# Multi-Transducer Sediment Echo Sounder for 3D Documentation of Submerged Archaeological Sites - a Case Study at a Prehistoric Pile Dwelling at Lake Mondsee (Austria)

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**Key words**: Hydrography, Lakes; Archaeology; Sediment Structure; Archaeological Underwater Prospection

## SUMMARY

A test of high end hydrographic surveying equipment of different manufacturers were carried out at the prehistoric pile dwelling "See" at Lake Mondsee (Austria), regarding high-resolution echo sounding and detection of embedded archaeological objects. The pile field is situated in a small bay near the lake outlet, where the core area of the site is about 100m long, 40 m wide and between 1 m and 8 m deep.

Multi beam echo sounder systems (Kongsberg, Teledyne, R2sonic), motion sensors and positioning systems (iXblue, Leica, SBG, Septentrio) as well as a unique multi-transducer sediment echo sounder (Innomar) were tested during a three weeks measurement campaign in May 2016.

Bottom coverage, resolution and accuracy were subjects of the investigation as well as the ability to return more than a single point from a ping (multi detection), which is actually useful when surveying a surface with features sticking out of the ground, like piles.

Special attention was given to the parametric narrow-beam sub-bottom profiler (SBP) Innomar SES2000 quattro. This recently developed device consists of four transducers arranged as a line array of one meter length for high across-track data density. An area with an extension of 140 m x 40 m was measured using a survey line spacing of one meter.

Data gridding of about 160 SBP-echograms resulted in a 3D volume model (voxel model) with a grid cell size of 25 cm x 25 cm x 1 cm. This uniform lattice can now be visualized in 3D with any common volume rendering program.

Dynamical views as well as time slices enable a proper visualization of sediment structures and the localization of embedded objects, like archaeological remains, with a high resolution.

## KURZFASSUNG

Im Mai 2016 wurde im Bereich der prähistorischen Pfahlbausiedlung „See" am Mondsee (Österreich) ein Test von hydroakustischen Messsystemen in Hinblick auf ihren Einsatz zur

archäologischen Prospektion durchgeführt. Neben Fächerecholotsystemen zur Dokumentation der Seebodenoberfläche wurde erstmals ein Multischwinger-Sub-Bottom-Profiler-System zur Dokumentation der Seebodensedimentschichten eingesetzt. Das resultierende Voxelmodel ermöglicht eine dreidimensionale Erforschung von im Boden verborgenen Objekten und Strukturen. Die Testmessungen haben gezeigt, dass die eingesetzten hydroakustischen Systeme in der Lage sind, auch in extremen Flachwasserzonen ihren Spezifikationen entsprechende Daten zu liefern, und als Ergänzung zu hochauflösenden Side-Scan-Sonaren einen Informationsgewinn für die archäologische Unterwasserprospektion darstellen.

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## 1. INTRODUCTION

### 1.1 Prehistoric pile dwellings

Some 1000 pile dwelling sites are known from around the Alps. They are spread across Switzerland, southern Germany, Austria, Slovenia, northern Italy and eastern France. They are often located on the shores of lakes, and, more rarely, in the flood plains of rivers (Fig. 1). Due to their location in waterlogged soil, constructional timbers, food remains, wooden tools and even items of clothing have survived. Therefore, these settlement remains offer more detailed insight into the prehistoric lifestyle: they are the most important sources for research into early farming communities in Europe.

Fig. 1a: Reconstruction of the pile dwelling site "Kammern am Attersee", Austria

Fig. 1b: Range of constructions of pile dwellings (UNESCO, 2015)

The prehistoric pile dwelling station 'See' is the eponymous find location of the Neolithic Mondsee group, and lies at the Eastern end of Lake Mondsee in a small bay the lake outlet. Because the water level of the lake did rise over time, most of the original piles are now around 1 meter to 8 meters under the actual water level (DWORSKY, 2011). The settlement proved to be one of the stations richest in finds in the Salzkammergut region.

„See" station was discovered in 1872 by M. Much, and in 1951, K. Willvonsede and K. Schaefer undertook the first dive examinations. In 1971/72, the Bundesdenkmalamt measured the station, and in 1982-86, J. Offenberger from the Bundesdenkmalamt undertook a surface documentation and find salvage (OFFENBERGER & RUTTKAY 1997, JANSA 2013). Since 1989, the finds are being appraised in an interdisciplinary research project at the Department of Prehistory at the Museum of Natural History in Vienna (UNESCO, 2015).

In 2011 the "See" station was part of 111 out of the 937 known archaeological pile-dwelling sites in six countries around the Alpine and sub-alpine regions of Europe, that were inscribed on UNESCO's World Heritage List.

### 1.2 Motivation and state of the art

In 2015 the county of Oberösterreich started an extensive archaeological project in collaboration with several Universities in Austria, with the aim to stimulate the research on prehistoric pile dwellings. Underwater geophysical prospection, as a powerful non-destructive method for the detection, mapping and preservation of monuments and sites, is one of the major topics of this research campaign. The research focus lies in the development of hydro acoustic procedures for a precise and detailed documentation of all structures of the surface of the site (lake bottom) and of all structures, that are hidden beneath the ground (sediment structures and objects).

The choice of technique to be used in search of submerged and the buried archaeology depends very much on the particular situation and on the different landscapes that have to be surveyed.

First attempts to document and monitor submerged pile dwellings using hydrographic surveying methods were realized successfully at the site Unteruhldingen at Lake Constance (Germany). Multibeam Echo Sounder (MBES) and Side Scan Sonar (SSS) were used to accurately map the surface of the lake bottom (KÖNINGER et al. 2013, WESSELS et al. 2013).

Due to the release of the multi-transducer Sub-Bottom Profiler SES-2000 Quattro from the German enterprise Innomar in 2015, it is possible to visualize sediment structures and to localize embedded objects like archeologic remains three dimensionally and with an excellent resolution and penetration. Several tests in the past with multi transducer prototypes but also the latest tests with the commercial product delivered excellent results (WUNDERLICH et al. 2005, LOWAG et al. 2010; MISSAEN 2015), thus an application for the underwater prospection of prehistoric pile dwellings looks promising.

The main goal of the case study was the comparison and evaluation of high resolution hydro acoustic sensors for the development of an efficient hydrographic survey methodology to document submerged archaeological sites.

This article is focusing on the methodology and the data acquisition process of the case study. Specific archaeological interpretation of the results is still ongoing and will be part of future publications.

## 2. SCOPE and TEST AREA

A test of high end hydrographic surveying equipment of different manufacturers were carried out at the prehistoric pile dwelling "See" at Lake Mondsee (Austria), regarding high-resolution echo sounding and detection of embedded archaeological objects.

In a first step a pre-selection of suitable instruments were carried out regarding their performance (data quality, productivity etc.) and their applicability on small boats and at regions of very shallow water depth. The selected enterprises were then invited to undertake a two days demonstration of their equipment at Lake Mondsee.

The test area is located at the eastern part of Lake Mondsee in Austria. The prehistoric pile dwelling "See" is situated at its east end, proximate to the discharge of the lake (Fig. 2).
The remains of prehistoric piles are showing a diameter between 2 cm to 20 cm and sometimes they stick out of the ground only a few centimeters or are totally covered by sediments (DWORSKY 2011). (Fig. 3).

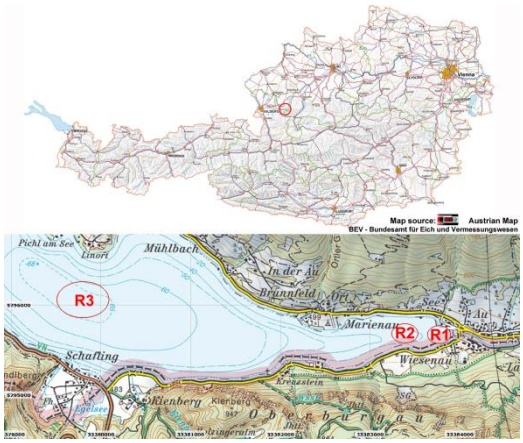


Fig. 2: Location of the test sites at "Lake Mondsee (Austria)"

Fig. 3: Remains of prehistoric piles of site "See" (source: POHL 2015)

The measurements were carried out at three regions of different water depth and topography (Fig. 2):

— Region "R1": Archaeological site; prehistoric pile dwelling "See"; water depth: 1 m - 10 m; rough topography

— Region "R2": water depth: ~ 15 m; smooth topography

— Region "R3": water depth: ~ 65 m; mostly flat terrain

## 3. METHODOLOGY AND RESULTS

### 3.1 Survey vessel and sensor installation

To realize the hydrographic survey of the archaeological site near the lake shore a shallow water hydrographic survey vessel was made available for the test campaign. Additional IT-infrastructure for on-board processing and online data validation as well as individual pre-installation of hydrographic components for each enterprise was provided.

iXBLUE (France) did support the test with the high-performance inertial navigation system HYDRINS, that delivers highly accurate real-time position, heading, attitude and speed data. Its installation and calibration was optimized for the hydrographic survey of the archaeological site using MBES. In addition to the real-time options, the INS raw data were stored for forward/backward post-processing of the sailed path to enhance the quality of the navigation data. The required position information was delivered using RTK-GNSS-equipment (Leica GS25 and Septentrio AsteRx-U).

Hydrographic data acquisition, navigation and processing were realized with the software package QINSy from QPS together with specific user interface and real-time data processing software of the instrument manufacturer.

### 3.2 Multibeam echo sounding

Three high-end Multibeam Echo Sounder (MBES) of leading manufacturers of "mid-range" systems (KRISTENSEN, 2016) take part in the campaign: EM2040C Dual Head (Kongsberg), Sonic 2024 (R2Sonic) und SeaBat T50-P (Teledyne Reson).

MBES calibrations were executed to find the mounting angle errors (roll, pitch and heading) of the multibeam transducer(s) by sailing particular patterns at test area R3 & R2 ("patch test").

At region R3 the efficiency and quality of MBES surveying of "deep" water areas were investigated, regarding archaeological prospection of unexplored lake portions. Back scatter information – even of "low order" compared to true side scan sonar (SSS) - and in some cases also water column data (WCI) can provide additional information about the lake bottom environment and provide further justification to conduct detailed prospection, like applying towed high resolution side scan sonar (see also QUINN, 2013, 79 ff.).

The shallow lake shore area at the archaeological site (test area R1) was surveyed with different swath angles in order to evaluate the data quality of the outer beams in relation to water depth and swath angle. Increased sound velocity coefficients of the upper water body at shallow lakes as well as MBES calibration errors and uncertainties in the INS-solutions are the main sources for errors at the out beams, thus swath angles should be restricted to less than 100° for accurate MBES surveys (Fig. 4a) (see also SOMBROWSKY, 2011; BURNETT, 2016).

Within region R1 three smaller areas of rough topography were selected, that includes natural and manmade objects of different size, trenches and the remains of wooden piles of the prehistoric settlement (Fig.6). The topography of these areas was measured with different frequencies, different swath angles, and from different directions by sailing along perpendicular tracks. Backscatter information delivers further information about the surface physical properties, thus increases confidence in interpretations of seabed features for the archaeological prospection (Fig. 4b).

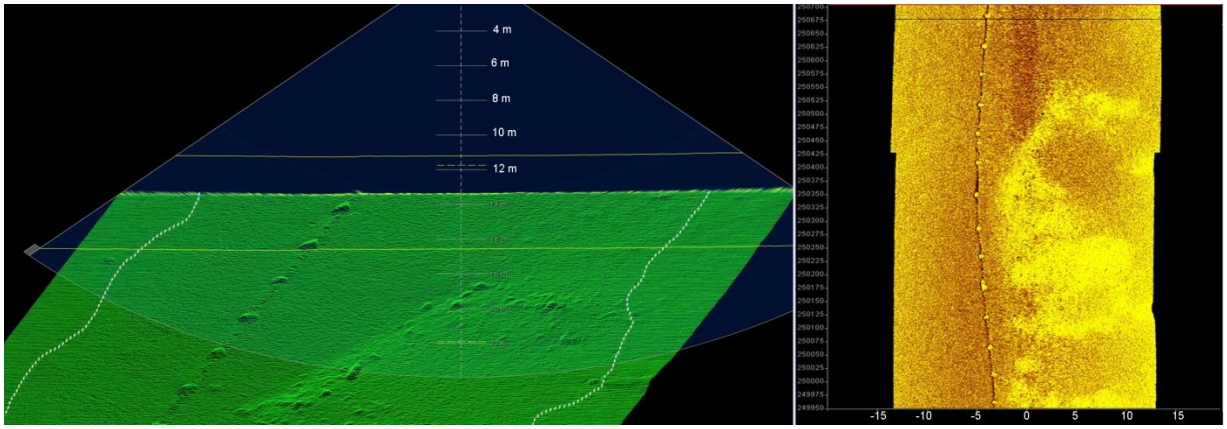


Fig. 4a) Critical outer beam zones due to wide swath angle (white doted lines)

Fig. 4b) MBES backscatter information

A very useful option of the detection of remains of piles is the Multi-Detect feature. Classical MBES provide one return ping within each beam, either from the top of the object (i.e pile) or from the ground. The Multi-Detect feature provides multiple detections within each beam. In this case a pile sticking out of the ground may be represented by several points out of one beam (Fig. 5).

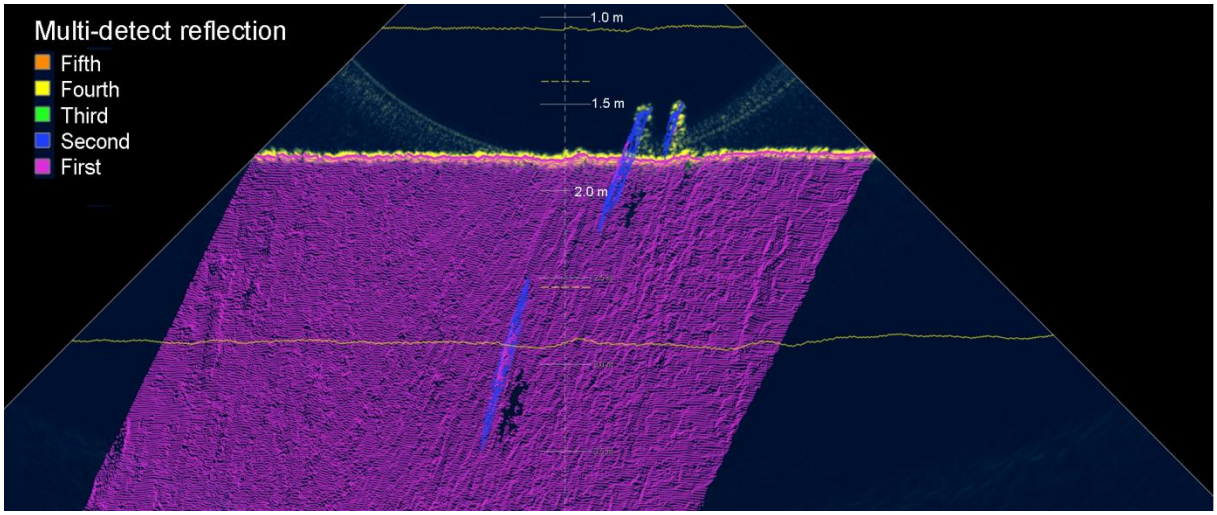


Fig. 5: MBES online fan view with "multi-detect" results at pile dwelling area R1

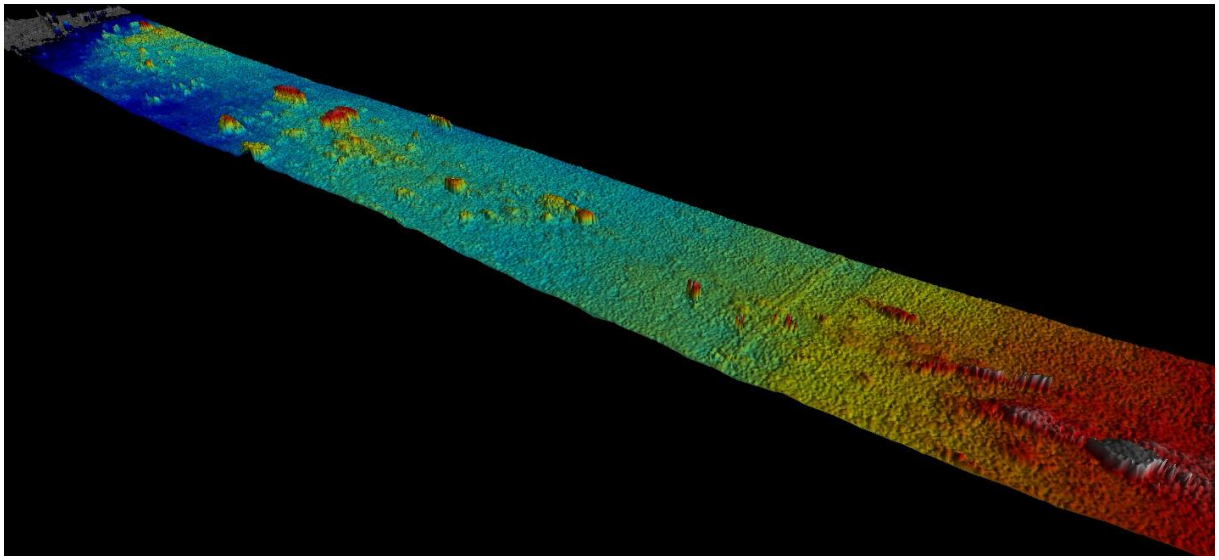

Fig. 6: MBES bathymetry of prehistoric pile dwelling site “See”; object heights <°15cm

### 3.3 Multi-transducer parametric sub-bottom profiler measurements

The main goal of the case study was the evaluation of the sediment echo sounder SES-2000 Quattro of Innomar regarding the detection of embedded objects, i.e. buried remains of piles.

The SES-2000 series are parametric echo sounders that are based on the concept of non-linear generation of acoustic waves. During simultaneous transmission of two signals of slightly different high frequencies at high sound pressure, a new frequency arise, with a frequency equal to the difference between the two primary frequencies. The resulting low frequency signal allows a better bottom penetration and a high vertical resolution. The SES-2000 device generates a low frequency between 4 kHz and 12 kHz based on primary frequencies of around 100 kHz. Thus the system is able to achieve a resolution of about 5 cm, an accuracy of ±2 cm + 0.02% of the water depth for the 100 kHz frequency, and about ±4 cm + 0.02% of the water depth for the chosen low frequency of 10 kHz (HEINE et al., 2013).

The applied SES-2000 Quattro consists of four transducers mounted side-by-side on a bar of one meter length. The bar is oriented perpendicular to the survey direction (across track) and thus delivers four sub bottom profiles for each survey line. Sailing with a navigation line distance of one meter results in a coverage of the whole area with equally spaced profiles of 25 cm across track distance.

40 tracks of 120 m length were sailed to cover the core area of the prehistoric pile dwelling “See” with 160 sub bottom profiles of 25 cm across track distance. RTK-GNSS positioning as well as high accurate motion compensation was applied also for these measurements to obtain undisturbed high resolution data sets (see also Missian, 2015). For the entire area a penetration of the lake bottom of more than ten meters could be achieved for the 10 kHz frequency measurements.

The software package ISI was used for postprocessing and georeferencing the standard 2D sections from the SBP-raw-data, like array geometry, offsets and lever arm correction. The individual traces were exported as scattered 3D sounding points including the amplitude value (XYZA format) and transformed into a uniform XYZA grid of 12,5 x 12,5 x 1 cm using the software SES Gridder.

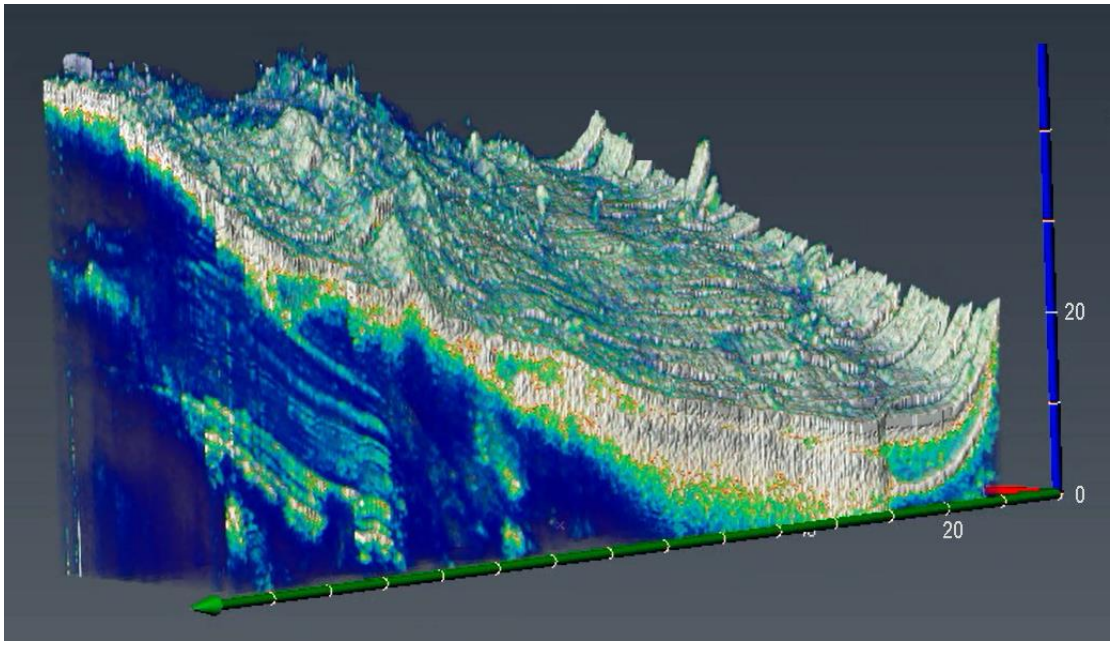


Fig. 7: Voxel model of the lake bottom sediment structures of the archaeological site

The volume renderer FEI Avizo was used to visualize the dataset in 3D by applying proper colour and opacitiy maps (Fig. 7). The resulting Voxel-model offers the possibility to explore and analyze the 3D data set in various ways, like dynamic visualization by creating movies (fly over, walk through) or applying clip planes to visualize time slices (Fig 8).

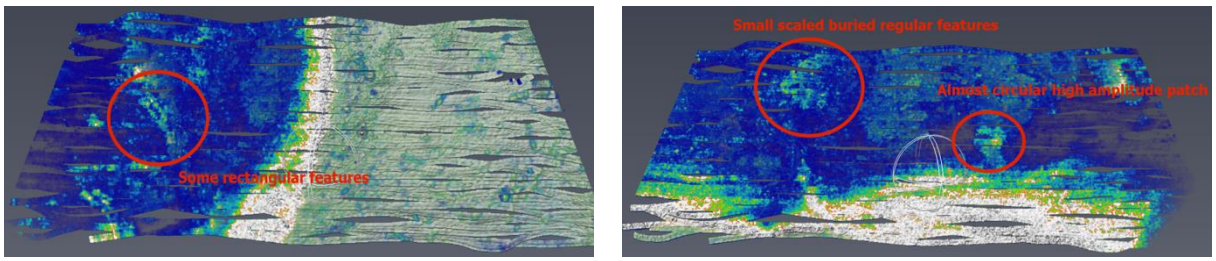


Fig. 8a: Geophysical interpretations based on time slice views (horizontal cuts) of the volumetric model

## 4. CONCLUSION

The test at Lake Mondsee was of great importance for the evaluation of multi beam echo sounder and sediment echo sounder for the archaeological prospection of prehistoric pile dwellings. It could be shown, that the multi-transducer sub-bottom-profiler is able to provide detailed and accurate information of structures and objects embedded in sediments of several meters of thickness. The resulting volumetric models offer manifold visualization possibilities to the scientists to gain invaluable findings based on this 3D acoustic investigation of the submerged archaeological site.
In this regard MBES delivers accurate bathymetric models of the topography with an almost moderate resolution and additional low grade backscatter information of the surface physical characteristic. It is the method of choice for first, rough prospections of areas of great extensions and great water depths, i.e. due to the accurate georeferenced backscatter data. Derived digital elevation models are furthermore ideal suited for accurate georeferencing and 3D visualization of high resolution side scan sonar data (SSS) of archaeological sites.

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