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Using of the magnetic prospection in Denmark.

Magnetic methods were used in Denmark in two different ways: first, for archaeomagnetic dating, and second for magnetic surveying.

The first magnetic survey in Denmark was carried out in 1965 on the Roman Age iron-smelting site Drengsted in Southern Jutland, which immediately showed the effectiveness of this method for searching for slag-blocks (Abrahamsen, 1965). Another archaeological objects, which create a strong anomalies, and therefore are perspective objects for magnetic survey, are pottery kilns. Several of them were investigated with magnetometer in the filed and also archaeomagnetically dated (Abrahamsen et al., 1982; Abrahamsen et al., 1991). A useful experience was obtained by geomagnetic field measurements over a reconstructed Bidstrup brick kilns (Hansen et al., 1980).Many age determinations of archaeological material has been carried out at the Geophysical laboratory of Aarhus University by Niels Abrahamsen, Niels Breiner and their colleagues. (Abrahamsen & Breiner, 1990, 1993; Abrahamsen, et al, 1998).

Since 1992 a systematically magnetic survey was carried out in South-West Jutland mostly on the Roman Age iron-smelting production centers by Olfert Voss (National Museum) and Tatyana Smekalova (St.Petersburg State University, Russia). There were also several promising magnetic surveys for the investigation of other archaeological objects. Some of these results are presented below.

For the conditions of Denmark, especially for Southern-Western Jutland, where almost all the **land is cultivated**, the only part of archaeological objects, still preserved are those, which were underground in ancient time: there are all kinds of pits (household pits, pit-dwellings, postholes); wells, ditches, and also slag-block etc.

The usefulness of the magnetic survey on the archaeological sites in Denmark was determined because of the combination of two conditions:
1) big enough contrast of the magnetic properties of archaeological material and surrounding matter - nonmagnetic mother rock, which is sand (see ***Table 3***);
2) very low noise level.

Table 3. Magnetic properties of archaeological material from Denmark.

Archaeological feature	Magnetic properties		
	Magnetic susceptibility $\varkappa$, ISO $\cdot 10^{-5}$	Remanent magnetic moment per mass unit, J_n, Am²/kg	Q – ratio $Q = J_n / J_r$
Blocks of slag (Snorup, SW Jutland, 200-600 AD)	50 ÷ 1700	5 ÷ 114 $\cdot 10^{-3}$	5 ÷ 212
Bog iron ore from Jutland	0.5÷0.3		
Fired bog iron ore from Jutland	2÷10		
Tile kiln (Veldbæk near Esbejrg in SW Jutland, ca 1790 AD)	10 ÷ 3,000		3.6 ÷ 25
Bricks from tile kiln (Kalø, first half of 1300 A.D.)	500 ÷ 1,000	5.4 $\cdot 10^{-3}$	
Filling of household pits and post holes (Snorup, Krarup, SW Jutland, 200-600 AD)	1.2 ÷ 2.6		
Filling of a pit-dwelling (Krarup, SW Jutland, 200-600 AD)	6.5		
Filling of the well (Snorup)	3		
Topsoil over the cluster of slag blocks (Snorup)	3 ÷ 5		
Topsoil outside the cluster of slag blocks (Snorup)	0.35÷ 2		
Dark soil from one of the ridge of Medieval field (Snorup)	0.9		
Sand close to the ridge of Medieval field (Snorup)	0.3		
Sand (Snorup)	0.1 ÷0.7		

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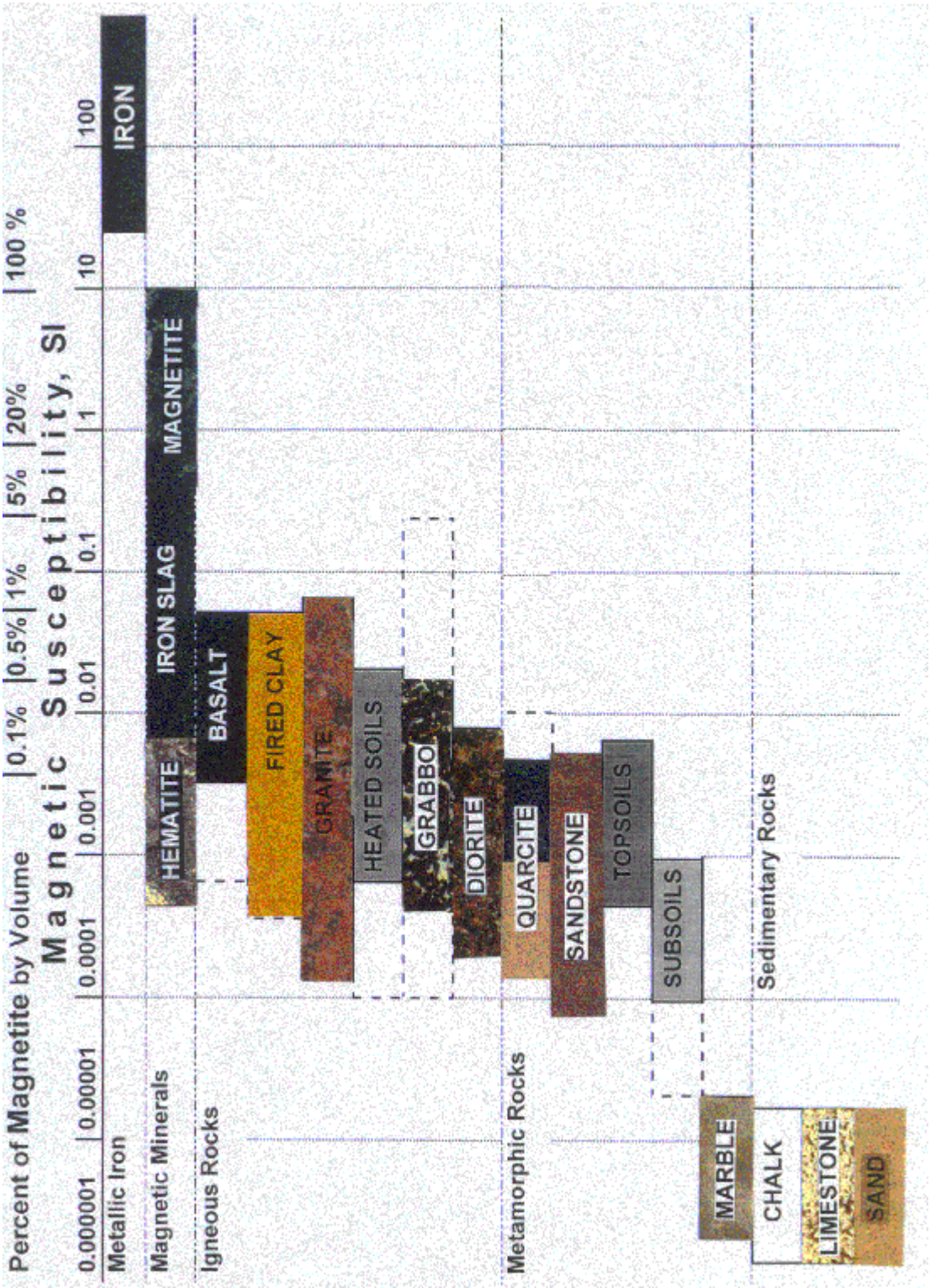

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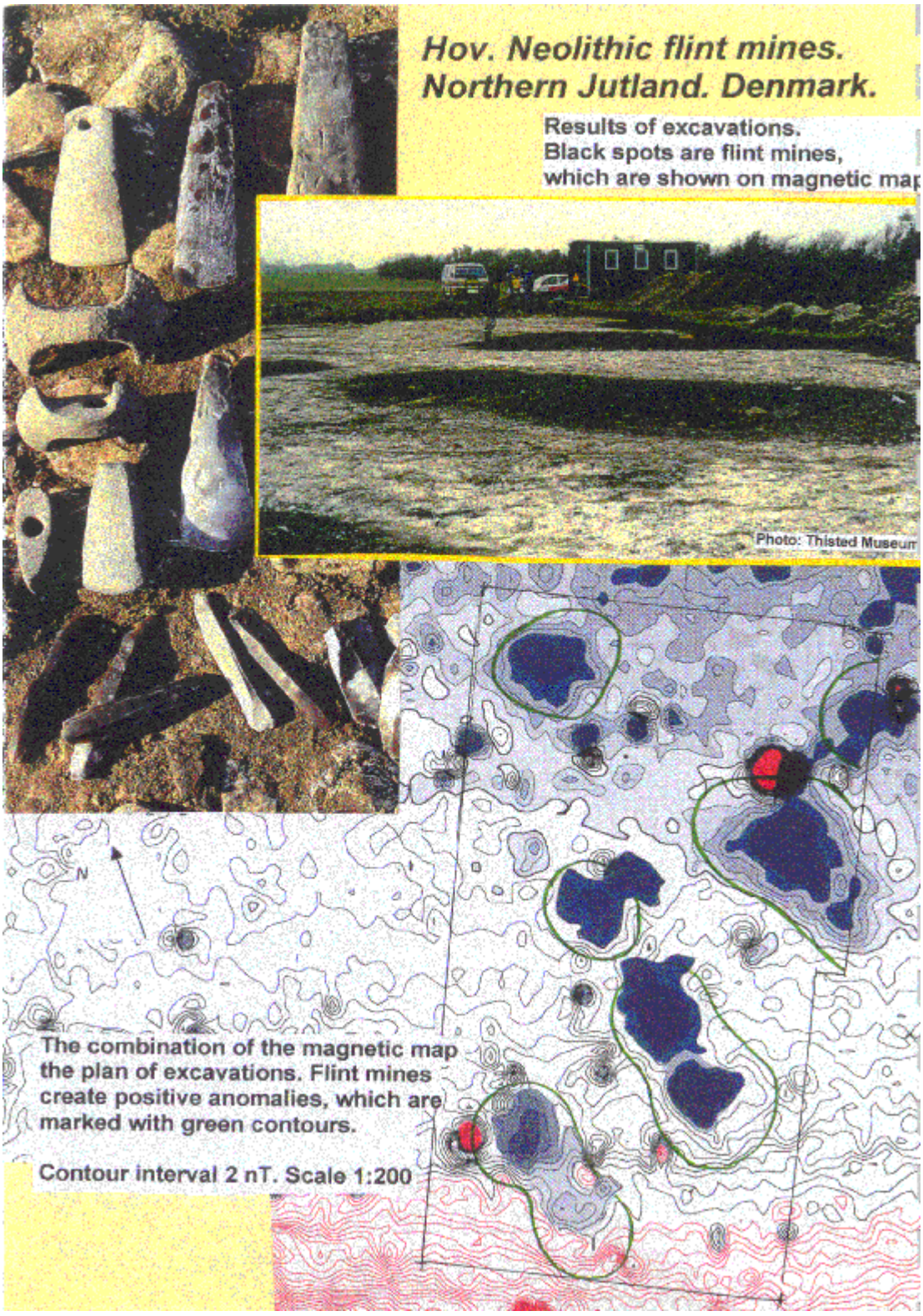

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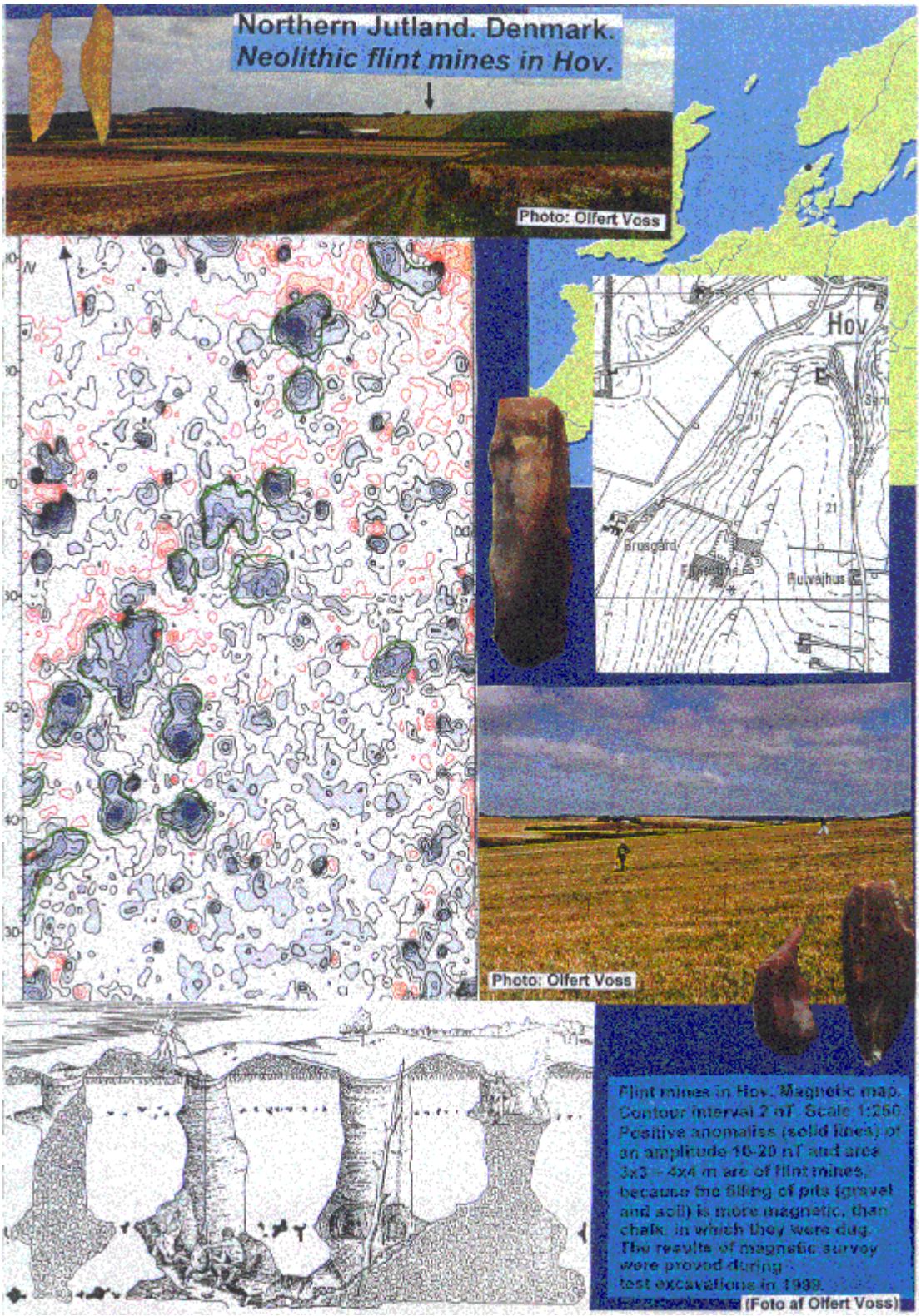

Advancing Overhauser, Potassium and Proton Precession Magnetometer Technologies for More than 2 Decades - "Our World is Magnetic!"

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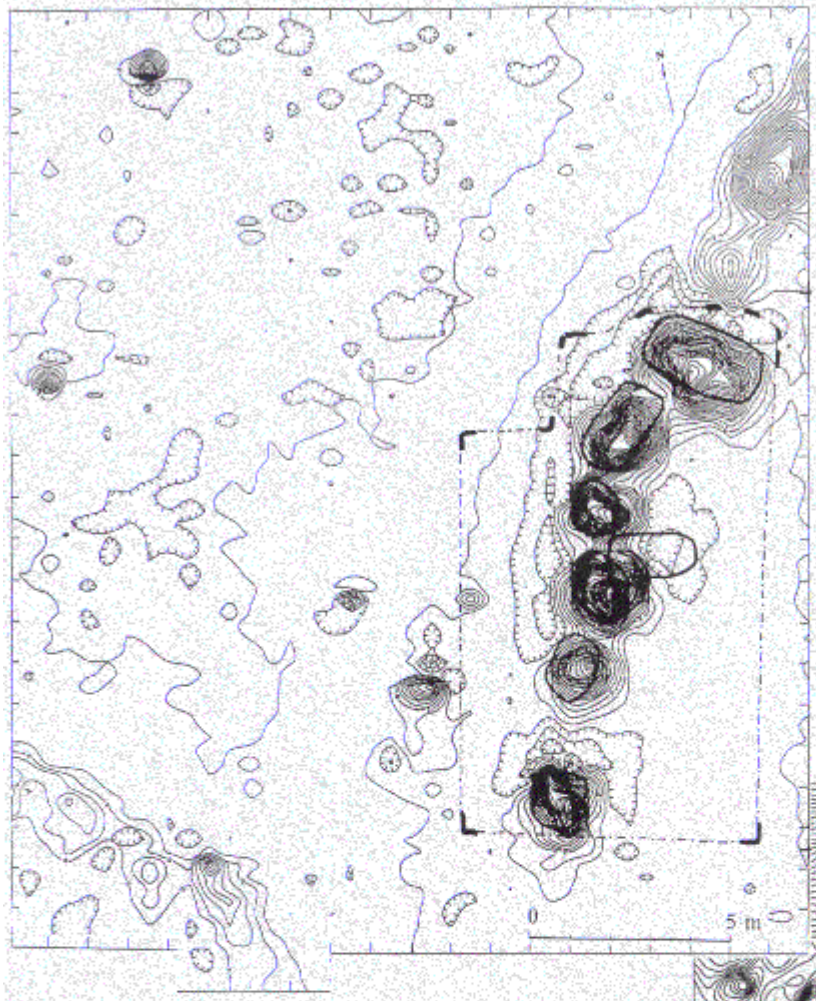
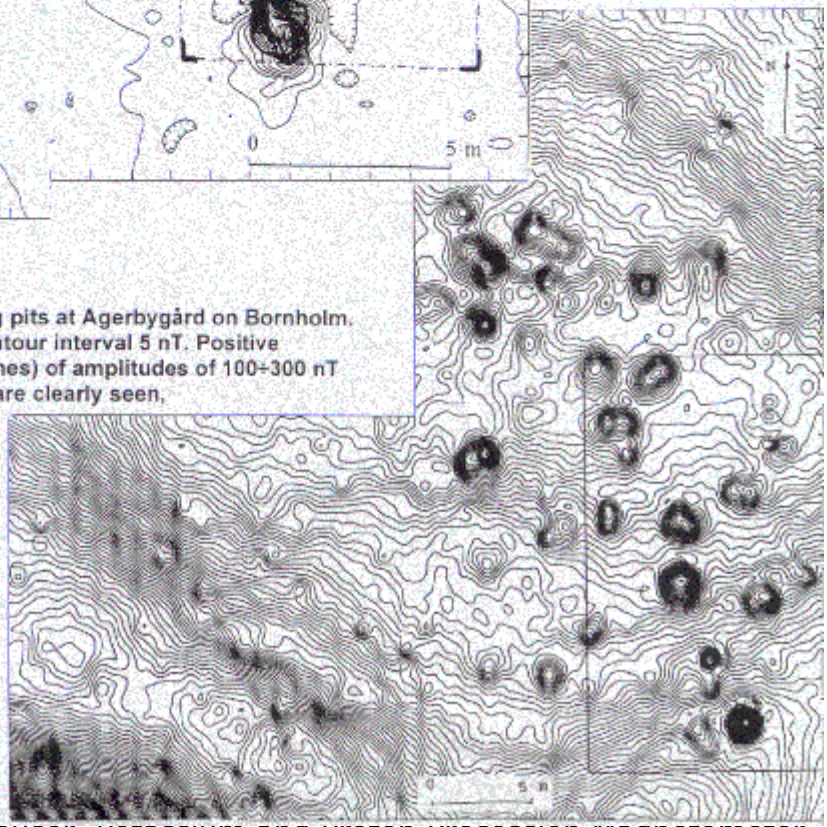
Denmark. Jutland and Bornholm. *Cooking pits.*



A row of cooking pits in Brødbæk near Holstebro. Magnetic map and the result of excavations. Contour interval 5 nT. Positive anomalies (solid lines) of amplitudes of 100÷300 nT are from cooking pits, which contain highly magnetized fired granite stones.



A group of cooking pits at Agerbygård on Bornholm. Magnetic map. Contour interval 5 nT. Positive anomalies (solid lines) of amplitudes of 100÷300 nT from cooking pits are clearly seen, even there is a strong magnetic background of granite mother rock.

Excavations, carried out on the marked areas in both cases, have completely proved the results of magnetic survey.

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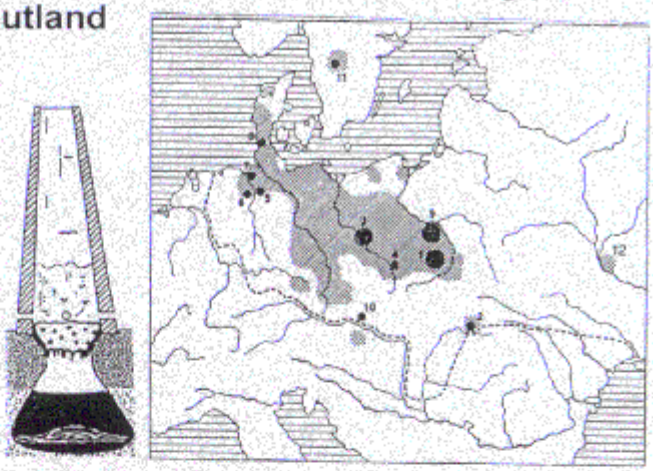
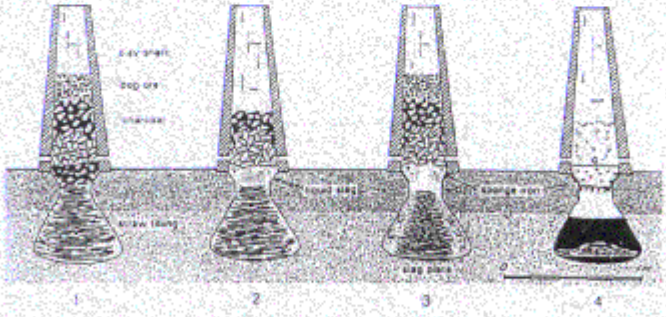
Magnetic prospecting of iron smelting sites with slag pits of Roman Age in SW Jutland

Iron smelting furnaces with clay shafts and underlying slag-pits were widely distributed throughout the western part of Jutland in the period 2nd-6th century AD (Voss 1993a, p.206). Almost 100 smelting sites from this period have now been located. Furnaces of this type are well known from a big area of Europe since the end of the first millennium B.C. to the first half of the first millennium A.D.



The distribution of the iron production centres with slag pits in barbaric Europe at the decline of antiquity. 1 - the Swietokrzyski iron smelting region; 2 - Novoklinovo (Carpatian Ukraine); 3 - the Lowest Silesian iron smelting region; 4 - the Opole iron smelting region; 5 - Westerholt, Kr. Rotherburg (Wumme); 6 - Hatten-Streckermoor, Kr.Oldenburg; 7 - the Lower Elbe iron smelting region; 8 - the west Jutland iron smelting region; 9 - the Mazovian iron smelting region; 10 - Sudice, Blansko District (Moravia); 11 - Ryd near Skovde (Vastergotland) (?); 12 - Uman (Ukraine) (after Mamzer, 1984, Fig.1).

During each smelt the slag run down into the underlying pit where it solidified and formed a slag block. **Each slag pit is a result of single smelt**; therefore **revealing number and weight of slag** blocks make it possible to determine **the total volume of iron production**, and **definition of the plan** of disposition of slag pit could give some ideas about the relationship of the industrial and living areas and **organization** of smelting process.



Reconstruction of the sequence by which a slag pit was filled during the iron-smelting process (after Voss, 1995a, p.2, fig.2).

Those blocks that have been well preserved have an average weight of almost 200 kg. For the condition of Southern-Western Jutland the top of the block was generally 30-35 cm below the surface, with the bottom of the pit measuring 50 to 70 cm below the surface.

Usually such a centers occupied big areas - we have the whole "fields of slags" of several or even several tens of hectares, numbers sometimes more than

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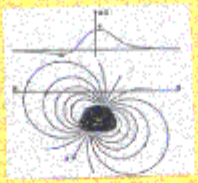
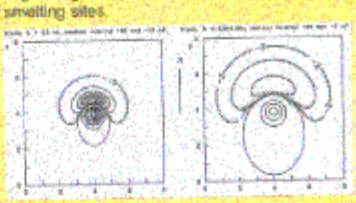
1000 slags. It is naturally, that traditional excavations on the whole area of a smelting site is not possible, and the excavations on separate plot do not give the complete picture about the production center.

Therefore there is a necessity to use an effective, fast and nondestructive method for the investigation of big areas of iron-production centers additionally to the traditional excavations. Unfortunately, there are no traces of slag blocks visible on air photo pictures, although the traces of Iron Age long houses are clearly seen. Magnetic prospecting, can be used to solve the problem of the investigation of smelting sites.

Slag blocks represent almost **ideal objects for magnetic prospecting**, because they actually are big magnetic masses in a shallow depth, which produce strong magnetic anomalies of several hundred nanoTesla, and in some cases, even several thousand nanoTesla.



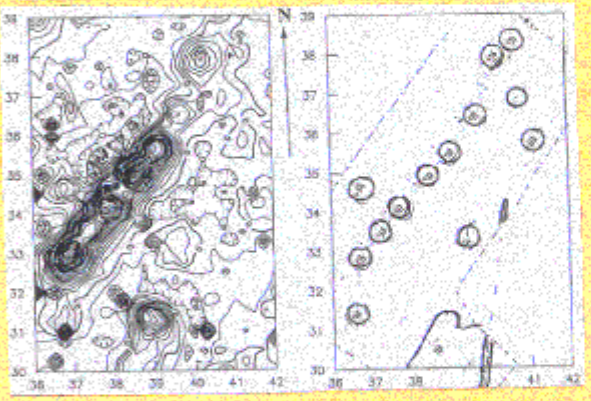


In favorable conditions magnetic prospecting is the most effective, fast and absolutely nondestructive method for the investigation of iron smelting sites, and the information one could obtain by magnetic prospecting is close to those, which is revealed during archaeological excavations. One can even determine a weight of slag, because there is a directly propotional dependace between the amplitudes of the anomalies and weight of slags.

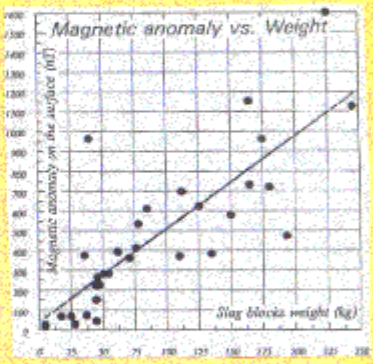
Snorup

Magnetic map. Contour interval 50 nT. Scale 1:100.

And the result of excavation: a row of 11 slag blocks.
See also a photo of these slags below



Snorup Slags:



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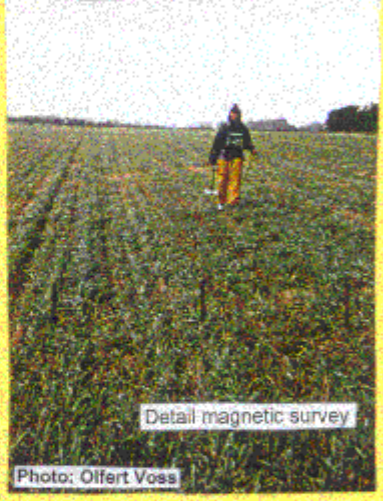
It was necessary to develop an **effective strategy** of field procedure for magnetic survey. Because the sites occupy big territories, in many cases **two stages** of magnetic survey were used.

In the initial stage of an investigation, so-called **"free search"** is carried out to determine the boundaries of the site, location of clusters, and some single slag blocks. At this stage, the operator measures the magnetic field with help of proton or Overhauser magnetometer without using a regular grid, but meandering while measuring at spacings of about 1-1.5m, and marks with small flags the anomalies, which seems to be of slag pits. The method of "free search" is characterized by a high speed (covering typically 3-4 hectares per day).

After having done the "free search" and revealed anomalous areas, then a **detailed magnetic survey** within a fixed grid is carried out on the selected areas.



Archaeologo-geophysical team, working in Snorup, with different types of magnetometers: cesium and Overhauser ones.
From right to left: Bruce Bevan, "Geosight" USA, Olfert Voss, National Museum, Denmark, Tatyana Smekalova, St.Petersburg State University, Russia