COMPARING TECHNIQUES APPLIED IN MAGNETIC INVESTIGATIONS OF IRON PRODUCTION SITES IN SW JUTLAND(DENMARK) AND THE LAUSITZ REGION(GERMANY)

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Abstract

Iron production based on bog iron ore and charcoal was locally performed in both SW Jutland in Denmark and the Lausitz region in Germany between 2nd century BC and 1300 AD. Although the furnaces were destroyed after the smelting process, many slag bodies remained just below the top soil. Magnetic investigation of iron production sites may include the surveying of relatively large areas in search for signs of former iron production and detailed investigations over located production sites to reveal their inner structure as well as the areal extent and number of slag bodies, and micromagnetic measurements over individual slag bodies with the purpose of age estimation based on inverse modeling of the magnetic anomaly. Since both areas differ in their geological environment, population density at different times, and the degree of technology at a particular time interval, the strategy of the survey must be adapted to the local situation. Based upon the predominant findings, different inverse modeling techniques must be used to give a structural interpretation. The differences and similarities of the magnetic investigation techniques utilized in both areas will be described. The advantages and drawbacks of different techniques, for example the so-called free search, will be discussed. Applied inverse modelling techniques for purposes such as structural interpretation or age estimation will also be represented.

INTRODUCTION

A systematic mapping of the iron production site in Snorup (SW Jutland) with magnetometers was begun in 1992. Magnetic detection of entire sites supplemented by excavations of smaller limited areas has proved to be an effective tool giving informations about the total amount of slag bodies still situated in the ground. Based on empirical relations between total field anomalies and weight of slag bodies (Smekalova et al., 1993), the total slag mass was estimated. Since 1995 the focus changed towards studies concerning measurement configurations and resolution (Koppelt et al., 1996), and age determination by palaeomagnetic investigations and inverse modelling of total field data (Abrahamsen et al., 1997; Koppelt et al., 1997).

Archaeological and metallurgical investigations of iron production sites in Lusatia (Lausitz), granted by the Volkswagenstiftung, started in 1995. Despite the technological aspects, the prospecting of iron production sites in the Lusatian region was of main interest. Lindner and Wagenbreth, hereafter denoted as LW, carried out a geomagnetic survey at 17 different sites (LW, 1996, 1997). It was performed in only one step, employing vertical gradient measurements at nodes of a rectangular grid with $\Delta = 1.0$ m. Here

Δ denotes the grid spacing. Based on the interpretation of these data, they suggested excavations at two to four plots per site. Since many excavations failed (rate of failure: about 75%), new geophysical investigations and a comparative study based on the experiences from Jutland were initiated.

MAGNETIC INVESTIGATIONS IN SW JUTLAND

A three step geomagnetic prospection technique consisting of

- qualitative survey by means of free search magnetic prospecting,
- quantitative magnetic survey over located clusters of slag bodies, and
- micromagnetic investigations of single anomalies

was developed and successfully applied.

Linear dimensions of a cluster of slag bodies varied considerably. A mean extension of about 4 – 10 m was found, whereas several clusters were even twice or three times as large. Anomalies at sensor elevation 0.5 m were still above 100 nT. Capitalizing these properties, the free search technique was used to localize clusters of iron slag pits. While meandering over the field at spacings of about 1.5 – 2 m, measurements with a quasi-continuously measuring magnetometer were taken. Every identified anomaly was marked with a wooden stake.

This method appeared to be highly effective, since probably only a few isolated slag pits were missed. On the other hand, the free search technique was found to suffer from human inability to detect anomalies with low amplitudes or to correlate anomalies over a large distance. This might be the reason that besides slag related anomalies, only little additional information about local settlement structures was found.

Once the clusters were marked, a regular grid of $\Delta = 0.5$ m was established. The detailed measurements represented the basic data set for the localization of slag pits. For that purpose we used an inverse modelling procedure based on the Marquardt-Levenberg algorithm (Tarantola, 1987). Excavations showed that the maximum error in determining horizontal co-ordinates of the body was ≤ 3 cm. The magnetic moment per unit mass M_m was calculated by computed magnetic moment and weight of an excavated body. The mean value of M_m was used for mass estimates of unexcavated bodies.

Figure 1: Secular variation curve (SV) for SW Jutland (Denmark), as obtained by dipole transformation from the british master curve (Clark et al., 1988), for the period of time 50 BC – 700 AD . The inversion results for three slag bodies from Snorup are given here after correction for magnetic refraction effects and a shift in declination by 8.5° eastwards were applied.

Isolated anomalies (see fig. 2) were studied in detail using micromagnetic data over a rectangular grid with $\Delta = 0.25$ m. The inverse modelling algorithm was applied to determine the direction of total

magnetization. Since there was evidence of shape anisotropy from palaeomagnetic and petromagnetic investigation results, an algorithm correcting for magnetic refraction effects was developed (Koppelt et al., 1997). Corrected inversion results are given in fig. 1.

PROSPECTING TECHNIQUES AND RESULTS IN THE LUSATIAN REGION

Whereas prospecting of iron production sites in Jutland was primarily based on magnetic detecting, archaeological prospecting was the basic source of qualitative information about the localization of iron production sites in the Lusatian region. It was performed by several persons searching for archaeological remains, lying on the earth surface, such as pottery or slag pieces. Areas with higher density of findings were marked and put on the map.

Hereafter LW did a magnetic survey with a Geometrics G858 caesium gradiometer. Vertical differences of the total magnetic field were measured at nodes of a regular grid with $\Delta = 1.0$ m (LW, 1996).

The interpretation made by LW(1996) failed in many cases, mainly for two reasons. The distribution of modern objects resulting from dense population, intense agricultural utilization of the area and strong military activities during the last weeks of world war II, shaded many wanted anomalies. On the other hand, several strong anomalies of modern and indifferent archaeological objects were interpreted in terms slag-related anomalies due to lack of resolution.

We did additional micromagnetic measurements on a rectangular grid with $\Delta = 0.25$ m at selected sites, to achieve higher resolution, and thus, to distinguish slag-related anomalies from uninteresting anomalies. For example, on a plot near Klitten a strong anomaly was found and interpreted by LW(1996) as a possible slag body. Micromagnetic measurements showed that the shape of the anomaly differed considerably from a typical anomaly of a slag body (see fig. 2). Excavations revealed a collapsed dome of burnt clay, probable a medieval oven for baking bread.

Figure 2: Typical anomalies of well-preserved slag bodies found in the Lusatian region (on the left, from Altliebel) and in SW Jutland (on the right, from Krarup). Micromagnetic measurements were taken at nodes of a rectangular grid with $\Delta = 0.25$ m. The contour interval is 20 nT. Both bodies were excavated and sampled for palaeomagnetic investigations.

The signal to noise ratio, defined as the number of slag-related anomalies with respect to the total number of anomalies, was much lower in the Lusatian region than in SW Jutland. Slag bodies were usually smaller. Their mean weight was about 30 ± 10 kg, compared to 200 ± 100 kg in SW Jutland. Although some anomaly clusters showed a linear dimension that is about 4 – 6 m, well-preserved slag bodies were rather seldom. In many cases only destroyed blocks or slag heaps were found. This might be due to the fact that this region must be considered as part of the southern boundary region with respect to the chief iron production centres in Central-East Europe. Through these properties, a magnetic survey is more problematic.

CONCLUSIONS

Considerable differences between expressions of archaeological remains of iron production sites in both areas, Lusatia and SW Jutland, were revealed by archaeological and magnetic investigations. They can be interpreted in terms of different site formation processes. Since anomaly patterns are strongly related to the actual expression of a particular pattern, different survey strategies must be applied. Such a strategy cannot be established without any information about the actual situation. Therefore, a certain feedback between magnetic survey and archaeological investigations must be formed, leading to a continuous adaptation of the survey technique to actual requirements.

Procedures that worked well in one region cannot be assumed to work in another. A technique like free search, for example, would be in the Lusatian region hardly as effective as in SW Jutland. Even a magnetic survey with $\Delta = 1$ m cannot be the final step. Much better results would be obtained by a walking mode survey with profile spacing of 0.5 m and variable node spacing not larger than 0.5 m. This is a standard procedure when utilizing a modern caesium magnetometer (Becker et al., 1993). Anomaly regions must be studied in detail using micromagnetic investigations, to distinguish slag-related anomalies from anomalies produced by modern iron objects or filled pits. The minimum grid spacing, required to recover a wanted signal at a given noise level, can be estimated based on relations found by Koppelt et al. (1996).

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