Archaeological site survey using 3D sub-bottom profiler

A case study from Phanagoria

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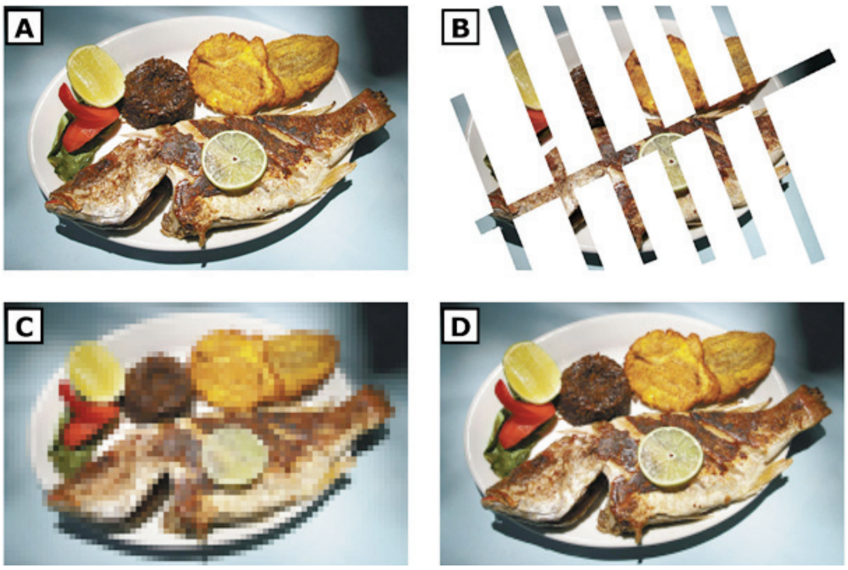


Fig. 1: Features of obtaining a seismic image of the geological environment (A) 2D seismic (B), three-dimensional seismic (C) and acoustic (D) survey.

Annotation

Phanagoria was the largest ancient Greek city within the territory of Russia. Just like many other Greek *poleis*, Phanagoria, founded in the 6th cent. BC on the shore of the Lake Korokondamitis (modern Taman Gulf) – was engaged in maritime navigation and commerce. In the 1st cent. AD the port and the coastal part of Phanagoria were flooded by the „Phanagorian" transgression of the Black Sea level. A new pier was built in the 3rd cent. But again it was flooded in the 7th cent. AD. Now all the flooded structures are covered by sandy-silt sediments and can be studied either by underwater excavations or using geophysical methods.

Since 2011 magnetic and seismic surveys have been conducted near the site of Phanagoria having an area of more than 15 hectares. As a result of these surveys, a number of interesting features were discovered. The majority of the study area in shallow water (water depth less than 1.5 m) remains poorly studied due to technical restrictions of the applied techniques and equipment.

The study of a flooded cultural layer and objects in this layer is complicated by the heterogeneous composition of soils with different physical properties. Furthermore line-based geophysical surveys does not allow for obtaining data with sufficient spatial resolution. Therefore, in the summer of 2016, a prototype of a self-propelled platform for performing three-dimensional seismic survey in shallow water areas (water depth is 1-3 m) was tested using the sub-bottom profiler Innomar SES-2000 compact.

Advantages and disadvantages of 3D seismic methods in the study of archaeological sites

The main advantage of three-dimensional seismic methods lies in the fact that the information coming to the receiving elements from different directions is registered and processed together, which makes it possible to correctly reconstruct the spatial position of the reflecting boundaries and to obtain a 3D picture picture of the feature under study that is impossible for the profile observations (Voskresensky 2006).

Archaeological objects where located on the bottom can be detected with the use of bathymetric survey and sonar survey, but these methods do not allow for studying objects beneath the seabed.

If the local object is located outside the survey line at 2D survey, then on the seismic section it can appear as a lateral reflection or as a diffraction, which cannot be correctly taken into account. There is another problem in shallow water – a local object located far from the survey line may not be noticeable due to the large angle of approach of the reflected waves, or due to the insufficient recording length of the seismic trace.

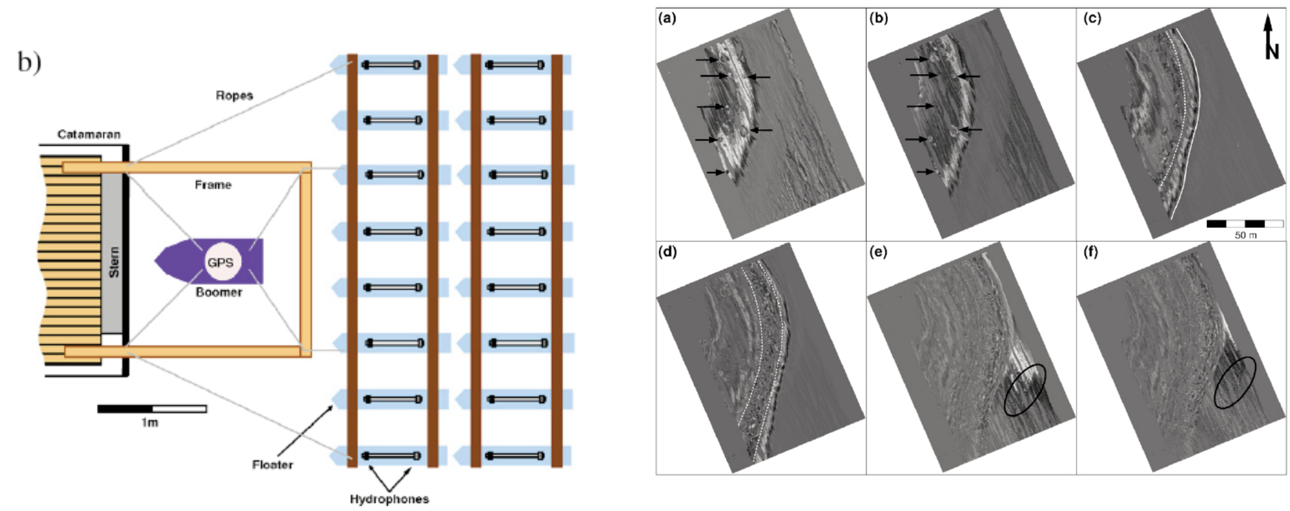


Fig. 2: Show of SEAMAP 3D and time-slices of survey area with seismic features of potential archaeological relevance marked by arrows,lines and ellipses: a) 1.3 ms (c.1.0 m), b) 1.7 ms (c.1.25 m), c) 2 ms (c.1.5 m), d) 2.7 ms (c.2.0 m), e) 3.67 ms (c.2.75 m), f) 3.73 ms (c.2.8 m).

To study the structures with spatial distribution (for example, buried industrial structures, sunken vessels, remains of buildings) and to detect small local anomalies, three-dimensional (3D) surveys are more efficient as they can overcome the shortcomings of 2D surveys. Figuratively the difference between the data from line-based versus areal observations, can be demonstrated by the illustrations on Fig. 1 (from Vestrum – Gittins 2009).

In the shallow water areas, detailed 3D surveys are complicated by technological and methodological aspects, the most important of which are high density of observations and accuracy of elements location on the array. Also, certain limitations are related to the width of the receiving array that can reduce productivity and increase operational costs.

Existing methods of three-dimensional offshore seismic surveys

Over the past twenty years, scientific groups and commercial organizations have developed technologies and methods for three-dimensional seismic survey in water areas, but most of them are unsuitable for work in shallow waters. A review and classification of all methods is given in Shmatkov et al. 2015; Gainanov et al. 2017; Monrigal et al. 2017. In this article are considered the technologies that can be used for archaeological research.

SEAMAP 3D

The SEAMAP 3D system was developed in 2004-2006 at the Christian Albrecht University, Kiel, Germany. SEAMAP 3D is used to study archaeological sites in shallow water. In 2007, port facilities and a fortress were portrayed in the harbor of Hedeby with its help. Hedeby was situated on the border between the Carolingian Empire and Scandinavia, in what was to become part of the German Empire (Müller 2013).

SEAMAP 3D is based on a self-propelled catamaran towing a transceiver system mounted on a rigid frame measuring 8 × 4 m. To obtain a data system we used a „boomer“ type source with a frequency of 100-6000 Hz, a differential GPS receiver in RTK mode, a 32-channel seismic station based on a 24-bit ADC. The vertical resolution of the system is 1 dm. To register the data, 8 4-channel seismic streamers fixed at 0.5 m are used.

Archaeological surveys using SEAMAP 3D were conducted at two sites in Turkey. The seismic time-slices obtained as a result of the surveys can help to single out a seabed, geological structures and a potential archaeological site (Fig. 2).

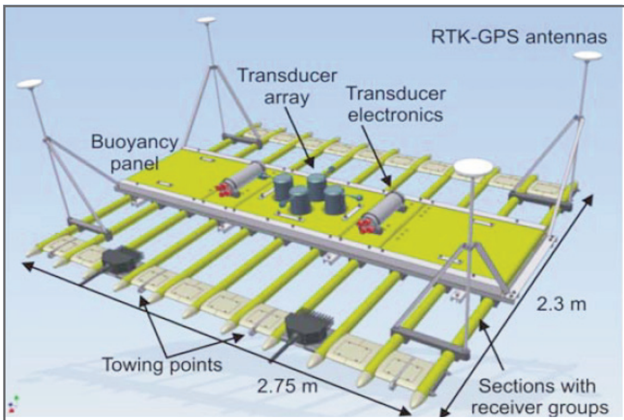
3D Chirp

The 3D Chirp system is developed at the National Oceanographic Center of Southampton. The system consists of a plastic frame of 2.75 × 2.3 m, positive buoyancy modules, four piezoceramic sources with a frequency range of 1.5 to 3 kHz, 60 hydrophone groups located at 0.25 m intervals, and four DGPS-receivers, providing accuracy of shooting up to 2 cm horizontally and 2.6 cm vertically. The compactness of the system makes it possible to use it from small vessels in transit zones, rivers and lakes (Fig. 3, left).

The 3D Chirp system was used to investigate the vessel „Grace Dieu“, sunk in the Hamble River, Southampton. The 30 × 30 m polygon was worked in RTK mode with an accuracy of 2 cm vertically and up to 1 cm horizontally, the size of the bin in the final seismic cube is 12.5 cm (Fig. 3, right).

Multi-Transducer System SES-2000 quattro

The system SES-2000 quattro was developed by Innomar Technolo-



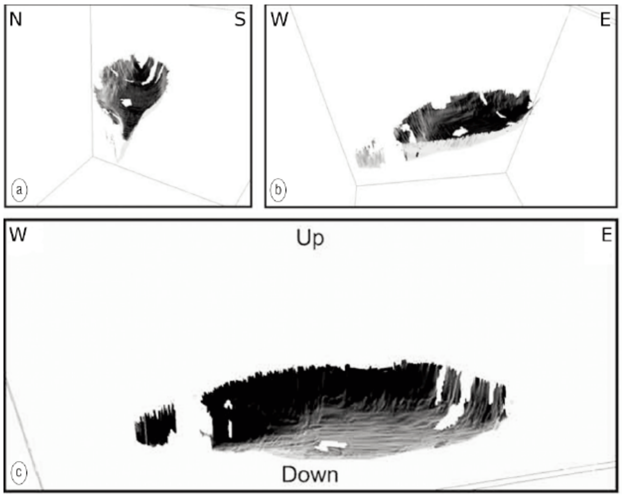
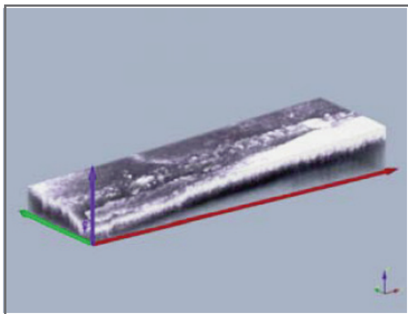


Fig. 3: System 3D Chirp (left) and three-dimensional reconstruction of the sunken ship „Grace Dieu" (right).

gie GmbH, Germany, from several sub bottom profilers SES-2000. Non-linear signals make it possible to form a pulse with a narrow radiation pattern, which together with high resolution and high pulse periodicity gives a detailed image of the upper part of the bottom sediments. The transceiver antennas are located on a rod with an interval of 0.5 m (Lowag 2010).

To study a 130 m x 40 m polygon containing the remains of a viking building, the Multi-Transducer System SES-2000 mtx processed 40 profiles. As a result of post processing, the vertical resolution of the survey was 2 cm. Using an operating frequency of 10 kHz, it was possible to identify the underwater part of the flooded structure and create its three-dimensional model (Fig. 4).



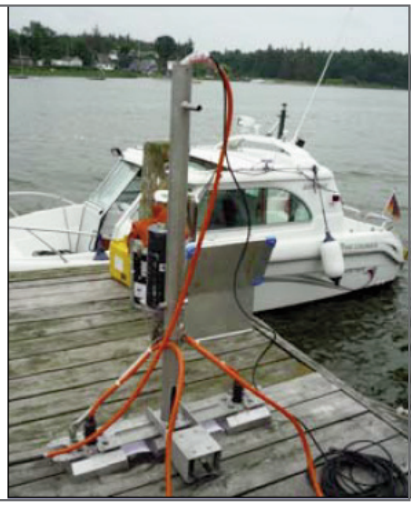


Fig. 4: Show of SES-2000 quattro (right) and three-dimensional picture of geological settings (left).

Sub-bottom imager

The Sub-Bottom Imager (SBI) system is developed by PanGeo Subsea to produce a three-dimensional image of the geological environment. The system is universal, because it can be installed on a ship, ROV or AUV. To generate the signal are used 3 high-frequency chirp sources with a frequency range from 4 to 16 kHz. Receiving hydrophones are located perpendicularly to the direction of survey,

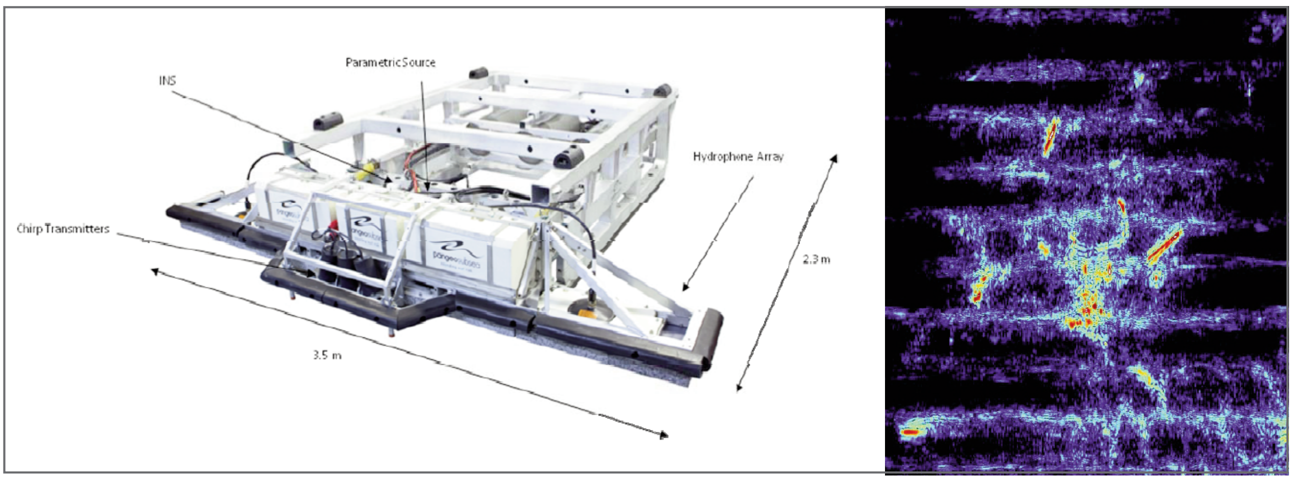


Fig. 5: Sub-bottom imager (left) and example of data (right).

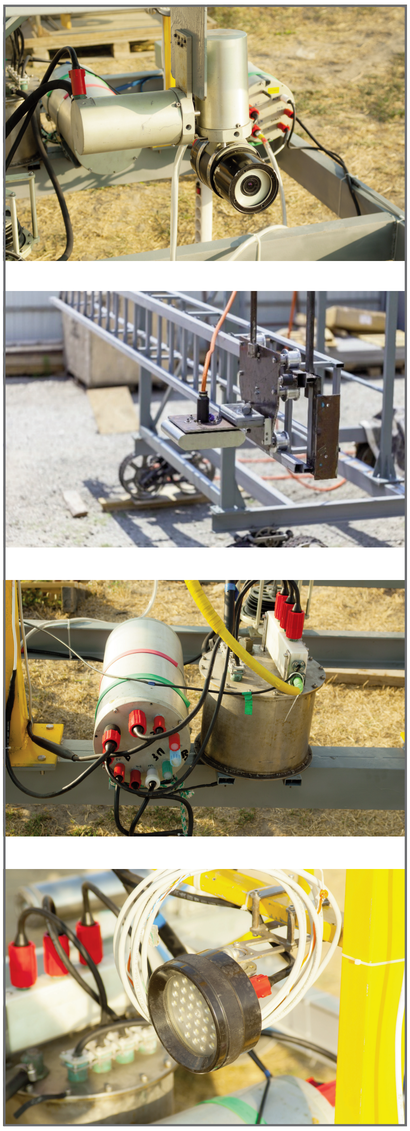


Fig. 6: Components of ROV MSS-350: Top: Full-HD Camera; below top: Sub bottom profiler SES-2000 compact on the carriage; above bottom: Power box and transformer: bottom: LED lights.

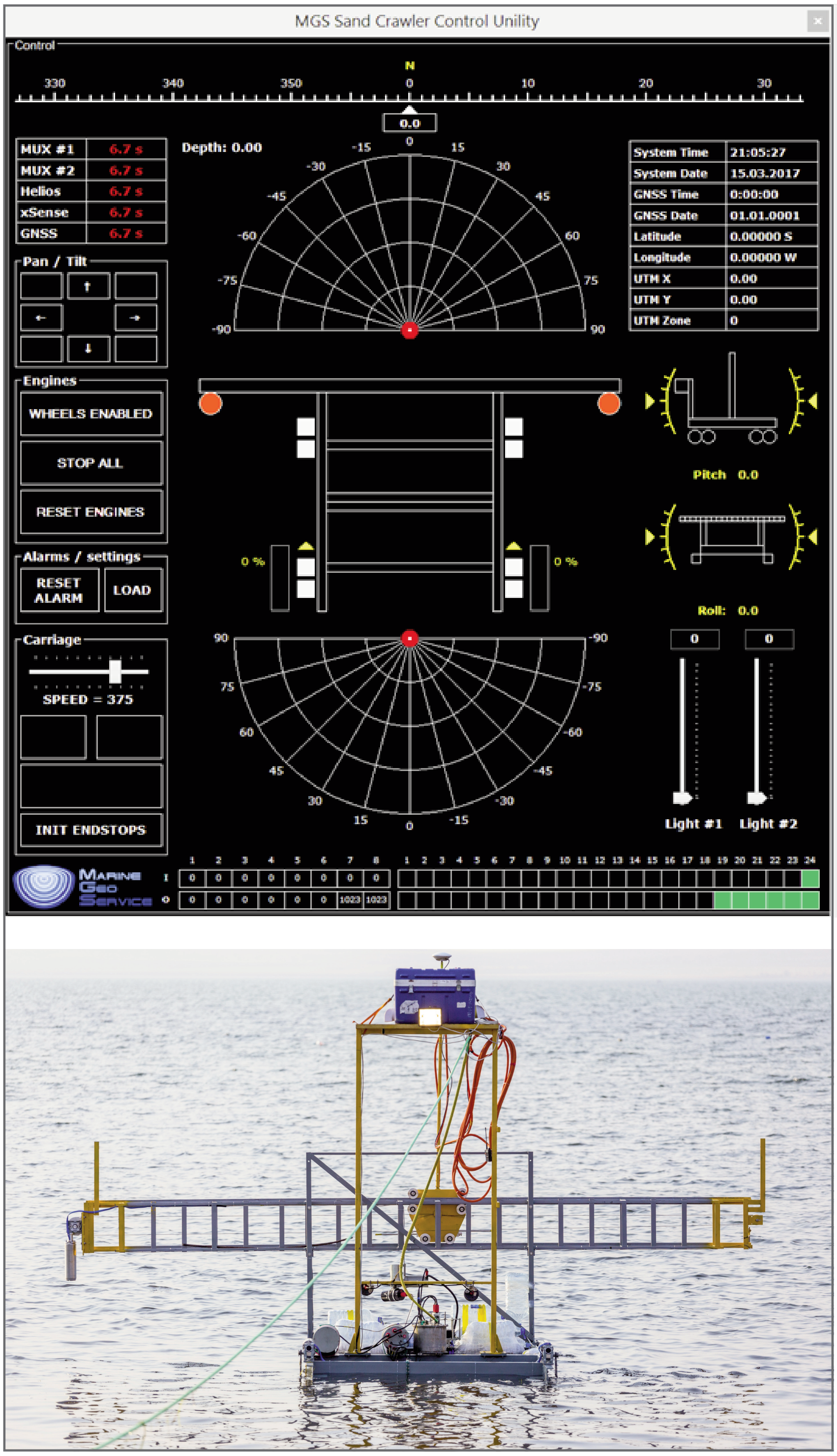


Fig. 7: Software MGS Sand Crawler Control Utility (above), "Sleipnir" at the start position (bottom).

which allows obtaining data on the structure of the geological setting in a strip up to 5 meters wide. In addition to the successful use of SBI in engineering geology, this system was used to study an archaeological site – a shipwreck of the 18th century (Fig. 5).

Sleipnir

For three-dimensional seismic surveys in the submerged part of the Phanagoria Marine Geo Service (Russia) was developed "Sleipnir" system consisting of a propelled remote-controlled platform and sub bottom profiler SES-2000 compact with operating frequencies 2-15 kHz and 100 kHz. The platform is assembled on a frame 2.4 × 2.7 m, on which are installed 4 wheel pairs with thrusters, electronics in sealed boxes; vertical frame for electronics in the splash-proof box; truss structure with a length of 5.5 m for the carriage movement with an sub bottom profiler. For the energy transfer and data exchange with the platform the components of remotely operated underwater vehicle MSS-350 were used (Fig. 6) as well as specially designed software (Fig. 7).

The "Sleipnir" system is operated by the operator from the shore by a long cable (350 m). The "Sleipnir"

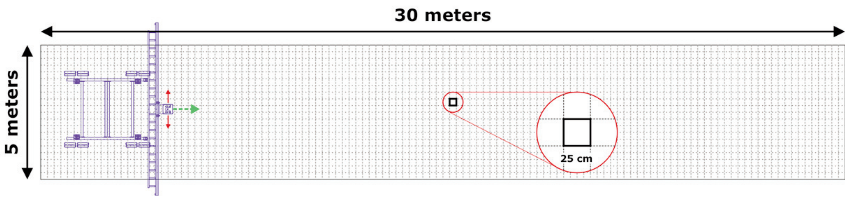


Fig. 8: Survey area covered with grid of 25x25 cm.

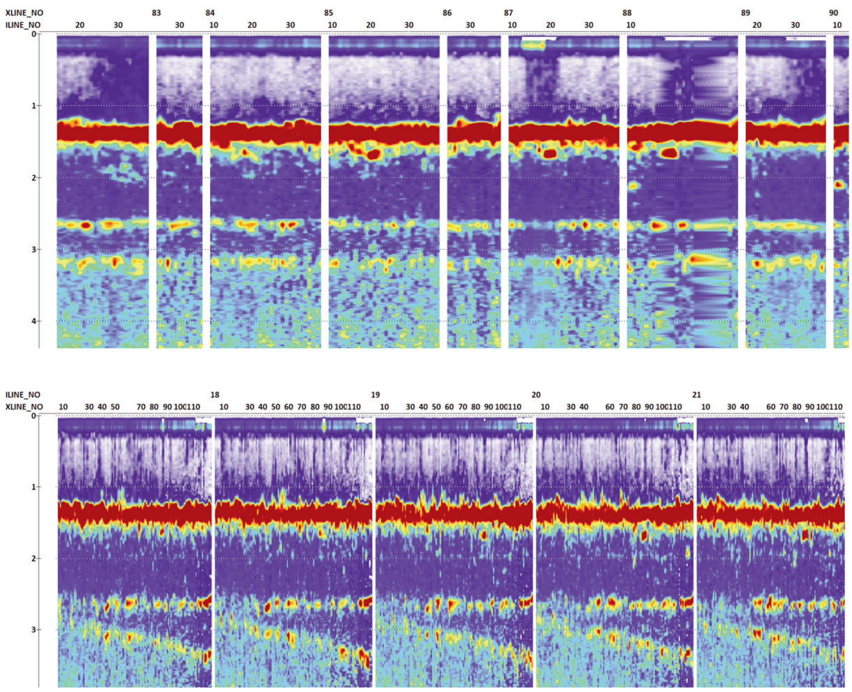


Fig. 9: Example of time sections with buried objects (inline direction at the top and cross-line direction in the bottom).

system control station is located on the shore, from which the operator, using telemetry and Full-HD data, controls the movement of the platform and starts the survey process.

The positioning of the SES-2000 transceiver provides a differential Trimble SPS 461 GNSS receiver in RTK mode, fixed above the transceiver of the sub bottom profiler, which gives a decimeter-precision accuracy of the coordinate reference of measurements (Fig. 8). The GNSS base station transmitting RTK corrections is located 1.5 km from the work area.

The technique of survey provides that the "Sleipnir" platform under remote control goes to the initial position - to the depth of the sea about 1 m. The next upon the command of the operator, begins shooting in the start-stop mode: the mobile carriage with the SBP scans line with a length of 5 m. Then the platform is shifted forward by 0.2-0.25 m, and the carriage moves the SBP in the opposite direction (Fig. 9).

Field trials of the Sleipnir system in the shallow water area (1-3 m) were performed in the summer of 2016 at study area of the Phanagorian expedition of the Institute of Archeology of the Russian Academy of Sciences. 3D SBP survey area with size of 50 × 50 m was chosen based on previous 2D data. Planned line spacing was equal 5 meters. During the trials we discover some issues in movement the platform along the profile due to different soil properties at the sea bottom. For example, we determine that wheel drive does not provide sufficient displacement of the platform through the bottom areas covered with soft mud. Thus during the trials the Sleipnir system performed a seismic acoustic survey of a 30 × 5 m with planned bin size of 25 × 25 cm (Fig. 10).

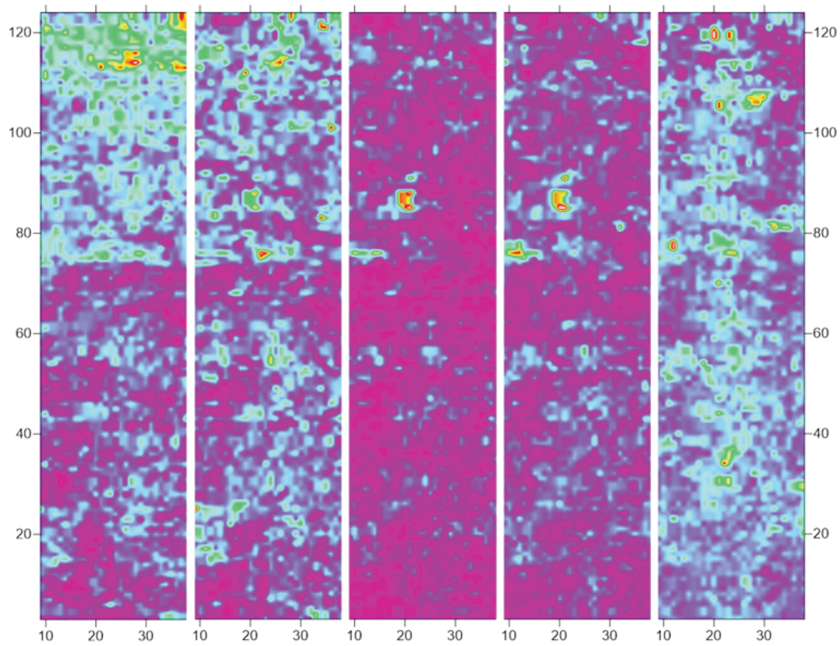
Survey data were preliminary processed in ISE software by Innomar. Data smoothing, trace summing and amplitude correction for spherical divergence procedures were applied to raw data. RadExPro software by Deco Geophysical SC were used for further processing that comprises geometry and data QC, static correction computation, 3D CDP binning and stacking. During data analysis, time slices of RMS amplitude cube were also used for identification of buried objects. Some examples of final image are shown below (Figs. 11–12).

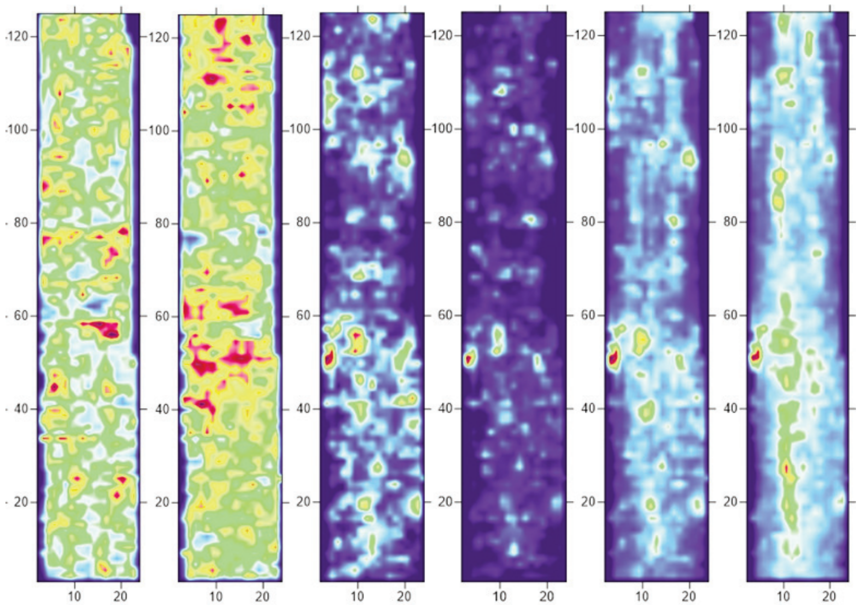
Conclusions

The tests of the "Sleipnir" system showed that the results of three-dimensional seismic survey are much more informative than a survey on a grid of parallel lines from the side of a small vessel. The "Sleipnir" system is applicable for a wide range of tasks and has a number of advantages:

- Controlled and stable position of the platform ensures accuracy of positioning and quality of survey;
- Work at any time of the day with with waves to sea state three;
- The system can be equipped with various geophysical and hydrographic equipment;
- No vessel is required for the survey.

At the same time, the test of "Sleipnir" performed in 2016 shows that the wheel drive of the platform has insufficient mobility in silt sediments and requires other constructive solutions. In 2018 Marine Geo Service plans to perform a 3D seismic survey using improved techniques that will help to inhance the imaging of the ancient port of Phanagoria.





Figs. 10-11: Sequence of time slices of RMS amplitude cube at intervals 1.5-1.9 m and 1.3-2.05 m.

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Credits of figures

Fig. 1: Vestrum - Gittins 2009; Fig. 2: Müller 2013; Fig. 3: left: Gutowski 2008, right: Vardy 2011; Fig. 4: Lowag 2010; Fig. 5: Dinn 2012; Figs. 6-11: The authors.

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