PLAN FOR AN ELECTROMAGNETIC SURVEY
ON NICKEL MINE HILL SULPHIDE BODY,
DRACUT, MASS.

by

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Submitted in partial fulfillment
of the requirement for the
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Signature of Author: ________________________

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ACKNOWLEDGMENTS

The author wishes to render thanks to Professor F. L. Foster, in charge of this thesis, for a ready willingness to give advice. Professor R. G. Hudson furnished appreciated encouragement. The geological part of this work would have been much less clear but for the help of Professor F. K. Morris. Other expert advice was received from Professor W. H. Newhouse and Professor A. C. Lane (of Tufts). He also wishes to thank the various students, among them, C. A. Price, a second-year mining student, and Leonidas Keolyos, a senior electrical student, for assistance rendered in the field.
OBJECT

The purposes of this survey were: (1) to learn the technique of the Two-Frame method of electromagnetic prospecting by application of the method to a pyrrhotite outcrop at Dracut, Mass.; (2) to apply geological principles as much as possible to the electromagnetic survey of the area.
INTRODUCTION

The remark is often made that the successful miner is not the man who strikes ore, but rather the man who knows just when to quit. If the electromagnetic survey is considered in much the same light, it can be a great aid. The author believes as much is gained by choice of a proper area, geologically speaking, as by much interpretation of electrical data gained there. If, upon application of his structural geology, one can decide on no particular area, he should discard the survey of that region entirely. Mr. Hans Lundberg, influential in the development of electromagnetic methods, is of the same opinion regarding the geological preparation.

It is certain, therefore, that the interpretation geologically is just as important with regard to the eventual electrical results as is the proper interpretation after the field procedure. Disturbing bodies are eliminated as much as possible from the start. The trend, also, of the geological formation must always be correlated with the readings as the work progresses.
SUMMARY

The author felt, from his experiences in prospecting work, that much unnecessary effort could be saved by a union of electromagnetic and geological reconnaissance. There is, at present, not sufficient harmony between the two methods of attack, but a proper background of geological field technique can as well direct, as aid, in the interpretation of geophysical results. This work, therefore, consists of applications of geological reconnaissance and of the electromagnetic method.

The mere term "anomaly" means an unusual response due to a disturbing orebody or zone. Properly, one can form laboratory analogies of anomalies in the field by use of so-called "synthetic" orebodies, as metallic masses covered with earth or salt water. The response of a given formation to the electromagnetic method is rarely dependent on a single mineralized zone, but rather on many such zones, and particularly on water. This thesis sets up a plan for applying such an electrical survey in a suitable area.
I. SELECTION OF THE SITE OF THE SURVEY

Type of Area Sought. Due to interference by trolley and power lines, it was deemed inadvisable to attempt geophysical work around Cambridge. An area of mineralization in which would be duplicated conditions of a region successfully prospected by this method was sought. After some trouble in this regard, Professor W. H. Newhouse suggested the Dracut pyrrhotite body. This region, in many respects similar to Sudbury, Ont., which yielded fine results to electromagnetic work, has proved a suitable as well as stimulating project. The location of Nickel Mine Hill is shown on Map 1.

Suitability of Other Methods. The author believes, as a result of dip needle work, that the magnetometer, or even dip needle, could give good indication at Dracut. The ore is highly permeable. It is doubtful whether or not the presence of pyrrhotite in small quantities throughout the norite and of small pyroxenite masses would not interrupt the indications from massive sulphides. The magnetic method is preferable from the point of view of simplicity, cost and effort, while the electromagnetic is more accurate. The wisest course in
such a case is to check up the magnetic with the electromagnetic survey. A possible application of the equipotential method could be found by determining the outline of the orebodies under the glacial debris to the north, east, and west of the open cut; for, in cases of soil cover, such as here, the equipotential method is equally effective.

**Determination of the Conductivity of Sulphides and Surrounding Rock.** Beyond the self-evident low resistivity of the massive sulphides, the resistivities of other samples of rock and sulphides were tested. The method used was a simple Wheatstone Bridge method with galvanometer and direct current. The results are sufficient for estimation of the following resistivities:

- **Massive ore** - About one ohm per cubic centimeter.
- **Mixed norite and sulphides** (gradation from massive to normal norite)-about 200,000 ohms per cubic centimeter.
- **Normal norite** - Several million ohms per cubic centimeter.

The massive ore, therefore, is an excellent conductor in comparison with the norite. The small amount of sulphides disseminated throughout the normal norite gives it no extraordinary resistivity value.
Previous Work\textsuperscript{1} - Shafts, Prospects and Sulphide Outcrops

The following are shown on Map III: (a) open-cut; (b) 61-foot shaft; (c) small shaft, and prospects. It may be surmised, therefore, that since discovery some development work has been done. It is possible that the deposit was worked as long ago as 1640, certainly before 1710\textsuperscript{2}. In 1726, the property was supposed to have yielded gold and silver. During the Revolution the shaft was sunk, it is said, to a depth of 43 feet. The first attempt to recover nickel was made by a company in 1876 - the shaft was continued down to its greatest depth, 61 feet. Again, in 1883, the mine was worked. Accompanying the latter operations was a small stamp milling plant in 1876 and a small furnace smelting plant in 1883. Iron, nickel and cobalt were obtained by a chlorination roasting with salt. A crushed stone quarry, 1923, shown on the map, encountered sulphides in its operations.

It seems certain, therefore, that all three classes of workings date from the recent development work, for the workings would have fallen in completely by this far date. Perhaps the open-cut, however, is much older.

\textsuperscript{1}Bibliography II-1, pp. 20, 35; Bibliography I-3.
\textsuperscript{2}Bibliography I-3.
The repeated attempts at working, though commercially unsuccessful, the small recovery plants, the presence of an old road, lend a slight possibility to a renewal of operation in case of extended discoveries.

Outline of Work

The plan of work to be undertaken was:

(1) Sufficient geological reconnaissance and Two-Frame readings to understand the sulphide distribution;

(2) Geological prospecting about the open-cut area;

(3) Brushing and laying out of loop and transit lines;

(4) Rehearsals of Two-Frame Method;

(5) Actual application of the method to the sulphide body.

General Geology of Nickel Mine Hill

To understand the proven principles of sulphide formation at Dracut, it is well to recall that the norite stock is post-Cambrian in type. A study of such an outcrop (Fig. 1) as occurs near the contact of the norite and the Merrimac quartzite behind the quarry (outcrop marked on Map II) explains the principal types of rock found. These
are normal norite, fine-grained norite, porphyritic norite, and pyroxenite. The interpretation of this outcrop is as follows. After intrusion into the quartzite, the stock developed a fine-grained contact cap due to chilling and, in the first stages of consolidation of the interior magma, this broke into the innumerable inclusions all around the contact. That a particular pyroxenite now differentiated is seen by inclusions of it in the normal norite. Hence the normal norite consolidated about the earlier rocks. Streaks of coarser norite-porphyry appeared soon after where cooling was faster than otherwise. The pegmatite shown represented the last siliceous phase of consolidation. The sulphides were probably injected into shear zones formed at or after this pegmatite stage. Probably, also, before this stage of injection, small sulphide bodies, such as are present in many places in the norite, had segregated out. A later mineralization left small quartz stringers through the stock.

Schlieren due to concentration of volatiles were noted at the quarry; and, since the ones observed come from concentration of volatiles before complete solidification, bear an intimate relation, no doubt, to the injection of the sulphides.

1 Bibliography I-3.
Fig. 1, Outcrop behind Quarry

Fig. 2, Open Cut Outcrop
The Dracut norite is intruded into the Merrimac quartzite, of probable Cambrian age, and is intruded by the Andover granite, of Carboniferous or post-Carboniferous age. Its age, therefore, ranges from Cambrian to Permian. Since all the rocks of the area (their geology is given in Map II) but norite have suffered regional metamorphism, the norite must be later than the last period of deformation, or Pennsylvanian. Triassic faulting probably affected the stock.

Remarks on Geology Pertinent to Prospecting

The field work in preparation for the survey — consisting principally in the proper estimating of the strike of the mineralized zone — was productive of gratifying results.

The author's geological observations were confined to the deposition of the ores. He believes that valid evidence uncovered points to quite an extensive zone of mineralization for delimitation by the electromagnetic survey. It is fortunate from the geophysicist's point of view that few geologists in their reconnaissances of unimportant areas can spare the time to investigate more than the conditions of ore deposition. The scientific
prospector must approach the area with an attitude, it is true, for applying general principles of geology, but he must be attentive, above all, to the development aspects of the deposit.

Reconnaissance Geology

Reconnaissance and Mapping of North Shear Zone.
The first day's work consisted of a general reconnaissance of the norite stock, and plane-table mapping of a significant shear zone. The problem was approached from a prospector's point of view, since, beyond general directions as to the location of the norite, no information had been gained by the author and assistant. The stock was located after a consideration of the topography, but unfortunately the pyrrhotite body was not found on that day. Professor A. C. Lane, a few days after, kindly indicated on a map the old mine, hidden away about 500 yards from our previous plane-table station.

The finding, however, of traces of an old road some time previous had led the author to believe that the pyrrhotite was not far away; and for future reference certain very evident shears and quartz stringers were mapped. No doubt, such short reasoning from topographic
expression is not generally justified: the true prospector checks up at every step. But hypotheses are sometimes better than nothing.

This shear is indicated in red on a large topographic map (Map III). The strike of the shear points directly with a series of glaciated gulleys on the northwest extremity of the stock, then along an evident scarp into the region of pyrrhotite outcrop. The gulleys, undoubtedly, are due to shearing and glaciation, but contrary to Burton and Spalding¹, the author does not believe that faulting of the region has produced a fault scarp such as they mention. Glaciation has rounded the scarp, and could well have carved it from a pronounced shear zone. The quartz stringers the author considers multo-post and unimportant, and they are not noted on the map. As can be seen from the contours, glaciation has produced a monadnock with the northern toe scoured off; since this material is deposited on the southern heel, the glaciation was from the north. In this manner was produced the scarp adjoining the northern shear zone - not by faulting.

¹Bibliography, I-1, p. 19.
²Idem.
of shearing, beyond that of the northern extremity, can be gained from this procedure.

Reconnaissance of Open-Cut Outcrop. The next day's activity, with more information on the location and type of deposit, resulted in the finding and examination of the nickeliferous pyrrhotite exposed in the open-cut. Here the advisability of considering shear, rather than schlieren, for extensions of the body was revealed. According to Professor F. K. Morris, the Germans are quite proficient in demonstrating the flow structure of batholiths, stocks, and other intrusive bodies by mapping of schlieren on an extended scale. A survey of this type would probably determine much with regard to the trend of the pyroxenite. Since the pyroxenite bears close association with the sulphides at the Key West Mine in Nevada, and at the Lancaster Gap Mine in Pennsylvania, as well as in the open-cut, data on the determination of the trend of the sulphides might result. For the author's purposes such an extended mapping was impractical.

The reconnaissance proved that shear was associated with, and an important condition of, sulphide deposition.

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1 Bibliography, I-1, p. 41.
2 Bibliography, I-4, p. 803.
3 Bibliography, I-1, p. 44.
Fairbanks states\(^1\): "A shear zone occurs to the south of Burns Hill in which the shearing is developed roughly parallel to the elongation of the stock and along the strike of the quartzite. The norite of this zone exhibits flow structure and has been intensely altered and crushed. Long-drawn-out 'segregations' containing pyrrhotite and resembling the ore of the mine are abundant in this zone. In a few places calcite-sulphide veins cut through the sheared norite, and some patches of actinolite are found. The shearing produced a readily permeable zone for the late magmatic mineralizers referred to in this paper as paulopost." The chief of these minerals were pentlandite and pyrrhotite\(^2\). The location of Burns Hill is shown on the Nickel Mine Hill Map, Map II, together with the location of the open-cut outcrop. They occur in the same stock and are not far distant. The above description of the Burns Hill deposit could well be applied, with the exception of calcite-sulphide veins, to the open-cut outcrop. Furthermore, more than one outcrop of pyrrhotite is in the direction of shear (Map III).

The reconnaissance of the open-cut produced the sketch given (Fig. 2). The strike of the shear in the

\(^1\)Bibliography, I-3, p. 403.
\(^2\)Bibliography, I-3, p. 408.
adjacent rock could not be clearly made out. The most important points to notice are (1) comparatively vertical zone brecciattion, indicating shear, and, (2) the presence of one horse completely surrounded by sulphides, and of another not entirely surrounded. These were noted carefully. In no way can the author account for (2) when he considers the injected or intrusive nature of the deposit, except by the obvious explanation that the rock was first sheared, then the sulphides deposited in the shear zone. Thus correlation with the Burns Hill outcrop is practically perfect. sulphides What additional sulphides are found should extend along the northern shear zone (a rather wide zone) from the open-cut outcrop; for certainly the vertical, dikelike form of the sulphides would indicate that the shear in which the sulphides formed guided them. Hence, most likely some other shear the northern zone is mineralized. The author is not able to differentiate the earlier shear of deposition from later possible shears, but since the vertical bare rock scarp rises in a straight line, to the south, the first shear is delimited to a definite zone in general perpendicular to the strike of the open-cut.

A nearly vertical dip seems indicated, but whether this is deceptive, as is often the case (witness

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1 Bibliography, I-4, pp. 801, 802, 807, 808.
gash veins), or how far down the deposit extends in dip, can be properly turned over to survey.

Elimination of Unsuitable Areas. Advantage was taken of the physiography (Map IV). It is simple to trace out the bare rock over whole regions, all of which was noted on a sketch and immediately discarded from further consideration. In this way the survey pattern (see Fig. 4) was laid out. Concerning the low-lying drainage area, particularly to the northeast, the author makes no statements, for it is under cover and not exposed to view. He suspects that the comparatively great drainage in the open-cut and the moist character of the northeast area, particularly after a rain, are due to the shear-zone structure.

Surface Prospecting. The distribution of float from the pyrrhotite body could not be used as a check on the zonal distribution of the ore. As stated, the glacier has gouged out the northern sheared regions; a surface expression of depression could have been left, but debris has covered this up. Slopes are too slight for float to travel far.

Dip Needle Line. A dip-needle line (Fig. 3) was taken across the outcrop of pyrrhotite, at the head

\(^1\)Bibliography, II-3.
Fig. 3

Dip-Needle Traverse along Open-Cut
of the open-cut. The diagram of this run revealed that
the body of outcropping pyrrhotite was generally vertical,
and not wide. As can be seen, in a southerly course ex-
tending in line with the open-cut the curve reaches a peak
at 10 feet and returns below at 20 feet. Between 0,
the northerly revealed contact of the pyrrhotite and the
southerly contact, therefore, is a matter of 10 feet ap-
proximately. If time had been available, more extended
lines in the same manner parallel to the open-cut might
have shown something of other sulphide bodies; but with so
much interference from other magnetic material, as boulders
on the surface and pyroxenite, only the broad indication
of ore could have been accepted. Dip needle runs were
taken to some extent farther from the open-cut, but due to
a steep gradient of ground, yielding often negative indica-
tions, and to the presence of much smelter slag and many
appreciable ore dumps, the results have been neglected.

*Power Line.* The presence of a large 120,000-
volt power line to the west necessitated a pace and com-
pass survey with a Brunton to determine that it was far
enough away (600 yards) to give no interference to the
electrical readings.

*Conclusions.* The author considered it best,
therefore, to note the structural features at the outcrop
(including its dikelike form) and the shear evidence at
the open-cut walls and in line with it, and, in general, in laying out the base-line for the survey, to follow along the line of the shear scarp. He feels certain that more sulphides will be encountered. Indeed, another small outcrop occurs a short distance/towards the north scarp from the open-cut. What the true dip and strike of the deposit is, together with its extent, and whether it is accompanied by others, is left to the electromagnetic field work to indicate.

Character and Distribution of Sulphides

Pyrrhotite. This mineral composes the great bulk of the mineralized zone. It is easily attracted to a magnet, and able, when drawn near a dip needle, to cause it to oscillate. The open-cut outcrop contains pyrrhotite with very little else; but it is found in other places (prospects and shafts on Map III) in not such massive occurrence. The massive pyrrhotite at the open-cut, too, grades into wall rock. It comes, in minute quantity, in all types of the gabbro, but in greatest amount in the coarse pyroxenite and in the fine-grained rock similar in composition. The pyrrhotite is often found in connection with pyroxenite. Even the stock itself contains some small amount of pyrrhotite\(^1\). Due to the fact that the pyrrhotite

\(^{1}\)Bibliography, I-1, pp. 34, 36, 43.
has been found to replace gangue mineral, it has been placed in the paulopost period in the norite's consolidation history.

Minerals of Open-Cut. The open-cut minerals are listed as follows by Fairbanks:

<table>
<thead>
<tr>
<th>Magmatic</th>
<th>Paulopost</th>
<th>Multopost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetite</td>
<td>Basaltic hornblende</td>
<td>Marcasite</td>
</tr>
<tr>
<td>Olivine</td>
<td>Pentlandite</td>
<td>&quot;Polydymite&quot;</td>
</tr>
<tr>
<td>Augite</td>
<td>Pyrrhotite</td>
<td>(undetermined)</td>
</tr>
<tr>
<td>Hypersthene</td>
<td>Biotite</td>
<td>Limonite</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>Serpentine</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Actinolite</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unknown</td>
<td></td>
</tr>
</tbody>
</table>

The nickel in the sulphides, undoubtedly, is due to the pentlandite. The analyses of Burton and Spalding showed a small percentage of nickel in the mine sulphides, about one per cent, and they concluded that ordinary fine crushing and Wilfley table separation was as good a method of separation as any. Platinum, as at Sudbury, could appear in traces.

1 Bibliography, I-3, p. 411.
2 Bibliography, I-4, pp. 799, 801, 870.
3 Bibliography, II-1, p. 67.
4 Bibliography, II-1, p. 70.
5 Bibliography, I-3.
Secondary Minerals. A really close examination of the Hill was first made by Fairbanks in 1912. No doubt the secondary mineralization that he found has been guided by the shearing in much the same way as the paupost mineralization. It is important to note that these minerals were overlooked before. Chalcopyrite and other sulphides, in the so-called calcite-sulphide veins, occur in a zone of shearing on the northern edge of the stock. But, it must be noted, this secondary or multopost mineralization is not in much evidence in the list of open-cut minerals.

Sulphide Theories of /\ Deposition. (a) The ratio of sulphides /\ to norite should be the same as at Sudbury, Ontario\(^1\). (b) The /\ occur in connection with a pyroxenite dike\(^2\). The survey should throw some light on these questions, as well as give some idea of the partial deposition of the ores at Sudbury\(^3\).

Layout of the Loop and Transit Survey

Layout of the Loop. The location of the loop and the survey plan is given on the large topographical map (Map III) and the dimensions of the loop and survey

\(^1\)Bibliography, I-3.
\(^2\)Bibliography, I-3.
\(^3\)Bibliography, I-4, p. 803.
are given in a separate diagram (Fig. 4). Besides these, a small topographical map (Map IV) of the Nickel Mine Hill area is included to give a better idea of the topography as a whole.

Due to lack of wire necessary for a larger loop, it was decided to use a 300 by 900 foot loop instead of the standard 3000 by 1500, or 1800 by 450 foot loop. This necessitated a close study and elimination of unsuitable ground, that is, reduction of the survey to mineralized areas. Since, by this time, the strike of the deposit was quite apparent from reconnaissance work, the undesirable areas were easily left out of the plan. Topography was an aid in elimination, for bare rock outcrops to the south of the base-line shown on the maps. Likewise, the glacial debris has filled small gouged-out gulleys parallel to, and near, the expected strike, and it may be surmised that the shear and oxidation of the ore played a part in causing them.

**Base Line of Transit Survey.** The base-line, therefore, was first of all laid out along the supposed line of strike. A plane-table arrangement was used to approximate a line at right angles to the open-cut, and equal distances measured along it. When the transit lines had been decided upon, the transit base line was run along this first one in order to provide a check on
Fig. 4

Loop Layout and Transit Survey
the work. The arrangement and distances of this survey are given in the plan diagram. Especial care was taken that the angles checked, but not such close attention was given to the taping of distances.

Accuracy of Transit Survey. A discussion of the accuracy of this survey might be included, but is comparatively unimportant. To begin with, the accuracy of such a survey need not be very great, not even so much as that of an ordinary land survey, because other sources of error are present. The errors resulting from departure of the horizontal frame from a horizontal position alone, errors in locating and reading null points, variations of the note of the buzzer with consequent audible trouble in the headphones, far overshadow those due to the geometry of the layout. Here it is to be noticed that a large number of errors, such as variation in frequency of the buzzer, are eliminated from the ratio nature of the readings along the lines.

Checking. Undoubtedly the transit work was sufficiently precise, for closure on station lines usually checked to within a few feet, and angles to within a few minutes. The last line to the west, however, was laid off incorrectly due to steepness of topography, and will have
to be lined in with a Brunton, taking as a reference the near side of the loop. This loop line has been well-checked.

Plan of Transit Survey. As stated, the base-line was run out at approximately right angles to the open-cut. Equal distances (see Fig. 4) of a hundred feet were measured out on it from the survey point. This consisted of a small stamped cross-mark at the head of the open-cut, in solid outcrop of ore. Then, by the use of the brush-hook lines were run out on each side of the base-line, and station markers put at fifteen-foot intervals. The markers consisted of small wooden stakes, somewhat smaller than the base-line stakes.
II. THE TWO-FRAME METHOD

Principles of the Electromagnetic Methods

Basic Advantages\(^1\).

(1) Requires no grounded electrodes and is independent of surface conditions.
(2) Presence of an insulating sandwich layer not detrimental to readings.
(3) Water indication is least at low frequencies.

Application. The electromagnetic method is applicable to ores of suitable conductivity. They are the native metals, the sulphides (except sphalerite) the arsenides and the antimonides\(^2\). The absence of conductors other than ore is desirable. Graphitic schists, for example, cause interference. The texture of an ore, of course, has an immense effect on its conductivity. A trial run is the best test of the area. It is to be noticed that an electromagnetic method is usually both a reconnaissance and detail method. The best success of the electromagnetic survey is at depths under 300 feet.

\(^1\)Bibliography, III-3, p. 16.
\(^2\)Bibliography, III-3, p. 16.
**Theory of Electromagnetic Methods.** The fundamental theory of each of the electromagnetic methods is the same, namely, that a primary field from a vertical or horizontal current-excited coil causes currents in conductors and that these set up a secondary field that interacts with the primary field. Anomalies of intensity, direction and phase are thus produced in the primary electromagnetic field. See Fig. 9 for vector diagram, Figs. 5, 6, 7, and 8 for curves. Usually it is possible to consider the magnetic vector and neglect the electric vector, since the permeability of a substance increases with the conductivity, and far exceeds the conductivity in effect. The electric vector can be detected.

The resultant magnetic field is elliptically polarized. Let us consider the magnetic vector of the datum primary field and of n orebodies. The resultant rotating vector at any moment is made up of component vectors along the axes

\[
X = A \sin (wt + \alpha_1) \\
Y = B \sin (wt + \alpha_2) \\
Z = C \sin (wt + \alpha_3)
\]
**Electromagnetic field around a flow of current.**

*Fig. 5*
SECONDARY CURRENT FLOW INDUCED IN CONDUCTING BODIES BY PRIMARY CURRENT IN CABLE.

Fig. 6
Diagrams of horizontal components of electromagnetic field.

a. Around concentrated current flowing through orebody.
b. Around current in cable and barren ground.
c. Around current induced in orebody.
d. Around current directly supplied.
e. Actually observed while surveying.
f. Purely caused by orebody.

Fig. 7
A profile illustrating the change in the horizontal and vertical components of the magnetic field over an excited ore-body, using alternating current in a loop \( A, B \).

Fig. 8
These may be written

\[ X = A_1 \sin wt + A_2 \cos wt \]
\[ Y = B_1 \sin wt + B_2 \cos wt \]
\[ Z = C_1 \sin wt + C_2 \cos wt \]

The resultant of the sine terms is
\[ H_1 = P \sin wt \]
and the three cosine terms result in
\[ H_2 = Q \cos wt. \]
Since these differ in phase by \( \frac{\pi}{2} \) the resultant is a rotating vector tracing out an ellipse. This is the silence plane or polarization ellipse\(^1\).

It is better to take points as far from the loop as possible, as the orebody anomaly then is in greater ratio to the primary field.

Frequency methods are exceedingly complex at high frequencies, but at low frequencies (0.3 to 2 kilocycles) the ordinary laws of magnetic induction apply. The ellipse of polarization for this case is elongated enough to be considered a linear vector.

Classification of Methods. The electromagnetic response may be gained in a number of ways\(^2\):

\(^1\)Bibliography, III-4, p. 133.
\(^2\)Bibliography, III-4, p. 140 et seq.; III-8, p. 12.
(A) Primary field supplied by point-shaped or linear electrodes. Direction, intensity and phase shift of the resultant field measured with induction coils and telephones or with chemical rectifier and millivoltmeter. Horizontal intensity a maximum, vertical intensity zero above center of conductive body.

(B) Primary field supplied inductively by insulated loops, with direction, intensity and phase shift of the resultant field determined with induction coils and telephones or with chemical rectifier and millivoltmeter. Horizontal intensity a maximum above the edges, vertical intensity a minimum above the center of the conductor. The vertical primary coil, or generating loop, is used for directional anomalies, while the horizontal loop of insulated wire laid out on the ground is used for phase shift and intensity anomalies.

(C) Radio waves - regular transmitter with vertical loop-aerial, and receiver, with tilting loop on a stand required. Anomalies in the nature of reception, in variation in intensity of reception with wave length, in frequency and in damping are recorded. Theory and practice both complicated.

Methods of exploring inside and outside of a horizontal loop as in (B) are popular and effective. The
primary field is approximately vertical 85 feet from the
loop\(^1\), and can be represented by the expression

\[ H = H_0 \sin \omega t \]

and the field of the orebody, being out of phase, can be
represented by

\[ H = H_0 \sin (\omega t + \alpha) . \]

A current in the search coil is thus generated out of phase with the primary current by the angle \( \alpha \).

Detection. Three methods of detection are possible: (1) compare the strength of the vertical field at one point directly with the strength at another point; (2) locate magnetic equipotentials of the electromagnetic field by means of search coils, and plot; (3) find silence plane of the polarization ellipse and determine its axes by noting the current in the coil when it measures the horizontal component in the silence plane. The phase relations between the conjugate diameters of the polarization ellipse may also be deduced.

Two-Frame Method. The comparison method, used in Europe and America by Sundberg, has had some success.

\(^1\)Bibliography, III-1, p. 60.
It is denominated the "Two-Frame Method" here. Not only the direction but the relative intensity of the electromagnetic field produced by the eddy currents of the orebody and the primary field current can be measured. Two coils are used for searching, so wound that the induced currents counteract one another. If the intensities at two subsequent stations are in phase, their ratio can be determined by keeping one coil horizontal and turning the other until no sound is heard in the telephones. With the intensities of the two stations not in phase, the ratio of the strength of the vertical fields in the two coils is given by the secant of the angle of tilt when the sound in the phones connected into the circuit is a minimum.

The manipulation of the two frames, therefore, is for the purpose of arriving at a neutralizing balance between the current of the oriented operating frame and of the horizontal frame, held farthest from the loop. This silence point makes for reliable readings.

Errors Using a Single Coil\textsuperscript{1}. The variables of this response are, therefore, in the case of the use of a single coil, to be placed in two classes: (1) due to change of direction, phase and intensity of the resultant

\textsuperscript{1}Bibliography, III-5, pp. 22, 87.
field; (2) due to errors in manipulation of the instruments. The standard series of curves for the magnetic field values over an excited orebody is shown in Figs. 5, 6, 7, 8. These values are as constant as the source of the field; in the case of a buzzer contact variables render the current fluctuating to a degree. Furthermore, the curves are not usually perfectly to type. Alluvial or terrestrial distribution of current is subject to many more variable conditions than simple metallic conduction in a predetermined path. There is both a lack of focus and of homogeneity in subsurface flow of current. It has been aptly remarked that a dissipation of energy is the same, practically, as though it were destroyed. In addition to an actual dispersal of current or stray currents in the heterogeneous conducting medium, the presence of other bodies and water adds disturbances that confuse the readings. The great problem in the method often is to eliminate the indication of everything but that thing sought. Absorption of energy by the ground itself varies in different localities; so likewise the warped terrain is reflected in variation of readings. Frequently, too, the phase differs in the slight distance between two subsequent coil stations. It is better to employ a 500-cycle generator instead of a buzzer due to the better wave form received by the search coil.
Fig. 9
Vector Resultant Field

Primary Field

Fig. 11
Angles $\alpha_1$ and $\alpha_2$

Fig. 10
Angle $\xi$

Plan View

Front Elev.

Side Elev.

Fig. 12
Angle $\delta$

Plan

Plan

Elevation
Errors in Two-Frame Method. Such errors are eliminated to a good extent in the Two-Frame Method by taking the ratio of the field at two points over the orebody.

Procedure in Taking Two-Frame Readings

Readings Along Lines. At a point 85 feet from the loop is placed an operating frame free to move about horizontal and vertical axes; and at 15 feet the horizontal frame is held by an assistant. The proper angular (see below) readings are recorded. From certain of these the ratios $V_1/V_2$ and $H_1/H_2$ can be calculated. $V_1/V_2$ is the ratio of the vertical component of the electromagnetic field at points 1 and 2, and $H_1/H_2$ the corresponding horizontal field ratio. The horizontal frame is then moved 15 feet to point 3, and the readings repeated. Thenceforth, the horizontal frame is kept 30 feet ahead of the operating frame. The operating frame readings are taken at successive 15-foot stations of the survey line. For layout of the loop and stations, see Fig. 4. A tabular recording of angles is made. $V_1$, $H_1$, $V_1/V_2$, $H_1/H_2$, $V_2$, $H_2$, $V_2/V_3$, $H_2/H_3$, and so on, are easily calculated. The ratio $V_1/V_2$ is changed to $V_1/V_2$ reduced by division by the
normal vertical component of the field of the loop. $H_1/H_2$ is considered as already reduced. In this way other values at every point of the plan of survey (Fig. 4) can be calculated. The values of $V_1/V_2$ and $H_1/H_2$ are plotted in the obtaining of the curve, at the point 1.

Thus complete curves of the vertical field ratios and of the horizontal field ratios are plotted along a given line from the loop. Likewise, the curves of $V$ and $H$ are plotted from each operating-coil station value.

**Phase Shift.** Even with a single orebody the difference in phase between the field from the ore and that from the loop may be of use in indicating the orebody. Some advocate this method entirely.

**Further Information**

The reader is referred to F. L. Foster's Report\(^1\), to gain further explanation of certain facts of the actual survey. The following points can be easily found, and therefore are not repeated:

- A closed loop is preferable.
- Reasons for working outside of the loop.

\(^1\)Bibliography, III-1.
Calculation of results -

Derivation of \( \frac{V_1}{V_2} = \frac{K_2}{K_1 \sin \alpha} \).

Theory of curves obtained. Their derivation.

Determining width of conductors.

Determining dip of conductors.

The "qualitative" test.

**Scale of Plotted Results**

All the values obtained are plotted on a scale of 1 inch = 60 feet for distance, and 1 inch = 0.01 unit for electrical data.

**Procedure**

**Frame Constant.** The method of obtaining the frame constant is treated by Foster\(^1\). This must be done at the first of the survey.

**Layout of Survey Plan.** (Fig. 4).

**Frame Technique.** The survey is then begun. The horizontal frame is held horizontal by means of the level bubble at a point farther from the loop. The

\(^1\)Bibliography, III–1.
amplifier is switched on and angles of minimum sound
located by two observers with telephones. The method of
adjusting the operating frame to get these angles is im-
portant.

vertical Angle \( \varepsilon \). The operating frame is first sighted
along the line through its radial-scale sights. It is
then turned off the line to a minimum response angle.
This is the angle epsilon.

Angles \( \alpha_1' \) and \( \alpha_2' \). The horizontal frame
is connected in. By moving about the horizontal axis a
position of null or minimum sound is located. Another
such position is found to the opposite side of the vertical,
the second angle approximating the first. Their average
gives \( \alpha \), the required value at point 1.

Angle \( \delta \). The horizontal frame is disconnected.
Now a turning of the operating frame through an angle of
ninety degrees (at right angles to \( \varepsilon \) position in a hori-
zontal plane) and adjustment about the horizontal axis
gives the angle \( \delta \).

Vector Explanation of Angles. The angle \( \varepsilon \)
represents the angle at which the electromagnetic vector
is completely within the plane of the vertical loop, hence
when sound is least, if any. See Fig. 10.
The angles $\angle_1'$ and $\angle_2'$, or $\angle_1$, their average, are the angles at which the horizontal frame balances out the component of the resultant perpendicular to the operating frame. The parallel component, since the frame is oriented with it, causes no current. See Fig. 11.

In the case of the angle $\mathcal{D}$, the vector is again completely within the plane of the operating frame. See Fig. 11.

**Interpretation of Curves**

**Curves Obtained.** The curve given (Fig. 13) represents the principal points of the curves obtained. The following facts are discussed elsewhere:

$V_1/V_2$ reduced curve
- maximum point - boundary of orebody nearest loop.
- minimum point - approximately the other boundary.

$H_1/H_2$ curve
- Points where curve crosses the unity line indicate boundaries.

$V_1$ curve
- Points of inflection indicate boundaries.

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1 Bibliography, III-1.
Fig. 13.
Geophysical Prospecting
Results of
Two-Frame Inductive Method
Buchans, Newfoundland
1929
Scale: 1 inch = 60 ft.
and
1 inch = 0.1 electrical unit

Note: Position of railroad track is near point 185. These distances are measured from the axis producing the primary field.
H$_1$ curve

Maximum point - indicates nearest boundary.

Depth of Conductor - if the point of maximum secondary vertical field is projected on the unity line, and the point of inflection is projected likewise, the distance between the two points gives the depth of the conductor.

Calculation of Normal Vertical Field

Mention has been made that the $V_1/V_2$ values are reduced by division by normal vertical field values.

Two methods, the more exact (Fig. 14) and the approximate (Fig. 15) are given.

Approximate Method. This may be used in a case where the distance to the loop is small compared to the length of the long side. In the case of a loop 6000 by 900 feet, taking the more exact method as a basis of true values, the field at a point 300 feet from the long side and 2000 feet from the short side was 5.44 per cent below that of the more exact method.

The result calculated on the 900 by 300 feet loop at a point 85 feet from the long side and 350 feet from the short side was 12.9 per cent below that of the
Fig. 14, Calculation of Normal Field Outside Loop 900' x 300'

Point 1: \[ B = \frac{\sin \alpha - \sin \beta}{a} + \frac{\sin \varepsilon - \sin \delta}{b} - \frac{\sin \eta - \sin \theta}{c} - \frac{\sin \gamma - \sin \lambda}{a + x} \]

\[ \alpha = \tan^{-1} \frac{350}{85} = \tan^{-1} 4.353 = 77.06^\circ \]
\[ \beta = \tan^{-1} \frac{550}{85} = \tan^{-1} 6.470 = 81.21^\circ \]
\[ \gamma = \tan^{-1} \frac{350}{385} = \tan^{-1} 0.909 = 42.03^\circ \]
\[ \varepsilon = \tan^{-1} \frac{385}{350} = \tan^{-1} 1.100 = 47.70^\circ \]
\[ \delta = \varepsilon - (90 - \alpha) = 47.70 - 90 - 77.06 = 34.76^\circ \]
\[ \lambda = \tan^{-1} \frac{550}{385} = \tan^{-1} 1.412 = 53.02^\circ \]
\[ \eta = \tan^{-1} \frac{385}{550} = \tan^{-1} 0.699 = 35.00^\circ \]
\[ \theta = \eta - (90 - \beta) = 35.00 - 90 - 81.21 = 26.21^\circ \]

\[ a = 85 \text{ ft} = 2592 \text{ cms} \]
\[ b = 550 \text{ ft} = 16800 \text{ cms} \]
\[ c = 550 \text{ ft} = 16800 \text{ cms} \]
\[ a + x = 385 \text{ ft} = 11730 \text{ cms} \]

\[ B = \left[ \frac{0.9747 + 0.9882}{2592} + \frac{0.7396 - 0.5670}{10680} - \frac{0.5736 - 0.2417}{16780} - \frac{0.6720 + 0.8194}{11730} \right] \]
\[ = 0.1 \left[ 15.73 + 1.617 - 1.7808 - 12.72 \right] \times 10^{-5} \]
\[ = 63.846 \times 10^{-6} \text{ gauss/ampere} \]
Calculations of Normal Field outside Loop 900' x 300'

Approximate Method

\[ B = 0.1 \sum \frac{\sqrt{a^2 + b^2}}{ab} \times \frac{1}{30.5} \text{ gauss/ampere} \]

where:-

- \( B \) = Normal Field intensity of point taken
- \( a \) = Horizontal distance in feet
- \( b \) = Vertical distance in feet

\[ B = \frac{1}{30.5} \left[ \frac{\sqrt{350^2 + 85^2}}{350 \times 85} + \frac{\sqrt{550^2 + 85^2}}{550 \times 85} + \frac{\sqrt{350^2 + 385^2}}{350 \times 385} - \frac{\sqrt{550^2 + 385^2}}{550 \times 385} \right] \]

\[ = \frac{1}{30.5} \left( 1.209 + 1.190 - 0.386 - 0.317 \right) \times 10^{-2} \]

\[ = 55.6 \times 10^{-6} \text{ gauss/ampere} \]
more exact method. The error, therefore, of many stations would be quite appreciable.

The approximate method, therefore, is only good one for this small loop calculation from a ratio standpoint. The reader is referred to Hudson's Manual\(^1\) and and Edge and Laby\(^2\) for the formulae used in derivation of the general field expressions. The latter also gives the approximate expression used by the author.

**Description of Apparatus**

The complete detail of apparatus is given in the report of F. L. Foster\(^3\).

**Summary of Work Done**

By geological reconnaissance and other methods the general strike of sulphides was determined, and some idea of their distribution gained for Two-Frame Survey. The open-cut area was laid off preparatory to a few days of actual Two-Frame Survey. The frequent rehearsals inculcated the technique of the Two-Frame Method in the author's mind.

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\(^1\)Bibliography, III-10, p. 188, eqs. 781, 782.

\(^2\)Bibliography, III-5, p. 279.

\(^3\)Bibliography, III-1.
Conclusions

The strike of the shear to the north is the strike of the sulphides about the open-cut.
There is good reason to believe that much more pyrrhotite occurs.
The nickel content of the sulphides is probably too low to ever warrant large-scale production.
The actual Two-Frame Survey will delineate the extent of the sulphides in a short time.
Other conclusions are to be found in the body of the thesis.
III. SUGGESTIONS FOR FURTHER WORK

Mapping of Schlieren

The structure of the sulphide body could well be determined in this way.

Survey of Related Areas

The low-lying drainage area to the northeast, below the open-cut, might easily be prospected by many methods, especially the equipotential. The author believes that for a prospecting class this would be a good location. Burns Hill would be another likely area. He suggests that any independent prospector consider transportation difficulties, as well as the momentary fascination of such work for students who soon are enveloped in other work. The best plan would be to camp on Nickel Mine Hill.

The location of other bodies of sulphides in other norite stocks might be possible. These occur some miles away.

Pneumotectic Deposit

Much information is to be gained on such a type of deposit here.
Cobalt and Platinum

Cobalt (see "Previous Work") and traces of platinum are probably present, and the area should interest the mineralogist.

Dip-Needle and Magnetometer

This area is ideal for application of either instrument. The question of whether or not the main orebodies are in pyroxenite dikes (see p. 22) could be thus investigated.
IV. BIBLIOGRAPHY

I. Geology


II. Mining


III. Electromagnetic Method


2. Outline of Lectures, Foster, F. L., mimeographed sheets for use of mining students in Geophysical Prospecting, 3.13, Massachusetts Institute of Technology.


7. Traité Pratique de Prospection Géophysique,  
Alexanian, C. L., Libraire Polytechnique Ch. Béranger,  
Paris et Liège, 1932.

8. Geophysical Methods of Prospecting, Heiland, C. A.,  
Colorado School of Mines Quarterly, Golden, Colorado,  
March, 1929.

The reader is referred to "A Selected List of Books and  
References on Geophysical Prospecting", Heiland, C. A.,  
and Wantland, Dart, Colorado School of Mines Quarterly,  
Golden, Colorado, July, 1931, for further information.
V.

APPENDIX A

MAPS I - IV
MASSACHUSETTS - NEW HAMPSHIRE
LOWELL SHEET

Map I
Map of Dracut norite stock.

Map II
CONTOUR MAP
OF
NICKEL MINE HILL
DRACUT MASS
BURTON-SPALDING SURVEYORS
CONTOUR INTERVAL 10 FEET
SCALE 200 X 200 FT

Map IV