

Magnetic susceptibility in archaeological prospecting

By A. J. Clark

Sensitive magnetometers have been used for many years for locating and planning archaeological sites. Originally developed in the 1950s for detecting pottery kilns by the thermoremanent magnetism of their baked clay construction, magnetometers were immediately found to respond also to ancient pits and ditches backfilled with topsoil.

Studies had shown that topsoil generally has a higher magnetic susceptibility, or 'magnetisability', than most bedrocks and subsoils. This is initially due to the concentration in topsoil of iron minerals, especially oxides, weathered from the parent bedrock or from deposits once covering it. The susceptibility is increased (or enhanced) by vegetation fires and fermentation effects, and oxidation-reduction cycles associated with alternate wetting and drying of the soil; all of these tend to convert the iron compounds to the quite strongly magnetic oxide maghaemite ($\gamma\text{-Fe}_2\text{O}_3$). Because of this susceptibility, soil, like the kilns, is also magnetised by the Earth's magnetic field. Human occupation, with its accompanying rubbish and especially fires, further increases these effects, leaving a permanent magnetic imprint on the soil. When incorporated in the fillings of pits and ditches, this magnetic soil reinforces the Earth's field locally and is detectable by magnetometers, but these cannot see the overall effect of topsoil magnetism. This requires a magnetic susceptibility meter measuring the response of the soil to the meter's own internally generated field, and independent of the Earth's field.

The standard magnetic susceptibility equipment used worldwide is the Bartington Instruments MS2/MS3 system. This compact system can be used with field sensors, or

samples can be taken to the laboratory, where more refined measurements can be made.

The development of magnetic susceptibility surveying has moved in parallel with the evolving requirements of archaeological prospecting. Originally, magnetic surveys tended to be of limited extent, with the objective of planning the cut features such as ditches and pits which were regarded as the last remnants of many archaeological sites. For this magnetometers were used, and susceptibility measurements were mostly used for testing soil samples (to ascertain whether there was sufficient magnetic contrast between topsoil and natural for a magnetometer survey to be effective), locating features on cleared surfaces during excavation, and stratigraphic studies. It became clear that the topsoil on many archaeological sites was sufficiently mixed with ancient occupation soil to show an appreciable susceptibility enhancement at the surface. This provided the opportunity to use the method for rapidly defining the general area of sites without the necessity of locating individual features. The first susceptibility surveys were very coarse: a scatter of samples taken over wide areas, for instance to indicate the extent of suburban spread along a Roman road outside a town.

One of the earliest and most revealing was the pre-excavation survey of the prehistoric henge monument of Coneybury, close to Stonehenge (Fig. 1). It was also one of the most detailed, with readings taken on a grid of only about 0.7m. The survey, on harvested arable land, showed two remarkable things. A central group of high readings was interpreted as the position of a fire. Careful excavation from the surface showed that these readings coincided with the maximum density of burnt stones, confirming that they did indeed represent a fire. There was no sign of this when natural chalk was reached, although the position was

central to the henge and a setting of small pits, suggesting a ritual function. If the topsoil had been machine cleared in what was then the normal way, without a susceptibility survey, this major piece of evidence, preserved only in the soil, would have been lost. In contrast, between the fireplace and the entrance the soil was shallower, and diagonal lines of low readings show where the plough had cut into the chalk, diluting the topsoil and reducing its magnetic susceptibility.

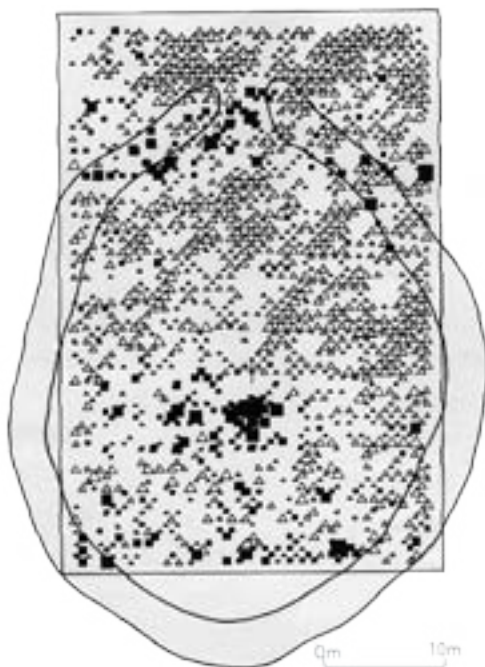


Fig.1. Coneybury henge monument. Topsoil magnetic susceptibility survey superimposed on the outline of the ditch as defined by magnetometer. Readings above the average site background level are shown as black squares of proportionate size; readings below average as white triangles. Readings over the topsoil hearth rose to 42×10^{-5} SI units, about 33% higher than the background level.

In view of this obvious plough damage, the lack of dispersion of the fire-heated soil was

remarkable: it seems to have been due to the levelness of the site, and possibly the bringing up of deep and previously undisturbed soil by the plough. With sites on sloping ground, allowance normally has to be made for downhill soil movement, although the coherence of features can survive.

Perhaps the greatest power of magnetic susceptibility surveying is its ability to detect occupation sites quite independently of whether actual archaeological features exist or not, or whether the topsoil is more magnetic than the underlying layers. All that is necessary is that someone should have lit a fire. The only visible sign of occupation might be a mere scattering of flint chips.

The method can also be highly effective over igneous geology, where a magnetometer survey can be completely vitiated by the strong and irregular magnetic fields of jumbled boulders and stones. Extracted samples are measured away from this magnetism, but the field sensor will also be unaffected by it, and even by the magnetic susceptibility of the stones, if the soil is not too shallow. The only real problem conditions seem to be where sites are masked by alluvium or colluvium deposits, although root, worm and plough action may cause sufficient vertical soil mixing for the susceptibility effect to be detectable at a depth of 0.5m or even more.

Archaeology is now a mature component of the British planning process. The EC Directive on 'The assessment of the effects of certain public and private projects on the environment', adopted in 1985, was given legal effect in England and Wales in 1988 as the Town and Country Planning (Assessment of Environmental Effects) Regulations. These required that those applying for planning consent should commission assessments of the effect of their developments on a variety of

environmental factors. In the EC Directive these included the cultural heritage, interpreted archaeologically in the British regulations as scheduled ancient monuments. This schedule is necessarily limited to the more obvious sites and monuments, while many lie unknown beneath the ground. In 1990, the regulations were strengthened by the issuing of a British Government guideline recommending to regional planning authorities that consent for development should be conditional upon the developer commissioning a full archaeological evaluation of the land involved.

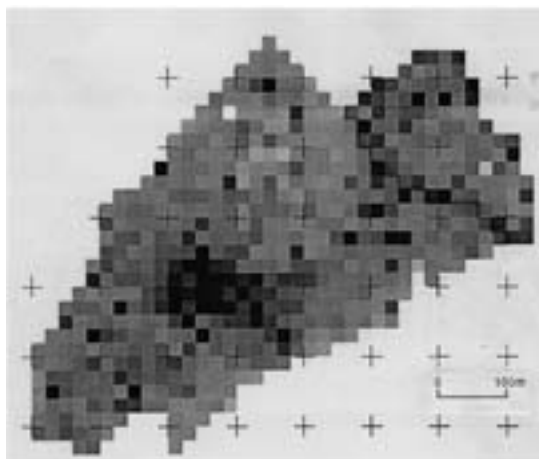


Fig.2. Part of a large assessment (evaluation) survey of a development site. Each half-tone square represents a reading taken with the MS2B laboratory sensor on an extracted topsoil sample. The main positive response is from a Roman site just below centre. Plotting range: White - black = $6.22 \times 10^{-8} \text{SI/kg}$.

This has led to a surge in archaeological assessment activity, applied, for instance, to road widening schemes up to 50km long and a reservoir project several square kilometres in area. Much can be achieved in the archaeological assessment of such areas by a combination of air photography and systematic field walking, but these are generally ineffective on pasture and will

benefit from supplementary geophysical evidence elsewhere. The most sensitive and economically feasible way to fulfil this need is by magnetic susceptibility survey, followed if necessary by detailed magnetometer and possibly resistivity survey of archaeological sites thus revealed.



Fig.3. The MS2D field sensor in use

Such a susceptibility survey can be made using a field sensor or by taking samples on a grid as coarse as 20 or 25m. Samples can be subjected to more detailed and refined analysis in two ways. In the MS2B laboratory sensor, a dual frequency facility can show whether a significant-looking reading is due to human involvement or is affected by magnetic contaminants; samples can also be subjected to a heating test to ascertain their fractional

conversion to maghaemite, which increases the reliability with which archaeological variations can be distinguished from changes due to the geological background.

An example of an assessment survey is shown in Fig. 2, in which the values of readings on a 20m grid are presented as a half-tone grey scale. The survey covers 24.4 hectares, about a quarter of a square kilometre, the 610 samples being collected by one person in two days. The objective is totally different from that of the Coneybury survey, the whole of which would fit into three of the 20m squares, yet a Roman site is clearly revealed by high readings near the centre.

A different approach to large surveys is to use the MS2D field sensor only (Fig. 3). With the collected samples measured in the laboratory, it is most practical to use mass-specific susceptibility (X). The field sensor however looks at the volume susceptibility (κ) of a hemisphere of soil beneath a loop coil placed on the ground. At Coneybury, conditions over a very limited area were ideally uniform, but when used over wide areas such readings may not be as good as those on prepared samples: coil contact may be affected by ground irregularity or vegetation cover which will vary from field to field, but this can be compensated for by taking a proportion of extracted samples for laboratory calibration, or a larger number of readings on a grid of 5 or 10m, so that less reliance need be placed on individual readings. Such finer grids can also resolve detail of great interest: as at Coneybury, the response is also affected by soil dilution effects caused by stones or displaced bedrock.

On a large scale these may represent remnants of old field banks and other landscape features, with the result that surveys of this type can reveal patterns of past landscape use which

confirm and complement the documentary studies of more recent periods that also form part of an archaeological evaluation. The location of ceremonial sites such as burial mounds and cemeteries is difficult because they lack the magnetic enhancement associated with dwelling and industrial sites, although these again may cause patterns of subsoil displacement detectable in this type of survey.

Further reading

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

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