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Using magnetic survey methods to delimit and characterize prehistoric iron production sites in Norway

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"Scanning" is an alternative way of initial assessment of archaeological sites, using a magnetometer in scan mode along a set distance interval of maybe 10 m or similar in advance of detailed systematic surveys, sounding an audio signal when taking readings above a certain threshold in the amplitude. The main purpose of scanning is therefore to narrow down the potential area to be targeted with detailed surveys, and it has been used especially when investigating vast areas (Clark 1996; Gaffney and Gater 2003). The biggest drawback, and the main reason against performing scanning as a way of assessing the potential for a geophysical surveying of sites, is that it does not record the spatial location of readings, resulting in a situation in which the interpretation of the results is biased by the investigator's experience or impression of the response. It is difficult to set an appropriate threshold without having a proper idea of the average response over a site, which is best gained naturally by full-area coverage. An analysis of unrecorded scanning performed on Irish road-building schemes between 2001–2010 illustrates this handicap, as it turned out that 71.2% of archaeological sites were not identified in this way (Bonsall 2014). While the inappropriateness of *unrecorded* scanning may be a relevant conclusion for a wide range of archaeological sites, it might be less relevant for the detection of iron production remains, such as slag and furnaces by *recorded* sampling. Initial tests with GPS-recorded scanning used to locate archaeological features, such as iron production sites and roasting sites for bog iron, have given encouraging results. At Gråfjell in the valley of Østerdalen in Hedmark county in Norway, otherwise elusive roasting sites for bog iron were located by GPS recorded scanning, as well as pits for coal production. This gave new insight into the spatial organization and transport of roasted iron ore compared to the location of iron production sites in this region (Rundberget 2007: 279–308; Larsen 2009: 221–223). Magnetic susceptibility sampling (MS) has also been used to determine the spread of slag over a site in England (Vernon 2004: 19–20). While MS might be preferred for locating areas of activity on cultivated land (Stamnes 2010), it has until now been untested on industrial sites located in mountainous and uncultivated areas in Scandinavia. It was therefore believed that performing recorded volume magnetic susceptibility sampling over iron production sites might yield encouraging results.

In the Trøndelag-region in central Norway, few of the so-called "rosette" iron production sites from the Early Iron Age (500 BC to AD 550) have been completely excavated and none have yet been surveyed in their entirety with geophysical prospection methods. Slag heaps are usually the only visible remnants at iron production sites and the location of roasting sites in relation to the iron production area is considered elusive (Farbregd *et al.* 1985; Stenvik 1987; 1996; 2003). "Rosette" sites take their name from a very specific layout with a reusable oven in the centre, surrounded by

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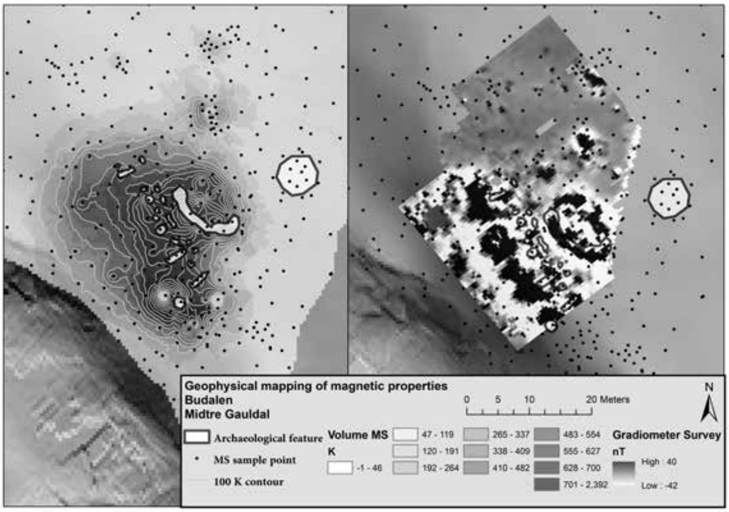

Fig. 1. Budalen: topsoil magnetic susceptibility mapping to the left, gradiometer survey to the right

Fig. 2. Panorama of the Tromsdalen site, view to the southeast

a series of pits of unknown purpose, giving them a characteristic layout reflected in their name. It was therefore decided to survey several iron production sites by recording the topsoil MS and performing detailed fluxgate gradiometer surveys. Special attention was paid to the possibilities of locating, delimiting and characterizing such sites, which have the potential to contribute importantly to knowledge of the spatial organization of prehistoric iron production in the region. The sites were surveyed with a Bartington MS2-D field loop and a handheld Bartington Grad 601-dual fluxgate gradiometer sensor array. The fluxgate gradiometer surveys were conducted with a traverse interval of 0.5 m and an inline sampling interval of 0.125 m. At Budalen, 640 topsoil MS readings were recorded with a RTK GPS over an area of 7567 m^2, an average of 3.4 m between readings. At Tromsdalen, 431 topsoil MS readings were taken over an area of 3865 m^2, an average of 3 m between readings. The susceptibility datasets were interpolated to raster surfaces by ordinary kriging, ensuring both

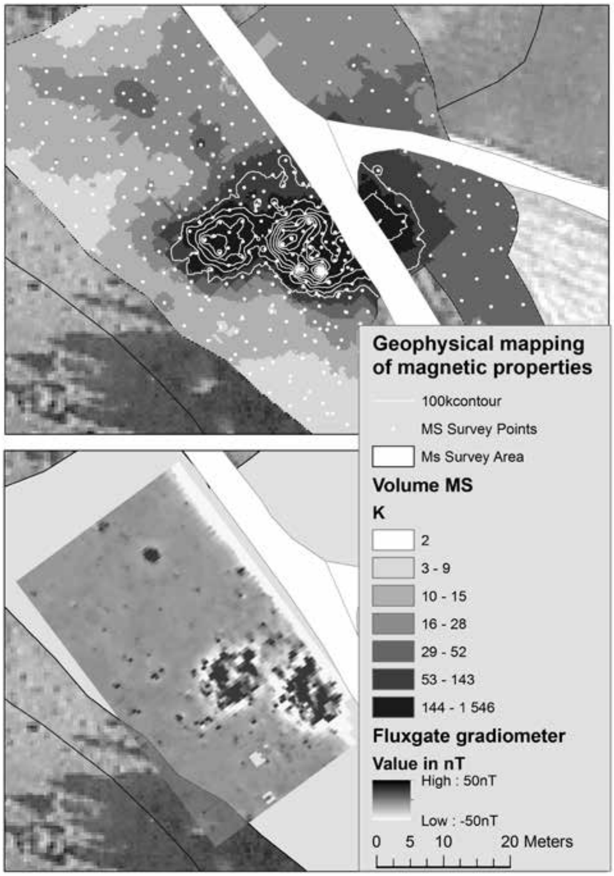

Fig. 3.Tromsdalen: topsoil magnetic susceptibility mapping in the upper part of the image, gradiometer survey in the lower part

a good statistical spatial fit, as well as the additional benefit of providing maps over the prediction standard error; a measure of the quality of the interpolations performed (Isaaks and Srivastava 1989). The properties of ordinary kriging as an interpolation method make a grid-based sampling strategy, when the average distance between each GPS recorded is so low, unnecessary for volume magnetic susceptibility sampling used as a way of locating and delimiting archaeological sites.

Two sites were chosen, the site at Budalen in Midtre Gauldal Municipality and the site of Tromsdalen in the Verdal Municipality, both with known iron production sites.

The site of Budalen (Fig. 1) is located close to a summer farm, which acts as a museum. While the site nowadays is considered to be far away from central settlements, the area is scattered with iron and charcoal production sites, pits for hunting elk or reindeer and tar-production pits, all dating to different periods. The area was surveyed as part of an archaeological field school run by the Norwegian

University of Science and Technology. The topsoil MS (Fig. 1, top) clearly delimited the site and more detailed mapping close to hotspots with increased values allowed smaller areas with high readings to be delimited to the north of the main production area. It is possible that these were roasting sites for bog iron. The semi-oval anomaly in the central part of the image is interpreted as a storage area for roasted iron, which was used subsequently as raw material for iron production. The amorphous gradiometer anomalies seen towards the southwestern part of the image are the slag heaps on sloping ground. The slag heaps typically show readings well above 50 nT, usually in the range of 100–250 nT. The iron production ovens, the potential bog iron roasting site and the assumed storage area for roasted iron show readings of 200 nT and more. The volume magnetic susceptibility of the storage area was in the approximate range of 500–2500 k, while the slag heaps typically were from 30 to 600 k. The potential roasting sites had readings of 20–2000 k, which is in very strong contrast to the surrounding readings observed in natural, non anthropogenic soils ranging only around 3–10 k.

The iron production site at Tromsdalen (Figs 2 and 3) was discovered as part of an archaeological registration scheme in advance of the extension of a larger chalk quarry in 2011, based on information provided by the landowner and test excavations. Apart from the iron production site, there is evidence of more permanent settlement in the area indicated through the presence of burial mounds. The site appears to have been damaged by the construction of a road several decades ago, which, according to the landowner, is how he became aware of the site in the first place. Again, the topsoil MS clearly delimited the site. The readings were higher over the slag heaps, often in the range of 200 k and higher, where the natural soils had readings in the range of 10–40 k. Similarly, the slag heaps at Tromsdalen often had a reading of 50 nT or more. In this survey, the sensor was positioned slightly higher owing to high tree stumps that could damage the equipment.

These two examples show how volume susceptibility mapping and detailed fluxgate gradiometer surveys can help in locating, characterising and delimiting iron production sites and archaeological features associated with such sites. Due to the strong magnetic contrast of iron production sites compared to the natural background, it is assumed that *recorded* fluxgate gradiometer scanning could help in locating such sites, depending on the magnetic properties of local geology. The results from recorded scanning preformed at Gråfjell support this notion. While full-area coverage is to be preferred, the vastness of performed landscape, in addition to topographical difficulties, dense tree coverage and other obstacles, might make GPS recorded scanning procedures a possible way of acquiring new knowledge of the whereabouts of previously unrecorded iron production sites. The cited examples of scanning at Budalen and Tromsdalen show how magnetic susceptibility sampling strategies easily delineated areas of intense iron production and how detailed gradiometer surveys have helped in characterising anomalies of archaeological origin on the sites.

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