ARCHAEOLOGIA ISLANDICA 2 (2002) 10-33

TIMOTHY J. HORSLEY & STEPHEN J. DOCKRILL

A PRELIMINARY ASSESSMENT OF THE USE OF ROUTINE GEOPHYSICAL TECHNIQUES FOR THE LOCATION, CHARACTERISATION AND INTERPRETATION OF BURIED ARCHAEOLOGY IN ICELAND

Geophysical survey techniques are well established to provide information about archaeological sites in many parts of the world, over a variety of landscapes and geology. However, one area where the application of systematic prospection has been neglected is Iceland, where a particular set of geomorphological and archaeological problems are present. This paper presents the results of the first systematic and integrated application of geophysical surveys in Iceland. High-resolution magnetometer and earth resistance surveys have been undertaken at eight archaeological sites, to obtain geophysical results for a range of features and geological conditions.

The results of these geophysical surveys have been integrated with other sources of archaeological evidence to allow a proper assessment of their success for not only locating buried remains, but also for their characterisation and interpretation.

Despite the potential limitations of igneous thermoremanent effects, tephra deposits and periglacial phenomena, the project has successfully demonstrated the ability of these routine techniques for archaeological prospection.

From this evaluation it is possible to provide strategies for the future use of such geophysical techniques as part of an integrated study of archaeological remains in Iceland, and to pinpoint areas where further research is necessary.

Timothy J. Horsley and Stephen J. Dockrill, Department of Archaeological Sciences, University of Bradford, UK

Keywords: church; earth resistance; evaluation; farm; geomorphology; gradiometer; igneous; magnetometer; medieval

Introduction

The routine application of archaeological geophysical survey techniques is well established as a means of locating, mapping and aiding the interpretation of archaeological sites in many areas of the world, over a variety of landscapes and geology (David, 1995; Boucher, 1996). However, one area where such prospection has been neglected to date is Iceland, probably as a result of a number of contributing factors, including the type and character of both the archaeology and geology, in addition to the inhospitable nature of many parts of the country.

This paper describes a preliminary assessment of the integrated use of magnetometer and earth resistance surveys undertaken in Iceland during the summer of 1999, as part of a wider study of the archaeological monuments and landscapes.

General principles of geophysical prospection

For the prospection of archaeological sites a great number of different geophysical techniques and instruments exist, each with their own capabilities and limitations. Most techniques work by detecting a contrast in the material properties of the subsurface, producing a geophysical anomaly. On an archaeological site each method can have different potential depending on the nature of the buried archaeology, geology and possibly climate and land-use.

Following data-collection it is then necessary to determine the causative body, and to interpret this as an archaeological feature (Horsley 1998, 17).

Geophysical surveys suffer from an inherent ambiguity in the conclusions that can be drawn, as many different subsurface configurations could reproduce the same observed measurements (Kearey and Brooks 1984, 8-9). It is often the case that processing is required to aid in the identification and interpretation of anomalies in a survey, but altering the raw data in any way must be undertaken with care.

Much has been written about the different geophysical techniques routinely employed in archaeological surveying, in particular the two methods employed for this evaluation: fluxgate gradiometry and earth resistance methods (see Clark, 1975; 1990; Keary & Brooks, 1984; Scollar et al., 1990, Telford et al. 1976, among others). A full background to the techniques and theoretical details will not be given here, and the reader is advised to look at these works, and to the guidelines for the use of geophysical techniques in archaeological field evaluations provided by David (1995) and Gaffney et al. (1991).

Archaeological prospection in Iceland

In recent years, Fornleifastofnun Íslands (FSÍ) has undertaken an interdisciplinary investigation of the settlement of Iceland, including topographical surveys of extant earthworks, chemical surveys and excavation (Friðriksson & Vésteinsson, 1998a, 1998b). However, geophysical prospection as an additional technique for site location and interpretation has never been systematically applied in Iceland, either on its own or as part of an integrated strategy.

Archaeological features are not always represented on the surface, but even where earthworks do exist, their morphologies may appear ubiquitous and defy attempts at qualification or characterisation (Dockrill and Gater, 1992). Geophysical surveys would be an effective and unique tool in aiding this multidisciplinary research in Iceland, in the non-destructive characterisation and interpretation of archaeological sites identified by other methods, or in locating new sites in its own right.

Before this can happen however, a proper and systematic assessment of the techniques in this new environment is necessary to allow an understanding of limitations of the methods, and the conditions that make a site suitable for survey work.

Iceland presents a particular set of geomorphological and archaeological problems for the case of geophysical prospection, and it was the aim of this project to evaluate the success of such methods for the location and interpretation of buried archaeology.

This research has investigated what, at present, appear to be the most important of these limiting factors for Icelandic geophysics: soils, geology, geomorphology and archaeology, although it is a combination of these and more which produce the complex result obtained.

Igneous geology and tephra

The principle constraint identified with archaeological prospection in Iceland is the nature of the geology of the island: being volcanic and hence igneous, this will have a effect on magnetic surveys undertaken over such bedrock (Clark 1990, 92-4; David 1995, 10).

A serious complicating factor with igneous material is the presence of a thermoremanent magnetisation, acquired when the rock first cooled (Burger 1992, 412, 438; Clark 1990, 92). This geological thermoremanance will produce an intense response, far greater than that due to archaeological deposits.

Igneous rock will also be present in glacial erratic material and, having been displaced, the magnetic directions of the rocks are randomly jumbled, which can produce 'noisy' background signals that obscure archaeological anomalies (Clark 1990, 94).

However, prior to this study no magnetometer data has been systematically collected over archaeological sites in Iceland. Little work in general has been directed into the effect of igneous parent material on archaeological prospection anywhere, and to date there have been no comprehensive studies into the effects of tephra deposits on magnetic surveys.

Geomorphic processes in Iceland

When compared to Britain a number of unusual geomorphic processes are active in Iceland that have implications for archaeological prospection. This fieldwork has revealed that for the results of geophysical surveys, geomorphological influences are as important as geological features.

When the soil temperature drops below 0°C, the transformation of soil water into ice, results in a marked increase in the overall soil volume. The resulting stresses bring about fragmentation, compaction and deformation of the soil constituents. These mechanical disturbances generate specific features whose nature and degree of development are related to the intensity of the frost, the water content and the characteristics of the soil materials (e.g. soil texture and porosity) (Courty et al. 1989, 160). It is clear that several periglacial processes tend to separate coarser and finer particles in soils, and repetitive freezing favours the fragmentation of coarse elements; after some time the initial characteristics of archaeological soils may have been irreversibly altered (Ibid. 1989, 161; Bird 1974, 720).

Currently no work has been done to assess the effect of such periglacial phenomenon as patterned ground, involutions and frost hummocks (thufur) on geophysical prospection.

Icelandic soils

For this project the available information regarding Icelandic soil types was fairly limited. This lack of pedological and geological information does not prevent geophysical survey, but is crucial in the understanding and interpretation of the results. It is hoped that details relevant to geophysical surveys might have been recorded during vegetation surveys, and that this resource could be made use of in future work.

Climatic conditions have a serious effect on the soils in Iceland where they slow down the rate of soil formation (Gerrard 1985, 81). Coupled with prevalent soil erosion this obviously presents a problem for the preservation of archaeological remains, and also for geophysical prospection. In one place, soil erosion might be so severe that wind erosion has exposed the archaeology or removed it altogether. Elsewhere, this soil will have been deposited, possibly burying remains beyond the detection limits of most prospection techniques.

Icelandic archaeology

Iceland additionally provides an unusual archaeological situation: geological deposits may both predate and post-date archaeology remains, since buried features may be sandwiched between parent material and tephra deposits. It is thus of interest to learn the effect of these circumstances on archaeological prospection.

There is also the nature of the archaeology to consider. Many excavations have revealed structures not built in stone, but of turf sods, sometimes with stone facings.

Is geophysical prospection capable of detecting buried turf remains within the collapse and back-fill of more turf and soil? Surveys might only be able to identify areas of activity, such as hearths or middens, but if combined with other evidence such as earthwork analysis, this would still be new and useful information for site interpretation.

As stated in the introduction, only very limited and certainly no systematic, assessment of geophysical surveys for the prospection of buried archaeology has been conducted in Iceland. Indeed, such methods have only been employed in a handful of instances prior to this study, in each case focussing solely on answering specific archaeological questions, not to fulfil a systematic assessment of the methods. One of the weaknesses of these targeting approaches has been the lack of proper understanding of the geophysical techniques employed together with a high working knowledge of geophysics and a sound appreciation for the archaeological and geological anomalies likely to be encountered.

It is important that the factors outlined above are fully understood before such geophysical methods can effectively be provided routinely and as a service.

It was the aim of this investigation to provide a preliminary assessment of the

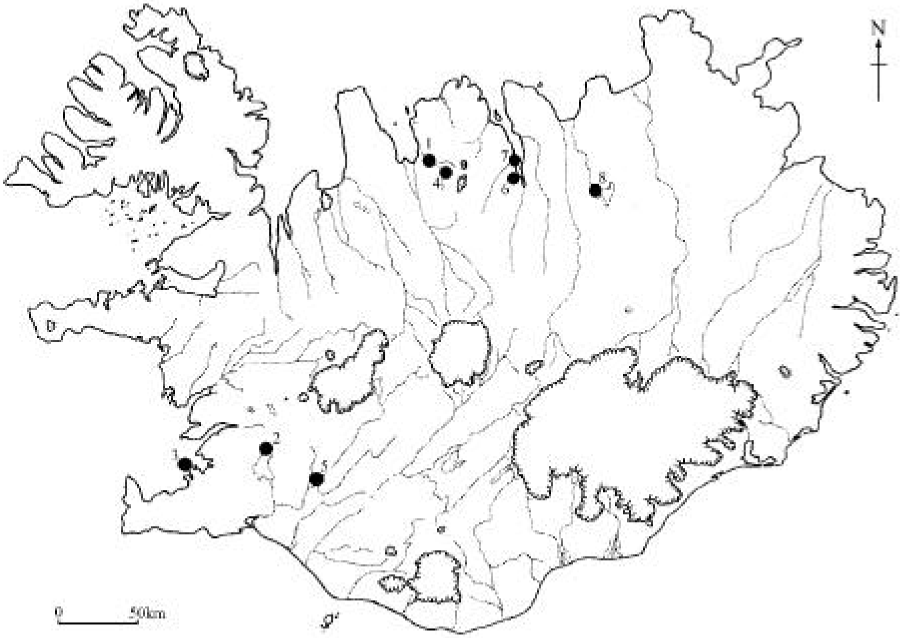

Figure 1. Sites investigated in 1999.
1. Neðri Ás; 2. Þingvellir; 3. Nes; 4. Hólar; 5. Skálholt; 6. Silastaðir; 7. Gásir; 8. Hofstaðir.

use of routine geophysical prospection techniques as part of an integrated study of the archaeological monuments and landscapes of Iceland.

Site selection

The opportunity to investigate sites in Iceland was the result of collaboration with the FSÍ, to whom acknowledgment is made for their enthusiastic inclusion of geophysical surveys with their own season of work. Working closely with the FSÍ has allowed geophysical prospection to be integrated with their own archaeological evaluations; in some instances parts of the survey areas were subsequently excavated, providing direct feedback for this assessment. In total, eight sites were investigated in this study, the locations of which are shown in Figure 1. Three of these, (Skálholt, Gásir and Hofstaðir), have been selected as case studies for discussion in the context of this paper, as they illustrate the problems and potentials of such surveys.

Fieldwork methods

At each location an area of archaeological remains was targeted for survey, known either from surface evidence in the form of earthworks, or from documentary sources. A grid of 20m x 20m squares was then established over the investigation area and, where time allowed, this grid was surveyed with both magnetometer and earth resistance techniques.

Earth resistance surveys

Earth resistance surveys were conducted using a Geoscan RM15 resistance meter using the twin probe configuration with a mobile probe separation of either 0.5m or 1.0m. For surveys with a mobile probe separation of 0.5m, readings of apparent resistivity were collected at 0.5m intervals along traverses spaced 0.5m apart. For the grids surveyed with a 1.0m mobile probe separation, readings were recorded at 0.5m intervals along traverses 1.0m apart. These high resolutions were chosen so as to gain the maximum information within time constraints.

Fluxgate gradiometer surveys

The magnetometer employed for this study was a Geoscan FM36 fluxgate gradiometer. Readings were recorded at the high resolution of 0.25m intervals along traverses spaced 0.5m apart, to provide a high level of detail. This was made possible by the use of a sample trigger connected to the instrument, which automatically records a pre-set number of measurements at regular intervals.

It was decided to collect data within a grid by walking in the so-called 'zigzag' fashion, as opposed to 'parallel'. In this way the direction of travel alternates between adjacent traverses to maximise survey speed, allowing a greater area to be covered. However, the magnetometer is always kept facing in the same direction, regardless of the direction of travel, to minimise heading error (Horsley, 1998). It is acknowledged that collecting measurements in this way can produce defects in the data. 'Bunching' within the data is caused by differences in the handling and orientation of the instrument in alternate traverses causing a pronounced striped effect parallel to the traverses (David 1995, 19).

Data processing

Geophysical data often benefits from the application of pre-treatment and processing techniques, specifically applied to remove background noise or to correct for collection defects. For this purpose a dedicated computer program is often used to process a survey data set and aid in its interpretation. The package employed for processing and display of survey data for this assessment was the dedicated Geoplot software, of which both Geoplot 2.02 (© 1994 Geoscan Research) and Geoplot 3.0 (Beta version GPW3045R © 1999 Geoscan Research) were used.

The Surveys

Gásir, Eyjafjörður

Gásir, near Akureyri on the west coast of Eyjafjörður, was an important trading centre in medieval Iceland, dating to before 1400 according to documentary evidence (Friðriksson 1994, 95). Visitors to the site today are presented with a great number of earthworks - the remains of trading booths that stretch along a natural harbour. Another circular earthwork to the west, at a distance from the booths, may indicate the site of a church and churchyard, although the exact nature of these remains has never been confirmed through archaeological evidence (Ibid. 1994, 96-7).

In 1907, Daniel Bruun and Finnur Jónsson excavated four of the booths and in the building interpreted as the probable church (Bruun & Jónsson, 1908; Jónsson, 1908; and Bruun, 1928). More recently, in 1986 Margrét Hermanns-Auðardóttir excavated four trial trenches in different areas of the site, including an investigation of the church (Hermanns-Auðardóttir, 1987).

The remains at Gásir present an ideal situation for the assessment of geophysical techniques since the surface features allow the anomalies detected to be readily compared with known archaeology. Gásir poses many archaeological questions and it was hoped that these surveys might also provide new information about the site. Aerial photographs of the site clearly reveal the large surviving earthworks, however the question arises whether the limit of these remains accurately indicates the limit of buried archaeology. Geophysical surveys might reveal if activity continues in the areas outside the earthworks, in addition to providing archaeological information for the amorphous earthworks.

The bedrock in the region consists of basalt strata formed during the Tertiary period, 5-10 million years ago (Hallgrímsdóttir 1997, 2), which outcrops on the higher ground at the site. The land in which the remains are situated is given over to horse pasture and is covered with well-established thufur, up to 0.5m in height.

A grid, 40m x 100m, was established to included the churchyard, a number of booth remains, and an apparently 'archaeologically quiet' area in between. In this way the geophysical responses to a variety of features could be assessed.

Magnetometer results

The results of the magnetometer data (see Figure 2b for a processed plot) have revealed a number of interesting anomalies. The most striking of these are visible at the western end of the survey area, where a circular positive anomaly containing a rectilinear positive anomaly has been detected, coinciding with the remains of the church and churchyard. Other intense anomalies in this region correspond to the areas where the basalt bedrock outcrops, and are interpreted as being of geological origin.

The area of booths also reveals itself as an area of broader effects, with some intense positive anomalies following regular shapes. This contrasts to the zone between the booths and churchyard where it is still quite magnetically noisy, but the anomalies are less intense and small scale.

Figure 2c presents an interpretation of the main anomalies recorded. The bank of the churchyard boundary appears as a positive linear magnetic anomaly, in some places there are two of these linear anomalies parallel to each other. These might be the response to magnetic rocks within the bank, possibly as stone facings, which have not previously been recorded. Similar anomalies are seen in the area corresponding with the church structure. As concluded by Bruun and Hermannsdóttir, the church was con-

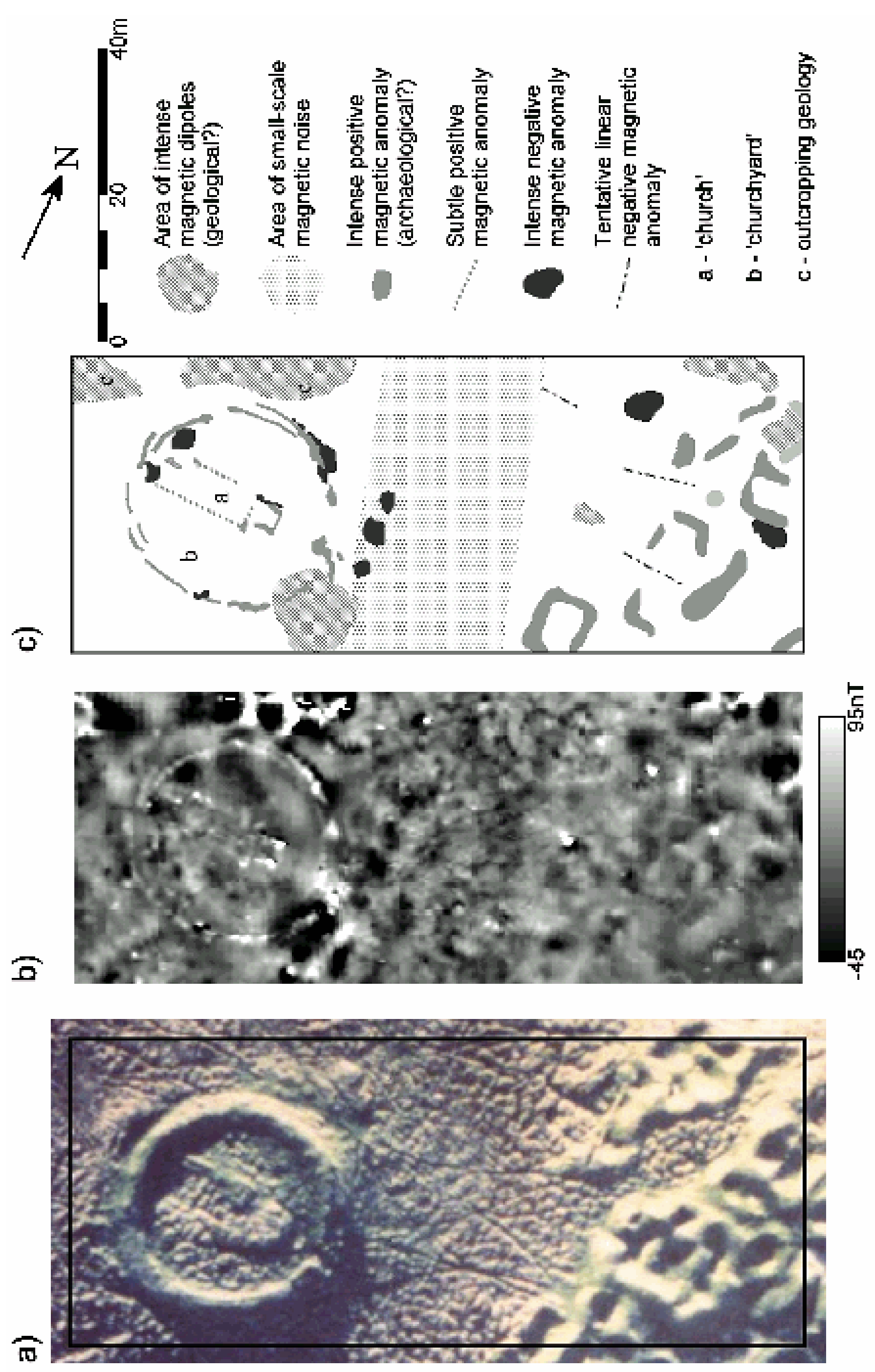

Figure 2. Gásir, Eyjafjördur. (a) Aerial photograph of the survey area (after photo by Björn Rúriksson); (b) processed fluxgate magnetometer data (after interpolation and low pass (Gaussian) filtering); (c) interpretation.

structed over a stone foundation (Bruun, 1928; Hermannsdóttir, 1987), and these results indicate that the magnetometer is responding to individual, near-surface igneous rocks.

The results from the area over booths are at first sight not entirely clear, although with comparison to the aerial photograph (Figure 2a), many of the positive anomalies coincide with the high banks.

The data also indicates quite a clear difference between the booth area and the region between this and church earthworks where no surface features exist. This might confirm that booths were not present in this area.

Earth resistance results

Only a small area over the churchyard was surveyed with the earth resistance meter, however the results show great potential for future use of this method at Gásir. The bank of the churchyard has been detected as a low resistance anomaly, although such a feature might be expected to produce a high resistance response due to the better drainage. Low resistance anomalies over turf banks and mounds were detected elsewhere in Iceland in this survey (e.g. Neðri Ás - midden, Nes - farm mound), and implies that the turf used in their construction is water retentive. This would result in the thick turf deposits found in such features to be better electrical conductors than the surrounding soil. Curiously, there are bands of very low resistance linear anomalies within the bank, roughly coinciding with the positive magnetic anomalies thought to be due to rocks. However there are no positive resistance anomalies indicating buried stones. These lower resistance anomalies might be due to bands of more-retentive turfs, although the underlying cause for these results can only be confirmed by excavation.

Both survey techniques have been influenced by the presence of frost hummocks, or thufur, a periglacial phenomenon that distorts the ground surface. They are visible on the plots as areas of background noise, although the effect is more intense in the earth resistance data. At present the degree to which these hummocks affect the results of an earth resistance survey is not known.

Conclusion

Geophysical surveys at Gásir have only been undertaken over a small sample of the site, yet demonstrate the potential of these method for providing archaeological information for this site and for similar features elsewhere.

Such prospection could be used to provide evidence for the use of some of these booths, and possibly locate areas of industrial activity. By surveying a much greater area, it should be possible to determine the extent of the booths, and hence define the full extent of this important site.

Skálholt, Árnessýsla

Situated in the lower part of the Biskupstungur valley between the rivers Hvítá and Brúará, Skálholt is one of Iceland's places of special historical interest. Within two centuries of the set-

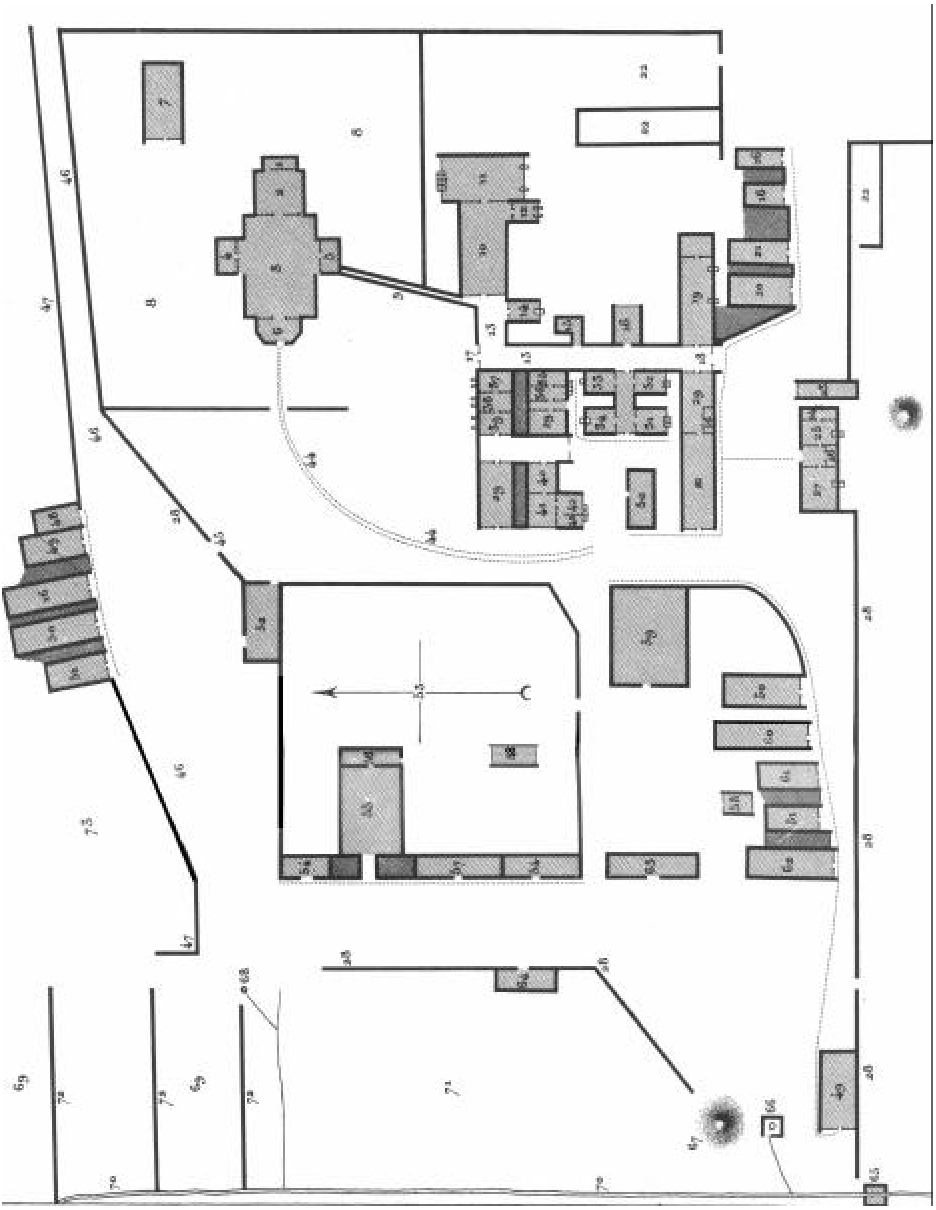

Figure 3: Plan of the Cathedral and farm at Skálholt, dated 1784 (After Ágústsson 1989, 296).

tlement of Iceland, the first bishopric was founded at Skálholt in 1056 for South Iceland, and soon a second at Hólar in 1109 for North Iceland.

When the modern cathedral building was constructed in 1954 there was great archaeological interest in the remains of the medieval Cathedral (Ólafsson 1988, 7-9), yet very little archaeological work has been undertaken into the associated farm at Skálholt. A 'map' of the Cathedral and farm complex dating to 1784 survives (see Figure 3), although comparison with the few features that are still visibly today reveals that it is not an accurate plan. However, this plan does provide an indication as to the farm size, number of buildings, and even details the use of each room at that time.

Geophysical surveys were undertaken immediately to the south of the modern cathedral building, over land owned and maintained by the Skálholt Church Trust.

The bedrock of this region is Pleistocene lava (Hallsdóttir 1987, 3), however it is not clear which tephra layers are present at the site.

The documentary evidence for the farm makes Skálholt another ideal site for an assessment of archaeological prospection techniques. Today only the two sunken streets and huge midden mounds are visible on the surface, yet particular buried remains can be expected allowing a useful evaluation with the additional benefit of providing new information about the history of Skálholt.

Magnetometer results

Figure 4 shows that in general, a high level of small-scale magnetic noise has been detected, interpreted as being due to individual buried rocks, possibly as a rubble spread from buildings which once stood in this area. Not visible in the data are the intense regular anomalies detected at many other sites (see Gásir (Fig. 2b) and Hofstaðir (Fig. 6a)) and attributed as the magnetic response to the strong geological thermoremanence. This may be due to a thick layer of wind blown deposits on top of the bedrock, thereby causing a greater distance between the parent material and the surface and dramatically reducing the anomaly intensities. Off-site augering had not hit bedrock at the auger's maximum depth of 1.15m. It is believed that this reduced geological input has allowed a number of positive magnetic anomalies to stand out from the background noise and look distinctly like the expected responses to buried archaeological features. These magnetic anomalies are the first seen during this assessment in Iceland, which differ from the responses to geology or rocks, and are therefore very interesting. Many dipole anomalies are still present, but there are positive and negative linear anomalies in addition to broader areas of positive magnetisation. Due to the fact that the general level of magnetic noise is still fairly high, it might be expected that strongly magnetic features, such as accumulations of burnt material, are the cause of these anomalies. This hypothesis is backed up by a soil sample collected at a depth of 5cm in one of the positive features. This consisted almost entirely of peat ash, and later laboratory measurements produced an enhanced magnetic

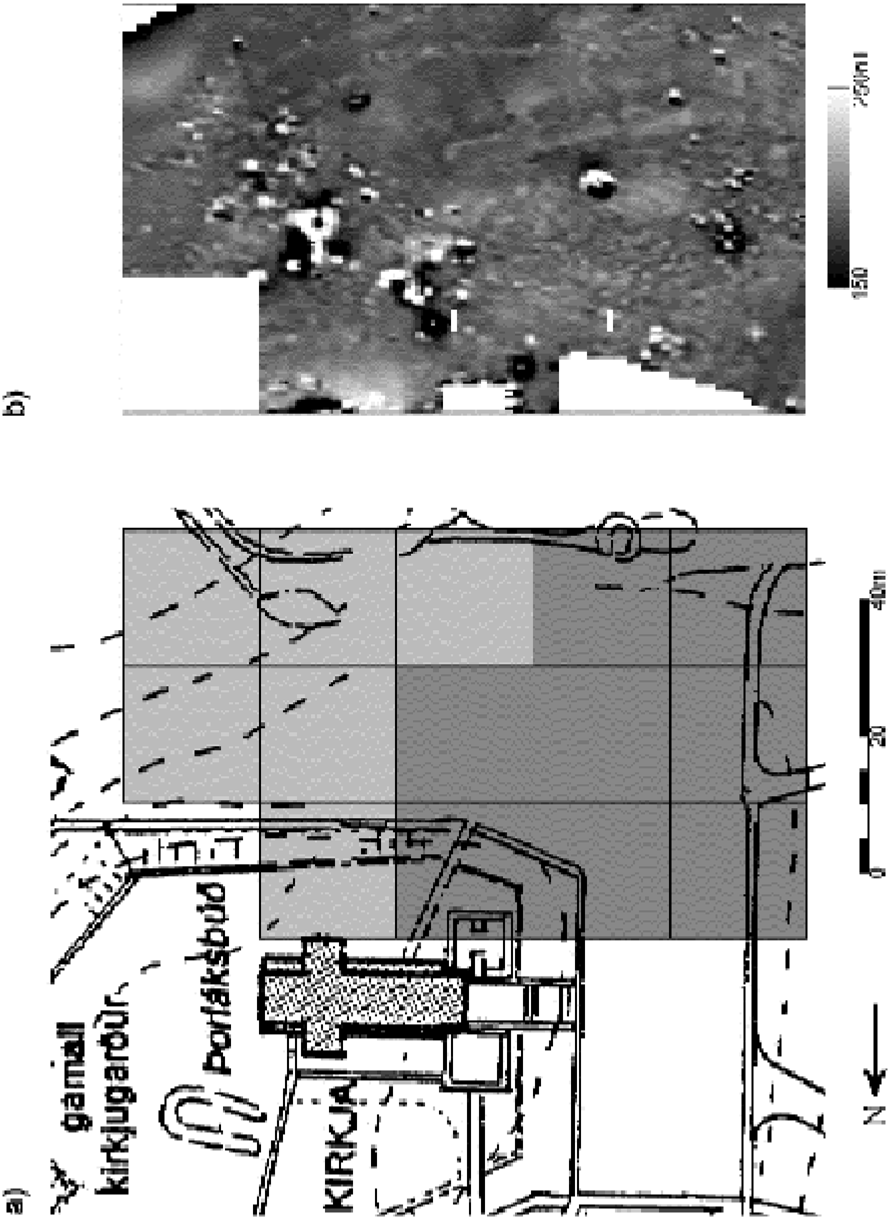

Figure 4: Skálholt, Árnessýsla. (a) survey area; (b) interpolated fluxgate gradiometer data.

susceptibility. (594 compared to a background value of 170 $x10^{-8}m^{3}kg^{-1}$).

Linear anomalies, composed of many discrete magnetic dipoles and running along and parallel to the southern edge of the survey area, coincide with the stone-lined sunken lane in this area, and are therefore interpreted as the responses to individual rocks used in its construction.

Earth resistance results

The earth resistance survey has been very successful, clearly locating a great number of linear high resistance anomalies interpreted as being due to the buried stone foundations for a great number of buildings.

The results, presented in Figure 5, clearly show a wealth of archaeological detail in this small 60m x 60m area. A large number of rectilinear anomalies are visible, the majority of which are interpreted as the responses to buried structural remains. Other less intense anomalies may be due to compacted floor features or paths

The mound on which the Cathedral sits is seen as an area of higher resistance, probably indicating its compacted nature, yet there are anomalies visible within it, which might be due to its construction. (The intense linear anomaly is due to the re-roofed tunnel, the top of which is only a few centimeters below the surface.)

The southern survey grids are also of a higher resistance, coinciding with the area of long grass, although it is not clear if this is related in any way.

A full and detailed archaeological interpretation will be included in the forthcoming geophysics report for Skálholt.

While these results can be compared directly with the site plan of 1784 (Fig. 3), it should be remembered that the geophysical techniques are not detecting a single phase, as represented in the map. The survey results will detect all the physical contrasts in the soil within the limitations of the technique, which may be due to many archaeological phases. However, comparison with the plan does reveal a remarkable correlation between the buildings and the high resistance anomalies, although on a slightly different orientation to that implied by the plan.

Geophysical surveys at Skálholt have demonstrated that these techniques are very successful in detecting buried features at the site, for which there is no surface evidence. It appears that intense geological and geomorphological effects seen at many of the other sites in Iceland are less dominating here, allowing the more subtle archaeological anomalies to be identified.

Interpreted on their own, the earth resistance data reveals a number of anomalies typical of stone wall foundations, and when combined with the documentary evidence for the approximate location of farm buildings, this interpretation can be confirmed.

The results of the fluxgate gradiometer are less clear, however a number of magnetic anomalies have been detected which are attributed to archaeological sources. Not only does an area of magnetic noise roughly coincide with the

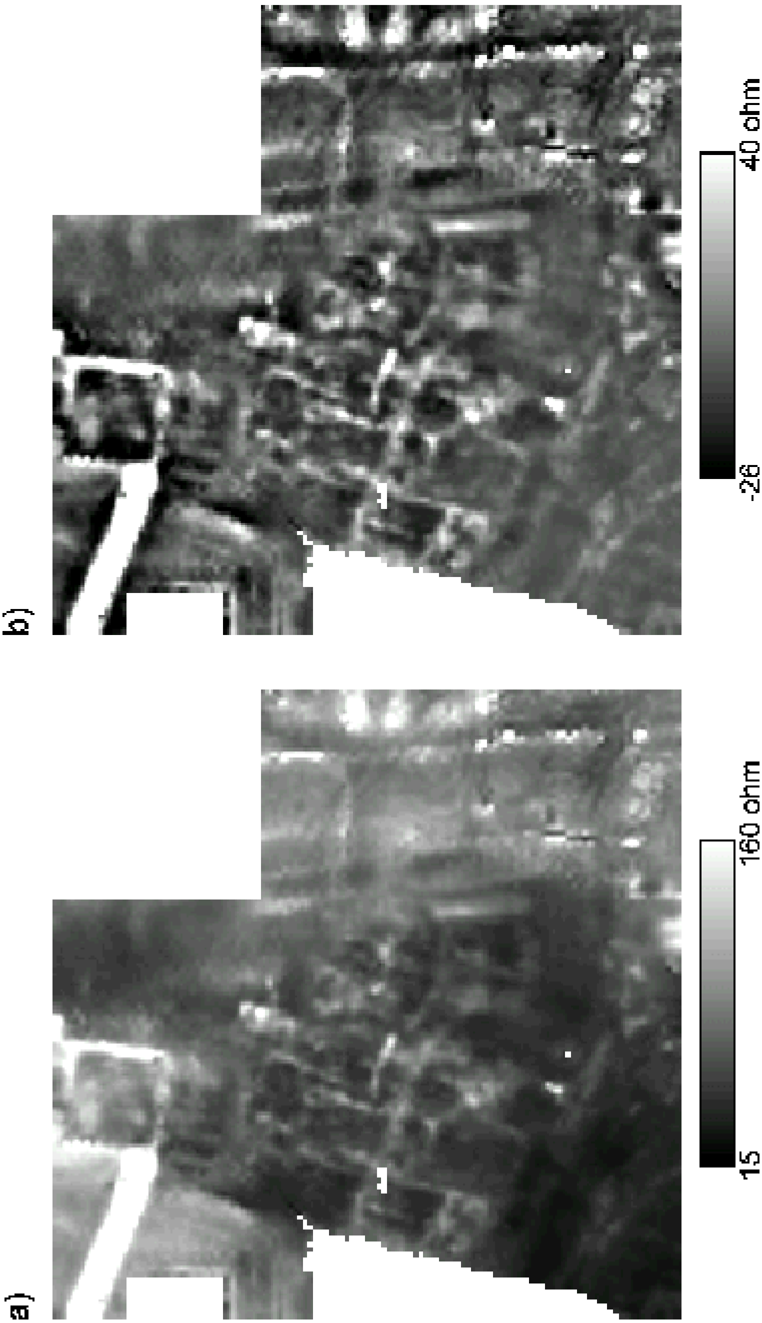

Figure 5: Skálholt, Árnessýsla - earth resistance survey (a) interpolated data; (b) high-pass (Gaussian) filtered and interpolated data.

building remains revealed in the earth resistance survey, but linear positive anomalies also reveal buried features in their own right. Some of these anomalies can be compared with anomalies in the earth resistance survey and demonstrate the complementary nature of these two survey methods.

Hofstaðir, Mývatnssveit

The farm of Hofstaðir in North East Iceland has been a focus of archaeological interest throughout this century, in particular on the Viking Age great hall (skáli) long considered a temple or 'temple-farm' site (Friðriksson and Vésteinsson, 1997a).

Since 1996, a Field School has been held at Hofstaðir, run jointly by the FSÍ and NABO (The North Atlantic Biocultural Organisation), and in 1999 provided the opportunity for geophysical surveys to be fully integrated with their own investigations.

Hofstaðir is located within the valley of the Laxá river in Mývatnsveit, NE Iceland, centred on Grid Ref. 461488/568107 (Lucas, 1998). The region around Lake Mývatn lies on the Ódáðahraun lava fields (Hjálmarsson and Astridge, 1998). The proximity of the farm to Mývatn and the Mid-Atlantic Ridge means that this basalt will be quite recent, less than 10,000 years old (Ibid. 1998).

Although the area of the present homefield is generally level, both excavation and geophysical evidence at Hofstaðir show that the depth of soil down to the geology is quite varied. In one place, augering revealed that solid rock was only 0.2m below the surface, while the 1999 excavation of the pit-house only c.60m away, extended to a depth of almost 2m and had not hit bedrock.

Archaeological deposits at Hofstaðir are sealed between layers of aeolian deposits, including sands and tephras (Sigurgeirsson, 1998; Simpson et al., 1998). The main tephra layers associated with cultural deposits at the site include the Landnám tephra, formed in 869-873 AD, H-1104/1158, V-1477 and V-1717 (Sigurgeirsson 1998), and a summary of the tephrochronological studies at the site may be found in this reference.

“Today, the farmland at Hofstaðir is used for growing hay, usually cut and dried in the first weeks of August. Turf cutting has taken place on the site in recent years” (Jónsson and Jónsson, pers. comm.).

A variety of surface features exist at Hofstaðir providing some evidence for the subsurface archaeology. These include the walls of the Viking-Age long-house, the farm mound, turf boundary banks and other slight earthworks indicating the sites of former structures associated with the farm. Geophysical investigations were undertaken over many of these features, although only the results from the survey over the farm mound and the area immediately to the east are presented here.

Still in use, the present day homefield is relatively flat and free of thufur, although in places there are bands of parallel ruts, similar to those caused by ploughing, but may be artefacts of turf-

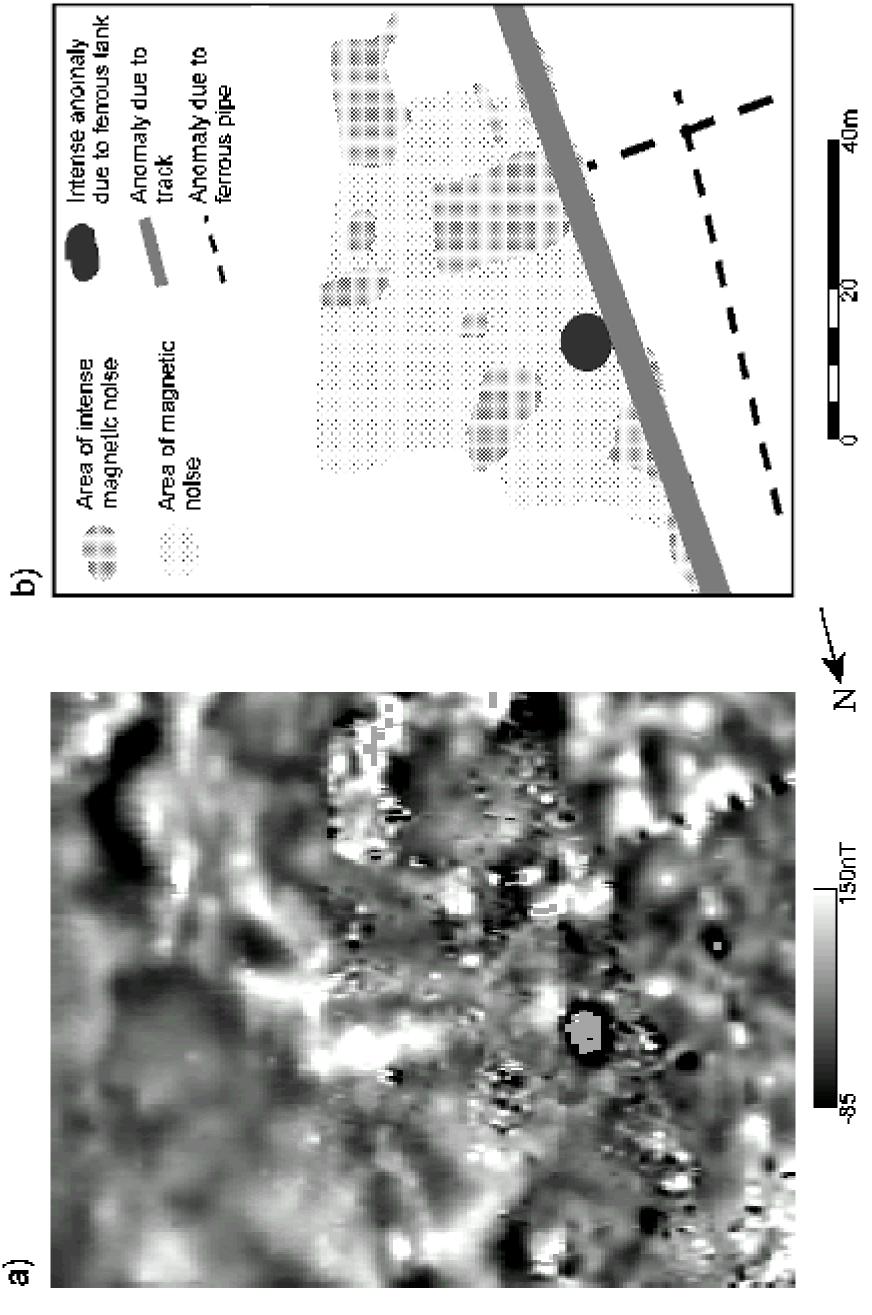

Figure 6: Hofstaðir, Mývatnssveit - fluxgate gradiometer survey. (a) interpolated data; (b) interpretation.

cutting (Friðriksson, pers. comm.). Around the eastern perimeter of the farm mound the ground is quite disturbed by many well-formed thufur, and at the time of survey this area stood out due to the bright yellow flowers of numerous buttercups. The rest of the farm mound is not mown due to the uneven ground, and as a result is colonised by well-established grasses. The western edge of the farm mound roughly coincides with the modern track that passes over the top, although it is not known whether buried structures exist on this western side.

One of the archaeological aims of the geophysical surveys was to attempt to locate the remains of a church known to have existed on the eastern side of the farm mound. There are no surface indications for the location of this or a churchyard.

Magnetometer results

A processed plot of the fluxgate gradiometer survey is presented in Figure 6. The data was collected in the 'zig-zag' fashion and as a result the plots suffer from quite severe bunching effects. This is especially noticed around the intense anomalies caused by the background geology. The data would be free of this defect had a 'parallel' approach been adopted, but it is the small-scale jumbled noise detected which is of interest, and the striping does not detract from this archaeological information. Walking 'zig-zag' allowed a greater survey area to be covered at Hofstaðir, however it is recommended that future magnetometer surveys be conducted in a different manner.

As the previous surveys have shown, the intense geological anomalies limit the type of archaeological features that can be detected, and it is often the smaller scale jumble of magnetic dipoles due to individual rocks that provide useful information. This is certainly true of these results. During data processing, a low-pass (Gaussian) filter was employed in an attempt to remove the bunching discussed above, however it was found that this also reduced the small-scale detail, resulting in a loss of information.

The interpretation (fig. 6b) simply indicates the areas of small-scale magnetic noise, and the identifiable anomalies of the modern track and two buried pipes. The general area of magnetic noise corresponds well to the area of the farm mound, and it is interpreted that the more dense areas are due to clusters of rocks, and might therefore indicate the sites of buried structural remains. Some rectilinear features can be made out within the noise, but it is difficult to make any firm conclusions.

A large area to the east of the farm mound is free of this noise, and while this might be indicative of a lack of loose rock debris in this area, it cannot be concluded that it is free of any archaeological activity. Subtle anomalies might be present but are overwhelmed by the igneous geology.

Earth resistance results

The results of the earth resistance survey over the farm mound are presented in Figure 7. The survey was conducted at the high resolution of 0.5m x 0.5m to record a maximum level of information.

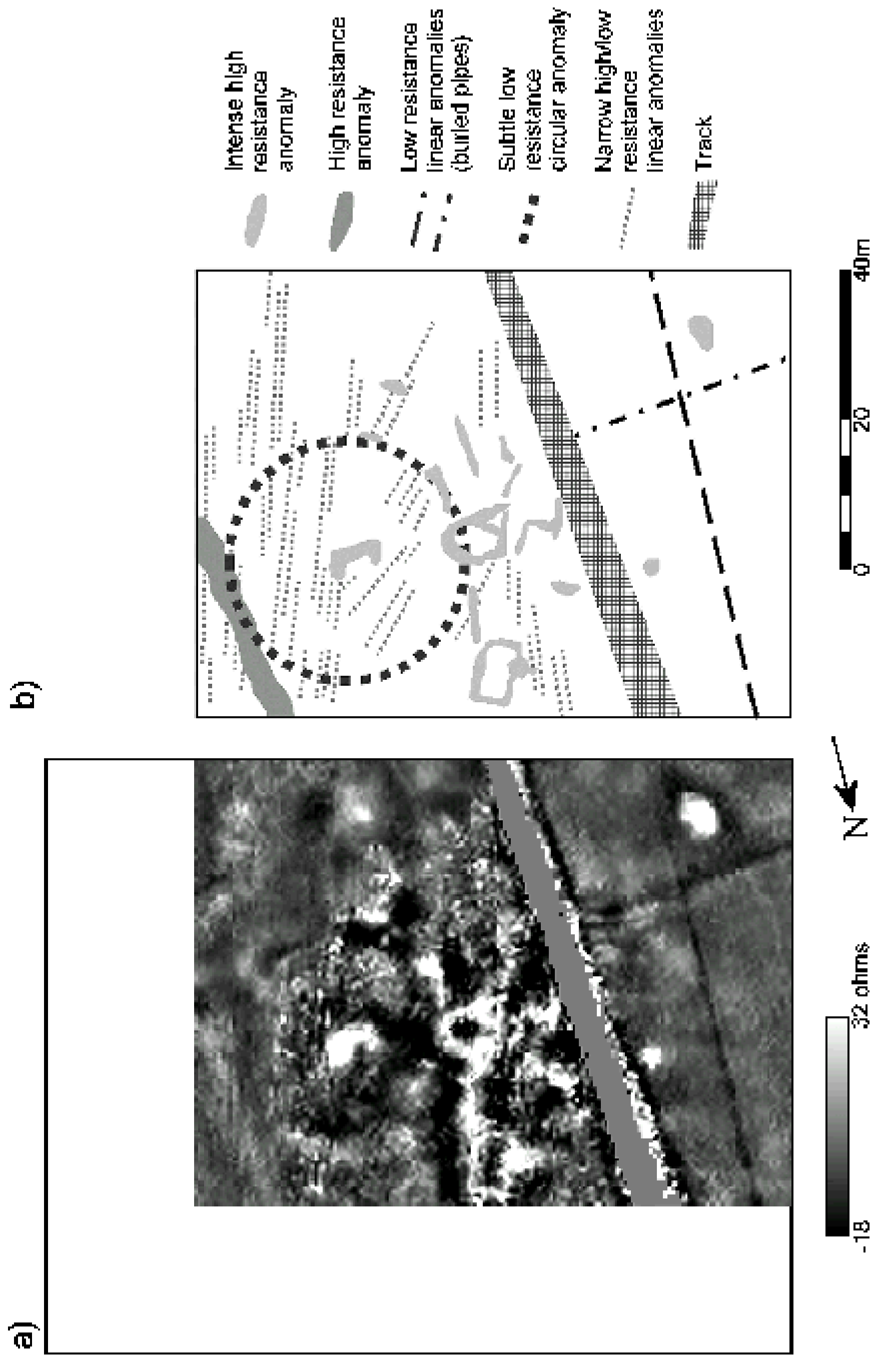

Figure 7: Hofstadir, Myvatnssveit - earth resistance survey (0.5m probe separation) on the farm mound. (a) high-pass (Gaussian) filtered and interpolated data; (b) interpretation.

Figure 7 reveals that many of these anomalies have a regular form, with some linear and rectilinear features visible. These are interpreted as being the responses to buried stone foundations for structures originally in these locations.

As stated above, one of the aims of the surveys in this area was to locate any features associated with a church, and this has been achieved. A high resistance anomaly has been detected to the east of the main cluster, and in the area where the church was expected. Almost rectilinear, this anomaly could be structural in origin, but with anomalies only detected on three of the four sides. Although oriented east-west and about 6m x 4m, on its own this rather amorphous anomaly cannot be confidently identified as a church. However this anomaly is seen to be situated at the centre of a circular anomaly of low resistance, about 30m in diameter. This ring of low resistance might be due to an infilled boundary ditch or bank, and is consistent with a medieval Icelandic church. This was later confirmed by excavation when a number of graves were discovered within the area (Gestsdóttir 1999, 44). It does not appear that either method has detected these graves.

A very subtle positive linear anomaly can be made out in the northeastern corner of the survey area, and might be due to the buried remains of a bank, possibly a field boundary.

Two linear low resistance anomalies have been detected to the west of the track, which could be interpreted as infilled ditches. However, these coincide with the positions of the ferrous pipe anomalies seen in the gradiometer survey, and can be positively identified as the response to these modern pipe trenches.

Within the survey area to the east of the track, a number of linear high and low resistance stripes are visible. These are real anomalies, not survey defects, and can be seen to be on a slightly different orientation to the survey grid. During the data collection, a number of linear depressions were noticed on the farm mound, probably be caused by tread marks of a bulldozer employed to level buildings on the farm in the 1970s. These would certainly produce anomalies like those detected.

When the results of both geophysical surveys over the farm mound are compared, it can be seen that the gradiometer survey has successfully detected the church anomaly as one of the areas of intense dipole anomalies. Other anomalous areas can then also be confidently interpreted as being due to buried structural remains, as they too coincide with areas of high resistance.

Geophysical surveys within the farm of Hofstaðir have proved successful not only for the detection of anomalies, but also for the interpretation and assessment of buried remains at the site, therefore improving the archaeological understanding of the site.

Anomalies detected during the earth resistance surveys and subsequently confirmed by excavation indicate that this technique has the potential to locate and identify cut features into sediments, in addition to the more clearly defined stone features. Both these sets of evidence have then been used to confirm the results of the gradiometer survey for the detection of structural remains, and demonstrate the potential for this technique.

At this stage in the development of an understanding of such methods in Iceland, the results from Hofstaðir demonstrate the necessity for both positive and negative geophysical results to be backed up by trial excavation.

Discussion of results

Earth resistance

Earth resistance has been shown to positively identify buried features where no surface indications remain, and to be applicable in many situations although some limitations caused by periglacial phenomenon and wet ground conditions need further investigation. The main advantage of this technique over the fluxgate gradiometer is that it is not severely overwhelmed by geological effects.

At Skálholt and Hofstaðir this method has been used to detect and correctly identify known archaeological remains, where the precise positions of buried features was unknown. In addition, the results from Gásir and other sites not reported here demonstrate the potential for this technique as an aid in the interpretation of known features, where the visible surface remains may be amorphous and unclear.

A problem of surveying on wet ground was observed in the earlier surveys, most likely due to 'geometric effects', although it is not entirely understood yet. Once this effect had been recognised, earth resistance surveys were conducted when the conditions were dry, and successfully avoided these survey defects.

Periglacial effects caused other limitations, where a number of unusual anomalies were recorded. Most influential were surface deformations such as thufur. These produce intense localised anomalies and create a noisy background against which anomalies due to buried features can become less clear.

The fine sampling interval adopted in Iceland, 0.5m x 0.5m, has allowed a high level of detail to be recorded, however it can be seen that a coarser interval of 1.0m x 1.0m can still be used to successfully locate sites. This choice will depend upon the aims of the survey, as well at time constraints.

Magnetometry

Although in many cases the magnetometer data is overwhelmed by the intense background geological signal, it has been demonstrated that it is often possible to distinguish discrete rocks in an archaeological deposit from bedrock, even where these natural anomalies dominate the data.

At Gásir it is possible to identify anomalies attributed to buried stone walls, despite the near-surface igneous geology producing strong thermoremanent effects. There is also a distinguishable variation produced by the booth earthworks that might allow the extent of the archaeological remains at the site to be defined. However, the much deeper aeolian deposits overlying the bedrock at

Skálholt reduce this thermoremanent input, allowing more subtle archaeological anomalies to be detected.

An important discovery from this project concerns the data collection method for magnetometer surveys. Many of the surveys revealed an enhanced effect of 'bunching' produced when data is collected in the 'zig-zag' fashion, possibly exaggerated by the strong geological anomalies. The only solution is to undertake carry out gradiometer surveys in the 'parallel' fashion. Unfortunately this will increase the time taken to survey each grid, but will produce clearer results.

It has been demonstrated that the most information of archaeological value was produced by the small-scale noise caused by individual rocks associated with structural remains. Being small anomalies, these are best identified at a higher resolution of surveying than might ordinarily be undertaken. Consequently it is advised that a high resolution of data collection, i.e. 0.5m x 0.25m, is employed for most effective and informative results.

Magnetic susceptibility

Throughout this assessment it was possible to collect only a limited number of soil samples for measurement of magnetic susceptibility at Bradford.

The preliminary results imply that, despite very high natural background values (generally in the range 100 to 250 SI $x10^{-8}m^3kg^{-1}$), archaeological sediments associated with burning produce strong enhancements, with values above 400 SI $x10^{-8}m^3kg^{-1}$, and even as high as 1800 SI $x10^{-8}m^3kg^{-1}$(midden material from Neðri Ás). However, it is not known how effective this method would be for reconnaissance surveying, as in many areas aeolian deposits overlay the archaeology and the natural mixing processes in the soil might not be extreme enough to bring enhanced material to the surface. Instead, this technique might prove valuable by aiding the interpretation of deposits during excavation by distinguishing between samples with natural and anthropogenic enhancement.

Detection of archaeological remains

As a preliminary evaluation, it was necessary to target archaeological remains known from other sources to allow a proper and confident assessment of these techniques to be made. Surveys at a number of sites, and over different remains make it possible to talk generically about certain feature-types.

Many sites presented visible earthworks constructed of turf. As discussed earlier in this paper, a lack of good building stone has meant that many structures and field boundaries are constructed of turf. Where geophysical surveys included such remains, they were shown to appear as low resistance anomalies. This might be surprising since such extant remains could be expected to be better drained and therefore possess a higher resistance. These results therefore seem to indicate that the turf is water retentive, and it might be possible to use this characteristic for the future prospection of now-buried turf remains.

Buried stone walls have been detected in earth resistance and magnetometer surveys, despite the intense geological effects. Discrete magnetic dipole anomalies clearly distinguish individual rocks from the solid bedrock, and alignments of these anomalies can reveal buried walls. Comparison of the magnetometer results with resistance data has confirmed this interpretation.

The geological input is dramatically reduced on sites where deeper aeolian deposits lie above the bedrock, as at Skálholt. In such situations, the geology is at a greater distance from the instrument, allowing the subtler archaeological anomalies to be detected. It should therefore be possible to assess the potential of a magnetometer survey at a site by first measuring the soil depth with an auger, although this has yet to be tested.

At both Gásir and Þingvellir, booth remains have produced distinct magnetic and resistance anomalies, although the small survey area at both sites prevents their full understanding at present.

Conclusion

This preliminary study has successfully demonstrated the effectiveness of routine archaeological prospection techniques in Iceland, particularly when undertaken as part of an integrated study as discussed here. The benefits of combining earth resistance and magnetometer surveys has also been illustrated, and that where possible earthwork surveys, aerial photography and trial trenching should also be used to better understand the geophysical results and therefore the archaeology.

Future Work

This assessment of geophysical techniques in Iceland is the first step in integrating geophysical surveys with other forms of archaeological evaluations. While a number of important questions have been answered during the course of this study, many more have been asked, and further research is necessary to allow the maximum information to be extracted from geophysical surveys.

A better understanding of the limitations caused by geology and geomorphology is required, so that effects produced by these features may be discriminated from archaeological anomalies.

When geophysical surveys are integrated into archaeological evaluations, the time scale of most projects poses severe constraints on field geophysicists (Gaffney et al. 1991, 1). It is therefore necessary that a full understanding of the viability and limitations of the use of geophysical techniques in such evaluations be obtained before contract fieldwork can be undertaken efficiently.

Acknowledgements

This project was carried out by T.J. Horsley for an Archaeological Prospection MSc Dissertation under the supervision of S.J. Dockrill, at the Department of Archaeological Sciences, University of Bradford. The MSc course was funded with a NERC studentship, and the author is grateful to NERC for its help with costs towards the fieldwork. Fieldwork was undertaken in collaboration with the FSÍ and thanks are due to their staff, in particular to Orri

Vésteinsson, Adolf Friðriksson, Hildur Gestsdóttir, Garðar Guðmundsson and Mjöll Snæsdóttir. The authors would also like to thank Dr. Roger Walker for loaning the *Geoplot* packages for data processing undertaken throughout this study.

The survey locations discussed within were made available through the generosity of the landowners: Skálholtsstaður (Skálholt); Friðrik Gylfi Traustason and Guðrún Björk Pétursdóttir (Gásir); and Ásmundur and Guðmundur Jónsson (Hofstaðir).

Helpful discussions and contributions were also provided by Oscar Aldred, Andy Dugmore, Throstur Freyr Gylfason, Guðrún Kristinsdóttir, Gavin Lucas, Tom McGovern and NABO, Karen Milek, Dr. Armin Schmidt, Magnús Sigurgeirsson, Ian Simpson and all those at the 1999 Field School in Archaeology at Hofstaðir.

References

Ágústsson, Hörður (1989). “Húsagerð á síðmiðöldum”. In Líndal, Sigurður (Ed.) *Saga Íslands*, Vol. IV, 261-300.

Bird, J.B. (1974). “Geomorphic processes in the Arctic”. In Ives, J.D. and Barry, R.G. *Arctic and Alpine Environments*.707-710.

Boucher, A.R. (1996). “Archaeological feedback in geophysics”. In *Archaeological Prospection,* 3: 129-140.

Bruun, D. & Jónsson, F. (1908). “Det gamle Handelssted Gásar”. *Videnskabernes Selskabs Forhandlinger* No.3. København.

Bruun, D. (1928). *Fortisminder og nutidshjem paa Island.* København.

Burger, H.R. (1992). *Exploration Geophysics of the Shallow Subsurface.* Prentice Hall, New Jersey.

Clark, A. J. (1975) “Archaeological prospecting: a progress report”. *Journal of Archaeological Science,* 2: 297-314.

Clark, A. J. (1990). *Seeing Beneath the Soil. Batsford,* London.

Courty, M .A., Goldberg, P. and Macphail, R. (1989). *Soils and Micromorphology in Archaeology.* 1st Edition. Cambridge University Press, Cambridge.

David, A. (1995). *Geophysical survey in archaeological field evaluation. English Heritage,* London, Research & Professional Services Guideline No 1.

Dockrill, S.J. and Gater, J.A. (1992). “Tofts Ness: Exploration and interpretation in a Prehistoric landscape”. In Spoerry, P.S., (ed.). *Geoprospection in the Archaeological Landscape.* Oxbow, Oxford.

Friðriksson, Adolf (1994). *Sagas and Popular Antiquarianism in Icelandic Archaeology.* Avebury, Aldershot.

Friðriksson, Adolf & Vésteinsson, Orri (1997a). “Hofstaðir Revisited”. *Norwegian Archaeological Review,* Vol. 30:2, 103-112.

Friðriksson, Adolf & Vésteinsson, Orri (1998a). “Fornleifaskráning - Brot úr íslenskir vísindasögu”. *Archaeologica Islandica* 1, 14-44.

Friðriksson, Adolf & Vésteinsson, Orri (1998a). “Isleif - A database of archaeological sites in Iceland”. *Archaeologica Islandica* 1, 45-46.

Gaffney, C.F., Gater, J.A. and Ovendon, S.M. (1991). *The Use of Geophysical Techniques in Archaeological Evaluations.* Institute of Field Archaeologists, Technical Paper No. 9, Birmingham.

Gerrard, (1985). “Soil erosion and landscape stability in southern Iceland: a tephrochronological approach”. In Richards, K.S., Arnett, R.R. and Ellis, S. (eds.). *Geomorphology and Soils.* 79-95.

Gestsdóttir, Hildur (1999). “The Medieval Churchyard”. In Lucas, G. (Ed.) *Hofstaðir 1999 Framvinduskýrslur/Interim Report.* 44-54.

Hallsdóttir, Margrét (1987). *Pollen analytical studies of human influence on vegetation in relation to the Landnam tephra layer in southwest Iceland.* Lundqua Thesis 18, Lund University, Department of Quaternary Geology.

Hermannsdóttir, Margrét (1987). “Fornleifa-rannsóknir að Gásum og víðar í Eyjafirði árið 1986”. *Súlur* 27:3 39.

Hjálmarsson, J.R. & Astridge, C. (1998). “Lake Mývatn”. Special Iceland Review Supplement. *Iceland Review.*

Horsley, T.J. (1998). “Nine Ladies Stone Circle, Stanton Moor, Derbyshire: Report on Geophysical Survey 1998”. *Ancient Monuments Laboratory Report Series,* 68/98.

Ives, J.D. and Barry, R.G. (1974). “Arctic and Alpine Environments”. *Methuen*, London.

Jónsson, Finnur (1908). “Hinn forni kaupstaðir ‘at Gásum’". *Árbok* 1908.

Kearey, P., and Brooks, M. (1984). *An Introduction to Geophysical Exploration.* Blackwell Scientific Publications, Oxford.

Lucas, G. (1998). “Prehistory at Hofstaðir: An Introduction to the 1996-1997 Excavation”. *Archaeologia Islandica,* 1: 119-122.

Lucas, G. (Ed.) 1999. *Hofstaðir 1999 Framvinduskýrslur/Interim Report.* Forn-leifastofnun Íslands FS102-91017, Reykjavík.

Ólafsson, Guðmundur Óli (1988). *Skálholt.* Kirkjuráð íslensku þjóðkirkjunnar.

Richards, K.S., Arnett, R.R. and Ellis, S.(Eds.) (1985). *Geomorphology and Soils.* George Allen & Unwin, London.

Scollar, I., Tabbagh, A., Hesse, A., and Herzog, I. (1990). *Archaeological Prospecting and Remote Sensing.* Cambridge University Press, Cambridge.

Sigurgeirsson, Magnús Á. (1998). “Gjóskulagarannsóknir á Hofstöðum 1992-1997”. *Archaeologia Islandica,* 1, 110-118.

Simpson, I.A., Milek, K.B. & Guðmundsson, G. (1998). “Archaeological Sediments and Site Formation at Hofstaðir, Mývatn, NE-Iceland”. *Archaeologia Islandica,* 1, 129-142.

Spoerry, P.S., (ed.) (1992). *Geoprospection in the Archaeological Landscape.* Oxbow, Oxford.

Telford, W. M., Geldart, L. P., Sheriff, R. E. and Keys, D. A. (1976). *Applied Geophysics.* 1st Edition. Cambridge University Press, Cambridge.