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GEOPHYSICAL EXPLORATION

SEAFLOOR ENGINEERING

Unique New Technology Enables Archaeology in the Deep Sea

An Exploration into How to Excavate a Shipwreck in 170 Meters' Water Depth

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The Ormen Lange field is located in the Norwegian Sea, 100 kilometers northwest of the coast of mid-Norway. It is Norway's largest gas field, and was proven through drilling by Norsk Hydro AS (Oslo, Norway) in 1997. The development of the Ormen Lange field includes the installation of a subsea production system, which will be piped directly to an onshore processing and export plant. The gas will be transported by the world's longest subsea export pipeline approximately 1,200 kilometers from Norway to Easington, England. When it reaches full production, the field will meet 20 percent of the United Kingdom's demand for gas.

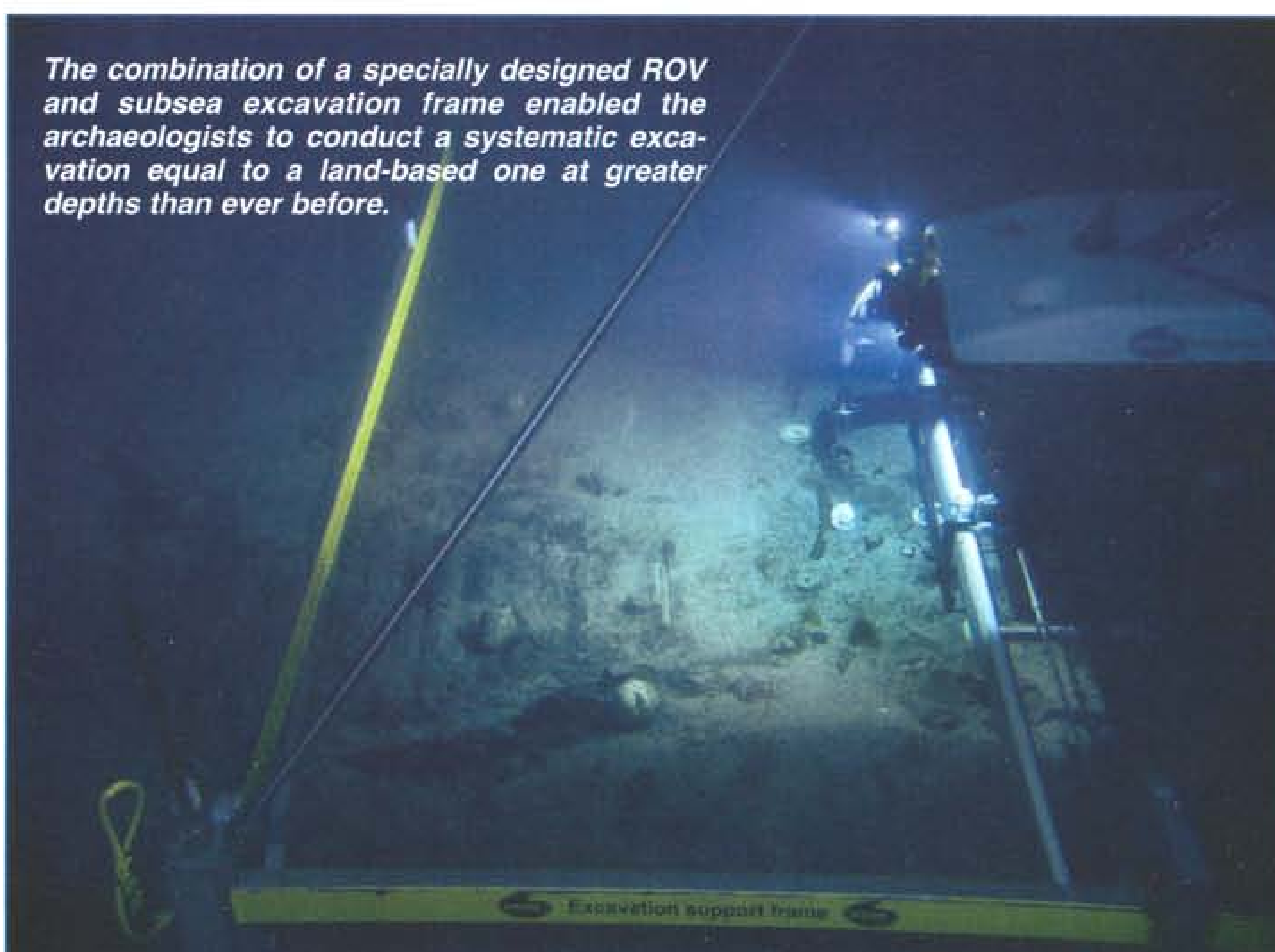
In 2003, in connection with a survey of the planned gas pipeline routes, archaeologists from the Norwegian University of Science and Technology (NTNU) located a shipwreck in 170 meters' depth. Since the shipwreck is protected under the Law of Protection of Cultural Heritage, additional investigations of the wreck site were necessary prior to the installation of the pipelines. During 2004 and 2005, advanced technology and new methods were used to document and excavate the site, making it the most technologically advanced underwater archaeology project ever undertaken.

The marine archaeological investigation, conducted pursuant to the Norwegian Cultural Heritage Act, was financed by the Ormen Lange license and other participants in the development.

Marine Archaeology in Deep Water

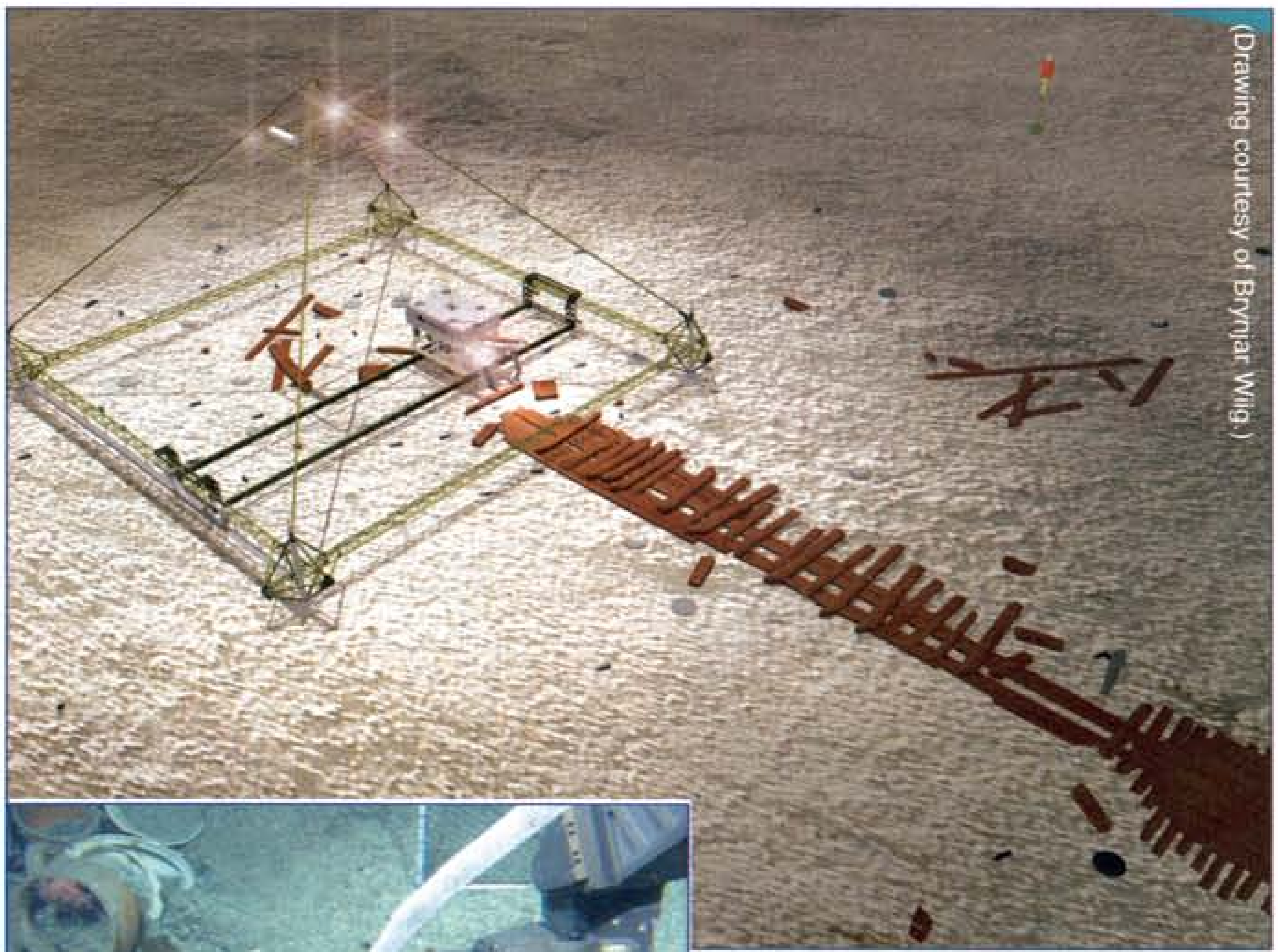
Once the wreck was located, it was determined that the site was historically significant and in a state of good preservation. The ship appeared to be splayed open due to decay of the deck timbers and upper works of the ship. Some of the remaining ship's timbers were exposed, while others were partially or completely covered with sediment. The stern section of the wreckage contained artifacts such as porcelain, stoneware, pewter, glass, wood, bronze, coins and iron.

Due to a substantial water depth of nearly 200 meters, scuba diving was impossible and the use of remotely operated vehicles (ROVs) to conduct all mapping, surveying, sampling and excavation was mandated. ROVs are not new tools in marine archaeology. Cruder versions, predominantly designed for the oil industry, have been used by historians and archaeologists to locate wrecks and collect objects for many years in the United States, Mediterranean and the Black Sea. However, the bulky, crude devices

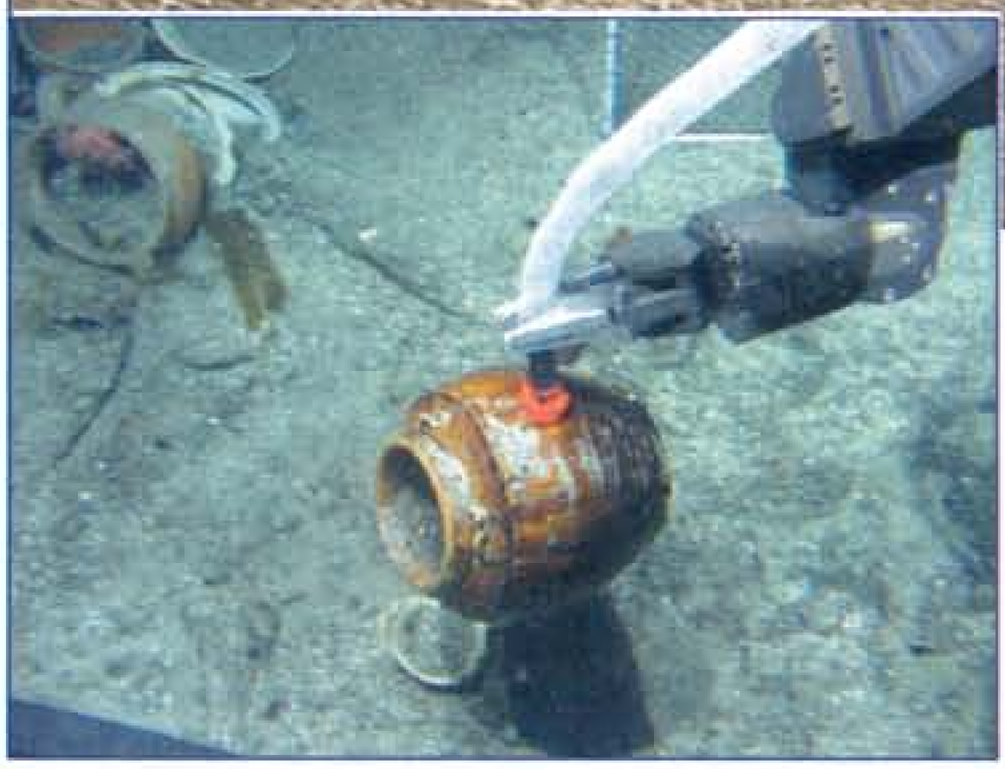


The combination of a specially designed ROV and subsea excavation frame enabled the archaeologists to conduct a systematic excavation equal to a land-based one at greater depths than ever before.

(Photo courtesy of the NTNU.)



(Drawing courtesy of Brynjar Wiig.)



(Photo courtesy of the NTNU.)

(Top) The ROV docked on the subsea excavation frame.

(Bottom) A ceramic vessel is recovered from the site with a suction picker.

have often disturbed the very sites they were sent to investigate, destroying historical artifacts in the process. In addition, these ROVs were never designed for marine archaeological tasks. This is why most other deep-sea archaeological operations have been limited to documentation and sampling.

NTNU has been developing marine archaeological methods and conducting projects in the deep waters around Norway and abroad since the early 1990s. Over the past decade, NTNU has participated in or directed marine archaeological projects in Norway, the United States, Greece, Malta, Bulgaria, Portugal, Greenland, the United Arab Emirates, Argentina, Chile and Mexico. This work has resulted in the discovery and documentation of numerous historic shipwrecks.

When it became clear that extensive documentation and excavation of the site would be necessary prior to installation of the pipeline, it was decided that this unique experience would be used to develop a special marine archaeology ROV. The system was designed in close cooperation with Sperre AS, who also built and operated the ROV. The two-ton electric work-class ROV is capable of carrying the special tooling needed to document and excavate deepwater sites. Another, smaller Sperre ROV system was used as a back-up for film documentation and tasks that required simultaneous use of two ROV systems. This setup successfully enabled the project to conduct all tasks that could previously only be accomplished by divers.

Detailed Documentation

The pipeline routes and area surrounding the shipwreck were first surveyed with several different high-resolution side scan systems and a Reson AS (Slangerup, Denmark) ROV-mounted multibeam system to construct detailed maps of the seafloor. A Kongsberg Maritime (Kongsberg, Norway) scanning sonar was used to create an even more resolute acoustic model of the wreck site in micro-bathymetry mode.

The shipwreck site itself and the area surrounding the wreck was then surveyed with video cameras to establish the full extent of the site, and to locate artifacts that may have become disassociated with the main wreck site over time. A detailed visual inspection of a 400 by 800-meter area surrounding the main shipwreck structure revealed 179 man-made artifacts in the immediate vicinity, the majority of which were modern. However, the inspection revealed a spread of shipwreck-related artifacts to the south and southwest of the wreck—downhill from the main wreck site.

This visual inspection utilized seven high-resolution video cameras, including broadcast cameras on the ROV. Hydrargyrum medium-arc iodide gas lamps were used in conjunction with flood and wide flood reflectors to give remarkable wide-area illumination, compared to traditional lights.

Paired lasers were used to introduce a scale in selected video images in combination with various measurement rods that were also positioned on the site.

Special cameras were used to collect video and photomosaics of the main shipwreck site. Due to rapid attenuation of light underwater, the only way to get a large-scale view of a bigger site is to build up a mosaic from smaller local images. The mosaic technique was used to construct an image with a far larger field of view and level of resolution than could be obtained with a single photograph. The photomosaics were created by flying the ROV over the site at a constant altitude with the camera pointed parallel to the site in an elevation view. After the site had been completely photographed, the collected images were processed in a software program developed by Woods Hole Oceanographic Institution (Woods Hole, Massachusetts) that joins image borders so that the edge between them is not visible.

To be able to collect high-resolution data, the ROV was equipped with closed-loop control. This enabled the ROV to operate in an automatic mode and run dense survey patterns over the site along pre-programmed survey lines at constant altitude. This is a task that a human operator would be incapable of carrying out with the required accuracy.

An array of Kongsberg long baseline (LBL) transponders were installed around the wreck site and used for positioning the ROV and as the main control parameter for the closed-loop control along with a Doppler log and various other motion sensors.

The data was fed into a specially developed software package from Sperre, created in cooperation with EIVA (Hasselager, Denmark) to output the necessary control signals for the ROV.

Finally, the area surrounding the wreck site was surveyed with state-of-the-art sub-bottom profilers and a magnetometer to determine the full extent of the site buried beneath the sediment. In many cases, archaeological material will be completely buried underneath the sediment and can, therefore, not be located by visual aids. Three different sub-bottom sets were collected and plotted in ESRI's (Redlands, California) ArcGIS program and compared to the available bathymetry, side scan data and photomosaics. This pre-excavation documentation phase formed the basis for a preliminary site analysis and site plan.

"Once the wreck was located, it was determined that the site was historically significant and in a state of good preservation."

Excavation

Due to a risk that the site would be damaged by the pipeline, it was decided that the shipwreck should be uncovered and partly excavated. The project team designed a unique excavation support frame to investigate in detail and partially excavate the shipwreck. The ROV docked onto a platform on a 10 by 10-meter steel frame. From the control room aboard a research vessel, the ROV pilot can move the docking platform in all directions on the frame by motorized cogwheels. Sitting still a few centimeters above the shipwreck, the ROV poses no risk to the thousands of fragile artifacts scattered on the seabed. Positioning is based on rotation sensors on the frame, backed up by high-resolution directional sonar sensors with resulting sub-centimeter accuracy. Positioning input from the LBL system was also recorded. The frame allowed the archaeologists to excavate the seafloor with great precision so that the maximum amount of data could be extracted, while carefully handling any artifacts to be recovered. The combination of the specially designed ROV and the frame enabled the archaeologists to conduct a systematic excavation equal to a land-based one at greater depths than ever before.

A specially developed marine archaeology dredge was developed by GTO Sediment AS (Trondheim, Norway) to remove the sediments and uncover fragile items. Sediments were filtered through a sediment collection basket. Two hundred small artifacts were later collected from this device. An altimeter was used to measure trench depth.

When an artifact had been uncovered, it was picked up using a seven-function Kraft Telerobotics Inc. (Overland Park, Kansas) Raptor force-feedback manipulator arm. The force-feedback function enabled the device to pick up fragile artifacts, but artifacts were mainly lifted by a specially developed suction picker used as the main recovery tool. The suction picker lifts artifacts with a small suction cup connected to a pump by a hose. When the pump is started, the suction cup can be used to pick up even the most fragile artifacts. More than 200 artifacts were recovered without any damage. Some artifacts were also lifted by specially developed tooling that was constructed onsite. The artifacts were stored in internal collection baskets in the ROV or lifted in external collection baskets. Artifacts recovered range from tiny buttons to large ceramic vessels and stone plates in excess of 50 kilograms.

The project contracted with ESRI to develop a software module in ArcMap to record images and data about artifacts as they were excavated from the shipwreck.

The program was used to record all significant data in real time, while video from the ROV-mounted cameras were store using a VisualSoft (Aberdeen, Scotland) digital video recording system. Various additional attributes were stored with the video in VisualSoft, enabling users to coordinate data in the ESRI database with digital video.

Shipwreck

Nearly 500 artifacts were recovered from the site, making it the most comprehensive and detailed excavation ever carried out by an archaeological institution in deep water.

The bulk of the artifacts are German, English and Chinese, but there is also pottery with origins in Spain, The Netherlands and Southeast Asia.

The English stoneware does not have traces of use, and was probably part of the cargo. The ceramic pots from Southeast Asia, on the other hand, seem to have been in use onboard the vessel. Based on the artifacts discovered, it seems likely that the Ormen Lange shipwreck was an English or Dutch trade ship from the mid to late-18th century that navigated along the Norwegian coast to or from northern Russia. A substantial number of Russian coins and other artifacts point to this. The vessel appears to have been carrying a profitable cargo of spirits, which may have been accompanied by a load of grains, salt or a similar perishable cargo which did not survive. Traces of Russian buckwheat were among the items recovered. Wine was an important trade item throughout Europe and was also extensively used when crews were bartering with the locals.

Deep water was the last frontier for marine archaeology. This new technology enables archaeologists to investigate and excavate cultural heritage in deep water with the same precision and standards as on land—this has never been done before.

Research into the material collected from the wreck site will hopefully yield the necessary clues needed to identify the vessel. There is ongoing archival research in Norway, England, The Netherlands, France, Spain, Portugal and Russia, and this will hopefully reveal the identity of the ill-fated vessel. /st/

For more information on this subject matter, visit our Web site at www.sea-technology.com and click on the title of this article in the Table of Contents.

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