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Large-scale high-resolution GPR and magnetic prospection in West Jutland, Denmark

Erich Nau[a], Lis Helles Olesen[b], Petra Schneidhofer[a], Manuel Gabler[a], Roland Filzwieser[a] and Esben Schlosser Mauritsen[c]

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In the last 30 years aerial archaeology has not been widely used in Danish archaeology. The ongoing project "An aerial view of the past — aerial archaeology in Denmark (2009–2018)" is the first regular work with aerial archaeology in Denmark. Especially in the region of West Jutland, repeated flights over the area have resulted in the discovery of hundreds of new archaeological sites (Helles-Olesen *et al.* 2011). Even though aerial archaeology works very well under the present conditions, new

[a] Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Vienna, Austria
[b] Holstebro Museum, Holstebro, Denmark
[c] Ringkøbing-Skjern Museum, Skjern, Denmark

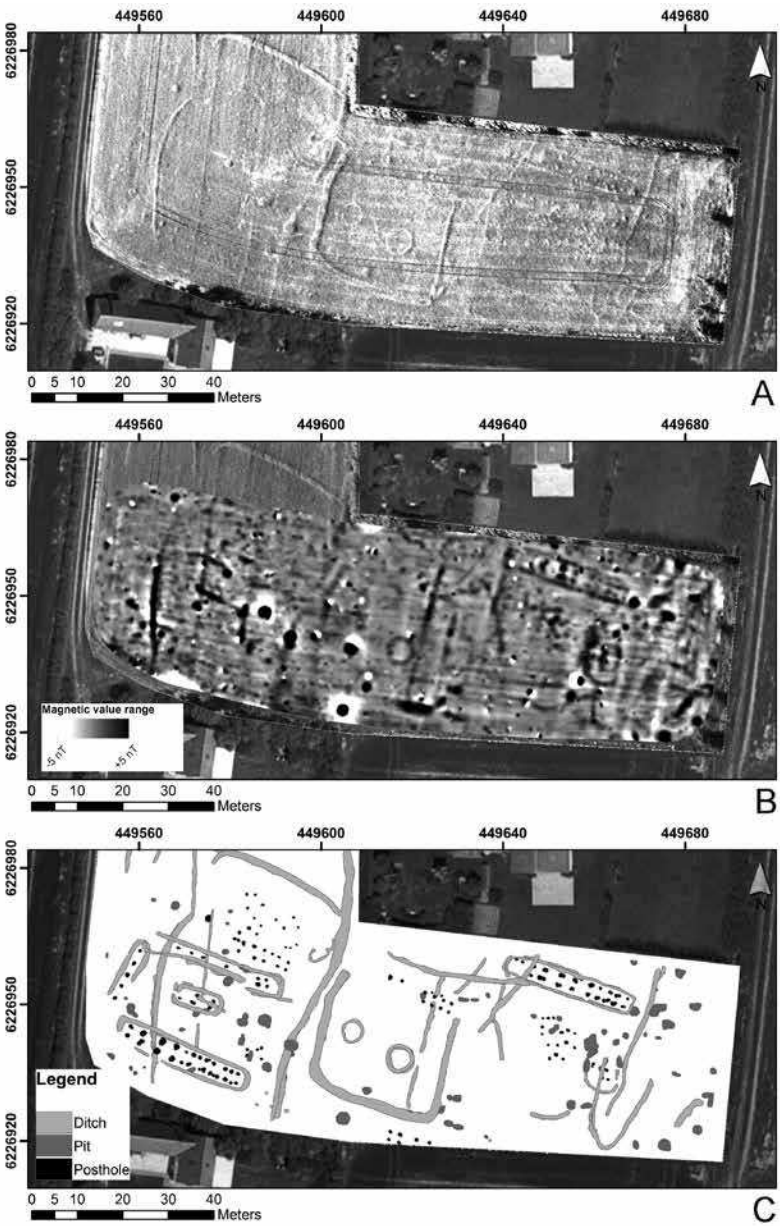

Fig. 1. Vesterager: A – aerial photography showing several remains of longhouses, fences, ditches and pits; B – magnetic data of the same area revealing a high grade of conformity with the aerial image; C – combined archaeological interpretation of aerial images and magnetic prospection results

research avenues have emerged as a result of recent technological and methodological developments in large-scale, high-resolution geophysical prospection methods and the potential arising from the complementary use of both remote sensing and ground-based geophysical techniques. The success of this integrative approach in this part of Denmark is attributable to very favourable environmental conditions, since West Jutland is almost entirely covered by glacial sands, deposited along the melting glacier at the end of the last ice age. The very uniform sandy soils and the flat agricultural landscape offer ideal conditions for aerial archaeology, as well as for large-scale motorized geophysical prospection. Finally, high contrasts between archaeological structures and the homogenous soil matrix turn crop- and soil-marks into a perfect image of buried archaeology.

In the summer of 2014, the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology (LBI ArchPro) joined the ongoing aerial archaeological research project mentioned above, conducted by Holstebro Museum, the added goal being to investigate the complementary use of GPR and magnetic prospection in a pilot study. Over the past five years the LBI ArchPro has gathered considerable experience in implementing large-scale high-resolution geophysical–archaeological prospection surveys in Scandinavian countries and has focused, as one of its research objectives, on the detailed documentation and investigation of Viking Age landscapes (Trinks *et al.* 2014; Gabler *et al.* 2013). Among these case studies are the well-known Viking Age sites of Birka-Hovgården and Uppåkra in Sweden, and Oseberg, Gokstad and Borre in Norway. In order to broaden the focus to include Danish Viking Age and early medieval sites, five test areas at Stadil, Skarum Mølle, Vesterager, Rysensten and Norreby, all located within a 50 km radius of the town of Ringkøbing, were chosen for a pilot study in West Jutland. Thanks to extensive aerial archaeological prospection surveys conducted by experienced archaeologists from Holstebro Museum, solid archaeological reference data and considerable experience already existed for all of the chosen sites.

From August 31 to September 6, 2014, a team from the LBI ArchPro, supported by archaeologists from Holstebro Museum, visited West Jutland for the first campaign of fieldwork. Three different motorized survey systems were applied: a 16-channel 400 MHz MALÅ Imaging Radar Array (MIRA) GPR system with a resolution of 8×8 cm, one 6-channel Sensors & Software SPIDAR GPR array with a spatial sampling resolution of 25×5 cm, and a motorized Fluxgate gradiometer array (Foerster) with a measurement resolution of 25×10 cm. Approximately 37 ha of magnetic prospection data and approximately 22 ha of high-resolution GPR data were collected within five days of fieldwork. The survey conditions at this time could be described as ideal. The fields were harvested and easily accessible, and the weather conditions were good. As expected, the potential of the magnetic prospection method was proven. Sandy soils display a homogeneous, low magnetic signature and present an ideal soil matrix for the detection of embedded archaeological features, supported by the large contrast between magnetic backfill and the surrounding material. Likewise, the well-drained sandy soils in combination with the dry spell that preceded the fieldwork created excellent conditions for the GPR surveys. GPR velocities of up to 16 cm/ns and signal penetration depths of up to 3.5 m, instead of the commonly encountered 1.5–2.0 m, came as a positive surprise for the prospectors.

The paper presents an overview of the project area and detailed results from two selected sites, Vesterager and Rysensten. The rather small site of Vesterager (0.5 ha total investigated area) is a farmstead dating to the Late Iron and Viking Ages. The remains of several longhouses and pits, enclosure fences (ditches and postholes), already known from aerial images, were confirmed by the geophysical prospection (Fig. 1). There was a high level of agreement between anomalies recorded by geophysical prospection and features detected by aerial archaeology, but also several previously unknown pits and ditches were discovered. The orientation of the newly detected ditches indicated several superimposed settlement phases. High-resolution GPR surveys revealed numerous further circular ditches and other settlement structures, like pits and postholes. Furthermore, the dissolution of seemingly larger individual features into several smaller ones (e.g., ditches that are composed of very closely spaced postholes) has led to a substantial increase in detailed knowledge about the site.

The medieval settlement site of Rysensten is the largest of the single sites surveyed within this pilot study, covering some 20 ha of magnetometer and 12 ha of GPR data. The newly collected data revealed a large number of different archaeological features. Many longhouses and other settlement structures were already known from aerial archaeology. Many of these features were confirmed by the results of geophysical prospection and several new features complementing archaeological knowledge were discovered. Especially in the relatively wet parts within the survey area, aerial imagery had difficulty in detecting archaeological features. A more differentiated picture of the settlement structure is to be expected based on several clusters of observed settlement traces distributed over the entire surveyed area.

The picture observed in all the other surveyed areas was much the same. In general, one noted a large degree of conformity of the detected features between the individually applied methods. However, in several cases structures could be seen only in one of the available datasets. While the sedimentological conditions have proven to be very favourable for aerial archaeology and magnetometer prospection, the three-dimensional GPR data demonstrated several issues and showed that actually the assumed homogeneous soils were composed of diverse sedimentological layers within the extensive sand deposits, formed by the periglacial processes. In many cases very complex beddings, massive ice wedges and palaeochannels became visible in the large-scale, high-resolution GPR data, complicating the detection and interpretation of present archaeological features. Further archaeological and geoarchaeological research (targeted excavations and corings) would be desirable in order to derive a better understanding and interpretation of the combined prospection results. Concluding, it can be said that the demonstrated complementary application of a diverse range of prospection methods and in particular their integrated archaeological interpretation has led to considerable new, detailed archaeological knowledge of the archaeological sites under investigation.

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