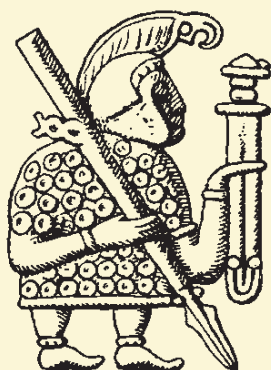


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JOURNAL OF
SWEDISH ANTIQUARIAN
RESEARCH



2026/2

Geophysical investigation of a plateau at Kugghamn

Ground-penetrating radar survey at Björkö, Sweden

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Hedberg, E., Isaksson, S., Kalmring, S., Lidén, K. & Viberg, A., 2026. Geophysical investigation of a plateau at Kugghamn: Ground-penetrating radar survey at Björkö, Sweden. *Fornvännen* 121. Stockholm.

To investigate a plateau at the Viking Age settlement of Birka-Korshamn, Björkö, Sweden a 31 x 16 m terrace was surveyed with a single-channel ground-penetrating radar (GPR). A 500 MHz antenna was used to detect archaeological features. The research questions aimed to investigate any remains of archaeological activities in connection to an earlier identified wharf, establish a stratigraphy, get information about the geology and compare the data with other archaeological sources, e.g. LiDAR, aerial photographs, inventories and excavations. The survey identified two unregistered burial mounds not visible above the ground connecting the large burial fields at the site while house structures connected to the terrace were more difficult to establish even if the data clearly indicates several archaeological features.

Keywords: ground-penetrating radar, LiDAR, Birka, late Iron Age

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Introduction

The Viking Age settlement Birka on the island of Björkö near Stockholm, Sweden has a long history of archaeological investigations and surveys (Stolpe 1872; Arbman 1940/1943; Arrhenius 1990; Holmquist Olausson 1993; Bolin et

al. 2010; Trinks 2014; Olsson 2017; Isaksson et al. 2020). The latest investigations have been focusing on the northern part of the island, away from the settlement area that is surrounded by a rampart (Isaksson et al. 2022). The motiva-

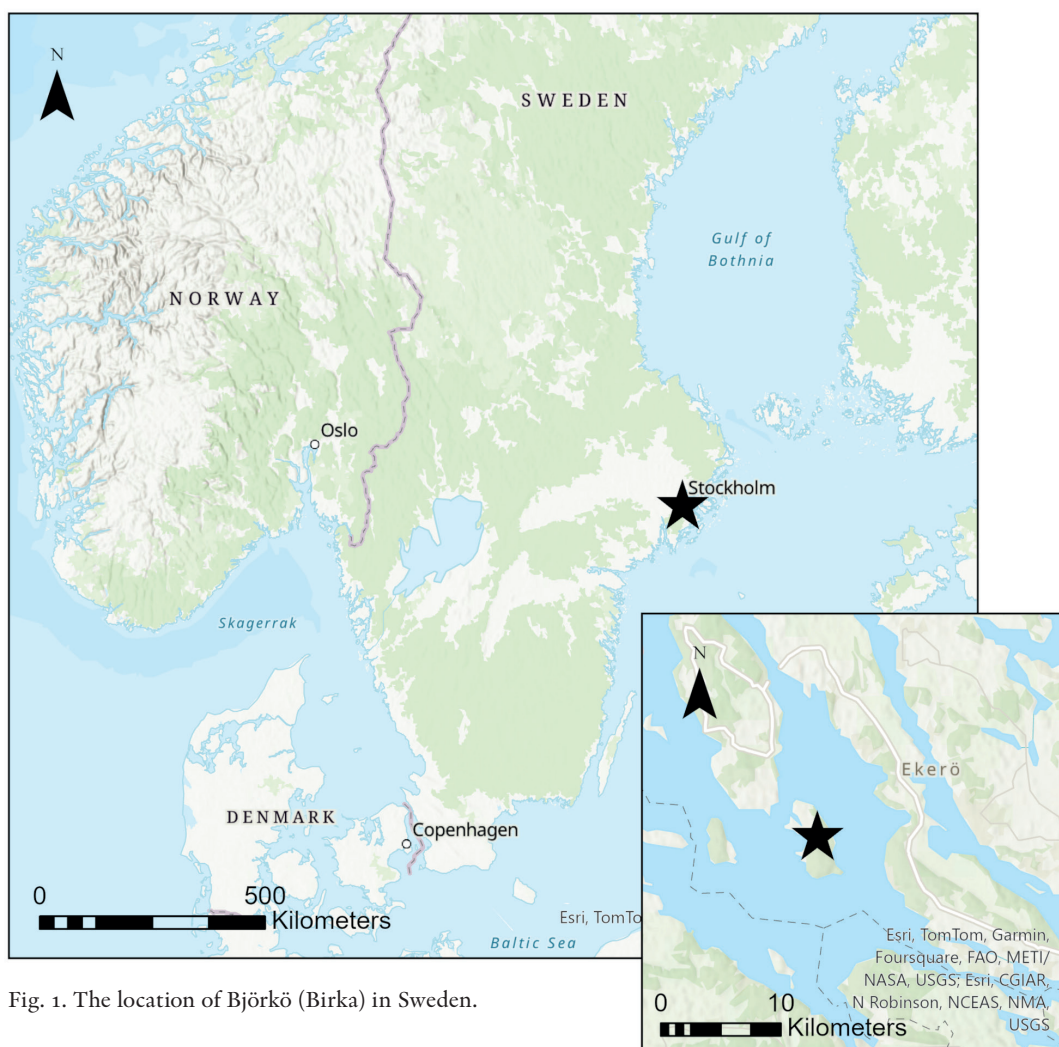


Fig. 1. The location of Björkö (Birka) in Sweden.

tion was that two small bays, Kugghamn and Korshamn, forming natural harbors, has been suggested as alternative landing sites to the settlement harbor at Birka.

In Kugghamn, recent seminar excavations detected and excavated a Viking Age shipyard with a large assembly of iron nails and other finds (Isaksson et al. 2022). Slightly above the shipyard is an elevated rectangular area, a terrace, that has been suggested as a foundation for a house (Hermodsson 2004). We investigated this area with a 500 MHz cart mounted ground-penetrating radar (GPR) in spring 2022.

Ground-penetrating radar works excellent in these kinds of environments since it can detect features buried below the ground such as walls, post-holes and floor layers, without the need of archaeological excavations (Conyers 2016).

The purpose of the survey was primarily to find if the geophysical survey could detect any archaeological remains connected to the house terrace. And if so, could any stratigraphy such as different building phases be established? We further wanted to find out whether any other geological information could be drawn from this. And finally, how GPR data compare

to the previous archeological sources, such as LiDAR.

Background/The site

Birka

Birka is situated on the island of Björkö in Lake Mälaren in the parish of Adelsö, 30 km from present-day Stockholm (fig. 1). In the Viking age, the island consisted of two separated islands, Björkö in the north and Grönsö to the south that, due to the postglacial land elevation, now constitutes one island covering an area of c. 4 x 1,5 km (Ambrosiani & Clarke 1992).

The Viking age activities in Birka date to 750–975 AD even though there are indications of activities predating this to the Vendel Period. Birka had long-distance trading contacts with Western Europe in the early Birka Period (750–860 AD), contacts that shifted eastwards in the late Birka Period (860–975 AD). The activities in Birka ended c. 975 AD when the late Viking age center shifted to Sigtuna, 33 km further inland (Clarke & Ambrosiani 1993).

Archaeological areas

Birka consists of the 16,5 ha settlement in the Black Earth (Svarta Jorden, L2017:1568) and the Black Earth's harbor (Svarta jordens hamnområde, L2017:1507), and was once surrounded by a rampart (Stadsvallen, L2017:1958) connected to the hillfort (Borg, L2017:1477) with its associated garrison (Garnisonen, L2013:3917). There are also numerous burial grounds with an estimated 3000 burials, in Hemlanden (L2017:1904), Norr om borgen (L2017:1478), Borgshage (L2017:1478), Kvarnbacka (L2017:2006), Grindsbacka (L2017:1779), Lilla and Stora Kärrbacka (L2017:1417) and Ormnös (L2017:1716) (fig. 2).

Previous geophysical investigations at Birka

Several different prospection surveys have been undertaken at Birka (e.g. Ambrosiani & Clarke 1992; Kalmring 2020). Already in 1976, Birgit Arrhenius performed a phosphate mapping outside of the town rampart which suggested an older settlement outside the town rampart (Arrhenius 1976). The phosphate mappings were continued by Lena Holmquist at Grindsbacka

where an older farm had been suggested (Holmquist Olausson 1982).

Viberg et al. (2011 with references therein) gives a detailed overview of the geophysical prospection activities at Birka, and where he describes the first geophysical prospection survey that was conducted in preparation for the Birka Project in 1990 by a team from Kiel University, Germany. They conducted GPR and magnetometry surveys using an analogue 129 MHz Oyo system and a proton magnetometer in vario-meter configuration. A 50 x 50 m area was surveyed with GPR with 1 m spacing in both X and Y directions. Several geophysical and geochemical prospection surveys were then conducted at Birka between 1996 and 2000 (Kristiansson 1996; Andrén & Lindeberg 1997; Stavrum 1997; Wählander 1998; Masters 1998; Wedmark 1999; Stålberg 2000). However, in 2006 the first high-resolution geophysical prospection was conducted at Birka using a 500 MHz GPR system (Sensors and Software NogginPlus) and a Förster magnetometer system (FEREX STD 40.032) with four gradiometer probes mounted 50 cm apart. The GPR survey covered 0,5 ha with a 25 cm profile spacing which generated high quality data showing a large number of detailed archaeological structures, such as property slots, an older town rampart, numerous Viking Age houses, paths and graves (Trinks & Larsson 2007; Trinks et al. 2007; 2008). In 2008, a GPR pilot study was performed, using a 400 MHz MALÅ Imaging Radar Array (MIRA) consisting of 16 channels with 8 cm crossline spacing by MALÅ Geoscience in collaboration with the Swedish National Heritage Board. Three ha were covered with exceptional resolution resulting in the discovery of numerous new archaeological structures (Trinks et al. 2010). This survey aimed to cover the entire island with high-resolution ground-penetrating radar and magnetometry and was summarized in several articles (Trinks & Larsson 2007; Trinks et al. 2007; 2008; 2010; 2013; 2014). However, not all areas of the northern part of the island were covered in this survey (Trinks et al. 2013).

The latest GPR survey at Birka was performed in Korshamn, where two house terraces were identified and investigated in 2017 (Kalm-

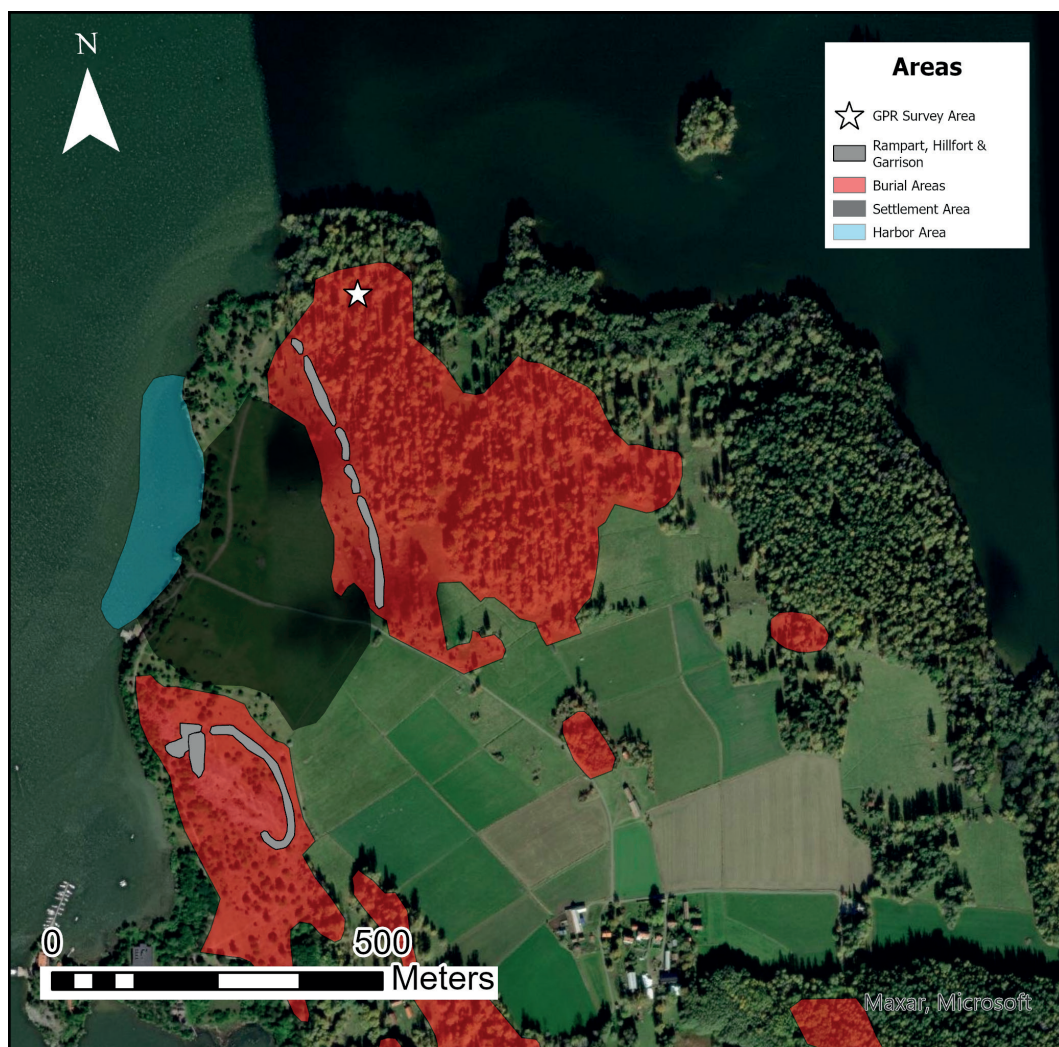


Fig. 2. The GPR survey area, marked with an asterisk, at Björkö and registered ancient/historical monuments from the National Heritage Board RAÄ (2023).

ring et al. 2017). The first terrace, situated in the east part of Korshamn, measured 30 x 15 m with two ramps on each side of the terrace. Here the layout of a larger house, 26 x 9 m with curved walls, was identified. There were also indications of smaller and shallower house structures inside the house, that were interpreted as possible internal structures. The second terrace, also situated in the eastern part of Korshamn, had two different building phases, a younger

hall building, 23 x 8,5 m, that was built during the Viking age with an older building beneath. There are also traces of destroyed burial mounds in the geophysical data in the area, not visible above ground (Kalmring et al. 2017).

The site/Kugghamn

The name Kugghamn, including its different variants e.g. Kuggholms udde, Kuggholm, Kugghabns-udd, Kuggehabn etc., is intriguing

and has been discussed since long (see e.g. Hyenstrand 2018). The name is also problematic in terms of what it actually refers to, is it “kogg”, the ship type as suggested by a number of authors (e.g. Lindkvist 1926; Arbman 1939; Ellmers 1984; Isaksson et al. 2022), which would then support the idea that the site was a harbor site. More complicated is the shift from Kuggholms udde (with variants) towards Kugghamn, that is a shift from the meaning cape towards the meaning harbor (Holmquist 1987; Holmquist Olausson 1993). During spring 2022, an excavation took place at Kugghamn, situated in connection to the burial ground Hemlanden. It was conducted as a seminar excavation by the Archaeological Research Laboratory, Stockholm University, to map maritime remains on Björkö's northern shore (Isaksson et al. 2022).

Previous excavations, in 2020 and 2021 in the same area, identified a shipyard (L2022:2719) slightly below a somewhat elevated flat area (Isaksson et al. 2022). According to Hermodsson (2004), who previously had identified the remains of the shipyard as a ditch or a possible naust, the feature might have had a connection to a possible house foundation in its immediate vicinity, thus indicating that the flat area or plateau represented a house terrace (Hermodsson 2004). The plateau above the shipyard therefore seemed suitable for a ground-penetrating survey to try to identify possible house structures and to enhance the knowledge about the context of the wharf at Kugghamn. The plateau is flat with few visible remains above the ground, which made it difficult to investigate with LiDAR and aerial photographs.

Method/Geophysical investigations

Ground-penetrating radar

Ground-penetrating radar (GPR) is a geophysical method where high-frequency electromagnetic radar pulses are transmitted from a surface antenna into the ground. The time elapsed from when the energy is transmitted, reflected from buried features and sediments and then received back at the surface is measured, processed and converted to depth-slices that is then used for identification of anomalous features (Conyers 2013, p. 2).

GPR has been used in archaeological investigations since the mid-1970s, starting in the US (Vickers 1976) and where the first investigations were performed in Sweden in the late 1970s/early 1980s (Fridh 1982; Wihlborg 1980; Romberg 1980; Bjelm & Larsson 1980; 1984; Burenhult & Brandth 2002). GPR has shown to be useful to identify floors, pits, cooking features and walls, where floors and pit structures produce planar reflections generated from horizontal compact soil layers. Often associated with floors, are subfloor features, supports for roof beams, hearths, associated benches and other features. Cooking features and hearths as e.g. an outdoor baking oven where the heat of the fire tends to bake the oven bottoms creating a surface that retains water and produce a good radar reflection surface. Walls are commonly visible in GPR images especially when they are constructed from stone or other reflective materials (Conyers 2016, pp. 153–158).

The outcome of GPR surveys in archaeology is dependent on the soil and sediment mineralogy, clay content, ground moisture, depth of burial, surface topography, and vegetation (Conyers 2013, p. 15). GPR works best where there are strong contrasts in dielectric permittivity, and where electrical conductivity is low enough to allow radar wave penetration. The electrical properties of the soil need to be considered when trying to assess if an area is suitable for GPR. The energy will be dissipated in material of high conductivity so even a thin layer of clay can significantly reduce signal penetration or, in some cases, make GPR surveys ineffective. The primary advantage of GPR is the ability to provide a three-dimensional view of a buried site (Gaffney & Gater 2003, pp. 47–49).

Not many GPR surveys in similar areas as the one investigated at Birka have been performed in Sweden. An exception is the extensive surveys at Uppåkra (Viberg et al. 2011, p. 49; Trinks et al. 2013) and a few surveys at individual burial mounds and terraces in other areas (Persson & Olofsson 2004; Rundkvist & Viberg 2015). A small GPR survey was carried out at the iron age burial field at Sollerön (Bäck et al. 2023). Contrary to the situation in Sweden, ground-penetrating radar has been ex-

tensively used in Norway and Denmark. E.g. in Norway, the investigations at the iron age burial sites Borre (Draganits et al. 2015, Tonning et al. 2020), Gjelstad (Gustavsen et al. 2020), Bodøsjoen (Stamnes & Kiersnowski 2021) and at Borg in Lofoten (Kristiansen & Nau 2022). In Denmark the iron age settlement Vesterager (Filzwieser et al. 2018) and Viking Age and medieval sites in Jutland (Filzwieser et al. 2017). In Norway, there have also been investigations on snow-covered areas (Gabler et al. 2019), large-scale ground-penetrating radar surveys combined with archaeological trial trenching (Gustavsen et al. 2020) and investigations of pastoral mountain landscapes (Dahle et al. 2025).

Data acquisition and processing

The field work was carried out the 4–12th of May 2022. The survey area is covered with sandy moraine and was, in 700–900 AD, situated on a peninsula. Northeast of the terrace is a visible stone row, that could be part of a stone foundation, and nearby a ramp, possibly an entrance. In the north-western part of the terrace, rocks constitute the terrace's border. A looting pit is situated near the northern border of the survey area. Before the survey, ground vegetation consisting of thorny bushes were removed and the area was set up and measured. The entire survey area was then recorded with a GNSS system (Trimble R10 GNSS).

We used a Noggin Smart Cart GPR with a 500 MHz antenna by Sensors & Software. Data was collected with an inline spacing of 0.02 m and a crossline spacing of 0.2 m in two separate grids that formed a 31 x 16 m area. The lines were collected from two base lines (one at 0 and one at 16 m). The result was processed in the EKKO Project 3 software from Sensors & Software and the ReflexW 8.5.8 software by K. J. Sandmeier and converted into depth-slices.

The depth-slices were then extracted as mpeg-files with a step rate of 1 ns (5 cm) and individual slices were selected and transferred to ArcMap 10.8.1 for further interpretation.

Result

The most prominent features that could be detected were two, or possibly more, burial

mounds, identified by their high circular reflection marks in the data (fig. 3). Other structures were more difficult to interpret. A rectangular structure appeared in the northwest part of the survey area but was hard to connect to the structures above ground since it was not oriented in line with the terrace. There is also a rectangular structure seen in the bottom middle accompanied by dark circular areas, but also a semi rectangular structure in the top middle section (fig. 3).

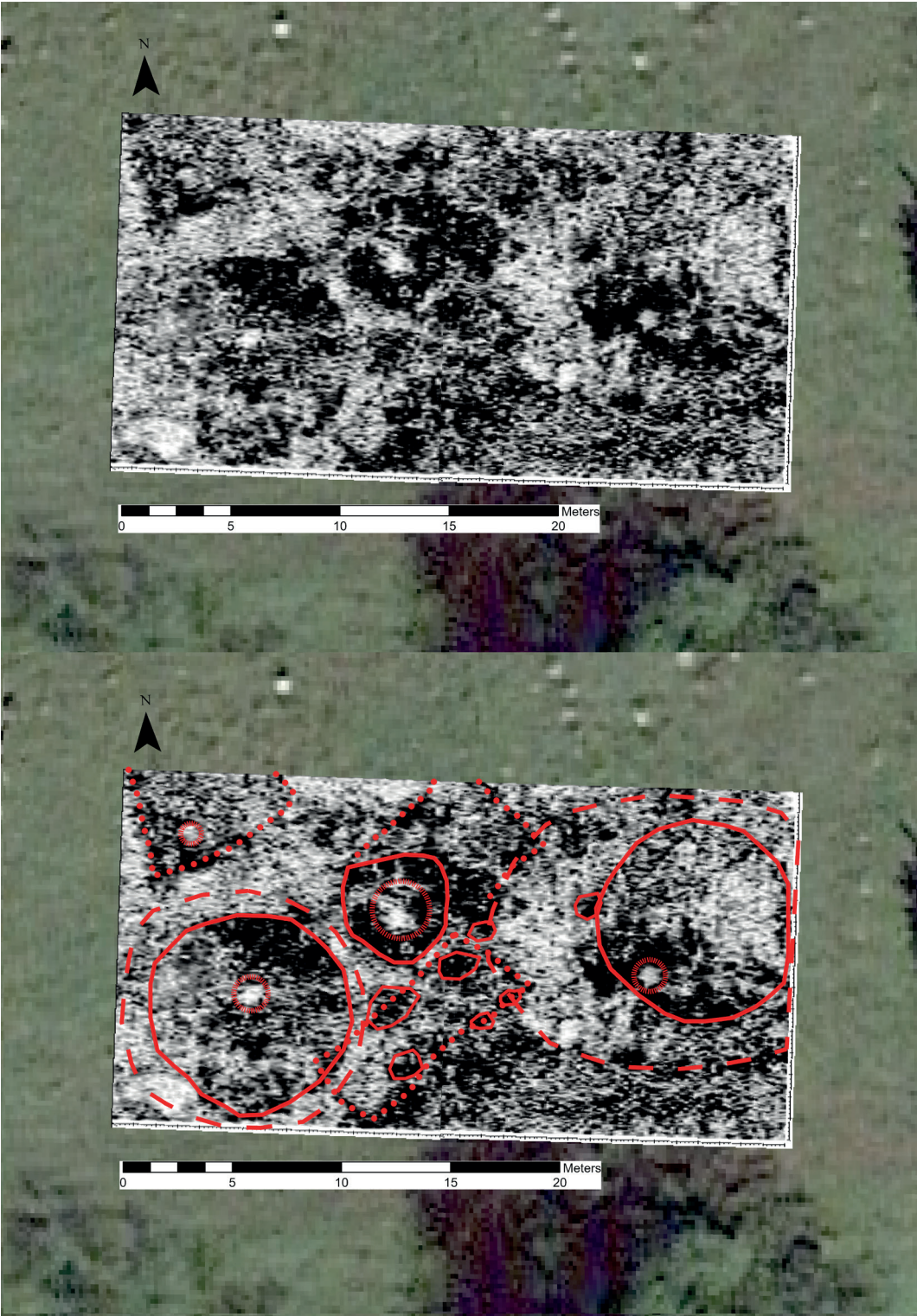
The first mound, seen in the upper level of the depth-slices, can be estimated to have a diameter of ca 8 m, and the second mound, seen in the lower level of the depth-slices to have a diameter of ca 10 m. A possible smaller mound between them measures around 6 m in diameter. The mounds appear at approximately the same depth, 20–45 cm. The strong reflections are most likely from a compact soil layer or stones/rocks. It is also possible to discern ring ditches around the first and the second mound (fig. 3). A possible fourth and fifth mound can be seen as vague reflections from areas of compact soil/stones. However, a minimum of two grave mounds can positively be identified in the radar reflections together with possible rectangular features in the north, northwest, and south. In some of the mounds, and even in the rectangular features, there are impressions that could be interpreted as pits or post-holes seen as white reflective circular areas (fig. 3). There are also circular features without any clear pattern and a curved shaped line that passes through the area, all which are difficult to interpret but could indicate archaeological structures.

Discussion

The aim of the geophysical survey was to identify archaeological remains on the terrace at

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Fig. 3. Georeferenced ReflexW depth slices above an aerial photograph of the plateau from Google Earth 2021. The first depth-slice (top) shows the area at an estimated depth of 35 cm and the second depth-slice (bottom) shows the same depth-slice with suggested interpretations.



Kugghamn, Björkö, Sweden, as well as other features of interest.

The geophysical survey was able to detect several archaeological structures. The most striking are two destroyed burial mounds (8–10 m) which existed prior or in connection to the terrace's establishment. In the north, northwest, and south we detected rectangular features and depressions, cutting through the burial mounds, that could be interpreted as pits/graves or post-holes, although this interpretation should be taken with caution.

We could identify some of the terrace's stratigraphy as constituting of three phases. A construction phase of the mounds, a demolishing phase where the mounds were destroyed and a phase for the establishment of the terrace which could all have happened within a relative short timespan or with longer intervals in between. The burial mounds have been removed prior or in connection to the establishment of the terrace. There are some indications of post holes which could indicate a hypothetical fourth and fifth phase when a building was raised and later removed, but this is uncertain. However, what is certain is that the area has been ploughed in historic times since it is registered as a cultivated field on a map from 1747. In particular, these agricultural activities may have adversely affected previously well-defined archaeological traces.

The area has also been disturbed by more modern activities, exemplified by the wheel-tracks from the pathway crossing the lower part of the terrace. Further, the local geology with stony moraine and past and present root activities makes the interpretation process complicated.

The previous LiDAR data of the terrace doesn't reveal much of the archaeological activities at the site, partly due to the low resolution. Here the geophysical prospection adds to the archaeological information with several archaeological structures, showing the strength of ground-penetrating radar as a research method and also that more than one prospection method is often necessary (fig. 4). The results could on the other hand benefit from a larger survey, taking into account the broader context as the pres-

ent survey provides only a limited perspective which complicates and also to some extent limits the interpretation. However, site conditions prevented such investigations.

There are still many questions to be answered about the terrace. Were there any structures at the site before, or in use, at the time of the establishing of the burial mounds. Are the circular white areas inside the mounds part of the original graves or created later as secondary graves or post-holes? Are the rectangular structures in fact part of buildings raised at the site, prior to the establishment of the terrace or part of past structures on the terrace? The terrace could have been established as late as the 18th century based on historical maps (Lantmäteriet, Storskifte 1762, Björkö nr 1–4). In that case, are these structures historical and part of the farming activities on the island? In the house terraces previously investigated in 2017 the burial mounds had been removed prior to the establishments of the terraces. Could this terrace have been created at a similar time as these terraces were created, and in that case be part of the activities taking place at that time. If so, was that in connection to the establishment of a chieftain's house at the nearby Korshamn?

The new harbor area at Birka?

There have been many theories of where the different harbors of Birka were situated. The shoreline within the town rampart is flat and unprotected while harbor features were necessary. At this shore, 16 oak poles have been found, belonging to a possible harbor construction. Assemblages of boulders and rocks that were part of two jetties were excavated in 1969, 1970/1971 and 2015/2016 (Ambrosiani 1973; 1992; Kalmring et al. 2021). According to Arbman (1939, pp. 45–57), this harbor was probably neither protected nor large enough to fulfill the needs of the town. However, on the northern part of the island there are two deeper bays that are more suitable as harbors, Kugghamn and Korshamn.

In a phosphate map of Björkö (1960) it was shown that the Black Earth had unusually high phosphate values with a sharp boundary across the valley between the present village and the

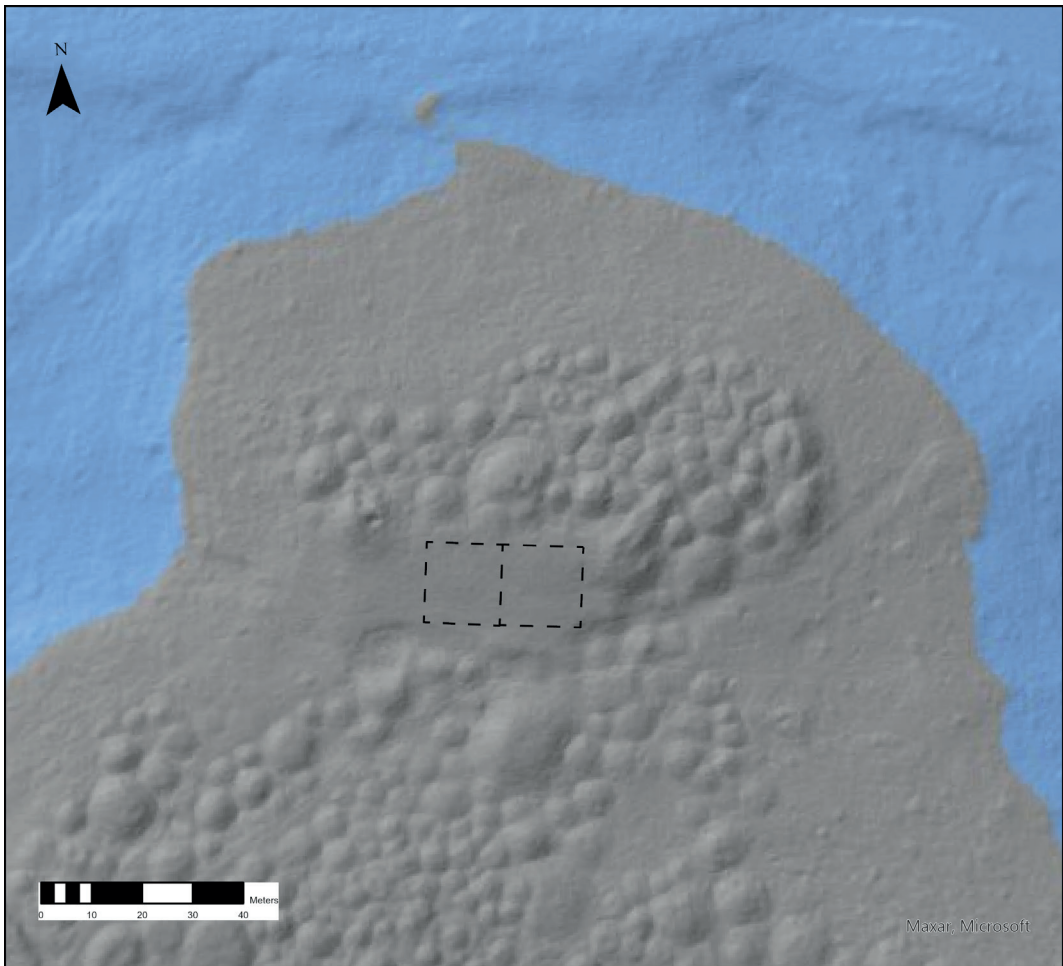


Fig. 4. The survey area, marked squares, and the hillshade model made of the National LiDAR data from Birkaportalen.

old Viking town. The map also showed that the boundary continued north beyond the rampart to the bay known as Korshamn, indicating that the habitation area may have been more extensive than visual today and that Birka probably became smaller before they built the rampart (Ambrosiani & Clarke 1992; Kalmring 2020). This motivated the excavations in Kugghamn (Isaksson et al. 2022) and the ground-penetrating surveys carried out in Korshamn north of the town (Kalmring et al. 2017) and where both showed that the inhabitation area did extend outside of the rampart as was indicated in the

phosphate maps. This survey further contributes to the information about this part of Björkö.

It is obvious that the large cemeteries on Björkö, as seen today, were originally even more extensive. At various times, previous cultivation has been cutting at the edges of the cemeteries. It is possible that cemeteries once surrounded all of the Black Earth area to the east extending from the northern to the southern shore. The cultivated area south-east of the Black Earth area no longer shows any visible signs of graves, but agricultural activities have occasionally revealed the remains of graves (Arbman 1939, p. 73). In

1872 Stolpe pointed out that the cemetery south of Borg was part of the cemetery in Hemlanden, and describes crop marks, resulting from grave mounds being flattened by ploughing, as rings with little or no vegetation (Stolpe 1872, p. 90). This could be one explanation why the grave field of Hemlanden is cut at several places, including the survey area in the north which connects Hemlanden with the graves on the north peninsular.

Comparisons

The GPR results were compared with earlier surveys of two house terraces in Korshamn (Kalmring et al. 2017). In that study, burial mounds were clearly identifiable, whereas house structures were more difficult to detect. Circular features were interpreted as postholes, comparable to those observed in the present survey at Kugghamn. However, the lack of a coherent spatial pattern complicates their interpretation. Even though there were no clear structures that could be connected to house remains, the terrace cannot be discarded as a house terrace, mainly due to the visible remains above ground; i.e. a straight row of stones and a ramp.

We could determine that two (or more) burial mounds had existed in the area and had been destroyed. Further, that they link to the burial field with the burial mounds on the other side of the terrace and are therefore part of the archaeological site 118:1. GPR surveys of burial mounds in Norway fits well with the identified mounds in our survey, which were estimated to have a diameter between 6–10 m and were displayed as round anomalies where the stone filling was prominent with strong reflections and possible visible ring ditches (fig. 3).

In Bodø for example eight destroyed circular burial mounds, ranging between 6–32 m in diameter, were detected in 2020 (Stamnes 2020). Further at Aske farm in Larvik municipality, Vestfold, depth-slices from a GPR survey showed an almost round anomaly that was interpreted as the remains from a removed burial mound (Gustavsen et al. 2013). A third example is the burial mound Rom in Slagedalen (Schneidhofer et al. 2017) where the data was interpreted as: “The stone packing presented the most prom-

inent feature in the geophysical data sets and formed the main element of the mound structure.” While the GPR data displayed an area of strong reflections, they also found a ring ditch surrounding the grave monument. It was noted that the ring ditch was only visible at 0,8–1 m depth which was well below the actual stone structure. This strengthens the interpretation that the visible structures in our survey are burial mounds.

In LiDAR, airborne laser scanning emits laser pulses toward the ground, which can produce multiple returns from surfaces such as vegetation and the terrain. These data are used to generate 3D models of the surface, where vegetation can be filtered out to reveal the ground. Such data were used as a comparison to the GPR data in our survey. We used LiDAR data acquired in the project New Nationwide Elevation Model (Ny nationell höjdmodell) from the land registration authority Lantmäteriet in 2009, with a resolution of 0.5 point/m². This data was also used by Sven Kalmring (Kalmring 2012) when he produced the Birka proto-town GIS that gives a new visualization of the monuments on Björkö, including the vast numbers of mounds and on which we based our interpretations in this survey. However, in the LiDAR data no archaeological features are visible in the surveyed area, i.e. the terrace, as compared to the geophysical data (fig. 4), thus emphasizing the importance of applying a multitude of methods while performing surveys.

Future investigations

As initially mentioned, above the ground there are several stone-rows visible on the terrace – indicating more permanent structures – and maybe even a house. In order to get more information without excavating the site other geophysical methods could be applied. Magnetometer surveys can provide information about magnetic anomalies caused by burnt features, such as hearths, kilns, and furnaces, as well as in-filled ditches and pits. Earth resistance surveys provide information about variations in soil resistance, often highlighting features such as walls, surfaces, roads, and other types of stone foundations, as well as ditches, pits, drains, and

graves. Electrical resistance is inversely related to electrical conductivity, which can be measured using electromagnetic induction (EMI), whereas ground-penetrating radar (GPR) responds to contrasts in dielectric properties rather than conductivity. Electromagnetic measurements can provide information about both the electrical conductivity of the soil and its magnetic susceptibility, enabling the detection of mounds, infills, buried stone structures and rubble, pits, and metallic artefacts (Clark 1996; Gaffney & Gater 2003; Dabas 2006; Aspinall et al. 2008; Conyers 2013; De Smedt et al. 2013; Schmidt 2013).

Conclusions

Overall, the geophysical surveys conducted on the terrace at Kugghamn, Björkö, Sweden provided archaeological data both on the geophysical setting of the site and on the existence of various archaeological remains, destroyed burial mounds and potential settlement remains, and enables reconstruction of at least two building phases. The ground-penetrating radar were able to detect archaeological features that were not visible above the ground nor in the LiDAR data showing the relevance of this method. We conclude that the terrace once was part of the burial field Hemlanden. This was before the creation of the terrace that removed several burial mounds. This would suggest the terrace were part of more recent activities after the construction of the burial field.

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