

Cesium Magnetometer Survey
at Kingscote, Gloucestershire, England

by

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Air photographs from the multi-spectral experiment mounted jointly by the Royal Commission on Historical Monuments (England) and the Museum of the University of Pennsylvania revealed crop growth anomalies in one large field in an area called Ashel Barn, a farm now owned by Mr. G.H. Nichols.

The field, measuring approximately 225 x 300 metres, was chosen for a comparison between a ground survey with magnetometers and aerial photo-interpretation. The Survey was conducted from September 12th to 17th, 1971 by members of the Museum Applied Science Center for Archaeology (MASCA) - namely, Froelich Rainey and Elizabeth Ralph, and volunteers Marina Bernaut and Sheelagh Murnaghan, assisted by R.C.H.M. staff. The magnetometers used and the method of surveying grids are described below.

MASCA CESIUM MAGNETOMETERS

1. Varian Associates Precision Portable Cesium Magnetometer Model 4920.

This instrument was designed specifically for archaeological prospecting by Varian Associates (611 Hansen Way, Palo Alto, California 94303, U.S.A.) at the request of the University Museum, University of Pennsylvania. The components are the read-out, cesium sensor (or sensors) and 30-volt battery pack. It is lightweight and readily portable. Its maximum sensitivity with one sensor is 0.1 gamma. The principles of operation as well as its application in the search for Sybaris in southern Italy are described by E. K. Ralph, Frank Morrison, and D. P. O'Brien in "Archaeological Surveying Utilizing a High-Sensitivity Difference Magnetometer", Geoexploration, vol. 6 (1968) pp. 109-122.

The Model 4920 contains also a difference circuit for use with two sensors. The second sensor may be used either in a gradiometer arrangement or it may be placed in a fixed location in the center of a grid. The second sensor serves to cancel out diurnal and other extraneous magnetic variations, and only the difference between the fixed and movable sensors is read. When operated as a difference magnetometer, the second sensor replaces the crystal oscillator to regulate the counting interval. The readings are no longer in gammas (γ),

but are adjusted to an arbitrary base reading of 80,000 units when the magnetic field at the two sensors is equal. The reading of the movable sensor may be converted to change in γ by the formula:

$$\Delta H = \frac{H_F}{80,000} [N - 80,000]$$

Where ΔH is the difference in γ between the fixed and movable sensors, H_F is the total field intensity (in γ) of the fixed sensor only; and N is the instrument reading in units. Since the total field intensity at Kingscote was approximately 47800 γ at the time of the survey, in the difference mode of operation, the sensitivity of the instrument is roughly double (0.6 γ /unit) than with one sensor only.

At sites with large anomalies of the order of 100 γ or more, this extra sensitivity is not required, but use of the difference circuit eliminates the tedious process of correcting readings for diurnal changes. The great advantage of cesium and of other alkali vapor magnetometers over proton magnetometers is speed. The measurement display interval in this instrument may be selected on the basis of desired speed of operation, from a minimum of 1.5 seconds to infinite (or manual). A built-in memory circuit "holds" the former reading after its 1.5 second measurement cycle. In practice, the readings can be viewed continuously by the operator who can see when significant anomalies are encountered and slow down to record changes in

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readings when anomalies are large. This prevents measurement
slew resulting from the averaging done by the readout.

This cesium magnetometer is especially suitable for
recording readings in a grid pattern.

2. Varian Associates Portable Search Magnetometer Model V-4971 -
Audio Type.

This instrument consists also of a readout, one cesium
sensor, and battery pack. The big difference is with the read-
out. This readout is very much smaller and simplified. It
contains an oscillator which can be varied with a control knob
to match the Larmor frequency from the sensor. This match is
made by obtaining a "null" or zero beat frequency on the read
out's built-in speaker. Then a reading can be taken from the
calibrated dial attached to the control knob. The dial range
is from 1 to 1000 and each unit is approximately equal to $1\frac{1}{2}$ γ .
(There is a coarser control for bringing the dial into range
in any particular magnetic field.) This readout is particularly
suitable for doing rapid exploratory lines. One sets the dial
at "null" and then while walking along, one need only listen
to changes in the audio tone from the loudspeaker to know
whether or not anomalies exist. If desired, one may pause to
take a reading to find out the approximate magnitude of each
anomaly.

This readout, referred to later as the "audio" readout, is most useful for preliminary exploration, and for finding the limits of sites beyond the areas covered in detail by grids. It is also the more suitable of the two for detecting narrow linear features such as shallow ditches.

GRID PROCEDURE

In most cases, after preliminary exploration along lines with the audio readout, grids are laid out in the areas of interest, to be covered in detail with the precision readout. For each grid, two parallel lines (one at each end of the grid) are marked with stakes at 10-meter intervals with tape measures. A rope, calibrated in 2-meter intervals, is then strung between the end stakes of each line. The man carrying the sensor then walks along this line (the zero line) and the adjacent two- and four-meter lines and pauses at each two-meter marker for a reading to be taken. Upon the completion of the first three readings, he then moves 2 meters into the grid, three more readings are taken, and so on in a serpentine fashion along the edge of the grid. After the completion of three lines, the rope is moved between the and strung/ next 10 meter stakes, and the sensor man then moves to the six-, eight-, ten-, twelve-, and fourteen-meter stations at each two-meter marker on the rope, and traverses the grid again, but with a serpentine pattern now five measurements wide.

Each reading is called out by the man carrying the readout and batteries, and is recorded by a third person in a notebook oriented in the same direction as the grid being traversed. In bushy or rough terrain, a fourth person coils and uncoils the 100-meter cable leading to the fixed sensor. When the grid is finished, the pages of the notebook are then put together with

Scotch "magic-mending" tape to form the complete grid.

The differential mode with 2 sensors is usually used for all grids with the second sensor placed in a fixed position in the middle of each grid. The usual height of the movable sensor is in the comfortable position at arm's length at one's side - about 75 cm above the ground. Grids may be varied in size, but it is frequently convenient to lay them out in 100 x 100 meter squares. This area can be covered at 2-meter intervals in a six to eight hour work day, depending upon the terrain.

After a grid has been taped together, contour lines of equal magnetic intensity are then drawn for easy visualization of magnetic patterns. In these plots, "0" represents 80,000 units; "10" = 80,010 units; "990" = 79,990 units, etc. In most grids, with average anomalies, contours are drawn at intervals of 10 units, or approximately 5 γ .

When several grids are made, one adjacent to another, the average base readings may be adjusted to be the same for each by placing an artificial anomaly such as a compass near the fixed sensor. Thus, a reading such as "40 units" in the second or subsequent grids represents the same difference in magnetism above background without anomalies (usually set at 20 units for convenience) as in the first grid. This aids in the interpretation of the final plots of magnetic contours by allowing adjacent grid maps to be connected directly together with no discontinuity.

At Kingscote four grids were made, the locations of which are shown in Fig. 2. These areas were chosen to correspond with the anomalies in the aerial photographs (described by John Hampton).

Grid No. 1 was centered on the most pronounced aerial anomalies and was done on the first day of field work. Unlike the subsequent grids, No. 1 was run at 1-meter intervals for the purpose of a detailed first test of the terrain. As one can see in Fig. 21A, we did indeed detect pronounced magnetic anomalies. One sees strong evidence of the "angle" anomaly corresponding with that in the aerial photograph, but in addition, west of the "angle" there is a definite rectangular feature, which is probably representative of a building.

After this trial, we proceeded to do Grid Nos. 2, 3, and 4, at 2-meter intervals. The combined plots of these grids are shown in Fig. 21A. If we overlay the transparency of Fig. 21A on the aerial photograph (Fig. 21), we see the good correspondence of the "angle" anomaly as well as other magnetic anomalies.

The two lines of possible ditches running east-west just south of the center of the field were not detected in Grid No. 2, but they do show clearly in Grid. No. 4. The contours of the latter were drawn at intervals of 5 units (rather than 10) since these "ditch" anomalies tend to be weaker than others detected previously.

Before Grid No. 4 was made, the region of the ditches was explored with the audio readout on a very foggy morning.

The magnetometer crew did short lines perpendicular to the possible lines of the ditches and while everyone else got lost in the fog, the crew, listening to the change in frequency, had pinpointed the lines of ditches precisely with ~~bamboo canes~~ ^{markers}. This was revealed about mid-day when the fog lifted. Grid No. 4 was made subsequently to see if the ditches could be detected with the precision readout and the more sensitive differential system. In this grid, they were detected, but not nearly so precisely as with the audio unit. The reason for this is that the grid was made at 2-meter intervals whereas with the audio, the change in tone was monitored continuously. The anomalies heard with the audio were a meter or less wide, and were therefore, not missed as they were in the grid system at 2-meter intervals. A plot of the audio anomalies is shown in Fig. 6.

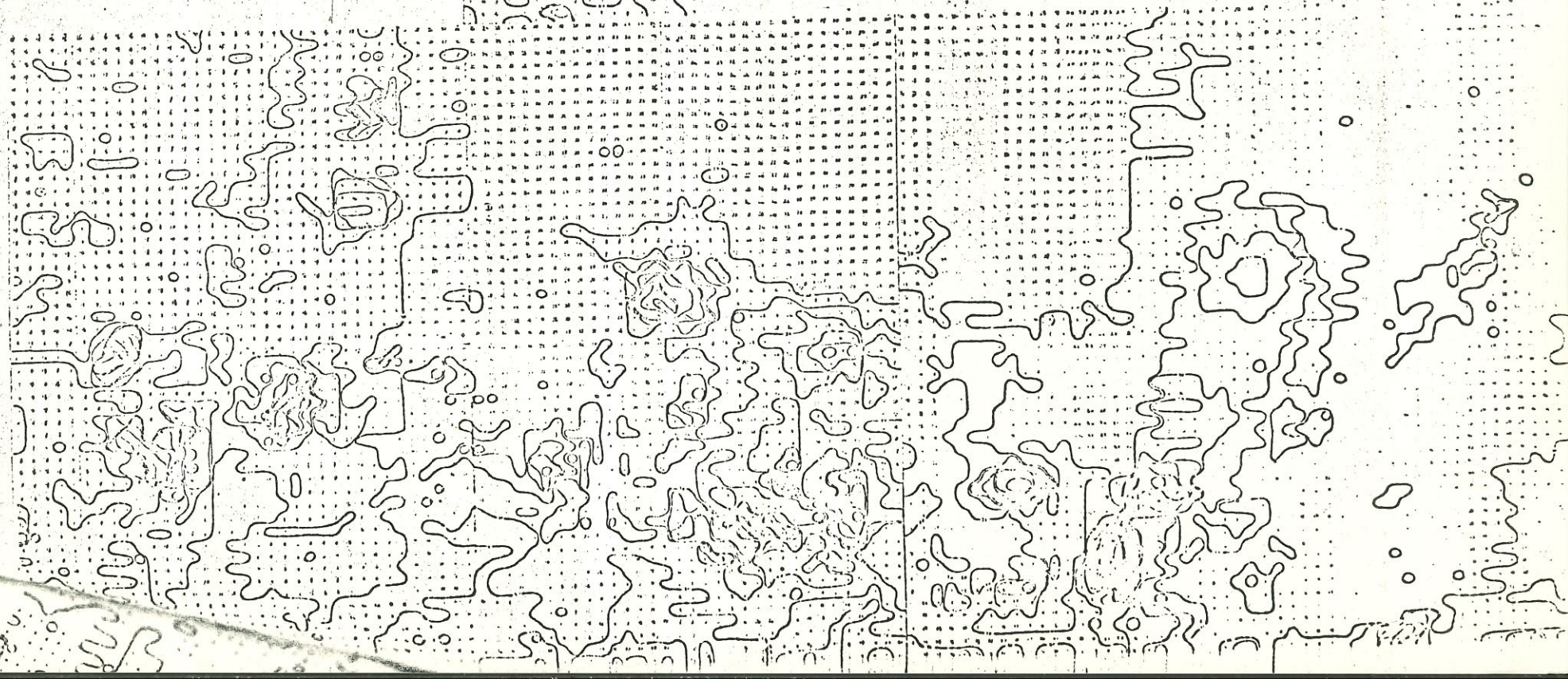
When we first plotted and looked at Grid No. 1 (~~Fig. 1~~) and also Grid Nos. 2 and 3, we wondered why the anomalies were so strong. The earth was dark brown in color and did not appear to be magnetic. The stones in the wall and elsewhere were less magnetic. Therefore, we put the movable sensor in a fixed position on top of the long stone wall (shown in Fig. 1^(B)) and tested bags of earth. About 300 grams of earth put on top or under the sensor caused a magnetic change of 5 gammas. The susceptibility of this soil was subsequently measured in the laboratory by Mike Tite*. This measurement and others for comparison from other sites are listed below.

* We are grateful to Mike Tite (Department of Physics, University of Essex) and to Martin Aitken (Research Laboratory for Archaeology and the History of Art, Oxford University) who visited the site and transported the sample to him.

<u>Sample</u>	<u>Magnetic Susceptibility</u>
Kingscote soil	110×10^{-6} emu/g
"Non-magnetic" soil	50×10^{-6} emu/g
Burnt house floor	400×10^{-6} emu/g
Fired clay from a hearth	1400×10^{-6} emu/g

As Mike Tite has commented, "...the Kingscote soil is reasonably high and consistent with the fact that the site is on Jurassic strata which would have a high iron oxide content."

Fig. 21A Combined plots of Grid Nos. 2,
3 and 4 made at 2-meter spacing. Contours
of Nos. 2 and 3 are drawn at 10-unit
intervals; and No. 4, at 5-unit intervals.



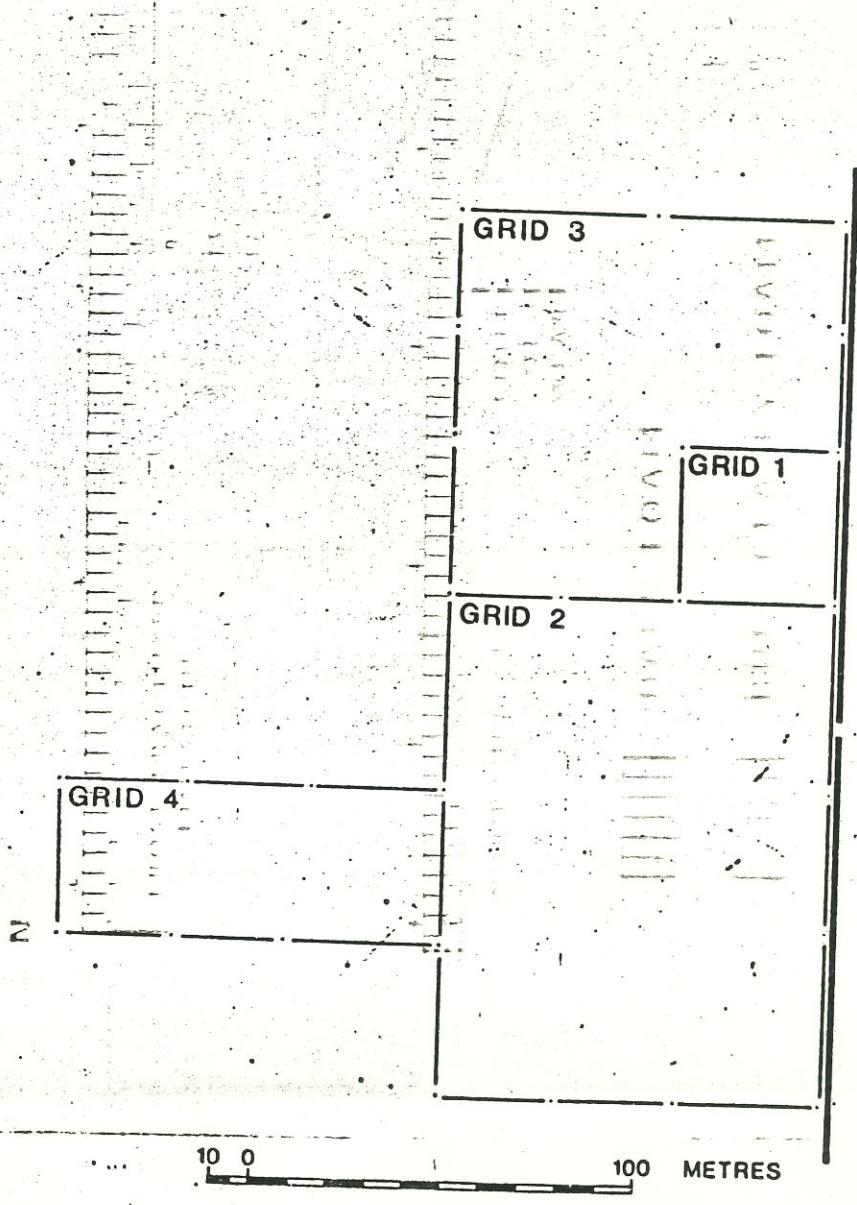
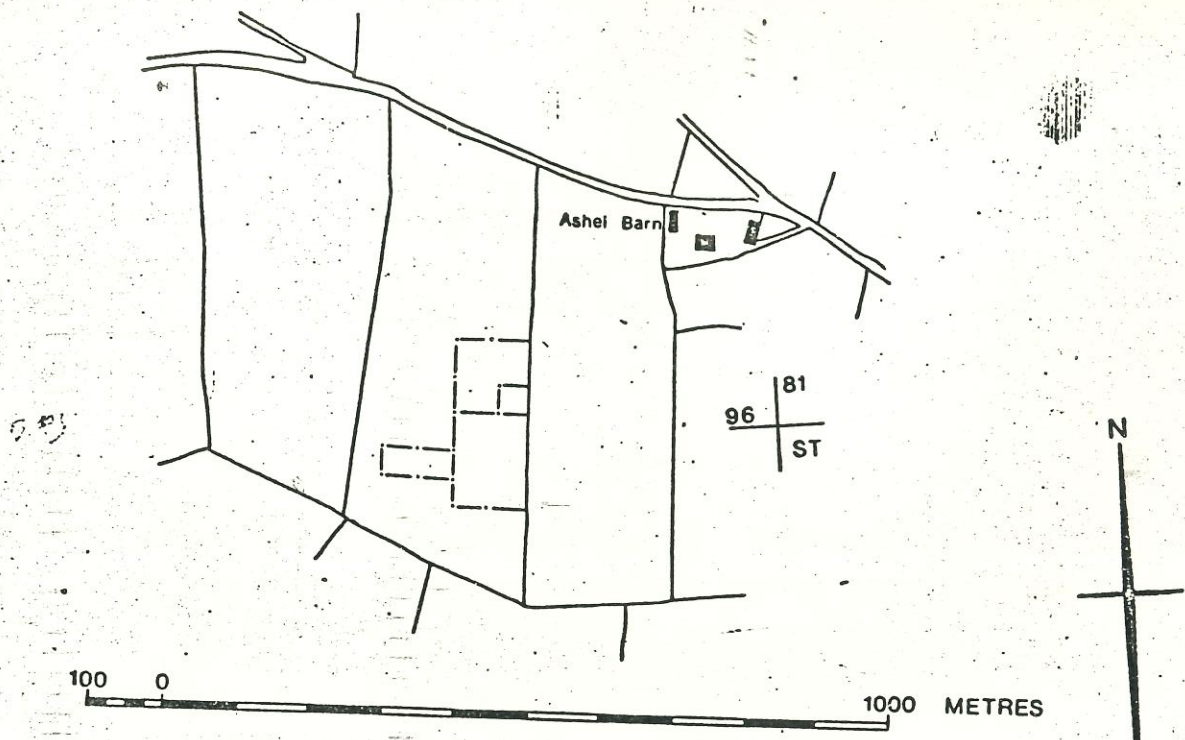
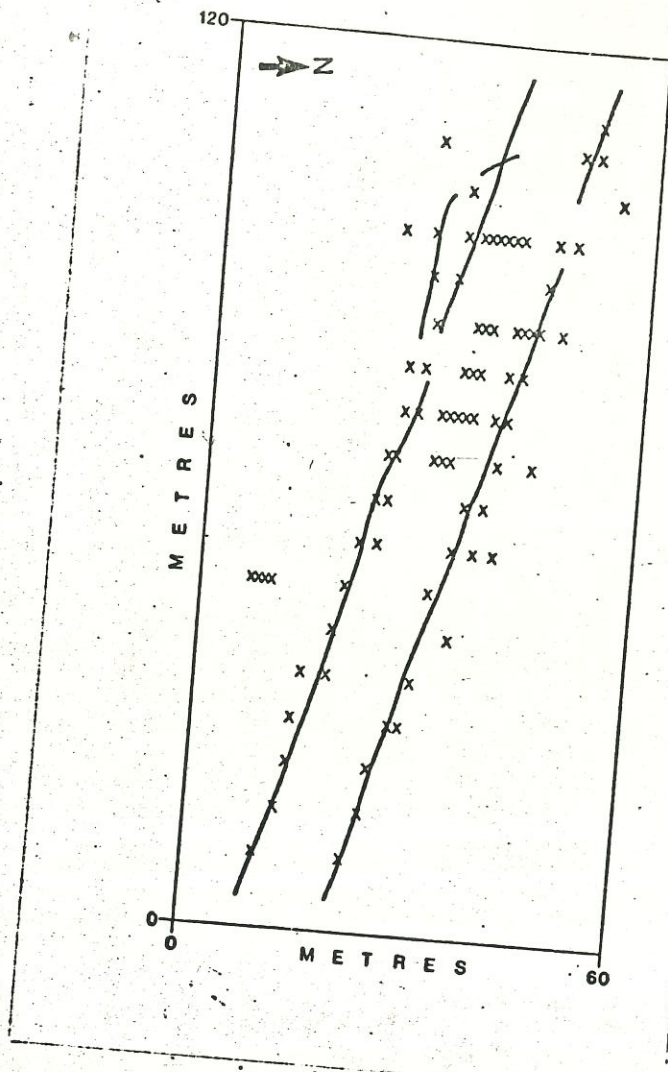


Fig. Appx 16, Fig. 23 Magnetometer grids, Kingscote, Gloucestershire



Appx. 6. Fig. 24 Kingscote . Plot of anomalies detected with audio readout in the region of grid No. 4.

x = magnetic anomaly
 - - = crop mark