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Geoarchaeology as an essential supplement for large-scale, high-resolution archaeological geophysical prospection: case study of Gokstad in Norway

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High-resolution, large-scale geophysical prospection had not been applied in Norwegian archaeology until recently. One reason for this were the challenging environmental conditions, which can include magnetic bedrock masking large areas, as well as moist, unsorted glacial sediments and clay-rich soils limiting the penetration depth of GPR signals. However, new developments in motorised data collection, data processing and visualisation, as well as the use of complementary prospection techniques have solved most of these issues rather successfully and have resulted in large-scale, high-resolution archaeological geophysical prospection (AGP) datasets. Since 2011, research carried out by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) and its Norwegian partners, the Vestfold fylkeskommune (VFK) and the Norwegian Institute for Cultural Heritage (NIKU), has focused on selected Viking Age landscapes in the province of Vestfold, among them the Slagen valley with the well-known Oseberg mound, the royal burial site at Borre, the harbour town Kaupang and the landscape of Gokstad (*http://lbi-archpro.org/cs/vestfold/*).

In 2011 and 2012, the surrounding area of the Gokstad mound, which accommodated Norway's largest ship burial, was subjected to large-scale, high-resolution geophysical prospection surveys carried out by a team from the Austrian ZAMG ArcheoProspections® in cooperation with the LBI Arch Pro, NIKU and VFK (Bill *et al.* 2013). This investigation was part of the interdisciplinary research project "Gokstad revitalised" (*http://www.khm.uio.no/english/research/projects/gokstad/*), led by the Museum of Cultural Heritage at the University of Oslo. The magnetic and GPR surveys covered several hundred hectares and subsequent data interpretation yielded detailed maps of a Viking Age settlement and cemetery site located approximately 500 m south of the Gokstad mound, thus providing significant new information for an overall understanding of the archaeological landscape at Gokstad. Not surprisingly, a substantial amount of the areas and corresponding prospection data was void of any kind of archaeological remains. It does not mean, however, that there was no relevant information contained in these areas. They displayed a range of anomalies, features and patterns that were believed to be of

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Fig. 1. Using a liner sampler to evaluate the interpretations of GPR and magnetic data sets

natural origin. In order to investigate these non-archaeological elements of the archaeological landscape in more detail, a pilot study was conducted, dealing specifically with the analysis of palaeoenvironmental information hidden in large-scale, high-resolution AGP data.

The geophysical prospection surveys at Gokstad covered 454 ha of high-definition GPR and 403 ha of magnetometry and were conducted using state-of-the-art motorised systems. Resolution varied between 8-12 cm cross-line spacing for GPR and 25 cm for all magnetic surveys. All data were processed using the in-house developed APsoft (ArcheoProspections®) software and visualised as georeferenced greyscale images (Trinks *et al.* 2010; Gabler *et al.* 2013). Where necessary, volumetric visualisation of the GPR data was generated using AVSExpress. Data were integrated in ArcGIS 10.2. Geoarchaeological investigations were conducted to further evaluate the interpretation of previously unknown elements in the AGP datasets and to better understand their sources. Augering was carried out at selected locations, based on the GPR data using handdriven gauge augers and liner samplers (Fig. 1).

Results of palaeoenvironmental analysis yielded information on the palaeo-hydrology of the Gokstad area, on the former Viking Age shoreline, as well as on the palaeotopography and geomorphological processes. Palaeochannel systems were the most distinct palaeoenvironmental features in the AGP data sets and three different systems have been identified. The significance of the palaeochannels for the archaeological interpretation of the Gokstad area became most evident at an intersection between the largest dendritic palaeochannel system and a burial mound potentially dating to the Viking Age. Stratigraphy inferred from the GPR data at this location helped to establish a relative chronology of events and marked the palaeochannel system as an

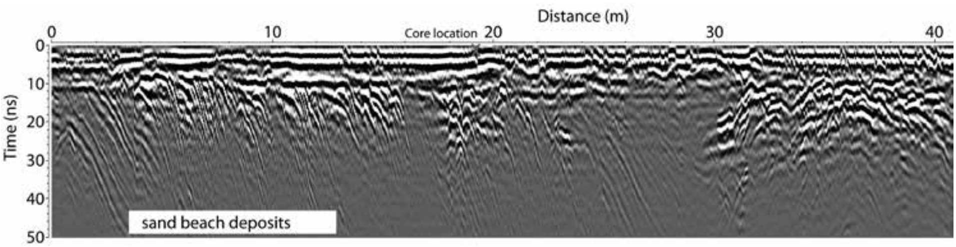

Fig. 2. Radargram displaying alternating reflective and absorbing layers interpreted as sand beach deposits. Note the core location for the geoarchaeological evaluation

important element of the Viking Age landscape at Gokstad even without a robust scientific dating strategy in place. The stratification was supported by volumetric data extraction as well as geoarchaeological investigations.

Palaeoenvironmental analysis yielded particularly valuable information on the former Viking Age shoreline. A pattern consisting of alternating reflective and absorbing features in the GPR data was detected close to the settlement traces and subsequently interpreted as sand beach deposits (Fig. 2). Geoarchaeological evaluation confirmed this initial interpretation and revealed layers of varying grain size classes as a potential source for the alternating pattern. The presence of sand beach deposits raised further questions regarding its formation and subsequent implications on the choice of settlement location and aided in the interpretation of some of the features situated close to the former Viking Age shoreline (Ambrosiani 2013).

The absence of archaeological features in the slope areas attracted attention. However, both GPR and magnetic datasets showed a wide range of unprecedented patterns of presumably natural origin that frequently occur in Norwegian datasets. Patterns included strongly reflective bands, areas indicating shallow buried bedrock as well as highly absorbing areas in between. Visualisation benefitted greatly from animating the datasets, which highlighted deviations from the current topography. These patterns were associated with the palaeotopography of the Gokstad area and illustrated erosion and accumulation processes since the land was exposed due to post-glacial land-rise more than 4000 years ago (Sørensen *et al.* 2007). Augering proved particularly helpful in verifying the initial interpretations and demonstrated that, when it comes to GPR data interpretation, one cannot infer soil texture information based only on amplitude strengths, as it only illustrates local contrast. Our analysis suggests that the slope areas present a more dynamic environment compared to the more stable lowlands, and that it provides more oxidised soils which could have been better suited for agriculture or pasture.

In conclusion, the pilot study demonstrated the potential of large-scale, high-resolution AGP data for providing valuable new information on past environments. It also highlights the importance of geoarchaeological evaluation, not just to address palaeoenvironmental interpretation, but as an essential element of the prospection work flow. In most cases, AGP data are readily available for palaeoenvironmental investigations and even if generated for archaeological purposes, can be used as a complementary source of information on further, more targeted investigations regarding landscape development and a comprehensive palaeoenvironmental understanding of the site under investigation.

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Archaeological prospection results in the surroundings of the Serapeion at Ephesus, Turkey

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For more than 15 years, the ZAMG (Central Institute for Meteorology and Geodynamics in Vienna), in cooperation with the Austrian Archaeological Institute (ÖAI), has been carrying out archaeological prospection using magnetics, georadar (GPR), resistivity and seismic methods in Ephesos, Turkey (Scherrer 2005).

In 2005, 2011 and 2014, an area of roughly 50,000 m^2 surrounding the Serapeion, one of the best preserved archaeological structures in Ephesos, was surveyed, partly in very difficult field conditions.

The Serapeion was built in the 2nd century AD on the northern slope of the Bülbüldag (*http://www.ephesus-foundation.org*). It takes up an area of approximately 100 m by 75 m. From the viewpoint of architectural history, this building is very significant, for one thing because it is so very well preserved (Heberdey 1915). Building blocks can still be found where they collapsed after the destruction of the temple, enabling archaeologist to reconstruct the temple with considerable accuracy (*http://www.ephesus-foundation.org*).

Refraction seismics were used along two lines running from north to south and positioned right and left of the ruined temple. The objective was to detect the rock surface and the thick-

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