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REPORT

(Queensland No. 3).

THE GEOPHYSICAL METHODS

OF

The Electrical Prospecting Company of Sweden

USED IN THE

Aerial, Geological and Geophysical Survey of Northern Australia.

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I. INTRODUCTION.

In prospecting for metalliferous deposits by geophysical methods, the bulk of the work must fall to the electrical and magnetic methods. These were used in the geophysical survey for the Aerial, Geological and Geophysical Survey of Northern Australia. Other methods will not be described as this report is necessarily a brief one. Further, only those methods and instruments used during the 1935 field season will be described below.

II. ELECTRICAL METHODS.

A. General Discussion.

A number of electrical prospecting methods have been developed to cover the various conditions met with in the field. For each, appropriate instruments have been designed and a technique worked out. Nevertheless, the methods may be divided into two groups as follows, according to the two main principles that are involved :—

(1) *Investigation of the Natural Earth Currents.*

Investigation of the natural electric currents in the earth caused by electro-chemical activity. This gives rise to the self-potential method.

(2) *Differences in Electrical Conductivity.*

All other electrical methods are based upon differences in electrical conductivity between the different rock formations beneath the earth's surface. These methods need an artifically created electric field. This electric field can be created in a number of ways, each of which causes a " normal " field of theoretically known distribution. A " normal " field can exist only over a uniform geological formation. If there are rock formations with different electrical conductivities present, distortions of this normal electrical field will be caused. To achieve the best results in every case, a method has to be selected which gives the clearest and most pronounced distortions of the electric (or electro-magnetic) field, so that the greatest possible number of physical facts are available for translation into geological conclusions. Such distortions are generally referred to as " indications ".

Several means exist for energising the ground and investigating the resulting current distribution. Usually alternating current of audio-frequency is used to energise the ground.

(*a*) *Energisation.*—This can be achieved either by direct contact with the ground (" galvanic ") through ground electrodes, or by an electro-magnetic field (" inductive ") arising from a current in an insulated wire loop laid on the ground. The electro-magnetic field induces currents in any conducting body within its influence.

The classification according to primary energization will not be followed at present.

(*b*) *Distribution of Current.*—The distribution of the underground currents is investigated by observations on either the electric or the electro-magnetic field.

(i) *The Electric Field* is investigated by observing the electric ground potentials at different points by means of secondary electrodes and a flying circuit.

(ii) *The Electro-magnetic Field* is investigated by means of search coils attached to a measuring circuit.

The investigation of the electro-magnetic field comprises the determination of the direction of the electro-magnetic field, its amplitude, and its phase at each observation point.

B. Classification.

Following the above principles, a classification of electrical methods can be made as follows :—

(1) *Self-potential Method.*—Observing the natural earth currents.

(2) *Potential Methods.*—Observing an electric field artifically applied to the ground.

- (*a*) *Equipotential Lines.*—Owing to the rather difficult geophysical conditions met in the northern part of Australia, no equipotential lines were actually traced. For information regarding the method, reference should be made to general geophysical literature.
- (*b*) *Wenner Method.*—Observing the specific electric resistivity of the ground.
- (*c*) *Racom Method.*—Observation of potential drops, or of ratios of consecutive potential drops, along a straight traverse.

(3) *Electro-magnetic Methods*—

- (*a*) *Observing the field direction* by means of angle drums or compasses and clinometers fastened on the frames.
- (*b*) *Sundberg's electro-magnetic compensator*, by means of which the amplitude and phase of the voltage induced in a search coil is determined.
- (*c*) *Turam method* in which the ratio and phase difference between the voltages induced in two search coils is observed.

III. ELECTRICAL METHODS AND INSTRUMENTS.

A. The Self-potential Method.

While the other geo-electrical methods require an electric or electro-magnetic field created artifically by a generator, the self-potential method makes use of natural earth currents. These currents are created by the electro-chemical activity often accompanying the oxidation process in sulphide bodies, &c.

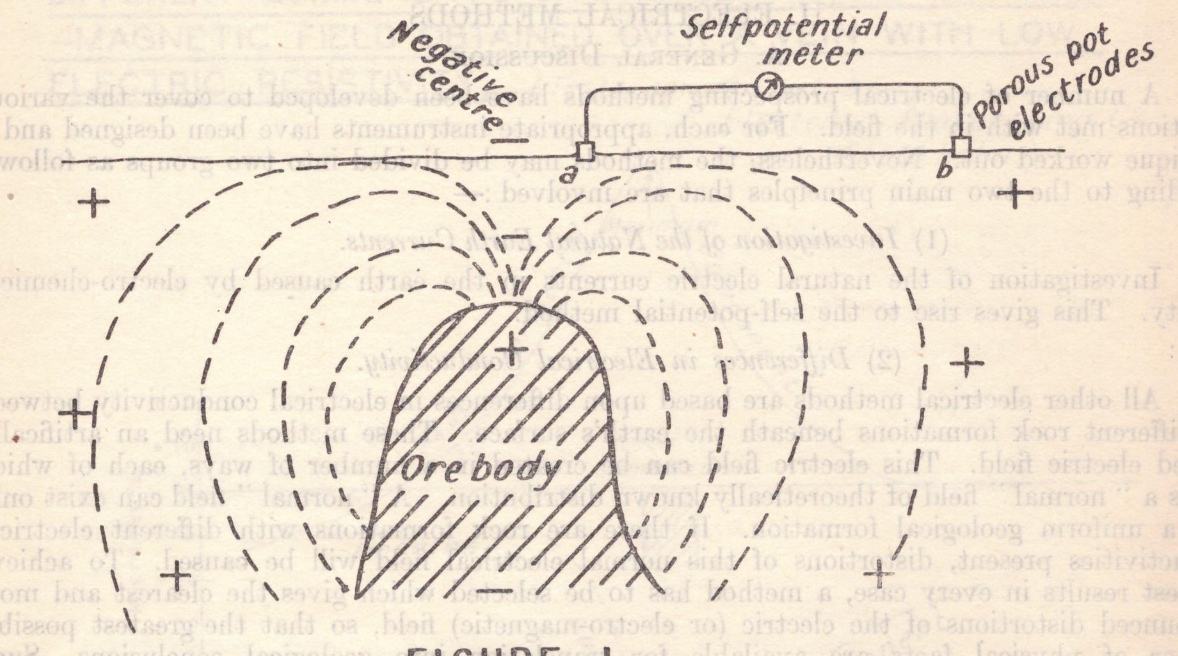

FIGURE 1

The above sketch illustrates the process and the method of observation. The currents flow down through the ore-body and return through the surrounding country, forming a complete circuit. The currents spread over large distances, but decrease with increasing distance from their electro-chemical source. The surface above the ore-body generally shows a negative centre with regard to the surrounding country.

Two non-polarising electrodes are connected with a measuring instrument which records the difference of potentials between the points *a* and *b*. These differences are usually small, of the order of less than half a volt. They were found to be smaller still (up to a maximum of 50 and 100 millivolts) at Trekelano. The sensitivity of the instrument had, therefore, to be high to allow the recording of these small potential differences.

The indicating instrument of the Electrical Prospecting Company is essentially a tube voltmeter with amplification, which has the advantage of being practically independant of the very high contact resistances encountered in the dry regions of North Australia, the inner resistance of the instrument being very high compared with that of other types of instruments in use. The contact resistances on the non-polarising electrodes were found, as a general rule, to be several thousand ohms. The sensitivity of the instrument can be altered and thus adapted to the strength of the self-potentials encountered.

When working with such small voltages the possibility of errors has to be guarded against, and consequently the readings have to be repeated and checked frequently. Ordinary metal electrodes cannot be used in measurements of natural earth currents, as chemical action starts on the surface of the metal electrode as soon as it comes in contact with the ground. This gives rise to polarization currents which would obscure the small natural earth currents. Porous pot electrodes filled with copper sulphate solution are used to avoid this effect. Actually porous pots with two chambers were used, a weak solution being in the outer and a concentrated one in the inner chamber.

As the self-potential method depends upon the electro-chemical activity underground, indications obtained with it give an independent check on indications obtained with the electrical methods which are dependent upon the electric conductivity of the ground.

B. Potential Methods.

(1) *Resistivity Measurements.*—For the resistivity determinations a Megger Ground Resistance Tester was used. The method adopted was first described by Wenner,* and consists of driving four electrodes into the ground equally spaced in a straight line. The two outer electrodes are connected to the current terminals of the megger and the potential difference

* Wenner F. A Method of Measuring Earth Resistivity. U.S. Bureau of Standards, Bulletin No. 258, 1916.

between the two inner electrodes is measured. The megger is constructed in such a way that the readings on the scale give the ratio of potential difference to current, which is equal to the resistance.

From Wenner's formula the specific electrical resistivity is given by $S = 2\pi a\ R$, where—

S = specific electrical resistivity.
a = distance between electrodes in centimetres.
R = readings in ohms.

The specific resistivity obtained is an approximate average of the resistivities of the soil or rock to a depth approximately equal to the electrode separation. Thus, a six feet electrode separation gives the specific electrical resistivity of the rock to a depth of about six feet. For several reasons the range of the instrument is limited to comparatively small spacings, and this is a disadvantage if the surface soil attains any great depth. Under such conditions the effect of the surface soil masks to a large extent the changes of resistivity in the underlying bedrock.

The resistivity measurements were difficult to determine satisfactorily owing to poor ground contacts. They were carried out primarily for the purpose of determining the specific resistivities of the different types of rock encountered.

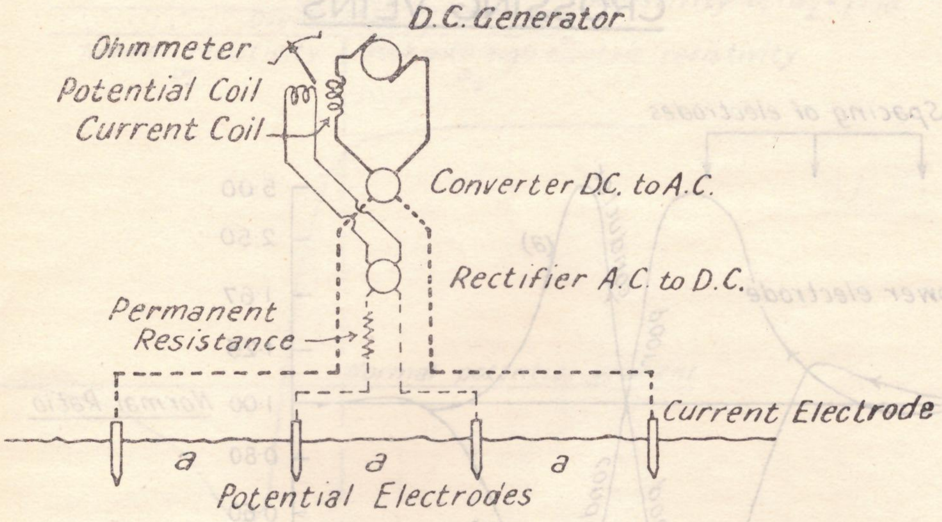

FIGURE 2

(2) *The Racom* (*Ratio Compensator*).—The current from an electric alternating generator (G) is grounded at two points (A and B) by spikes driven into the ground half a mile to a mile apart.

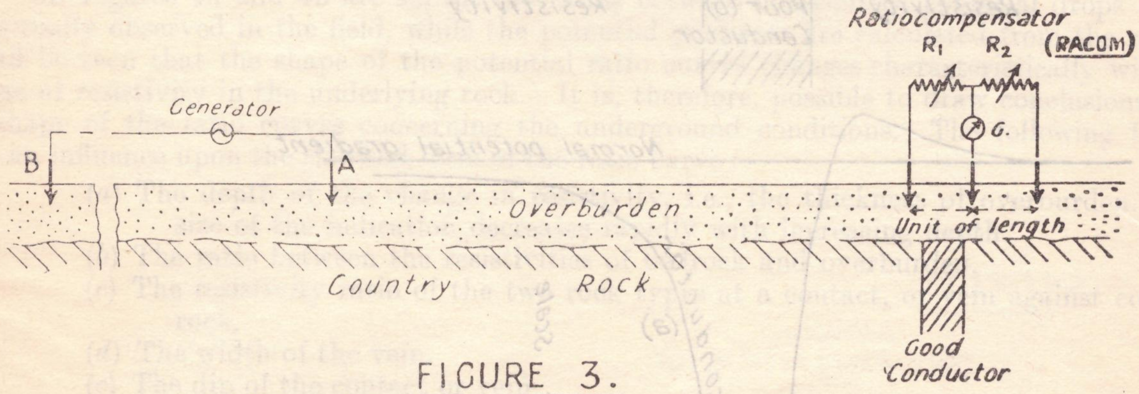

FIGURE 3.

From one of these ground electrodes (A) as a starting point, traverses are laid, preferably in such a way that they cross the area or feature to be studied approximately at right angles. If the survey is kept comparatively close to one ground electrode and it is assumed that the second electrode is far away, the influence of the second electrode (B) can be neglected. The potential distribution around the first electrode (A) is known and is independent of the absolute value of the specific electrical resistivity of the ground as long as the latter remains uniform throughout the area surrounding the ground electrode. If, however, changes occur in the electrical resistivity—e.g. at a contact of rocks of different resistivity, or if a good or poor conductor (a vein) is embedded in the country rock—then the potential distribution is distorted. If the deviation from the normal value of the potential at any point around the electrode is measured, it is possible to arrive at some conclusions regarding the nature of the changes in the electrical resistivity underground. For a mathematical treatment, reference should be made to "Electrical Prospecting for Auriferous Quartz Veins and Reefs", by H. Hedström, *Mining Magazine*, April, 1932.

If the potential drop between two points along the traverse is measured, keeping the distance between successive points along the traverse always the same, then the potential drop per unit of length (e.g. 10 metres, 30 feet, &c.) is obtained. The values measured, however, have to be corrected (apart from instrumental constants) for the distance of the observation points from the electrode. These potential gradients (potential drop per unit of length) are compared with the normal values. In practice, it is an advantage to measure the ratio between two consecutive potentials drops with the ratio compensator. A quick and accurate survey can be made with this instrument.

Both the potential gradients and the potential ratios are used in interpreting the results of a survey.

POTENTIAL DROP RATIOS & POTENTIAL GRADIENTS

CROSSING VEINS

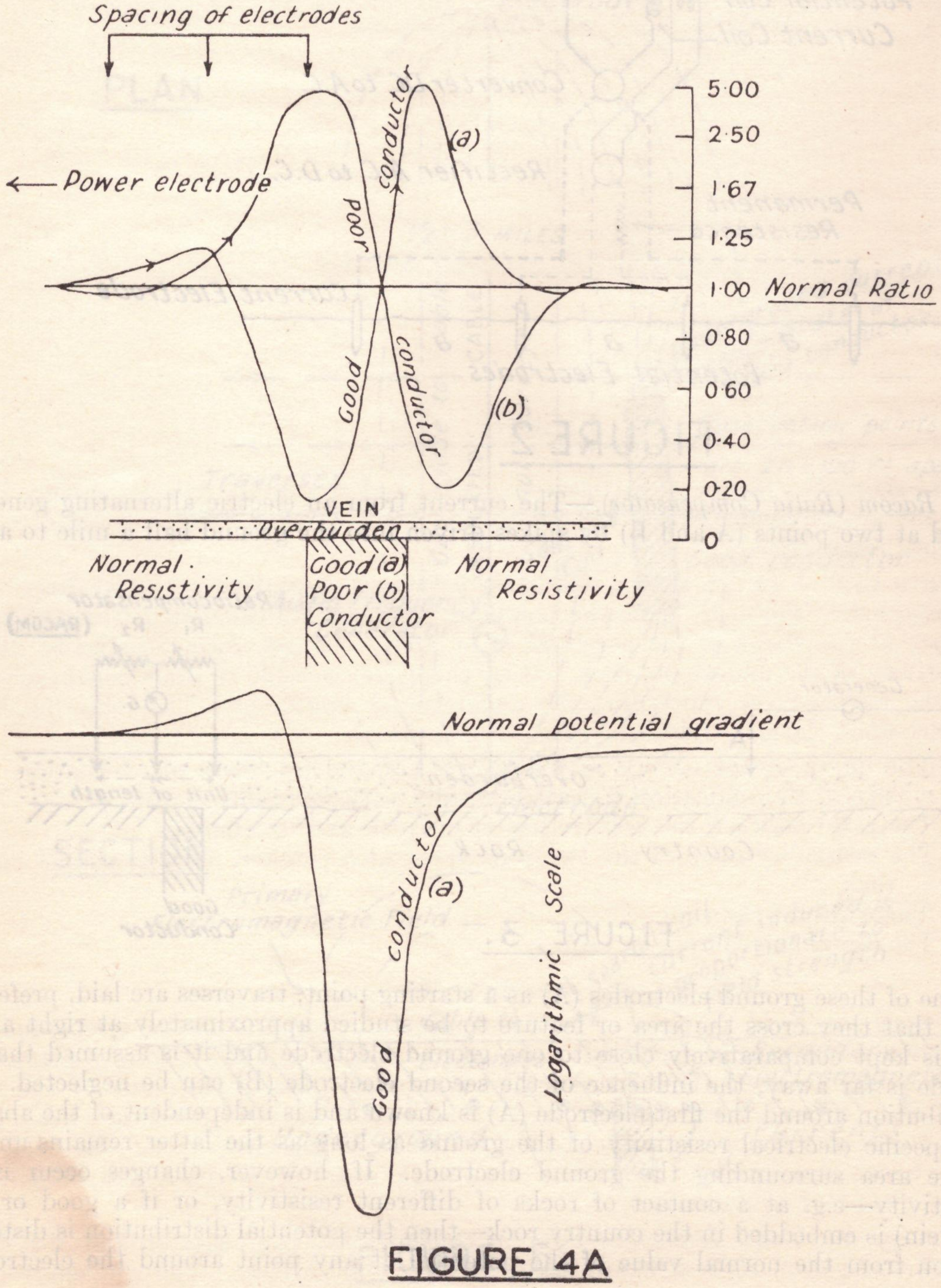

FIGURE 4A

POTENTIAL DROP RATIOS AND POTENTIAL GRADIENTS CROSSING CONTACTS OF ROCK FORMATIONS WITH DIFFERENT ELECTRIC RESISTIVITY

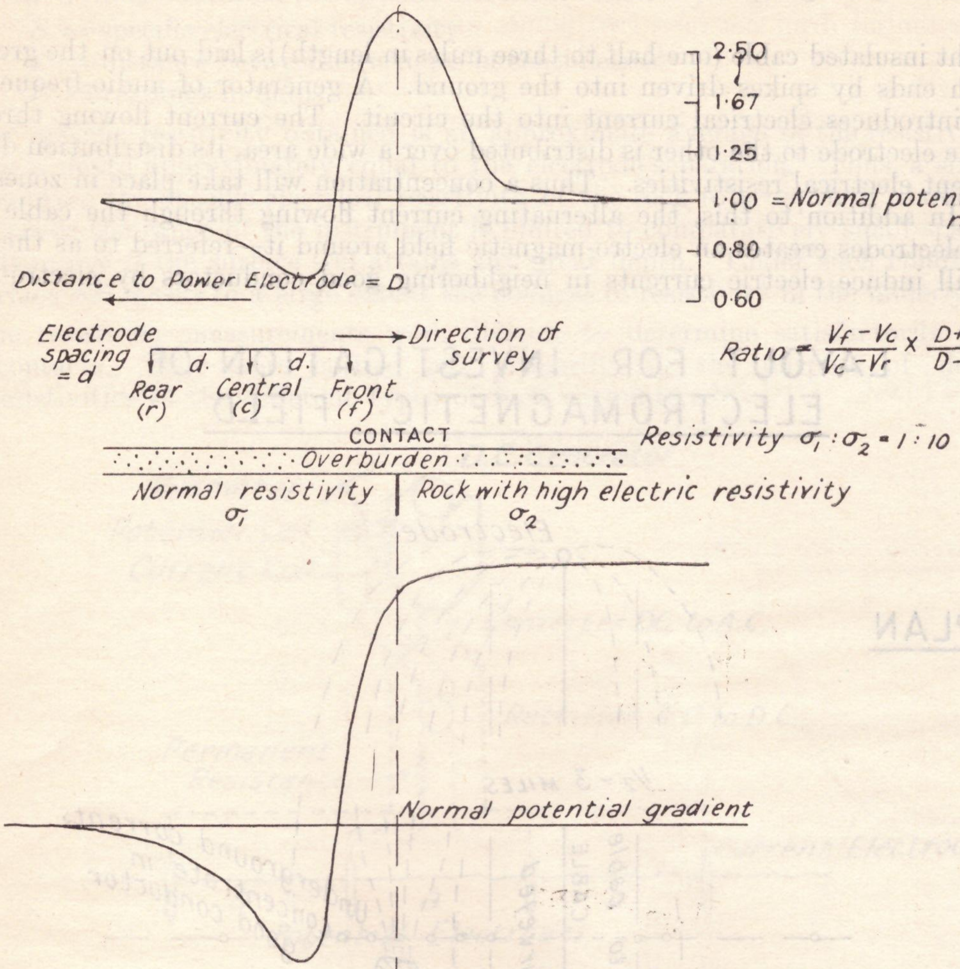

FIGURE 4B

Figure 4A shows the layout of an electric profile, and the results when crossing a good conductor (*a*), and a poor conductor (*b*), and Figure 4B when crossing a contact between rocks of different electrical resistivities.

On Figures 4A and 4B are shown the ratios between consecutive potential drops (these are actually observed in the field, while the potential gradients are calculated from the ratios). It will be seen that the shape of the potential ratio curves changes characteristically with the change of resistivity in the underlying rock. It is, therefore, possible to draw conclusions from the shape of the ratio curves concerning the underground conditions. The following factors have an influence upon the size and form of the ratio curve :—

(*a*) The depth of the change in resistivity, i.e., the thickness of overburden. The size of the indication decreases rapidly with increasing depth.

(*b*) The ratio between the resistivities of bedrock and overburden.

(*c*) The resistivity ratio of the two rock types at a contact, or vein against countrv rock.

(*d*) The width of the vein.

(*e*) The dip of the contact or vein.

C. Electro-magnetic Methods.

(1) *Observing the Field Direction.*—To determine the direction of the electro-magnetic field, the induction coil has to be mounted on a pivot so that it can be set in any plane. The strength of the induced current depends upon the number of lines of force cut by the search coil. The minimum current, which is indicated by silence in the field observer's headphones, is found when the search frame is parallel to the direction of the electro-magnetic field. The azimuth of the frame is determined by means of an angle drum or compass, and the tilt from the vertical by means of a clinometer.

(2) *Observing the Field Strength.*—Two instruments, the compensator and the turam, are used for the investigation of the strength of the electro-magnetic field. The compensator gives

the absolute value, while the turam gives the relative strength of the electro-magnetic field along traverses pegged out usually at right angles to the supposed striking direction of the feature to be examined.

Only a brief description of the theory of the electro-magnetic method is given in this report.

A straight insulated cable (one-half to three miles in length) is laid out on the ground and earthed at both ends by spikes driven into the ground. A generator of audio-frequency (300 or 600 cycles) introduces electrical current into the circuit. The current flowing through the ground from one electrode to the other is distributed over a wide area, its distribution depending upon the different electrical resistivities. Thus a concentration will take place in zones of good conductivity. In addition to this, the alternating current flowing through the cable between generator and electrodes creates an electro-magnetic field around it—referred to as the primary field—which will induce electric currents in neighboring good conductors by electro-magnetic induction.

LAYOUT FOR INVESTIGATION OF ELECTROMAGNETIC FIELD

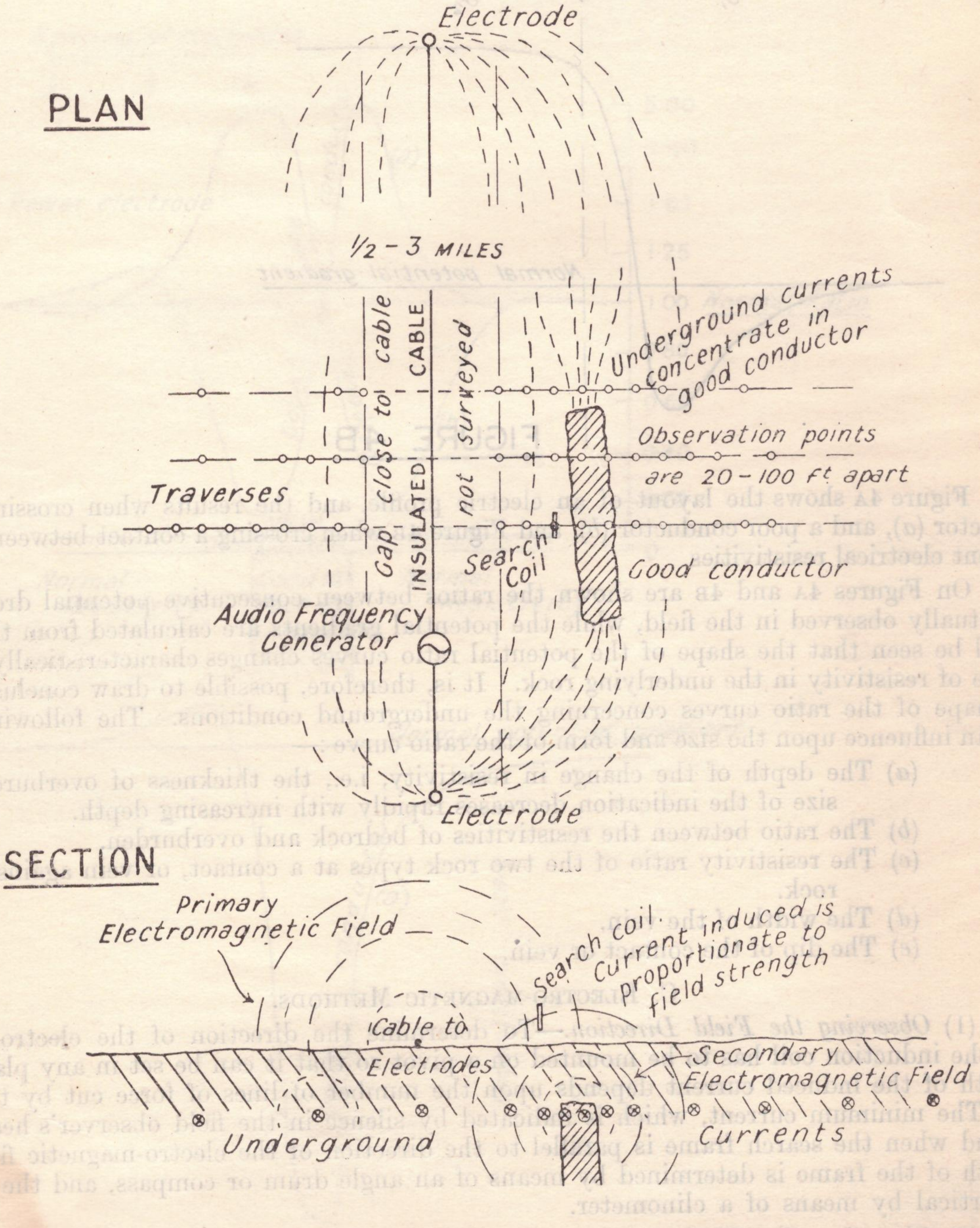

FIGURE 5

The ground currents themselves give rise to a new electro-magnetic field—the so-called secondary field—and this field, and consequently the underground current distribution causing it, can be investigated by portable induction coils. The electro-magnetic field induces electric currents in the induction coils, and the strength of these currents is proportional to the electro-magnetic field strength.

It must be remembered that the currents induced in the coil will comprise those coming from the primary field (the field surrounding the cable) and those from the secondary field (arising from the underground currents). The amplitudes of these two fields differ in phase. Consequently, due to the presence of this secondary field, the current in the coil will have a phase displacement compared with the primary current. The phase displacement is best illustrated by vector diagrams, of which Figure 6 gives an example.

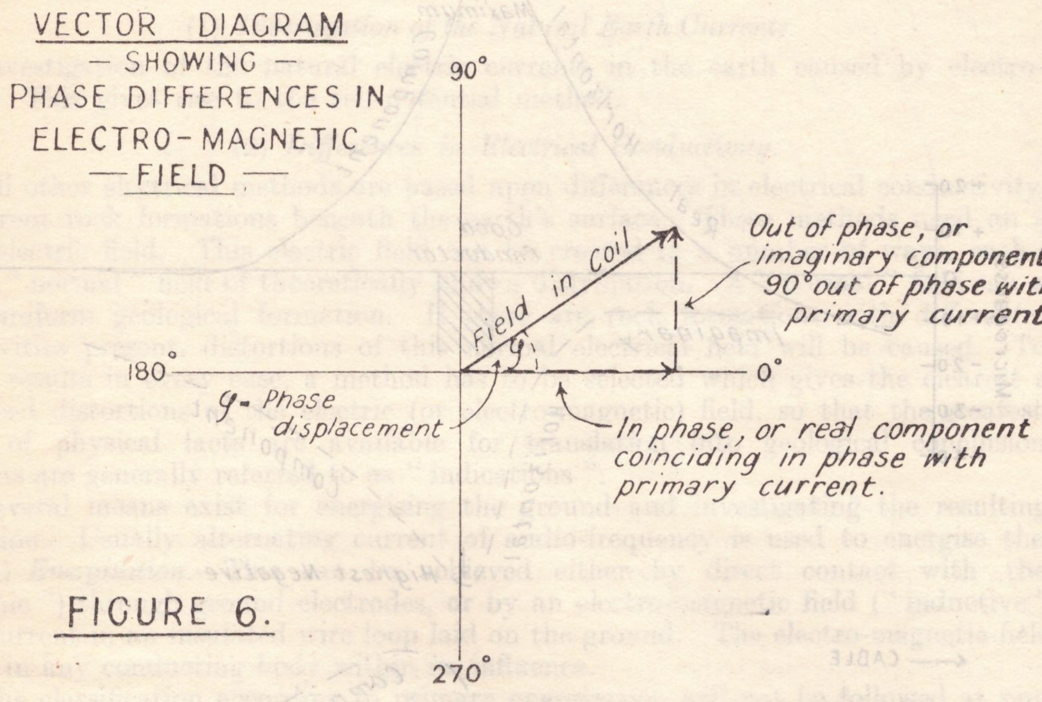

FIGURE 6.

As is made evident in the diagram, any current set up in the search coil and defined by its amplitude and phase (in relation to the primary current) can be divided into two components, the "in phase" and the 90 degrees "out of phase" component.

(3) *The Electro-magnetic Compensator*.—The electro-magnetic field strength is investigated at regular intervals along traverse lines. Profiles are then plotted with the observation points as abscissae and the corresponding field strength as ordinates. The measuring apparatus consists of an alternating current compensating bridge, by which the electro-motive force induced in the search coil is compared with a constant electro-motive force induced in a coil (feed coil) kept in a fixed position directly on the cable line between the electrodes. This compensating arrangement allows the determination not only of the amplitude but also of the phase displacement of the electro-magnetic field. The compensator is calibrated in microgauss (gauss x 10^{-6}) per ampere primary current to avoid complications due to fluctuations in the primary output. The apparatus allows the measurement of the "in phase" and the 90 degrees "out of phase" components. The "in phase" component is generally called the real, the "out of phase" the imaginary component.

The field vector can have any direction in space, but by placing the search coil either horizonatally or vertically it is possible to measure the vertical and horizontal components separately. A complete determination of the electro-magnetic field at any point consists therefore, of the following components :—

Real or in-phase	..	Horizontal component
Imaginary or out-of-phase		
Real or in-phase		Vertical component.
Imaginary or out-of-phase		

All are measured in microgauss per ampere primary current.

Numerous laboratory tests have been carried out in Stockholm, to determine the shape of the curves obtained by plotting the values of the different components when crossing conductors under varying conditions. Figure 7 shows the results of such a test of a good but narrow conductor in a vertical plane—corresponding to a narrow vertical vein. The conclusions given below apply to such a case.

DIFFERENT COMPONENTS OF THE SECONDARY ELECTRO-MAGNETIC FIELD OBTAINED OVER A VEIN WITH LOW ELECTRIC RESISTIVITY. *(Tests carried out by Electrical Prospecting Co Stockholm.)*

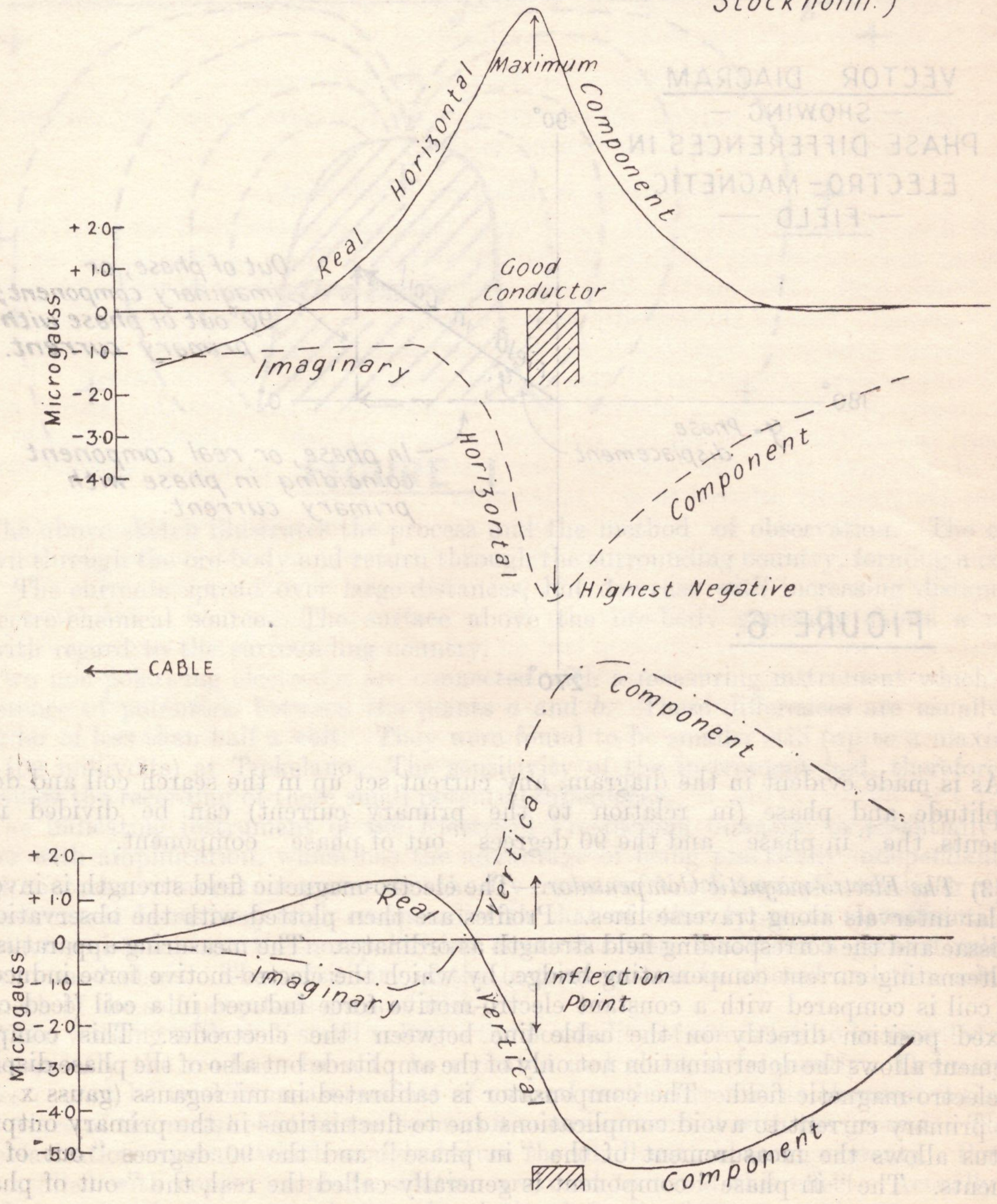

FIGURE 7.

All four aforementioned components are shown. The following points should be noted :—

(*a*) The Real Horizontal Component shows a maximum directly over the good conductor.

(*b*) The Imaginary Horizontal Component shows a minimum in the same point. The sign is negative.

(*c*) The Vertical Component is characterized by an inflexion point over the good conductor. The Real Vertical Component has—counting from the cable line—first a maximum, then a minimum ; the Imaginary Vertical Component shows first a minimum, then a maximum.

The size and shape of these components depend upon the size of the good conductor, the thickness of overburden, the dip and the ratio of resistivity of vein to country rock.

Thus a considerable amount of information may be obtained from a complete interpretation of all four components when the survey is carried out under favorable conditions.

(4) *The Turam.*—The turam is used to investigate spatial variations in the strength of an electro-magnetic field. Whereas the compensator gives the absolute values of amplitude and phase at the observation points, the turam compares the currents induced by the electro-magnetic field in two induction coils. Usually two frames held horizontally and kept always a certain distance apart are used, and a comparison is made between the vertical components at the two points. Each frame is influenced by the primary field (caused by the cable) and the secondary field (caused by the underground currents). The two frames will not only give different amplitudes of the electro-magnetic field, but also a phase difference. If both frames are at the same place and in the same position, so that in both the same currents are induced, the ratio of the two amplitudes is equal to one and the phase difference between the two frames is zero, but as soon as one frame is placed at another point or position, the ratio and phase difference will change. If the two frames are moved along a traverse and observations taken at consecutive points, the amplitude and phase can be determined with reference to the first point of a traverse. The relative values of the real and imaginary vertical components at the observation points along a traverse are thus obtained in terms of the amplitude and phase at one point of the traverse.

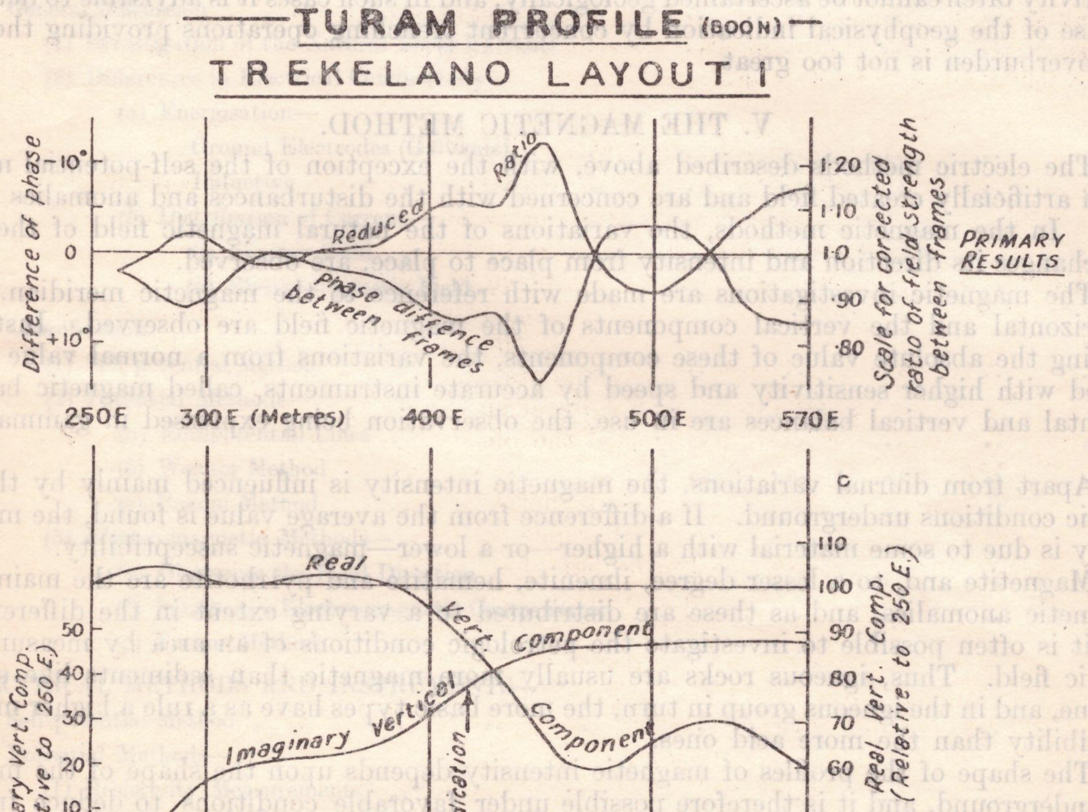

FIGURE 8

Figure 8 shows the ratios and phase differences and also the real and imaginary vertical components deduced from them.

The turam method is especially suitable for rapid reconnaissance surveys. The rather complicated geological and geophysical conditions encountered in the Cloncurry field called for the drawing of contour maps. The compensator was more suitable for this purpose and the turam was used, therefore, only to a slight extent.

IV. THE EFFECT OF THE ELECTRICAL RESISTIVITY OF ROCK FORMATIONS ON THE INTERPRETATION OF RESULTS OF ELECTRICAL METHODS.

The electrical restivities of rocks and minerals, from which the distortions in ground current distribution arise, have a wide range.

The highest electrical conductivity is shown by the sulphides—chalcopyrite, pyrite, &c.—and sulphide ore-bodies will therefore cause marked current concentrations. In addition, however, some rocks show a certain electrical conductivity due to the fact that they are more or less porous and the pores are filled with liquid. This electrolytic conductivity of the rocks depends upon the pore volume and also upon the conductivity of the liquid filling the pores. A serious difficulty in ore prospecting is often to discern between a current concentration due to sulphides or to a highly porous schist or clay, especially when sulphate of copper, &c., is present in the moisture, as the electrical conductivity of such waters is increased and thereby also the conductivity of the rocks containing such waters.

Conclusions can be drawn from the shape and size of the electrical indications as to shape and size of the good conducting zones. The ratio of the electrical conductivity of the conductor to that of the surrounding country rock is also helpful. It is only by a combination of geophysical and geological reasoning, however, that it is possible to arrive at conclusions as to the nature of the good or poor conducting material.

The geo-electrical methods to-day are so far advanced that the position, size and shape of a good or poor conductor, or of a contact between rocks of different conductivities can be determined, providing the observations are made by a careful and skilled observer, and the geological conditions are not too complicated. Uncertainty and errors generally appear at the translation of geophysical results into geological terms. The exact cause of good or poor conductivity often cannot be ascertained geologically, and in such cases it is advisable to determine the cause of the geophysical indication by concurrent trenching operations providing the depth of the overburden is not too great.

V. THE MAGNETIC METHOD.

The electric methods described above, with the exception of the self-potential method, need an artificially created field and are concerned with the disturbances and anomalies in such a field. In the magnetic methods, the variations of the natural magnetic field of the earth, which changes its direction and intensity from place to place, are observed.

The magnetic investigations are made with reference to the magnetic meridian. Both the horizontal and the vertical components of the magnetic field are observed. Instead of measuring the absolute value of these components, the variations from a normal value can be observed with higher sensitivity and speed by accurate instruments, called magnetic balances. Horizontal and vertical balances are in use, the observation being expressed in gammas (10^{-5} gauss).

Apart from diurnal variations, the magnetic intensity is influenced mainly by the local magnetic conditions underground. If a difference from the average value is found, the magnetic anomaly is due to some material with a higher—or a lower—magnetic susceptibility.

Magnetite and, to a lesser degree, ilmenite, hematite and pyrrhotite are the main causes of magnetic anomalies, and as these are distributed to a varying extent in the different rock types, it is often possible to investigate the petrologic conditions of an area by measuring the magnetic field. Thus, igneous rocks are usually more magnetic than sediments like shale or limestone, and in the igneous group in turn, the more basic types have as a rule a higher magnetic susceptibility than the more acid ones.

The shape of the profiles of magnetic intensity depends upon the shape of the magnetic body underground, and it is therefore possible under favorable conditions to deduce from the form of the magnetic curves, the shape and extent of the magnetic body.

Experience has shown that gold reefs and lodes are only occasionally suitable for prospecting by magnetic methods, as quartz, carbonates, pyrite and limonite have low magnetic susceptibilities. However, magnetic prospecting can be used successfully in cases where the gold is associated with hematite or magnetite bodies or impregnations, or where the magnetic properties of a certain bed or structure can be associated with the auriferous deposit.

(Sgd.) SEPP HORVATH,
for The Electrical Prospecting Company of Sweden.

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LIST OF PUBLICATIONS.

PERIODICAL REPORTS.

Report for Period Ended 30th June, 1935 .. } In one publication.
Report for Period Ended 31st December, 1935 }
Report for Period Ended 30th June, 1936.

INDIVIDUAL REPORTS.

WESTERN AUSTRALIA.

No. 1, McPhee's Patch Area, Pilbara Gold-field, by K. J. Finucane, M.Sc.
No. 2, The North Pole Mining Centre, Pilbara Gold-field, by K. J. Finucane, M.Sc.
No. 3, Lalla Rookh Mining Centre, Pilbara Gold-field, by K. J. Finucane, M.Sc.
No. 4, The Nullagine Conglomerates, Pilbara Gold-field, by K. J. Finucane, M.Sc.
No. 5, The Nullagine River Concessions, No. 695 H, Pilbara Gold-field, by K. J. Finucane, M.Sc.
No. 6, Talga Talga, Pilbara Gold-field, by K. J. Finucane, M.Sc.
No. 7, The Blue Spec Gold—Antimony Quartz Veins, Middle Creek—Nullagine District, Pilbara Gold-field, by K. J. Finucane, M.Sc.
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No. 9, Bamboo Creek Mining Centre, Pilbara, Gold-field by K. J. Finucane, M.Sc.

NORTHERN TERRITORY.

No. 1, The Pine Creek Gold-field, by P. S. Hossfeld, M.Sc.
No. 2, The Union Reefs Gold-field, by P. S. Hossfeld, M.Sc.
No. 3, The Golden Dyke Mine and Adjacent Areas, by P. S. Hossfeld, M.Sc.
No. 4, Report on Magnetic Prospecting at Tennant Creek, by J. M. Rayner, B.Sc., and Appendix, by P. B. Nye, M.Sc., and J. M. Rayner, B.Sc.

QUEENSLAND.

No. 1, The Mount Freda—Canteen Area, Soldiers Cap, Cloncurry District, by C. S. Honman, B.M.E.
No. 2, The Gilded Rose Area, Cloncurry District, by C. S. Honman, B.M.E.
No. 3, The Geophysical Methods of the Electrical Prospecting Company of Sweden, used in the Aerial, Geological and Geophysical Survey of Northern Australia, by Sepp Horvath.
No. 4, Geophysical Report on the Soldiers Cap Area, Cloncurry District, by J. M. Rayner, B.Sc., and P. B. Nye, M.Sc.
No. 5, Geophysical Report on the Trekelano Area, Cloncurry District, by J. M. Rayner, B.Sc., and P. B. Nye, M.Sc.
No. 6, Geophysical Report on the Dobbyn Area, Cloncurry District, by J. M. Rayner, B.Sc., and P. B. Nye, M.Sc.