RESEARCH REPORT SERIES no. 49-2013

STONEHENGE, WILTSHIRE
REPORT ON MAGNETIC SUSCEPTIBILITY SURVEY, JANUARY 2013

Neil Linford

REMOTE SENSING

ENGLISH HERITAGE

Research Report Series 49-2013

STONEHENGE, WILTSHIRE

REPORT ON MAGNETIC SUSCEPTIBILITY SURVEY, JANUARY 2013

Neil Linford

NGR: SU 122 421

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)

The Research Report Series incorporates reports by the expert teams within the Investigation & Analysis Division of the Heritage Protection Department of English Heritage, alongside contributions from other parts of the organisation. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series, the Architectural Investigation Report Series, and the Research Department Report Series.

Many of the Research Reports are of an interim nature and serve to make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers must consult the author before citing these reports in any publication. Opinions expressed in Research Reports are those of the author(s) and are not necessarily those of English Heritage.

Requests for further hard copies, after the initial print run, can be made by emailing:
Res.reports@english-heritage.org.uk
or by writing to:

English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD
Please note that a charge will be made to cover printing and postage.

SUMMARY

A topsoil magnetic susceptibility survey was conducted over areas of visible turf damage related to the location of pyrotechnic sculptures that formed part of the 'Fire Garden' installation erected at Stonehenge, Wiltshire as part of the cultural Olympiad celebrated in July 2012. Strong winds at the time of the installation resulted in a greater degree of fire damage to the turf in the immediate vicinity of the individual sculptures than had been anticipated. Field measurements revealed discernible patterns of topsoil magnetic susceptibility enhancement related to areas of turf damage still visible six months after the event. Magnetic models calculated from the field data suggest this disturbance may well influence the interpretation of future geophysical survey of the monument.

CONTRIBUTORS

The field work was conducted by Neil Linford and Andy Payne from the English Heritage Geophysics Team. Pete Horne, Head of Remote Sensing Team, provided a rectified version of the cover photograph to update Figure 1 during the editing of this report.

ACKNOWLEDGEMENTS

ARCHIVE LOCATION

Fort Cumberland.

DATE OF FIELDWORK AND REPORT

The fieldwork was conducted on the 30th January 2013 and the report was completed on 15th February 2013. The cover photograph shows an aerial photograph of the monument following the event depicting areas of turf damage (27497_051 23 July 2012 © English Heritage).

CONTACT DETAILS

Geophysics Team, English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth, PO4 9LD.
Dr Neil Linford; tel. 02392 856761; email neil.linford@english-heritage.org.uk

CONTENTS

INTRODUCTION

As part of the cultural celebrations staged in support of the London 2012 Olympic games a temporary 'Fire Garden' installation was created in July 2012 surrounding the monument at Stonehenge, Wiltshire. Due to adverse weather conditions the installation was only active for 2 of the planned 3 nights and strong winds caused considerably more fuel to fall from the individual pyrotechnic sculptures onto the unprotected ground surface than expected. Despite the generally wet conditions at the site visible turf damage and scorch marks were evident following the event and led to concerns that more permanent damage to the site may have occurred.

The thermal alteration of iron minerals is well documented and can result in changes to both the colour and the magnetic properties of soils in immediate contact with sources of heat exceeding ~150°C (Thompson and Oldfield 1986; Canti and Linford 2000; Linford and Canti 2001). For short term exposure to burning the depth to which soil will be affected is likely to be relatively shallow, perhaps less than 0.05m, although this may still be sufficient to produce a persistent concentration of enhanced magnetic material that will influence subsequent geophysical measurements.

The aim of the current survey was to determine whether visible areas of turf damage at the site are associated with local magnetic enhancement of the soil and whether these might be sufficient to cause a detectable magnetic anomaly.

The site (AMIE SU 14 SW4) lies over Cretaceous Upper Chalk (Geological Survey of England and Wales 1950) where soils of the Icknield association have developed in the immediate vicinity of the site (Soil Survey of England and Wales 1983). More recent deposits of compacted material were introduced to cope with increased visitor numbers and may have only been partially removed when the monument was set back to grass. Weather conditions during the field work were generally good, with some passing rain showers.

METHOD

Areas of fire damaged turf, still visible at the time of the survey, were recorded by measuring a central point using a Trimble 4700/4800 kinematic differential global positioning system (GPS).

Measurements of volume specific magnetic susceptibility (SI measurement system) were made *in situ* using a Bartington MS1 meter and MS2-D field loop at 0.1m intervals along orthogonal transects located over two areas of visible turf damage (Figure 1; Cole *et al.* 1995; Dearing 1999, pp50-52). A single comparative trial transect was also collected using a MS2-F field probe which measures magnetic properties in much closer proximity to the sensor.

RESULTS

i) Visible areas of turf damage

Table 1 details the most likely areas of turf damage related to the Fire Garden installations identified during the survey, each appearing as a sub-circular patch of discoloured sward with a broken annulus of bare soil, still evident 6 months after the event (Figure 1, [01 – 11]). Other potential sites were also recorded, but did not seem so convincing, but these and further areas of surface damage can be seen on the aerial photographs taken 23 July 2013 (see cover). Spot magnetic susceptibility measurements were made over the turf damage sites in Table 1 and from these [02] and [09] were selected for more detailed investigation.

Table 1

Site identifier	Notes
[01]	A halo of readings ~20 × 10^{-5} follows the damaged turf with a central high (ferrous detritus?) value of >300 × 10^{-5}
[02]	Selected for detailed measurements (Figure 2(F)-(H))
[03]	Central peak value of ~20 × 10^{-5}
[04]	No detectable magnetic anomaly
[05]	Interference from floodlight cable run
[06]	Interference from floodlight cable run
[07]	No detectable magnetic anomaly
[08]	Interference from floodlight cable run
[09]	Selected for detailed measurements (Figure 2(A)-(C))
[10]	Maximum recorded value of ~50 × 10^{-5}
[11]	Maximum recorded value of ~20 × 10^{-5}

ii) Detailed Magnetic Susceptibility measurements

Orthogonal transects of measurements through site [09] demonstrate a background magnetic susceptibility of κ = ~20 × 10^{-5}, with peak anomalies [MS1-4] occurring over the annulus of the visibly damaged turf (Figure 2(A)-(C)). The highest values, κ > 60 × 10^{-5}, are found at [MS1] with lower values at [MS2-4] still discernible above the apparent background response. As the MS2-D field coil is sensitive to a hemi-spherical volume of soil approximately equal to the radius of the coil (~0.25m), a comparative traverse was collected using the MS-2F field probe to investigate the potential depth of any topsoil magnetic enhancement (Figure 2(A)). The MS-2F probe measures a comparatively small volume of soil in close physical contact with the diameter sensor tip (<0.02m^2), although this may often be compromised by vegetation preventing good contact with the bare topsoil (Dearing 1999, Table 4.3). The results demonstrate a generally good correlation between the two field sensors, although [MS1] appears to be better represented in the deeper penetrating data set and [MS2] seems more likely to be due to a near-surface response.

Similar orthogonal transects collected over [02] (Figure 2(F)-(H)). revealed a lower level of background magnetic susceptibility of **κ = ~**10 **×** 10^{-5}, with relatively subdued anomalies over the bare earth at [MS5] and [MS7], together with an apparent suppression of readings at [MS6]. In this case, it is difficult to suggest a clear correlation between any magnetic susceptibility enhancement and the area of visible turf damage.

iii) Magnetic models

Future geophysical survey at Stonehenge using geophysical instrumentation sensitive to the magnetic properties of the topsoil will, in principle, be capable of detecting any localised enhancement associated with the turf damage sites. This is likely to be of greatest concern with respect to magnetometer and (in-phase) electromagnetic (EM) instruments, providing measurements can be made in area of the site that are sufficiently devoid of recent ferrous disturbance (cf Payne 1995; Linford *et al.* 2012). To assess the potential impact this may have on subsequent geophysical survey results a theoretical magnetic model was calculated based on a near-surface, annular distribution of enhanced magnetic susceptibility approximating the dimensions of the fire damaged turf.

Lateral plans of the models are shown in Figures 2(D) and (I) with the enhanced layer extending from the surface to a depth of 0.2m and a magnetic susceptibility contrast of $\kappa = 50_{[09]} \times 10^{-5}$ and $\kappa = 8_{[02]} \times 10^{-5}$ used respectively. Synthetic data was created for a 0.5m separation vertical gradiometer collecting data over at a 0.125m x 0.25m sample interval with the addition of 0.1nT Gaussian distributed random noise and is shown as both a traceplots (Figures 2(D) and (I)) and linear greyscale images (Figures 2(E) and (J)). A field magnitude of 50000nT, inclination = 68° and declination = 0° was assumed for both models (Linington 1972; Linford and Canti 2001).

The results demonstrate that whilst magnetic anomalies could be generated by both areas of turf damage, it seems that only the response over [09] is likely to be detectable above background noise levels. More highly sensitive, short vertical baseline magnetometers may well prove more sensitive to the detection of weaker anomalies (Schultze *et al.* 2007).

CONCLUSION

Whilst the majority of turf damage related to the Fire Garden sculptures has now recovered, some of the sites visible at the time of this survey correlate with the presence of near-surface magnetic enhancement of the topsoil. The degree of enhancement appears highly variable with some sites producing either no detectable anomaly, or any response being masked by the presence of recent ferrous disturbance. This would appear to be due to the specific nature of the individual pyrotechnic sculptures and the relative exposure of the individual sites to the prevalent wind direction at the time of the event.

Detailed measurements over two selected sites confirm a pattern of susceptibility enhancement matching the visible turf damage and suggest detectable magnetic anomalies could be recorded over these sites. The longevity of the magnetic anomalies is difficult to assess. Although the geophysical response to burnt features can remain persistent within the archaeological record, given the size and near-surface nature of the fire damage it seems likely that the magnetic enhancement will be more ephemeral and become dissipated through natural weathering and worm action. Repeat measurements at appropriate intervals, perhaps annually, are recommended to assess the persistence of the disturbance. Whilst the monument has previously been subject to earth resistance, fluxgate gradiometer and ground penetrating radar coverage any future geophysical survey should take account of the location of the fire garden sculptures, perhaps best recorded through aerial photography following the event.

LIST OF ENCLOSED FIGURES

REFERENCES

Canti, M G and Linford, N T 2000 'The Effects of Fire on Archaeological Soils and Sediments: Temperature and Colour Relationships'. *Proceedings of the Prehistoric Society*, 66, 385-395.

Cole, M A, Linford, N T, Payne, A P and Linford, P K 1995 '*Soil Magnetic Susceptibility Measurements and their Application to Archaeological Site Investigation'*. In Beavis, J and Barker, K (Editors), Science and Site: Evaluation and Conservation (Bournemouth University: Bournemouth University). 114-162.

Dearing, J 1999 'Magnetic susceptibility' *in* Walden, J, Oldfield, F and Smith, J (eds), *Environmental Magnetism: a practical guide*, 6. Quaternary Research Association, London, 35-62

Geological Survey of England and Wales 1950 Salisbury, England and Wales Sheet 282, Drift edition. Chessington, Surrey.

Linford, N, Linford, P and Payne, A 2012 *'Stonehenge Monument Field And Barrows, Wiltshire, Report On Geophysical Surveys, September 2010, April And July 2011'*. English Heritage Research Reports Series 34/2012.

Linford, N T and Canti, M G 2001 'Geophysical Evidence for Fires in Antiquity: Preliminary Results from an Experimental Study'. *Archaeological Prospection*, 8, 211-225.

Linington, R E 1972 'A summary of simple theory applicable to magnetic prospecting in archaeology'. *Prospezioni Archeologiche*, 7, 9-60.

Payne, A 1995 'Geophysical Surveys at Stonehenge 1993-4' *in* Cleal, R M J, Walker, K E and Montague, R (eds), *Stonehenge in its Landscape – Twentieth-century Excavations*, English Heritage Archaeological Report, 495-510

Schultze, V, Chwala, A, Stolz, R, Schulz, M, Linzen, S, Meyer, H-G and Schuler, T 2007 'A super-conducting quantum interference device system for geomagnetic archaeometry. Archaeological Prospection 14: 3.'. *Archaeological Prospection*, 14 (3), 226-9.

Soil Survey of England and Wales 1983 Soils of England and Wales: Sheet 6 - South East England Harpenden, Lawes Agricultural Trust.

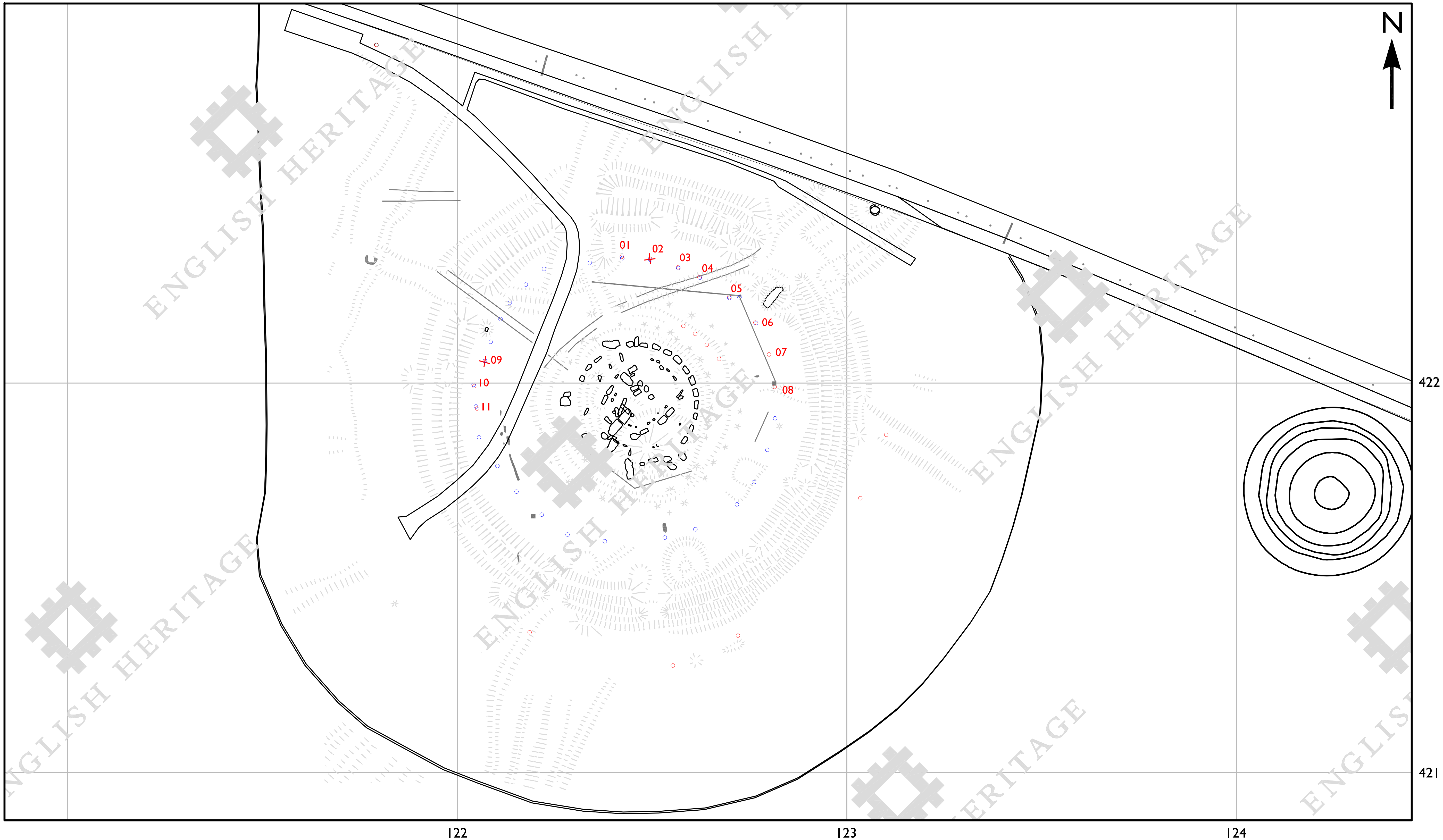
Thompson, R and Oldfield, F 1986 *Environmental Magnetism*, London, Allen and Unwin.

Figure 1

STONEHENGE, WILTSHIRE

Location of magnetic susceptibility measurements over fire damaged turf, January 2013

SU1242



0 90m

1:1000

01-11 Visible turf damage, January 2013

02/09 Magnetic susceptibility transects

Possible turf damage

Possible turf damage from rectified AP

GPR anomalies of recent/known origin (Linford *et al.* 2012)

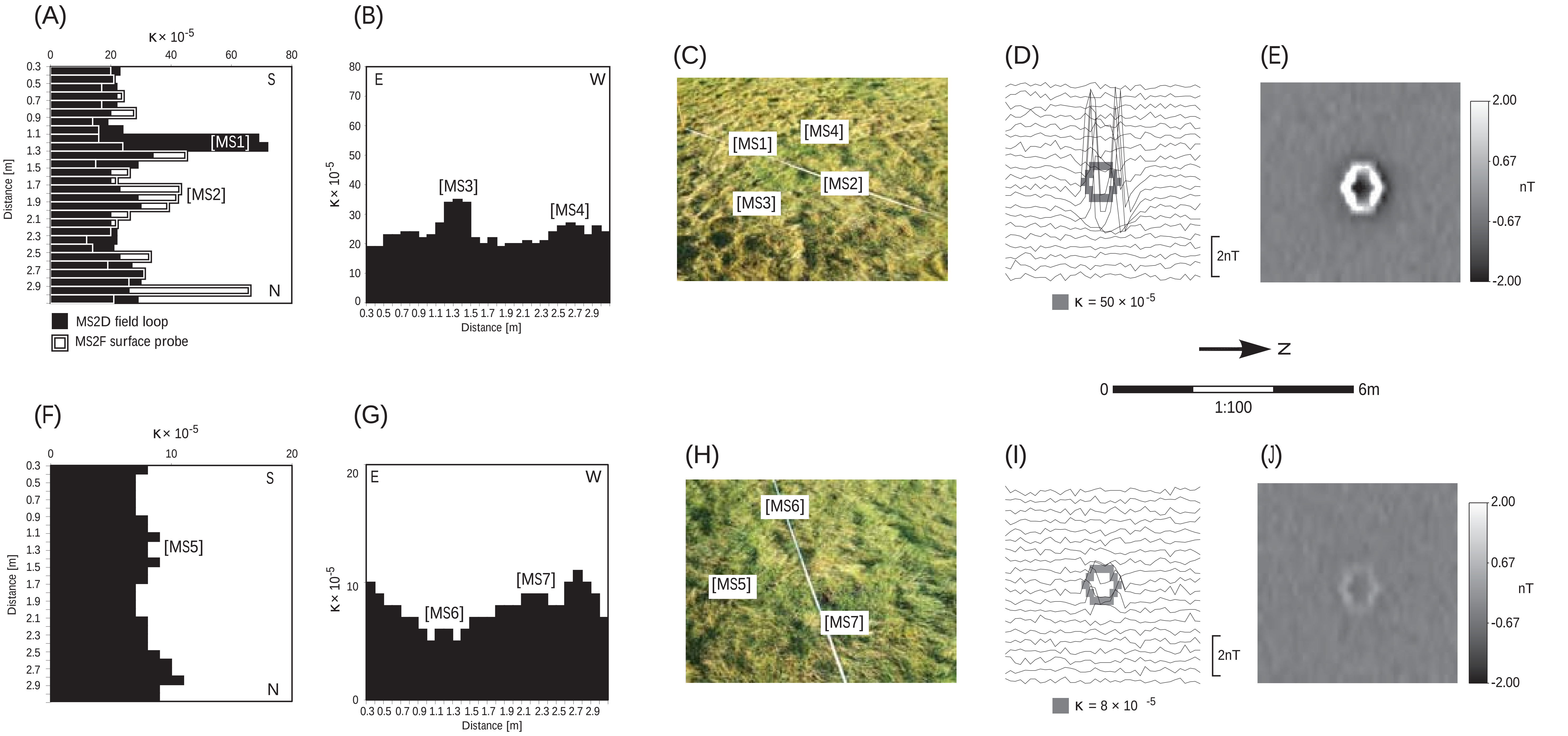
Geophysics Team 2013

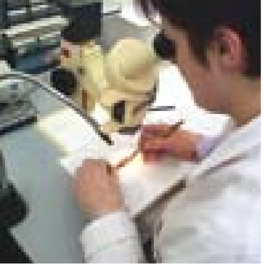
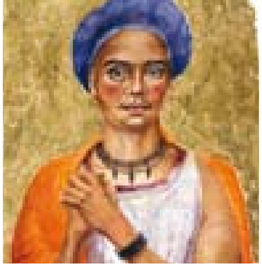
ENGLISH HERITAGE

STONEHENGE, WILTSHIRE

Magnetic susceptibility survey over fire damaged turf.

Figure 2





ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

* *Aerial Survey and Investigation*
* *Archaeological Projects (excavation)*
* *Archaeological Science*
* *Archaeological Survey and Investigation (landscape analysis)*
* *Architectural Investigation*
* *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
* *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE