# INDUCED POLARIZATION (IP) ANOMALY IN THE BROADLANDS GEOTHERMAL FIELD

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*ABSTRACT*

*An IP anomaly, discovered in 1973 during resistivity surveying, exists over an area of about 100 × 300 m coinciding with the resistivity boundary marking the southern edge of the Broadlands geothermal field. Detailed IP, resistivity and magnetic surveys over the site reveal unusual fine structure in the resistivity pattern and a small magnetic anomaly.*

*The cause of the IP anomaly was investigated in 1980 by a 156 m deep drillhole. Low resistivities (5 to 15 Ωm) and temperatures of up to 100°C measured in the lower half of the hole are consistent with the complex surface resistivity pattern. Downhole logging runs confirmed the existence of the IP effect and from measurements on cores the main IP zone was identified as a layer of sand lying between 25 and 45 m deep. To date, petrologic examination of the cores has not identified any minerals that seem capable of causing the IP effects. Disseminated metallic sulphides known to cause such anomalies in other places are absent.*

## INTRODUCTION

Reconnaissance resistivity surveys in the early 1960s (Hatherton et al. 1966) which first drew attention to the large size of the low resistivity hot water reservoir within the Broadlands geothermal field provided the inducement for deep drilling, further geophysical, geological and geochemical exploration and the eventual decision to develop the field for electricity generation. As part of the follow-up geophysical work several detailed resistivity surveys (summarised by Risk et al. 1977) were made to more accurately delineate the lateral resistivity boundary of the field. In one of these (made in June 1973 and discussed by Risk, 1975), interference attributed to the induced polarization (IP) effect was noticed on several resistivity records from the south of the field. In 1975, the region surrounding the sites of the IP interference (see Fig. 1) was explored in detail with close spaced resistivity, IP and magnetic surveys. A 156 m deep drillhole (BRM5) was drilled in November 1980 to investigate the cause of the IP anomaly. This paper summarises the information gathered from the exploration programme up to September 1981.

## RESISTIVITY MEASUREMENTS

In addition to revealing the existence of the IP effects the 1973 survey (Risk 1975, Fig. 4) showed that the anomalous region straddles the resistivity boundary zone of the field and that within the zone the apparent resistivity pattern is more complex than the gradual transition from low to high apparent resistivity observed over other portions of the field's boundary. In a later survey which mapped the entire resistivity boundary of the field a complex apparent resistivity pattern was again found only within the IP zone (Risk et al. 1977, Fig. 2c, lines RE and RD). In both cases deviations of the electric field occurred at secondary resistivity highs and lows.

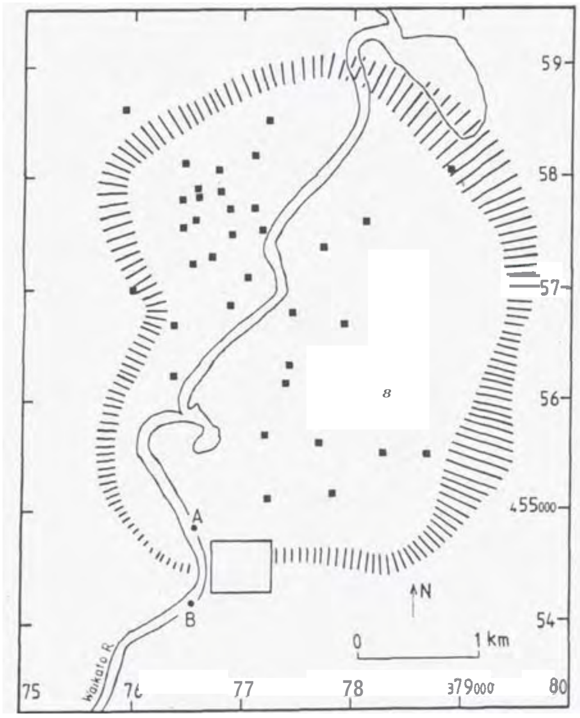



*Fig. 1: Broadlands Geothermal Field. Hatching represents lateral resistivity boundary zone separating 2 to 5 Ωm rock inside from 20 to 50 Ωm outside. Squares are deep (≈1 Km) drillholes. A and B are the resistivity/IP current electrode sites. Rectangle is the IP zone explored in detail.*

Fig. 2a shows contours of apparent resistivity obtained from a third survey made over the IP zone in November 1975 using current electrodes A and B (Fig. 1) as the source bipole. A 25 m long north-south oriented potential dipole was used to measure apparent resistivities at the positions of the dots on Fig. 2a. To the north of the topographic scarp (and throughout most of the interior *of* the field) the apparent resistivities are less than 5 Ωm. To the south of the IP zone values greater than 20 Ωm, typical of the exterior of the field, occur. Nearly coinciding with the scarp is a secondary apparent resistivity high with values reaching about 20 Ωm. About 50 m south of the scarp there is a secondary low with values down to about 5 Ωm. The location of the secondary highs and lows are consistent with those obtained in the earlier surveys.

## INDUCED POLARISATION (IP) MEASUREMENTS

The current source used for these IP and resistivity measurements generated a waveform shaped as an interrupted square wave of the type commonly used for time domain IP prospecting (Bertin and Loeb 1976). The IP effect, when present, manifests itself as a transient superimposed on the square wave electric field being measured by the IP receiver. It usually originates from charge separation processes within the rock and is often found in rocks containing disseminated metal sulphides.

IP transients were observed at the sites in Fig. 2b with numbers alongside but the threshold of transient detection was higher than would have been desirable because of background noise and rather unsatisfactory damping characteristics of the available instruments. To avoid any possibility of confusing IP transients with transients arising from instrument damping, the residual amplitudes were read 6 seconds after disconnection of the current (of period 60 s). In IP prospecting such delays would be considered excessive and only very strong IP transients would be detectable with this measurement technique.

Fig. 2b gives the magnitudes (in mV/V) of the residual transients, measured in the 1973 and 1975 surveys. Recordings were made along the full length of each traverse line but strong detectable transients were observed only near the scarp. Since the damping effects would have been more likely to have masked positive (in the same phase as the source waveform) transients than negative (opposite phase) ones it is likely that the zone of positive transients to the south of the scarp is more extensive than depicted in Fig. 2b.

The region of negative transients coincides with the location of the secondary apparent resistivity highs in Fig. 2a, and although the data are few, positive transients and secondary apparent resistivity lows seem to coincide. From the earlier resistivity surveys (Risk 1975, Risk et al. 1977) in which electric field azimuths had been observed with 2-component receiver dipoles, it was shown that anticlockwise azimuth rotations occurred over the secondary apparent resistivity highs and clockwise rotations over the lows.

## MAGNETIC MEASUREMENTS

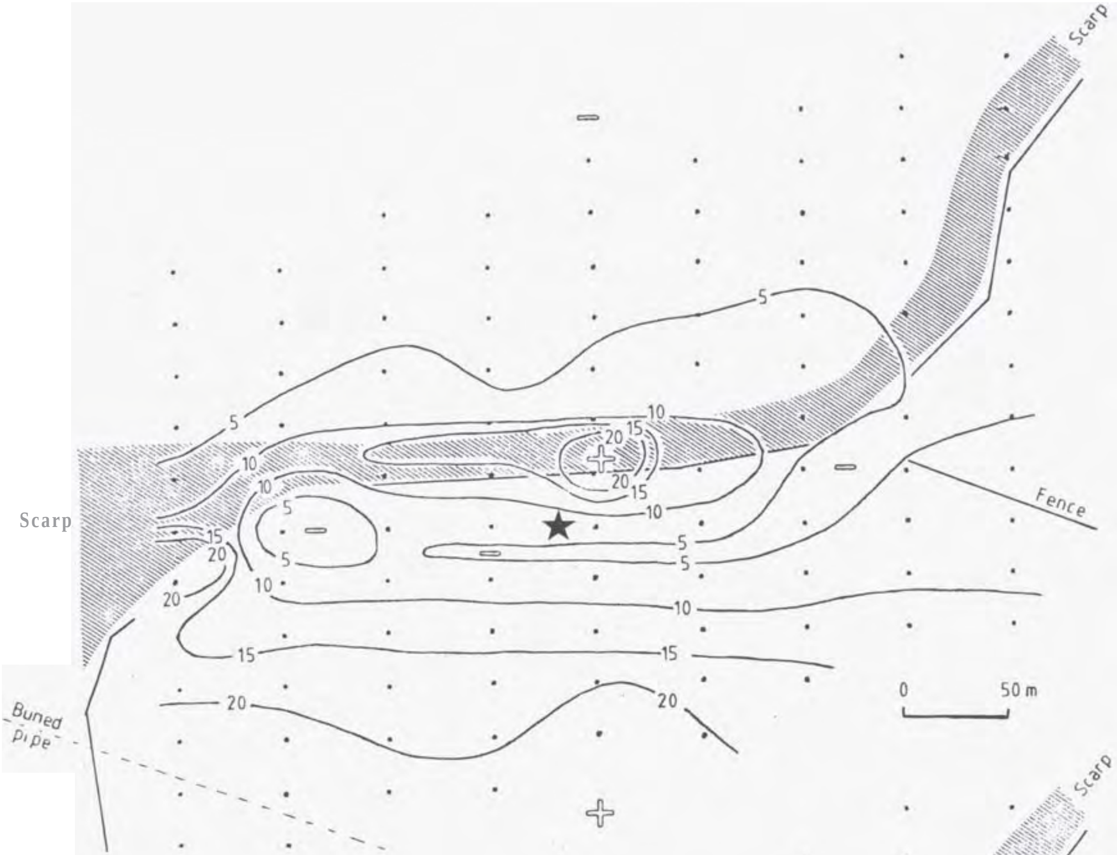
Total field magnetic measurements were made at all grid points using a portable proton magnetometer. Differences of field strength between each site and the base station, after allowing for diurnal variations, are plotted in Fig. 2c.

South of the IP tone, the magnetic field is, on average, about 80 nT greater than in the north. Thus the IP zone seems to separate two distinct magnetic zones each having a nearly constant field. The abruptness of the transition and the fact that smaller gradients were observed in earlier regional magnetic surveys (Hochstein and Hunt 1970) indicate that the source is shallow-seated, possibly lying within a few hundred metres of the surface. A likely explanation is that the magnetic susceptibility at shallow depths to the south of the IP anomaly is greater by about $3 \times 10^{-3}$ SI units than to the north. It is suggested that the susceptibility in the north may once have been similar to that south of the IP zone but has been destroyed by prolonged exposure to geothermal fluids. This would imply that the IP zone marks the edge of the field in agreement to the interpretation of the resistivity data.

## INTERIM CONCLUSIONS AND CHOICE OF DRILLSITE

The geophysical exploration showed that the rather rare IP phenomenon occurs over a small area straddling the resistivity boundary of the field at a place where the boundary zone is only about 100 to 200 m wide, much narrower than commonly observed in geothermal fields. Little has been done in expioring for IP in geothermal fields but it has been observed in other New Zealand fields and in Yellowstone National Park (Zohdy et al. 1973) where it was mostly attributed to the presence of disseminated pyrite mineralization. Such mineralization is known to exist in wells at Broadlands particularly in BR16 (the most south-easterly well shown in Fig. 1). IP anomalies found during mineral exploration in non-geothermal environments are also commonly caused by disseminated metal sulphides like pyrite (Bertin and Loeb 1976).

From the resistivity data it was reasoned that the low was the more diagnostic of the secondary anomalies, and taking into account the separation of about 50 m between secondary highs and lows, it was tentatively concluded that a conductive body lies at a depth of 50 m or SO below the secondary resistivity low. A body of disseminated sulphide mineralization would be expected to be both conductive and cause IP effects and this seemed the likely cause of the anomalies.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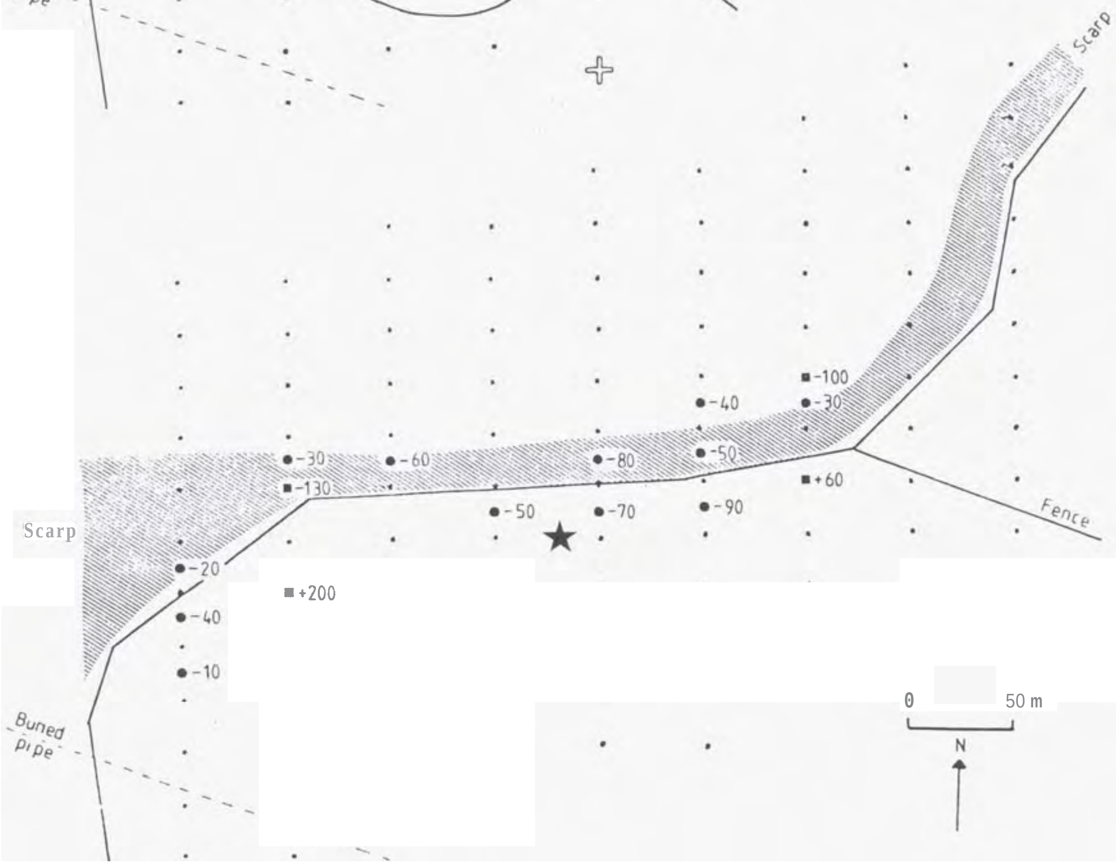
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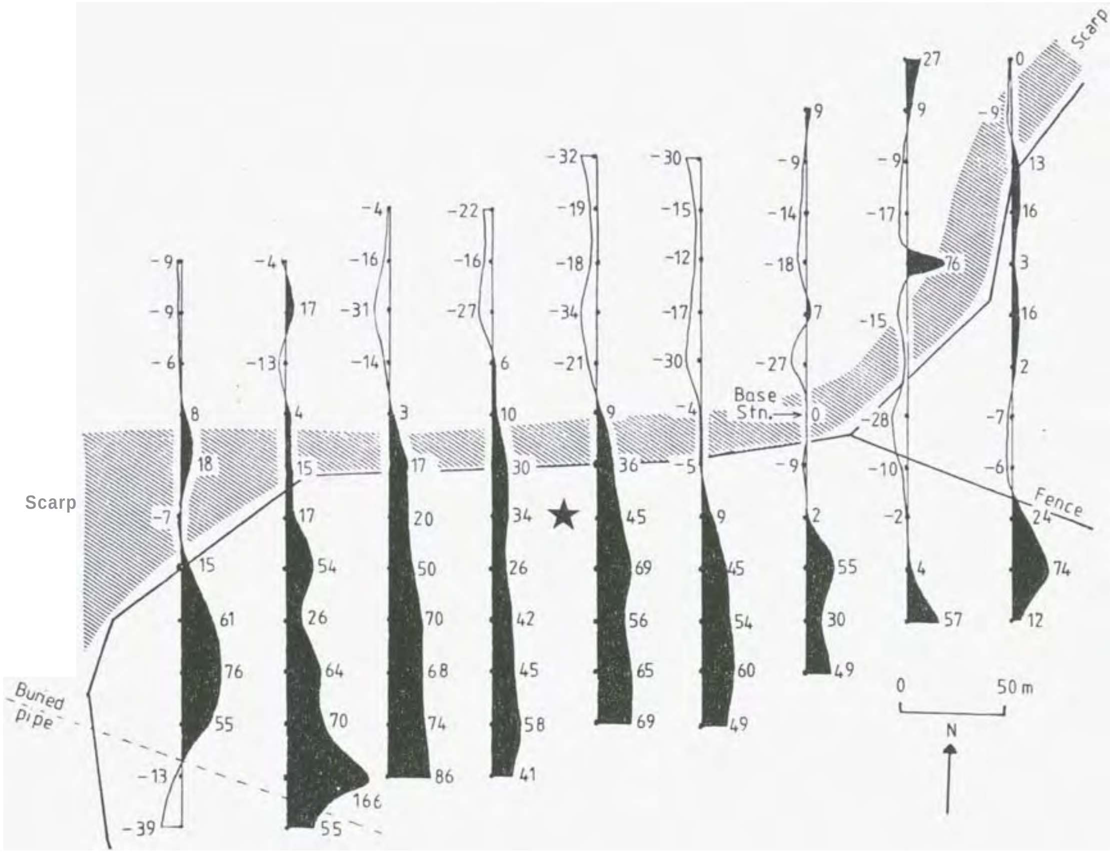


2c

*Fig. 2 Surveys over area outlined by rectangle in Fig. 1. Hatching is a 5 m high scarp at the edge of a river terrace. Solid lines are fences. Star indicates drillhole BRM5 site.*
*(a) Contours of apparent resistivity (in Ωm).*
*(b) IP results made using interrupted square wave of period 60 s. Transient amplitudes were measured 6 s after current was interrupted. Expressed in mV/V as ratio of transient amplitude to steady voltage during "on" interval. No transients observed at sites where no value is shown. Squares indicate sites measured in 1973, dots in 1975.*
*(c) Magnetic anomalies (in nT).*

When, in 1980, permission was granted to drill an exploratory hole to 150 m depth, the site shown in Fig. 2 was chosen. Along the east-west bearing it lies near the middle of the anomalous zone and in the north-south direction is about 10 m north of the centre of the secondary resistivity low.

## FINDINGS FROM THE DRILLHOLE

The hole (BRM5) was drilled to 156 m with cores taken at 12 levels. Stratigraphic core examination (I.A. Nairn, personal communication, 1981) revealed that all cores are tuffs. Down to 57 m they were fairly incompetent comprising poorly-sorted pumice-crystal sands and silts with occasional occurrences of a black magnetic mineral, presumably magnetite. At deeper levels were found more competent cores of finer material made up of dark grey fine pumice silts and sands with occasional pebbles of silicified mudstone but little magnetic material. Cores from the bottom 10 m of hole were of interbedded very poorly sorted pumice and crystal sands. Apart from being slightly silicified they appeared unaltered even though the bottom temperature is 101°C (see Fig. 4). Thus, visual examination of the cores revealed no minerals likely to explain the IP anomaly.

Plain casing was set in the hole to 67 m. While the lower part of the hole was temporarily uncased some electrical logging runs were made by M.C. and P.H. Syms and myself using a single downhole (current and potential) electrode connected to separate current and potential electrodes at the surface. This arrangement has poor resolving power. The resistance (R), self potential (SP) and IP parameters $P_1$ and PFE measured (see Fig. 3) tend to reflect the cumulative effects between the surface and the downhole probe of the related rock properties rather than those at the position of the probe itself. However relative changes can be inferred. Variations of the R parameter suggest that resistivity is lower than average from 75 to

95 m depth and below about 125 m. The SP curve mirrors the R log. The most important finding was that the IP parameters have high values confirming that a strong source of IP exists somewhere near the hole. The slight drop-off of the IP levels with depth implies that the IP effects either is diminishing with depth or perhaps is concentrated at a shallower depth than the range logged.

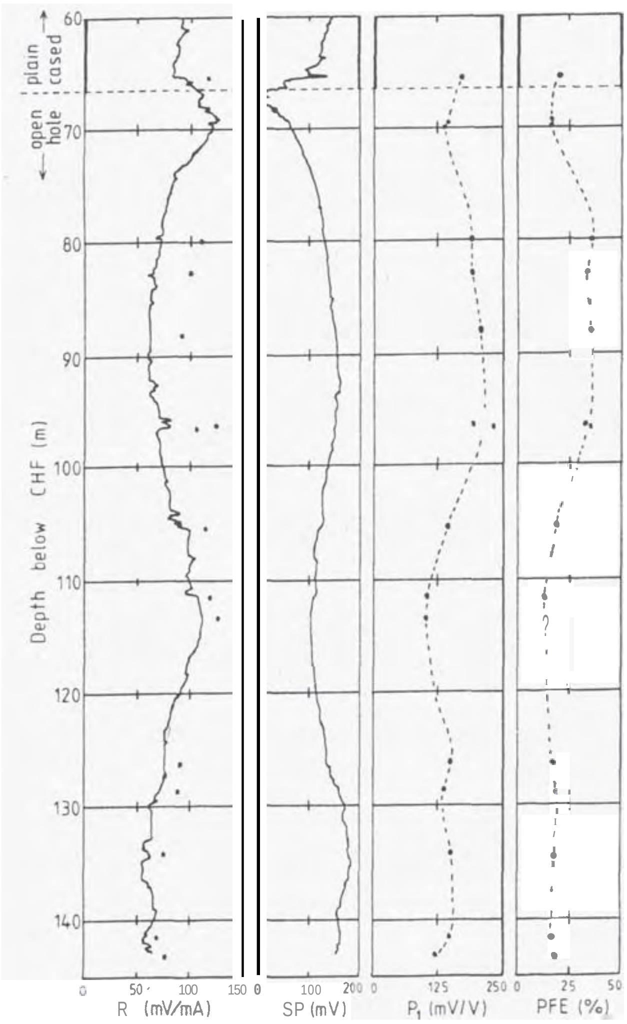


*Fig. 3 Downhole logs using 3 electrode arrangement. R - resistance, dots represent spot measurements (0.05 Hz) and solid line continuous log (23 Hz); SP - self potential; $P_1$ - IP parameter as for Fig. 2b but with period of 20 s and delay of 1 s; PFE - percentage frequency effect IP parameter obtained from the two R values.*

Results of laboratory measurements made on cores and cuttings are shown in Fig. 4. On cores from above the 70 m level high resistivities (15 to 75 Ωm) were obtained comparable with the surface measurements south of the site (shown in Fig. 2a). Below 70 m, the resistivity drops to between 5 and 15 Ωm verifying the earlier prediction that a conductive body lies beneath the site although even lower resistivities had been expected.

Very high IP levels were obtained on two cores from the 25 to 38 m depth interval while lower values (but above the background level) were obtained for other depths. High IP values were also measured on drill cuttings from 40 to 50 m depth but these data are considered unreliable because of the likelihood of false readings from contamination or IP suppression from remanent drilling mud. It was concluded that the main IP source lies at about 25 to 38 m depth.

Core samples of gravelly uncompacted sands (derived from pumiceous rhyolite tephra) from this depth range were subjected to a detailed petrological examination by Dr C.P. Wood. He found that they contained no sulphides such as pyrite or pyrrhotite and that the detrital magnetite content is less than 1% which seems typical of magnetite concentrations for such sediments in the Taupo region. Many common minerals were identified but none that are known to cause IP effects. The material shows no sign of hydrothermal alteration but there are traces of hydrothermal clays which appear to be not in equilibrium with each other or with fresh pumice glass present and are almost certainly of detrital origin.

Thus, at September 1981, no petrological explanation for the IP effects has been established. Four months after drilling, after having almost dried out, the cores from 25 - 38 m were remeasured and still had quite strong IP effects. Further rechecking of the measurements on the cores and of possible causes (or false indications) of IP will have to be made.

## CONCLUSIONS

At present important questions concerning the minerals causing the IP anomaly remain unanswered but some conclusions can be made about other aspects of the problem.

Low resistivities in the bottom half of the hole confirm the presence of a conductive body beneath the secondary resistivity low in Fig. 2a. Since the temperatures exceed 100°C this body seems to have a connection to the main part of the field passing beneath the (presumably) colder material causing the secondary resistivity high.

Agreement was found between the inferred positions of the edge of the hot water reservoir at shallow depths obtained from resistivity and magnetic data. The high temperatures show that the hot reservoir extends at least this far south but there are no more southerly holes to test whether it is, in fact, cold south of the resistivity/magnetic boundary.

Strong IP indications from surface measurements, cores, cuttings and downhole logging established, without doubt, the existence of the

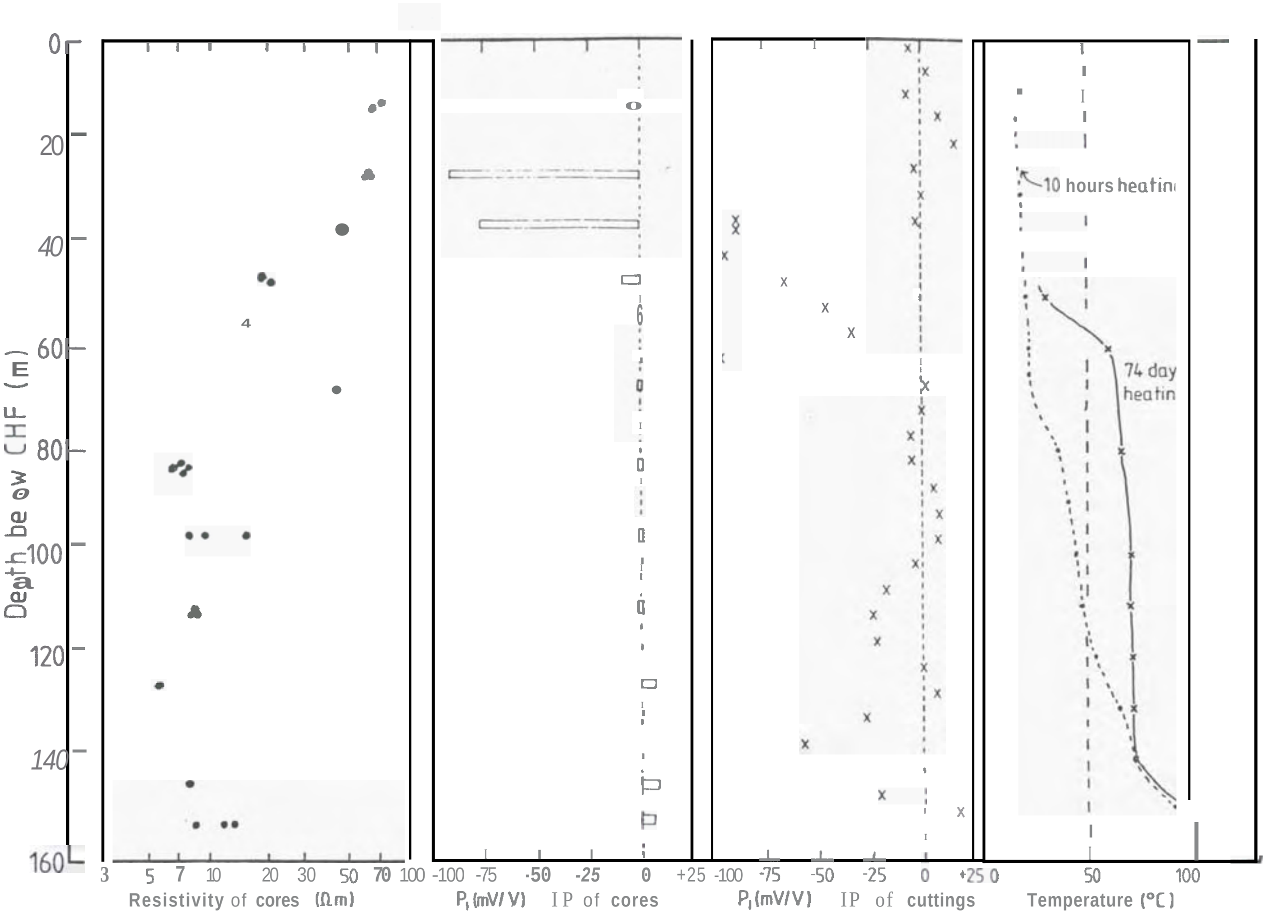


*Fig. 4 Temperature and measurements of cores plotted against depth below casing head flange (CHF) which is about 0.3 m above ground level.*

IP phenomenon at this site. However the exact position of the anomalous body and details of the cause of its IP property are at present uncertain.


## ACKNOWLEDGEMENTS

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