures and a low oxygen rate which are favourable to preservation. On the other hand, these sites cannot be experienced first hand and today are continuously jeopardised by activities such as deep trawling that destroy their surface layer. The VENUS project will improve the accessibility of underwater sites by generating thorough and exhaustive 3D records for virtual exploration. The project team plans to survey shipwrecks at various depths and to explore advanced methods and techniques of data acquisition through autonomous or remotely operated unmanned vehicles with innovative sonar and photogrammetry equipment. Research will also cover aspects such as data processing and storage, plotting of archaeological artefacts and information system management. This work will result in a series of best practices and procedures for collecting and storing data. Further, VENUS will develop virtual reality and augmented reality tools for the visualisation of and immersive interaction with a digital model of an underwater site. The model will be made accessible online, both as an example of digital preservation and for demonstrating new facilities of exploration in a safe, cost-effective and pedagogical environment. The virtual underwater site will provide archaeologists with an improved insight into the data and the general public with simulated dives to the site. The VENUS consortium, composed of eleven partners, is pooling expertise in various disciplines: archaeology and underwater exploration, marine robotics and instrumentation, knowledge representation and photogrammetry, virtual reality and digital data preservation.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Virtual Reality

1. Project Summary

The VENUS project aims to provide a virtual exploration of deep underwater archaeological sites. Virtual exploration of our underwater environment will permit both experts and the general public to study interesting archaeological sites in a safe, cost-effective and pedagogical environment.

Precious underwater archaeological sites, for example ship-

wrecks, are continuously jeopardized by activities such as trawling that destroys the crucial surface layer of the site. The generation of a thorough and exhaustive 3D record of these wrecks consequently gains importance daily. These sites can never be experienced first hand by the majority of archaeologists or the general public: our project will provide a faithful accurate 3D immersive reconstruction of the

site providing virtual access to all. Our project is composed of five objectives: Initially we will define a series of best practices and procedures for collecting and storing data in an efficient, economic and safe way from the underwater archaeological site.

Our second objective will be to survey wrecks, (at various depths), using AUVs / ROVs (Autonomous Underwater / Remotely Operated Vehicles) and various techniques of data acquisition (sonar + photogrammetry). We will then provide archaeologists with software tools for signal, data and information processing and management. The generation of these tools is our third objective and will allow the extraction of digital models and management of confidence levels of the data collected from objective two.

Our fourth objective is to generate virtual reality and augmented reality tools for the immersive interaction and visualization of the models created in objective three. These tools will provide archaeologists with an improved insight into the data and the general public with simulated dives to the site. Finally we will disseminate our results via a dedicated website and publications within the field of archaeology, sea exploration, photogrammetry and virtual reality.

2. Project Objective

The VENUS project aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeology sites. This exploration relies on the accurate construction of a virtual submarine environment representing the site. The VENUS project is a pipeline of five steps:

- Data acquisition on the site;
- Data processing and storage;
- Construction of a virtual model of the site;
- Plotting archaeological artefacts and information system management;
- Dissemination of the procedures adopted for data acquisition and processing, as well as software tools and end-results of the project via traditional and internet publication.

This pipeline process will provide a fully functional virtual environment for archaeologists and the general public. Each step raises interesting research problems and technical challenges.

2.1. Motivations

The studies on ground archaeological sites, as well as shipwrecks sites, have always aimed at obtaining very accurate graphical representations of reality. As soon as appropriate tools became available, there was also a trend towards obtaining 3D representations on graphic displays. Over recent years, the field of archaeology has witnessed increasing interest in Virtual and Augmented Realities, or more generally Mixed Reality. The technologies available have

paved the way for the presentation (in a realistic manner) of reconstruction assumptions of archaeological sites, either for freely exploring these assumptions in a Virtual Reality framework, or by exploring the site itself mixed with a reconstruction assumption within an Augmented Reality framework. [CWSB01] Underwater archaeology is a challenging issue for Mixed Reality since the environment may not be accessible to man and is often considered hostile. As a matter of fact, deep wrecks are out of reach for divers, (beyond 60m, traditional air diving is prohibited and diving beyond that limit requires gas mixtures and significant surface facilities). [Bas70].

Wreck preservation in the open sea is facilitated due to several factors such as darkness, low temperature and low oxygen rate. However, deep wrecks are now jeopardized by emerging deep trawling that destroys the surface layer of the sites and thus scrambles legibility. Indeed, the twenty year old assumption that deep wrecks would be protected from trawling is not true anymore as trawls can nowadays be deployed down to depths of 1000m. Therefore, many of these wrecks are likely to be destroyed even before they can be studied. More generally, this project is oriented toward

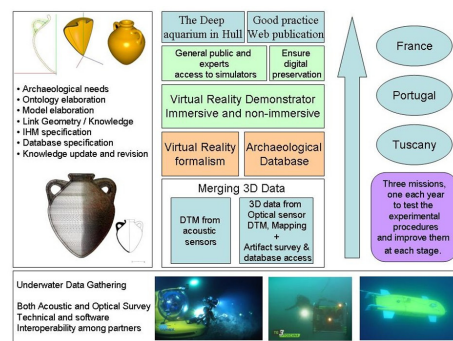


Figure 1: VENUS project architecture diagram.

both kind of sites, those reachable by divers and those reachable only with submersible vehicles; in both cases the project will develop methodologies and techniques for data acquisition by means of unmanned vehicles, i.e., Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs). The use of AUVs and ROVs will be a great improvement in terms of efficiency, economy and safety and will permit high quality automatic data capture. Regardless of diver accessibility, an underwater site is out of physical and practical reach for the majority of archaeologists and for the general public: our project aims at drastically changing this situation, by making the site virtually accessible to everybody. Due to the complexity of this ambitious project we will have always two points of view: the first one is to offer to archaeologists best practice, efficient, safe and cost effective tools to collect and manage archaeological data from shipwrecks; the second point, is to show what can be achieved without the constraint of a tight budget (which is generally

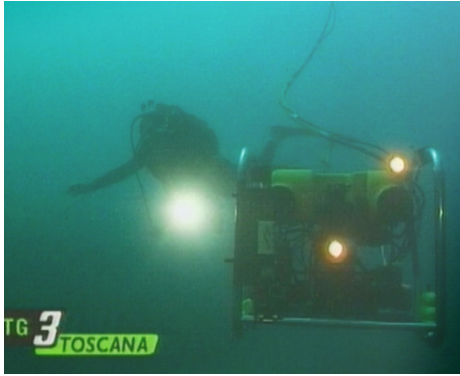


Figure 2: *ROV and Diver, ISME.*

the case in archaeology). The budget has a particularly high influence on the technological aspect of this project: especially for underwater data acquisition and virtual reality immersion. In this project it is also planned to survey a deep shipwreck in order to apply the entire VENUS platform to a shipwreck in an excellent state of conservation and to show some possible immersive VR applications. We now present the five general objectives of this project and in addition, Objective Six, "Missions in open sea" which represents the three missions necessary to collect data and test and improve the methodologies adopted.

2.2. Objective one: Underwater exploration best practices and procedures

The first aim is to define a series of procedures and best practices for collecting data in an efficient, economic and safe way on underwater archaeological sites:

- Efficiency is related to the automatic collection of enough data, of sufficient good quality to allow for a satisfactory virtual reconstruction;
- Economy relates to the possibility of using, with suitable adaptations, "off-the-shelf" equipment, that archaeologists can easily get and employ;
- Safety has to do with the reduction of risks and inconvenience for human beings when operating at great depths and/or in a hostile environment.

The key technology we propose to exploit in pursuing this objective is based on the extensive use of Uninhabited Underwater Vehicles (UUVs), both remotely and autonomous vehicles (ROVs/AUVs). UUVs, equipped with acoustic, magnetic and optical sensors of various kinds, are becoming the tools "par excellence" in underwater archaeology as the technology offers ever increasing user-friendly and economical solutions, in particular because they allow the exploration and preservation of sites located at prohibitive depth for divers (see Proceedings of The International Congress

on The Application of Recent Advances in Underwater Detection and Survey Techniques to Underwater Archaeology, Bodrum, Turkey, 2004; Proceedings of Workshop on Innovative Technologies for Underwater Archaeology, Prato, Italy, 2004 and the references therein). [ABB04] [SP04] However, the potential of an approach that combines underwater robotics technology and virtual and augmented reality in gathering data and then simulating underwater archaeological sites have not yet been completely explored nor exploited. In particular, data gathering procedures have not been optimized with respect to post processing. Also, best practices about the combined use of different kinds of UUVs and sensory systems and devices have not yet been defined. *Measure of success:* A thorough and clear defini-

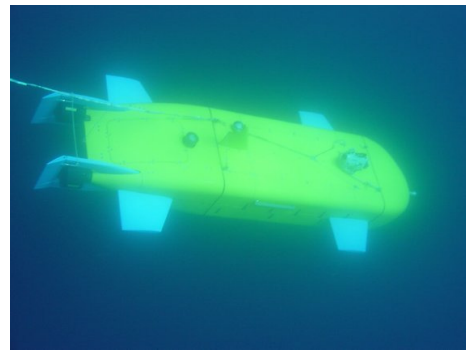


Figure 3: *Autonomous Underwater Vehicle (AUV) of IST.*

tion of the platforms, sensors, and methodologies that will be used to acquire, process, and display underwater archaeological data. Namely: i) definition of the platform (AUV, ROV) configurations and equipment that will be used to gather vision and acoustic data and of the interfaces required to ensure inter-partner systems compatibility, ii) full assessment of the compatibility of the DTM (digital terrain map) + photogrammetric data with 3D Virtual/Augmented reality systems, and iii) development of software for image processing to compensate for refraction errors that arise in the process of acquiring vision data underwater. [PSO05], [SDV*04].

2.3. Objective Two: Underwater 3D survey merging optic and acoustic sensors

The second objective aims at defining practical procedures for merging optical and acoustic data, acquired during the surveying of underwater sites, into a coherent representation. [CWSB02].

The project will witness the application of advanced techniques for underwater data acquisition and processing to the mapping of selected archaeological sites. An Autonomous Underwater Vehicle (AUV) and a Remotely Operated Vehicle (ROV), equipped with acoustic and vision sensors (for sonar mapping + photogrammetry), will be used to acquire relevant data in an efficient, systematic, and safe manner

at the sites, including one that is out of reach for divers. [DL05].

The need of geo-referencing the gathered data will be considered. Steps will be taken to endow the vehicles with navigation systems capable of providing information on their position with the accuracy that is required for the applications envisioned. [BT00], [GZ03].

Simplified underwater photogrammetric techniques will be developed to allow the use, after appropriate image processing, of software originally conceived for terrestrial photogrammetry. A semi-automatic surface densification technique will be developed in order to automatically generate a large amount of 3D point data based on multiple image correlation and to facilitate the time consuming photogrammetric process during the plotting phase (in the laboratory). A convenient tool for digitalization will be developed, offering to the archaeology community a convenient way to make accurate 3D measurements based on the product of the merging operation: a 3D mesh and a set of oriented photographs in the same reference system. [DDPL05], [DSL03].

We plan to make at least three experimental surveys, two in shallow water (on wrecks already studied) with archaeologists and divers and the final one in deep water to enhance the innovative aspect of this project. These surveys will be performed by conforming to the data collection guidelines specified in objective one.

Measure of success: Data gathering by means of robotic tools and the integration of acoustic and photogrammetric data at a sufficiently small scale will make virtual access, exploration and study of underwater archaeological sites possible. Access to these sites are currently beyond reach for the large majority of archaeologists and, in many cases, for the general public. The demonstration that i) archaeological surveys can be automated by using underwater robots that are easy to program seamlessly, and ii) sufficient navigational accuracy can be achieved so as to meet the precision requirements compatible with the scale dimensions envisioned, will provide quantitative indicators of the results obtained and a measure of success.

2.4. Objective Three: managing and revising archaeological knowledge

Objective three aims to provide underwater archaeologists with software tools for signal, data and information processing and management. These tools will allow for the extraction of digital models and management of confidence levels of the data collected from objective two. [Ace03] In the last decade, the tools developed for managing archaeological data have only focused on the geometric aspects; however, in order to integrate the archaeologist's knowledge and designing tools managing both data and knowledge, an appropriate representation of the archaeological knowledge is required. [BHLW03].

Another important factor is the management of this knowledge. We deal with pieces of information of different nature

that also originate from different sources characterized by various degrees of confidence. The methods of acquisition differ and provide data of unequal quality. Moreover, most of the time, the pieces of information are incomplete, uncertain, or inaccurate and have the potential to conflict with each other and hence may need the definition of fusion operations. Different cases arise according to the nature of the data used for fusion.

[JP00] The proposed work for this particular objective starts with a case study of archaeologist knowledge and procedures in order to define data management systems and a virtual universe.

We plan to investigate how artificial intelligence methods and tools could be used to represent the archaeological information and to perform revision and fusion according to the following points:

- to design and build specific ontology: by analyzing the relevance of the objects which can be handled in a particular archaeological application, independently of the expected data; to carefully examine their definition and the kind of implicit knowledge it carries; to compare how the data, with their quality depending on the observation process, and the recording process, can fit with the object definition; [SDP03]
- To design which knowledge representation formalisms are suitable to represent semi-structured information, paying attention to the specificity of the archaeological data: 3D spatial reference, topological relationships and spatial correlations, specific expert knowledge and specific ontology;
- To select which fusion strategy is best suited to the representation formalism chosen according to the nature of the situation, and the availability of relevant data, and their degree of quality and reliability. For instance, revision is relevant if one data set is strongly reliable;
- To assess the tractability of the fusion: How can the nature of the data help in defining tractable classes of problems for merging? How should existing general algorithms be adapted for merging? How can heuristics be defined that stem from the specificity of the nature of data to speed up algorithms?
- To define reversible fusion operations. This stems from the fact that, in general, the existing fusion operations developed in the field of artificial intelligence are not reversible; this is in contrast with the fact that reversibility is mandatory when facing real scale applications. [NS97], [BBJ*05].

Measure of success: The first draft of the "archaeological ontology" description, in Task 3.2, must be able to encompass most of the various features, properties, processes or behaviours collected during the first months of discussion between the computer scientists and the archaeologists of the consortium. A "typical" archaeological campaign will be summarized and described at the beginning of the project, as a baseline test bed for the further representation formalisms.

A confrontation of this baseline to external expert will permit to measure its relevance, and therefore, to measure the relevance of the representation formalisms against it.

2.5. Objective four: Mixed reality modelling

Archaeologists need to explore and make an inventory of deep wreck sites unreachable by divers as these sites may be jeopardized by deep trawling in the next few years. The digital preservation aspect should also be addressed by this objective. [CVM04].

The main goal of objective four is therefore to immerse archaeologists inside a virtual universe depicting a reconstructed archaeological site, for example a shipwreck, and allow them to work on this site as naturally as possible. The digital model generated in the previous section will then be used, with the help of virtual reality and mixed reality, for constructing immersive, virtual environments that enable archaeologists and general public to experience an accurate and fully immersive visualization of the site.

Archaeology is a challenging issue for Virtual and Augmented Reality (and more generally Mixed Reality) as these techniques can offer a realistic rendering of reconstruction assumptions either within the framework of Virtual Reality for exploring these assumptions or within the site itself by using Augmented Reality. [AVLJ01], [ATP*04].

Up to now, virtual reality has been used in archaeology only in the context of assumptions visualization which is already suitable for general public, the goal here is therefore to produce an immersive interface which could enable archaeologists to study a site reconstruction using the surveys, but also to generate reconstruction assumptions directly in virtual immersion. This project tackles the concept of augmented reality. More specifically, within the framework of underwater archaeology, the main difficulty of this type of exploration lies in the expensive deployment of heavy equipment to enable a team of archaeologists to explore, make an inventory and chart an underwater site before expressing the slightest assumption about the nature of a wreck or its cargo. Virtual Reality would also provide an overall view of a site and allow data exploration in a contextual way. Novel interaction and visualization techniques will be developed in order to meet the requirements of this objective. [LSB*04] Completing this objective should offer the opportunity for archaeologists to explore a digital mock-up of a wreck site built upon the digital models mentioned in the previous objective. This exploration should be immersive in order to maintain the same framework as real dives (without any risk or constraints), but should also offer new opportunities to archaeologists. Ultimately this virtual environment should offer the same tools as during real dives (such as navigation, measures, annotations, etc.). This environment should also provide new tools for creating reconstructions assumptions of various artefacts discovered on the wreck site in order to enrich the database created from the site.

Such a virtual exploration should also be performed by sev-

eral researchers at the same time, by offering Collaborative Work facilities. [PCVH04]. In addition, Collaborative work raises the problem related to hardware requirement for each of the researchers. Some of them might have access to high level hardware such as immersive platforms, whereas others may only have access to a simple desktop computer. The key idea would therefore be to build several demonstrators using the same engine:

- An immersive demonstrator using purely immersive devices such a VR helmet and data gloves for interacting with the site;
- A semi-immersive demonstrator using stereo large scale screen and 3D joystick (or data gloves) to interact with the site;
- And finally a low end platform using only the standard devices of a desktop computer. Each of these various platforms may require specific interaction models, but the goal is to keep the same functionalities on the different platforms.

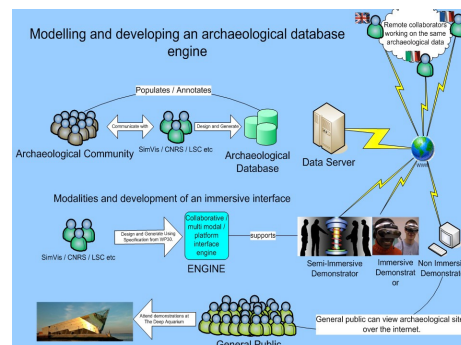


Figure 4: Synoptic schema of integrated Virtual Reality in VENUS.

Measure of success: All the functionalities developed in these various demonstrators are based on a case study of archaeologists working modalities in order to define interaction modalities and available tasks within the virtual universe connected to the underlying archaeological database. This is why the last task of this objective is devoted to the demonstrator evaluation on the basis of the previous case study by archaeologists.

2.6. Objective five: dissemination

The ultimate objective of the project is scientific dissemination in the fields of archaeology, marine exploration, photogrammetry and virtual reality through the publication of best practice recommendations, a set of open source software tools, and online preservation of an exemplar archive. Dissemination will be organized in four stages:

1. to refine digital preservation techniques so that they can be readily applied to the unusual range of data formats captured during underwater archaeological investigation;

2. to ensure that partners within the consortium learn about digital preservation;
 3. to promote best practice in digital preservation through publication of a short practical guide based on this shared experience;
 4. to adopt and trial these best practice techniques within the project.
- The first objective will be achieved through completion of a desk-based study, supported by a number of data audits carried out at the start of the project. The principal investigator for this work package will be a digital preservation specialist who will spend time with active fieldworkers, surveying the techniques that they use and establishing the most appropriate methods for digital preservation associated with these file formats. This preservation path, based on an implementation of the OAIS reference model for digital preservation and the PREMIS metadata model, will provide a preservation manual for long term curation of digital data;
 - The second objective will be met in part through the data audit process described above whereby the principal investigator will discuss issues of digital preservation informally with project partners, and report back to them the results of that research. The objective will be mainly met through the organization of a two-day project workshop on digital preservation to which senior members of each partner organization will be invited. This workshop will be managed by the Archaeology Data Service and will draw from existing curricula that the UoY-ADS offer on digital preservation;
 - Participants at this workshop will be invited to form an editorial committee and nominate a peer review group who will assist the principal investigator in the writing of a short guide to good practice for underwater archaeology. This guide will join the existing guides in the much praised "Guide to Good Practice" Series (<http://ads.ahds.ac.uk/project/goodguides/g2gp.html>). It will be distributed in print to all partners and key stakeholders, as well as being made available for free online for all readers;
 - By the end of the project, partners will not only have adapted their tools to ensure digital preservation, but they will be in a position to apply that best practice in real life situations. An exemplar archive will be lodged with the UoY-ADS and preserved into perpetuity. This scholarly archive will also be disseminated online alongside other research archives maintained by the UoY-ADS. It will therefore be available for reuse and interrogation by all visitors to the UoY-ADS site and will stand as a worked example of good practice to demonstrate the project outcomes to the wider profession.

To avoid duplication of efforts in a rapidly changing field a "technology watch" will be maintained, in close collaboration with the EPOCH 6th Framework Network of Excellence. The project team will present reports on its activities at appropriate technology and humanities conferences. Finally, the 3D and virtual reality aspects of the project make it appropriate for wider public dissemination, which will be most effectively achieved via the Internet.

Measure of success. The success of the workshop and subsequent Guide to Good Practice will be measurable by the extent to which the standards are endorsed and taken up by the sub-discipline of underwater archaeology. The number of Guides sold, and the number of visits to the on-line publication provides one measure of the visibility of the Guide. Previous Guides in the series, such as that for GIS, have sold out and have had to be re-printed. They have been widely and positively reviewed, and have been adopted by national and international standards bodies, and cited in undergraduate and postgraduate reading lists. The successful dissemination of the exemplar archive is also measurable, to same extent, by the number of visits to the site. This will be monitored by UoY-ADS standardized benchmarks for site visits, and can be compared against other online resources. The web site can be promoted through the UoY-ADS outreach programme and related publications, and qualitative feedback can also be collected.

2.7. The case study: The Mediterranean archaeological context

If the "first civilizations" were born in the Eastern Mediterranean from the Near East, this sea has been empty for millennia before becoming the main stage of shocks, conflicts and discovery of civilizations. From Marathon to Lépante, from Punic Wars to crusades, the Mediterranean space/area is full of historical reappearances and lights coming from the dead world. Beyond its current political divisions, it is divided into three cultural communities: Christian, Islamic and the Greek orthodox universe, that is an affiliation more or less linked to Rome, Carthage and Constantinople. One particular period interests us here. In ancient times, by imposing its will and political unification on the Mediterranean world, Rome did not erase the cultural differences but built its internal sea as a gigantic trading crossroad where oils and brines from Spain would cross with corn from Egypt, wines from Algeria and Rhodes, slaves from Nubia, ceramics from Gallia, marbles from Greece and bronzes from Italy. [ANS04], During the Roman Empire, among all these various products coming from the Mediterranean, a great quantity of Portuguese amphorae were sailing from Hercules Pillars to the Rhine frontiers and carried the famous Lusitanian fish sauce. Today underwater archaeology opens, from the deep past of the sea, a direct route to these shipwrecks, complex works that testify the wealth and the diversity of exchanges and of men. In this project, the methods of excavation, the systems of data capture and of the data's visualization and the coop-

eration of archaeologists and multinational specialists, will enable historical restoration of these trades and to continue these faraway sailing journeys, brutally interrupted. We plan to make three experimentations in different archaeological contexts and under different sea conditions. The first one, led by MIBAC-SBAT in Tuscany will focus on a very interesting archaeological site near the Pianosa island, and will be considered as a shallow water (-36m) mission. The wreck site consists of a large area of mixed amphorae probably due to more than one wreck superposition. The sec-



Figure 5: A view of the site close to Pianosa, Photo Alessandro Parotti, 2000

ond experimentation, in Portugal, concerns two sites: a probable Roman period wreck on the southern coast of Portugal (Algarve) where amphorae (Beltan IIb) were recovered by fishermen at a depth of 50m in the ocean; the other one lies on the Portuguese east coast, near Troia (a Roman industrial complex for processing fish, and wine from the surrounding area, which used locally produced amphorae). This shipwreck probably contains amphorae and may be the result of a geomorphologic process that has buried structures and amphorae.

The third one is an extremely well preserved shipwreck near Marseille. Discovered in 1999 by COMEX the "Calanque de Port Miou" is probably the most beautiful wreck in the Marseilles area nowadays. The site was explored by MCC in the



Figure 6: The "Calanque de Port Miou" photograph from ROV of COMEX.

year of its discovery, in 1999, with heavy logistics provided

by COMEX.

The wreck site (which seems to be still intact) presents a very large tumulus of Roman wine amphorae, Dressel 1A. Visible on 22 m length and ten meters broad, it is located at a depth of 120m.

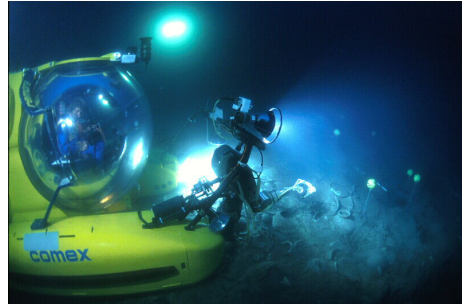


Figure 7: The submarine REMORA 2000 of COMEX during the Grand Ribaud F excavation, 2000. Photo Frederic Bassemayousse.

3. Conclusion and future work

This paper has described a new project that focuses on the virtual exploration of underwater sites. Our international research group has expertise in a wide range of areas including archaeology and underwater exploration, marine robotics and instrumentation, knowledge representation and photogrammetry, virtual reality and digital data preservation. Research conducted throughout this project will contribute to all these disciplines. This European Community funded project began on the 1st July 2006 and will last for 36 months. A dedicated project website is available here: <http://www.VENUS-project.eu/>

4. Acknowledgements

Work partially supported by the European Community under project VENUS (Contract IST-034924) of the "Information Society Technologies (IST) programme of the 6th FP for RTD".

The authors are solely responsible for the content of this paper. It does not represent the opinion of the European Community, and the European Community is not responsible for any use that might be made of data appearing therein.

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