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Archaeological Prospection

Kjell Persson

A number of different geophysical and geochemical methods have been evaluated in order to adapt them to archaeological prospecting. The purpose was to find an optimal combination of a few methods for interactive prospecting to obtain maximal information from the upper layers of the soil. After a lot of measurements and excavations on different soils a concept of interactive archaeological prospecting is recommended. Electromagnetic mapping with a one-meter slingram, phosphate mapping with a combination of field and laboratory analysis and electromagnetic profiling with ground penetrating radar have proved to give the information needed for a good excavation result.

Introduction

Within the SIV-project the Archaeological Research Laboratory at Stockholm University has conducted comprehensive research with a number of geophysical and geochemical methods. The purpose has been to adapt these methods to archaeological prospecting.

Methods for detecting chemical and physical anomalies in the ground, caused by human activities, have been used in archaeology for many years. Some of them, like soil-phosphate analysis, have proved to give good results when conducted by archaeologists and have helped answer archaeological questions. Often investigations have been conducted by geologists or geophysicists with archaeological issues in mind, but too seldom in these cases has any account been taken of the methods and instruments appropriate to the investigation of archaeology.

Our aim has been to find ways of using the methods optimally in order to get maximal information about anthropogene changes in the upper layers of the soil.

Material and methods

Geochemical (mainly soil phosphate analysis, but also pH, CO_3^{2-}-analysis and Fe^{3+}-analysis) and geophysical (magnetometric and electromagnetic) methods have been used in attempts to find settlements connected to the boat-graves at Vendel church and in order to locate a possible landing spot for boats at Lake Vendel. The area around Husby and the Ottar mound in Vendel have also been examined. Comparative surveys have been conducted at the boat-grave cemeteries in Valsgärde and in Tuna, Alsike. In Vendel a soil-phosphate mapping had been carried out by the local homestead society under the guidance of professor Birgit Arrhenius in 1980. This mapping, together with ordinary map and archive studies formed the background material when the investigations at Vendel church began, and dictated the choice of methods and instruments used at the site.

Archaeological prospecting with geophysical and geochemical methods aims to find places where the upper soil layers have different chemical and physical properties compared to their undisturbed surroundings. To interpret the results and for the understanding of which anomalies have an anthropogene prehistoric genesis it is necessary to first determine both the natural properties of the soils in the area and which anomalies are connected to known historical activities. This investigation is made by studies of older maps and geological maps (soil-, bedrock- and geophysical maps).

Anomalies with no geological or historical explanation have then been chosen for further mapping and test-coring and in the end areas for excavation have been pointed out.

Phosphate analysis

Soil phosphate analysis has been used in archaeology for many years (Arrhenius 1935). The Archaeological Research Laboratory has, ever since it was founded in 1976, worked hard to spread the use of soil phosphate analysis and to develop this method. This project attempts to integrate phosphate analysis with other prospecting methods in order to support the site analysis. The purpose has been to achieve an interactive field prospection where the results from the different methods can be used to pinpoint the places for test-cores and excavation. We realized early the need of a new, improved field method. After some years of experimentation we were successful and an indicator test strip for phosphate analysis of soil and water is now patented and produced by Merck in Germany (Persson 1996, 1997). The test strip makes it possible to get a quantitative analysis of soil phosphate content immediately in the field.

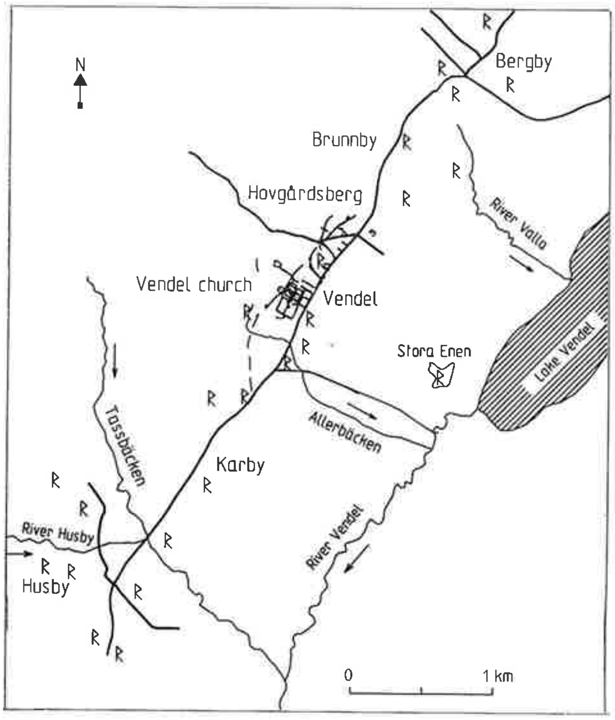

Figure 1. Map showing the area around Vendel church.

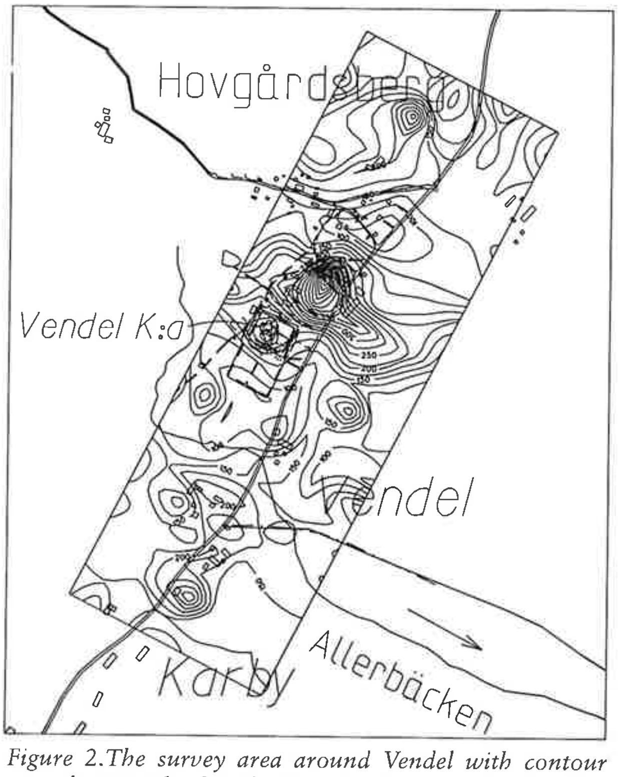

Figure 2.The survey area around Vendel with contour map showing the distribution of soil phosphate. Equidistance 25 P°.

We have used these strips to check areas indicated by other methods and we have been able to delineate more accurately which areas should be sampled for further laboratory analysis. In this way we can get a quicker and more cost effective confirmation of possible cultural layers and their extension than if we had used only the ordinary laboratory soil phosphate analysis.

VLF

The first geophysical method in use was VLF (Very Low Frequency). The instrument is a small hand-held receiver that can measure how a low frequency electromagnetic radiation reacts when it passes over electric conductors in the ground. The method was developed by geologists for ground water surveys etc. (Keary & Brooks, 1984:230-232).

The instrument we used was a Geonics EM-16 borrowed from the Geological Dept., Stockholm University.

Magnetometer

Later on in co-operation with the *Swedish Geological Survey* a mapping with a magnetometer (gradiometer) was made. The instrument was a mine detector borrowed from the *Swedish Air Force*. A magnetometer measures passively the current earth-magnetic field, which in general is homogenous. If there are ferromagnetic materials, mainly iron, in the soil, they will be magnetized by the earth-magnetic field and secondary magnetic fields arise. These are dependent on the magnetic permeability and magnetization of the material. The total field, the earth-magnetic and the secondary fields together, is changed both in density and direction compared to the normal earth-magnetic field (Keary & Brooks, 1984:171–197).

The earth-magnetic field itself varies partly because of magnetic pulses and partly because of changes in the bedrock composition. These natural variations are often of much higher altitude than the variations caused by the magnetic material in the soil. A usual way to solve the problem of magnetic pulses is to connect the magnetometer to another magnetometer, which acts like a base station within the area. The base station can then be used as a reference for the variations caused by the magnetic pulses. Another way, which solves both the problems with magnetic pulses and variations caused when passing over changing bedrock, is to use a gradiometer. A gradiometer consists of two magnetometers, in our case two fluxgate magnetometers. They are placed on a vertical bar 0.5m from each other and they measure in opposite directions. Hence the signals from the earth-magnetic field to the two magneto-

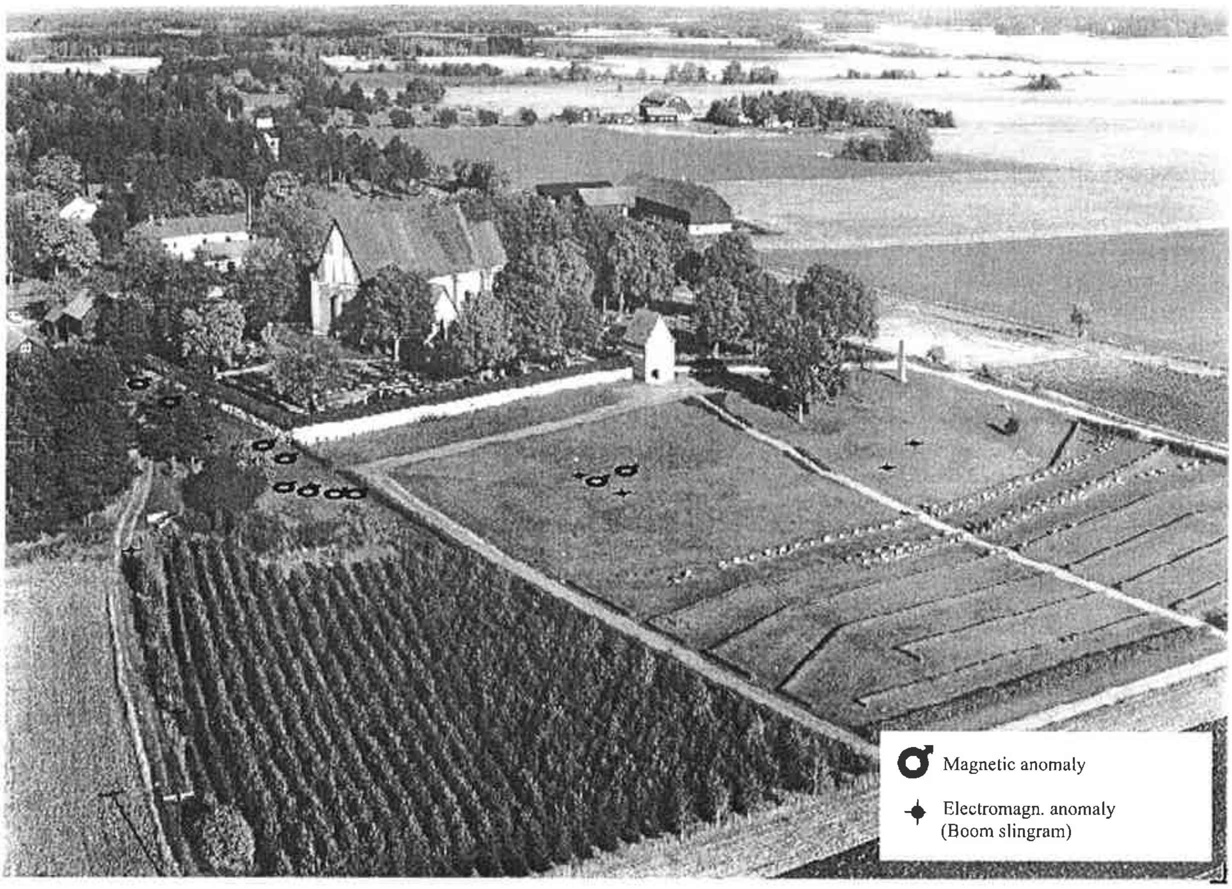

Figure 3. View over the area around Vendel church seen from SW with symbols at geophysical anomalies. Air-photo by Jan Norrman, RAÄ.

meters will give a zero-result even if magnetic pulses arise or if you walk over a border between different bedrock and different magnetic fields. However, a magnetic material buried at a few meters depth will influence the lower magnetometer much more than the higher one, owing to the fact that the power of a magnetic field decreases with the square of the distance from its source, and the instrument therefore will detect a difference, a gradient, and can be used to detect magnetic material on 0–5m depth.

Slingram

Slingram is an electromagnetic, inductive method. A primary electromagnetic field is generated by a transmitting coil. If there is electrically conductive material in the upper layers of the ground, this primary field induces small currents in the soil and they generate in turn secondary magnetic fields. In a receiving coil the total field, the primary and secondary fields together cause a current that can be detected. The disturbance of the primary field can be used to evaluate the electric conductivity or the magnetic susceptibility in the ground (Keary & Brooks, 1984:226–228). The distance between the transmitting and the receiving coil is vital for the detection depth and the accuracy. A longer distance between the coils gives more detecting depth but also less accuracy.

The presence of metals in the ground will effect the electro-magnetic response and cause high anomalies. Other important factors are the presence of water and ions in the soil. The water content is dependent of the porosity of the soil, and the porosity is drastically increased if the content of organic material is increased.

A cultural layer often consists of a high degree of totally or partly decomposed organic material and has therefore both high water content and many ions. Anomalies caused by varying water content are much lower in amplitude than those caused by metals, but an instrument with high accuracy can very well detect such anomalies. Anomalies in a cultural layer caused by metals tend to overshadow the anomalies caused by increased water content, but by filtering and processing the signals it is possible to see even the variations in the lower amplitudes.

Geonics EM 31

The receiver and the transmitter coils on this instrument are separated by a 4m long boom. The optimal detection depth is three quarters of the distance between the coils and the maximal depth is one and a half

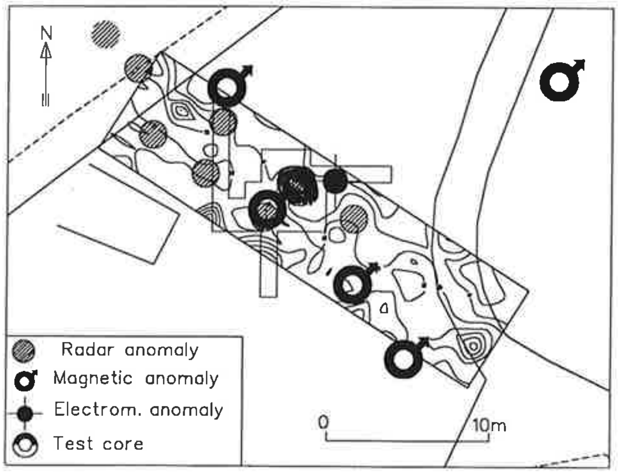

Figure 4. Map over the survey area west of Vendel church with the shape of the trench. The contour map shows the electromagnetic response. Contours in mS/m. Equidistance 5 mS/m. Other anomalies marked with symbols.

times the distance, which gives a maximal detection depth of 6 metres. EM 31 is a geological instrument and is used mainly for soil mapping. Our first mapping was made in co-operation with the Swedish Geological Survey and we were able to point out two areas with electro-magnetic anomalies, which on later excavation have proved to be caused by metals.

Geonics EM 38

In order to obtain higher accuracy another instrument (EM 38) was leased. The distance between the coils is one metre and hence the optimal detecting depth is three quarters of a metre and the maximal detecting depth one and a half metre. The EM 38 can detect small metal

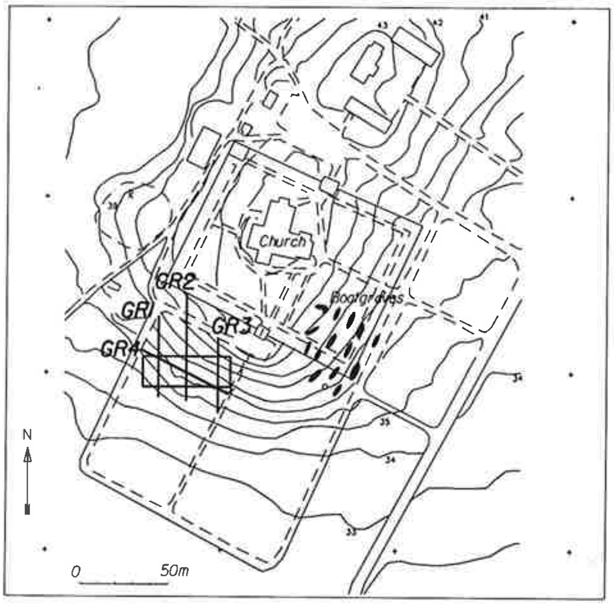

Figure 6. Map over the area around Vendel church showing the boat-grave field, survey area and the radar lines.

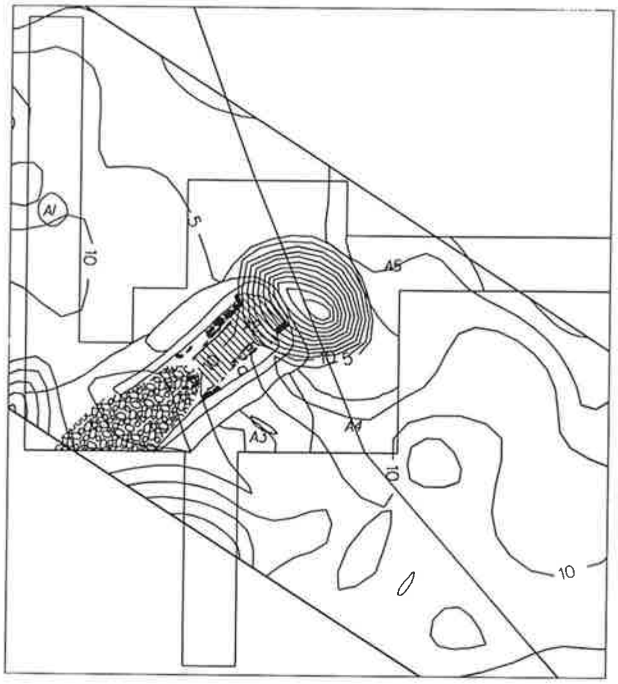

Figure 5. The trench west of Vendel church with features. The bricks in the furnace filled with black. SW of the furnace the bell-pit with symbolic stone-fill. Contours in mS/m, equidistance 5mS/m.

objects and small changes in the electro-magnetic response caused by varying water content. The measured data is digitalized and collected in the field automatically and transferred to a field computer, which makes it possible to produce maps already in field.

The first attempts with the leased instrument were so successful that we applied for, and got, money from HSFR to buy an instrument, and we now own one of three instruments in Europe.

Metal detector

An ordinary metal detector uses the same method as the slingrams. Two coils are placed in the plate which is put to the ground. The distance between the coils is usually about one decimetre and therefore the detecting depth is maximally 1.5 decimetre. The accuracy is very high and a good instrument can detect very small metal fragments. In our project we observed a demonstration by a group of Danish archaeologists under the guidance of Dr. Margareta Watts, which showed that the metal detector is very well suited for artefact searching at presumed settlements or grave fields

Ground Penetrating Radar

Ground penetrating radar, or GPR, is an instrument sending short pulses of high frequency electro-magnetic waves, radar waves, into the ground through a transmitting antenna placed on the ground. In soils

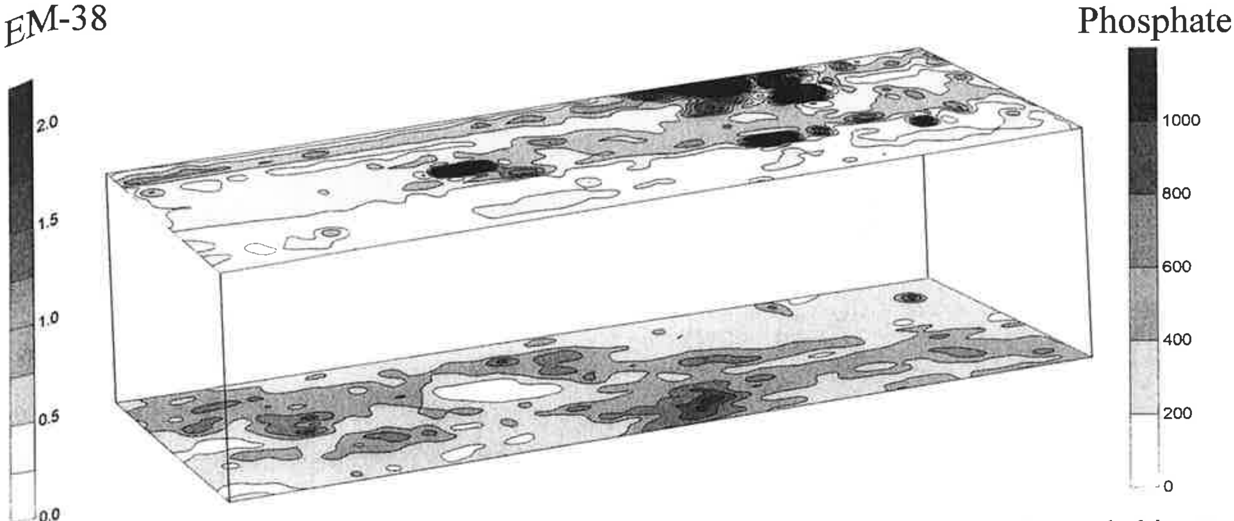

Figure 7. The survey area south of Vendel church showing the electromagnetic response in parts per thousand of the primary field (ppt), equidistance 0.25 ppt, upper and soil phosphate content in P°, equidistance 200 P°, lower.

with different electric properties, mainly differences in the dielectric constant, the waves travel at varying speeds. At borders between two layers with different electric properties part of the wave energy is reflected and the rest is diffracted, bent and continues to the next layer where the procedure is repeated.

With a receiving antenna, also placed on the ground, the reflections are registered. By monitoring the results against known behaviour of radar in different soils the depth of the borders between the different layers can be plotted out from a field computer (Clarke 1990).

Our investigations with GPR have been carried out in co-operation with the Royal Technical Institute in Stockholm with a Pulse-EKKO IV radar.

Results

The first phosphate mapping was made 1980 in a 600 metres broad area along the main road from Karby to Hovgårdsberg (fig. 1). The results show a number of enrichments (fig.2). The highest enrichment is placed N/NE of the Vendel church. Studies of old maps show that at different times there have been buildings at this place and therefore we decided not to go further with the investigations of that anomaly. The area we decided to focus on was around the church from the vicarage in the north to the fields south of the church.

The first geophysical instrument in use was the VLF-receiver. The survey pointed out some anomalies, which could not be interpreted as caused by human activities. They were probably caused by water-filled cracks in the bedrock under the Vendel esker. Due to the limitations in accuracy we decided not to proceed with this method. Anyhow there are other instruments of the same type with higher accuracy which should be tested in archaeological surveying, for instance ABEM:s WADI.

The next survey was made with gradiometer and a 4m boom slingram, EM-31. Both instruments show the measured data directly on the display and the gradiometer also had a audio generator which gave a sound detection with increased frequency and sound level

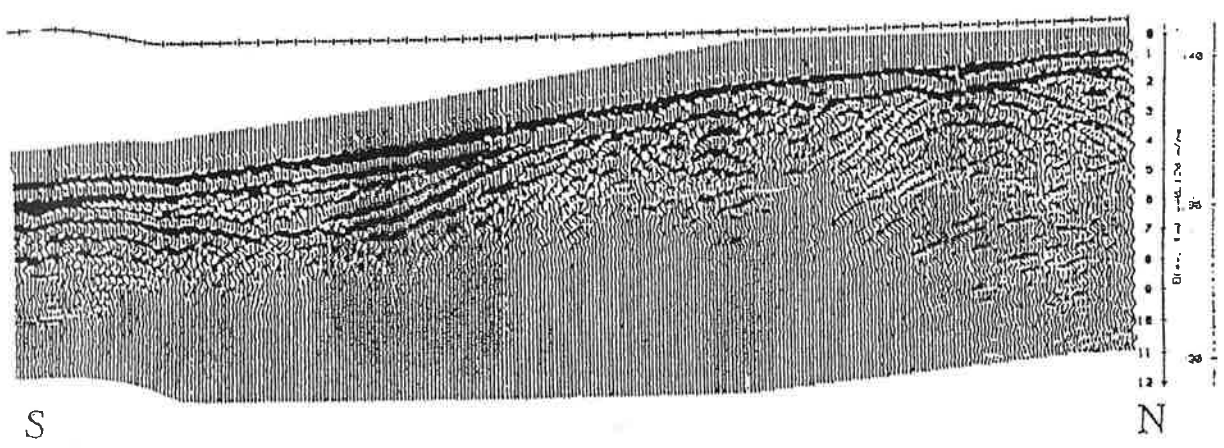

Figure 8. Radar profile GR 2 south of Vendel church showing the different layers. In the southern part to the left the underlaying accumulated horizontal layers on the older terrace.

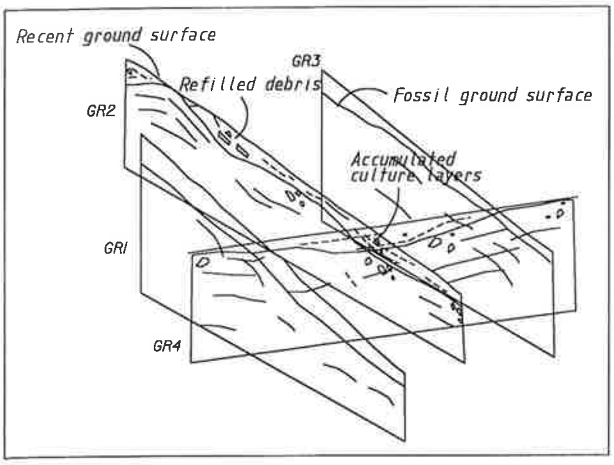

Figure 9. Interpretation of radar profiles GR 1-4 south of Vendel church.

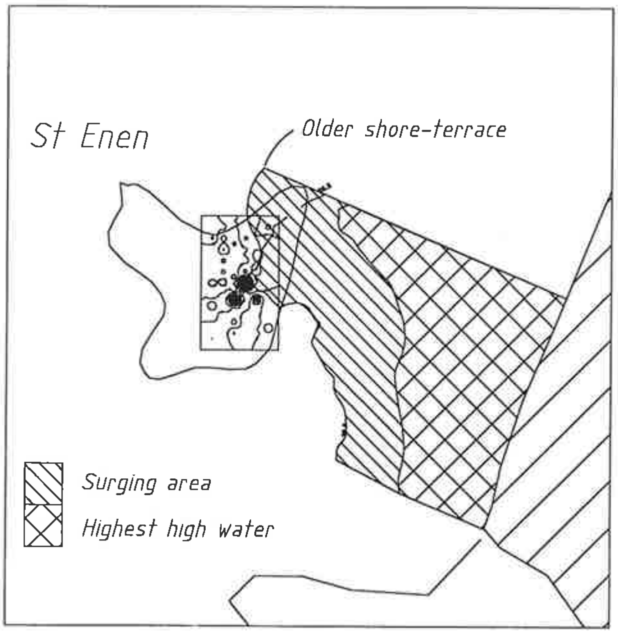

Figure 10. Map over Stora Enen with the shore terrace and the highest water level. Contour-map showing soil phosphate distribution.

when placed right over a magnetic artefact. These instruments were in our case used for a screening survey. The whole area was screened during continuous measuring and we marked out the anomalies in field. The result pointed out one area just west of the south-west corner of the church wall and one on the slope south of the church wall (fig. 3).

West of Vendel church

For a closer look at the area west of the church wall, a survey was made with GPR and EM-38 slingram. The radar measurements consisted of two parallel profiles and the EM-38 survey was made in a one metre grid over the earlier indicated area. In one place, pointed out by three independent methods, a test core was taken with a 5 cm spiral corer. In the core we found charcoal, burned clay and two separated dark-coloured layers. The different anomalies helped us to choose the place for excavation (fig. 4).

The results from the excavation showed that the anomalies were caused by the bottom of a furnace, which had been used for bronze casting. The furnace, which was placed right in the middle of the trench (fig. 5) was made of bricks and had probably been used for church bell casting. Below the furnace we found a bell pit with mould fragments (Anund 1995, Isaksson & Arrhenius 1994).

South of Vendel church.

At an area on the esker slope just south of the church anomalies had been pointed out both by the magnetometer and the boom slingram. The area had a visible terrace shape and on that terrace there were visible remains of an old court-house from the 18th century. A more extended survey was then carried out on the terrace with soil sampling for a laboratory phosphate analysis, a more accurate electro-magnetic mapping with Geonics EM-38 and altogether four radar profiles (fig. 6–7).

The radar profiles showed under the recent ground surface what we interpreted as a flat terrace with a number of accumulated cultural layers (fig. 8–9). Soil samples taken with a geological stick and analysed with phosphate test strips showed that these layers had a high content of soil phosphate. (Sanglert 1995). Later excavations have confirmed the interpretation and we have found a number of cultural layers from different periods and a large number of artefacts on the terrace.

The interactive prospection during ongoing excavation has proved to be of great help as well for making the right decisions in field as for the archaeological interpretation of layers, artefacts and activity areas (Isaksson 1997).

A possible harbour.

At the south-western shore of Lake Vendel there is a till mound. Since the isolation of the Lake Vendel this would have been the most suitable place geographically to land with boats coming from the Fyris river through the Vendel river and heading to the area around the boat-graves in Vendel. The mound is easily drained compared to the surrounding glacial and post glacial clay. There were houses on the mound during the medieval period and the place is named "Stora Enen" (fig. 1). Our investigations aimed to see if we could find indications of prehistoric activities.

Archive studies showed that there had not been any project to lower the water level in Lake Vendel in order

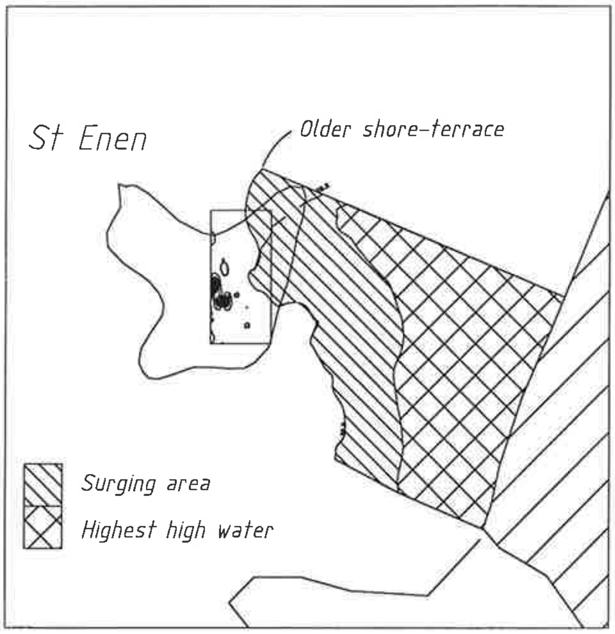

Figure 11. Map over Stora Enen. Contour-map showing soil electromagnetic response.

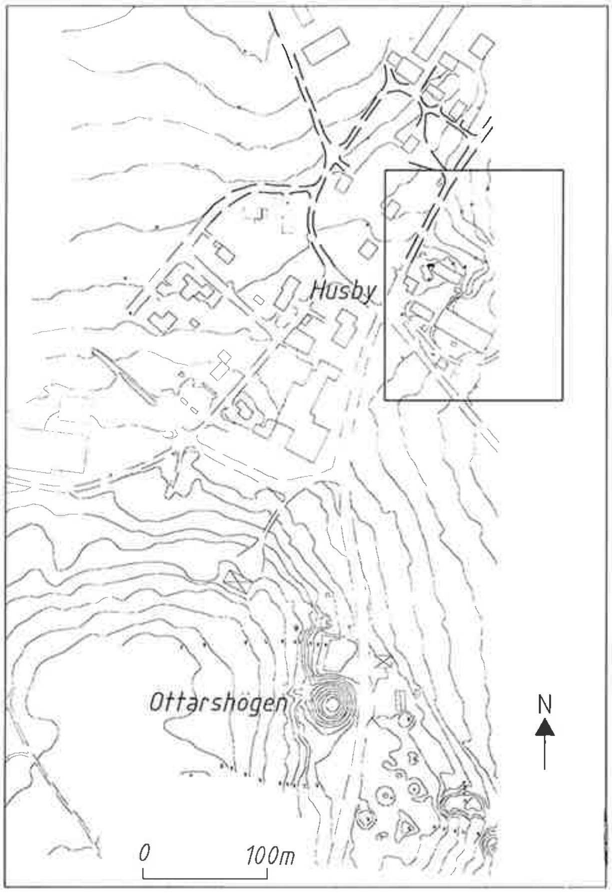

Figure 12. Map over the area around Husby showing the survey area in rectangle.

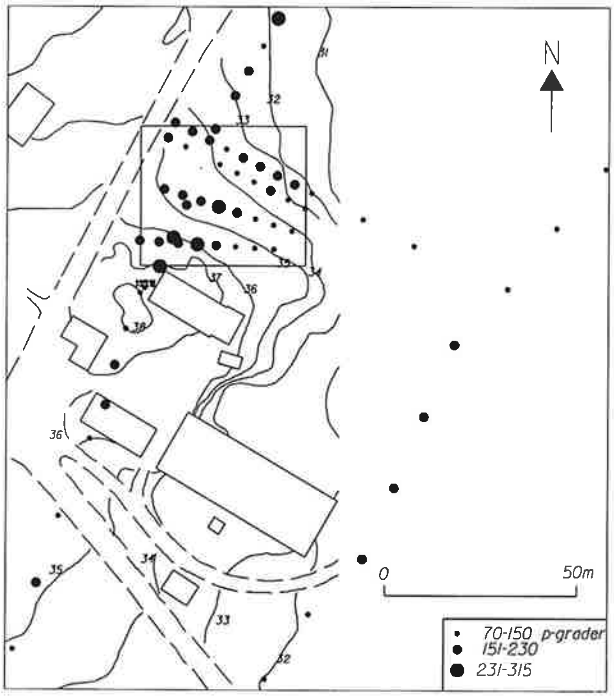

Figure 13. Map over Magasinsbacken in Husby with scaled filled circles showing the soil phosphate content in P° and the area with visible terraces in rectangle.

to gain land for farming. Permission and funds to do so were obtained in 1846, but disagreements among the landowners stopped the whole project. Instead the lake was dammed in 1890–1892, and dredging work carried out at the outlet into the Vendel river as an attempt to minimize the damage to the fields caused by spring floods. In 1957 the bottom profile of the river was broadened and a new dam at the outlet was built. All this means that the area around Lake Vendel has had the same topography since the lake was isolated from the Lithorina sea during the Bronze Age.

By combining data from SMHI, the *Swedish Meteorological and Hydrological Institute,* concerning variations in the water level in Lake Vendel and topographic mapping, using a theodolite, we could see where the highest water level had been on the mound during the spring floods. The data from SMHI was collected during the period 1917–1930 and the 'metre above sea level'-values from different times have been corrected to the recent sea level due to the landlift.

The soil phosphate mapping of an area on the mound at "Stora Enen" showed anomalies in connection with the former shore-terrace, which is the highest level the waves reached. Electro-magnetic mapping pointed out an area with enriched electric conductivity adjacent to this (fig. 10–11).

The results from the different surveys show that prehistoric activities may have occurred at "Stora Enen". The anomalies, placed just above the highest shore terrace, suggest that this could have been used as a landing place for boats during Vendel and Viking Periods (Ekström 1994).

Husby.

Since 1995 the Archaeological Research Laboratory has performed archaeological surveys in Husby, Vendel parish in order to find prehistoric settlements connected to the Ottar mound. Phosphate mapping, conductivity mapping with Geonics EM-38 and ground radar profiling showed layers from possible settlements between and under the graves at the grave field east of the Ottar mound (Karlsson 1996).

Further phosphate mapping in order to try to discover the location of medieval Husby were carried out in 1996 by Öjvind Karlsson. Earlier studies and indications made us choose an area at Magasinsbacken, NNE of the Ottar mound, for more detailed prospecting (fig. 12). Soil samples were taken along a few lines to cover visible topographic terraces (fig. 13). The highest values of soil phosphate content were found in an area with three different levels of terraces. The dense sampling at that area made it possible to produce a contour map for soil phosphate (fig. 14). The result shows one place with very high phosphate content. It is today used as enclosed grazing land for horses, but within that grazing land there are obvious differences in deposits of phosphate, which implicate that these variations are caused by something else than the recent grazing. Grazing itself does not mean an enrichment of phosphate but rather a decreasing of the soil phosphate buffer. Even if hay is added during winter, the animals use the food for growth and the animal bodies are not deposited in the grazing land when they are slaughtered. Some of the added nutrients in the hay is re-deposited to the ground as urine and excrement's, but the high phosphate content in soil here with more than 300 P° (mg P_2O_5/100 g soil) can not be explained as caused by grazing. It is more likely caused by organic debris around houses. With further prospecting, coring and excavation we hope to be able to confirm this.

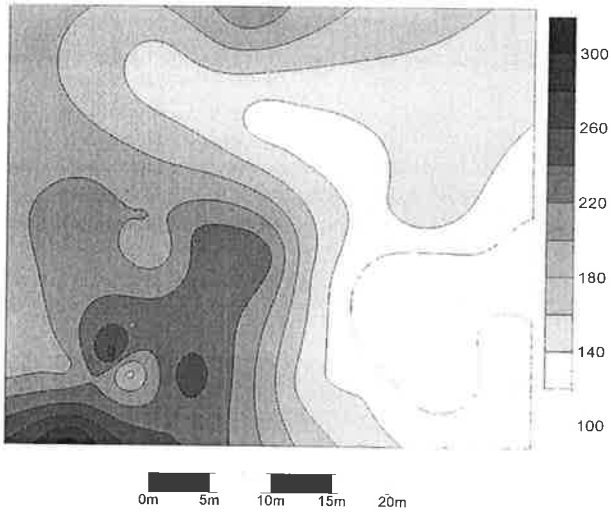

Figure 14. Contour-map showing the soil phosphate content in Magasinsbacken, Husby. Contours in P°, equidistance 20 P°.

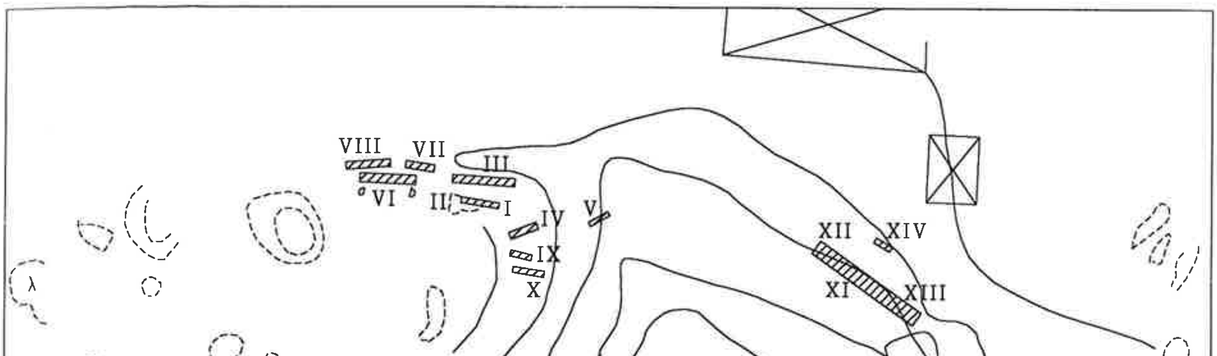

Fig.15. Map over the boat-grave field at Tuna in Alsike showing the boat-graves and topographic contours, equidistance 1 m. After T. J. Arne 1934.

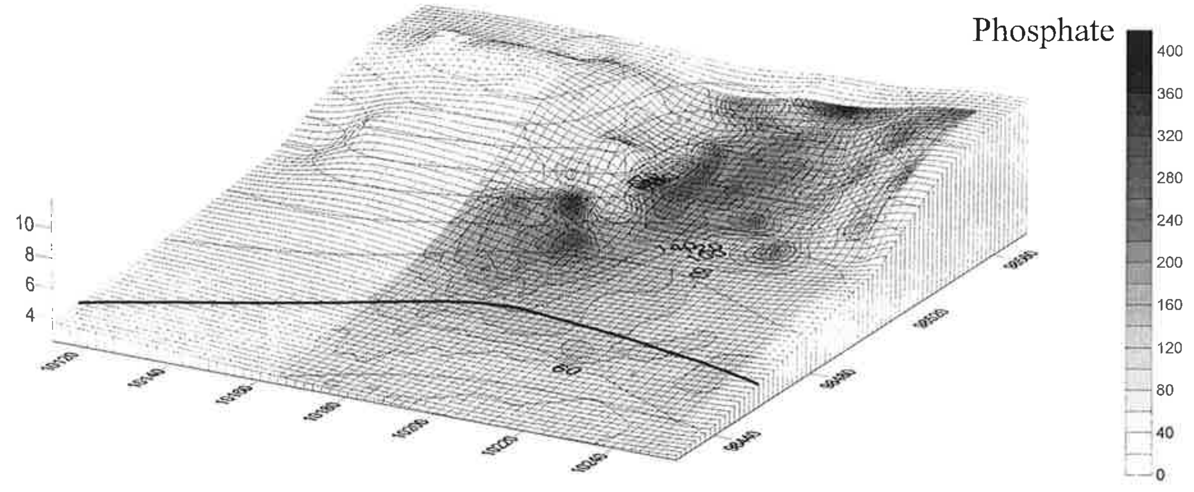

Figure 16. 3-D topographic model of the area, equidistance 1 m, with contour-map showing the soil phosphate content in P°, equidistance 20 P°. Contour 4 meters above sea level in thick line.

Tuna in Alsike.

At Tuna in Alsike parallel investigations have been carried out in order to find settlements connected to the boat-grave field. Studies of archives and old maps and an inventory of the site led us to choose an area covering the two hills with the boat-graves and down to the clay field between the hills (fig. 15). A great number of soil samples were taken and the topography of the whole area was mapped with a total station. On sampling ceramics, pieces of slag and charcoal were found in the clay field. Using Geosoft's SURFER programme the results from the levelling and the phosphate analysis have been combined (fig. 16). They show greatly enriched soil phosphate content in the clay field, mainly just above the Viking Age shoreline, 4 metres above sea level. The high soil phosphate content here cannot be explained by farming but is interpreted as remains of some kind of settlement activity (Johannesson 1997). Further prospecting with test coring should be done in attempts to confirm this interpretation.

Valsgärde.

The investigation of the settlement at the boat-grave cemetery in Valsgärde is being carried out by the Archaeological Institution at Uppsala University and is part of the SIV-project. As a co-operation within the SIV-project between Uppsala and Stockholm, AFL has carried out an electro-magnetic mapping with Geonics EM-38 in order to find possible structures and to delineate the settlement area in Valsgärde (fig. 17). The measurements were made in the clay field and we hoped to be able to detect structures with electro-magnetic properties differing from the surroundings under the ploughed layer.

The results show some places with anomalies (fig. 18). The amplitude of the anomalies are rather low and they are not caused by metals, but similar to results obtained earlier from cultural layers with a high content of organic material. The geometry of the anomalies also makes it possible to interpret them as caused by houses, for instance by lines of walls or pole pits. A 60 metre long trench in the same area made by excavator in 1995 shows a similar pattern. In the northern part was a hearth and in the southern part structures like post-holes (Norr 1996).

As well as the electro-magnetic survey, AFL has carried out phosphate analysis on soil samples taken by

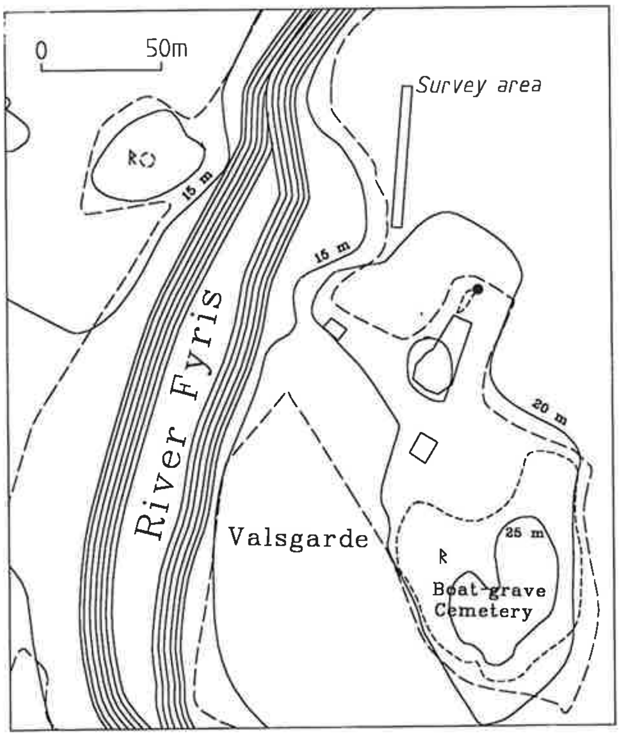

Figure 17. Map showing the area around the boat-grave field in Valsgärde with the survey area in rectangle. By Svante Norr.

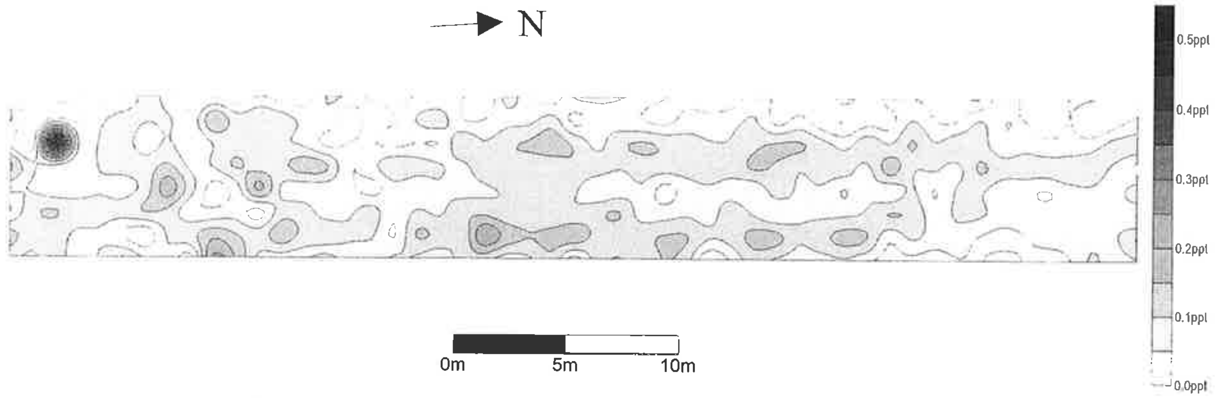

Figure 18.Contour-map showing the soil electromagnetic response in parts per thousand (ppt) in Valsgärde, equidistance 0.05 ppt.

Svante Norr as an attempt to delineate the terrace with remains of houses on the esker at Valsgärde. Further electro-magnetic mapping is planned to be carried out by AFL in the Valsgärde area during autumn 1997.

Summary

For some time tests of different geo-chemical and geophysical prospection methods have been carried out within the SIV-project. Altogether seven different geophysical instruments, different methods for soil phosphate analysis and some other geo-chemical methods have been tested and evaluated. The methods have been used to find the right place for excavation but also as an interactive prospection during the excavation. This has made it possible to define the direction for extension of trenches during excavations and sometimes even given indications as to what finds should be expected in excavating the next layer. Accurate levelling and digital mapping of the excavation area have been made with total-stations and GIS and CAD have been used for production of maps and profiles.

The method tests have provided us with knowledge of how we should plan a prospection in order to obtain maximal information about where to excavate and sometimes about what we can expect to find in the next layer. This in turn gives us a better way to make use of the economic resources and the time.

The survey method we have found to be most suitable is first to use ordinary archive and map-studies and then electromagnetic mapping with Geonics EM-38 and soil phosphate mapping. At suspected areas test-cores should be taken with a geological stick or a spiral corer for inspection and analysis of eventual cultural layers and finally a profile survey with ground radar should be carried out.

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