Submersible ground penetrating radar (SGPR) – chances and limits for underwater investigations

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Abstract
Results of submerged ground penetrating radar (SGPR) measurements show spectacular detailed depositional structures of lake floor sediments, which could not be revealed with any other geophysical method yet. Due to its very high resolution, GPR is particularly suitable for archeological prospection on land surfaces and now on lake floors. A case study showed that a submerged archaeological site in Lake Constance (boulder mounds, the so-called "Hügelis") is interfingering with the sedimentary record. Depositional history reveals that the site must be human-made and dates back to the prehistorical period. 14C ages of sediment and wood poles proved Neolithic age of the more than 170 boulder mounds comprising over 80,000 metric tons of rock.

Keywords
archeology; Lake Constance; Neolithic boulder mounds; sedimentology; underwater ground penetrating radar

Introduction

Land based GPR is well established and successfully applied since years in archaeological prospection (e.g. Leckebusch 2001; Wallner et al. 2021), sedimentology (Franke et al. 2015), and engineering geology. Rarely, GPR systems were used already from boats on the water surface (Sambuelli et al. 2009; Baum et al. 2014; Fediuk et al. 2022). However, using GPR-systems underwater was not possible yet due to the lack of submersible systems. This study shows the high scientific potential of lake floor GPR surveys by constructing a submersible ground penetrating radar (SGPR) and applying it at the floor of Lake Constance (SW-Germany).

Materials and methods

A commercial GPR system (GSSI Inc., Model SIR 4000, 200MHz antenna) was modified to use it underwater (Fig. 1). A survey wheel running on the lake floor controlled the system and a dragged RTK buoy on the lake surface ensured underwater positioning.

The system emits a short electromagnetic pulse with a nominal center frequency of 200 MHz. The pulse is reflected at boundaries where the dielectric permittivity of the penetrated material changes. Such a boundary corresponds to geological layer changes as well as to boundaries, which were formed when the ground was disturbed or extrinsical material was brought in by human activities.

Submerged GPR (SGPR) penetrates deep when water and sediments have a low conductivity. Lake carbonates usually show a low conductivity whereas clay-rich sediments show high conductivities. Hence, the system works well in most sweet water lakes, but is limited in penetration depth in clay rich sediments. In saline lakes or in the sea SGPR will not show a sufficient penetration depth due to the high conductivity of the water.

Results

The SGPR system revealed sedimentary structures and architecture in the sub-littoral of Lake Constance. Data allowed reconstructing the depositional history and sediment fluxes (Wessels and Hornung 2019). Subsequently the potential for archeological prospection was recogni-

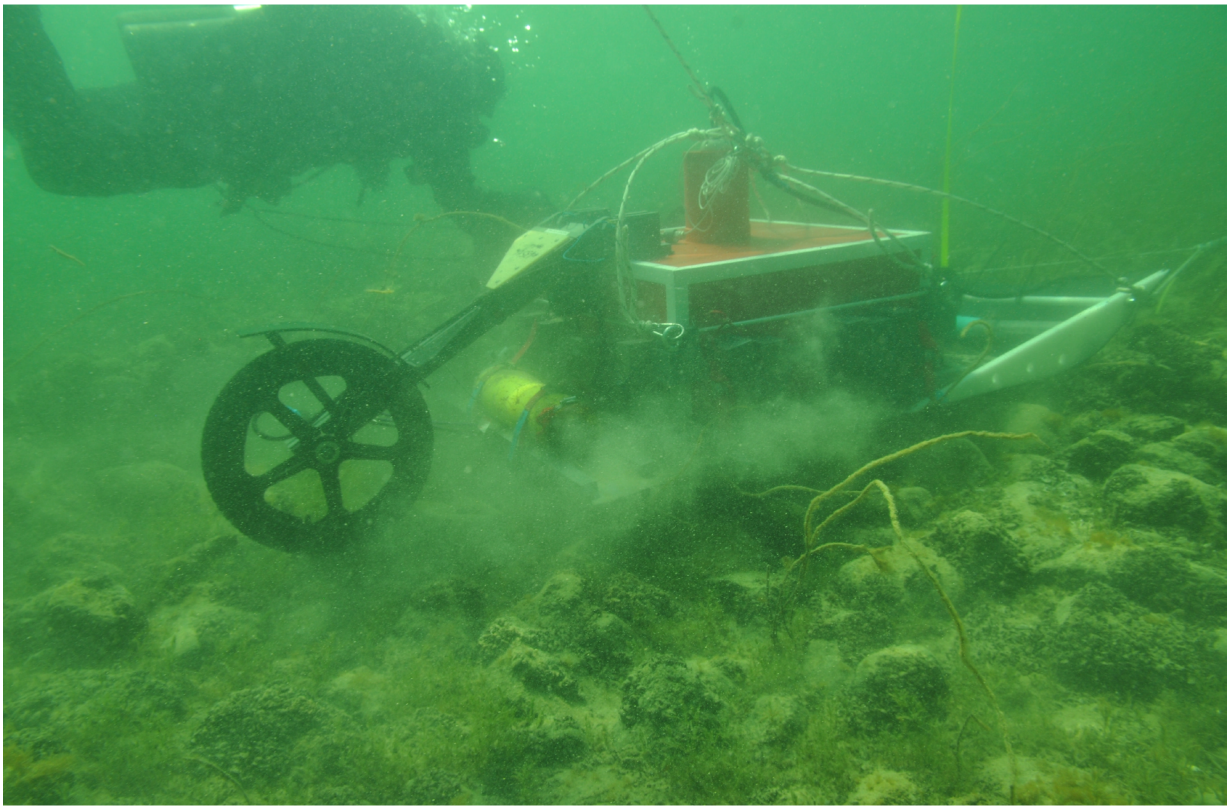

Fig. 1: Submersible ground penetrating radar (SGPR) in action on a Neolithic boulder mound in Lake Constance. Photo: AATG, Matthias Schnyder.

zed. In 2015, mysterious boulder mounds were discovered at the Swiss coastline of Lake Constance (IGKB 2015). The scientific question was to clarify if these mounds were the summits of a glacial moraine buried in the lake sediments or if the mounds were sitting on top of the sediment and hence were human-made. Figure 2 shows the SGPR section of one of the investigated mounds. The glacial moraine subducts 100m before the boulder mound and is overlained by different types of sediment reflected by different radarfacies types. The boulder mound is located on top of these sediments. Hence, it is not a summit of the glacial moraine – it is an independent structure, which interfingers with the topmost part of the lake sediments. Towards the lake, some boulders rolled or felt down the former slope. Then the deposition of lake sediments continued for almost another 100m covering also parts of the mound.

In conclusion, the boulder mound was human-made exactly at the transition from the littoral to the sublittoral. The mound was originally higher to let fall or roll down boulders towards the former lake slope. After the destruction of the mound deposition continued for a long time, hence, the mound should date back at least in prehistoric times. A subsequent underwater excavation revealed wood poles of an average of 3500 yrs. cal. 14C age BC and sediment dating of the layer with the fallen boulders supported this Neolithic age (Leuzinger et al. 2021).

Discussion

Hydroacoustic methods such as the 'subbottom profiler' are usually restricted to max. 1-3 m penetration into the sediment and show reasonable resolution to detect sedimentary or archaeological structures. Water-based seismic methods like the 'boomer' or 'pinger' method can reach significant penetration depths of several tenths of meters. However, resolution is not sufficient to resolve archaeological or sedimentary structures. As all acoustic methods rely on mechanical properties, they have problems to generate reflections when gas is present in the sediments, which is quite common in the subsurface of lake floors. Advantage of these methods is that they are independent of electrical properties of the sediment (e.g. conductivity)

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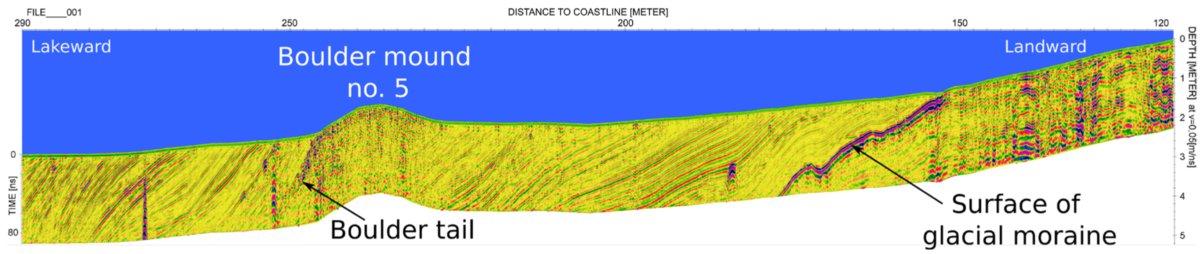

Fig. 2: SGPR section of the Neolithic boulder mound no. 5 in Lake Constance. Note that the mound is sitting inside and on top of the sediment and the glacial moraine is far beyond the mound. Boulders at the lakeward slope rolled or felt downdip and were covered with subsequent sediments. Deposition of lake carbonates continued after the boulder mound formation far out into the lake. Modified after Leuzinger et al. (2021).

and work even in clay-rich sediments and in salt water.

The GPR method overcomes resolution, insufficient penetration depth problems, and the electromagnetic waves can penetrate through layers with higher gas content. Additionally GPR may reveal material properties to some extend (Owenier et al. 2018; Fediuk et al. 2020). Probably electromagnetic properties revealed by GPR reflections can be used to distinguish rock boulders and wood trunks in lake floors.

For a long time lacustrine GPR surveys were restricted to the lake surface using non-metallic boats to float the antenna over the site. Due to significant energy losses in the water column, the application was limited to the shallow littoral zone e.g. 1-2 m water depth. The submersible GPR (SGPR) developed at the Darmstadt University of Technology is the first system, which can truly dive down to the lake floor and record detailed sections with sufficient penetration depth, superior resolution (cm-scale), and clarity of data.

Conclusion

Submersible GPR systems turned out to reveal crucial data about even small-scale sedimentary and archaeological structures in lake floors. Based on an integrated concept of lithofacies and radarfacies interpretation, it is possible to interpret depositional history, environment and palaeoclimate conditions from these data.

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