COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT
BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

BULLETIN No. 44

MAGNETIC PROSPECTING

AT

TENNANT CREEK,

NORTHERN TERRITORY, 1935-37

by

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C.8137/57.

CONTENTS

ILLUSTRATIONS

TEXT FIGURES

PLATES

ABSTRACT.

The geophysical surveys described in this report were performed during 1935–1937 by the Aerial, Geological and Geophysical Survey of Northern Australia, but the results were not fully published at that time. As mining development has shown that the Tennant Creek Field, originally considered as a goldfield only, now has possibilities as a base metal field, it was considered desirable that the leading features of the surveys and the results thereof be presented in a unified report.

The report is confined mainly to geophysical aspects and refers only to the detection of magnetic bodies. Three types of anomaly were observed, and are classified as minor, major and regional. The minor anomalies appear to be of little significance, and the surveyed areas were not large enough to completely delineate the regional anomalies, which are almost certainly associated with the regional geology. The major-type anomalies are well suited to interpretation by theoretical methods. A method of interpretation based on polarization by induction has been applied to these anomalies, and testing performed to date indicates that this method shows the position of the body causing an anomaly with sufficient accuracy for the siting of an exploratory drill hole. In general, a reasonable estimate can be made also of the extent in depth of the body.

More complete evaluation of the magnetic results would be assisted by accurate delineation and interpretation of the regional anomalies. An airborne magnetometer survey, with this object in view, has recently been completed by the Bureau and should give valuable information on the structure and limits of the field.

Illustrations are presented showing contour maps of most of the major anomalies, and, for the most important areas, observed magnetic profiles are shown alongside profiles based on theoretically determined dimensions of the bodies causing the anomalies. Four appendices give details of the mathematics involved in the method of interpretation which has been adopted.
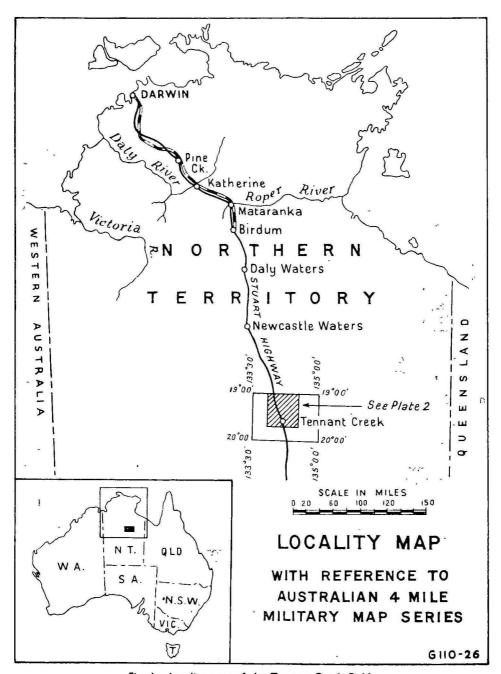
Fig. 1.—Locality map of the Tennant Creek Field.

INTRODUCTION.

The surveys described in this report were performed during 1935–1937 by the Aerial, Geological and Geophysical Survey of Northern Australia. Two progress reports on the work were published, namely those by Nye and Rayner (1936) and Richardson, Rayner and Nye (1937). A third progress report (Richardson and Rayner, 1937) was written but not published, and a fourth and final report (Richardson and Rayner) was planned, but not written, as the A.G.G.S.N.A. was disbanded at about that time.

For several reasons, it appears desirable that the leading features of the survey be presented in a unified report, and that the material which it was planned to include in the third and fourth reports be made available, particularly to those interested in the further development of the Tennant Creek Field. Owing to the nature of the anomalies obtained, the results are of great technical interest. The geological information now available is much more complete than was the case when the previous reports were prepared. Further, mining development has shown that the Tennant Creek Field, originally considered as a goldfield only, offers at least the possibility of the presence of base metal ore bodies of major dimensions, and a large-scale testing programme based on magnetic surveys may well be an economic proposition.

The present report discusses the work mainly from the geophysical aspect. For reasons mentioned in the next section, attempts at detailed geological interpretation on the basis of information available at present would be premature.

Of the authors of the previous reports on geophysical work, Messrs. P. B. Nye and J. M. Rayner, as senior officers of the Bureau of Mineral Resources, Geology and Geophysics, are associated with the present report. No report on the magnetic surveys at Tennant Creek would be complete, however, without acknowledgment of the work of Mr. L. A. Richardson, who was responsible for the planning and supervision of all the field work.

THE TENNANT CREEK GOLDFIELD.

The Tennant Creek Goldfield lies in the Northern Territory, and is approximately at the geometrical centre of the Australian Continent (Fig. 1). Gold production began in 1934, and up to the end of 1952, about 250,000 tons of ore had been treated of an average grade of 1 ounce per ton. This production has come from about 120 mines, which are scattered over an area of about 2,500 square miles. Since the resumption of mining after World War II., production has been almost entirely from the Eldorado, Enterprise, Noble's Nob, Northern Star and Peko Mines, all of which are still operating. Slight copper mineralization has been noted in several outcrops, and most of the drill holes put down on the field have shown traces of sulphides. Recently, mining development at the Peko Mine has revealed a copper orebody, which is stated to contain reserves of 1,000,000 tons of copper ore, containing 7 per cent. copper.

The terrain is relatively flat, consisting of isolated ranges of low hills, separated by wide areas of alluvium. The area of outcrop is only a small fraction of the total area of the field, and for this reason, geological evidence is scanty, and is, in many cases, insufficient to enable major structural features to be determined with certainty. The geology of the field has been briefly discussed in various official publications, but all previous reports may be

considered as being superseded by that written by Ivanac (1954), from which the geological map shown on Plate 1 is taken. Ivanac's report is directed mainly towards the potentialities of the field as a gold producer, and is authoritative in this regard.

Experience shows that evidence from surface geology and shallow mine workings does not provide adequate information on the presence of sulphide bodies. In a field where the proportion of outcrop is as small as at Tennant Creek, improvement in geological knowledge is greatly dependent on information derived from exploration at depth, by deep mine workings or drilling. Such exploration is being actively carried on by several mining companies but general conclusions on the occurrence of sulphide ore bodies on the basis of present knowledge would be premature. The following brief notes are based on Ivanac's report, and on discussions with Mr. J. Elliston, of Mining and Prospecting Services Ltd.

The major part of the outcropping rocks of the field consists of sandstones and mudstones known as the Warramunga Group. To the north these rocks grade into sandstones and quartzites, known as the Ashburton Sandstone, while over a small area in the eastern portion, they are overlain uncomformably by the Rising Sun Conglomerates. These rocks are considered to be of Proterozoic age. They have been intruded by soda granite and related porphyrys, which crop out in the centre of the field, and also at its southern boundary. At the eastern edge of the field, the Pre-Cambrian rocks are overlain unconformably by rocks of Cambrian age. The western boundary of the field has not yet been established.

The ore deposits are confined to rocks of the Warramunga Group. These are generally highly contorted, and contain numerous pipe-like bodies, which, in the outcropping portions, consist of massive siliceous specular hematite. In what follows, these bodies will be referred to by the general term of " ironstone " bodies, agreeable to the practice adopted in previous reports. Outcrops in all stages of denudation are present, from large bodies which have been shown by mining development to extend into the primary zone, to areas of hematite rubble, which are considered to represent ironstone bodies completely denuded. Mineralogical evidence indicates that most of the outcropping hematite is secondary, derived from the oxidation of magnetite. It may be expected, therefore, that ironstone bodies below water level will consist predominantly of magnetite.

It is considered that two types of ironstone bodies are present on the field, namely:—

1. Bodies whose emplacement is controlled by structural features such as fissures, shear zones and fault zones. Most of the bodies described by Ivanac are of this type.
2. Bodies formed by selective replacement of lenses of sedimentary breccia. The Peko ore body, and other outcropping and concealed bodies east of the Peko, are considered to be of this type.

Ivanac's examination shows that although many of the bodies appear, in outcrop, to consist of massive hematite and quartz, in depth they generally consist of hematite lenses, pipes and stringers in brecciated sediments. However, the Peko ore body in depth is relatively homogeneous, consisting of an outer shell of quartz and magnetite, surrounding a central core of magnetite intimately mixed with chalcopyrite. It will be shown later that the results of

the magnetic survey indicate that bodies in the oxidized zone behave in different ways, which can be explained by supposing that some of the bodies are subject to complete oxidation but others are not. It appears reasonable to suppose that these various characteristics may be correlated, so that bodies of type (1) contain considerable inclusions of sediments, and are subject to complete oxidation, while bodies similar to the Peko are to a large extent protected from oxidation. The evidence generally supports this supposition, but cannot be considered sufficient to establish it.

The hematite bodies generally have a very steep dip and are considered to be genetically associated with the granitic intrusion.

With insignificant exceptions, all ore bodies are associated with ironstone bodies. It has been recognized from the commencement of mining on the Tennant Creek field, that the gold ore shoots, although often of high grade, are very limited in dimensions. Ivanac's mapping has established the reason for this. It appears that the occurrence of gold-bearing ore is subject to two controls—

1. The nature of the sediments. The competent sandstones have supported tectonic stresses without fracturing, and do not allow easy entry to mineralizing solutions. The less competent mudstones have, in restricted zones, been extensively fractured, and have been favourable to the entry of the gold-bearing solutions.

2. The extent of the mudstone horizons has been controlled by a complicated system of small-scale faulting and shearing, probably existing before the period of mineralization. This means that the auriferous beds are generally of small dimensions.

In any particular case, these controls can be evaluated only by very detailed geological mapping, for which the amount of outcrop is generally insufficient. It is therefore only rarely that a non-outcropping gold ore shoot can be located.

The copper ore body at the Peko Mine is also associated with a hematite-magnetite body, but is on quite a different scale. It is of considerable dimensions, and could be located economically by diamond drilling. The possible discovery of further ore bodies of this type offers the only inducement to a large-scale exploration programme in the field.

PURPOSE OF THE SURVEY.

At the time when the Tennant Creek survey was undertaken, the detailed geological information abstracted above was not available. The problem was envisaged as a technical one in the first instance, to determine, if possible, whether or not outcropping ironstone bodies persist in depth, and if any indication could be observed of the presence of bodies completely concealed. In view of the general association of gold with ferruginous bodies, the magnetic method was an obvious choice for preliminary testing. The method proved very successful and was used exclusively. Although geological information was insufficient to determine controls on ore deposition, it was known that ore shoots were short and irregular, and it was realized that prospecting a completely concealed body for gold would be quite uneconomical. However, it was hoped that the discovery of a major development of ironstone at depth close to an established ore body would be useful as an indication that suitable conditions for the presence of ore might exist at considerable depth, and that exploration could confidently be directed towards the concealed body.

TECHNICAL DETAILS.

The work was performed using magnetic variometers of the Schmidt type manufactured by E. R. Watts and Sons Ltd. Two types of variometer were used, measuring the vertical and horizontal components of the earth's field respectively. As would be expected in the magnetic latitude of Tennant Creek, it was found that the vertical component gives the clearest indication of the presence of concealed bodies, due to the fact that the anomalies observed are predominently positive. For reasons discussed in a later section, it was found that profiles obtained with the horizontal variometer are particularly convenient for some aspects of the interpretation procedure. The method adopted was to survey the whole area to be examined using the vertical variometer, and to read only selected traverses with the horizontal instrument.

After the first preliminary tests, it was decided that all base lines should run east-west, and traverses north-south. This allows of most convenient operation of the instruments, and is suited to the interpretation methods used and to the general strike of the country. Surveying was by theodolite and chain. Base lines were laid out east-west by compass, and true bearings later observed by theodolite.

The parties were also equipped with absolute magnetic equipment with which observations were made at the absolute magnetic station, established by the Carnegie Institute of Washington in 1912, near the Old Telegraph Station. The results of these · observations, together with the results of later re-occupations of the same station, are given in the next section. Absolute observations were also made at the main base station near the Eldorado Mine, to which all field observations were reduced, thus enabling all observations to be connected approximately on an absolute basis. For further instrumental details reference should be made to the previous reports.

RESULTS.

The results of absolute magnetic observations at the station near the Old Telegraph Station are given in Table 1.

TABLE 1.

Results of Observations at Absolute Magnetic Station near Old Telegraph Station, Tennant Creek.

Date.	Declination.		Inclination.		Horizontal Intensity.		Observer.
	L.M.T.	Value.	L.M.T.	Value.	L M.T.	Value (gammas)	
26th July, 1912	10·6	4° 00·0′ E.	13·8	48° 25·6′	10·6	33475	CIW
15th July, 1936	..	..	12·3	48° 52·5′	..	..	AGGSNA
16th July, 1936	11·4	4° 18·5′ E.	..	..	11·4	33170	AGGSNA
12th June, 1945	13·5	4° 29·0′ E.	11·5	48° 51·5′	11·0	33262	AGGSNA
1st August, 1952	11·7	4° 30·8′ E.	..	..	13·5	33184	BMR

Three types of anomalies were observed in the routine surveys:—

1. Minor-type anomalies.—These consist of violently disturbed readings, sometimes covering considerable areas. The readings are quite erratic, and arise from magnetic material at very shallow depth. They were observed over outcropping ironstone or ironstone rubble, and occasionally over soil-covered areas, containing detrital ironstone materials at depths of a few feet.

2. Major-type anomalies.—These are large, regular anomalies of considerable extent, obviously arising from magnetic bodies at depth.

3. Regional-type anomalies.—These are broad regular anomalies showing comparatively small variations in magnetic intensity over large areas.

The results are shown on Plates 3 to 16. Where major-type anomalies were observed, the results are shown as contours of vertical magnetic intensity. The contours were obtained from profiles, from which the minor-type anomalies had been smoothed. Over some areas the profiles did not provide a basis for drawing such contours. These areas have been grouped on Plates 12 to 16, and actual profiles are shown. Some of these areas show examples of the regional-type anomalies.

INTERPRETATION OF RESULTS.

GENERAL.

Attempts at detailed interpretation of results have been confined to the major-type anomalies. Little can be said concerning the regional-type anomalies, as the areas surveyed were not large enough to delineate them completely. Their regularity indicates that they are almost certainly connected with the regional geology, and it appears that a complete magnetic survey of the field with an airborne magnetometer would provide information which could be of considerable assistance in determining structural features. An airborne magnetometer survey of the Tennant Creek area was recently completed by the Bureau.

The minor-type anomalies require no interpretation. They are due either to strongly magnetic sections in the hematite outcrops or to magnetic detritus, either on the surface or covered by a small thickness of alluvium. As regards the outcropping hematite, there is no reason to suppose that the intensity of magnetization would have any relation to gold concentrations. Hematite detritus might possibly contain gold if it were derived from the weathering of an auriferous body. The chance of such material containing gold would be about the same as that of a hematite outcrop chosen at random containing gold. Prospecting experience indicates that this chance is small. For this reason, there is no justification for recommending the testing of anomalies of this type.

Attention has been directed mainly to the interpretation of the major-type anomalies. The basis of the methods used and the results in general are discussed in the body of the report. Mathematical details of the interpretation procedure are described briefly in Appendix A.

PRINCIPLES OF THE INTERPRETATION OF MAGNETIC ANOMALIES.

The literature on interpretation of magnetic anomalies is considerable. The problems involved are discussed in standard works on geophysical prospecting, such as Heiland (1946), in which references to the literature may be found.

The problem presents theoretical difficulties, some of which are common to all types of geophysical interpretation, while others are peculiar to the magnetic method. Any problem in geophysical exploration involves the measurement of a potential field, and the relating of this field to its source. The measurement of the field is an experimental problem, which can always be solved. However, in relating the observed field to its cause, a major difficulty arises at the outset. The problem of calculating the potential field due to a known distribution of physical properties is, in general, capable of unique solution (although in practice the computation may prove hopelessly difficult). The reverse problem, of calculating the actual physical distribution from the potential field, cannot be solved uniquely. Restrictive assumptions must be made to obtain a definite solution.

Assuming that a correct solution can be obtained for the distribution of physical properties, it is now necessary to relate this distribution to the actual geological units involved. This is peculiarly difficult in the case of magnetic measurements, for the following reasons:—

1. Unlike gravitational potential, for example, magnetic potential is a polar phenomenon. This causes extra complexity in mathematical treatment.

2. The magnetic properties of natural bodies are not simple. In general, the magnetic effect of a body in the earth's field contains two parts. One is due to polarization by induction in the existing field, and can be evaluated approximately providing there is sufficient basis for assuming that the body approximates to a relatively simple geometrical shape. The other part is due to permanent magnetism. This is critically dependent on the nature and geological history of the body, and no assumption concerning it can be justified on theoretical grounds.

The process of interpretation involves making assumptions concerning the shape and aspect of the body, and the nature of its magnetization. The potential distribution to be expected is then computed and compared with the observed results. The computation is repeated using various assumptions, until a calculated potential distribution is obtained which fits the observations to a degree of approximation considered sufficient. As well as being very laborious, this process can be misleading if its inherent uncertainties are not appreciated. Practically speaking, the diagnostic value of the observations is not very high. Calculations may be made for bodies of very different shapes, and the results when plotted together may appear easily distinguishable. In practical use, where it is a question of using observations which generally do not fit any of the calculated values very closely, it is often doubtful which of several very different assumptions best fits the results. Also, it can be proved on theoretical grounds, which are discussed in Appendix B, that in a great number of instances of practical importance, it is impossible to distinguish between the magnetic effects due to a sphere and those due to an ellipsoid of the same volume centred at the same point. These facts must always be borne in mind as providing a criterion for determining the accuracy of interpretation which can justifiably be aimed at.

In metalliferous prospecting, it is generally not necessary to interpret the magnetic field distribution over large areas. The problem usually requires the locations of bodies of relatively small dimensions, whose magnetic properties are in marked contrast to those of the surrounding rocks. For

this purpose, the observed field is separated into two portions, a normal field and an anomalous field. The normal field is generally uniform, except insofar as it contains large-scale variations due to the different magnetic properties of major geological units. The remainder of the observed field consists of isolated anomalies due to the smaller bodies being sought. The separation of this part of the field is generally straightforward, though particular instances may arise in which there is cause for doubt. When the anomalous field has been separated from the normal field, the interpretation involves the determination of the body causing the anomaly.

The nature of the assumption to be made concerning the magnetization of the body causing an anomaly is fundamental to the accuracy of the interpretation. It is, however, quite impossible to justify any particular assumption either on the basis of the magnetic measurements alone, or on physical principles. Full treatment of the question is the province of text books on magnetic prospecting. However, as it is impossible to refer to any text book which is satisfactory in this regard, it is considered that a brief discussion of the principles involved is not out of place in the present report.

Various methods of classifying magnetic bodies (in the geological sense) may be adopted, depending either on the nature of the bodies themselves, or on the nature of the magnetic anomalies they may be expected to produce. Unfortunately, these various classifications overlap, and it is therefore impossible to find a simple physical basis for classification which will at the same time serve to distinguish the types of anomaly to be expected.

To distinguish bodies according to whether their magnetism is permanent or induced is superficially attractive, but has little practical significance. The property of "remanence", or the power of acquiring permanent magnetism, is possessed in a marked degree by magnetite and pyrrhotite, to which, in the final analysis, the vast majority of magnetic anomalies are due. It can, therefore, be safely assumed that any body capable of causing a magnetic anomaly is also capable of acquiring permanent magnetism. Likewise, any magnetic body in the earth's field will certainly acquire induced magnetism, which may be permanent. The main distinction of practical importance is between bodies which are either magnetized in the direction of the earth's field or permanently magnetized as a whole in some other direction, to a degree much stronger than the magnetization induced in the present earth's field, and bodies which have permanent magnetization in directions which vary in different parts of the body.

A more practical distinction is on the basis of shape, between bodies whose shape may be approximated by a simple mathematical formula (such as a surface of the second or lower degree) and those whose shape is so complicated that no such approximation is possible. However, this may cut across the distinction on the basis of magnetization, as a body of even the simplest shape may acquire erratic permanent magnetization in the course of its geological history.

The study of the physical bases of magnetism has advanced greatly during the last few years, and the results obtained from experiments on ferrites and other artificial materials provide basic principles which can be applied to the much more complicated subject of rock magnetism. However, this application is only in the initial stages at present. A very convenient summary of the present state of knowledge in this regard is given by Nagata (1953). A brief consultation of this book will suffice to show the extreme complexity of the physics involved.

Once a particular assumption concerning the shape and magnetization of a body can be made, the anomaly to be expected from the body may be calculated, for comparison with observed results. The completeness of this calculation varies. If the assumption made is relatively simple, fairly detailed calculations are possible. If the shape or magnetization (or both) are complex, detailed calculations may be impossible, and the only results to be expected may be empirical. There is, however, one major mathematical difference in the results of these calculations. If the assumed body is simple enough, the shape of the calculated anomaly curve depends only on the position of the body and not on its shape. If the assumed body is complex, either in shape or magnetization, the calculated anomaly will depend on the shape of the body, as well as on its position. For accurate interpretation, it is vital that observed anomalies be correctly classified on this basis. However, in many instances the results themselves do not provide a basis for doing this. If an observed anomaly is irregular in form, it may be assumed that it is caused by a body irregular either in shape or magnetization. If, however, an anomaly is of regular form, so that it is a perfect match to one calculated for a simple body, it is still not certain that this matching is not fortuitous. The best that can be done is to use available geological information to make an assumption concerning the body causing the anomaly, and to hope that, if the assumption is completely wrong, the observed anomaly will not fortuitously resemble the calculated one, but will differ from it sufficiently to arouse some doubt as to the correctness of the assumption.

It is apparent that any interpretation of a magnetic anomaly involves several assumptions, which generally have very little justification. Unfortunately, testing is never sufficient to evaluate these assumptiions in detail; in fact, it is difficult to conceive that this would ever be possible. An interpretation is generally considered justified if it predicts that the magnetic body can be encountered in a drill hole at a particular position and depth, and if this prediction is confirmed with reasonable accuracy. For complete testing, it would be necessary for the shape of the body to be completely outlined and for its magnetization to be examined in complete detail. This is obviously impracticable. It is likely, therefore, that many of the uncertainties at present involved in magnetic interpretation will remain unresolved.

METHOD OF INTERPRETATION ADOPTED.

Inspection of the contour plans of the Tennant Creek magnetic anomalies shows that the contours of the vertical component are roughly circular, indicating that the magnetic bodies are probably pipe-like bodies, similar in shape to the bodies which crop out. The observed profiles, after smoothing of surface effects, are extremely regular. It was therefore decided to endeavour to fit the profiles by curves, calculated on the assumption that the magnetic body is a sphere polarized by induction in the earth's field. This procedure was originally suggested by J. M. Rayner. A few tests showed that a remarkably close fit could be obtained, and this process was made the basis of the interpretation procedure. The qualification mentioned in the previous section must always be borne in mind, however.

On general geological grounds, a magnetic body of spherical shape must be considered as unlikely. A better approximation would be to consider the body as an ellipsoid of revolution. The parameters of such an ellipsoid could be so adjusted as to give a reasonably close approximation to the shape of any body which has one section roughly circular. The use of this approximation is discussed in Appendix B, based on Koenigsberger (1928).

Briefly, the formulae involved are too complicated to provide the basis of a practical interpretation procedure. Also, it can be shown that, in general, the results tend to approximate closely to those obtained from the spherical assumption, and in a few cases tried, where it was thought that this might not be so, the difference between results obtained on the two assumptions would not be significant in practice. It appears, therefore, that there would be no advantage in using the more general assumption. The matter has an important bearing on the physical significance of the calculated body which is discussed on pp. 13 *et seq.*

The mathematical details are given in Appendix A. The only feature which may be novel is the method of treating the data in order to eliminate the laborious process of fitting curves by trial and error. Briefly, the process is as follows:—

1. It is assumed that the major portion of the anomaly is due to a spherical body polarized by induction in the present direction of the earth's field. It is obvious on geological grounds and from the profiles over some anomalies, that this assumption is likely to be far from the truth. However, even in such instances, the method used is sufficiently accurate for siting exploratory drill holes.

2. The position of the anomaly is sited generally by drawing contours of the vertical component of the magnetic field.

3. A profile is read with the horizontal magnetometer over a north-south traverse as close as possible to the centre of the anomaly.

4. This profile will show in general three turning points, a maximum to the north of the centre, a minimum a little to the south, and another rather indefinite maximum considerably to the south. Considering only the two central turning points, the centre of the body is vertically below a point north of the minimum position, dividing the distance between the maximum and minimum in the ratio $0 \cdot 75$ to $0 \cdot 28$. The depth to the centre of the sphere is obtained by dividing the horizontal distance between maximum and minimum by $1 \cdot 03$. (These figures apply only to the magnetic latitude of Tennant Creek.) Similar figures have been computed for the vertical component profiles, but, as mentioned later, the turning points in these profiles are commonly rather indefinite.

5. Theoretical profiles are computed and compared with the actual ones. The divergences may be used to obtain an estimate of the departure of the body from spherical shape, but, for reasons discussed later, this requires extreme caution.

6. To obtain an estimate of the depth to the top of the body, it is necessary to compute the size of the body. This can be done only within fairly wide limits, as it involves an assumption concerning the effective susceptibility of the material of the body which is at best extremely doubtful. Also, other considerations are involved, and these are discussed in the next section but one.

When a value for susceptibility can be assumed, the radius of the body is obtainable from the following formula:—

$$H = 3 \cdot 26 \times 10^5 \, K \, \frac{r^3}{z^3}$$

where H is the magnitude of the anomaly in gammas, as measured by the difference between maximum and minimum values on the horizontal component profile, K is the susceptibility in *c.g.s.* units, r is the radius of the body, and

z is the depth to the centre. (The figures in the above equation apply only to the magnetic latitude of Tennant Creek.) A nomogram for the solution of this equation, when r and z are measured in feet, is shown in Fig. A4, Appendix A. The factors governing the choice of a value for the susceptibility are complex and are discussed in detail in the next section.

SUSCEPTIBILITY OF MAGNETIC BODIES AT TENNANT CREEK.

There are strong indications that the major-type anomalies at Tennant Creek are caused mainly by material in the primary zone. The following facts give adequate support for this conclusion:—

1. The depths to the centre of the bodies, calculated on the spherical assumption, are 500 feet or greater, with a few exceptions. Ground water level on the Tennant Creek field stands at about 250 feet, measured from the flats, and may be as much as 400 feet below the tops of the hills.

2. The above statement regarding the depths to the centre of the bodies holds in some cases where surveys have been conducted over hematite outcrops, which have been shown by mining development to extend into the primary zone. In these cases, there is certainly a large mass of rock, which often contains strongly magnetic material, above water level, yet no indication of its presence was obtained. The Eldorado No. 2 anomaly is a very clear example of this. Information supplied by Mr. F. A. Campbell, consulting geologist, who mapped the workings in detail, shows that the main outcrop on the Eldorado lease has been followed down pitch by drill holes at least as far as water level, and that the No. 2 anomaly is almost certainly due to the bottom portion of this body. The anomaly is small and the shape of the contours indicates that it is probably terminated at the bottom by some feature such as a fault plane at no great depth. There is probably a much greater mass of ironstone above water level than below, yet the portion below water level gives the only detectable anomaly.

These outcrops are generally strongly but irregularly magnetic at the surface, and presumably the same conditions hold throughout the weathered zone. The fact that they give no large-scale anomalies may be attributed to the purely random distribution of magnetic poles. In this connexion, however, it must be borne in mind that a few examples have been noted of anomalies, of regular shape, arising from bodies at shallow depths, certainly above water level.

The most striking examples observed are the Peko anomalies Nos. 4 and 5, which can be fitted closely on the basis of spherical bodies centred at depths of 310 feet and 194 feet respectively. Considerable portions of the bodies responsible for these anomalies are certainly above the general ground water level of the field. Their presence suggests the possibility that the nature of some of the ironstone bodies is such that they are, to a large extent, protected from oxidation. As mentioned earlier, there is some geological support for this conclusion.

Having established as a reasonable assumption that the major-type anomalies arise essentially from material in the primary zone, it is necessary to make some estimate of the susceptibility of these bodies. As stated previously, mineralogical evidence indicates that the magnetic material in the primary

zone is predominantly magnetite. It is therefore possible that the larger anomalies are caused by bodies which are composed very largely of magnetite. The value quoted by Heiland (1946) for the susceptibility of magnetite is 0·8 c.g.s. units. However, this figure cannot be adopted for the following reasons:—

1. The figure required is the effective susceptibility, which involves the susceptibility of the material and a demagnetizing factor which depends on the shape of the body in rather a complicated way. Examples of the demagnetizing factor for ellipsoids of various aspects are given by Nagata (1953). The value of the demagnetizing factor depends on the departure of the body from three-dimensional symmetry, and, for ellipsoids having one dimension much greater than the others, on the inclination of the magnetizing field to the long dimension. Actual values may be obtained from Nagata (p. 82). For the present purpose, it is sufficient to say that the value of the demagnetizing factor (N) for a sphere is

$\dfrac{4\pi}{3}$, and for a body of the type expected at Tennant Creek, a rough estimate, using Nagata's data, suggests that N could be as low as 0·25.

The effective susceptibility of the body is given by $K^1 = \dfrac{K}{1 + KN}$,

where K is the susceptibility of the material of the body. For substances such as magnetite, K can approach 1. It is obvious that, if K is very small, K^1 is nearly equal to K, and as K approaches 1,

K^1 tends to the upper limit $\dfrac{1}{1 + N}$.

Thus for a spherical body, K^1 cannot be greater than

$\dfrac{1}{1 + \dfrac{4\pi}{3}} = 0·192$. If the body departs greatly from spherical

symmetry, K^1 can approach much closer to 1, and a reasonable

upper limit for bodies at Tennant Creek might be $\dfrac{1}{1·25} = 0·8$.

2. Many of the bodies in the weathered zone are not composed of massive ironstone but contain considerable inclusions of sediments. It is possible that the bodies in the primary zone have the same character, and the effective susceptibility as a whole might therefore be less than that of the magnetic material.

3. Both of the above factors tend to reduce the effective susceptibility. On the other hand, Heiland quotes several instances in which it is stated that observed anomalies could be explained only by assuming that the body involved had a susceptibility much higher than that which would be expected of the material comprising it.

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In some cases, a figure for effective susceptibility considerably greater than 1 is required. Physically this would mean that the body possesses permanent magnetization considerably stronger than the induced magnetization due to the present earth's field. Intuitively, it is difficult to admit the possibility of this, unless there is reason to believe that the magnetic body may have, at some point in its history, been subjected to a field much stronger than the earth's field. Intuition is not always a reliable guide in potential problems; however, considering the extreme difficulty of acquiring complete knowledge of the position, shape, and state of magnetization of geological magnetic bodies, it is felt that the cases quoted by Heiland can only be regarded as doubtful at the best.

For these reasons, the assumption of a particular value for the effective susceptibility of a magnetic body on purely theoretical grounds must have very little justification. Figures may be obtained empirically for some of the Tennant Creek bodies, which give an order of magnitude. The Eldorado No. 1 anomaly can be attributed to a spherical body centred at 580 feet, and the fit of observed and calculated values is close. An exploratory drill hole on this anomaly encountered hematite at 213 feet. The drill hole was sited on rising ground, and water level at the site may be taken as 300 feet. The material encountered is probably the weathered portion of the body causing the anomaly, and its presence affords reasonable evidence that the magnetic portion of the body begins at water level. On this reasoning, the radius of the body could be as great as 280 feet. Applying these values to the nomogram shown on Fig. A4, Appendix A, the susceptibility is obtained as $3 \cdot 2 \times 10^{-2}$ c.g.s. units. The Peko No. 1 anomaly has been fitted using the assumption of a spherical body centred at 580 feet (although, as mentioned later, the fit of observed and calculated profiles is far from close). This body certainly extends to water level and above. Using the same figure as above for the radius (280 feet), the susceptibility obtained is $0 \cdot 1$ c.g.s. unit approximately. The largest anomaly so far obtained on the field, the Black Angel No. 1, can be attributed to a spherical body centred at 475 feet. Assuming that the top of the body reaches water level at 250 feet, its radius may be taken as 225 feet, and the susceptibility obtained is $2 \cdot 2 \times 10^{-1}$ c.g.s. unit. The shallowest major anomaly discovered, the Peko No. 5, is centred at 194 feet. If this body reaches the surface (i.e., its effective radius is 194 feet) the susceptibility required is 4×10^{-3} c.g.s. units. Similarly, the Peko No. 5 anomaly, centred at 310 feet, requires a susceptibility greater than 10^{-2} c.g.s. units.

On the basis of these figures, it appears that, for the purpose of calculating the dimensions of the bodies causing the magnetic anomalies at Tennant Creek, a value of $0 \cdot 1$ c.g.s. unit for effective susceptibility is a reasonable average. The calculations shown later indicate that, other things being equal, the linear dimensions of the body vary inversely as the cube root of the effective susceptibility, so that, if the assumed value of susceptibility were in error by a factor of two, the calculated linear dimension would be in error by a factor of about $1 \cdot 2$. The actual physical significance of the calculated linear dimensions is discussed in the next section.

It is desirable to emphasize that the use of this figure has very limited implications with regard to the nature of the magnetic material, or the state of magnetization of the body. As mentioned earlier, the effective susceptibility of the body is only indirectly related to the susceptibility of the magnetic material. With regard to the nature of the magnetization, the method of

interpretation assumes only that the magnetization is originally due to polarization by induction in the earth's field. As the bodies apparently contain a considerable amount of magnetite, it is certain that most of the magnetization is now permanent.

DETERMINATION OF THE SHAPE OF A MAGNETIC BODY.

As shown in Plates 17 to 20, the fit between observed and calculated profiles varies considerably for different anomalies. For example, the vertical component profiles on the Wheal Dorea anomalies bear no resemblance to the calculated ones and it is obvious that the shape of the bodies is very far from spherical. The profiles over the Peko anomalies Nos. 1 and 2 are generally similar in shape to the calculated spherical profiles, but are different in dimensions. On the other hand, in the case of anomalies such as the Eldorado No. 1, and the Peko Nos. 4, 5 and 12, the fit between observed and calculated profiles is close. The extent to which this closeness of fit indicates closeness to spherical shape must be regarded as doubtful on several grounds. The figures quoted in the previous section for the radii of bodies causing certain of the larger anomalies show diameters of the order of 500 feet. Other things being equal, bodies at comparable depth giving anomalies of one-tenth the amount of those quoted would still have diameters approaching 200 feet. Most of the anomalies observed would fall within this class. However, a large proportion of the outcropping bodies have horizontal dimensions less than this, and it is unlikely *a priori* that concealed bodies would be generally larger in horizontal section than outcropping ones. For this reason, it is unlikely on practical grounds that the calculated diameter of the spherical bodies can be taken as a measure of the horizontal dimensions of the actual bodies. As it is common for outcropping bodies to have vertical dimensions much greater than their horizontal section, there is no difficulty in supposing that the calculated diameter of the body could be a measure of its vertical extent. The calculations of Koenigsberger, discussed in Appendix B, provide some general guidance in this regard. The main conclusion to be drawn from his results is that, over a very considerable range of conditions, there is no perceptible difference between the magnetic effects of a sphere and those of an ellipsoid of revolution of the same volume centred at the same point. Where these conditions are not fulfilled, he draws certain general conclusions, which are stated here merely for completeness. Considering only an ellipsoid whose axis of revolution is vertical, if the ellipsoid is very oblate (i.e., its horizontal extent is much greater than its thickness), the anomaly in the vertical component is less than that due to a sphere, by comparison with the anomaly in the horizontal component. If the ellipsoid is very prolate (i.e., its vertical extent is much greater than its horizontal dimensions), the reverse is the case.

Examination of the Peko No. 1 anomaly gives a good indication of how little reliance can be placed on any but the most immediate theoretical considerations. The contours of the vertical magnetic component (Plate 4, Sheet 3) are almost circular (neglecting the narrow protuberance to the east, which is obviously due to a magnetic body at shallower depth than the main body). On the basis of these results, it could reasonably be expected that the horizontal section of the Peko body would be almost circular. However, it is obvious from the sketch of the body as exposed by development (Plate 21) that this is very far from being the case. The body is actually lens-shaped, with an easterly strike, and its north-south dimension is very much smaller than its east-west dimension. The contours certainly give no indication of this. It appears, therefore, that any conclusions as to the shape of the bodies in horizontal section would be most hazardous.

Pending a great deal more testing by drilling, it is considered that the following conclusions represent the extreme limit to which interpretation can safely be taken at present:—

1. The centre of the calculated sphere will be reasonably close to the centre of that portion of the body which consists essentially of magnetite.

2. The calculated diameter of the body, assuming a value of effective susceptibility of $0 \cdot 1$ c.g.s. units, will be, in general, much larger than its diameter in horizontal section, but will be less than its vertical extent.

3. The shape of the contours of the vertical magnetic component may or may not give an indication of any lack of symmetry in the horizontal section of the body.

A type of discrepancy between observed and calculated profiles which was observed on several occasions is the disappearance of the minimum value on the vertical component, associated with a lower value of horizontal intensity at the southern end of the profile. It is not considered that the calculations so far performed provide a safe basis for accounting for this discrepancy. However, the fact that such discrepancies are well marked on the Peko No. 1 anomaly suggests that they may be due to extension in depth. Other discrepancies of less striking type are not uncommon, but it is felt that any suggestions to account for them would be pure guesswork.

DISCUSSION OF RESULTS.

GENERAL.

The results obtained in the various areas surveyed are discussed in detail (as far as geophysical aspects are concerned) in the present section. The location of the areas is shown on Plate 2. Plates 3 to 16 show the results of the surveys, in the form of contours of vertical magnetic intensity where the profiles provide a basis for drawing such contours, otherwise as profiles of vertical magnetic intensity. Plates 17 to 20 show observed and calculated profiles over the major anomalies. These are drawn on the basis of a preliminary interpretation, as it is considered that an indication of the degree of fit which would be obtained by a single trial would be useful for the purpose of the present report. In most cases no further fitting is justified, but on a few anomalies it is obvious that the fit could be improved. Certain of the less-pronounced or more deep-seated anomalies were not surveyed in sufficient detail for interpretation, as there was no reason to attach any special significance to them at the date of the survey. In one case a major gold mine has been established close to such an anomaly, and the presence of the anomaly possibly has somewhat increased significance due to this fact.

Where a figure for the radius of the body is given, it is based on a susceptibility figure of $0 \cdot 1$ c.g.s. units.

TESTING.

During the course of the survey, a diamond drill was put at the disposal of the A.G.G.S.N.A. for the purpose of test drilling on anomalies discovered, and six holes were drilled. The results of the drilling are discussed in detail in previous reports (Rayner and Nye, 1936: Richardson, Rayner and Nye, 1937), and are mentioned in summary fashion in the present report. It should be noted that the drilling rig was in poor condition, and was incapable of

penetrating the ironstone bodies. Consequently, the results of the drilling, although proving the presence of magnetic bodies, gave no information as to their size or aspect.

Since the end of the survey, several mining companies have carried out a considerable amount of diamond drilling on the field. Most of this drilling was sited on geological grounds, and was not intended to test the magnetic anomalies. However, several holes have been drilled by Eldorado Tennant Creek Ltd., Peko Mines N.L., and Kia Ora Gold Corporation, to test specific anomalies. Information on the results of this drilling has been made available by courtesy of the companies concerned.

It is desirable to stress once again the incompleteness of this testing from the physical point of view. Cores taken during the A.G.G.S.N.A. drilling were logged magnetically, by holding pieces of core close to a vertical magnetometer. This method will identify material of moderately high susceptibility or material permanently magnetised. In later drilling, as far as is known, even this limited amount of logging was not performed. No susceptibility measurements have been made on any of the cores, although for reasons given earlier, the practical significance of such measurements is doubtful.

Where an anomaly is caused by a body of massive ironstone, it can be identified immediately, as it is immediately obvious when a drill enters material of this type. However, the massive ironstone is not the only strongly magnetic material present on the field. In some drill holes, strongly magnetic chloritic schist has been encountered. This material has been seen only in drill cores, and it is not known whether it is invariably associated with massive ironstone, or whether it may occur in large bodies by itself. The only reliable method of using drilling to check the details of interpretation would be to log every hole with a magnetic logger.

Another point which must be borne in mind is that none of the A.G.G.S.N.A. holes was surveyed, nor, as far as is known, were any of the later holes, except those drilled by Peko Mines N.L. It is known that holes at Tennant Creek deviate considerably, and the course of unsurveyed holes is therefore doubtful. It may be pointed out, however, that from the very nature of the geological formations, magnetic surveying instruments such as the Tropari are of doubtful value at Tennant Creek, particularly in holes which intersect strongly magnetic bodies. A further point may be mentioned, which is of general application, but which is frequently overlooked by geologists and mining engineers. Drill hole surveying instruments such as the Tropari admit of the measurement of direction cosines of the drill hole at various positions along its length. Mathematically, this information is not sufficient to enable the course of the hole to be plotted uniquely. The computation of the course of the hole from direction cosines involves an integration. This integration can only be performed if the equation giving the position of the hole as a function of depth can be assigned to a definite mathematical type, or if the direction cosines of the hole are continuously recorded. Any of the practical methods for drill hole surveying on the basis of Tropari results at widely spaced points involves a tacit assumption concerning the course of the hole which may be a good deal more stringent than appears on the surface.

For the above reasons, the testing so far performed at Tennant Creek cannot be regarded as conclusive.

(1) RISING SUN—ELDORADO—MT. SAMUEL AREA (PLATES 3 AND 17).

This area is a strip running roughly east-west for a length of over 10 miles, and includes the Rising Sun, Weabers Find, Nobles Nob, Two Blues, Eldorado, Patties, Enterprise, Hammerjack, Red Ned, and Mt. Samuel Mines, most of which are, or have been, significant gold producers. The major anomalies observed are discussed below, beginning at the western end of the area.

The area west of the telegraph line (Plate 3, Sheet 1), including the Hammerjack, Red Ned, and Mt. Samuel workings, contains numerous very large ironstone outcrops, and correspondingly large areas are covered by hematite talus. For this reason, profiles were much disturbed by surface effects. After smoothing out these effects, three major-type anomalies were identified west of the telegraph line. These have been called the Eldorado anomalies Nos. 6, 7, and 8. Of these, the horizontal component profile has been observed only over anomaly No. 8. Horizontal and vertical component profiles observed along traverse 10800W are shown on Plate 17, together with profiles calculated for a sphere centred at 400N, at a depth of 195 feet. The observed profiles are much disturbed by surface effects, and the fit is therefore conjectural. The impression derived from the profiles is that the fit would be generally better if the centre of the sphere were put somewhat deeper, at about 250 feet. The radius of the body is about 70 feet. As the anomaly is immediately under the main outcrop on the Red Ned lease, the most likely explanation for it is that this body extends from the surface outcrop to a depth of at least 300 feet. It appears that most of the body is above water level, so that the body may be of the type which has been protected from oxidation, and therefore contains an appreciable amount of magnetite in the oxidised zone. Anomaly No. 6 is caused by a body slightly smaller, at a similar depth, which may, or may not, be directly connected with the most easterly outcrop on L.A. 364.

Anomaly No. 7 is a long zone, which is probably due to a line of several bodies at very much greater depth. The information for precise interpretation is lacking, but by comparison with similar anomalies in other parts of the field, it appears that the depth of the body or bodies causing this anomaly is of the order of 1,000 feet.

Proceeding easterly, no major anomalies are encountered until the Eldorado Mine is reached (Plate 3, Sheet 3). There, a series of 5 anomalies was observed, commencing near the Eldorado Mine and extending for about 1½ miles to the east. Anomaly No. 1 is a very well defined one, lying to the north of the Eldorado Mine. It has been fitted on traverse 500W (on the 1935 base line) by a sphere centred at 402N, at a depth of 580 feet (Plate 17). It appears that, if the centre of the sphere is shifted about 40 feet to the north, the fit is excellent. The radius of the body is about 200 feet. On this basis the magnetic material will extend between vertical depths of 380 and 780 feet at least. The upper limit of 380 feet is a little greater than the expected depth to water level, but not so much so as to throw any doubt on the interpretation. There is no evidence that this body is connected with any of the outcrops on the Eldorado lease.

Anomaly No. 2 has been fitted on traverse zero by a sphere centred at 845S, at a depth of 710 feet (Plate 17). The fit is good as regards the horizontal component profile, but the amount of the anomaly in the vertical component is rather less than that calculated. This may be due to the fact that the horizontal profile is disturbed by surface effects near the turning points. Assuming the interpretation is satisfactory, the radius of the sphere

is rather less than 280 feet, and the body would therefore extend between vertical depths of 430 and 990 feet. As mentioned previously, mining development has shown that this anomaly is almost certainly due to the bottom portion of the main outcrop on the Eldorado lease. It is obvious that the body cannot continue on an easterly pitch, otherwise the contours would widen to the east. As, in fact, the contours narrow rapidly to the east, it appears probable that the body causing the anomaly is terminated at the bottom by some feature such as a fault plane, at an acute angle to the direction of pitch.

Anomaly No. 3 on traverse 1500E has been fitted by a sphere at 920S, at a depth of 690 feet (Plate 17). The fit is fairly close, except at the extremities of the horizontal profile. The radius of the sphere is 180 feet, which would indicate that the body extends from 510 feet to 870 feet vertical depth.

Anomalies Nos. 4 and 5 lie considerably to the south of the line of Nos. 1, 2, and 3 anomalies. No. 4 has been fitted on traverse 2900E by a sphere centred at 2173S, at a depth of 485 feet. The fit is fairly close. The radius of this body would be about 120 feet, indicating an extent between 365 feet (approximately water level) and 605 feet in vertical depth. It is possible that this body would have an oxidized portion above water level.

Anomaly No. 5 has been fitted on traverse 4250E by a sphere centred at 2747S at a depth of 970 feet. The fit is excellent as far as the traverse extends. The radius of the sphere is 220 feet, indicating that the vertical extent of the body is between 750 feet and 1190 feet at least.

Further east, nothing of interest is encountered until the anomaly around 10,000E appears (Plate 3, Sheet 4). This has been fitted on traverse 10,400E by a sphere centred at 330S, at a depth of 970 feet (Plate 17). The comparison of observed and calculated profiles shows a type of discrepancy which has not been encountered elsewhere on the field. The shapes of the central portions of the curves are in close agreement. It is obvious that the fit of the horizontal component profiles requires a shift of the centre of the sphere about 100 feet to the north. However, to bring the vertical component profiles into agreement, a further shift of over 100 feet to the north would be required. On both vertical and horizontal components, the observed profiles are considerably different from the calculated ones at each end.

No explanation for this discrepency can be suggested with confidence. For reasons mentioned earlier, one is reluctant to attribute particular features on the profiles to the effects of dip. However, in this instance, the hypothesis that the body has a definite southerly dip appears particularly attractive.

The radius of the sphere would be 220 feet, and a vertical extent from 750 to 1,190 feet would be indicated. However, if the body actually has a pronounced southerly dip, the significance of these figures would be rather uncertain.

Further east, the profiles are devoid of character for some distance. Then a deep-seated magnetic feature appears, beginning west of Nobles Nob, and proceeding in a direction somewhat north of west through the Nobles Nob lease and adjoining leases to the end of the surveyed area. As the course of the feature would take it to the north of the Rising Sun workings, no indication of its presence was observed during the 1935 survey, which covered only a very limited area.

Superimposed on this feature is a small major-type anomaly on the Nobles Nob lease (GS520). The depth to the centre of the body causing this anomaly would be of the order of 200 feet, and if the body is composed of magnetic material of the usual susceptibility, it must be much smaller than the general run of ironstone bodies on the field.

The depth to the centre of the feature responsible for the deep-seated anomaly would be about 1,500 feet at the eastern end (on traverse 2700E) and would be much deeper on traverse 2400E on the Rising Sun layout, so that the magnetic zone as a whole pitches to the east.

It is rather difficult to assess the significance of the deep-seated magnetic zone. No particular attention was paid to it at the time of the survey. However, since that date, major gold mining operations have been established on lease GS520 (Nobles Nob), and the presence of the magnetic feature may have added significance. Considering the depth of the body concerned, however, it seems most unlikely that it is directly connected with any outcrop on the lease.
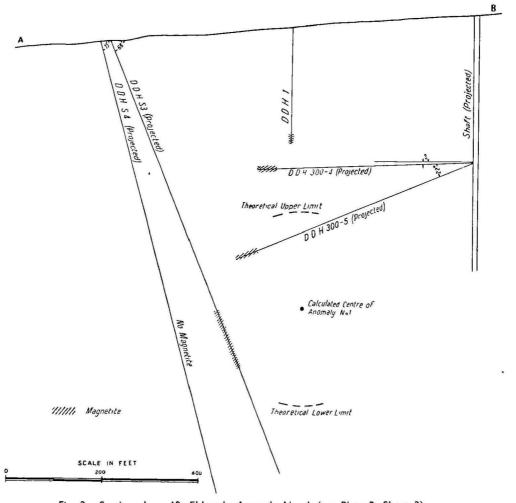
Fig. 2.—Section along AB, Eldorado Anomaly No. I (see Plate 3, Sheet 3).

Results may indicate that suitable conditions for the presence of gold ore bodies exist to a much greater depth than has been reached in mining operations, but as mentioned earlier, gold ore shoots are subject to several controls, and it is difficult to see how the presence of the body could be of any direct use in increasing ore reserves.

The results of the 1935 survey over the Rising Sun lease have not been shown on the plans, as only a small area was surveyed and no major anomalies were discovered.

TESTING.

Testing in this area has been confined to the Eldorado anomalies Nos. 1, 2, and 3. The body causing the No. 1 anomaly has been intersected by A.G.G.S.N.A. drill hole No. 1, and by drill holes S3, 300-4, and 300-5, drilled by Eldorado Tennant Creek Ltd. A north-south section through the site of drill hole No. 1 is shown in Fig. 2 with projected positions of ironstone intersected in the other
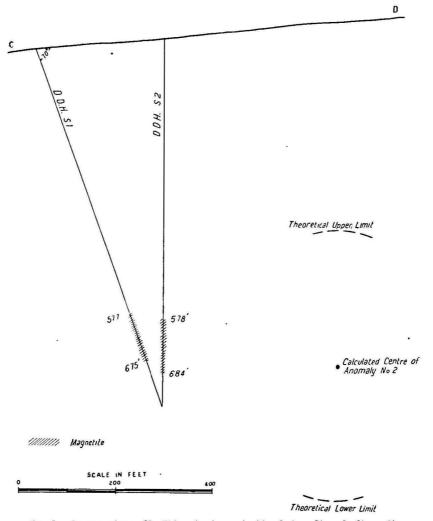
Fig. 3.—Section along CD, Eldorado Anomaly No. 2 (see Plate 3, Sheet 3)

drill holes. It will be noted from the plan that D.D.Hs. Nos. 300-4 and 1 are the only ones which intersected the body close to the calculated position of the centre. Drill hole S4 is so far east of the anomaly centre that it would not be expected to intersect the magnetic body. The drilling suggests that the body is lens-shaped, with a north-easterly strike and a northerly dip.

Drill holes S1 and S2 were drilled by Eldorado Tennant Creek Limited to test the No. 2 anomaly. A section through these drill holes is shown in Fig. 3. Although ironstone was intersected in each drill hole, it is obvious from the plan and section that the intersections are some distance north of the expected position of the body causing the anomaly. The anomaly cannot be considered as having been tested.

Anomaly No. 3 has been tested only by drill hole No. 2 of the A.G.G.S.N.A. This hole was collared at 1438E/800S. As the calculated centre of the anomaly is at 920S, the drill hole is 120 feet north of the optimum position. The drill hole penetrated a talc-carbonate-magnetite formation containing disseminated sulphides, between 413 feet and 452 feet, where drilling was stopped. In view of the displacement of the hole from the centre of the anomaly, it is not known whether massive ironstone is in fact associated with the anomaly, or whether the anomaly is due entirely to material of the type encountered in the drill hole.

(2) PEKO–GOLDEN FORTY–GREAT EASTERN AREA (Plates 4 and 18).

This is a strip about 6½ miles long, covering the Great Eastern, Golden Forty, and Peko mines, with a considerable extension west and north-west of the Peko. The results are of great interest because of the number and size of the major anomalies and the evidence of anomalies of the regional type, which may be of great importance, considering their proximity to the major copper ore body at the Peko.

At the eastern end of the area (Plate 4, Sheet 1), two small major-type anomalies were located near the Great Eastern Lease. Anomaly No. 11 has been fitted on traverse 16600E by a sphere centred at 1416S, at a depth of 515 feet (Plate 18). The fit is fairly good over the central portions of the profiles. The radius of the body is about 100 feet, indicating an extension from 415 to 615 feet vertical depth at least. Anomaly No. 10 has been fitted on traverse 15600E by a sphere centred at 1410S, at a depth of 730 feet. The fit is not particularly good, and suggests that the profile at the southern end may be disturbed by an anomaly originating from greater depth. Assuming that the interpretation correctly represents the upper body, its radius would be about 150 feet, and the body would extend at least from 580 feet to 880 feet vertical depth. The general magnetic high region with which these anomalies are associated continues to the eastern end of the layout, and it is probable that further surveys to the east would discover more anomalies.

Further west (Plate 4, Sheet 2), a complex of strong anomalies is encountered around the Golden Forty lease. Four main anomalies are indicated by the contours, the southern bodies, Nos. 6 and 7, being rather larger and deeper than Nos. 8 and 9. These anomalies have not been interpreted in detail, as the profiles due to each body are disturbed by the influence of the other bodies. In such cases interpretation would be a matter of trial and error, and an extra degree of uncertainty would be introduced. If it were necessary, it is probable that some idea of the depth to the bodies could be obtained after a few trials.

The next major anomalies are the line beginning at 5600E and continuing west past the Peko mine (Plate 4, Sheet 3). Horizontal component profiles were not observed over anomalies Nos. 4 and 5, and the interpretation is based on the vertical component. Anomaly No. 5 has been fitted on traverse 5200E by a sphere centred at 687S, at a depth of 194 feet (Plate 18). The radius of the body would be 70 feet. Anomaly No. 4 on traverse 4600E has been fitted by a sphere centred at 759S, at a depth of 310 feet, of radius about 120 feet. In both instances, the fit is very close. With bodies as close to the surface as these, it would be expected that considerable extension in depth would be reflected in the shape of the profiles. It is considered, therefore, that in these instances, the closeness of fit indicates that the bodies do not persist in depth, and that the No. 4 body would not persist below 450 feet, or the No. 5 below 250 feet. These bodies must be confined largely to the oxidized zone.

Anomaly No. 3 has been fitted on traverse 4000E by a sphere centred at 773S, at a depth of 485 feet. The fit is very poor, and although the profiles are much disturbed by surface effects, they suggest strongly that the effects due to two separate bodies are superimposed, one at moderate depth, and a shallower one to the south. It is understood from discussions with Mr. Elliston, of Mining and Prospecting Services Ltd., that the sharp displacement of the contour lines to the north, which occurs in this area, can be correlated with a fault, and it is possible that the body causing anomaly No. 3 has been affected by the fault.

Anomaly No. 2 has been fitted on traverse 3400E by a sphere centred at 400S, at a depth of 410 feet. The fit of the horizontal component profile is fairly good, except at the southern end. The observed vertical component profile is higher at the maximum than the calculated one, and the minimum at the south is practically absent. As mentioned previously, this type of discrepancy may indicate that the body has extension in depth considerably greater than the diameter of the sphere. The radius of the sphere would be about 180 feet, and it would be expected that the vertical extent of the body would be from 230 feet to 600 feet at least.

Anomaly No. 1 is associated with the Peko ore body, the presence of which was not suspected at the date of the survey. This anomaly has been fitted on traverse 600W by a sphere centred at 70S, at a depth of 580 feet. The fit shows the same type of discrepancies as the No. 2 anomaly. The profiles diverge widely at the southern end, and the maximum of the observed vertical component profile is greater than the calculated maximum value. These discrepancies may indicate considerable extension of the body in depth, but may equally well be due to the fact that as shown by mining development the horizontal dimensions of the body increase somewhat with depth. The radius of the sphere would be about 280 feet, and the body would be expected to have a vertical extent from 300 feet to 860 feet at least. Although it is known that the body extends to a greater depth than this, it appears reasonable to assume that it will not extend below twice the calculated depth to the centre, i.e., below 1,160 feet. The protuberance of the contours to the east is probably due to a protuberance in the body, at a relatively shallow depth.

West of the Peko mine, one major anomaly was located, the No. 12 anomaly (Plate 4, Sheet 4). This has been fitted on traverse 6200W, by a sphere centred at 210S, at a depth of 2140 feet. The fit is, practically speaking, perfect, as would be expected on the basis of Koenigsberger's results. The radius of the body would be about 480 feet, and the body may extend from about 1,700 feet to 2,700 feet vertical depth.

Further west, the results are of great interest, but the anomalies observed have been classed as regional-type anomalies at present. Due west of the No. 12 anomaly, some wide but relatively weak anomalies are present, but the main magnetically high area shifts to the north. This trend may also be reflected in the northerly tendency of the western end of the contours on No. 12 anomaly. Extension of the layout to the north revealed a magnetic high of large extent, which was not completely explored. This must be due to a large rock mass of higher susceptibility than normal, but at present there is no information as to its nature. Before any suggestions as to the cause of the results west of the No. 12 anomaly can be offered, it is essential that this "high" area be outlined and its nature determined. The results of this might have a very important bearing on the structural conditions associated with the Peko line in general.

Other very interesting results, which have been referred to regional-type anomalies, are present on the traverses between the Golden Forty and No. 5 anomaly. The general magnetic high associated with anomalies Nos. 4 and 5 bends sharply to the north, east of No. 5, and has a maximum on traverse 6200E (Plate 4, Sheet 2), which could almost be classed as a major-type anomaly. A possible explanation for such an anomaly would be that it represents the bottom portion of the large outcrop between 5800E and 6000E, in the same way as the Eldorado No. 2 anomaly is due to the bottom portion of the Eldorado outcrop. If the pitch of the body were checked and found to be to the east, this explanation would be not unreasonable except that it would require that the ironstone here were quite different in character from that causing the No. 5 anomaly. It is possible that the sharp southerly bend of the contours between 5400E and 5600E is associated with a structural break, such as a fault. If this could be confirmed by geological evidence, there would be less difficulty in supposing that the types of ironstone on the two sides of the fault have different properties. At present, however, it does not appear safe to interpret the anomaly on 6200E as being due to an ironstone body of the usual type. Farther to the north-east, less distinct anomalies are present, one on 6800E, and one of large extent centred at about 8300E. There is no reason to suppose that these are due to ironstone bodies of the usual type, and their cause is at present unknown.

TESTING.

Several drill holes have been put down by Peko Mines, N.L., to test anomalies in the Peko area, and by Kia Ora Gold Corporation and Australian Gold Development N.L. in conjunction, to test the Golden Forty anomalies. Information on the results of this drilling has been made available by courtesy of the companies concerned.

The Peko No. 1 anomaly was tested by A.G.G.S.N.A. drill holes Nos. 3 and 6, and by a drill hole put down by the Burea of Mineral Resources. However, as the body causing the anomaly has been well exposed by mining development, no further reference to these drill holes is necessary.

A sketch of the body to a depth of 500 feet is shown on Plate 21. The magnetic body is lens-shaped in horizontal section, with its major axis striking roughly west, and its north-south axis small compared with the major axis. It dips at about 70° to the north-west. Information on exploration at the 900-foot level is that at this level the body is larger in both horizontal dimensions than at the surface. Drill intersections show that the body persists to a depth of 1,000 feet at least.
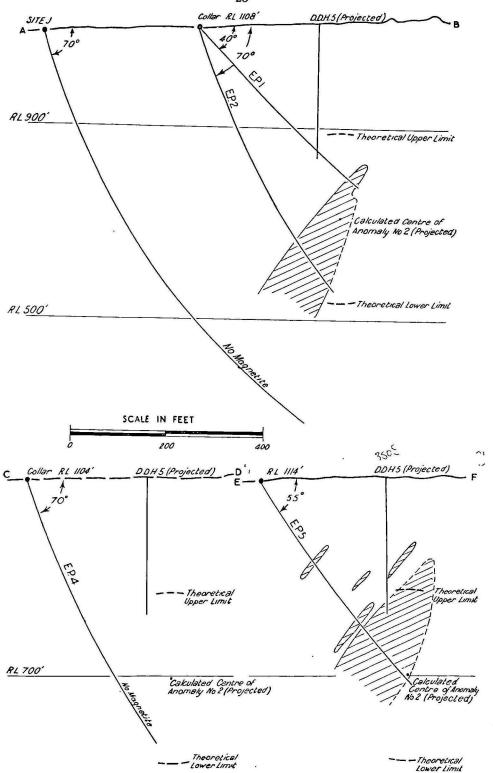
Fig. 4.—Sections along *AB*, *CD*, and *EF*, Peko Anomaly No. 2 (see Plate 4, Sheet 3).
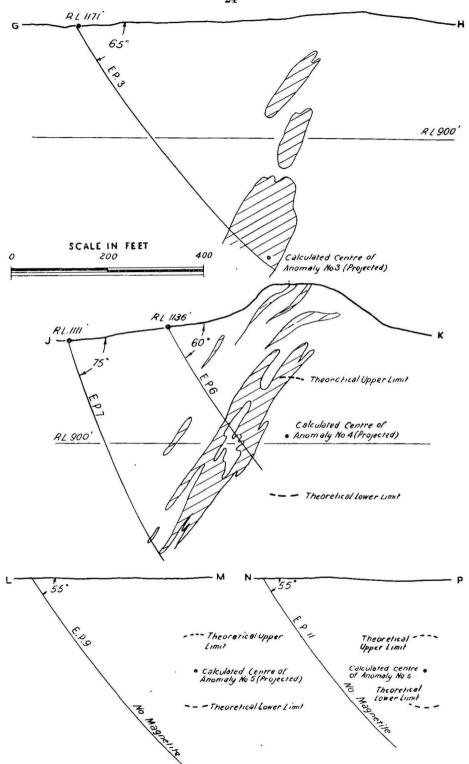
Fig. 5.—Sections along *GH* (Peko Anomaly No. 3), *JK* (Peko Anomaly No. 4), and *LM* and *NP*, (Peko Anomaly No. 5),—see Plate 4, Sheet 3.

The most interesting feature in the comparison of the magnetic results with the actual shape of the body is the extent to which the results fail to indicate the details of the shape. There is certainly no indication in the vertical force contours of the very large departure of the horizontal section from circular shape, and no indication of the direction of dip.

Anomaly No. 2 was tested by A.G.G.S.N.A. drill hole No. 5, and by Peko drill holes E.P.1, 2, 4, 5, and Site J. Sections through these drill holes are shown in Fig. 4. Drill hole E.P.4 is obviously too far to the west. Drill holes 5 and E.P.5 are properly placed to test the anomaly, and intersected ironstone at positions not far from the calculated ones. The fact that intersections were obtained in drill holes E.P.1 and E.P.2 shows that the body has a considerable east-west extension. No intersection was obtained at Site J. This may indicate that the hole has passed underneath the body, but, as it is so far west of the centre, it provides no conclusive evidence as to the extension of the body in depth. The body is lens-shaped and strikes east-west.

Drill hole E.P.3 was designed to test anomaly No. 3, but is obviously too far to the west. Ironstone was intersected (Fig 5), but as mentioned previously, the anomaly is of unusual shape, and no detailed conclusions were drawn as to the shape of the body or bodies causing it.
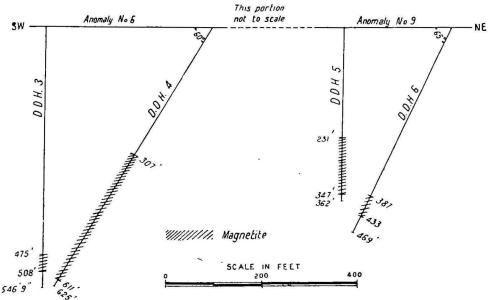
Fig. 6.—Section along AB, Golden Forty Anomalies Nos. 6 and 9 (see plate 4, sheet 2).

Drill holes E.P.6 and E.P.7 were designed to test anomaly No. 4, but are also too far to the west. They intersected bands of ironstone (Fig. 5) but do not provide any real information as to the cause of the anomaly. Drill holes E.P.9 and E.P.11 were designed to test anomaly No. 5. E.P.9 is too far to the east. E.P.11 is well placed, and the fact that it did not encounter ironstone is reasonable evidence that the body causing the anomaly does not persist in depth.

Four drill holes have been put down by Australian Development N.L. and Kia Ora Gold Corporation on the Golden Forty group of anomalies. A section through the drill holes is shown in Fig. 6. The bodies responsible for anomalies Nos. 6 and 9 were intersected. Further drilling is in progress.

(3) WHEAL DOREA AREA (PLATES 5 AND 19).

This area covers the Wheal Dorea, Peter Pan, and Big Ben Mines, with certain extensions which were suggested by the nature of the survey results. These mines have not been important producers. However, the results of the survey in this area are of particular interest, as it seems possible that the method of interpretation used may not give reliable results on anomalies of the type encountered here.

Four anomalies, number 1 to 4 (Plate 5, Sheet 1), were obtained over the leases, and another, much deeper, anomaly to the south-west. Anomaly No. 1 has been fitted on traverse 200E by a sphere centred at 260S, at a depth of 535 feet (Plate 19). As the vertical profile on 200E is very much disturbed by surface effects, the profile on traverse 400E, which appears relatively undisturbed, is shown for comparison. The fit of the horizontal component is passable, but the vertical component profile bears no resemblance to the calculated one, and is, in particular, considerably smaller in scale.

Anomaly No. 2 has been fitted on traverse 1,800E by a sphere centred at 175S, at a depth of 680 feet. The fit is only fair, and shows the same type of discrepancy as on No. 1 anomaly.

Anomaly No. 3 has been fitted on traverse 1,800W by a sphere centred at 642S, at a depth of 390 feet. The fit appears rather better than on Nos. 1 and 2 anomalies, although the vertical component profile is rather smaller in scale than the calculated one.

Anomaly No. 4 has been fitted on traverse 2,400W by a sphere centred at 747S, at a depth of 730 feet. The fit here is better than it appears, as the profiles are affected at the southern end by the large deep-seated anomaly to the south-west.

No figures are given for the radii of the spheres used, as the significance of such figures appears doubtful, due to the doubt as to the shape of the bodies.

The large anomaly to the south-west (Plate 5, Sheet 2) arises from a body at considerable depth and it is impossible to interpret it with any confidence.

TESTING.

A.G.G.S.N.A. drill hole No. 4 was planned to test anomaly No. 1. Due to blocking of this hole, drill hole No. 4A was drilled 2 feet south of No. 4. Comparison of the logs of the drill holes shows that the regional dip is to the north at about 45°.

A rough log of drill hole No. 4A is shown in Fig. 7. This shows an altered and mineralized formation, portion of which is magnetic, from 157 feet to 201 feet. The hole was stopped at 448 feet, and thus fell short of the calculated depth to the centre of the anomaly. As a test of the interpretation, the hole should have been taken to 600 feet at least. However, the formations intersected, considered in conjunction with the great difference between observed and calculated vertical component profiles, suggest that the anomaly may actually be due to the mineralized formation shown, and that its shape may depend on the shape and extent of the magnetic formation, rather than on its depth. It appears that any similar anomalies which may be encountered on the field should be interpreted with caution.

The results of several other diamond drill holes on the Wheal Dorea leases were made available by courtesy of Northern Mines Development N.L., but as these holes were neither suitably placed nor deep enough to test the magnetic anomalies, they do not call for any discussion here.
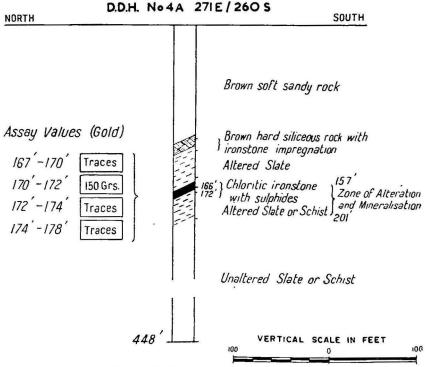
Fig. 7.—Graphic log of D.D.H. 4A, Wheel Dorea.

(4) ORLANDO AREA (PLATES 6 AND 19).

A small area was surveyed around the Orlando workings. Two major-type anomalies were located. The western one was fitted on traverse 2,600W by a sphere centred at 660N at a depth of 580 feet. This traverse was chosen for fitting, as profiles on 2,400W show clearly that the anomaly is due to two bodies, a small one with its centre at a depth of about 50 feet, and a deep-seated one. It was thought that traverse 2,600W would be relatively free from the effect of the upper body. From the fit of the profiles, some doubt may be felt whether this is, in fact, the case. The northern end of the vertical component profile is uniformly high. This suggests the possibility that a regional effect is present, which complicates the position, but the traverses were not extended far enough to the north to check this. The southern ends of the profiles show divergencies which it is tempting to ascribe to a southerly dip of the body, but, considering the possibility of regional effects, this can only be suggested very tentatively. It does not appear that the interpretation could safely be taken further under the circumstances, although there is no reason to doubt that a drill hole directed at the position of the centre of the sphere as specified would intersect the body.

The eastern anomaly is due to a body similar in depth and dimensions to that causing the western anomaly.

(5) BLACK ANGEL AREA (PLATES 6 AND 19).

A small area around the Black Angel workings was surveyed, and the two largest anomalies yet found on the field were discovered. No. 1 anomaly has been fitted on traverse 1,600E by a sphere centred at 382N, at a depth of 475 feet. The fit is reasonably close, except at the southern end of the profiles, where discrepancies exist of a type tentatively explained by extension in depth. The radius of the sphere would be about 300 feet, indicating that it would extend from 175 feet to 800 feet vertical depth at least. The body has a strike closely parallel to that of the line of outcropping bodies on the White Angel (or Devil) lease, and is probably directly connected with one or more of these bodies.

The No. 2 anomaly has been fitted on traverse 400W by a sphere centred at 40N, at a depth of 505 feet. The fit is of the same character as on the No. 1 anomaly. The radius of the sphere would be about 280 feet, and the magnetic body probably has a vertical depth extent from about 200 to 800 feet. The considerable extension of the contours to the east appears to be due to a relatively narrow easterly protuberance from the main body.

(6) LONE STAR AREA (PLATES 7 AND 20).

A small area was surveyed around the Lone Star mine, and one major-type anomaly was located. This anomaly has been fitted on traverse 300E by a sphere centred at 710N, at a depth of 545 feet. The fit is good, the discrepancies at the northern end being accounted for by the strong regional gradient which is present all over the area. The radius of the sphere would be about 110 feet, indicating that the body has an extent in depth between 435 feet and 655 feet. Several lines of weak anomaly are present on the eastern portion of the layout, and it is apparent from the profiles that the anomalies are of the usual type. Depths to the centre of the bodies causing these anomalies are of the order of 500 to 600 feet, but the cause of the anomalies is obscure. A survey on a regional scale would probably be of assistance in clarifying this point.

(7) WESTWARD HO AREA (PLATES 8 AND 20).

One major-type anomaly was located in the survey around the Westward Ho and Skipper leases. This has been fitted on traverse 3,000W by a sphere centred at 470S, at a depth of 835 feet. The fit is good. The radius of the sphere would be about 220 feet, and the body should have a vertical extent from about 600 feet to 1,050 feet at least. A zone of anomaly begins at the eastern end of the layout, but has not been followed far enough to determine its character or extent. Pending further investigation, it is presumed that it has a regional character. At the western end, the character of the profiles changes completely. This also is considered to be connected with the regional geology.

(8) BURNT SHIRT AREA (PLATES 9 AND 20).

One small major-type anomaly was located in the survey over the Burnt Shirt Workings. This anomaly has been fitted on traverse 1,000E by a sphere centred at 240N, at a depth of 390 feet. The fit is not very good. Although the profiles are rather disturbed by surface effects, it appears that the fit would be generally improved by placing the centre of the sphere at considerably greater depth. The radius on the interpretation shown would be 80 feet. If the centre of the sphere were at a depth of 700 feet, the radius of the body would be about 120 feet. In either case, the depth extent of the body would be of the order of 200 feet.

(9) MASCOT AREA (PLATES 10 AND 20).

The most interesting feature of the results over the Mascot area is an anomaly of the regional type, which extends over almost the whole layout. Typical profiles are shown on Plate 10, and it appears that the anomaly is of a type generally associated with contacts between formations of different susceptibilities. The approximate position of such a contact, as determined from the magnetic data, is marked on Plate 10. There is, at present, no information as to what the rock types involved might be.

At the western end of the layout, the anomaly becomes obscure, and two magnetic high closures which are shown on the plan have been taken as major-type anomalies. One of these has been fitted on traverse 1,000W by a sphere centred at 610S, and the other on traverse 200E, by a sphere centred at 410N. In each case, the centre of the sphere is at a depth of 390 feet. The fit is reasonable, except that profiles on traverse 200E are affected at the southern end by the contact anomaly referred to.

These anomalies present a puzzling problem. They do not appear to be anomalies due to ironstone bodies of the usual type, yet any other explanation raises difficulties, due to the fact that the anomalies are almost identical in size and shape, yet are located one on each side of the contact anomaly. The most likely alternative is that the anomalies are due to raised portions on a slightly magnetic basement rock. The contact anomaly is most simply explained by either:—

1. A contact between rock types of different susceptibilities, in which case it would be most unlikely that anomalies due to raised portions would be so similar, or

2. A difference in level in the same rock, such as would be caused by a step fault, in which case the anomalies might be of the same amount, but should come from different depths.

For these reasons, it appears most likely that the anomalies are due to discrete magnetic bodies. As they are so different in scale from the anomalies generally caused by such bodies at Tennant Creek, it would be hazardous to suppose that they are composed of material of the usual susceptibility. For this reason, there is no safe basis for calculating their dimensions.

(10) NORTHERN STAR AREA (PLATES 11 AND 20).

Profiles around the Northern Star lease were much disturbed by surface effects, and contours were therefore drawn only over the central portion of the area, in which two major-type anomalies were discovered. One anomaly was fitted on traverse 1,600E by a sphere centred at 960N, at a depth of 580 feet. The fit is not particularly good, and would be improved generally if the depth of the sphere were reduced to about 400 feet. On this assumption, the radius of the body would be about 60 feet, and the depth extent from about 340 feet to 460 feet. The other anomaly was fitted on traverse zero by a sphere centred at 760S, at a depth of 875 feet. The fit is moderately good, and the radius of the body would be about 200 feet, indicating a body extending in depth from about 700 feet to 1,100 feet.

TESTING.

A programme of testing by diamond drilling has been carried out by Northern Mines Development N.L. on the Northern Star and North Star leases, information on which was made available by courtesy of the company.

This drilling was based on geological considerations and was neither suitably placed nor deep enough to test the magnetic anomalies. It is worthy of mention here, as several of the holes intersected gossany ironstone in the oxidized zone, which apparently does not cause any large-scale anomaly.

(11) OTHER AREAS (PLATES 12 TO 16).

On the other areas surveyed, no major-type anomalies were discovered, so that they do not call for detailed discussion in the present report. The Pinnacles area (Plate 12) shows a very definite regional-type anomaly. The results from the Pinnacles Alluvial, Great Northern, Shamrock, and Hopeful Star areas are grouped on Plate 13, together with the results of a small detached survey over the Two Blues workings, which were covered at a larger scale in the Rising Sun–Mt. Samuel survey (Plate 3, Sheet 4). These areas show nothing of interest, except for an elongated anomaly on the Pinnacles Alluvial area, the cause of which is quite unknown. Plate 14 shows results over the Red Terror, Black Cat, Mammoth, and Extension areas, which also show nothing of interest, except for a regional anomaly on the Red Terror area.

The Great Western area (Plate 15) showed nothing of interest. On the Joker area (Plate 16) the contours show a definite magnetic relief. No anomalies were found which could be attributed to ironstone bodies, however, and it is considered that the observed anomalies must be interpreted on a regional scale. There is no evidence, at present, as to their cause.

A NOTE ON REGIONAL ANOMALIES.

Several anomalies, classed as regional, have been mentioned in the discussion of particular areas. In addition to these, it was noted that the general vertical intensity was considerably greater in the Peko, Black Angel, and Great Western areas, and considerably less in the Mammoth and Black Cat areas, than would have been expected from the magnetic values over the field generally. Anomalies of this type cannot be interpreted on present information. It seems very likely, however, that complete delineation of the regional-type anomalies by a survey over the whole field would give information which could be correlated with regional geology, and might be of great assistance in giving a more complete idea of structure than can be obtained from available geological evidence. An aerial magnetometer survey of the whole field has just been concluded by the Bureau of Mineral Resources, Geology and Geophysics, but at the time of writing the results have not yet been plotted or analysed.

A NOTE ON THE SCIENTIFIC INTEREST OF THE RESULTS.

Although the most immediate value of the magnetic surveys at Tennant Creek is economic, it is appropriate to draw attention to the great scientific interest of the results, particularly in the field of rock magnetism. Reference to the work of Nagata shows the extreme complexity of this field. The physical basis of the magnetic state is being intensely studied in connection with artificial materials. In order to apply the principles derived from this study to the magnetism of rocks, the prime need is for experimental study of rock samples. At Tennant Creek, we have bodies composed largely of magnetite, of great geological age, which, below water level, appear to have been very uniformly magnetised by induction in a field not significantly different from the present earth's field. One body is well exposed by mining development, and it is at least possible that exploration will provide sufficient

encóuragement to lead to the opening up of others. There are thus unique opportunities for sampling the bodies. A programme of research on the magnetic properties of these bodies would certainly provide a most valuable addition to present knowledge on rock magnetism.

CONCLUSIONS.

As stated previously, the present report is confined entirely to geophysical aspects and refers only to the detection of magnetic bodies. All known ore deposits on the field are connected with such magnetic bodies but it has been found that some magnetic bodies have no ore deposits associated with them. The discovery of a magnetic body (or an anomaly corresponding to one) does not mean necessarily that there will therefore be a gold deposit or a sulphide deposit associated with that body. It is, however, clear that the discovery of a magnetic body could lead to the finding of a gold or a sulphide ore deposit.

From the geophysical aspect, the following conclusions may be drawn:—

1. The Tennant Creek field is ideally suited to the magnetic method of prospecting. It is doubtful whether any other area could be found in which so many magnetic anomalies, both regional and small-scale, occur, of a type so well adapted to interpretation by theoretical methods.

2. A method of interpretation based on polarization by induction can be applied to anomalies observed in the field generally. Testing so far performed indicates that this method of interpretation will show the position of the body causing the anomaly with sufficient accuracy for siting an exploratory drill hole. It appears, however, that the observed results give no evidence of the dip of the body, or, within reasonable limits, of its shape in horizontal section. In general, it appears that a reasonable estimate may be made of the depth extent of the body.

3. In some instances, bodies in the weathered zone give no large-scale anomaly, and in other instances, it appears certain that anomalies were obtained from the weathered zone. This shows that the absence of a major-type anomaly does not mean that there is not a body present which is completely confined to the weathered zone, and suggests that the ironstone bodies may be of different character, some being subject to complete oxidation while others are not.

4. Before the significance of the magnetic results can be completely evaluated, it is considered most desirable that the regional anomalies be delineated and interpreted. An obvious method of doing this would be to survey the field completely with the airborne magnetometer. Such a survey has recently been carried out by the Bureau with traverses at intervals of a quarter of a mile. Although the results have not yet been plotted or analysed, a preliminary inspection of the profiles shows that they indicate the presence of most major-type anomalies as well as the regional anomalies. From this additional information it should be possible to provide information for interpreting the anomalies by a limited amount of ground magnetic work. The interpretation of the regional magnetic effects, checked by a limited amount of gravity surveying, should give much more information of the structure and limits of the field than can be obtained from available geological information.

ACKNOWLEDGMENTS.

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APPENDIX A.

MATHEMATICAL DETAILS OF INTERPRETATION PROCEDURE.

The method of interpretation is based on the assumption that the bodies causing the anomalies can be considered, to a first approximation, as spheres of magnetic material, polarized by induction in the earth's magnetic field. On general geological grounds, such an assumption must be considered unlikely. However, it has the following advantages from a mathematical point of view :—

(1) The potential due to such a spherical body is of the same form as that due to a dipole at its centre, and laborious integrations are unnecessary.

(2) If interpretations are based on north–south profiles crossing the body near its centre, the problem becomes a two-dimensional one, thus simplifying the calculations.

(3) The shape of the calculated profiles does not involve the size of the body. If any more-detailed assumption were made as to the shape of the body, the calculated profiles would involve actual dimensions, for which assumptions would have to be made. This would greatly increase the labour of fitting the results, and it would almost certainly be found that the observed profiles would not allow of deciding between very different assumptions.

As the calculations involve only elementary mathematics, they are presented in summary form. A more compact treatment of the basic portion, using vector notation, is given in various text books (e.g., Heiland, 1946).
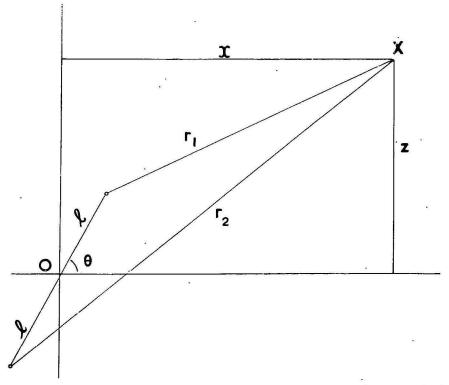
Fig. A1.—Geometric relations for calculation of potential due to an inclined magnetic dipole.

Consider the system shown in Fig. A1, consisting of a short bar magnet of length $2l$, centred at the origin. The potential at the point (x, z) is given by the equation :—

$$\Phi = P\left\{\frac{1}{r_1} - \frac{1}{r_2}\right\}, \text{ where } P \text{ is the pole strength.}$$

i.e., $\Phi = P\{[(x - l\cos\theta)^2 + (z - l\sin\theta)^2]^{-\frac{1}{2}} - [(x + l\cos\theta)^2 + (z + l\sin\theta)^2]^{-\frac{1}{2}}\}$

Expanding by the binomial theorem, and neglecting terms of the fourth and higher orders,

$$\Phi = \frac{2rP\,(x\cos\theta + z\sin\theta)}{(x^2 + z^2 + l^2)^{3/2}}.$$

Replacing $2rP$ by M, the magnetic moment, and allowing l to tend to zero :—

$$\Phi = -M \cdot \frac{x\cos\theta + z\sin\theta}{(x^2 + z^2)^{3/2}},$$

where the negative sign is chosen for south magnetic latitudes.

For a spherical body polarized in the earth's field, θ is the angle of dip, and $M = \frac{4}{3}\pi r^3 FK$, where r is the radius of the body, F the total earth's field, and K the effective susceptibility, which includes the susceptibility of the body and other factors discussed earlier.

Then the components of the anomalous field are given by

$$Z \text{ (vertical component)} = \frac{\partial\Phi}{\partial z} = M \cdot \frac{2z^2\sin\theta + 3xz\cos\theta - x^2\sin\theta}{(x^2 + z^2)^{5/2}}$$

$$H \text{ (horizontal component)} = \frac{\partial\Phi}{\partial x} = M \cdot \frac{2x^2\cos\theta + 3xz\sin\theta - z^2\cos\theta}{(x^2 + z^2)^{5/2}}.$$

For purposes of calculation, it is convenient to express these in terms of a single variable. Putting $\dfrac{x}{z} = t$, we obtain :—

$$Z = \frac{M}{z^3} \cdot \frac{(2 - t^2)\sin\theta + 3t\cos\theta}{(1 + t^2)^{5/2}} = \frac{M}{z^3} \cdot (A\sin\theta + B\cos\theta)$$

$$H = \frac{M}{z^3} \cdot \frac{(2t^2 - 1)\cos\theta + 3t\sin\theta}{(1 + t^2)^{5/2}} = \frac{M}{z^3} \cdot (C\cos\theta + B\sin\theta)$$

where A, B and C are functions of t, tabulated to slide rule accuracy at the end of this appendix.

For the purpose of fitting calculated profiles to observed profiles, it is necessary that some basis of matching the profiles be used, which does not depend on any assumed datum. The existence of turning points on the profiles provides a means of doing this. Differentiating the expressions for H and Z with respect to t, and equating the results to zero, the following equations are obtained for the positions of the turning points.

For H, $-2t^3\cot\theta - 4t^2 + 3t\cot\theta + 1 = 0$.

For Z, $t^3\tan\theta - 4t^2 - 4t\tan\theta + 1 = 0$,

so that each curve has in general three turning points.

These equations cannot be solved explicitly. However, as written, each equation is of the form

$$at^3 - 4t^2 + bt + 1 = 0.$$

Both equations can be solved by means of the simple nomogram shown in Fig. A2.

So far the calculations are of general application. The remainder of the calculations apply only to the magnetic conditions prevailing at Tennant Creek.

$$at^3 - 4t^2 + bt + 1 = 0$$
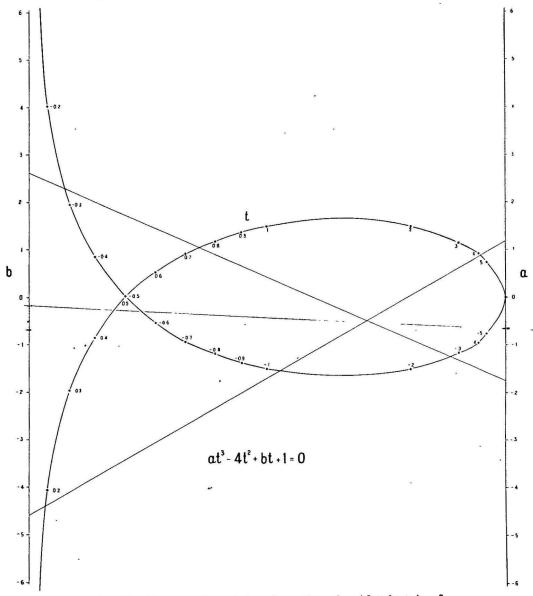
Fig. A2.—Nomogram for solution of equation $at^3 - 4t^2 + bt + 1 = 0$.

From the results of absolute observations given earlier, the following may be taken as values of the constants of the earth's field at Tennant Creek, sufficiently accurate for the present purpose.

$F = 0 \cdot 5$ gauss; $\quad \theta = 48° 50'$; $\quad \sin \theta = 0 \cdot 753$; $\quad \cos \theta = 0 \cdot 658$; $\quad \tan \theta = 1 \cdot 149$; $\cot \theta = 0 \cdot 875$.

Using these values to obtain a and b on page 34, we have :—

For Z, $a = 1 \cdot 149$, $b = -4 \cdot 596$, and solutions of the equation for the turning points are given by the nomogram as $t = 4 \cdot 4$, $0 \cdot 19$, $-1 \cdot 1$.

For H, $a = -1 \cdot 759$, $b = 2 \cdot 6235$, and solutions of the equation for turning points are $t = -2 \cdot 8$, $-0 \cdot 28$, $0 \cdot 75$.

The lines giving these solutions are shown on the nomogram.

The turning points corresponding to the large values of t are indefinite in each case, and of no value in interpretation. Considering only the two central turning points, we obtain the distance between them as follows :—

$$\text{for } Z, \; \frac{x}{z} = 1 \cdot 29$$

$$\text{for } H, \; \frac{x}{z} = 1 \cdot 03 \; .$$

Thus, if the actual distance x is measured on the profile, z may be calculated from these formulae.

For the purpose of adjusting the scale of the calculated profile to that of the observed one, it is necessary to select some dimension of the curves for comparison. The obvious one to use is the difference between maximum and minimum values. We therefore define the "amount" of an anomaly, in either H or Z profiles, as the difference between the maximum and minimum values. The theoretical values of the amount of the anomaly are obtained by substituting the values obtained for the positions of the turning points in the original equations for H and Z. As H varies rapidly in the neighbourhood of the extreme values, it is desirable to improve the accuracy of the roots of the equation obtained from the nomogram. Applying one stage of iteration to the roots $t = -0 \cdot 28$, and $t = 0 \cdot 75$, it is found that $t = -0 \cdot 275$, and $t = 0 \cdot 747$ are more accurate values for the roots. Substituting these values in the equation for H, we obtain

$$H = \frac{M}{z^3} \times 0 \cdot 58, \text{ when } t = 0 \cdot 747$$

$$H = \frac{M}{z^3} \times -0 \cdot 98, \text{ when } t = -0 \cdot 275 \; .$$

Thus the amount of the theoretical anomaly in H, defined as above, is $\frac{M}{z^3} \times 1 \cdot 56$.

By a similar calculation, the amount of the theoretical anomaly in Z, is $\frac{M}{z^3} \times 1 \cdot 915$.

Selected ordinates of the theoretical curves, for the magnetic latitude of Tennant Creek, are shown in the following table :—

t.	H.	Z.
2·0	$1·72 \times 10^{-1}$	$4·6 \times 10^{-2}$
1·5	$2·96 \times 10^{-1}$	$1·44 \times 10^{-1}$
1·0	$5·22 \times 10^{-1}$	$4·88 \times 10^{-1}$
0·747	$5·48 \times 10^{-1}$	..
0·5	$4·59 \times 10^{-1}$	1·32
0·19	..	1·695
0	$-6·58 \times 10^{-1}$	1·51
$-0·275$	$-9·4 \times 10^{-1}$	..
$-0·5$	$-8·35 \times 10^{-1}$	$1·87 \times 10^{-1}$
$-1·0$	$-2·9 \times 10^{-1}$	$-2·22 \times 10^{-1}$
$-1·5$	$-5·6 \times 10^{-2}$	$-1·64 \times 10^{-1}$
$-2·0$	$1·9 \times 10^{-3}$	$-1·03 \times 10^{-1}$

These values are plotted to an arbitrary scale in Fig. A3.

For any particular anomaly, the calculation of theoretical profiles involves the following steps :—

(1) Determine the depth to the centre and position of the centre, from the position of the turning points of either H or Z curves, as described previously.

(2) Reduce the values of t given in the table above, to actual distances, by multiplying by the calculated depth to the centre.

(3) Reduce these distances to positions on the layout, by adjusting the position of the centre to $t = 0$.

(4) Obtain ordinates by multiplying the values of H and Z shown in the table above by a factor, which may be either—

$$\frac{\text{amount of anomaly in } H}{1·56} \quad \text{or} \quad \frac{\text{amount of anomaly in } Z}{1·915}$$
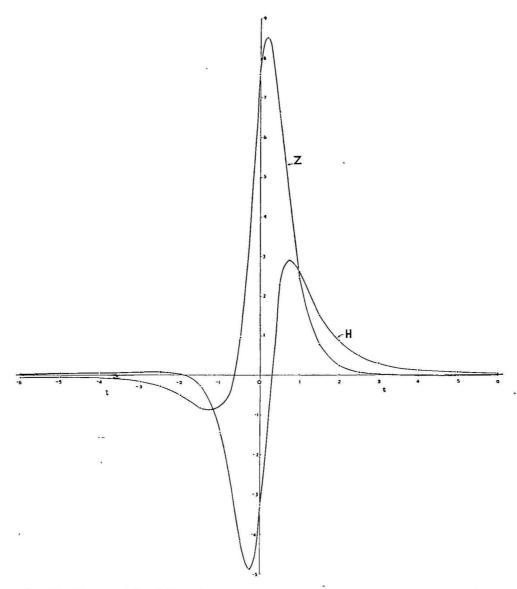
Fig. A3.—Theoretical *H* and *Z* profiles due to a magnetic dipole, plotted to an arbitrary scale.

Generally, it is more convenient to base the interpretation on the *H* profile.   This always shows reasonably well-defined turning points, whereas on the *Z* profile, it is common for the minimum value to be indefinite, or even to disappear altogether. Examples of the calculations are shown below for the Eldorado No. 1 anomaly based on the *H* profile and for the Peko No. 4 anomaly, based on the *Z* profile.

<u>Eldorado No. 1 anomaly.</u>   Traverse 500W.

Maximum on *H* profile at 850N.

Minimum on *H* profile at 250N.

Amount of anomaly in H, 1,260 gammas.

Distance between turning points, 600 feet.

Depth to centre of body, $\dfrac{600}{1\cdot03} = 580$ feet.

Position of centre of body, 402N.

t.	H.	Z.	$t \times 580$.	Grid Position.	$H \times \dfrac{1260}{1\cdot56}$	$Z \times \dfrac{1260}{1\cdot56}$
2·0	$1\cdot72 \times 10^{-1}$	$4\cdot6 \times 10^{-2}$	1,160	1,562N	139	37
1·5	$2\cdot96 \times 10^{-1}$	$1\cdot44 \times 10^{-1}$	870	1,272N	240	117
1·0	$5\cdot22 \times 10^{-1}$	$4\cdot88 \times 10^{-1}$	580	982N	423	396
0·747	$5\cdot8 \times 10^{-1}$	..	433	835N	470	..
0·5	$4\cdot59 \times 10^{-1}$	$1\cdot32$	290	692N	372	1,070
0·19	..	$1\cdot695$	110	512N	..	1,372
0	$- 6\cdot58 \times 10^{-1}$	$1\cdot51$	0	402N	$- 533$	1,220
$- 0\cdot275$	$- 9\cdot8 \times 10^{-1}$	..	$- 159$	243N	$- 795$	..
$- 0\cdot5$	$- 8\cdot35 \times 10^{-1}$	$1\cdot87 \times 10^{-1}$	$- 290$	112N	$- 676$	151
$- 1\cdot0$	$- 2\cdot9 \times 10^{-1}$	$- 2\cdot22 \times 10^{-1}$	$- 580$	178S	$- 235$	$- 180$
$- 1\cdot5$	$- 5\cdot6 \times 10^{-2}$	$- 1\cdot64 \times 10^{-1}$	$- 870$	468S	$- 45$	$- 134$
$- 2\cdot0$	$1\cdot9 \times 10^{-3}$	$- 1\cdot03 \times 10^{-1}$	$- 1,160$	758S	2	$- 85$

Peko No. 4 anomaly.   Traverse 4,600E.

Maximum on Z profile at 700S.

Minimum on Z profile at 1,100S.

Amount of anomaly in Z, 2,800 gammas.

Distance between turning points, 400 feet.

Depth to centre of body, $\dfrac{400}{1\cdot29} = 310$ feet.

Position of centre of body, 759S.

$t.$	$H.$	$Z.$	$t \times 310.$	Grid Position.	$Z \times \dfrac{2800}{1 \cdot 915}$
$2 \cdot 0$	$1 \cdot 72 \times 10^{-1}$	$4 \cdot 6 \times 10^{-2}$	620	139S	67
$1 \cdot 5$	$2 \cdot 96 \times 10^{-1}$	$1 \cdot 44 \times 10^{-1}$	465	294S	210
$1 \cdot 0$	$5 \cdot 22 \times 10^{-1}$	$4 \cdot 88 \times 10^{-1}$	310	449S	714
$0 \cdot 747$	$5 \cdot 8 \times 10^{-1}$	..	231	528S	..
$0 \cdot 5$	$4 \cdot 59 \times 10^{-1}$	$1 \cdot 32$	155	604S	1,930
$0 \cdot 19$	..	$1 \cdot 695$	59	700S	2,477
0	$- 6 \cdot 58 \times 10^{-1}$	$1 \cdot 51$	0	759S	2,205
$- 0 \cdot 275$	$- 9 \cdot 8 \times 10^{-1}$	..	$- 85$	844S	..
$- 0 \cdot 5$	$- 8 \cdot 35 \times 10^{-1}$	$1 \cdot 87 \times 10^{-1}$	$- 155$	914S	273
$- 1 \cdot 0$	$- 2 \cdot 9 \times 10^{-1}$	$- 2 \cdot 22 \times 10^{-1}$	$- 310$	1,069S	$- 324$
$- 2 \cdot 0$	$1 \cdot 9 \times 10^{-3}$	$- 1 \cdot 03 \times 10^{-1}$	$- 620$	1,379S	$- 150$

To obtain a value for the radius of the body, we proceed as follows. Calling the amount of the anomaly in H as previously defined, $\triangle H$, we have :—

$$\triangle H = \frac{M}{z^3} \times 1 \cdot 56 = \frac{4\pi r^3 F K}{3 z^3} \times 1 \cdot 56$$

If $\triangle H$ is measured in gammas and K in c.g.s. units, substituting $F = 50,000$ gammas, we have :—

$$\triangle H = 3 \cdot 27 \times \frac{10^5 r^3 K}{z^3}, \text{ with an equation of the same type for } \triangle Z, \text{ similarly defined.}$$

These equations may be solved for any value of K by the nomogram shown in Fig. A4.

Scales to be used in the following order

(1) Join value of ΔH (or ΔZ) to value of z

(2) Join intersection of this line and scale R to value of K

EXAMPLE

    For ΔH= 400 gammas, z=2 000 feet

    and K=10⁻¹ c g s unit, r=430 feet

ΔZ

ΔH

R

z

K
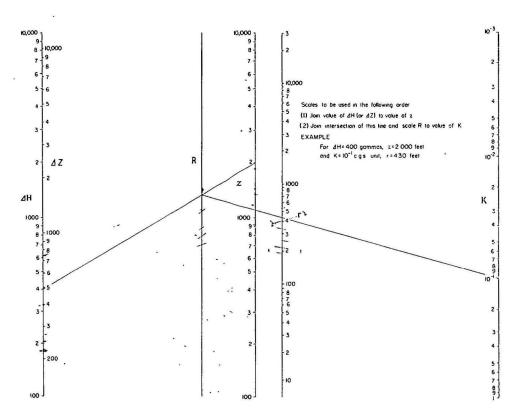
Fig. A4.—Nomogram for determination of the radius of the magnetic body, knowing the magnitude of the anomaly, the effective susceptibility and the depth to the centre of the body.

Functions used in Calculating Magnetic Profiles.

t.	A.	B.	C.
10	$- 9 \cdot 52 \times 10^{-4}$	$2 \cdot 97 \times 10^{-4}$	$1 \cdot 93 \times 10^{-3}$
9	$- 1 \cdot 3 \times 10^{-3}$	$4 \cdot 44 \times 10^{-4}$	$2 \cdot 64 \times 10^{-3}$
8	$- 1 \cdot 82 \times 10^{-3}$	$7 \cdot 05 \times 10^{-4}$	$3 \cdot 72 \times 10^{-3}$
7	$- 2 \cdot 64 \times 10^{-3}$	$1 \cdot 18 \times 10^{-3}$	$5 \cdot 45 \times 10^{-3}$
6	$- 4 \cdot 1 \times 10^{-3}$	$2 \cdot 17 \times 10^{-3}$	$8 \cdot 55 \times 10^{-3}$
5	$- 6 \cdot 7 \times 10^{-3}$	$4 \cdot 38 \times 10^{-3}$	$1 \cdot 43 \times 10^{-2}$
4	$- 1 \cdot 17 \times 10^{-2}$	10^{-2}	$2 \cdot 58 \times 10^{-2}$
3	$- 2 \cdot 2 \times 10^{-2}$	$2 \cdot 83 \times 10^{-2}$	$5 \cdot 35 \times 10^{-2}$
2·5	$- 2 \cdot 97 \times 10^{-2}$	$5 \cdot 24 \times 10^{-2}$	$8 \cdot 05 \times 10^{-2}$
2	$- 3 \cdot 77 \times 10^{-2}$	$1 \cdot 13 \times 10^{-1}$	$1 \cdot 32 \times 10^{-1}$
1·5	$- 1 \cdot 3 \times 10^{-2}$	$2 \cdot 34 \times 10^{-1}$	$1 \cdot 82 \times 10^{-1}$
1	$1 \cdot 77 \times 10^{-1}$	$5 \cdot 4 \times 10^{-1}$	$1 \cdot 77 \times 10^{-1}$
0·5	$1 \cdot 0$	$8 \cdot 6 \times 10^{-1}$	$- 2 \cdot 86 \times 10^{-1}$
0	$2 \cdot 0$	0	$- 1 \cdot 0$
$- 0 \cdot 5$	$1 \cdot 0$	$- 8 \cdot 6 \times 10^{-1}$	$- 2 \cdot 86 \times 10^{-1}$
$- 1$	$1 \cdot 77 \times 10^{-1}$	$- 5 \cdot 4 \times 10^{-1}$	$1 \cdot 77 \times 10^{-1}$
$- 1 \cdot 5$	$- 1 \cdot 3 \times 10^{-2}$	$- 2 \cdot 34 \times 10^{-1}$	$1 \cdot 82 \times 10^{-1}$
$- 2$	$- 3 \cdot 77 \times 10^{-2}$	$- 1 \cdot 13 \times 10^{-1}$	$1 \cdot 32 \times 10^{-1}$
$- 2 \cdot 5$	$- 2 \cdot 97 \times 10^{-2}$	$- 5 \cdot 24 \times 10^{-2}$	$8 \cdot 05 \times 10^{-2}$
$- 3$	$- 2 \cdot 2 \times 10^{-2}$	$- 2 \cdot 83 \times 10^{-2}$	$5 \cdot 35 \times 10^{-2}$
$- 4$	$- 1 \cdot 17 \times 10^{-2}$	$- 10^{-2}$	$2 \cdot 58 \times 10^{-2}$
$- 5$	$- 6 \cdot 7 \times 10^{-3}$	$- 4 \cdot 38 \times 10^{-3}$	$1 \cdot 43 \times 10^{-2}$
$- 6$	$- 4 \cdot 1 \times 10^{-3}$	$- 2 \cdot 17 \times 10^{-3}$	$8 \cdot 55 \times 10^{-3}$
$- 7$	$- 2 \cdot 64 \times 10^{-3}$	$- 1 \cdot 18 \times 10^{-3}$	$5 \cdot 45 \times 10^{-3}$
$- 8$	$- 1 \cdot 82 \times 10^{-3}$	$- 7 \cdot 05 \times 10^{-4}$	$3 \cdot 72 \times 10^{-3}$
$- 9$	$- 1 \cdot 3 \times 10^{-3}$	$- 4 \cdot 44 \times 10^{-4}$	$2 \cdot 64 \times 10^{-3}$
$- 10$	$- 9 \cdot 52 \times 10^{-4}$	$- 2 \cdot 97 \times 10^{-4}$	$1 \cdot 93 \times 10^{-3}$

APPENDIX B.

MORE GENERAL ASSUMPTIONS AS TO THE SHAPE OF MAGNETIC BODIES.

As stated previously, it is unlikely on geological grounds that magnetic bodies would be spherical, and an ellipsoid of revolution would be a much better approximation to the shape of the bodies at Tennant Creek. The magnetic effects of an ellipsoid of revolution, polarized by induction in the earth's magnetic field, have been calculated by Koengisberger (1928). The computations are elementary, in that they involve only elementary functions, but are very laborious, and separate calculations are necessary for ellipsoids of different proportions.

The only example calculated completely by Koenigsberger is that of a very oblate ellipsoid of rotation, with the axis of rotation vertical. His results are given below as an example :—

$$\frac{\triangle H}{H} = 3V_0 \frac{K}{1 - KL} \tan \theta \frac{zx}{\sqrt{X} (b^2 + v) (a^2 + v)^{\frac{1}{2}}}$$

$$+ 3V_0 \frac{K}{1 - KM} \left\{ \frac{(a^2 + v)^{\frac{1}{2}} x^2}{\sqrt{X} (b^2 + v)^2} - \frac{1}{2e^3} \left(\text{artan } l - \frac{l}{1 + l^2} \right) \right\}$$

$$\frac{\triangle Z}{Z} = 3V_0 \frac{K}{1 - KL} \left\{ \frac{z^2}{\sqrt{X} (a^2 + v)^{3/2}} - \frac{l - \text{artan } l}{e^3} \right\}$$

$$+ 3V_0 \frac{K}{1 - KM} \cdot \cot \theta \cdot \frac{zx}{\sqrt{X} (b^2 + v) (a^2 + v)^{\frac{1}{2}}}$$

where V_0 = volume of the ellipsoid
a = vertical semi-axis
b = horizontal semi-axis

$$L = - 4\pi \cdot \frac{1 + u^2}{u^3} (u - \text{artan } u)$$

$$M = - 2\pi \cdot \frac{1 + u^2}{u^3} \left\{ \text{artan } u - \frac{u}{1 + u^2} \right\}$$

$$b^2 - a^2 = e^2$$

$$u = \frac{e}{a}$$

$$l = \frac{e}{(a^2 + v)^{\frac{1}{2}}}$$

$$X = (x^2 + y^2 + z^2)^2 + (b^2 - a^2) \{ b^2 - a^2 + 2 (z^2 - x^2 - y^2) \}$$

$$v = \frac{x^2 + y^2 + z^2 - b^2 - a^2}{2} + \frac{1}{2} \sqrt{X}$$

and x, y, z and θ have the same meanings as in Appendix A.

Results for different shapes and aspects have to be calculated separately. The calculations for ΔZ have been performed by Koenigsberger for a variety of cases. The results have the same character as those quoted.

It is apparent that equations as complicated as the above are not suitable as a basis for a routine interpretation method. A further complication arises from the fact that the final expressions are in two parts, involving different demagnetizing factors, so that, in the general case, the form of the profiles depends on the value of the susceptibility. Several particular cases have been calculated by Koenigsberger. The main conclusion, as far as the present work is concerned, is that if the depth to the centre of the ellipsoid is greater than its dimensions, it produces magnetic effects which are indistinguishable from those due to a sphere of the same volume. Koenigsberger states that distinction between ellipsoid and sphere is theoretically possible, provided $\left| \dfrac{b^2 - a^2}{z^2} \right| \not< 0 \cdot 2$. Considering bodies of the dimensions and depths generally encountered at Tennant Creek, this requirement rules out many of the cases likely to be encountered. For the Peko No. 1 body, the following are rough values of the parameters as known as present :—

$$z = 600 \text{ ft.} \; ; \quad a = 400 \text{ ft.} \; ; \quad b = 50 \text{ ft.}$$

Under these conditions, $\left| \dfrac{b^2 - a^2}{z^2} \right| = 0 \cdot 45$ approximately, and the profiles should be significantly different from those due to a sphere. As stated earlier, this is the case. Similar differences are observable on the Peko No. 2 anomaly and on the Black Angel anomalies, but on the less pronounced anomalies, these discrepancies, if they exist, are so small in absolute value that they are readily obscured by other effects.

Considering Koenigsberger's calculations in conjunction with the general habit of the Tennant Creek magnetic bodies, it appears that the anomalies can be most safely attributed to pipe-like bodies whose extension in depth is generally greater than their diameter in horizontal section. According to the theory, the volume of the sphere calculated according to the method of Appendix A should be a measure of the volume of the ellipsoid. If, therefore, the horizontal diameter of the ellipsoid is much less than the calculated diameter of the sphere, then the vertical extent of the ellipsoid should be correspondingly greater. It is felt, however, that until the theory has been checked by underground investigation of several bodies, it would be unwise to apply this conclusion in full detail. In the present report, the more conservative conclusion has been drawn that magnetic bodies at Tennant Creek will generally be smaller in horizontal section than the calculated sphere, and will have a vertical extent at least as great as the calculated diameter of the sphere.

A further question of some interest is whether the assumption of spherical bodies will give a realistic interpretation when applied to a body which has a considerable extension in one dimension in a horizontal plane. An example of such a body would be a dyke polarized by induction. Mathematical treatment of this question would involve formidable difficulties. However, an argument can be presented which is at least plausible, though very deficient in physical basis. This argument is given briefly below, omitting a certain amount of elementary mathematical detail.

(1) The expression for the potential of the elementary dipole in three dimensions is—

$$\Phi = \frac{- M \left(x \cos \theta + z \sin \theta \right)}{\left(x^2 + y^2 + z^2 \right)^{3/2}} \; .$$

Intuitively, it appears that the general form of the potential due to a pipe-like body lying horizontally in an east–west direction would be obtained by integrating this expression with respect to y between $+\infty$. If the longer axis of the body is inclined at a moderate angle to the east–west direction, new variables (X and Y) may be introduced along, and at right angles to, the axis, and the integration performed with respect to Y. The resulting expression can then be differentiated to obtain Z and H profiles across the body at right angles. These integrations are easily performed.

The details are not given here, but it is found that the resulting profiles are not significantly different from those due to a sphere whose centre is at the depth of the axis of the body. The results of this integration have, of course, no physical significance. The effect due to a horizontal pipe-like body could be treated more rigorously by assuming the body to be a very thin ellipsoid of revolution, and allowing the major axis to tend to infinity. However, there is no reason to suppose that the results would be significantly different.

(2) The assumption is made that the difference between the effects due to a horizontal pipe-like body and a body such as a dyke, with considerable extension in depth, is of the same character as the difference between the effects due to a sphere and those due to an ellipsoid of revolution of considerable extension in depth.

It is obvious that it would be very difficult to justify this argument mathematically. The degree of validity to be allowed to it is, to some extent, a matter of personal preference. It is considered that it may be allowed to the extent that if observed profiles can be fitted, to a moderate degree of accuracy, by profiles calculated for a spherical body, the position of the centre of this sphere will be well within the body and can be used for siting an exploratory drill hole. It is obvious that any detailed deductions with regard to the dimensions or aspect of a body extended in a horizontal plane would have very little justification.

APPENDIX C.

A METHOD OF INTERPRETING TOTAL FORCE ANOMALIES.

The assumptions on which the method of interpretation described is based can also serve as a basis for a method of interpreting anomalies in total force as measured by the airborne magnetometer.

If we call $\triangle F$, $\triangle H$ and $\triangle Z$ anomalies in total force, horizontal and vertical components respectively, and F, H and Z the values of these elements which would be observed if the body causing the anomaly were not present, then :—

$$(F + \triangle F)^2 = (H + \triangle H)^2 + (Z + \triangle Z)^2$$
$$\text{and } F^2 = H^2 + Z^2 .$$

Subtracting, $2F \triangle F + (\triangle F)^2 = 2H . \triangle H + (\triangle H)^2 + 2Z . \triangle Z + (\triangle Z)^2$

Dividing through by $2F$,

$$\triangle F + \frac{(\Delta F)^2}{2F} = \frac{H}{F} . \triangle H + \frac{(\Delta H)^2}{2F} + \frac{Z}{F} . \triangle Z + \frac{(\triangle Z)^2}{2F} .$$

We now make the assumptions that :—

(1) anomalies are so small that their squares can be neglected in comparison with F, and

(2) the magnetic inclination is not disturbed by the presence of the anomaly. Therefore,

$$\triangle F = \triangle H \cos \theta + \triangle Z \sin \theta .$$

The results of airborne surveys indicate that the first assumption is reasonably justified at Tennant Creek, and the second one is rather less stringent.

Substituting the values previously calculated,

$$\triangle F = \frac{M}{z^3} \left\{ \frac{[(2t^2 - 1) \cos \theta + 3t \sin \theta] \cos \theta + [(2 - t^2) \sin \theta + 3t \cos \theta] \sin \theta}{(1 + t^2)^{5/2}} \right\}$$
$$= \frac{M}{z^3} \left\{ \frac{t^2 (3 \cos^2 \theta - 1) + 6t \sin \theta \cos \theta + 3 \sin^2 \theta - 1}{(1 + t^2)^{5/2}} \right\}$$

This expression can be treated in the same way as the expressions for $\triangle H$ and $\triangle Z$ (see Appendix A). Thus, by differentiating with respect to t, the condition for turning points is

$$t^3 (3 \cos^2 \theta - 1) + 8t^2 \sin \theta \cos \theta + t (7 \sin^2 \theta - 3) - 2 \sin \theta \cos \theta = 0$$

or, dividing through by $- \sin 2\theta$,

$$\frac{t^3 (1 - 3 \cos^2 \theta)}{\sin 2\theta} - 4t^2 + \frac{t (3 - 7 \sin^2 \theta)}{\sin 2\theta} + 1 = 0 .$$

By putting $a = \dfrac{1 - 3 \cos^2 \theta}{\sin 2\theta}$, and $b = \dfrac{3 - 7 \sin^2 \theta}{\sin 2\theta}$, this equation becomes

$$at^3 - 4t^2 + bt + 1 = 0 ,$$

which is solved by the nomogram given in Appendix A.

Substituting 48° 50′ for θ, as previously, we obtain $a = -0.3$, $b = -1.0$, and the turning points are obtained from the nomogram as $t = 0.395$, -0.65, and a large negative value which is not accurately obtainable from the nomogram as drawn. This value is not required for interpretation.

Thus the distance between the central turning points is given by $t = 1.045$, from which z may be calculated as before.

Substituting 48° 50′ for θ, we have, at Tennant Creek,

$$\triangle F = \frac{M}{z^3} \cdot \frac{0.299t^2 + 2.973t + 0.692}{(1 + t^2)^{5/2}} \,.$$

Selected ordinates of the variable part of $\varDelta F$ are given in the following table for the magnetic latitude of Tennant Creek :—

t.	$F(t)$.
3·0	0·039
2·5	0·071
2·0	0·145
1·5	0·304
1·0	0·702
0·5	1·289
0·395	1·332
0	0·692
− 0·5	− 0·41
− 0·65	− 0·462
− 1·0	− 0·351
− 1·5	− 0·162
− 2·0	− 0·077
− 2·5	− 0·034
− 3·0	− 0·017

These values are plotted to an arbitrary scale in Fig. C1.
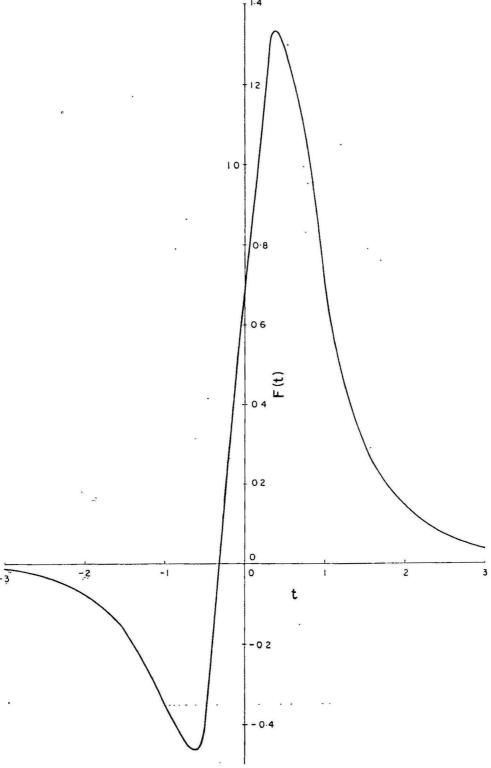
Fig. C1.—Profile of anomalous total field due to a magnetic dipole, plotted to an arbitrary scale.

To obtain a value for the radius of the body, we may proceed as before. If we now call $\triangle F$ the amount of the anomaly (in gammas), as measured by the difference between maximum and minimum, we have :—

$$\triangle F = \frac{M}{z^3} \times 1\cdot794$$

$$= \frac{4}{3} \frac{\pi r^3 F K}{z^3} \times 1\cdot794 \ .$$

Substituting $F = 50,000$ gammas, we have :—

$$\triangle F = 3\cdot76 \times \frac{10^5 \ r^3 \ \dot{K}}{z^3} \ , \text{ which may be solved as previously.}$$

APPENDIX D.

NOTES ON TWO MATHEMATICAL QUESTIONS.

The foregoing treatment leads to two remarks of a mathematical nature which are worthy of mention.

(1) To the mathematician, the whole of the treatment will appear singularly inelegant. The main reason for this is that the mathematics has been restricted to elementary functions, and the resources of potential theory have been applicable in only a very small degree.

The most powerful method of calculating magnetic potentials due to bodies of various shapes would certainly involve the use of the more special types of harmonic functions, and if the determination of such effects were the sole aim of the calculation, elementary methods would not be worthy of consideration. However, this is only part of the requirement. It is necessary that the results be obtained in a form suitable for comparison with observed results by some method of trial and error. For this purpose, there are real advantages in restricting the treatment to elementary functions. Also, the inherent uncertainties involved in the comparison are such that increased precision in the theoretical results is not likely to be of practical advantage.

(2) The question of elevation correction has not been considered. It is not customary to take elevation levels in magnetic surveys and any such requirement would seriously interfere with the speed of the work, which is one of the main advantages of the magnetic method of survey. On theoretical grounds, however, it is obvious that differences in elevation of the measuring points would certainly affect the results obtained over a body of restricted dimensions. As previously stated, the question has not been considered in the present work and the best method of treating it is not obvious. It should, however, be borne in mind.

PLATE 1

GEOLOGICAL MAP OF TENNANT CREEK GOLD-FIELD
NORTHERN TERRITORY

SCALE
2 1 0 2 4 6 MILES

GEOLOGY BY
J.F. Ivanac, N.H. Krasenstein, E.K. Carter,
B. Walpole and E.M. Bennett.

19° 15' 00"
19° 45' 00"
134° 30' 00"
134° 00' 00"

Reference

	Alluvium, scree, talus
Lower Middle Cambrian GUM RIDGE FORMATION	€mg	Fossiliferous cherts, sandy limestones, bedded sandstones
Lower Cambrian HELEN SPRINGS VOLCANICS	€ch	Altered basalts and pyroclashes
Upper Proterozoic ADAMELLITE	Pgr	Adamellite, Granodiorite, Aplite
PORPHYRY	€p	Adamellite Porphyry
RISING SUN CONGLOMERATE	Pur	Conglomerates, quartzite, sandstone
ASHBURTON SANDSTONE	Pua	Quartz conglomerate, quartzite, sandstone, basalt.
Lower Proterozoic (?) WARRAMUNGA GROUP	Pℓw	Sandstone, mudstone, shale

H Quartz hematite
Quartz veins
Jasper veins
Marine fossils
Established geological boundary
Established boundary - position approximate
Inferred boundary
Fault - definite ———— probable
Dip and strike of strata - inclined — vertical
Vertical cleavage
Apparent dip of cleavage on bedding plane
Direction and plunge of lineation
Pitch of minor anticline

Pitch of minor syncline
Outcrop and dip of strata determined by photo interpretation –
0°–15°
15°–45°
over 45°
Strike and dip of foliation - inclined
Roads - major
Roads - minor
Mines
Trig. Stations
(1297') Heights above sea-level

Mining Localities

CROSS-SECTION A-A' (Idealised)

Bureau of Mineral Resources, Geology and Geophysics. JUNE 1953.

NT 1-26

NORTH STAR · WHIPPET · QUEEN OF SHEBA · MARION ROSS · BLACK ANGEL · WOLSELEY · MT SAMUEL · SHAMROCK · BURNT SHIRT · PINNACLES · ELDORADO · RISING SUN · PEKO · LONE STAR · BLUE MOON · GOLDEN MILE

STUART HIGHWAY · BARKLY HIGHWAY · Overland Telephone Line

Kerramun · TENNANT CREEK · Owen Hills (969') · White Hill (1289') · Gum Ridge (1137') · Mt Cleland (1297') · Mt Rugged (1385') · Rocky Range (1330') · Mt Samuel (1129') · Quartz Hill (1390') · Station Hill (1413') · Red Bluff (1323') · Golden Mile

PLATE 2

TENNANT CREEK MAGNETIC SURVEY
AREAS SURVEYED

TENNANT CREEK MAGNETIC SURVEY
ELDORADO – MT. SAMUEL AREA
— PLAN SHOWING —
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE OF FEET
200 100 0 200 400 600 800 1000

WORKINGS ETC, AS AT 1937.
Magnetic Isoanomaly contours - constructed from
magnetic profiles after smoothing of apparent surface
effects.
Dense Ironstone shown thus
Magnetic Traverses
MINOR { Zones of Strong Anomaly shown thus:-
ANOMALIES { Areas of Irregular Anomaly   "   "

L.A.Richardson   Applied Geophysicist
Jm.Rayner   Consultant Geophysicist
12th February 1937

Note : Datum for Magnetic Contours - Eldorado
Main Base Station (1936) at 33Cw/1130n.

Lease Applications   shown   L.A. 397
Gold Sections (surveyed) -   G.S. 527
Name of Tenement   -   Red Ned

2500N ○ 2500N
2200N
2000N ○ 2000N
○ 2200N
1500N 1500N 1500N
1400N

L.A. 170
"Bob Ridley"
1000N
1000N
Dense Hematite
Dense Hematite and Manganese

Bulldust *Bulldust*

Soil with Schist *Combings* for Contouring

(No Major Anomalies present)

Profiles too Irregular

500N 500N 500N

Heavy Iron Talus

Schist Combings

Schist

Talus and Soil

Combings

"HAMMER JACK" L.A. 169
Dense Ironstone

00 *Ironstone Talus* 00

Dense Ironstone

BASE LINE BEARING 94° 14' 00" TRUE (90° MAGNETIC) Approximate.

Talus *Soil*

Schist Combings

Schist Combings

500S *Talus* *Schist Combings* 500S

Dense Ironstone

Dense Ironstone

G.S. 506
(Old L.A. 534)

L.A. 161

Schist *Hills*

Ironstone

Dense Ironstone Opencut

Dense Ironstone

1000S

"Enterprise"

L.A. 162

1200S 1200S

TENNANT CREEK MAGNETIC SURVEY
ELDORADO – MT. SAMUEL AREA
PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT OF THE MAGNETIC FIELD

SCALE OF FEET
200 100 0 200 400 600 800 1000

WORKINGS ETC, AS AT 1937.

Dense Ironstone shown thus:
Ironstone Breccia "

Magnetic Traverses ○——○——○
All distances are in feet

Magnetic North

MINOR ANOMALIES
Zones of Strong Anomaly shown thus:
Areas of Irregular Anomaly " "

L.A. Richardson *Applied Geophysicist*
Jno. Rayner. *Consultant Geophysicist.*
12th February 1937

Note Datum for Magnetic Contours:
Eldorado Main Base Station (1936) at 33GW/1150N.

Lease Applications   shown L.A. 161
Gold Sections (surveyed) " G.S. 506
Name of Tenement " "ENTERPRISE"

Overland Telegraph Line and Road

Edge of Irregular Magnetic Conditions

8800W 8600W 8400W 8200W 8000W 7800W 7600W 7400W 7200W 7000W 6800W 6600W 6400W 6200W 6000W 5800W 5600W 5400W 5200W 5000W 4800W 4600W 4400W 4200W 4000W 3800W 3600W 3400W 3200W 3000W 2800W 2600W 2400W

800S *Bulldust* 800S

R.G.H. 31.8.36

Bull Dust

1400N

Dense Haematite Outcrop

1000N

Landing Ground

For use by Euro Coy

Talus and Soil too Irregular for Contouring

Profiles   Talus and Soil

Bull Dust

(No   Major   Anomalies   Present)

Talus and Soil with small Haematite Rubble

Schist Combings

Schist Combings

Talus

Schist Combings

BASE LINE   BEARING 94° 4' 00" TRUE   (90° MAGNETIC)

DDH.S3   DDH.S4

Dense Haematite

Base Station 1935 (1936 Chords)

DDH°S1

Quartz Talus   Soil

G.S. 509

Bull Dust

ANOMALY N°1

Diamond Drill Hole N°1

DDH. S2

ANOMALY N°2

Schist Combings

ANOMALY N°3

D.D. Hole N°2

Old L.A. 624

Battery

Schist Combings

G.S. 506 (Old L.A. 534)

G.S. 505 "ELDORADO"

ELDORADO WEST BASE LINE (1935 SURVEY)

BEARING 270°12' (Mag)

G.S. 508

Schist Combings

Soil

L.A. 332

occasional Quartz Veins

with   Schist   Combings

Covered   by   1935   Survey

ELDORADO EAST BASE LINE (1935 Survey) BEARING 122°20' (Mag)

1500S

Talus

Soil

Ironstone Talus

Rugged

Ironstone Breccia

ANOMALY N°4

Schist Combings

2000S

Ironstone Breccia

2500S

L.A. 333

Hills

L.A. 334

ANOMALY N°5

"Cats Whiskers" Talus

and

Soil

Talus and Soil

TENNANT CREEK MAGNETIC SURVEY

ELDORADO–Mt SAMUEL AREA

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE OF FEET

200 100 0   200   400   600   800   1000

WORKINGS ETC, AS AT 1937.

Magnetic North

Dense Ironstone shown thus
Ironstone Breccia   "   "
Ironstone Talus   "   "

Magnetic Traverses
All distances are in feet

Lease Applications   shown   L.A. 332
Gold Sections (surveyed)   "   G.S. 505
Name of Tenement   "   ELDORADO

Vertical drillhole } Drilled by Eldorado Tennant Creek Ltd.
Inclined   "
A.G.G.S.N.A. vertical drillhole.

NB: Datum for 1936 Contours is 100 γ higher than 1935 Datum; i.e. Values of 1936 Contours are 100 γ lower than 1935 Contours.

Datum for 1936 Magnetic Contours = Eldorado Main Base Station (1936) at 336 W/1130 N

L.C.Richardson Applied Geophysicist.
J.M.Rayner. Consultant Geophysicist.
12th February 1937.

TENNANT CREEK MAGNETIC SURVEY

ELDORADO – RISING SUN AREA

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

LEGEND

Ironstone

Areas of Anomaly

Area of irregular Anomaly

The approximate Absolute Intensity value of datum for vertical component contours is 38370 gammas (July 1936 determination.)

SCALE OF FEET
400   200   0   400   800   1200   1600   2000

L.A.Richardson
PARTY LEADER

J.M.Rayner.
CONSULTANT GEOPHYSICIST
27.3.40

N

PLATE 3
SHEET 5

TENNANT CREEK MAGNETIC SURVEY
RISING SUN AREA
PLAN SHOWING

CONTOURS OF THE VERTICAL COMPONENT OF THE MAGNETIC FIELD

SCALE OF FEET

WORKINGS ETC, AS AT 1937.

Dense Ironstone shown thus

All distances are in feet.

Note: Datum for Contours= Eldorado
Main Base Station (1936) at 336w, 1130N

R.G.H 16 1-87

TENNANT CREEK MAGNETIC SURVEY

"GREAT EASTERN" AREA

— PLAN SHOWING —
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

WORKINGS ETC, AS AT 1937.
SCALE OF FEET

200 100 0 200 400 600 800 1000

L. A. Richardson *Applied Geophysicist.*
J. M. Rayner *Consultant Geophysicist.*
12th February 1937.

Lease Applications shown L.A. 330
Gold Sections (surveyed) · G.S. 513
Name of Tenement · "BLACK SNAKE"

Lease Applications shown in broken lines (eg L.A.672) are forfeited

Quartz Stringers shown thus
Dense Ironstone " "
Ironstone Breccia " "

N

"PEKO" BASE LINE
TRUE BEARING 95° 17'

RANGE
DALY
"BLACK SNAKE"
GOLDEN FORTY
Joins Peko-Golden Forty Area - Plate 4, Sheet 2.
G.S. 513 (L.A.124)
Quartz Talus
Quartz Talus
BULDIVA
BUTT

Schist Hills
L.A. 699
L.A. 695
L.A. 330
L.A. 672
Anomaly No. 11
Anomaly No. 10 (1935)
L.A. 629
L.A. 630
L.A. 634
Schist Combs
"GREAT EASTERN"
(BASE LINE)
TRUE BEARING "95° 17'
MAGNETIC BEARING
81° 30' (approx.)
Schist Combs

"Black Snake" Workings

Note: Datum for Magnetic
Contours = Eldorado Main
Base Station (1936) at 336W/1190N

00
500S
1000S
1500S
2000S
2500S
3000S

TENNANT CREEK MAGNETIC SURVEY

PEKO – GOLDEN FORTY AREA

— PLAN SHOWING —
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE OF FEET
200 100 0   200   400   600   800   1000

WORKINGS ETC, AS AT 1937.

N

Note : Datum for Magnetic Contours =
Eldorado Main Base Station (1936) at 336cm/1130N

Lease Applications   shown   L.A. 763
Gold Sections (surveyed)   "   G.S. 513
Name of Tenement   "   "GOLDEN FORTY"

L.A.Richardson   Applied Geophysicist
J.M.Rayner   Consultant Geophysicist
12th Feb. 1937

⊙ DDH.3   Vertical drillhole ⎫ Drilled by Kia Ora Gold Corporation
⊙ DDH.4   Inclined drillhole ⎭ and Australia Development N.L.

TRUE BEARING 95°17'   BASE   LINE   90°00'(Approx.) MAG.

Bulldust
Bulldust
Bulldust
Bulldust
Bulldust
Bulldust
Bulldust
Bulldust

L.A. 763
G.S. 513 (L.A. 241)
"GOLDEN FORTY"

Quartz-Porphyry Outcrop
Quartz Talus
Schist Talus
Ironstone Talus
Schist Hills
Quartz Outcrop

Anomaly No 2
Anomaly No 5
Anomaly No 6
Anomaly No 7

DDH.3   DDH.4   DDH.6

1500N   1000N   500N   500S   1000S   1500S   2000S   2500S   3000S

TENNANT CK. PLATE 4
(1938)
SHEET 3

TENNANT CREEK MAGNETIC SURVEY
PEKO-GOLDEN FORTY AREA
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE OF FEET

WORKINGS ETC, AS AT 1937.

⊙ E.P.4. — Diamond drill hole put down by Peko Mines N.L.

Bulldust

Anomaly Nº1

G.S. 514

Peko Lease

Bulldust

BASE LINE   TRUE BEARING 95° 17'
(Magnetic 90°00')

Bulldust

Anomaly Nº2

SITE

Anomaly Nº3

Anomaly Nº4

Anomaly Nº5

L.A. 763

Bulldust

PLATE 4
SHEET 4

TENNANT CREEK MAGNETIC SURVEY

"PEKO WEST" AREA

——— PLAN SHOWING ———
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE OF FEET
200 100 0 200 400 600 800 1000

Note: Datum for Magnetic Contours=
Eldorado Main Base Station (1936) at 336W, 1190N.

PLATE 4
SHEET 5

TENNANT CREEK MAGNETIC SURVEY

"PEKO WEST" AREA

——— PLAN SHOWING ———
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE OF FEET

200 100 0   200   400   600   800   1000

*Note: Datum for Magnetic Contours : Eldorado
Main Base Station (1936) at 336W, 1130N.*

Bulldust

Isolated
Schist
Hill

Bulldust with   irregular

patches   of   quartz   talus

and   occasional   quartz   outcrops

Low   ridges   with   ironstone   outcrops

Schist   Talus

Schist   costas

Bulldust

Bulldust

True Bearing 517°
Magnetic Bearing 1700

Joins Plate 4, Sheet 6.

R.G.H. 7-4-87

PLATE 4
SHEET 6

Joins Sheet Nº4.

TENNANT CREEK MAGNETIC SURVEY

"PEKO WEST" AREA

— PLAN SHOWING —
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

Note: Datum for Magnetic Contours = Eldorado
Main Base Station (1936) at 336W, 1130N.

SCALE OF FEET

200 100 0   200   400   600   800   1000

TENNANT CREEK MAGNETIC SURVEY

— WHEAL DOREA AREA —

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT OF
THE MAGNETIC FIELD

WORKINGS ETC, AS AT 1937.

SCALE OF FEET

200 100 0 200 400 600 800 1000

Datum for Magnetic Contours = Eldorado
Main Base Station (1936) at 33cm./1130N.

Southern
Extension

Dense Ironstone shown thus:
Milonitic material worked
as Lode shown thus:
Magnetic Traverses shown thus: —o——o——o—
All distances are in Feet.

Diamond Drill Holes shown thus:
D.D Hole No 4 at 271 E / 262 S.
" 4 ". 271 E / 260 S.

Lease Applications   shown L.A. 395
Gold Sections (surveyed)   · G.S. 526
Name of Tenement   " "Big Ben "

L.O. Richardson Applied Geophysicist
J.M. Rayner Consultant Geophysicist
12th February 1937

R.G.N. 12-12-36

PLATE 5
SHEET 2

TENNANT CREEK MAGNETIC SURVEY

WHEAL DOREA AREA

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT OF
THE MAGNETIC FIELD

SCALE OF FEET

Dense Ironstone shown thus.
Magnetic Traverses shown thus
All distances are in feet.

Note: Datum for Magnetic Contours = Eldorado
Main Base Station (1936) at 336W, 1190N.

PLATE 6
(1937)

TENNANT CREEK MAGNETIC SURVEY
"ORLANDO" AND "BLACK ANGEL" AREAS
PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE IN FEET

200   0   200   400   600   800

WORKINGS ETC AS AT 1937

L.R.Richardson
PARTY LEADER

Jno.Rayner.
CONSULTANT GEOPHYSICIST
27 . 3 . 40

N
Magnetic

"ORLANDO" AREA

Note re Orlando Main Shaft.
Depth 100', Fe. 0. 33', Slate horse(?) 93°-100'.
Fe. or Ferr. Slate at 100'. Bulk assay E.& W.
ends shaft 0-50' gave 8 dwt. per ton.
Across bottom of shaft at 15' assay gave 29 dwt.

Note: Information as to values etc. obtained
verbally from prospectors.

LA.772
LA.782
"ORLANDO"
"ORLANDO EAST"
L.A.815
Very approx. position of corner

ORLANDO AND BLACK ANGEL AREAS
LEGEND

Magnetic Contours (Values in Gammas)

Magnetic Contours constructed from smoothed Profiles (Values in Gammas)

Magnetic Traverses

Ironstone

Hematised Slate

The approximate Absolute Intensity value of
datum for vertical component contours is 38,370 gammas.
(July 1936 determination)

BASE LINE   BEARING 94°31'(TRUE) 90°(MAG.)

"BLACK ANGEL" AREA

N
Magnetic

"WHITE ANGEL"
Production: 63.7 tons, 36.1 ozs. Au.

Nº1 ANOMALY

Nº2 ANOMALY

"BLACK ANGEL"
Production: 400.8 tons, 346.85 ozs. Au.

"CRUSADER"
Production: 3.8 tons, 1.84 ozs. Au.

Pipe Beacon painted white

Open cut abt. 5' deep
Values present in Hematised Slate

Open Cut 7' deep
Values present in Hematised Slate

Values erratic
Mostly poor in costeans

BASE   LINE   BASE LINE   BEARING   90°(MAG.)

ZERO TRAVERSE

B.R.H. Aug '41.

"LONE STAR" AREA

PLAN SHOWING

CONTOURS OF THE VERTICAL COMPONENT OF THE MAGNETIC FIELD

DETAILED SURVEY OVER "LONE STAR" OUTCROP

LONE STAR AREA

TENNANT CREEK MAGNETIC SURVEY

DETAILED SURVEY OVER "ARIZONA" OUTCROP

MAGNETIC PROFILES

TENNANT CREEK MAGNETIC SURVEY
PORTION OF
WESTWARD HO AREA
PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE IN FEET

200 100 0 200 400 600 800 1000

WORKINGS ETC AS AT 1937

LEGEND

Ironstone
Ironstone Talus
Area of Irregular Anomaly
Magnetic Contours
Magnetic Traverses

"THE SKIPPER"

"WESTWARD HO"

94°14' (TRUE)

95°45' (TRUE)

95°16' (TRUE)

90° (MAGNETIC)

BASE LINE

MAGNETIC PROFILES

TRAVERSE 1000 E

950 E

900 E

850 E

DETAIL SURVEY
IN VICINITY OF
WESTWARD HO
WORKINGS

HORIZONTAL SCALE IN FEET
200 100 0 200

VERTICAL SCALE IN GAMMAS
400 200 0 400

The approximate Absolute Intensity value of
datum for vertical component profiles and
contours is 38370 gammas.
(July 1936 determination)

Jm Rayner
CONSULTANT GEOPHYSICIST
27 . 3 . 40

LA Richardson
PARTY LEADER

SEE ENLARGEMENT ABOVE

PLAN OF
COMPLETE WESTWARD HO LAYOUT
SHOWING MAGNETIC CONTOURS

SCALE IN FEET
800 0 800 1600 2400

TENNANT CREEK MAGNETIC SURVEY
BURNT SHIRT AREA
PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

SCALE IN FEET

WORKINGS ETC AS AT 1937
Ironstone shown thus

PARTY LEADER

CONSULTANT GEOPHYSICIST
27·3·40

NOTE: The approximate Absolute Intensity value of datum for vertical component profiles and contours is 38370 gammas and for horizontal component profile is 33200 gammas. (July 1936 determination).

MAGNETIC PROFILES

HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

Vertical Component Variations shown
Horizontal " " shown
Ironstone on Traverses shown

For construction of contours, surface effects have been smoothed from profiles, thus

TENNANT CREEK MAGNETIC SURVEY
MASCOT, EYES OF YOUTH AND MARY LANE AREA
PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT OF THE MAGNETIC FIELD

SCALE IN FEET

200 100 0 200 400 600 800

WORKINGS ETC AS AT 1937

N
Magnetic

LEGEND

Magnetic Contours with values in Gammas
Line of shallow-seated Magnetic Anomaly   xxxxxxxxx
Minor Type Anomaly (See Inset also)
Magnetic Traverses
Ironstone Outcrops
All distances are in Feet

L.A. Richardson
PARTY LEADER

Jno. Rayner.
CONSULTANT GEOPHYSICIST
27 . 3 . 40

ENLARGEMENT—"MARY LANE" & "EYES OF YOUTH" WORKINGS

100 50 0 100 200 300 FEET

MAGNETIC PROFILES

Vertical Component Variations shown

Horizontal

For construction of contours, surface effects have been smoothed from profiles thus ....

HORIZONTAL SCALE IN FEET
200 100 0 200 400

VERTICAL SCALE IN GAMMAS
200 100 0 200 400

TRAVERSE 1000 W

TRAVERSE 1600 E

TRAVERSE 3600 E

TRAVERSE 3200 E

The approximate Absolute Intensity values of datum for vertical component profiles and contours is 38970 gammas and for horizontal component profile is 33130 gammas (July 1936 determination)

NB: Traverse 1600 E. extended to 2500 S.

TENNANT CREEK MAGNETIC SURVEY
PORTION OF
NORTHERN STAR AREA

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

— SCALE IN FEET —

100   0   100   200   300   400   500

WORKINGS ETC AS AT 1937

L.C. Richardson   *J.M. Rayner.*
PARTY LEADER   CONSULTANT GEOPHYSICIST
27 . 3 . 40

LEGEND

GEOPHYSICAL:
Principal Zones of Magnetic Anomaly
Area of Irregular Anomaly (See Inset)
Magnetic Traverse
Magnetic Contours (Values in Gammas)
Magnetic Contours from smoothed Profiles (Values in Gammas)

GEOLOGICAL:
Hematite with Quartz
Limonite and Hematite (Gossan?)
Limonitic Material (Superficial?)
Jasper and Hematite
Black Ironstone (Gossan?)
Quartz
Quartz Talus
Hematite Talus

L.A. 766

L.A. 381

G.S. 516
(NB: G.S. 516 is now cancelled.)

N O R T H E R N   S T A R

N O R T H   S T A R

ZERO TRAVERSE

BASE   LINE   BEARING   90° (MAGNETIC)

Water Bore
40' deep
NC casting
Said reported
at 240'

The approximate Absolute Intensity value of datum
for vertical component contours is 38370 gamma
(July 1936 determination)

PLAN OF
COMPLETE NORTHERN STAR LAYOUT
SHOWING MAGNETIC CONTOURS

— SCALE IN FEET —
400 200 0 400 800 1200

Principal Zones of Magnetic Anomaly
Area of Irregular Anomaly

SEE   ENLARGEMENT

BASE LINE
90° (MAGNETIC)

L.A. 766

L.A. 381

L.A. 379

G.S. 516

TENNANT CREEK MAGNETIC SURVEY
THE "PINNACLES" AREA

— SCALE IN FEET —

200 100 0 200 400 600 800 1000

WORKINGS ETC AS AT 1937

Note: Magnetic Values not suitable for construction of Contours

LEGEND

- Dense Ironstone
- Ironstone Talus
- Siliceous Formation
- Anomalous Area

S.H.Richardson
PARTY LEADER

Jn.Rayner.
CONSULTANT GEOPHYSICIST
27 . 3 . 40

— INSET —
PLAN OF WORKINGS
"PINNACLES"

SCALE IN FEET
50 0 50 100

N
Magnetic

BASE LINE BEARING 94°14′ (TRUE) 90°00′ (MAGNETIC)

"WESTERN CHIEF" L.A. 733

L.A. 549 (Forfeited?)

G S 528

"ANOMALOUS" "PINNACLES"

MAGNETIC PROFILES

Vertical Component Variations shown Horizontal

The approximate Absolute Intensity value of datum for vertical component profiles is 38970 gammas and for horizontal component profile is 32850 gammas. (July 1936 determination)

HORIZONTAL SCALE IN FEET
300 100 0 100 200 300 400

VERTICAL SCALE IN GAMMAS
300 100 0 100 200 300 400

TRAVERSE 2800 E
2600 E
2400 E
2200 E
2000 E
1800 E
1600 E
1400 E
1300 E
1200 E
1100 E
TRAVERSE 1000 E

TRAVERSE 900 E
800 E
700 E
600 E
500 E
TRAVERSE 400 E

TRAVERSE 300 E
200 E
100 E
00
200 W
400 W
600 W
800 W
1000 W
1200 W
1400 W
TRAVERSE 1600 W

TRAVERSE 1600 W
2000 W
2200 W
2400 W
2600 W
2800 W
3000 W
3200 W
3400 W
TRAVERSE 3600 W

MAGNETIC PROFILES

HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

Vertical Component Variations shown

500 N

66 W

120 W

200 W

300 W

TRAVERSE 400 W

500 N

500 S

GREAT NORTHERN AREA

SCALE IN FEET

No.2 Anomaly indicating small
ironstone body at depth
over 100 Feet.

No.3 Anomaly indicating
shallow seated Hematization

BASE LINE BEARING 97° MAGNETIC APPROX.

No.5 Anomaly
indicating
shallow seated
Hematization

No.4 Anomaly
indicating
shallow seated
Hematization

Open Cut 30 deep - Production
287.9 tons (ironstone & crushrock)
357.04 dwt.

Foot of Slope

No.1 Anomaly indicating
small concealed ironstone body
at shallow depth (20-30)

PLAN OF LAYOUT SHOWING SURFACE FEATURES
AND ANOMALIES

Ironstone shown thus

*Magnetic values not suitable for
the construction of contours.*

PINNACLES ALLUVIAL AREA (L.A. 767)

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT OF
THE MAGNETIC FIELD

SCALE IN FEET

Ironstone shown thus....

L. A. 767.

BASE LINE BEARING 90°00'(MAGNETIC) APPROX

Schist

High hill

Quartz Talus

Bulldust flat

Quartz Talus

High hill

MAGNETIC PROFILES

HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

Vertical Component Variations shown
Horizontal

800 E

800 E

TRAV. 400 E

TENNANT CREEK MAGNETIC SURVEY

WORKINGS ETC. AS AT 1937

L.A.Richardson
PARTY LEADER

Jno.Rayner
CONSULTANT GEOPHYSICIST
27·3·40

PLAN OF LAYOUT SHOWING SURFACE FEATURES

Ironstone shown thus
Talus

DETAILED SURVEY

TWO BLUES
(ELDORADO-RISING SUN AREA)
(SEE PLATE 3, SH. 4)

SCALE IN FEET

*Magnetic values not suitable for
the construction of contours.*

MAGNETIC PROFILES

HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

26600 E

26500 E

26450 E

26400 E

26350 E

26300 E

26250 E

TRAV. 26200 E

Vertical Component Variations shown

G.S.504.

BASE LINE BEARING 90° (MAGNETIC) APPROX

"THE SHAMROCK"

PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT OF THE MAGNETIC FIELD

SHAMROCK AREA

SCALE IN FEET

800 E

200 E

00

200 W

1400 W

MAGNETIC PROFILES

VERTICAL SCALE IN GAMMAS

Vertical Component Variations

ENLARGEMENT
HOPEFUL STAR WORKINGS

SCALE IN FEET

BASE LINE
BEARING 94°14'(TRUE) 90°(MAGNETIC)

"Tightly strewn
Ironstone Talus"

"HOPEFUL STAR"
G. S. 511.

L. A. 519.

G.S. 512.

"EXTENDED"

G. S. 511

HOPEFUL STAR

SEE
ENLARGEMENT

L.A. 519
"EXTENDED"

G.S.512.
"EXTENDED EAST"

PLAN OF LAYOUT SHOWING SURFACE FEATURES

SCALE IN FEET

*Magnetic values not suitable for
the construction of contours.*

HOPEFUL STAR AREA

LEGEND

Ironstone
Ironstone Talus
Slate
Quartz
Crush Rock

MAGNETIC PROFILES

HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

1000 E

200 E

00

TRAVERSE 200 W

1000 W

Vertical Component Variations shown

TENNANT CREEK MAGNETIC SURVEY

WORKINGS ETC, AS AT 1937

L.A Richardson
PARTY LEADER

Jno Rayner.
CONSULTANT GEOPHYSICIST
27·3·40

RED TERROR AREA
PLAN OF LAYOUT SHOWING SURFACE FEATURES
SCALE IN FEET

NOTE
Magnetic Values not suitable for construction of Contours.

Approx. strike of cleavage shown

MAGNETIC PROFILES
HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

The approximate Absolute Intensity value for profiles is 38470 gammas. (July 1936 determination)

Vertical Component Variations shown

PLAN OF LAYOUT SHOWING SURFACE FEATURES
SCALE IN FEET

Note: Magnetic values not suitable for construction of contours.

BLACK CAT AREA
ENLARGEMENT BLACK CAT WORKINGS
SCALE IN FEET

PLAN

SECTION

Ironstone shown

MAGNETIC PROFILES
HORIZONTAL SCALE IN FEET

VERTICAL SCALE IN GAMMAS

Vertical Component Variations shown

Note The approximate Absolute Intensity value of datum for profiles is 38070 gammas. (July 1936 determination)

MAMMOTH AREA
PLAN OF LAYOUT SHOWING SURFACE FEATURES
SCALE IN FEET

BASE LINE BEARING 94'14 (TRUE) 90° (MAGNETIC)

G.S. 519.

NOTE: Magnetic values not suitable for construction of contours.

Ironstone shown
Quartz

The approximate Absolute Intensity value of datum for profiles is 38070 gammas. (July 1936 determination)

ENLARGEMENT MAMMOTH WORKINGS
SCALE IN FEET

MAGNETIC PROFILES
VERTICAL SCALE IN GAMMAS

Vertical Component Variations shown

THE EXTENSION AREA
PLAN OF LAYOUT SHOWING SURFACE FEATURES
SCALE IN FEET

MAGNETIC PROFILES
VERTICAL SCALE IN GAMMAS

The approximate Absolute Intensity value of datum for profiles is 38570 gammas. (July 1936 determination)

Vertical Component Variations shown

NOTE: Magnetic values not suitable for construction of contours.

TENNANT CREEK MAGNETIC SURVEY
GREAT WESTERN AREA

SCALE IN FEET

100   0   100   200   300   400

WORKINGS ETC, AS AT 1937

L.A. Richardson
PARTY LEADER

Jn. Rayner.
CONSULTANT GEOPHYSICIST
27-3-40

Ironstone bodies shown
(Fixed by Stadia)
Notes re. Values etc. supplied by Mc Entee (Part owner)
Ironstone outcrops, other than main ones, not thoroughly prospected.

MAGNETIC PROFILES

HORIZONTAL SCALE IN FEET

200   100   0   200   400   600   800

VERTICAL SCALE IN GAMMAS

2000   0   2000

Profiles showing Vertical Component Variations thus
Readings beyond range of instrument denoted by ∞ (i.e. ± about 14000 gammas)

The approximate Absolute Intensity value of datum for profiles is 38370 gammas.
(July 1936 determination)

Contour plan (top) showing base line bearing 95°25' (TRUE) 91° (MAGNETIC) APPROX.

MAGNETIC PROFILES
SHOWING
VERTICAL COMPONENT VARIATIONS

For construction of contours, surface effects have been smoothed from profiles, thus......

HORIZONTAL SCALE IN FEET
400   200   0   400   800

VERTICAL SCALE IN GAMMAS
400   200   0   200

Traverses: 10000E, 7500E, 5700E, 3800E, 3600E, 3400E, 3200E, 3000E, 2800E, 2700E, 2600E, 2500E, 2400E, 2200E, 2000E, 1800E, 1600E, 1400E, 1200E, 1000E, 800E, 600E, 400E, 200E, TRAVERSE 00

MAGNETIC PROFILES
SHOWING VERTICAL COMPONENT VARIATIONS
DETAILED SURVEY
IN VICINITY OF THE JOKER WORKINGS

HORIZONTAL SCALE IN FEET
100   50   0   100   200

VERTICAL SCALE IN GAMMAS
200   100   0   200

Traverses: 150 E, 100 E, 50 E, 00, 50 W, TRAVERSE 100 W

TENNANT CREEK MAGNETIC SURVEY
THE JOKER AREA
PLAN SHOWING
CONTOURS OF THE VERTICAL COMPONENT
OF THE MAGNETIC FIELD

N

SCALE IN FEET
400   200   0   400   800   1200   1600   2000

WORKINGS ETC. AS AT 1937

NOTE: The approximate Absolute Intensity value of datum for vertical component contours is 38570 gammas and for profiles is 38570 gammas.

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PARTY LEADER

J.M. Rayner.
CONSULTANT GEOPHYSICIST
27·3·40

ENLARGED PLAN
OF
THE JOKER WORKINGS

SCALE
50   0   100   200 FEET

Dense Ironstone boulders — BASE LINE

Light Ironstone Talus
Slate
Talus
High   Ground
Slope

PLATE 17

"ELDORADO" TRAV 500W
CENTRE OF BODY 402 N
DEPTH OF CENTRE 580'

"ELDORADO" TRAV ZERO
CENTRE OF BODY 845S
DEPTH OF CENTRE 710'

"ELDORADO" TRAV 1500E
CENTRE OF BODY 920S
DEPTH OF CENTRE 690'

"ELDORADO" TRAV 2900E
CENTRE OF BODY 2173S
DEPTH OF CENTRE 485'

"ELDORADO" TRAV 4250E
CENTRE OF BODY 2747S
DEPTH OF CENTRE 970'

"ELDORADO" TRAV 10400E
CENTRE OF BODY 330S
DEPTH OF CENTRE 970'

"ELDORADO" TRAV 10800W
CENTRE OF BODY 400N
DEPTH OF CENTRE 195'

LEGEND
OBSERVED HORIZONTAL COMPONENT VARIATIONS
VERTICAL
CALCULATED HORIZONTAL
VERTICAL

TENNANT CREEK MAGNETIC SURVEY
COMPARISON OF OBSERVED
AND CALCULATED PROFILES

PLATE 18

"PEKO" TRAV 5200 E
CENTRE OF BODY 687 S
DEPTH OF CENTRE 194'

"PEKO" TRAV 600 W
CENTRE OF BODY 70 S
DEPTH OF CENTRE 580'

"PEKO" TRAV 4600 E
CENTRE OF BODY 759 S
DEPTH OF CENTRE 310'

"PEKO" TRAV 3400 E
CENTRE OF BODY 400 S
DEPTH OF CENTRE 410'

TENNANT CREEK MAGNETIC SURVEY

COMPARISON OF OBSERVED
AND CALCULATED PROFILES

LEGEND

OBSERVED HORIZONTAL COMPONENT VARIATIONS
VERTICAL
CALCULATED HORIZONTAL
VERTICAL

HORIZONTAL SCALE IN FEET

"PEKO" TRAV 4000 E
CENTRE OF BODY 773 S
DEPTH OF CENTRE 485'

"PEKO" TRAV 15600 E
CENTRE OF BODY 1410 S
DEPTH OF CENTRE 730'

"PEKO" TRAV 16600 E
CENTRE OF BODY 1416 S
DEPTH OF CENTRE 515'

"PEKO" TRAV 6200 W
CENTRE OF BODY 210 S
DEPTH OF CENTRE 2140'

PLATE 19

"WHEAL DOREA" TRAV. 400E
VERTICAL SCALE 200γ

"WHEAL DOREA" TRAV. 200E
CENTRE OF BODY 260S
DEPTH OF CENTRE 535'
VERTICAL SCALE 200γ

"WHEAL DOREA" TRAV. 1800E
CENTRE OF BODY 175S
DEPTH OF CENTRE 680'
VERTICAL SCALE 200γ

"WHEAL DOREA" TRAV. 1800W
CENTRE OF BODY 642S
DEPTH OF CENTRE 390'
VERTICAL SCALE 200γ

"WHEAL DOREA" TRAV. 2400W
CENTRE OF BODY 747S
DEPTH OF CENTRE 730'
VERTICAL SCALE 200γ

"ORLANDO TRAV." 2600W
CENTRE OF BODY 660N
DEPTH OF CENTRE 580'
VERTICAL SCALE 200γ

"BLACK ANGEL" TRAV. 1600E
CENTRE OF BODY 382N
DEPTH OF CENTRE 475'
VERTICAL SCALE 1000γ

"BLACK ANGEL" TRAV. 400W
CENTRE OF BODY 40N
DEPTH OF CENTRE 505'
VERTICAL SCALE 1000γ

LEGEND

--·--·-- OBSERVED HORIZONTAL COMPONENT VARIATIONS
———×——— " VERTICAL "
—○—○— CALCULATED HORIZONTAL "
—○—○— " VERTICAL "

TENNANT CREEK MAGNETIC SURVEY
COMPARISON OF OBSERVED
AND CALCULATED PROFILES

HORIZONTAL SCALE IN FEET

Geophysical Section, Bureau of Mineral Resources, Geology and Geophysics G187-14

PLATE 20

"LONE STAR" TRAV. 300 E
CENTRE OF BODY 710 N
DEPTH OF CENTRE 545'

"WESTWARD HO" TRAV. 3000 W
CENTRE OF BODY 470 S
DEPTH OF CENTRE 835'

"BURNT SHIRT" TRAV. 1000 E
CENTRE OF BODY 240 N
DEPTH OF CENTRE 390'

TENNANT CREEK MAGNETIC SURVEY

COMPARISON OF OBSERVED
AND CALCULATED PROFILES

LEGEND

—·—×—·— OBSERVED HORIZONTAL COMPONENT VARIATIONS
—×—×—   "   VERTICAL   "   "
—○—○—   CALCULATED HORIZONTAL   "   "
—○—○—   "   VERTICAL   "   "

SCALES
HORIZONTAL 200 0 200 400 600 FEET
VERTICAL 200 0 200 400 600 GAMMAS

"MASCOT" TRAV. 1000 W
CENTRE OF BODY 610 S
DEPTH OF CENTRE 390'

"MASCOT" TRAV. 200 E
CENTRE OF BODY 410 N
DEPTH OF CENTRE 390'

"NORTHERN STAR" TRAV. 1600 E
CENTRE OF BODY 960 N
DEPTH OF CENTRE 580'

"NORTHERN STAR" TRAV. ZERO
CENTRE OF BODY 760 S
DEPTH OF CENTRE 875'

PLATE 21

PERSPECTIVE SKETCH OF PEKO ORE BODY
SHOWING
MAIN WORKINGS AT SURFACE, 300 AND 530 FOOT LEVELS

--- Outline of ore body

Note:- Grid shown is mine grid. Co-ordinates 1547 N/165 E
on mine grid, which is N.W. corner of "Peko" lease,
correspond to co-ordinates 350 N/1407 W on
geophysical grid.