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ELECTRICAL SURVEYS IN THE ALBERTA FOOTHILLS

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ABSTRACT

The results of some direct current and transient electrical surveys in the Alberta Foothills are described.

A discussion of the assumptions used in designing these surveys is provided.

Results obtained over a known gas field showed an increase of response with the transient technique as the gas field was approached, but the source of this effect was confined to the near-surface, unconsolidated, recently deposited material. No significant change of the transient response due to deeper consolidated layers was seen.

The results also indicate the need to consider the effects of frozen near-surface layers when doing transient electrical surveys in Alberta early in the year.

INTRODUCTION

The Department of Geology and Geophysics at the University of Calgary has operated a field school for the students involved in the geophysics degree program for the past four years. One objective of this field school has been to provide the students with meaningful exploration problems and, with this in mind, the electrical methods part of the school has been directed toward an investigation of the contrast between the electrical properties of the ground over known hydrocarbon reservoirs and of ground not associated with hydrocarbons in the Alberta Foothills.

These tests employed direct current (DC) and transient current measurement modes, with detailed depth-sounding profiles being obtained by using both modes at each test site.

THEORETICAL CONSIDERATIONS

Various models of the means by which oil and gas reservoirs can influence electrical measurements made over such reservoirs have been proposed. Some authors have concentrated on the reservoir itself, viewing it as a highly resistive structure (*e.g.*, Kinghorn, 1967; Eadie and West, 1980). Others have looked for high-conductivity associations with the reservoir (*e.g.*, Zonge *et al.*, 1981), while a third approach sees geochemical alteration of the rocks above the reservoir providing an electrochemical (induced polarization) effect (*e.g.*, Snyder *et al.*, 1980).

Depending on the geologic setting under investigation, each one of these concepts may provide for significant influence on electrical readings taken on the surface over the reservoir, or all may fail.

It therefore appears desirable to consider the means by which each of these concepts would affect the use of an electrical exploration system and, if possible, consider the probability that any of these models will operate in an area of interest such as the Alberta Foothills.

A comprehensive theoretical development of the electromagnetic effects associated with grounded-wire systems was provided by Sunde (1949), while a corresponding theoretical development for the electrochemical (induced polarization) behaviour of the earth to grounded-wire systems was provided by Seigel (1959).

These two pieces of theory permit us to recognize the following influences that the earth will have on the response of an electrical exploration device using a grounded (or galvanic) current delivery system, transmitting a time-variant current with a frequency band from DC to 10 kHz:

i) The DC resistivity
ii) The inductive coupling through the ground between the current delivery system and any potential measuring system
iii) Capacitative coupling between the current and potential systems

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I wish to thank my colleagues Dr. D.C. Lawton, Dr. J. Brown and Dr. E. Krebes for their efforts in providing the seismic surveys of several of the electrical sounding sites.

Much of the success of the field school has been achieved because of the generous assistance provided by a number of companies and I wish to thank them for their interest and invaluable help.

One group must not be forgotten, that being the students without whom this work would not be possible. They cheerfully endured the worst and best weather that May in the Alberta foothills can provide, and I know that they and the faculty members involved regard this field school as the most enjoyable part of the whole Geophysics Degree program.

iv) Propagation effects in the grounded current
v) Induced polarization effects due to the presence of metallic sulphides in rocks
vi) Induced polarization effects due to the presence of clay minerals in rocks

Items (i) to (iv) are consequences of electromagnetic theory, as shown by Sunde (*ibid.*), while items (v) and (vi) are jointly covered by Seigel's theory. Item (iii) can be ignored unless a downhole system is in use, as shown by Wait (1959).

The DC resistivity is, of course, a purely in-phase effect, but all the other effects can cause phase differences between the transmitting and receiving system plus variations of amplitude with frequency.

Each of these effects may be discussed separately, although in practice they are all observed together unless special methods are adopted.

DC RESISTIVITY

Resistivity sounding methods for layered ground are very highly developed, as described by Koefoed (1979). While a hydrocarbon reservoir may prove to be a highly resistive layer in some cases, it must also form a significant thickness in the total column of rocks that it occupies in order to be detectable by measurements of DC resistivity. Indeed, the deeper the reservoir is the thicker it must be, unless it achieves resistivities approaching those of a perfect insulator, which is not likely because saline water is normally present below and within such reservoirs.

Thus, in some cases, DC resistivity measurements may detect relatively shallow reservoirs but, in general, the DC resistivity method will not work well as a detector of reservoirs in the majority of hydrocarbon provinces. We can be confident that it will not be able to detect gas reservoirs at depths of 3000 m in the Alberta Foothills, because the method does not possess the resolution to be able to detect even highly resistive gas reservoirs of little more than 200 m thickness at depths of that order.

INDUCTIVE COUPLING

Inductive sounding of a layered earth has been employed in a number of special situations (*e.g.*, Ryu *et al.*, 1972; Duckworth, 1970), but it is almost always used where the layers become more conductive with depth, and is most successfully applied to situations involving no more than three layers and preferably two. Its application to the investigation of a hydrocarbon reservoir represented as a resistive layer underlying a conductive layer is unlikely to be successful, because of its low sensitivity to such a situation, as shown by Wait and Fuller (1972).

Even if inductive sounding were to be employed, the choice of transmitter would normally fall on a non-grounded loop or coil rather than the grounded-wire type of transmitter, because this would provide a simpler theoretical situation that is free of the current propagation effects present in a grounded system.

If a major thickness of conductive rocks were associated with a reservoir, such as an underlying porous rock layer saturated with saline water, then it might be possible to detect such an association by means of inductive sounding.

In the Alberta Foothills the conductors caused by saline water associated with the reservoirs are unlikely to be outstanding, in view of the predominantly marine depositional environment of the whole basin.

PROPAGATION EFFECTS IN THE GROUNDED CURRENT

Sunde (*ibid.*) showed that, for an electrode configuration in which the current and potential lines are laid perpendicular to each other on the surface of the earth, inductive effects will not be seen. Thus any frequency-dependent effects seen with this arrangement of electrodes will be due to the propagation of the current that is injected into the ground by the electrodes.

For a homogeneous earth, Sunde's theoretical development shows that a perpendicular array of electrodes will measure the true resistivity of that earth regardless of the frequency of the transmitted current. However, when the ground is layered and each layer has its own characteristic resistivity, the measured resistivity becomes not only an apparent resistivity, but also frequency-dependent. For very low frequencies the measured apparent resistivity is asymptotic to the familiar DC apparent resistivity, whereas for high frequencies it is asymptotic to the true resistivity of the first layer. This can be seen in Figure 1, which displays apparent resistivity versus electrode spacing and versus frequency for a particular electrode spacing.

Thus, while a depth sounding using a frequency scan of the grounded current with fixed electrode spacing can be made, it can only show the same layering that would be shown by a DC survey for which the sounding variable would be spacing of the electrodes.

Successful employment of the grounded propagation effect to sound the resistivity layering of the earth was achieved by Kinghorn (1967) over the Kern County oil field and by Wynn and Zonge (1975) over a playa lake deposit. It can be seen, however, that the method must be subject to all the constraints that we recognize as applying to DC resistivity work. The only advantage of using the time or frequency dependence of the grounded propagation effect is that it provides layer information without moving the electrodes.

One inevitable difficulty with this concept is that, if the ground contains any component that is electrochemically polarizable, this too will cause time- or frequency-dependent variations of potential (even in an unlayered earth), and that no arrangement of electrodes will allow these electrochemical (IP) effects to be separated from the propagation effects. If we add the fact that for any of the conventional colinear electrode arrays, such as the dipole-dipole, Wenner and Schlumberger arrays, the effects detected will also include inductive coupling, the situation can be seen to approach a complexity that makes interpretation extremely difficult.

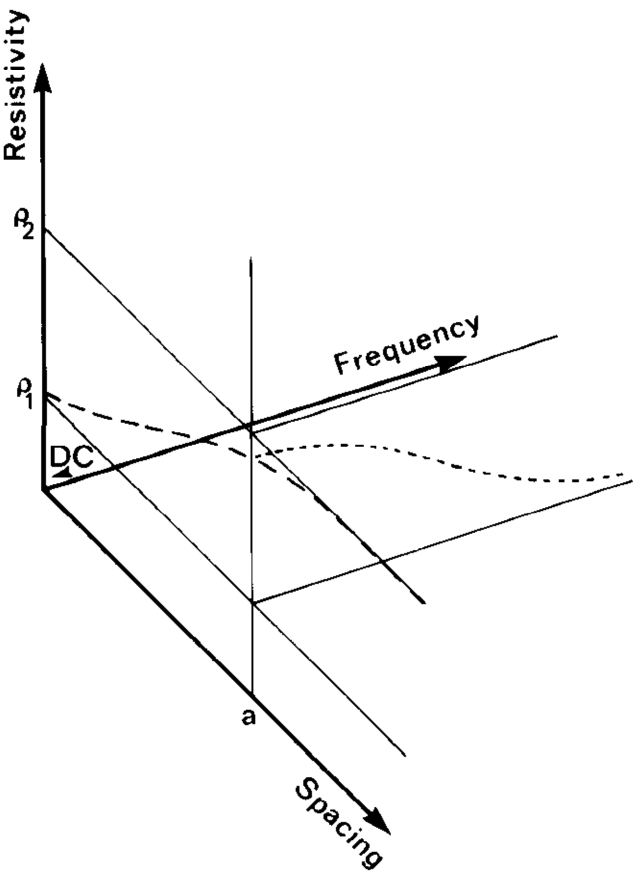

Fig. 1. Depth information may be obtained either by measuring DC resistivity as electrode spacing varies (dashed curve), or by observing change of resistivity due to propagation effects as frequency is increased (dotted curve) with the electrode spacing fixed. In the two-layer case shown, the first-layer resistivity ρ_1 provides the asymptote for small spacing or high frequency, while the second-layer resistivity ρ_2 is the asymptote for large spacing or low frequency.

INDUCED POLARIZATION EFFECTS DUE TO DISSEMINATED SULPHIDES

When a metallic mineral is introduced into the preexisting pores of a rock, the resistivity of that rock becomes strongly frequency-dependent because of the storage of electrical charge at the interfaces between the mineral and the pore fluid. This effect may also be seen as a decaying current when the stored charge dissipates after the primary current — which caused the charge to be stored — is switched off. The time constant for this decay has been shown by Pelton *et al.* (1978) to be several seconds, so that the effect would usually continue to exist after the relatively short-term constant effects due to inductive coupling and propagation have died to negligible levels. This disparity in decay constants permits an empirical separation of IP and electromagnetic effects simply by delaying observations till the electromagnetic effects have died away. No exact time can be quoted, but delays of the order of 400 ms have been found effective in metallic-mineral exploration.

Even very low volume percentages of metallic mineral (*i.e.*,~1%) can have an important influence on the electrical properties of rocks, especially when low porosities are involved. The distribution of the mineral is important to this concept in that, for best effect, the mineral must be disseminated throughout the host rock.

Thus, we may expect that if a hydrocarbon reservoir can cause an emplacement of finely disseminated metallic sulphide minerals in the rocks above the reservoir, as proposed by Snyder *et al.* (1980), this will cause those rocks to display anomalous transient signal behaviour due to the induced polarization effect. It may also lead to confusing effects in the DC resistivities measured over those reservoirs, as shown by Duckworth (1981).

Sulphide minerals are commonly found within hydrocarbon reservoirs, as shown by Clavier *et al.* (1976), so that the formation of low concentrations of such sulphides above a reservoir appears possible, provided the trapping mechanism is not too effective.

INDUCED POLARIZATION EFFECTS DUE TO CLAY MINERALS

The presence of clay minerals in rocks has been found to cause an induced polarization (IP) effect comparable to that due to metallic minerals.

The means by which clays cause this effect is poorly understood, but the following facts are clear:

i) The higher the ion exchange capacity of a clay, the stronger the IP effect it generates.
ii) The ionic composition of the pore fluid in a rock has a strong influence on the IP effect due to clays. (It also influences the IP effect due to metallic minerals.) Of particular interest is the fact that highly saline pore fluids tend to suppress the IP effects due to clay (or metallic minerals).

Studies of these effects have been provided by Anderson and Keller (1964), Vaquier *et al.* (1957), and Keevil and Ward (1962).

We may speculate that changes in pore-fluid chemistry may alter the clays and therefore also their ion exchange capacity; or that even without a change in the clay, the IP effects due to the clays may be enhanced or suppressed by modifications of the pore fluids.

This concept of interaction between clays and modified pore fluids appears to allow either stronger or weaker IP effects over hydrocarbons, depending on the types of clays already present and the chemical changes the hydrocarbon causes in the pore fluid of the overlying rock.

EVALUATION OF THE BEST MODEL FOR THE ALBERTA FOOTHILLS

It appears that the only reasonable possibility for finding anomalous electrical responses at surface over hydrocarbons in the foothills area lies in a geochemical alteration of the rocks overlying the hydrocarbon, and the IP effects that may result.

The tests conducted in the field work described here were designed to investigate the IP response of the ground in accordance with these conclusions.

EQUIPMENT

The equipment employed in these tests consisted of a Huntec Mk4 Induced Polarization receiver and a Phoenix IPT-1 2.5-kw transmitter with high-precision timing module.

Selected sites were also covered with shallow seismic refraction surveys using a Geometrics Nimbus ES-1210 12-channel signal enhancement system with a Mapco Betsy Shotgun source.

PROCEDURE

At each sounding site a current pole was established by placing a stainless steel rod in a 4-cm-diameter water-filled auger hole cut to a depth of approximately 1 m. The second current pole was located at a distance of 1 km. Soundings were obtained by mapping the potential distribution around the end of this dipole along lines colinear with and perpendicular to the dipole, as shown in Figure 2. In mapping the potential, a reference electrode was established and fixed, in a location that could be regarded as being at zero potential with respect to the dipole by virtue of its distance from it. Potential differences with respect to this electrode were measured by using a single moving electrode along a traverse away from the dipole. This procedure minimized the movement of electrodes and thereby minimized one source of noise in the readings. It also permitted the use of a multicore cable to control the moving electrode. This cable provided 24 electrode contact points, which were arranged to increase in separation logarithmically as distance from the current dipole increased, as shown in Figure 2. Each of these contact points could be connected individually to the receiver by means of a roll-along switch.

Electrodes used in measuring potential are normally a nonpolarizing type, but because such electrodes are inconvenient and expensive, a plain metal-stake type of electrode was used in this work. Comparative tests between the nonpolarizing and metal-stake electrodes showed that the Huntec Mk4 receiver is able to record identical information with either type of electrode, because of its ability to separate signal from DC or low-frequency effects due to electrode contact potentials. The use of metal-stake electrodes allowed a ground contact to be established for each of the 24 contact points at reasonable cost, so that movement of the electrode merely required the sequential connection of each electrode to the recorder.

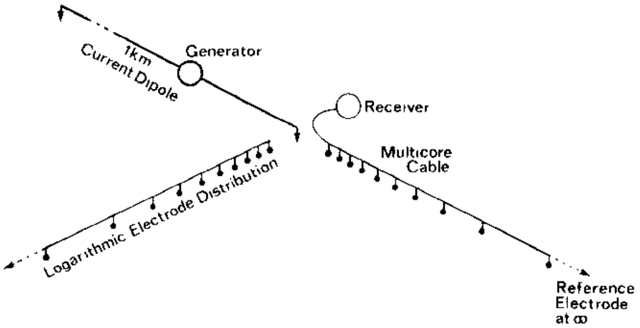

Fig. 2. The arrangement of electrodes used in these experiments. The potential electrode array was distributed logarithmically, with a multicore cable being used to connect the electrodes to the receiver in sequence.

Once the spread of electrodes was established, the measurements of DC and transient potentials out to distances of as much as a kilometre took about one hour. Two such soundings could be performed in one day.

At sites where access allowed, the potentials along a traverse perpendicular to the dipole were also measured, as shown in Figure 2. If any dip existed in the layers beneath the spread, this was immediately shown by the difference in DC resistivity sounding results for the colinear and perpendicular spreads. In the event that a site proved to display no dip effects, an additional use could be made of the data to determine if the detected transient effects were due to an electrochemical (IP) cause or an electromagnetic cause. This is possible because, for a colinear electrode array over a horizontally layered earth, transient signals due to electromagnetic causes are a mixture of inductive and propagation effects, whereas for the perpendicular spread they are due solely to propagation. Thus, transient effects should show significant differences between the results for the two spreads if they are of electromagnetic origin. Induced polarization transients should display no differences between the two spreads.

The data for each sounding site were presented in bilogarithmic display as shown in Figure 3. The DC potential (Curve A) is discontinuous because the transmitted current had to be changed to allow the measured potentials to be kept within the full scale range of the recorder.

The transient data were normally presented as chargeability (m), which is the area under the decay curve normalized with respect to the primary potential and measured in milliseconds, as shown in Figure 4. The signal transmitted was usually of 8-s period with a 50% duty cycle (*i.e.*, 2 s on and 2 s off with reversed polarity). The integration limits for m were chosen to be 450 ms and 1450 ms. This delay of 450 ms before the beginning of integration provided for the rejection of short-time

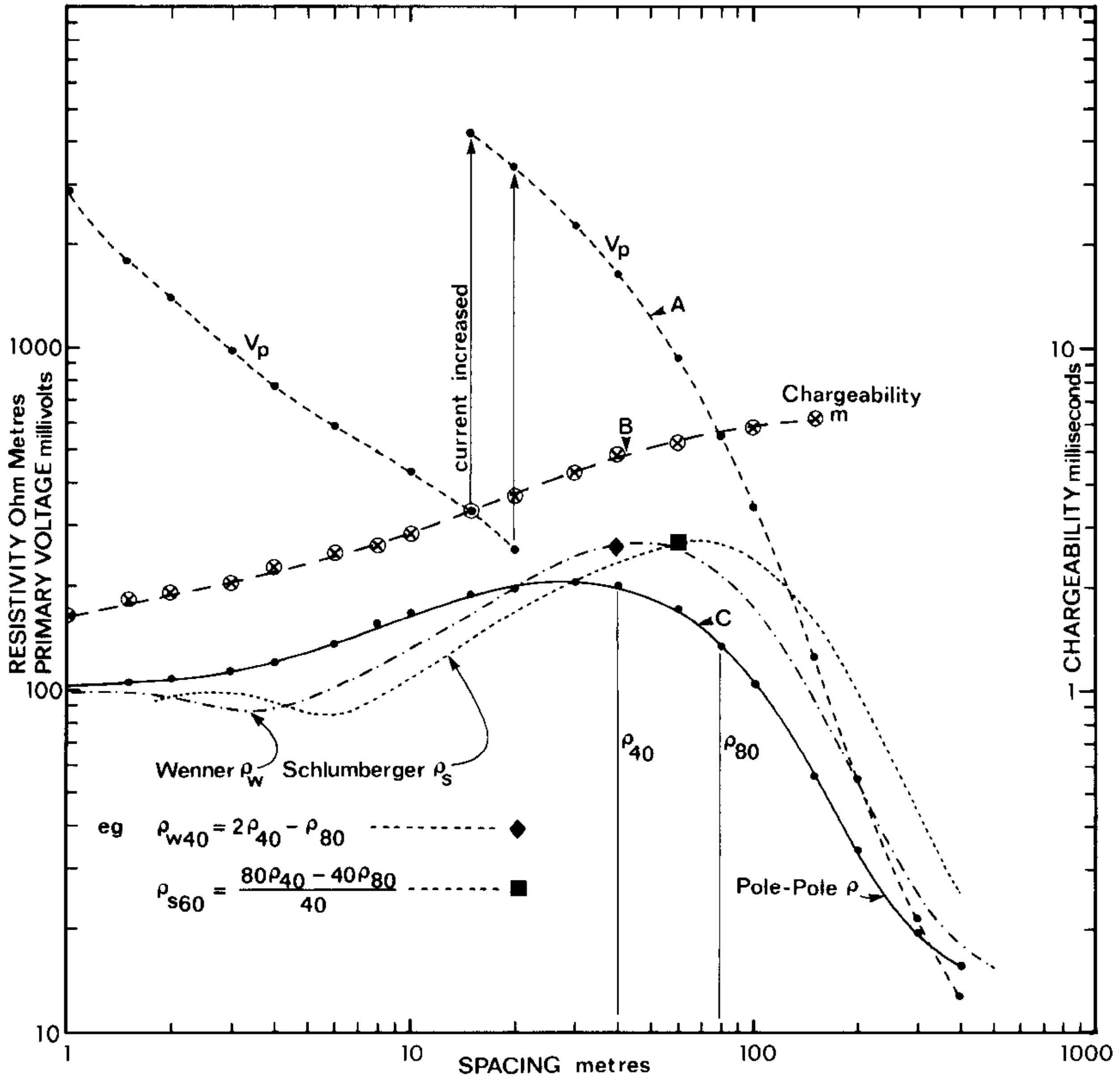

Fig. 3. This diagram depicts the bilogarithmic plot of primary voltage (Vp), of chargeability (m) and of resistivity (ρ) for a typical sounding. Examples of the procedures for transforming pole-pole resistivities to the Wenner or Schlumberger Form are also shown.

constant decays of electromagnetic origin. The integration and normalization was performed automatically by the Huntec Mk4, and the readout of m could be plotted as shown (Curve B) without any additional reduction.

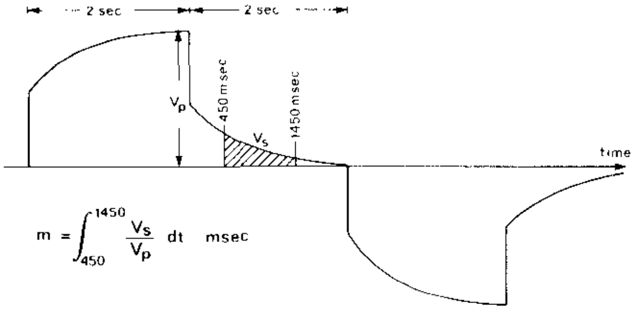

Fig. 4. A 50% duty-cycle signal (2 s on and off) was used in transient soundings. The decaying effects in the off period were measured in terms of chargeability (m), which is the area under the decay curve normalized to the primary voltage (Vp). Vs is the secondary voltage.

The conversion of DC potentials into the apparent resistivities of curve C was achieved by means of the following expression for colinear traverse:

$$\rho_{app} = \frac{\Delta V}{I} \cdot 2\pi a \cdot \frac{(L+a)}{L} \tag{1}$$

and for perpendicular traverses

$$\rho_{app} = \frac{\Delta V}{I} \cdot 2\pi a \cdot \left\{ \frac{(L^2+a^2)^{1/2}}{(L^2+a^2)^{1/2} - a} \right\} \tag{2}$$

where ΔV was the observed potential in volts
I was the transmitted current in amperes
a was the separation of the movable potential electrode from the near current pole in metres
L was the length of the current dipole in metres

For small values of 'a' both these expressions reduce to the expression for pole-pole array, *i.e.*,

$$\rho_{app} = \frac{\Delta V}{I} \cdot 2\pi a \tag{3}$$

Expressions (1) and (2) can be seen to be the pole-pole expression modified by a geometric correction factor due to the second current pole.

INTERPRETATION METHODS

The pole-pole electrode array used in these surveys has been relatively little use in resistivity or IP work, so that theoretical aids to interpretation are not as well developed as they are in the case of the Wenner or Schlumberger arrays. In order to take advantage of the sets of theoretical curves available for the Wenner and Schlumberger arrays, the data acquired in these surveys were transformed to the Wenner or Schlumberger form before being interpreted.

The expression used in transforming to the Wenner form of data was

$$\rho_{app} = 2\, \rho_{app\,(PP,a)} - \rho_{app\,(PP,2a)} \tag{4}$$

where the apparent resistivities are taken from the Pole-Pole (PP) sounding curve as shown in Figure 3.

In the case of transformation to the Schlumberger form of data where 'a' is half the separation of the current electrodes of the Schlumberger spread, the expression is

$$\rho_{app\,(Sch,a)} = \frac{(a+x)\, \rho_{app\,(PP,a-x)} - (a-x)\, \rho_{app\,(PP,a+x)}}{2x} \tag{5}$$

where 2x is the distance between pairs of points on the PP sounding curve and 'a' is the distance to the point midway betwen those two points as shown in Figure 3. Expression (5) may be shown to be identical to the expression given by Das and Verma (1980), provided that x is small compared with a.

Examples of these transformations are shown in Figure 3, and a comparison between a Wenner curve derived by transformation and a curve measured with a Wenner array is shown in Figure 5. Samples of the application of equations (4) and (5) are shown in Figure 3, using resistivity values taken from the PP curve at 40 m and 80 m. This results in the Wenner equation generating a data value for a Wenner spacing of 40 m whereas the Schlumberger equation generates a data value for a Schlumberger spacing of 60 m. It was found that if the PP data contained noise due to lateral variations in surface resistance, this caused the transformations to be very unstable, to the extent that interpretations derived from the transformed curves became unreliable. This could happen even if the PP data were not visibly noisy as plotted.

Final interpretation of any sounding curve was achieved by interactive curve matching by means of an interactive graphic display controlled by an Apple II microcomputer. The software for this system employed the digital filter method for generating sounding curves that was described by Ghosh (1971).

RESULTS

The sounding curves shown in Figure 6 were obtained along the 1A highway to the west of Cochrane between Grand Valley Creek and the junction of 1A highway with the forestry trunk road. Sites A, B and C were located to the east of the mapped location of the Wildcat Hills gas field, while site D was located on the gas field as shown in Figure 6.

The resistivity curves show the geologic conditions to be very uniform over the 4-km distance separating sites A and D. The resistive second layer that occurs at all the sites is probably the unconsolidated remains of the bed of glacial lake Calgary, and the underlying conductive third layer is probably the Cretaceous Brazeau Formation. The banks of the nearby Bow River, which have been cut down into the Cretaceous, provide immediate support for this identification of the layers.

This uniformity in the near-surface geology for all the sites was fortunate in that it allowed us to be confident that, if any significant change in the transient electrical measurements occurred from site to site, it was not due to changes in near-surface geology, and therefore had a higher probability of being due to a geochemical alteration.

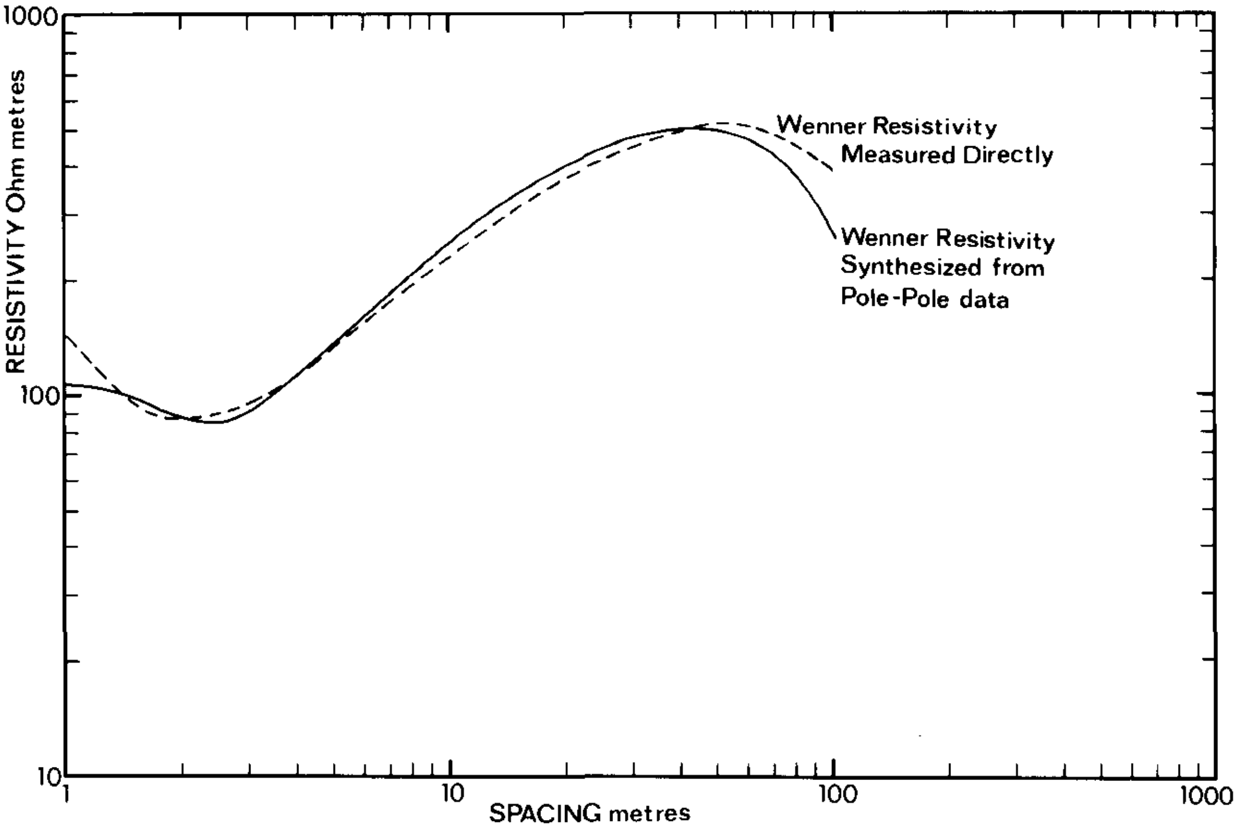

Fig. 5. Example of a resistivity sounding measured directly with a Wenner array and synthesized from pole-pole measurements made on the same site.

At site A an interpretation of the resistivity sounding curve showed the layer thicknesses to be 8.5 m for layer one and 23.5 m for layer two. A seismic refraction profile over this site along the same line also showed a three-layer structure but with significantly different thicknesses, these being 5.7 m for layer one and 8.1 m for layer two. Comparison of these figures with the section exposed by the banks of the Bow River indicates that the greater thickness for the second layer, which was shown by the resistivity, provides what is probably the more realistic depth to the base of the unconsolidated material. All the curves showed a general increase of chargeability with electrode spacing, so that the Cretaceous rocks appear to be more polarizable than the overlying unconsolidated material.

The chargeability curves of Figure 6, for electrode spacings less than 20 m, show an increase of response toward the gas field. This increase was not repeated in the effects recorded with larger spacing, so that it appears improbable that the shallow depth effect is the result of geochemical alteration due to the gas field, because it is difficult to see how an ascending geochemical influence can affect the near-surface, recently deposited, unconsolidated materials without affecting the underlying Cretaceous rocks. An additional feature of this shallow depth effect is that a corresponding decrease of resistivity toward the gas field is also shown by Figure 6. Such a decrease could result from an increase of porosity or a change of the ionic composition of the near-surface ground water, or a change of the clay content of the surface layers. However, only a change of clay content or clay type would be likely to cause the increase of chargeability as well as the decrease of resistivity.

The chargeability curve for site B suggests that the Cretaceous rocks are more polarizable at that site, but it was located 3 km from the mapped location of the gas field. This apparently strong chargeability effect may have been caused by cultural disturbance of site B, because site A on the opposite side of the road did not show it.

The difficulty of obtaining reliable chargeability readings in areas containing pipe lines, phone lines and power lines is shown by the curve for site D, on which the prominent peak was caused by crossing a phone line.

Ground noise made chargeability readings very difficult to take for distances greater than 200 m, so that only in the case of site B were chargeability readings pursued beyond 200 m of spacing.

The difficulty of finding a site on the gas field free of pipe lines was such that only site D proved suitable for work over the reservoir. Unreliable results were expected and confirmed when soundings were attempted near any pipeline.

In order to be free of cultural effects, a further survey was undertaken in the Waiparous Creek area of the

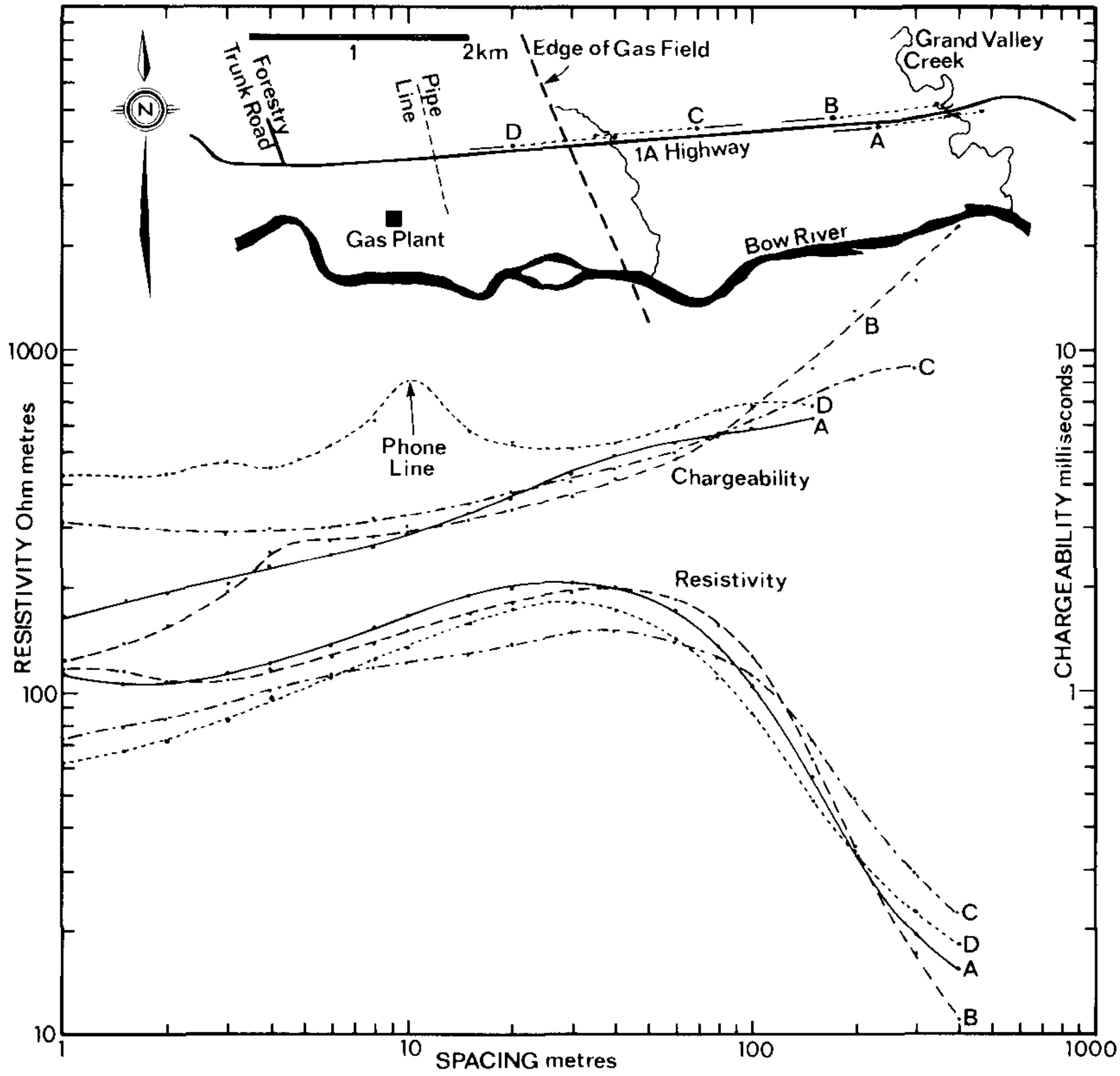

Fig. 6. Resistivity and chargeability soundings made on and off the Wildcat Hills gas field located west of Cochrane. No significant difference was seen between soundings on and off the gas field for electrode spacings greater than 60 m.

Bow Crow Forest. The site was located 4 km west of the Forestry trunk road and 2 km north of Waiparous Creek. The sounding site was chosen for ease of access and freedom from trees. It was located on the outcrop of the Wapiabi shale of Cretaceous age. Local outcrops showed a 60° dip toward the west, and a glacial till cover of approximately 2 m thickness was expected.

These tests were conducted in late April and early May, and it was found that the surface layers of the ground were still frozen even when snow cover had been melted off for several weeks. To observe the effect of the thawing of the near surface, one sounding was repeated several times over a period of three weeks; the effects can be seen in Figure 7. This site displayed a five-layer structure which was visible in both the resistivity and the chargeability. Other soundings conducted within 300 m of this site showed similar layering, but a good deal of difficulty was experienced with erratic results which were probably caused by the electrode spread crossing patches of still-frozen ground.

The sounding curves shown in Figure 7 were the best examples obtained. They raise the immediate question of the origin of horizontal layering in a shale which both the local outcrops and regional mapping indicate to be steeply dipping. The first two layers were in the superficial material, which was frozen below a depth of approximately 0.5 m. The third layer, which started at about 1 to 2 m depth and extended to about 30 m, was probably within the shale, as were layers four and five. While the water table may explain one of the upper interfaces in this layered sequence, some other explanation for the deepest interfaces is required. Perhaps a local flattening

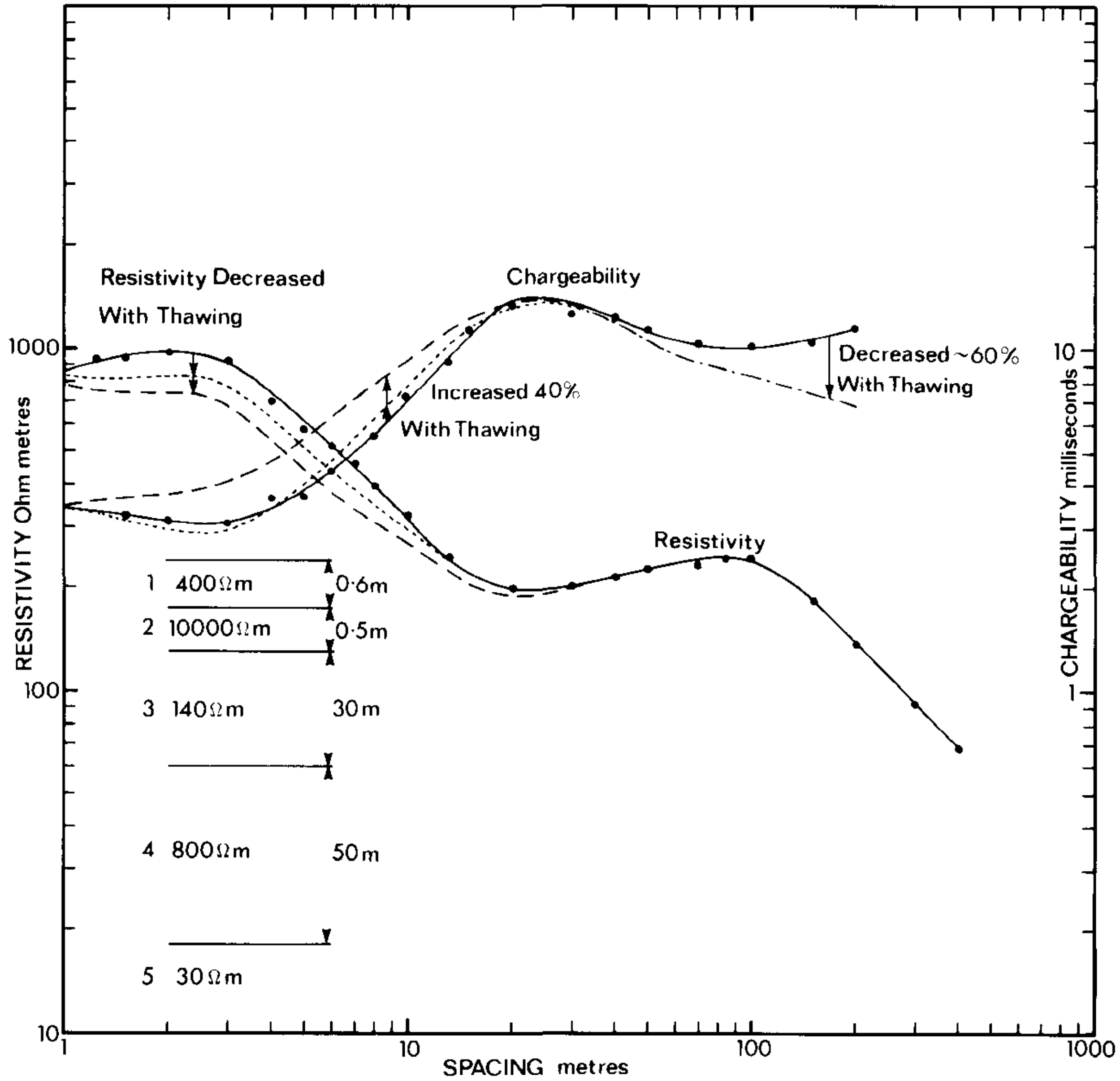

Fig. 7. Resistivity and chargeability soundings made at the same site as in Figure 6, just north of Waiparous Creek on the Blackstone shale. Soundings were repeated over a period of three weeks to observe the effects due to thawing of near-surface frost layers. The layer interpretation is based on the pre-thaw resistivity sounding.

of the shale occurs under the test site, but all indications are that flat-lying bedding is rare in this area.

An even more puzzling question lies in the change of the chargeability sounding curves as the near-surface layers thawed out. Thawing caused a progressive decline in the resistivity of the second layer, as was to be expected. However, it also caused an unexpected increase in the cheargeability in the part of the curve influenced by the second layer, while a corresponding decrease occurred in the part of the curve influenced by layers four and five, yet, as expected, those layers showed no change of resistivity. The magnitude of these changes in chargeability, which was as much as a 40% increase for the shallow layers and a 60% decrease for the deep layers, indicates that these changes were not simply uncertainty in the readings. The consistency and smooth behaviour of these curves supports this contention, as does the invariant behaviour of the chargeability of the third layer. An explanation for these changes cannot be offered without further investigation of this and other nearby sites, but their implications for electrical measurements made in Alberta must be considered. It is clear that a patchy frozen surface can have a strong influence on transient chargeability readings made on it, and that the effect will be unpredictable. It is probable that the apparent decrease of the chargeability of the deep layers was due to a change in the surface over which the more distant electrode positions lay, rather than to any real change of chargeability at depth.

The generation of spurious transient chargeability readings by frozen ground is well known in metallic mineral prospecting in permafrost areas. The tests discussed here suggest that care must be taken in using results obtained in Alberta if the near surface is likely to contain residual frost layers. Only repeated readings over a period of weeks will reveal the effects of such seasonal influences.

Aside from the frost problems at the Waiparous Creek site, the layering within the shale and the significantly enhanced chargeability of the third layer appear to be due to some form of alteration of the shale. Such an alteration may be a weathering effect, but it does not appear that this would be an unusually deep weathering influence for Canadian conditions.

CONCLUSIONS

Although the test over the Wildcat Hills gas field appears to be negative, it must be conceded that conditions at this site were not favourable to the concept that hydrocarbons can cause anomalous electrical responses, because the reservoir depth is 3000 m and a considerable thickness of recent material covers the area.

The Waiparous Creek tests pose more questions than they answer, and a good deal of additional work is needed to explain the effects seen at that site. This work will consist of mapping the layered zone by means of electrical soundings, and using refraction seismology to see if the layering is also represented by velocity contrasts.

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