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Short Report

Tracing High-temperature Crafts: magnetometry on the Island of Gotland, Sweden

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ABSTRACT Gradiometer surveys have been carried at three Iron Age and early medieval sites on the island of Gotland, Sweden. Previous experiences of poorly executed magnetic surveys combined with a misconception among archaeologists that the Gotlandic sedimentary bedrock would preclude the success of any magnetic investigations on the island have, until now, prevented the extended use of the method within archaeological projects. The purpose of the present study was to test this presumption while searching for *in situ* buried remains of high-temperature crafts, such as metal and glass working. The location of the survey grids was guided by concentrations of previously recovered high-temperature craft finds from metal detector surveys and excavations. The results indicate that the magnetometer is a valuable tool for detecting the presence of preserved high-temperature craft structures in the Gotlandic soil. An additional result indicates that in this area the magnetometer can easily identify remains of ploughed-over Iron Age stone foundation houses and stone boundary walls. This is possible because of the prehistoric population's preference of using glacially deposited, igneous rocks in such constructions. It can thus be concluded that the uniformly non-magnetic character of the Gotlandic bedrock provides excellent conditions for conducting magnetic surveys. Copyright © 2012 John Wiley & Sons, Ltd.

Key words: Magnetometry; metal detector; Gotland; Sweden; metal work; high-temperature crafts.

Introduction

After a somewhat reluctant start, geophysical prospection has been increasingly used within Swedish archaeology and its advantages have been proven repeatedly (e.g. Trinks *et al*., 2009, 2010; Viberg and Wikström, 2011). Certain Swedish regions are still, however, more or less blank spots on the geophysical map. This paper presents a pilot study of the applicability of magnetometry at three sites in such an area, Gotland, one of the large islands in the Baltic Sea (Figure 1).

With the exception of a small number of unpublished surveys of limited quality, where the surveyor failed to identify a majority of the archaeological remains found during the subsequent excavations (Gunilla Wickman-Nydolf, personal communication, 2012), as well as a recent large-scale multisensor gradiometer survey at Västergarn (Christoph Killger, personal communication, bc), Gotland has seen no use of magnetometry, neither in contract archaeology nor in research. Given the magnetic homogeneity of the Gotlandic sedimentary bedrock it should, depending on the nature of the superimposing drift material, be well suited for magnetic surveying (Gaffney and Gater, 2003, p. 78f; David *et al*., 2008, p. 15). To verify this a study of three ploughed-over settlement sites with rich remains left by high-temperature crafts, was launched by the Archaeological Research Laboratory in 2010.

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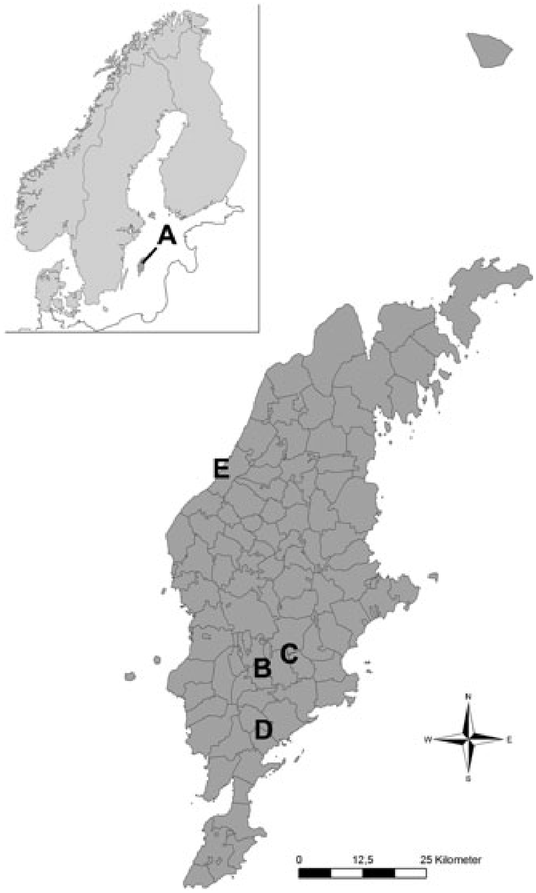

Figure 1. (A) Location of Gotland. Sites mentioned in the article: (B) Odvalds, Linde parish; (C) Lyrungs, Stånga parish; (D) Nygårds, Eke parish; (E) Visby, Province Capital.

The use of magnetometry to investigate such sites is by no means new (e.g. Aitken, 1958; Fulford *et al*., 1992; Vernon *et al*., 1998, 2002; Jones, 2001; Powell *et al*., 2002; Linford and Welch, 2004; Smekalova *et al*., 2008; Walach *et al*., 2011). In Sweden, however, magnetometry surveys for archaeological prospection were not carried out until 1977 (Fridh, 1982), after which it was used only sporadically until the mid-2000s (Viberg *et al*., 2011).

Geological background and cultural development of Gotland

Gotland is located in the Baltic Sea approximately 90 km east of the Swedish mainland (Figure 1). The bedrock consists mainly of sedimentary rocks deposited during the Silurian Period, but the latest glaciation left rich deposits of moraine sediments and igneous rocks all over the island. Several significant gravel ridges were deposited along the maximum landward shorelines during transgressions in the Baltic Sea basin. These played crucial parts in the settlement pattern of the island as they offered easily accessible and well-drained land (Burenhult, 1999, p. 194).

During the first few centuries AD, low stone walls started to be constructed throughout the landscape, accompanied by longhouses built with massive dry stone foundations (Figure 2). The stone used in these constructions, generally igneous rocks brought to the island by means of the ice sheet during the glaciations, were collected as the land was cleared (cf. Nihlén and Boetius, 1933; Nilsson, 2011). A particular Gotlandic prehistoric cultural trait of great importance to the understanding of the settlement pattern was the practice of moving farmsteads around their local lands, i.e. not to rebuild a house where it once stood (Östergren, 1989; Nilsson, 2011). Hence, a great many Gotlandic Iron Age and early medieval settlements are found in fields that are ploughed regularly. This has been established predominately via metal detector surveys from the late 1970s up to the present, on a scale unseen in other parts

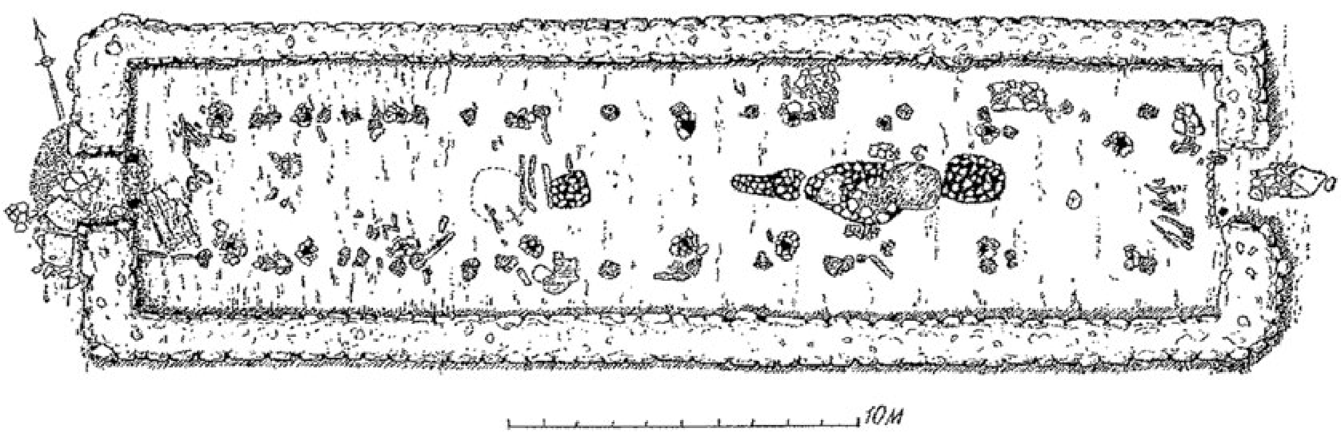

Figure 2. Remains of a Gotlandic Iron Age house with dry stone foundation. Dune in Dalhem parish (after Stenberger, 1945).

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of Sweden (cf. Östergren 1989; Andersson, 1999). A relatively large proportion of the finds recovered during these metal detections are associated with metalworking. Beside slags of various kinds these also include metal impregnated hearth lining, smelts, hack metal, casting jets and miscasts. Thus it is often possible to pinpoint possible metalworking sites within the settlements via finds from metal detections. The clearly defined insular Gotlandic culture lasted up until around 1150 AD when it seems to have been thoroughly annexed into the Continental High Medieval cultural sphere (Carlsson, 1979; Myrberg, 2008).

Surveyed sites

As mentioned earlier, initially three sites were selected to be surveyed (Figure 1). All three sites have been subject to metal detection or were partly excavated and have yielded finds produced by high-temperature crafts. In two cases, Odvalds in Linde parish (Gustafsson and Viberg, 2011) and Nygårds in Eke (Ström, 2001), the finds derived mainly from metalworking, whereas the third site, Lyrungs in Stånga, yielded finds from glass working (Carlsson, 1976; Huttu, 1996). The latter site was chosen as a reference-site because the remaining below-ground structures have been partly confirmed by excavation.

The purpose of the magnetic surveys was to investigate whether any features and constructions of stone, sand and clay left by high-temperature crafts were still *in situ* below plough depth. The distribution of finds from metal detection was used to locate grids for the magnetometer surveys; clusters of high-temperature craft finds were interpreted as possible remains of fragmented features such as furnaces, kilns or forges, possibly partly preserved below plough depth and hence traceable via magnetic survey.

Methodology

During all surveys a single probe Foerster Ferex 4.032 fluxgate gradiometer was used measuring the vertical gradient of the Earth's magnetic field. The cross-line distance for these measurements was 0.5 m and the in-line sampling distance was 0.1 m for all surveyed areas, with data collected in zigzag formation. Although it is, for several reasons, preferable to survey larger areas (cf. Gaffney *et al.*, 2002, p. 3; Kvamme, 2006, p. 205f) the sizes of the surveyed areas were guided by the distribution pattern of finds previously located by metal detection, and therefore rather small. This was deemed a suitable approach as this was to be regarded as an evaluation of the applicability of magnetometry on Gotland, and larger area surveys will be conducted at these sites in the future. The results are destaggered and corrected for zero mean traverse (ZMT). The data from Stånga have, because of shallow geological features influencing the data, also been high-pass filtered. The remaining stripy pattern (visible in Figures 3–5), which was not completely removed by the ZMT, can be explained by the prevalent strong buffeting winds causing probable heading errors. The total magnetic field intensity in Visby, Gotland (Figure 1) is roughly 50 900 nT, a value constantly fluctuating because of, for example, diurnal variation and magnetic storms, and the magnetic declination is ca. 5° (Swedish Geological Survey). All magnetic maps in subsequent sections have both grid north (large arrow) and magnetic north (small arrow) indicated.

Results

Nygårds, Eke parish

The site has been repeatedly subject to metal detection, which has yielded numerous finds rendered by both ferrous and non-ferrous metalworking (Andersson, 1999, 2000; Ström, 2001; Figure 3). Judging from other finds, dating from the Migration Period (ca. AD 400–550) up to the High Medieval Period, the area was utilized for habitation for around 800–1000 yr. A concentration

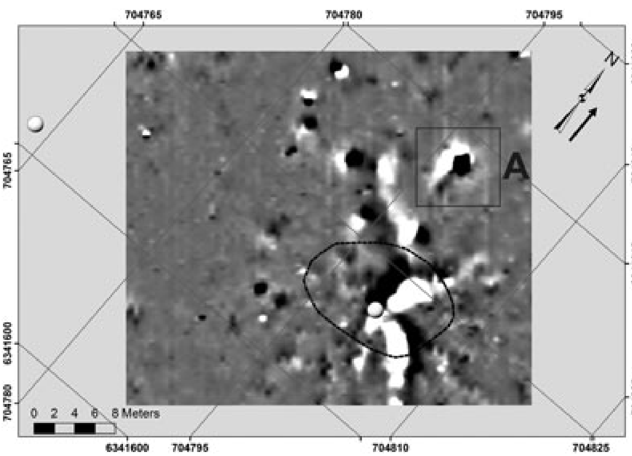

Figure 3. Results from the gradiometer measurements at Nygårds, Eke parish, Gotland. A concentration of high-temperature craft finds, located by metal detector, and dark soil is indicated by the black dashed oval. (A) The location of a probable furnace (see detail in Figure 4). Rectangle around (A) indicates the location of the measured data in Figure 4. Grey circles indicate the location of important metal work finds. Grey scale: −16 nT white to +24 nT black. Coordinates in Sweref 99TM.

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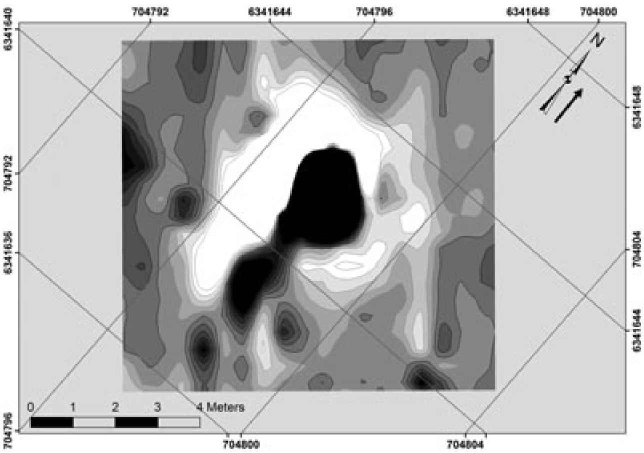

Figure 4. Results from the gradiometer measurements at Nygårds, Eke parish, Gotland. Detail of the probable iron bloomery furnace (A in Figure 3). Grey scale: −10 nT white to +10 nT black; contours = 2 nT interval. Coordinates in Sweref 99TM.

of bronze smelts and hearth lining indicate the presence of large-scale bronze casting (Figure 3). The areas utilized for metalworking are still visible as elevated, darker patches in the plough soil, littered by fragments of fire-cracked stones.

A grid of 35 by 40 m was investigated over this area. The result reveals several anomalies most likely caused by high-temperature craft activities. Several anomalies exceed 400 nT in strength and have directions of magnetization that, for the most part, differ by more than 30° from present-day magnetic north (Figure 3). The magnetic declination has, in nearby Denmark, never exceeded 30° during the Iron Age (Bevan and Smekalova, 2001, p. 22, figure 13; Abrahamsen *et al*., 2003, p. 93, figure 2) and it is reasonable to assume that the directions of magnetization on Gotland have similar declination values during this period. *In situ* fired features would be expected to have the direction of their high–low anomalies oriented closely toward magnetic north. A firm correlation can be seen when magnetic data are compared with the clusters of bronze objects (Figure 3). The magnetic bipolar anomalies in this area have maximum positive values of 75–130 nT and are, despite their apparent linear appearance, probably caused by several smaller discrete features in close proximity with each other. Southeast of this concentration several smaller bipolar anomalies, with measured values of up to 100 nT, can be observed. Most probably they also are caused by smaller discrete features related to the same activities as the previously mentioned bipolar anomalies. A number of other strong anomalies in the magnetic data are caused either by ferrous objects in the topsoil or ploughed-over structures, possibly connected to iron production. One especially interesting anomaly, denoted (A) in Figure 3, with positive values of 466 nT resembles the signature from a furnace from Ewecote, North Yorkshire, England, archaeomagnetically dated to the high- and late Middle Ages (Vernon *et al*., 2002, p. 125; Powell, 2003). This is also similar to other examples of excavated furnaces dating to the Roman Iron Age in Sweden (e.g. Forenius *et al*., 2007).

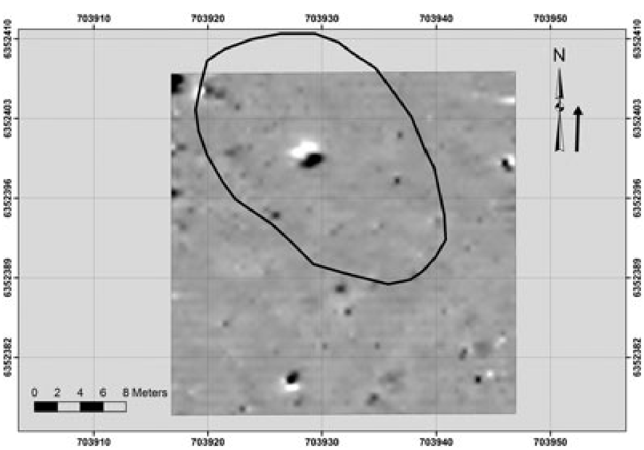

Figure 5. Results from the gradiometer measurements at Odvalds, Linde parish, Gotland. A concentration of high-temperature craft finds, located by metal detector, and dark soil is indicated by the black oval. Grey scale: −16 nT white to +24 nT black. Coordinates in Sweref 99TM.

Odvalds, Linde parish

The site at Odvalds has been subject to metal detection on several occasions and three Viking Period silver hoards have been found in the field. The hoards may indicate three previous locations of the farm Smiss, now situated ca. 500 m to the east. Two grids of 30 by 30 m were surveyed, and the results of one are presented in Figure 5. These lack the apparent abundance of anomalies connected to high-temperature crafts that are clearly visible in the data from, for example, the Nygårds site. The area is, as evidenced from excavations, for example, highly affected by ploughing, leaving few structures *in situ* (Gustafsson and Viberg, 2011). One bipolar anomaly with a possible anthropogenic origin is visible within the metal detected concentration but this feature is, using the half-width rule (see e.g. Breiner, 1999) probably situated in the plough zone at a depth of ca. 0.25 m. Several anomalies are visible in the data, but the majority are most likely caused by the presence of ferromagnetic objects in the upper plough zone.

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Lyrungs, Stånga

The location of the survey grid of 30 by 40 m at Lyrungs was governed by evidence of high-temperature crafts discovered during previous excavations when a presumed early medieval workshop was discovered within the remains of an earlier Iron Age building with a dry-stone foundation (Carlsson, 1976, 1979; Huttu, 1996). Measurements revealed that the noise level of the geological background were relatively low, with the lowest and most uniform values in the northern parts of the survey grid (Figure 6). This was also, from the outset, the least likely part of the survey grid to contain archaeological structures.

The southern part of the grid is dominated by a terrace with remains of a large Iron Age building with massive stone foundations, which are all highly visible in the magnetic data (Figure 6). The anomalies, together forming a typical longhouse shape, are probably visible because of the apparent preference of using igneous rocks in the construction. Such stones were also incorporated in the stone walls and field boundaries in the area. A possible field boundary, not visible above ground, is visible in the magnetic data and connects to the terrace (Figure 6). This feature presumably connects to a field boundary mapped during an inventory of the field systems in 1975 (Carlsson, 1979,p. 72, figure 51).

As mentioned above, a smaller early medieval workshop was discovered within the larger stone foundation. This structure is, as opposed to the large Iron Age building, missing from the magnetometer data. Judging from a large number of glass tesserae recovered during excavations there is evidence for glass working in the building (Carlsson, 1976). One of the anomalies in the magnetic data, possibly caused by the presence of a high-temperature craft structure, was investigated by excavating a 1 m^2 test pit during the autumn of 2011 (Figure 7). It revealed a linear concentration of small fire-cracked stones and an abundance of burnt clay, glass tesserae and fragmented ceramic loom-weights. The row of stones running diagonally through the square evidently indicates the wall line of a former building. Depth estimation using the half-width rule reveals that the source of the anomaly is most likely situated at a very shallow depth of 0.1 m. This indicates that the structures visible in the test pit are the likely source of the bipolar anomaly visible in the magnetic data.

Discussion

From a geophysical point of view the results from the three surveyed sites can be positioned along an increasing axis, whereby the results from Odvalds in Linde yielded the least amount of useful information. The results from Lyrungs are informative but associated with some issues concerning the interpretation of the origin of the anomalies given the complicated stratigraphy of the surveyed site. The results from Nygårds in Eke yielded the most promising results, but are also more enigmatic because it has not, as yet, been possible to investigate the cause of the anomalies more closely.

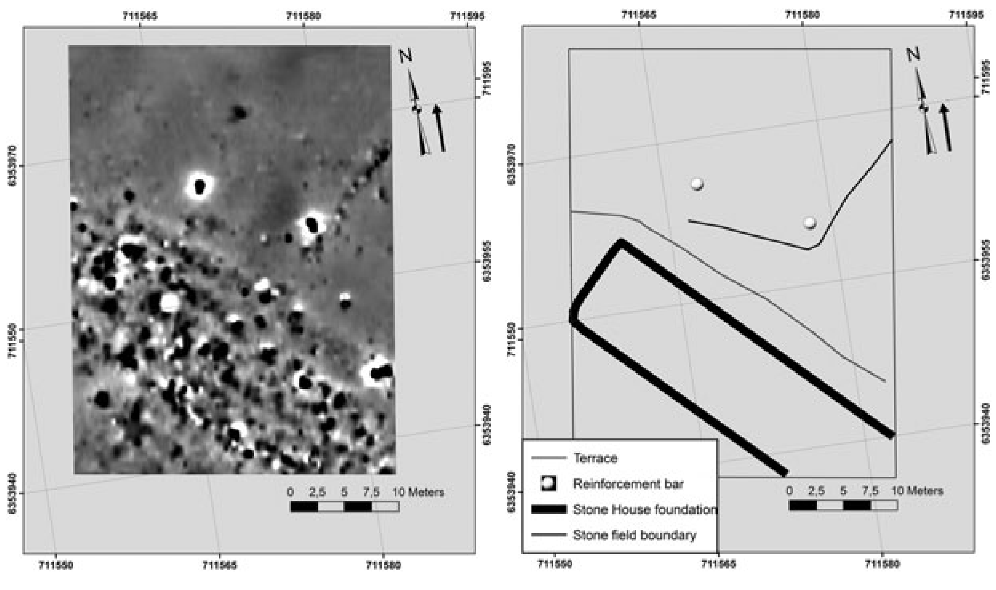

Figure 6. (left) Results from the gradiometer measurements at Lyrungs, Stånga parish, Gotland. Grey scale: −10 nT white to +10 nT black. (right) Interpretation of the larger structures in the gradiometer data from Lyrungs, Stånga parish, Gotland. Coordinates in Sweref 99TM.

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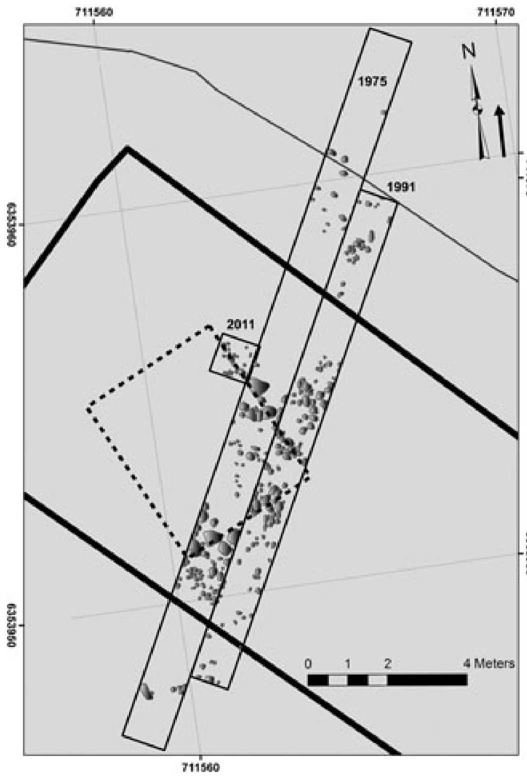

Figure 7. Comparison between the interpretation of the gradiometer data and previous excavations at Lyrungs, Stånga parish, Gotland. Results showing the investigated stone constructions from the excavations in 1975, 1991 and 2011. Dashed rectangle indicates the suggested direction and size of the early medieval workshop.

At Odvalds in Linde most of the settlement deposits have been irreversibly disturbed by ploughing, leaving only the deepest layers *in situ* below plough depth. The above-mentioned bipolar anomaly (Figure 5) with a possible anthropogenic origin might be related to the metal detected area of high-temperature craft finds, but the estimated depth beneath the sensor makes this interpretation uncertain.

Within the survey grid at Nygårds in Eke it is possible that some of the more prominent magnetic anomalies are caused by the extant remains of early iron furnaces (cf. Serning, 1979; Rydén, 1979). Accordingly, the field at Nygårds might hold remains of craft activities separated in time by several hundreds of years. To some extent the results resemble those caused by lightning strikes (e.g. Bevan, 2009), but the clear correlation with the metal detector finds and the dark colour of the soil in this restricted area favours an archaeological origin for most of the anomalies, presumably connected with metal working. Large amounts of stones have been cleared from the field at Nygårds, but there are many left, especially, according to the landowner, in the lower plough zone. Such stones with high magnetic properties might also explain some of the measured anomalies. It is also interesting to note that small pieces of fired clay found in areas where demolished kilns have been situated will be visible in the magnetic data as dipolar anomalies, similar to those caused by ferrous objects (Aspinall *et al.*, 2008,p. 68f). This might shed further light on the possible source of some of the anomalies from the Nygårds site.

An important observation at Lyrungs in Stånga is that features built of igneous rocks can be clearly defined by means of magnetic survey. This is of course not surprising, given the local geology, but the results might still signal an important future use of magnetic surveys on the island. During recent centuries the Gotlandic landscape has been remodelled on a previously unseen scale in order to increase farmland and ease land use. This has included removal of monuments such as Iron Age buildings with stone foundations. The resulting fields often yield rich finds during metal detecting but it is often hard to delimit the actual location of the structures removed. The results from Lyrungs encourages further studies of ploughed-over sites because they indicate that magnetic survey might be able to pinpoint remains of such structures still present below plough depth.

Conclusion

The results of the study presented above show that magnetic survey can fulfil an appropriate role within Gotlandic archaeology. On the two sites subject to metal detection a clear correspondence could be observed between features indicated by the distribution of finds and field observations on one hand and magnetically identifiable anomalies on the other. At Stånga, where the known distribution of finds is limited to the excavated areas the magnetic survey was of great value for the interpretation of the site, even though the complexity of the local stratigraphy made interpretation challenging. The strong response from the igneous stones in the house foundation furthermore made it difficult to identify the magnetically less pronounced remains of the early medieval workshop. On a general level it has, as expected, been possible to show that the uniformly non-magnetic character of the Gotlandic bedrock seems to offer very good prerequisites for magnetic survey, even though more sites needs to be evaluated and further surveys, covering larger areas at the above-mentioned sites, need to be carried out. Based on these results, a combination of metal detecting and magnetic survey could be recommended for the investigation of archaeological sites situated in similar geological settings.

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