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Detection and mapping of shipwrecks embedded in sea-floor sediments

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ABSTRACT

The paper discusses the detection of shipwrecks embedded in sea-floor sediments using a Chirp sub-bottom profiler. From a methodological-historical perspective it presents four examples of recent chirp recordings of verified shipwrecks embedded in different types of sediment environments, from different geographical and geological areas and from different periods. The effects of shallow water depths, different sediment types, recording speed and different (2D and 3D) sub-bottom profiler systems are briefly discussed. It is concluded that Chirps are well suited for survey purposes, producing high quality 2D profiles of good resolution and satisfactory penetration depth. Furthermore, the equipment is easy to handle from a small boat and allows flexible sailing. This type of 2D data is cheaper and faster to acquire and is easier to interpret and apparently also provides better resolution and detail than present 3D systems. Chirp data are therefore of great value in identifying and outlining shipwrecks hidden in the sea floor in survey situations where larger areas must be covered. The overall conclusion is that there are grounds for optimism with regard to this method of detection of maritime archaeological targets.

1. Introduction

Side-scanner and multibeam systems are well-suited for detecting and mapping shipwrecks that lie partly exposed above the sea floor. Obtaining more detailed information about shipwrecks buried within and covered by sea floor sediments represents a different problem. To be able to distinguish such wrecks located below the sediment surface, as well as the buried parts of wrecks with elements of their construction visible above the sea floor, requires the use of instruments that can penetrate the sea-floor sediments, either physically (probes, corers, water jets etc.) or by remote sensing.

A pioneering and well-known example of the maritime archaeological application of sub-bottom profilers was Edgerton's use in 1968 of a 'mud pinger' (5 & 12 kHz) to locate the 1545 shipwreck of *The Mary Rose* below the sea floor (McKee, 1973). Throckmorton's work in 1971–72, using a 5 kHz EG & G 'penetrating pinger' in combination with a magnetometer and a side-scan sonar for locating anomalies resulting from the naval battle at Lepanto in Greece, should also be noted as an important early advance (Throckmorton et al., 1973). The same is true of Meissner and Stümpel's recording of the sediment-embedded Viking ship 'wreck 1' in Haithabu harbour prior to its excavation in 1979 (Meissner and Stümpel, 1979).

Another case from 1989 is interesting, because it demonstrated that the shape of a Medieval wreck embedded in sea-floor sediments at Sundekilen, Norway, could be successfully recorded with a conventional echo sounder (Simrad EA 300P) due to its absorbance of the acoustic signal. The acoustic result confirmed the previous record of the shipwreck's outline made using probes (Fig. 1) (Nævestad, 1991: 275–290).

From the 1990s onwards the work with subbottom profilers has continued on the theory based experimental level but never really gained acceptance for systematic survey of larger areas (Arnott et al., 2002; Grøn et al., 1998; Quinn et al., 1997a, 1997b).

With early sub-bottom profilers, with only one transducer used both for emitting and receiving the signal, water depth was a critical factor. The vibration from signal emission had to be halted before the transducer could receive. This took some time, meaning that the first part of the reflection from the sea floor could not be received in very shallow water. Normally, about 2 m of water was required between the transducer and the sea floor. Recently, modern systems, with separate emitting and receiving transducers, have been shown to produce reasonably good images with only a few decimetres of water below the fish (Grøn et al., 2007; Grøn and Boldreel, 2014; Grøn et al., 1998). It is generally assumed that sub-bottom systems have a problem in penetrating sandy sea-floor sediments. However, experience shows that a Teledyne Chirp III, sweeping the frequency interval 2–23 kHz, gives reasonable penetration of sandy sediments and fairly good results (Boldreel et al., 2010)

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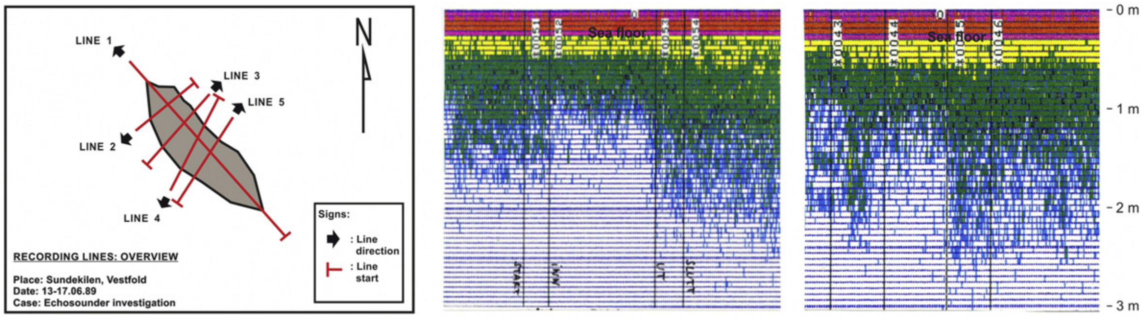

Fig. 1. The Medieval shipwreck at Sundekilen, Norway, which is totally embedded in the sea-floor sediments, could be outlined as a feature because it absorbed the acoustic signal such that it had shallower penetrations than outside the wreck. The precise outline of the wreck had, prior to this experiment, been determined by probing. Middle: recording of line 1, right: recording of line 4. Approximate depths below sea level (Nævestad, 1991: 275–290).
Graphics: D. Nævestad.

if these sediments contain just a small fraction of organic matter or a small silt component, while pure sand can be problematic in terms of producing a signal reflection.

It appears that chirp systems have an advantage over conventional sub-bottom profilers, operating with one or two frequencies, sparkers, boomers and parametric systems for the detection of archaeological anomalies that are normally characterised by a restricted horizontal extent, for example shipwrecks, poles etc. On the other hand, parametric systems are superior for the detailed detection of larger scale stratigraphical features of geological significance. The theme of this paper is the use of acoustic high-resolution sub-bottom profilers for the detection of wreck parts embedded in sea-floor sediments. Four cases are presented where chirp recordings show sections through shipwrecks totally or partly embedded in sea-floor sediments: the Ottoman period shipwreck Akko 4, Israel (Galili et al., 1991: 12–13; Galili et al., 2002, 2010), the Late Renaissance wreck Lundeborg 1, Denmark (Skaarup, 1984), the Medieval barge (AD 1184) Haithabu 4, Germany (Kühn, 2004), and a modern steel barge found off Tønsberg, Norway. All four cases were confirmed by divers prior to or after the acoustic recording.

It is important to recognise that, relative to geological and geophysical recording as these are practised today, different sailing strategies and different interpretation routines are required for maritime archaeological sub-bottom seismics (Grøn and Boldreel, 2014).

Whereas 3D systems can be useful for detailed recording of archaeological structures of restricted extent that have already been recognised, they are not presently suitable for reasonably rapid distinction of important smaller anomalies (e.g. poles and stakes) embedded in hard (e.g. sandy) sea-floor sediments, in contrast to the softer sediments found at the case sites of Hedeby/Haithabu and Grace Dieu (Gutowski et al., 2008; Mueller et al., 2013; Plets et al., 2009). A further problem associated with 3D survey systems is that their resolution is heavily reliant on the precision of their 3D-positioning systems which, in turn, is considerably more weather-dependent than for 2D systems (e.g. Gutowski et al., 2008; Müller et al., 2009). Due to this present requirement to distinguish between detailed recording of sites and large-scale survey, the improvement of maritime archaeological 2D sub-bottom survey strategies is an important priority in maritime archaeology (Grøn and Boldreel, 2014).

Experience shows that interdisciplinary integration is essential to obtain useful results. Often the procedure will involve sub-bottom profiling being used to map anomalies that represent potential archaeological features. These are then verified or rejected by diver investigation involving probes, water jets, air lifts etc. A crucial advantage is that the method facilitates targeting of the underwater investigation and thereby increases efficiency significantly.

This paper also aims to demonstrate that significant results can be obtained in maritime archaeological surveys with 'off-the-shelf' equipment. In order to obtain good results, careful testing of the qualities of the various systems on the market is essential, as the salesmen for the different brands tend to exaggerate the abilities of their systems and understate the problems involved in obtaining good recording of the archaeological features in which their customers are interested.

2. Akko 4, Israel

2.1. Background

In order to test if the Teledyne Chirp III worked well in shallow water in the sandy sediments off the coast of Israel, in March 2014 a test-run on a known Ottoman period shipwreck, Akko 4 (Galili et al., 2002: 13, Galili et al., 2010: 194, 201), was agreed between the Leon Recanati Institute for Maritime Studies, University of Haifa, Israel, the Norwegian Maritime Museum, Oslo, Norway, and the Department of Geosciences and Natural Resource Management, Section of Geology, University of Copenhagen, Denmark.

The historical walled city of Akko (Acre, St. Jean d'Acre, Akka) lies at the northern extremity of Haifa Bay, in the north of Israel. It has a continuous settlement history from the Early Bronze Age to the modern era, serving as an important port (Dothan and Goldmann, 1993; Makhouly and Johns, 1946; Masters, 2009). The town and harbour were conquered by the Ottomans in 1516 (Masters, 2009:9). In the 18th and 19th centuries, Akko was considered a strategic key position in relation to the Holy Land and Syria. During this period several naval campaigns took place in the waters off Akko, involving both local and European armies and navies. At the same time, Akko harbour was used for commercial purposes and for survey expeditions to the Holy Land and, as a consequence, merchantmen called there. Ships of various types and from various fleets – European, eastern Mediterranean and even American – used Akko harbour. The Akko 4 shipwreck represents the remains of one of these ships.

Akko 4 was discovered during an underwater survey conducted by the Israel Antiquities Authority (IAA) in 1990 (Galili et al., 2002, 2010). In this survey, Akko 4 was designated 'target 14'. The aim was to locate and document archaeological finds in and around Akko Harbour prior to the construction of a marina. A remote sensing survey was carried out by the Israel Oceanographic and Limnological Research Institute (IOLR) combining a Geometric 880 proton magnetometer and an O.R.E. (Ocean Research Equipment) 3.5 kHz sub-bottom profiler. The area was surveyed by E–W profiles spaced 10 m apart. Positioning during the survey was carried out with a Motorola mini ranger installed on the boat utilising two land stations. The results from the proton magnetometer were poor due to the presence of large amounts of iron scrap in the area, so that most (20) of the potential archaeological anomalies were distinguished with the sub-bottom profiler (Fig. 2) and subsequently checked by diver archaeologists. Of these original 20 anomalies, eight proved to be wrecks of sailing vessels partly embedded