SOME RESULTS FROM A VLF ELECTROMAGNETIC SURVEY IN BRADGATE PARK, LEICESTERSHIRE

by

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Summary

Results from a Very Low Frequency (VLF) electromagnetic survey conducted in Bradgate Park, Leicestershire, are presented. Certain anomalous zones, displayed on a map of contoured Fraser filtered values, correlate with known geological features. The results suggest that surface deposits of Keuper Marl and Pleistocene boulder clay are the principal causes of anomalous readings, and that the present distribution of these deposits is controlled by the underlying structure and lithology.

Introduction

Electromagnetic (EM) prospecting methods use electromagnetic fields to induce current flow in conductive material in the ground. By measuring the secondary magnetic field produced by these currents, information about the distribution of conductive material may be obtained. Zones of high conductivity often relate to lithological horizons and geological structures, such as fault zones.

A Very Low Frequency (VLF) electromagnetic survey was undertaken in Bradgate Park, near Anstey, Leicestershire, as part of a project to investigate the potential of EM prospecting techniques for geological mapping. In Bradgate Park there are outcrops of steeply dipping Pre-Cambrian strata, and the contacts of an igneous intrusion, a porphyritic microdiorite known as markfieldite. This study was designed to illustrate the response of these geological features to electromagnetic fields.

In this paper some results of the survey are presented and discussed in relation to the known geology. It is stressed that the survey was not intended as a rigorous geophysical investigation of the park, and that scope exists both for further interpretation of the results obtained so far, and for more detailed VLF surveys.

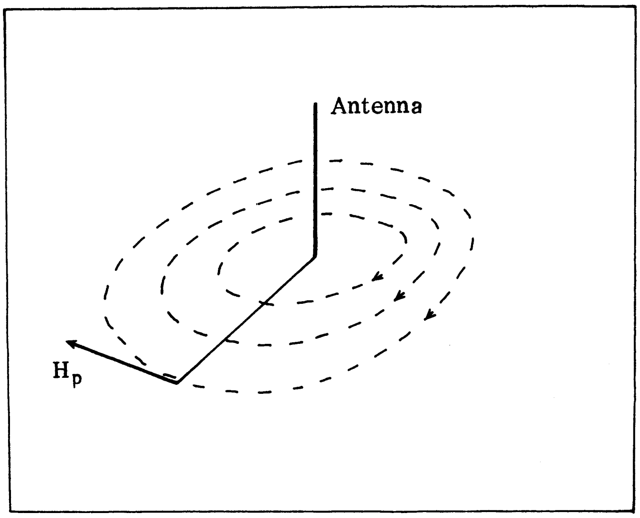
Theory

The theory of VLF electromagnetic surveying has been thoroughly reviewed by Patterson & Ronka (1971). The method uses EM fields generated by military radio transmitters. The transmissions are in the frequency range 15-25 KHz, and at present give essentially worldwide coverage.

The transmitting antennae, which can be considered as electric dipoles, produce three modes of wave; a ground wave, a sky wave and a space wave. At distances greater than several wavelengths, the main mode of propagation is as a sky wave in a waveguide bounded by the Earth's surface and the ionosphere.

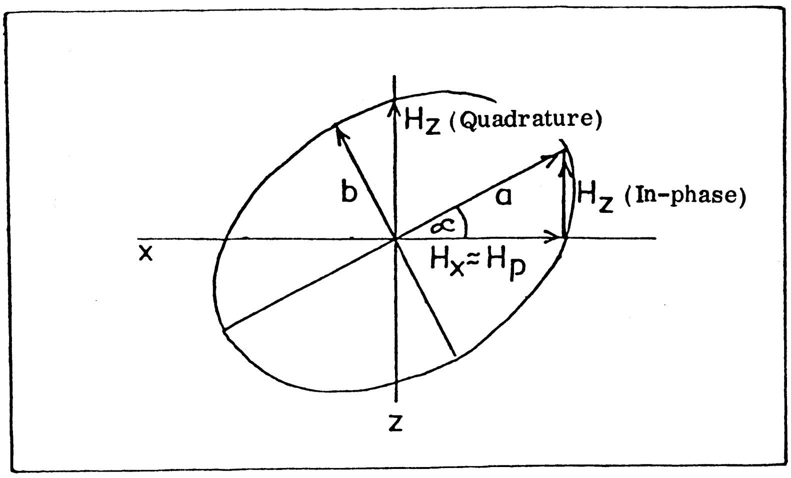
Mercian Geologist, Vol 7, No.4,
1980, pp.279-289, 8 text-figs.

An electromagnetic wave can be resolved into electric and magnetic components. At large distances from the transmitter, the primary magnetic field component (Hp) of the sky wave is effectively horizontal, and is polarised cylindrically about the transmitter (text-fig.1).



Text-fig. 1: Cylindrical polarisation of the primary magnetic field about a transmitter antenna.

A primary magnetic field passing through a conductive body induces within it electrical currents. The flow of these currents induces a secondary magnetic field which combines with the primary field to give a resultant magnetic field which is elliptically polarised in the vertical plane containing the traverse direction (text-fig. 2).



Text-fig. 2: Ellipse of polarisation of the resultant magnetic field.

Measurements of the tangent to the tilt angle (α) of the resultant field, and its ellipticity (b/a), approximate to measurements of the components of the vertical magnetic field which are in-phase, and $\pi/2$ radians out-of-phase (quadrature) with the primary magnetic field.

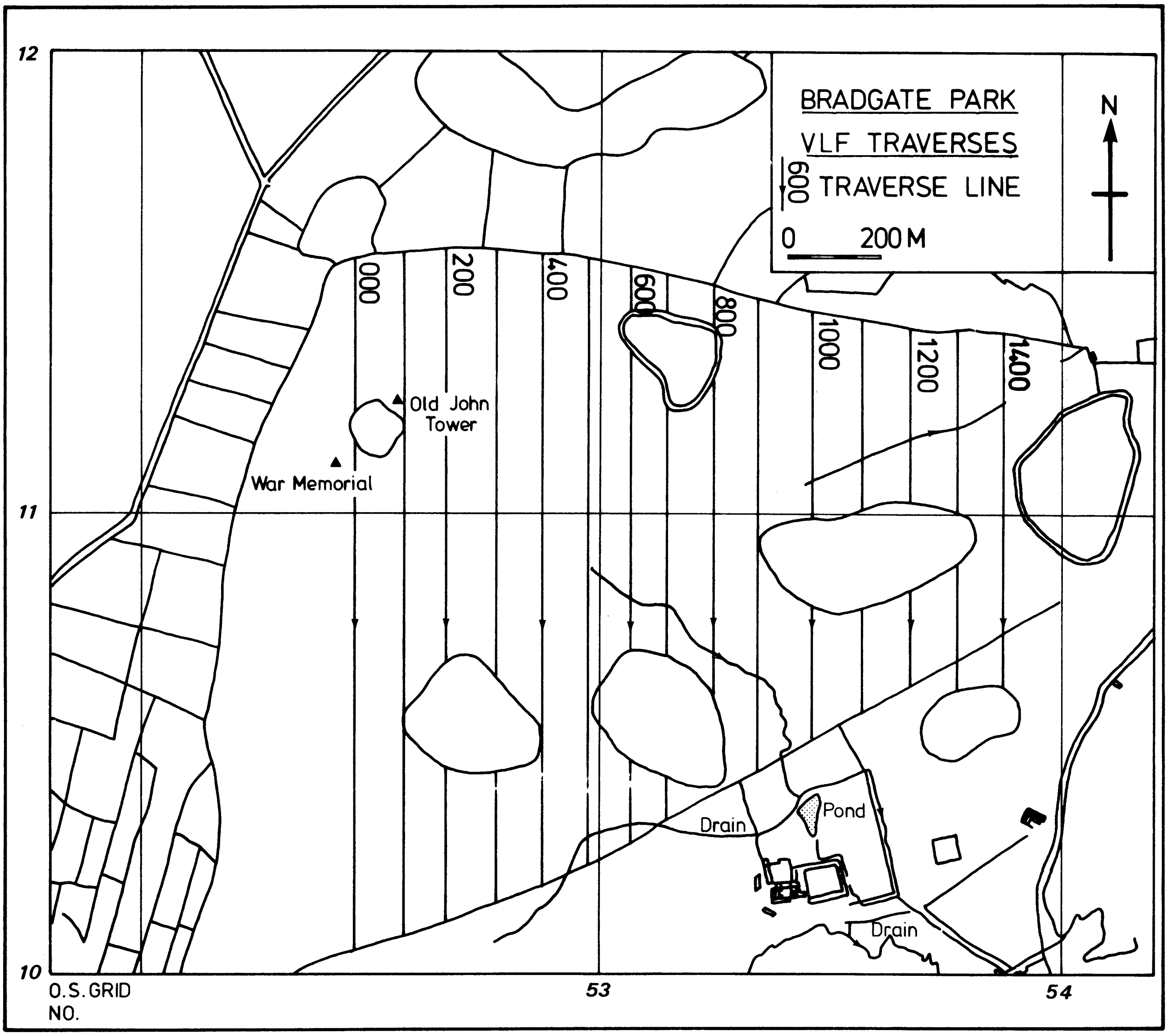
The tilt angle and ellipticity of the polarisation ellipse are measured by manual nulling of the signal detected by search coils in a receiver. Readings are generally displayed as approximate in-phase and quadrature components of the vertical magnetic field, expressed as percentages of the primary magnetic field.

Survey Method

The direction in which traverses are made is dictated partly by the position of the transmitter, and partly by geological strike. Ideally, a transmitter is chosen that will give a primary magnetic field direction perpendicular to the geological strike. Since induced currents flow perpendicular to the primary magnetic field, such a transmitter induces the maximum amount of current.

Olsson (1978) stated that the most useful traverse direction is perpendicular to geological strike. This is true even when the primary magnetic field vector is not perpendicular to strike. Traverse lines should therefore be perpendicular to strike, and the transmitter used which generates a primary magnetic field closest to the traverse direction. This condition usually limits the choice to one or two transmitters. When more than one suitable transmitter is available, that giving the clearest signal is used.

The transmitter chosen for this survey was NAA, Cutler, Maine, U.S.A. (17.8 KHz), and traverse lines were set out as in text-fig. 3. The receiver used was a Geonics EM 16, which requires only one operator.



Text-fig. 3: Traverse lines used in Bradgate Park for transmitter station NAA, Cutler, Maine, U.S.A. (Long.67°17'W., Lat.44°39'N.).

An interval of 100 m between traverses was chosen to enable rapid completion of the survey. Resolution of anomalous zones could be improved by using a 50 m interval, although Parasnis (1973) states that lateral resolution in VLF surveying is generally poor, due to the essentially two dimensional nature of most anomalies.

Fourteen traverse lines were surveyed, although readings were not taken in certain wooded enclosures designated as conservation areas. Readings along traverses were taken at 10 m intervals, which was chosen to permit numerical processing of the readings.

Presentation of Data

Initial presentation of data is as simple profiles of receiver readings plotted against position along traverse. Anomalies are easily recognised, but detailed interpretation requires the use of digital filtering techniques coupled with a certain amount of geological information.

The filtering technique devised by Fraser (1969) calculates the differences between the sums of consecutive pairs of readings. The filter converts the typical inflexion type anomaly into maximum values which are amenable to contouring. Only in-phase values are generally used in this filter.

A second type of digital filter, devised by Karous and Hjelt (1977) was used to compute an apparent sub-surface current distribution (Ia). If H_{1-7} are seven consecutive, equi-spaced VLF readings, either in-phase or quadrature, then:

$$Ia_4 = 0.102H_1 - 0.059H_2 + 0.561H_3 - 0.561H_5 + 0.059H_6 - 0.102H_7$$

Values computed using this equation are normally plotted and contoured to give a vertical cross-section. Maximum positive values of current concentration in such sections can be used to estimate the dip and depth of conductive bodies.

Results

Positive Fraser filtered VLF values have been plotted on a map (text-fig. 4) and contoured. An exponential contour interval has been used to permit display of anomalies of different intensity. Three examples of anomalies related to geological features have been selected for discussion using the geological map shown in text-fig. 5.

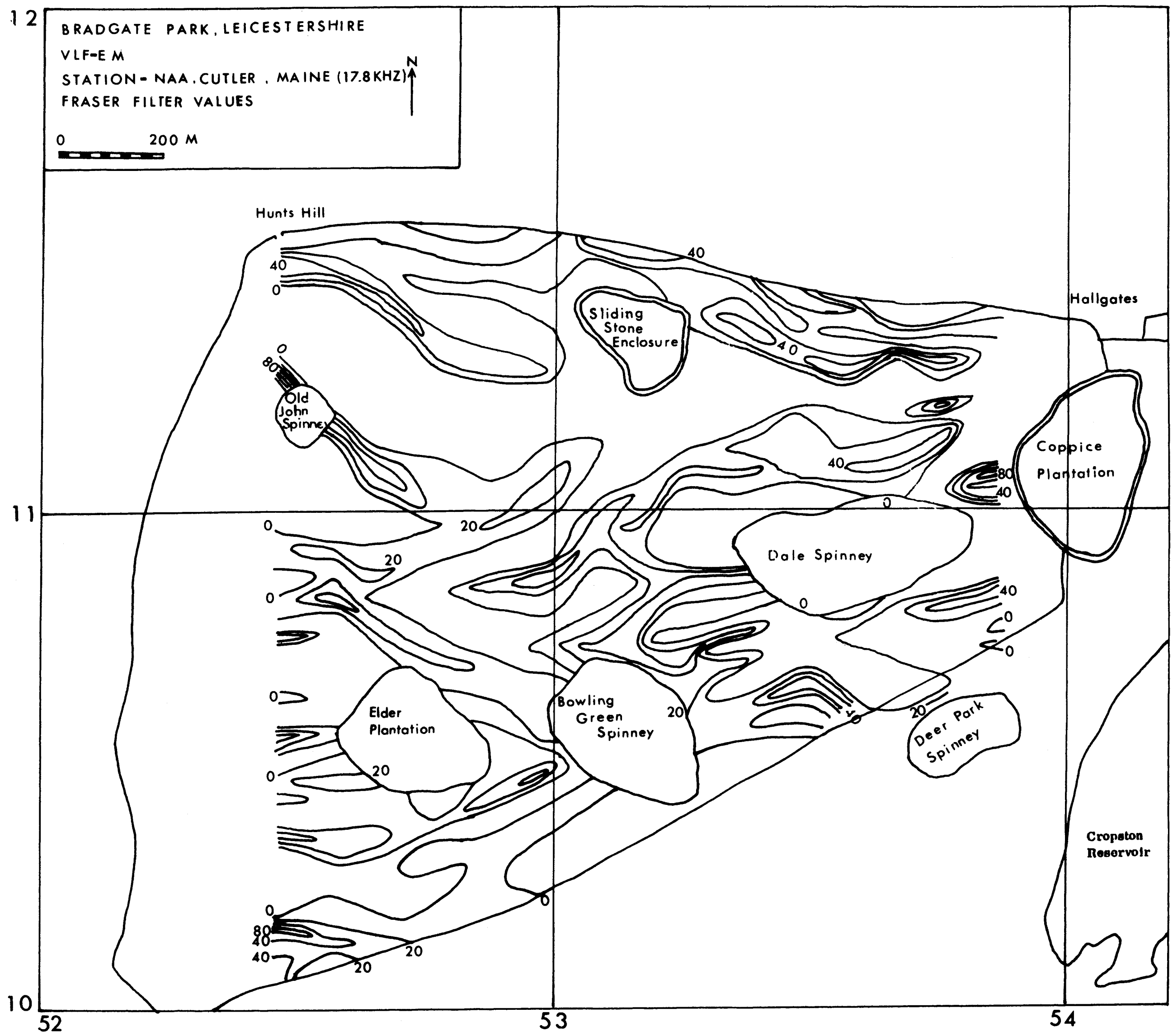
The anomalies east of Sliding Stone Enclosure and passing between Dale Spinney and Coppice Plantation are caused by a covered reservoir and a 30 inch diameter water pipe, and are not considered further.

Example 1

The north-west corner of the park is underlain by an accumulation of boulder clay, possibly covering Keuper Marl in a buried basin. The south-west margin of this basin is bounded by a fault which runs through Old John Spinney. This fault is clearly delineated by the VLF measurements, as is the northern edge of the basin. Both features correlate with zones of large positive Fraser filtered values, shown in text-fig. 4.

A Karous-Hjelt section (text-fig. 6) shows current concentration, associated with the fault, reaching a maximum very close to the surface, and decreasing with depth. This suggests that the source of the anomaly is shallow. If the source of the anomaly were a conductive fault zone, the lines of maximum current concentration would probably extend to a greater depth than shown. The source is therefore likely to be a small buried valley, infilled with boulder clay, whose position is controlled by that of the fault.

The plot of apparent current distribution is not for a line perpendicular to that of the fault, so any angles determined from the section will only be apparent angles.



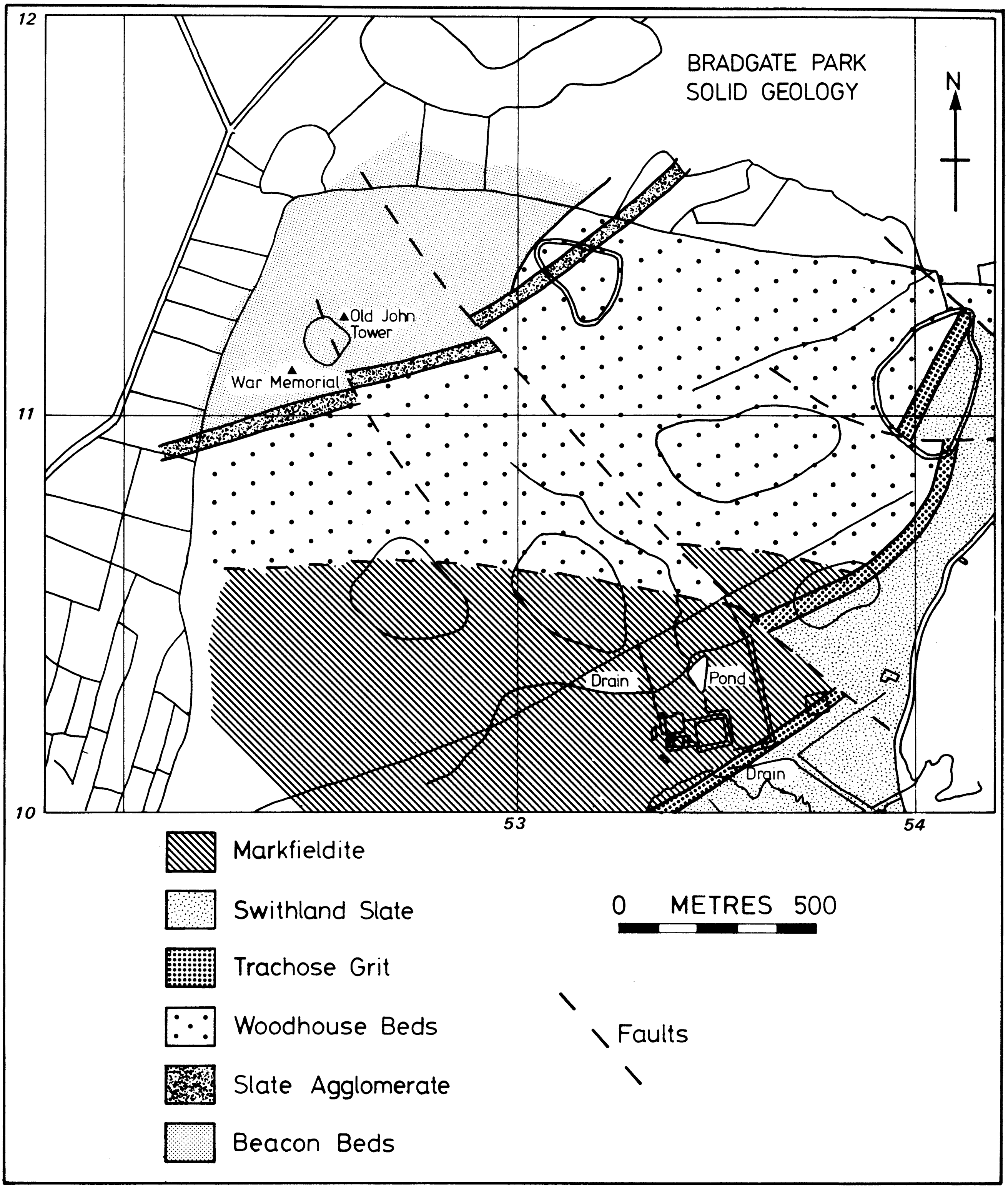
Text-fig. 4: Contoured positive, Fraser filtered VLF electromagnetic measurements, Bradgate Park.

Example 2

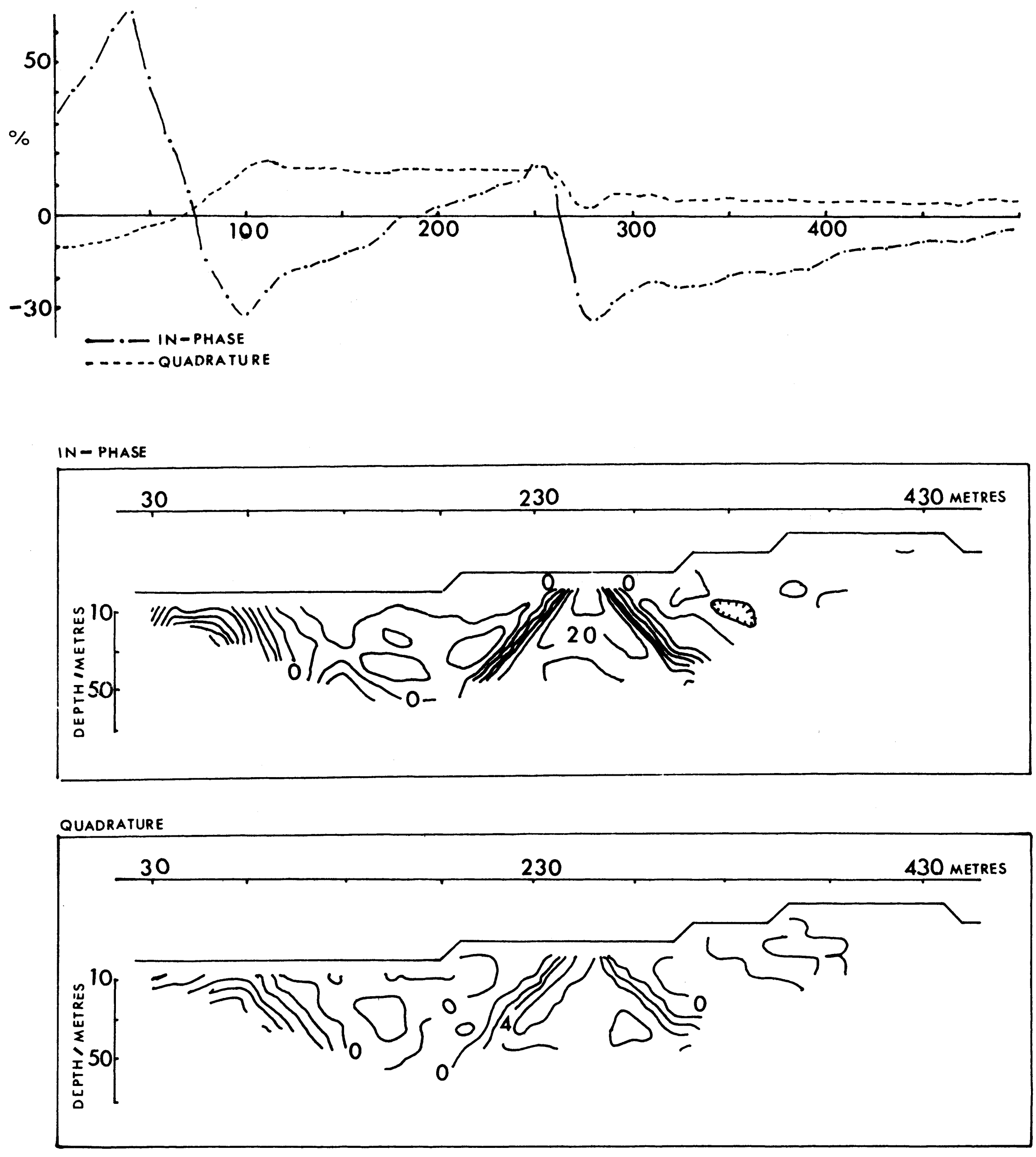
Text-fig. 7 shows results from part of a traverse beginning about 350 m south of the War Memorial. This shows a pair of anomalies about 200 m apart. These are almost certainly due to the margins of a sheet of boulder clay. This is indicated by the Karous-Hjelt section which shows regions of maximum current concentration corresponding to the edges of the boulder clay.

The northern edge of the boulder clay is about 800 m along the traverse, and dips steeply to the north. The southern edge appears to be controlled by the large markfieldite intrusion whose contact has been mapped in the vicinity of the 930 m point. Maximum current concentration suggests a near vertical contact. This could be the edge of the clay abutted against a buried scarp.

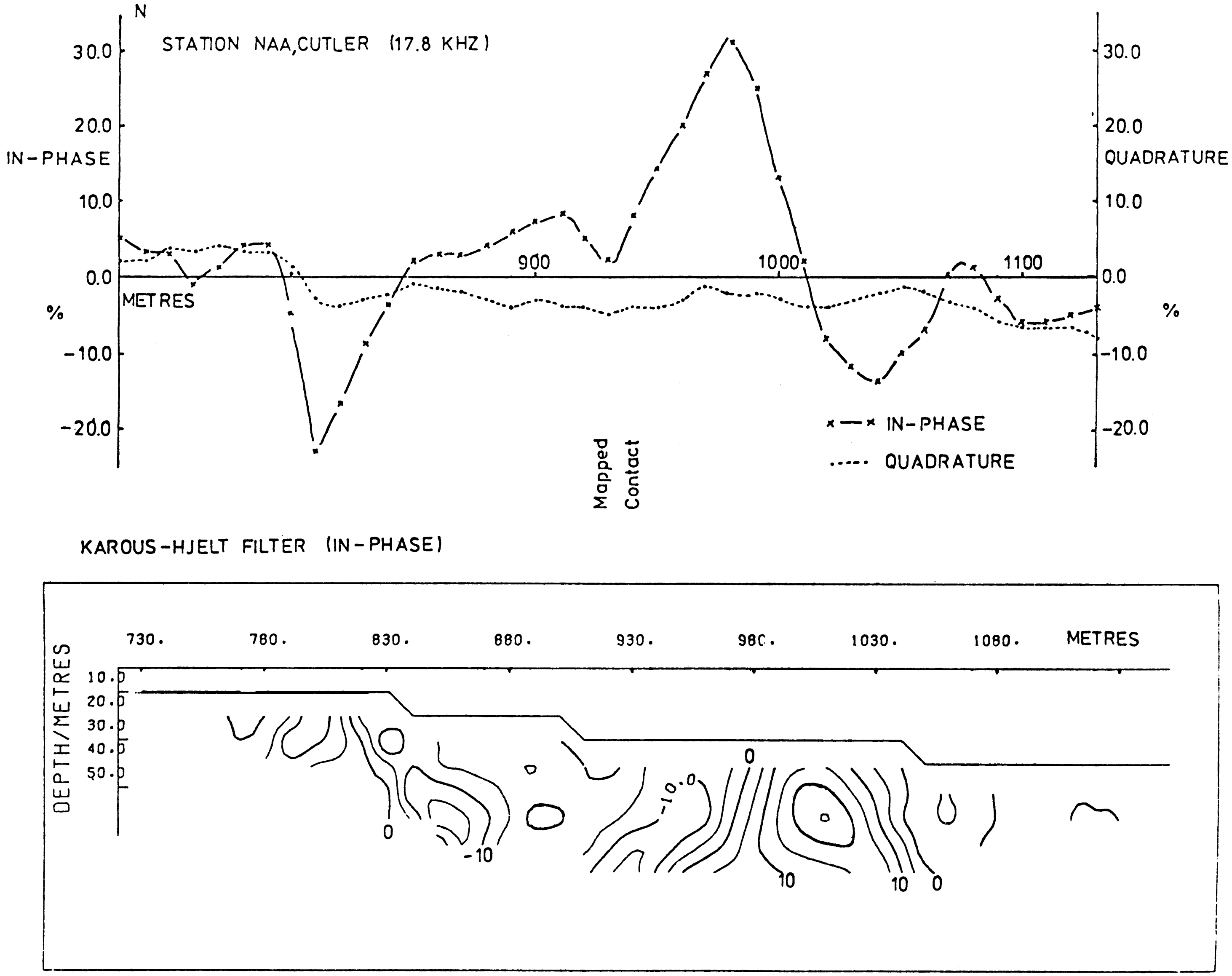
The maximum current concentration occurs at about 30 m depth. This suggests that the thickness of the boulder clay against the scarp is about 30 m. Two points should be noted, however. Firstly, the deeper parts of the section may not correspond to real features but may merely be a response of the filter to the use of values from two adjacent anomalous



Text-fig. 5: Map of the Precambrian Geology of Bradgate Park.
(Adapted with kind permission from Ford, 1975)



Text-fig. 6: VLF electromagnetic profile (top) and corresponding apparent current distribution sections, line 000.



Text-fig. 7: VLF electromagnetic profile (top) and corresponding apparent current distribution section (in-phase), line 000.

zones. More experimental studies, possibly using scale models, are needed to enable the response of the filter to be understood in such situations.

The second point is that the depth of penetration of the VLF signals is uncertain. Electromagnetic methods usually detect meaningful signals down to one skin depth (t_s) of conductive strata, where

$$t_s = \sqrt{\frac{2\rho}{\mu w}} \text{ metres}$$

and ρ = resistivity in ohm-metres

μ = magnetic permeability (usually $4\pi.10^{-7}$Henries/m.)

w = angular frequency (= 2πf radians/sec.)

The frequency (f) used in the survey was 17.8 KHz.A Schlumberger DC resistivity sounding made near the Hallgates entrance, gave resistivity values for boulder clay in the range 5-45 ohm-metres. This would limit VLF penetration to between 8 and 25 m. Three other resitivity soundings gave much higher resistivity values for the boulder clay, of over 1000 ohm-metres. The problem of uncertain depth of penetration must lead to cautious treatment of apparent current distribution sections, and an awareness that deeper features indicated by the section may not be real.

The implication of the steep southern contact between boulder clay and markfieldite is that the contact is a buried fault scarp. The possibility that the northern edge of the markfieldite is faulted has been mentioned by Ford (1975) among others, but surface evidence for this is poor. In addition, the previously mapped position of the contact is 60-70 m north of the position suggested by the VLF measurements. Since exposure is poor in this region, the VLF measurements may offer a better indication of the true position of the contact than the results of surface mapping.

By comparing text-figs. 4 and 5, it can be seen that although the contact extends to the east of Bowling Green Spinney, the anomaly is not continuous along its length. This is not surprising since the boulder clay cover is known to be irregular. Where the markfieldite is deeply buried by boulder clay, no anomaly would be expected because of signal attenuation by the boulder clay. The north-eastern corner of the intrusion is defined by an anomalous zone 150 m north-west of Deer Park Spinney. This anomaly is probably caused partly by the major N.W.-S.E. trending fault, and partly by the edge of the boulder clay against the intrusion.

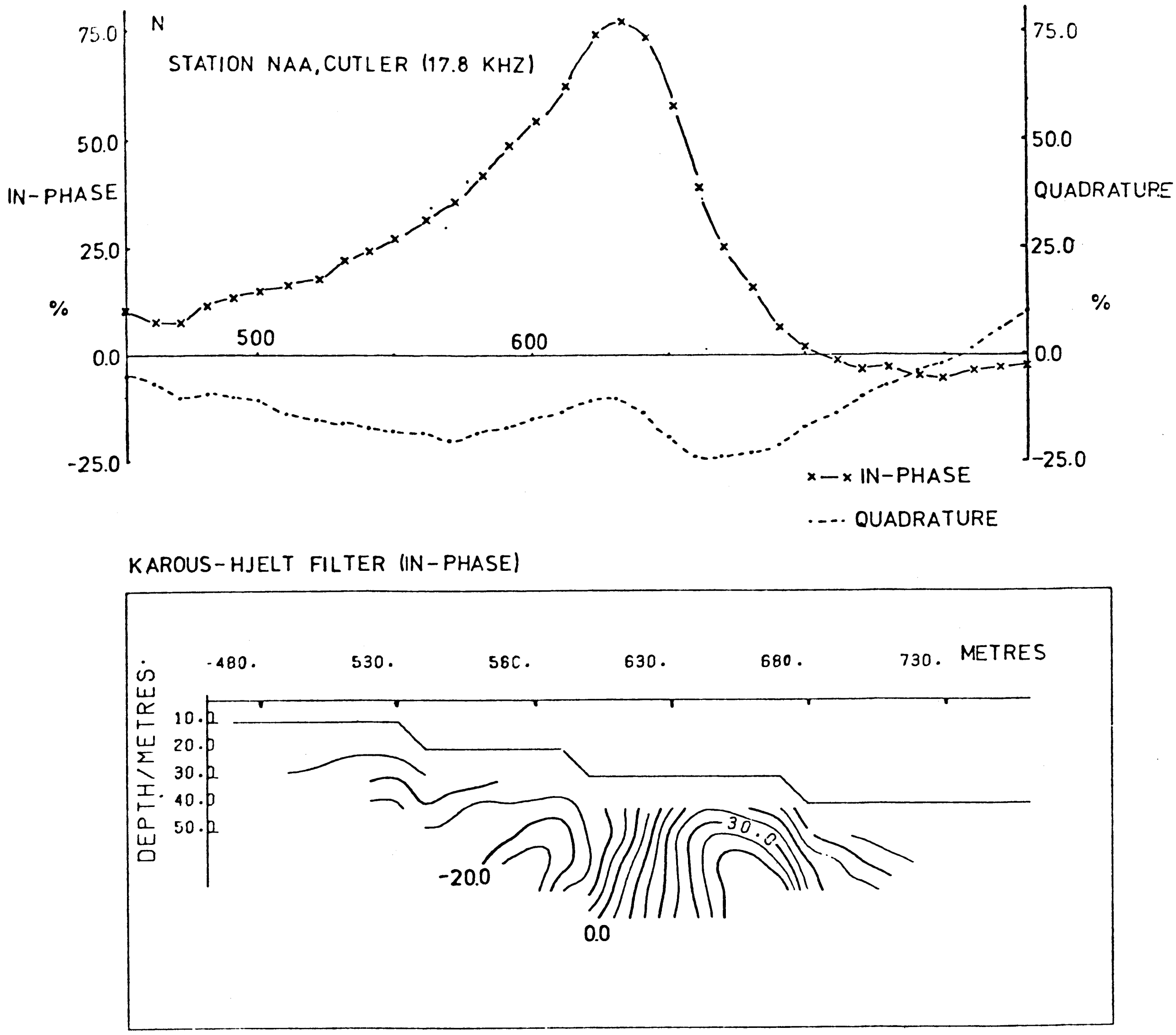
Example 3

A major fault is known to cross the park, running N.W.-S.E. from about 100 m east of the Hunts Hill entrance, between Bowling Green Plantation and Deer Park Spinney, towards Deer Barn. The mapped position of the fault coincides with intermittent VLF anomalies. This is considered to be a consequence of the fault acting as a control on accumulations of boulder clay and Keuper Marl, in a similar manner to that of the markfieldite intrusion.

Text-fig. 8 shows an apparent current distribution section for a line extending south from a point 300 m south of the eastern edge of Sliding Stone Spinney. A zone of maximum positive current concentration reaches the surface about 650 m along the profile, and dips south at about 65°.

The mapped position of the fault is 20-30 m to the south of this point. The VLF measurements may again, however, indicate the true position of the fault, in view of the limited exposure. Similar patterns of current concentration occur in the two adjacent lines to the west, and Fraser filtered values (text-fig. 4) in grid area 531109 also suggest a fault controlled anomaly.

The absence of substantial anomalies in regions of high ground supports the suggestion that boulder clay abutted against a buried fault scarp, and not a conductive fault zone, causes the anomalies.



Text-fig. 8: VLF electromagnetic profile (top) and corresponding apparent current distribution section (in-phase), line 800.

Summary and Conclusions

A map of Bradgate Park showing contoured, positive Fraser filtered VLF values (text-fig. 4) is presented, and three examples of anomalies caused by geological features have been discussed. In each case, anomalies are shown to be caused primarily by current flowing in Pleistocene boulder clay, and possibly Keuper Marl, known to cover much of the park, and whose distribution is partially controlled by the underlying Pre-Cambrian geology.

VLF measurements have enabled delineation of two faults, and results support the suggestion that the northern contact of the markfieldite intrusion is faulted. Several constraints on the credence given to the interpretation must be noted. These provide suggestions for further study, both in terms of VLF surveying in general, and for VLF surveying in Bradgate Park in particular.

Firstly, the Karous-Hjelt filter has yet to be fully assessed. Members of the Applied Geophysics Unit of the Institute of Geological Sciences have undertaken some investigations into its response to a variety of conductive structures (Patrick, 1978), and their findings should shortly be available as an open-file report. Work is clearly needed to assess the affect on VLF anomalies, of two or more conductors in close proximity, and of topography, especially when using the Karous-Hjelt filter.

No topographic corrections have been applied to measurements made in this work. Fraser filtering attenuates anomalies due to topography (Whittles, 1969) so that the results shown in text-fig. 4 are largely unaffected by topographically generated anomalies.

Finally, although regional geological strike appears to exert some control on the VLF anomaly pattern, no clear indication of either Pre-Cambrian lithological boundaries, or the dip of strata, was obtained from the survey.

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