

SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C.

Avhandlingar och uppsatser

N:o 319.

ÅRSBOK 16 (1922) N:o 9.

PRACTICAL EXPERIENCE  
IN ELECTRICAL  
PROSPECTING

BY

HANS LUNDBERG

*Pris 2,00 kr.*

STOCKHOLM 1923

KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER

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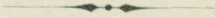
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The magnetic methods were adopted in Sweden long ago and have been developed to a high degree of *utility* in prospecting and the examination of strongly magnetic ores which have no outcrops. The absence of similar methods for non-magnetic ores has therefore been felt all the more keenly for a long time. In Sweden the first attempt was made in 1906, under the superintendence of Professors W. PETERSON and K. WALLIN, to make use in practical prospecting of the varying electrical conductivities of different metals in accordance with the method of DAFT and WILLIAMS. This first attempt was followed by extensive operations with a view to discovering a method, at once reliable and convenient, for the investigation of ore deposits by electricity. A brief account of a number of these operations has been given in the Year Book of the Geological Survey of Sweden for 1913. But it was not until 1918, when the mining engineers HANS LUNDBERG and HARRY NATHORST invented their apparatus, that a method of real practical importance was attained.

During the period subsequent to 1918 assiduous endeavours have been made to develop and improve the electrical methods still further, chiefly by the writer of the following paper (who is also one of the inventors of the 1918 method), in the service of Bergsbyrå, Ltd., and of the Geological Survey of Sweden, and also by others. The result of these endeavours is that there are now electrical methods which are just as important in prospecting for non-magnetic ores as the magnetic methods are for the strongly magnetic ores. These electrical methods have already led to remarkable discoveries which could not have been made without them. The present moment has therefore been considered opportune to publish an elementary description of the procedure adopted by Bergsbyrå, Ltd., and the Geological Survey of Sweden in their investigations, and also to illustrate by suitable examples the results attained. It is my hope that this account, written by one who has had a greater opportunity than any other person in Sweden of acquiring experience in this sphere, will lead to an enhanced interest in the employment of the electrical methods for prospecting purposes, and thereby lead to new valuable discoveries of non-magnetic ores.

Stockholm, December 1922.

*Axel Gavelin.*

In 1913 Mr. G. BERGSTRÖM made a report<sup>1</sup> on trials which had been made with electrical prospecting. This report drew up *for the first time* lines for a practical method of prospecting. Since then this method has been further developed and improved in Sweden, as well as in other countries.

The arrangement of *extended* electrodes,<sup>2</sup> which was invented in Sweden in 1918, has proved, however, to be of great importance for the success of the method. This method has been successfully applied ever since 1918 by Bergsbyrå, Ltd., of Stockholm, at about sixty different orefields in Sweden, Norway, Finland and Spain.

The discovery of the great deposits of copper and sulphur pyrites in the Skellefteå district must be considered to be the finest result attained so far with the improved method. Systematic electrical investigations, in conjunction with geological surveying in this field, have been carried on annually ever since the autumn of 1918, when the first deposit, Kristineberg, was discovered. Several deposits have been discovered during the course of these investigations.

As no practical results of electrical prospecting for totally masked ore-fields have been published, an account will be given in the following pages of the investigations made of two of the largest ore-fields of the Skellefteå district, *Kristineberg* and *Bjurfors* (Fig. 1).

*The Kristineberg ore-field* was discovered in the late autumn of 1918 while making a small, preliminary investigation across country covered with drift. The investigation was concluded in the summer of 1919.

*The Bjurfors ore-field* was struck in the summer of 1922 after searching large tracts of drift-covered country for several years.

### The principles of the method.<sup>3</sup>

By applying a potential difference between two points on the ground, an electrical field is generated in the earth. The nature of this field mainly depends on the electrical conductivity of the earth.

<sup>1</sup> Sveriges geologiska undersökning. Årsbok 1913. N:o 6. Sthlm 1914.

<sup>2</sup> System LUNDBERG & NATHORST.

<sup>3</sup> In regard to the purely theoretical treatment of these problems reference is invited to the articles by C. SCHLUMBERGER, C. BERGHOLM, H. LUNDBERG etc. See the Index of Literature.

A field produced in this manner is best investigated by studying the distribution of the potential. This can be done by direct observation of the potential at a number of accessible spots on or below the surface of the earth. It is simplest, however, to study *surfaces* of equal potentials. *Curves* of equal potentials can be traced on the ground to indicate exactly the outcrops of these equipotential surfaces. If these curves are transferred to a map a clear idea will be had of the appearance of the electrical field, or the distribution of the potential in the earth.

In homogeneous ground the distribution of the potential can be determined theoretically, and the appearance of the equipotential curves calculated. If, on the other hand, the ground consists of rocks or minerals with different conductivities, variations occur in the normal distribution of the potential, and perturbations will show themselves in the appearance of the equipotential curves on the surface. Thus good conductors seem to thrust the curves apart, while bad conductors seem to cause constriction. The illustration (Fig. 2) shows the appearance of the curves with a good conductor, *A*, and with a bad conductor, *B*.

†1-231056. S. G. U., Ser. C, n:r 319, Hans Lundberg.

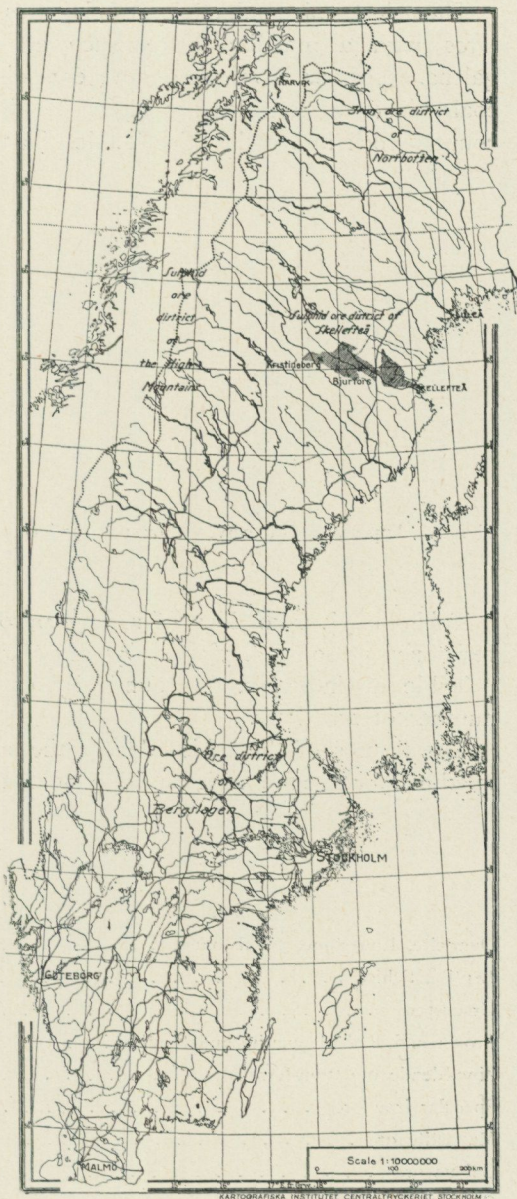


Fig. 1.

The electrical conductivity of the ores is therefore most important. Ores with a metallic lustre, such as chalcopyrite, sulphur pyrite, galena, specular iron, magnetite etc., also graphite and a number of coals, have a considerably higher conductivity than the surrounding country rock and soil. (See Tables I and II.)

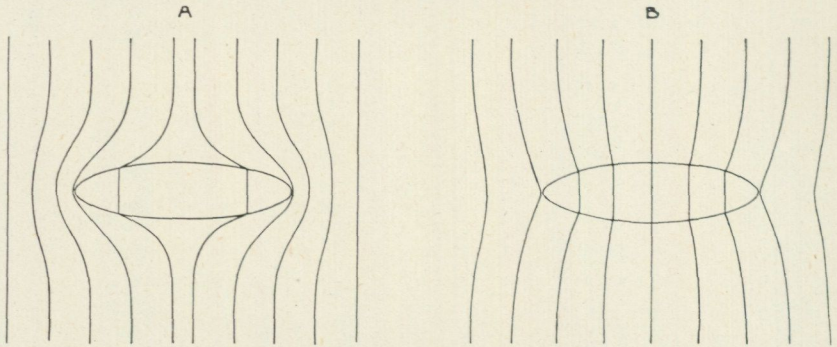


Fig. 2. Appearance of curves above: a good conductor (A) and a bad conductor (B).

Table I gives an idea of a few approximate values of the specific resistance of some *perfectly dry samples* of rocks and ores.

Table II indicates, in round figures, the specific resistance of a number of *minerals*.

The figures of the tables denote the specific resistance  $W$  expressed in ohms for a cube with an edge of one metre.

Table I.

<i>Rocks:</i>	<i>W ohm/m<sup>3</sup></i>
Quartzite, Limestone, Sandstone . . . . .	ca. 1,000,000,000
Leptite, Schists . . . . .	ca. 10,000,000
Greenstone . . . . .	ca. 1,000,000
Brown and Red Haematite and Spathic iron ore . . . . .	ca. 1,000,000
Zinc-blende ore (non-ferrous) . . . . .	ca. 1,000,000
Specular iron ore . . . . .	1—0.1
Magnetite ore . . . . .	1—0.01
Galena ore . . . . .	ca. 0.01
Chalcopyrite ore . . . . .	ca. 0.001
Sulphur pyrite . . . . .	ca. 0.001

**Table II.**

<i>Minerals:</i>	<i>W ohm/m<sup>3</sup></i>
Rock salt . . . . .	9.0.10 <sup>14</sup>
Calcite . . . . .	5.0.10 <sup>12</sup>
Quartz . . . . .	3.8.10 <sup>9</sup>
Mica . . . . .	1.5.10 <sup>8</sup>
Serpentine . . . . .	2.0 10 <sup>2</sup>
Siderite . . . . .	71.0
Marcasite . . . . .	0.1
Chalcopyrite . . . . .	0.01
Molybdenite . . . . .	0.008
Magnetite . . . . .	0.006
Specular Iron . . . . .	0.008—0.004
Graphite . . . . .	0.0003
Pyrite . . . . .	0.0002
Pyrrhotite . . . . .	0.0001
Galena . . . . .	0.00003

This enormous difference in the conductivity is, however, balanced to a certain extent by the percentage of moisture. The conductivity of rocks and soils depends, in fact, on their moisture. Table III<sup>1</sup> gives an example of how conductivity varies with the rise in the moisture. For ordinary ground  $W = 75-150$  ohm per  $m^3$ .

**Table III.**

(The specific resistance of water used  $W$  ca. 10 ohm/ $m^3$ .)

<i>Material.</i>	<i>Percentage of water</i>	<i>W ohm/m<sup>3</sup></i>
Yellow river sand . . . . .	0.86	830
» . . . . .	1.52	380
» . . . . .	2.37	230
» . . . . .	3.3	170
» . . . . .	5.8	120
» . . . . .	7.4	100
» . . . . .	9.5	95
Garden soil . . . . .	3.3	1,670
» . . . . .	4.4	910
» . . . . .	5.7	475
» . . . . .	8.2	205

<sup>1</sup> Ann. d. Physik. Volume 32, 1907. Pages 858 and 859.

<i>Material.</i>	<i>Percentage of water</i>	<i>W ohm/m<sup>3</sup></i>
Garden soil . . . . .	10.0	156
> . . . . .	13.5	84
> . . . . .	17.3	60
Clay . . . . .	4.4	1450
> . . . . .	6.8	345
> . . . . .	9.2	150
> . . . . .	13.4	73
> . . . . .	16.1	50
> . . . . .	28.0	16
> . . . . .	45.0	14.5
> . . . . .	58.6	14.1

Finally, the structure of rocks has also a certain influence on the distribution of the potential.

*By studying the distribution of the potential in the surface of the ground, a conclusion can be formed as to the nature of the sub-soil.*

Irregularities in the ground which disturb the potential distribution, also affect to a certain extent the magnetic field surrounding the electrical field. By observing at various points the size and strike of the said field the approximate position of the disturbances can be fixed.<sup>2</sup>

At Bjurfors the writer has had an opportunity of comparing this method with potential investigations.

### The arrangement of the electrodes.

In conductors of great size, such as the earth, the total electrical resistance of the current circuit depends mainly on the immediate surroundings of the electrodes. It is therefore necessary to provide a large favourable contact area between the ground and the electrodes. The electrodes are therefore often given a certain horizontal extension, which has also other advantages of great practical importance.

<sup>2</sup> This »intensity method», introduced by K. SCHILOWSKY, has been further evolved by H. R. CONKLIN in U. S. A., by E. RAVEN and N. GELLA in Germany, and by M. VOS. K. SUNDBERG and the writer in Sweden. See the Index of Literature.

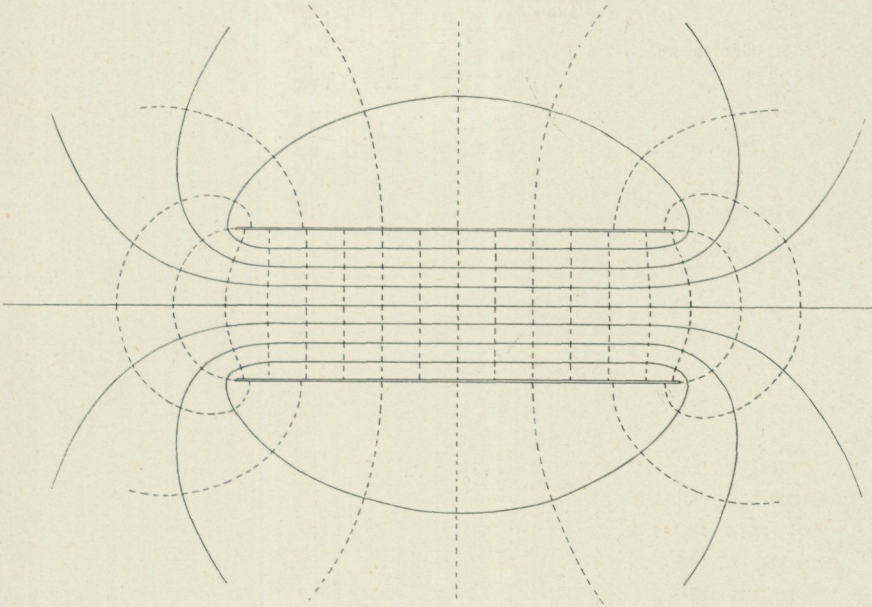


Fig. 3. Appearance of superficial field by linear electrode system. Equipotential curves, as well as current curves (dotted).

As has been already mentioned, the electric field can be calculated in the case of homogeneous ground. The appearance of the field then depends on the arrangement and form of the electrodes. For example, if the length of the electrodes is made great in proportion to their distance from one another, this proves of great advantage. The figures (Nos. 3 and 4) show the arrangement which is now used with very extensive parallel electrodes, the »linear arrangement» (Fig. 3), as compared with the »polar arrangement» previously used (Fig. 4).

By means of the linear arrangement a simple, homogeneous field is obtained between the electrodes. The equipotential curves thus become straight lines.

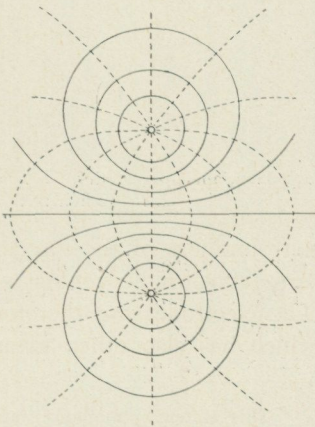


Fig. 4. Appearance of superficial field by polar electrode system. Equipotential curves as well as current curves (dotted).

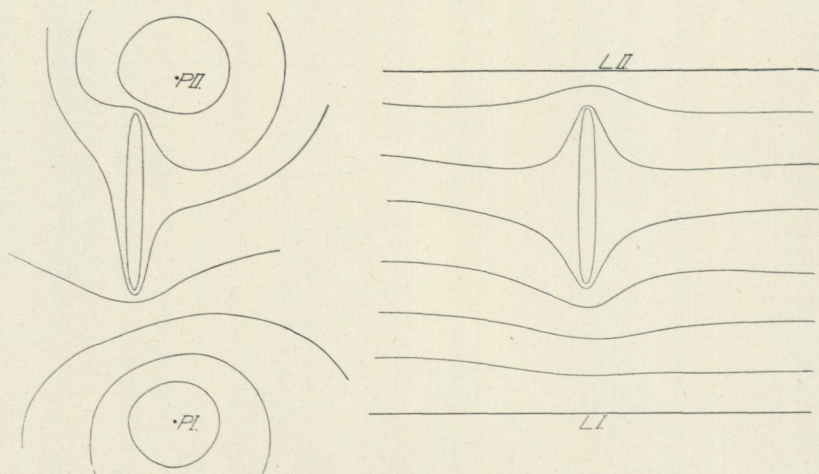


Fig. 5 A.

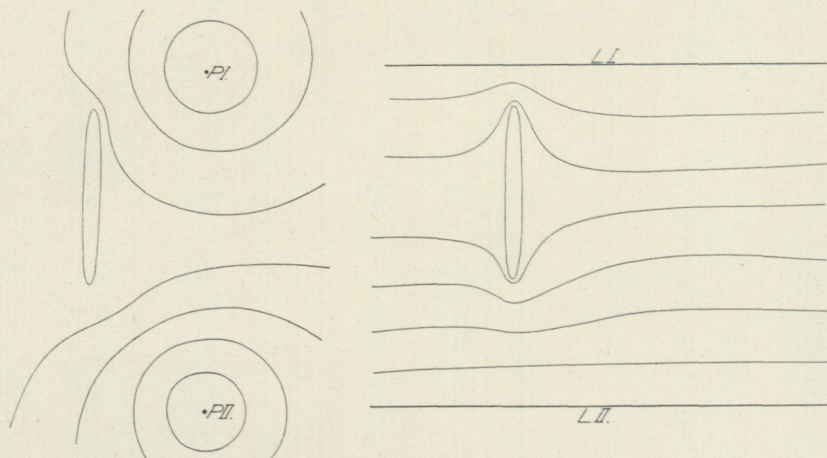


Fig. 5 B. Same ore-bodies, deformation of polar, as well as linear fields: Simple ore in centre of field: A. Simple ore in outer part of field: B.

The interpretation of the disturbances which an ore causes in the field is also simplified by the linear arrangement (Fig. 5 and 6). It also gives a greater chance of systematically investigating an area and of expediting investigations considerably.

#### Apparatus.

As a source of current a generator is used which provides a single-phase alternating current with a constant frequency. The electrodes

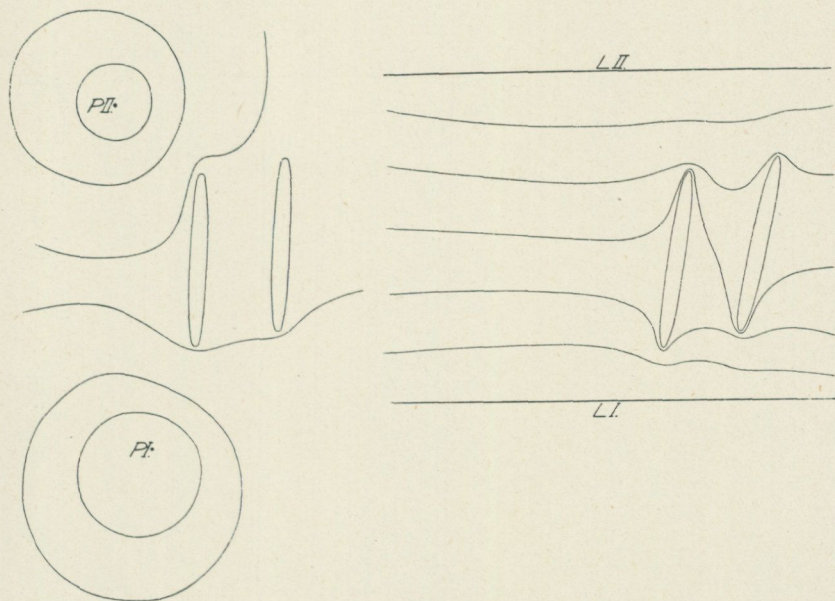


Fig. 6. Same ore-bodies: deformation of polar, as well as linear, fields: Two ores in outer part of field.

consist in most cases of metal wires which are arranged to come into contact with the ground for purposes of conduction. The electrodes can be made from 100 to 1,000 metres long or more. The distance between them can be varied according to the depth to which it is desired to investigate. The greater the distance between the electrodes the greater is the depth attainable.

The poles of the generator are connected to the electrodes by means of insulated wires.

In tracing the equipotential curves, use is made of a movable »searching-circuit» consisting of two metal rods, »searching rods», fitted with insulated handles and connected to an insulated line attached to a telephone. (Fig. 7 A.)

In direct observation of the potential are also used a movable circuit, a »resistance-bridge» consisting of three rods connected to each other and to a telephone across a variable ohmic resistance. (Fig. 7 B.)

When using the intensity method the magnetic field is studied by recording the induced voltage in a movable coil. In direct observation a sensitive galvanometer is used in series with a rectifier (crystal-detector or audion). (Fig. 7 C.)

If it is desired to find out so-called isointensity curves, two coils connected in series to a telephone can be used. (Fig. 7 D.)

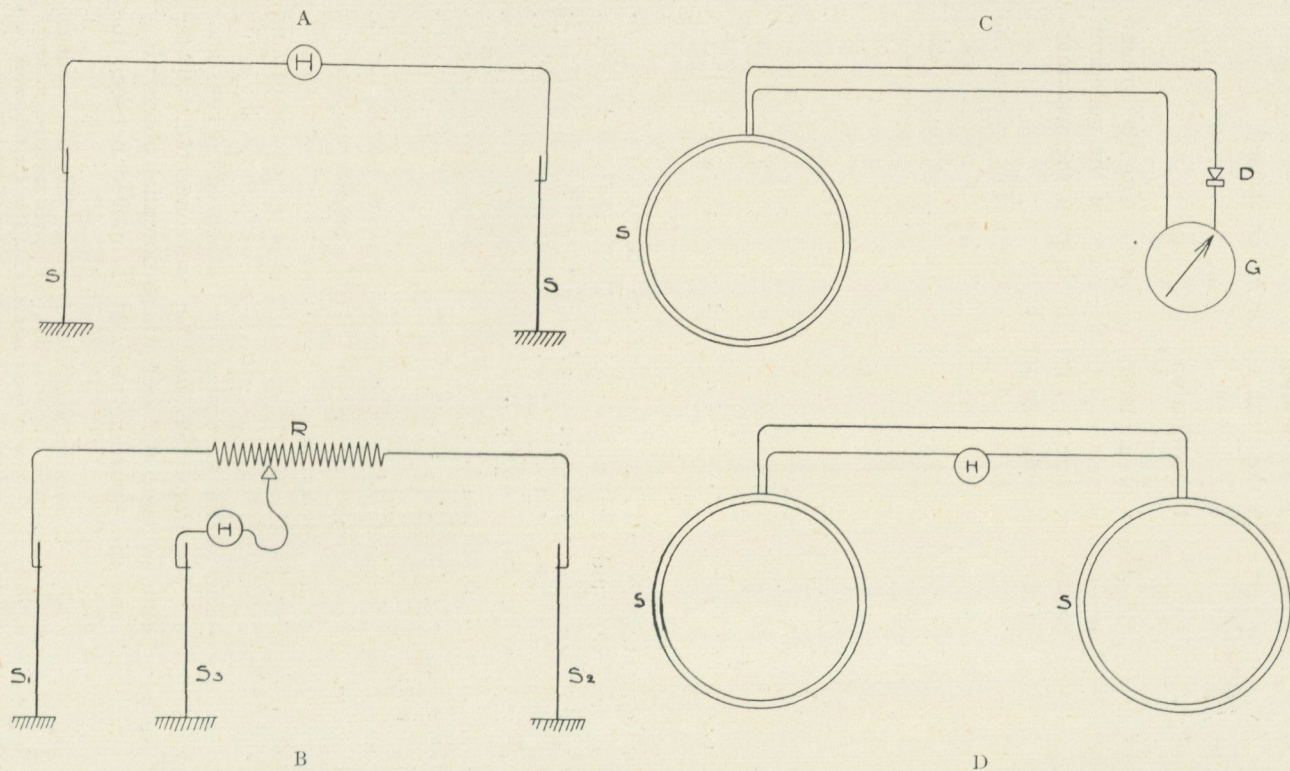


Fig. 7. Apparatus for investigating electrical and magnetic fields: A: Searching circuit for tracing equipotential curves. (S = »Searching rods»; H = telephone). B: Resistance bridge for measuring potential (R = resistance). C: Current coil used for measuring intensity (G = galvanometer; D = rectifier; S = current coil.) D: Current coils for tracing isointensity curves.

In cases where the sensitiveness of the telephone is not sufficient, an amplifier can be utilized to strengthen it.<sup>1</sup>

For mapping the curves in the field a tachymeter is used.

### Investigation.

When the electrodes have been placed in contact with the ground in a suitable manner and connected with the poles of the generator, the equipotential curves are traced with the help of the searching-circuit (Fig. 7 A) in the following manner.

One of the searching rods is placed at a point *a* (Fig. 8) and the other alternately at, say, points *b*, *c*, and *d*. Let us now suppose that a sound corresponding to the frequency of the generator is heard in the telephone at *b* and *d*, but that nothing at all is heard at *c*;

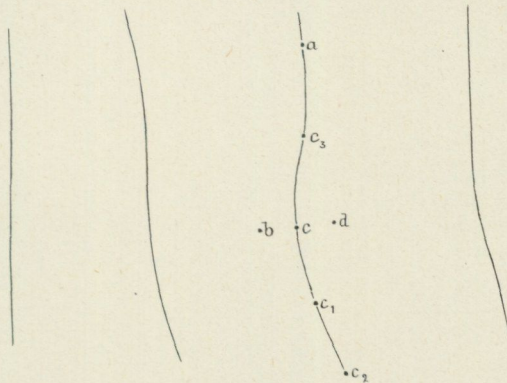


Fig. 8. Tracing of equipotential curves.

*a* and *c* thus are at the same potential. Several other points, *c1*, *c2*, *c3*, at the same potential as *a*, are traced in a similar manner. If these points are joined up, an equipotential curve is obtained. In this way other curves are traced and all are marked out on the ground and mapped.

Direct potential observations are made with the help of the resistance bridge (Fig. 7 B). The rods, *S1* and *S2*, are connected with the ground at two points outside the area where potential observations are to be made, and the »sounding-rod», *S3*, is moved between the

<sup>1</sup> The first attempts to use an amplifier were made in 1919. They were continued in 1920 and 1921, when a transportable type was tried, but proved defective in several respects. It was only in 1922, when a really good amplifier suitable for field-work was obtained, that it became possible to derive the full benefit of this instrument.

†2—231056. S. G. U. Ser. C, n:r 319, Hans Lundberg.

observation points. By noticing how the sound vanishes in the telephone, points at the same potential as that touched by the »sounding-rod»  $S_3$  are sought out on the variable resistance (R). The potential is then read off on the resistance by a graduated rule.

*Reconnaissance.* In order to obtain a general idea as to the electrical conductivity of a field a preliminary investigation is carried out by tracing equipotential curves at fairly large, regular distances from one another. The illustration (Fig. 9 A) shows an area where the curves clearly indicate the position of a zone with a considerably higher conductivity than its surroundings.

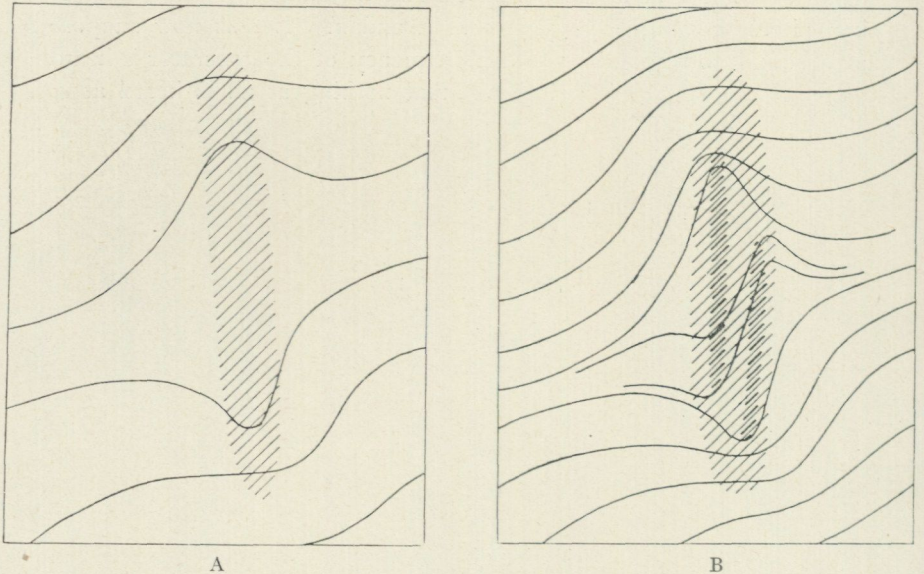


Fig. 9. Equipotential curves of. A: reconnoitred area; B: area examined in detail.

*Detailed Investigation.* The area which has been indicated and found in the reconnaissance to have a higher conductivity is afterwards submitted to a closer scrutiny. Several new curves are traced in suspected places between those already drawn, so that as clear and detailed a knowledge as possible may be obtained of the position and form of the conductor. The illustration (Fig. 9 B) shows the same area after a detailed investigation.

*Measuring the Potential.* The variation of the potential in the most disturbed areas is afterwards more closely examined by detailed potential observations. By this process a further knowledge can be obtained in regard to the boundaries, dip and strike of the conductor.



Fig. 10. Tracing of equipotential curves (In summer).

### Interpretation.

When the investigation has been finished, the equipotential curves and potential observations are both transferred to a map, which is used in interpreting the result.

It is often found to be very difficult, even in simple cases, to make theoretical calculations, owing to anomalies in the distribution of the potential. It is therefore necessary to restrict oneself to indicating approximately the extent and strength of the disturbances.

The fall of potential ( $E$ ) is everywhere dependent on the density of the current ( $I$ ) and the specific resistance ( $R$ ) of the ground, in accordance with Ohm's Law:

$$E = I R$$

Three distinct areas which bear reference to the fall of potential can be found in an electric field around the ore (Fig. 12): (a) neutral ground; (b) the ore itself, and (c) the disturbed areas around the ore.

In *neutral ground* (a) the specific resistance is very great, and although the density of the current is low (except in areas quite close to the electrodes), the fall of potential is fairly large. That on neutral ground is taken as the standard.



Fig. 11. Tracing of equipotential curves (In winter).

In *the ore* (b) the current-density is very great, but on the other hand the specific resistance is so slight that the fall of potential becomes quite *insignificant* compared with the standard.

*The disturbed area* (c) which, to the great advantage of the method of investigation, is several times as large as the ore itself, can however be divided into *an area with a diminished density*,  $c_1$ , and *an area with a concentrated density*,  $c_2$ . The specific resistance in *area*  $c_1$  is the same as on neutral ground; while the current density is lower, the fall of potential becomes *weaker* than the standard, though never so weak as in the ore. In *area*  $c_2$  there is a greater density of current than on neutral ground, and the specific resistance is the same. Thus

the fall of potential in this case becomes *greater* than the standard.

During the earlier stage of the method the result was interpreted entirely on an empiric basis, with the help of experience from previous investigations of familiar ground, and from experiments on a small scale with artificial ores.

The disturbance indications, which were then marked on a map, were divided into two classes, »strong» and »weak», according to the deformation of the potential field.

During late years objective methods of interpretation have been elaborated for indicating the *approximate extent* of the various conductors independent of their position in the electrical field.

A good interpretation of the map is obtained in the following manner: — The distance between neighbouring equipotential curves is measured and the variation of the distance is expressed as a function of the distance between the same curves on neutral ground. The

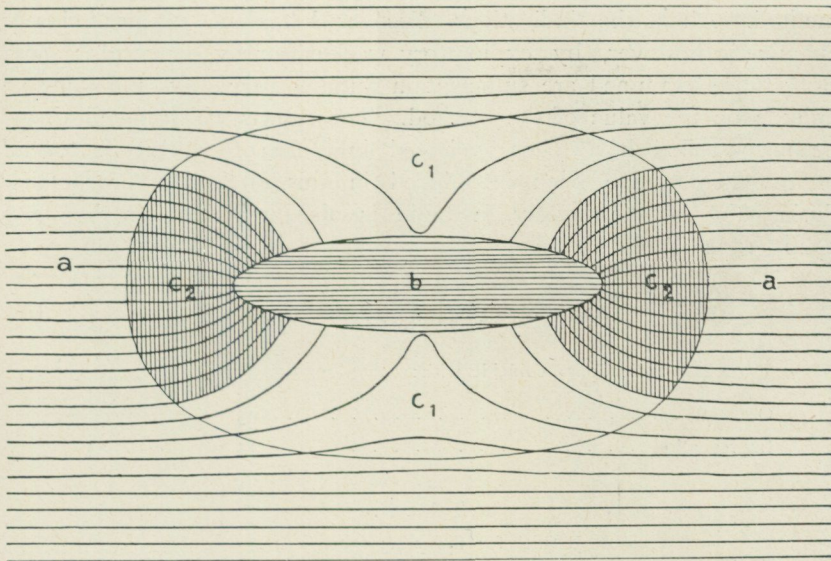


Fig. 12. Current curves: a, Neutral ground; b, The ore;  $c_1$ , Disturbed areas, with diminished density;  $c_2$ , Disturbed areas, with concentrated density.

values of anomalies in the normal distribution of the potential are hereby obtained. Isoanomaly curves are obtained if points of equal values are connected, and the map then receives a characteristic appearance.

A distinct minimum is obtained above the conductor. The limits of this minimum coincide, within a few metres, with those of the conductor. Just beyond the conductor, however, and especially towards the ends, more or less distinct maxima are obtained. The limits of the indication then become more strongly marked. The maxima correspond to the deformation of the equipotential curves far beyond the ends of the ore.

*Boundaries of ores* can moreover be fixed approximately by drawing profiles of the potential. Those profiles can be observed either directly on the ground, or also be constructed with the guidance of the map.

#### *The relation between »indications» and ore.*

The most important factor in judging the value of the electrical prospecting method is the agreement between the »indications» and the existing ores.

Practical experience in Sweden is now comparatively wide, as about sixty deposits of ore have hitherto been investigated with this electrical

method. All of the »indications» discovered have not yet been closely examined, however, by exploratory working or by diamond-drilling. Still, those examined are sufficient in number to justify expressing an opinion on the value of the method. The results which have hitherto been controlled have been collected in Table IV. But as several improvements have been introduced in this method of prospecting during the last few years, a table is also included for the years 1920—1922 (Table V).

**Table IV.**

Results for the years 1918—1922.

»Indications» coincide with:	Strength of »indications»	
	Strong	weak
Ore . . . . .	25	7
Impregnation . . . . .	14	24

**Table V.**

Results for the years 1920—1922.

»Indications» coincide with:	Strength of »indications»	
	Strong	weak
Ore . . . . .	13	0
Impregnation . . . . .	7	7

It is quite clear from the tables that strong »indications» correspond in the majority of cases with ore, and weak »indications» with impregnations. A number of strong »indications» however do correspond with impregnations, which are too poor to classify as ore. The greatest difficulties in electrical prospecting are, however, caused by impregnations of graphite, pyrites, magnetite or specular iron, which stand midway between a quality worth mining and one of no interest whatever on account of their low percentage of metal. These impregnations often have very good conductivity. No *general method* of distinguishing between »indications» caused by impregnations and those caused by ores has yet been elaborated. As a rule, however, most »indications» of impregnations, especially those caused by sedimentary graphite schists, can be distinguished from ore »indications».

Potential investigations, in contrast to other methods of prospecting, give a good idea of the shape of the conductor. Therefore, if the geology of the ore-field is known, the form and extent of the »indication» usually will decide whether the latter corresponds to an ore-body, an impregnation or a graphite schist. The ore-bodies in a field usually have a certain characteristic form. Impregnations of pyrites etc. are usually considerably larger than the ore-bodies, and graphite schist

often differs from ores by its regularity and extensiveness in the field. An electrical investigation should therefore always be conducted in conjunction with a geological survey.

Cases often occur when the ore is surrounded by impregnations. If the divergence in the percentage of metal is not too inconsiderable, the ore-body has the appearance of a stronger indication within a weaker one. If several ores lie close to each other they can usually be distinguished in the indication with the help of potential profiles (see below Figs. 15 and 16). If the distance between the different parallels amounts to one metre, or more, these can be distinguished already by the detailed investigation.

Contrary to what is often stated, the degree of moisture in the soil has little disturbing effect, and »indications» are never caused by water.

Metal objects, such as pipes, which happen to be in the ground, naturally cause perturbations in the electrical field.

Electric power cables above ground, on the other hand, do not interfere with the investigation, as their frequency is totally different.

The depth of the covering soil is of great importance. A greater depth naturally diminishes the strength of the »indication». Thus it is often possible, by the strength of an »indication», to determine the depth of the cover. The decrease is so slight, however, that with the average depth of soil an ore in the field never fails to cause »indications».

In the cases hitherto investigated the soil has been as deep as 40 metres without any considerable decrease being noticed in the »indication». Theoretically, even a small ore-body should be observed as deep as 100 metres with the electrodes 1,000 metres apart.

### **The Kristineberg Ore-field.**

#### *History.*

The occurrence of ore-boulders at Rävliiden, (called »Repeljavelk» by the Lapps) west of Kristineberg (Fig. 13) in the parish of Lycksele, was known to the inhabitants long before the new settlement was established at Kristineberg in the 'Eighties. No investigation was made, however, as only boulders of sulphur pyrite had been noticed.

During the scarcity of sulphur pyrite in 1917, Consul Häggbom, Skellefteå, remembered these boulders, of which he had heard when visiting Malå in his youth as official agricultural adviser. On his initiative mining claims were therefore taken in the autumn of 1917 round about the boulders.

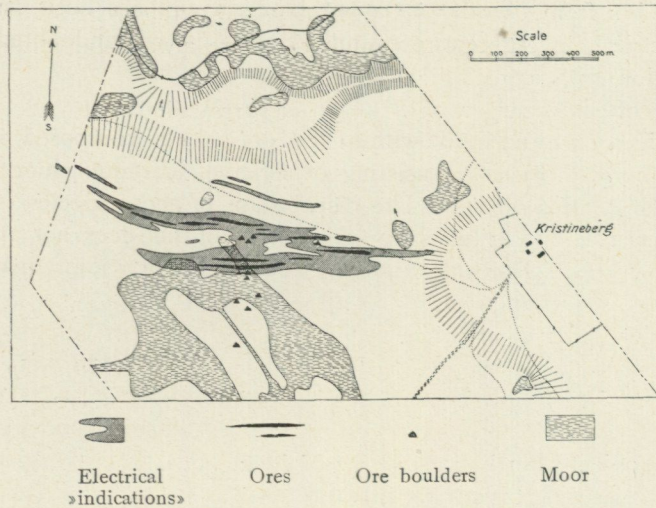


Fig. 13. Situation map of Kristineberg.

Mining experts who were consulted considered, however, that the mother lode ought to be sought in the immediate vicinity of the boulders. As there were no outcrops near, it was supposed that the strike was from north to south, coinciding with the rows of boulders which had been discovered. Excavations were made in accordance with this supposition, far south of the ores as well as in their immediate neighbourhood (the exploratory workings marked in black on the electrical map (Pl. I), without ore being found.

In October 1918 a small preliminary investigation was made. It immediately became evident that the general strike was from east to west, and that the ground contained several good conductors. One spot was pointed out as being favourable for making an opening. A fine copper ore was discovered there later on in the autumn.

In the summer of 1919 further electrical examinations were made across a large area round about the boulders. Strong »indications» were obtained and these were followed up eastwards as well as westwards.

The drift was now immediately removed at several of the strongly indicated spots, and ore was laid bare in six different places. The depth of the covering drift varied between one and six metres.

Thanks to the electrical investigation it proved possible to discover and localise in less than a month an ore-field, the ore area of which was estimated by the writer, after the investigation, at about 7,000 sq.metres.

Since then the work of laying bare the ore has been carried on every year, and the entire estimated ore-area will undoubtedly soon be shown.

#### *Geology.*

The rock around and within the ore-field is composed solely of metamorphosed species consisting of sericite, quartzite, chlorite-quartzite and chlorite schists. The distribution of these species (see geological map) (Pl. I) is very irregular, but this does not appear to affect the ores. The entire country-rock is slightly impregnated with pyrite.

The ores form eight regular, elongated, steeply dipping lenses, I—VIII, of coarse-grained pyrite without pyrrhotite and with more or less chalcopyrite. The content of sulphur is 30—36% and, on an average, 32.5%. Two ore-bodies, II and VI, contain a good percentage of copper, 1—5% Cu; in certain parts more. The average content of these ore-bodies amounts at least to 2.5% Cu.

The area of the visible ore is about 5,000 sq. metres. The probable total area is about 6,500 sq. metres. The breadth varies between 2 and 12 metres, but in most cases it is about 6 and 7 metres. The percentage of ore in the lenses is rather high, 70—80%.

#### *The electrical survey.*

The investigation has been carried out with the electrodes 160—200 metres apart. Only 5—8 curves have been traced in the electrical field between the electrodes. No measurements have been taken for purposes of control, so that the entire survey must be considered to be a reconnaissance.

The investigation followed the »indications» eastwards and westwards out on to neutral territory. The area north and south of the »indications» was also investigated.

The result of the investigation is shown on the electrical map (Pl. I), equipotential curves, as well as the interpretation of the result in strong and weak »indications», being also denoted.

If this map be compared with the geological map, it will be seen to agree very well. A number of »indications» which have no corresponding ores on the geological map are in reality caused by strong impregnations (the ends of »indication» I, the »indications» east of III and IV, the weak »indications» in the middle of the field and the great »indication» farthest to the north), and also by long veins of sulphur pyrites which are too narrow to indicate as »ore» (the small »indications» south of VI and the narrow »indication» south of VIII). The connection between the ores and the electrical »indications» is therefore better than is shown on the geological map. Every »indica-

tion<sup>s</sup> which has been closely examined has been readily assignable to an ore, to a vein or to an impregnation.

As previously mentioned, it is in many instances possible to derive from an electrical survey conclusions as to the formation of the ores, e. g. if they are narrow or broad, if they become pointed gradually or suddenly. A good example of this is to be found in ores III and IV, which are broadest at their eastern end, and gradually become narrow towards the west.

### The Bjurfors Ore-field.

#### *History.*

The first ore-boulders on Bjurberget (Pl. II) were discovered in 1903 by the owner of Bjurfors' farm. Some people from Skellefteå, who were interested in mining, took the first mining claims and carried out extensive digging and blasting operations quite near the boulders. Several new boulders were then found, among them one rich in copper. This stimulated the people to new attempts, but the work was stopped in 1904 as no ore had been found.

Mining claims were again taken around the boulders in 1907. Mining experts who visited the spot considered, however, that the possibilities of finding the mother lode were very slight.

In 1917 claims were taken round the boulders for the third time. On this occasion those concerned were advised to try the electrical prospecting method. In the autumn of 1918 a small reconnaissance was made quite near the boulders but without any positive result.

In the summer of 1920, 40 new claims were taken from the boulders towards the north-west into the granite of Bjurberget. A minor reconnaissance in a part of this area also gave a negative result.

In August the same year geological surveys of the district for the *Geological Survey of Sweden* were began. Immediately, boulders were discovered to the north of the river Malån. It turned out, however, that the glacial striae on Bjurberget ran N 32° W, but that the row of boulders extended to the N 55° W.

This last direction agrees on the whole with that of the drumlins. Therefore it was supposed that the blocks came from the NW with a tendency towards WNW.

North of Malån, however, there is a great sandy plain, Malånsheden, which entirely covers the moraine. This prevented further studies of the boulders. In the direction of the glacial transport, the moraine does not reappear until at Norrliden, at a distance of 2<sup>1</sup>/<sub>2</sub> kilometres. No further ore-boulders were found. The mother lode

was therefore supposed to exist between the rapids, Bjurbergforsen, in Malån, and Norrliden.

This suspected area was in reality the largest which had hitherto been subjected to a survey by the electric method. Preliminaries were commenced in October 1920.

In the meantime a geological survey was made of the immediate neighbourhood. At Norrliden, in the supposed direction of the glacial-transport, an outcrop of sericite-quartzite was found with strong impregnations of pyrites, and round about were outcrops of metamorphosed greenstone. Those outcrops resembled certain impregnated boulders at Bjurberget. As the reconnaissance on the sand plain of Malånsheden had, however, given a negative result right up to within one kilometre northwards from the boulders, investigations were now transferred to Norrliden around the pyritic quartzite outcrops. A comparatively strong »indication» was obtained, which was followed eastwards, as well as westwards. Towards the west the »indication» became dissolved in a zone of black, pyritic schist. As the covering of drift was slight, extensive exposures of the »indication» were made. It was at first supposed that this »indication» was the mother lode of the Bjurfors boulders, but the exposures showed that this was not the case. The »indication» had been caused by a rather poor breccia of pyritic impregnation.

In the following year, 1921, the electrical survey was continued southwards to Jonkmyrberget. The result here was also negative. South-west of the lake Örträsktjärn an »indication» had been found extending eastwards. In comparison with the »indication» at Norrliden, it was, however, considered weak and therefore was not examined further.

Thus in the autumn of 1921 no indication was discovered which was considered to contain ore. The possibility remained that the ore might be in the very rapids of Malån, Bjurbergforsen, immediately beside the boulders. It was therefore decided to investigate the rapids. This was done in December 1921, when they were frozen, and a broad, weak zone was discovered immediately to the north of the river bank.

In the spring of 1922 the »indication» at Bjurbergforsen was again more closely examined. Its weak character, which moreover was hardly an »ore-indication», was hereby confirmed. But as the »indication» was the first to the north of the boulders, and it seemed necessary to determine the nature of the unknown country-rock beneath this »indication», a diamond bore-hole was made at the »indication» where it was intersected by the direction of the glacial transport from the finest and northernmost boulder. The boring was stopped at 101

metres, when the »indication-zone» had been traversed. No ore was found; only small patches of chalcopyrite here and there.

The electrical reconnaissance was in the meantime continued westwards across Svanvaken, where a very large boulder had been discovered the previous year, containing compact pyrrhotite, with zincblende and sulphur pyrite. A large, though weak, »indication» was obtained near this block. South-east thereof a small, but considerably stronger, »indication» was recorded at Bjurbäcken.

The »indications» ceased, however, farther west and the survey was transferred eastwards to Bjurliden.

In the summer of 1921 a peasant had struck here a huge boulder of ore which contained zincblende and sulphur pyrite. After further geological investigations there was found a similar, though poorer, boulder,  $1\frac{1}{2}$  kilometres north-west of this boulder and about half a kilometre south of Malån. The search for boulders was renewed the following summer and a large number, several of which were very big, was found right on towards Malånsheden. A reconnaissance with a magnetometer gave a negative result.

The electrical survey was therefore transferred to Bjurliden from Svanvaken. Strong »indications» were immediately observed. These were divided between two zones, one of which was at Malån, the »Rutsele zone», and the other several hundred metres farther south, the »Bjurlid zone». Both of these zones were intersected however by the glacial transport line of the Bjurliden boulders. The mother lode was thus to be sought at one of these points of intersection.

As the »Bjurliden indication» was supposed to have the slightest covering of soil, a test shaft was sunk there. At the »Rutsele indication», where the covering was thicker and the surface of the rock situated far beneath the surface of the waters of Malån, the »indication» was inspected by diamond-boring.

The shaft which was sunk into one of the edges of the »indication» reached rock at a depth of 9 metres. After a further descent of 1 metre ore was struck.

In sinking the shaft, however, boulders were found in the moraine, which, like a number of those on Bjurliden, were of a different type to the ore discovered in the shaft. A shaft was therefore driven into the opposite edge of the »indication» in order to determine whether there were boulders on the north side. The moraine was reached after 4 metres of sand. Here were found several boulders with zincblende etc. similar to those on Bjurliden. The zinciferous Bjurliden boulders had therefore probably come from the »Rutsele zone».

The boring at the east end of the »Rutsele zone» after 19 metres

of sand and moraine, chiefly gave grey leptite, more or less of a flinty nature with small bands of amphibolite. Straight under the »indication» the leptite was very schistose for 6 metres in breadth and impregnated by pyrites and pyrrhotites. Certain streaks also contained graphite.

While the »Rutsele» and »Bjurlid zones» were being bored and excavated, the electrical examination had followed up both the »indication» zones westwards for about 2 kilometres. The rock here was covered with deep sand, often 35 metres, without any appreciable weakening of the »indications». In a deep ravine, called Örräskgraven, formed by a catastrophal drainage of this lake in the 'Eighties, a boulder of zinc-blende, mispickel, boulangerite and pyrite, and some poor boulders of pyrite and pyrrhotite were found at a spot where the moraine had become exposed.<sup>1</sup>

Beside the boulder, and on the north side of the »Rutsele zone», a single small »indication» was recorded which might correspond to the mother lode of these boulders. The Malån cuts down through the sand into the moraine, but no ore-boulders have been found there, only numerous boulders of schistose hälleflinta impregnated with pyrite. The moraine is everywhere else covered with deep sand, so that it was impossible to study the boulders at the other »indications».

The »indications» ceased in the »Rutsele», as well as in the »Bjurlid zone» about 2½ kilometres from Rutselet.

About one kilometre farther west three strong »indications» were discovered far out on Malånäsheden. The electrical examination, which had now passed north of the Bjurfors boulders, here just touched the »indication» to the south of Örräsktjärn, which was previously suspected. The most easterly »indication» was situated in the direction of the glacial-transport of two boulders of poor ore, found in a ditch and a well on the Crown croft of Rasbo, where the moraine was reached by digging. The western »indication», on the other hand, lay N 40° W of the Bjurfors boulders, about 2 kilometres distant. The row of boulders from Bjurbergsforsen up towards Bjurfors farm has, however, a distinct direction N 55° W, so that the glacial transport had probably been diverted by the granite hill of Bjurberget. Out on the level plain, on the other hand, the glacial-transport had been normal.

A diamond bore-hole was now bored in the eastern »indication» and ore was found immediately below nine metres of earth. First of all poor sulphur pyrite was found, then rich copper pyrite which was

<sup>1</sup> The mispickel contained 195 gr. Ag. and 3.5 gr. Au. per ton; the zinc-blende and boulangerite 366 gr Ag. and 3 gr. Au.

bored exactly 14.6 metres, including two minor streaks of country rock.

Nineteen years after the discovery of the first boulders and after three years of systematic investigations, the ore in the Bjurfors field thus was struck, thanks to electrical prospecting in the middle of a sandy plain beneath about 10 metres of drift, and 2 kilometres from the nearest ore-boulder.

### *Geology.*

As the rock surrounding the Bjurfors ores is covered with deep sand and moraine a detailed geological map thereof cannot be drawn. Certain conclusions can, however, be drawn from the numerous outcrops in the east and west of the field. Those show leptite with layers of amphibolite. The metamorphism does not, as in the Kristineberg environs, extend far from the ore bodies, so that the metamorphism was of no assistance in searching for the ore.

### *The Electrical Survey.*

*The reconnaissance.* Pl. III. During the first years the investigations were carried out with electrical fields, »squares» of small dimensions, 1—8 hectares (2.5—19.8 acres). A number of these »squares» have been inserted in the map (Pl. III). The irregular course of the curves near the electrodes as well as on neutral ground immediately becomes evident on comparing them with the curves in the large »squares», which have been examined later. The »indication» at Norrliden, examined with small »squares» is, however, very distinct. 5—10 curves have been traced in every »square». 4—5 hectares (about 10—12 acres) were surveyed on an average daily. The staff consisted of *one* observer and *one* surveying assistant. No amplifier was used during the investigation so that the latter was often very arduous and time-wasting when tracing curves on very dry or frozen ground.

In the survey of 1922 considerably larger »squares» were used, with 80—120 hectares (about 200—300 acres) between the electrodes. Reconnaissance curves were traced 100—150 metres apart, as compared with the previous 20—30 metres in the small »squares». It was found that even with these great distances between the curves the weakest »indications» could be recorded. The reason for this has already been pointed out, viz. that the field is affected far beyond the conducting body.

30—100 hectares (75—247 acres) a day have been reconnoitred with

a staff of 2 observers and 2 surveying assistants; in tracing the equipotential curves about 1,000 points are obtained by each observer a day; No great difficulties were experienced in tracing curves even on very dry ground when an amplifier was used.

*The detailed investigation.* As the limits of the ore zones were often definitely determined during the reconnaissance, it was possible to restrict detailed investigations to comparatively small areas; more than 30 % of the »square» has seldom been subjected to a detailed scrutiny.

Curves were then traced within the »indication» zones until a sufficient knowledge of the »indication» was obtained (Pl. III). Potential and intensity observations were also made at the Bjurfors »indications» *All electrical investigations were concluded at every place before the work of exploration and boring was commenced.*

The »indications» which were exposed, and the results of which therefore can be compared with the real facts, are described below: —

The *eastern Bjurfors* »indication» is the one which is best known so far in the Bjurfors field. It has been examined by means of four diamond-bored holes Bf I—Bf IV. The covering of drift is 7—10 (Pl. III and IV).

The ore is uniformly lenticular, about 200 metres long and, on an average, 10 metres broad, i. e. an area about 2,000 sq. metres. The ore has a very steep dip towards the south. The foot-wall consists of a broad band of more or less metamorphosed amphibolite. The latter contains, apart from rich impregnations, a second-rate copper ore several metres broad. It therefore ought to be a fairly good electrical conductor. The impregnation as well as the second rate copper ore (c:a 20 % S and 1.3 % Cu.) are probably broadest and richest between the bore-holes Bf II and Bf III.

The hanging-wall, on the other hand, consists of leptite which at the contact becomes metamorphosed into sericite-quartzite with impregnations of pyrite. The impregnation ceases altogether, however, a few metres from the ore.

In the reconnaissance this »indication» was at once announced very distinctly by the strong deflection of the curves towards the western electrode and by an increasing deformation of the curves as close as 200 metres outside the »indication» proper. The length of the perturbation area was almost 500 metres.

A detailed inspection immediately proved that there is a very strong »indication», which has a very sharp boundary towards the south; towards the north, on the other hand, the intensity diminishes at a considerably lower rate.

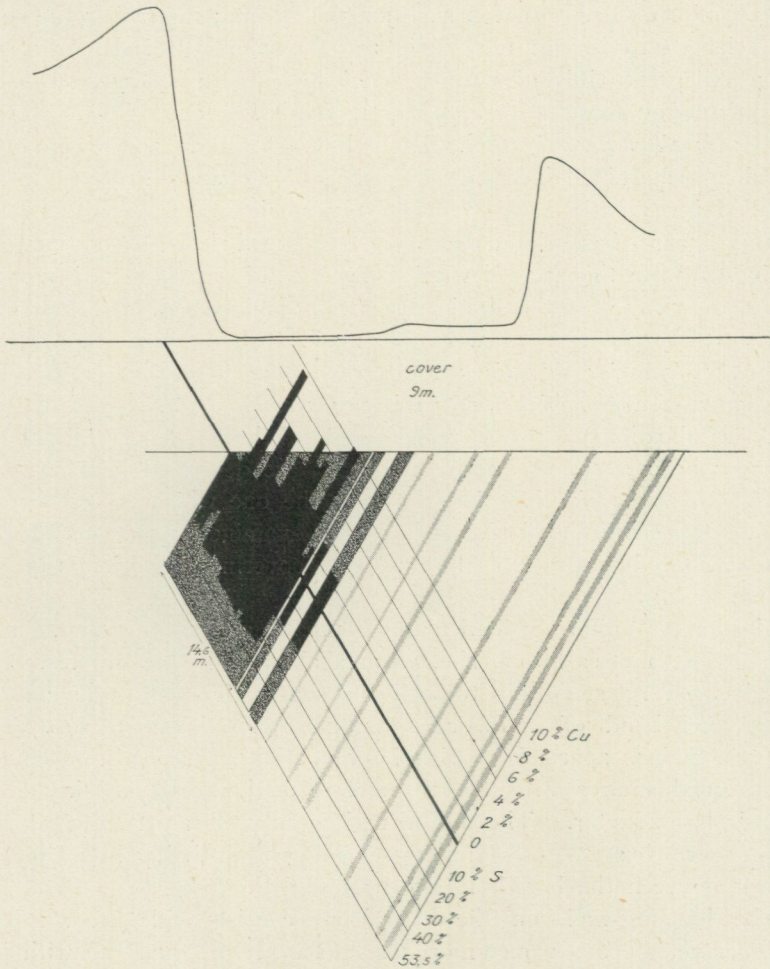


Fig. 14. Potential profile and bore-hole section Bf II.

The nature of the »indication» can best be seen from the »isoanomaly curves» (Pl. IV). As previously mentioned, these »curves» give the approximate form of a zone. A comparison between the idea of the ore zone thus obtained and that actually established by drilling will show that they agree substantially.

The narrowing of the »indication» towards the east, as well as towards the west, is confirmed by the drill holes Bf I and Bf IV. The broad parts in the centre of the »indication» at bore holes Bf II and Bf III also correspond with the great width of the ore zone.

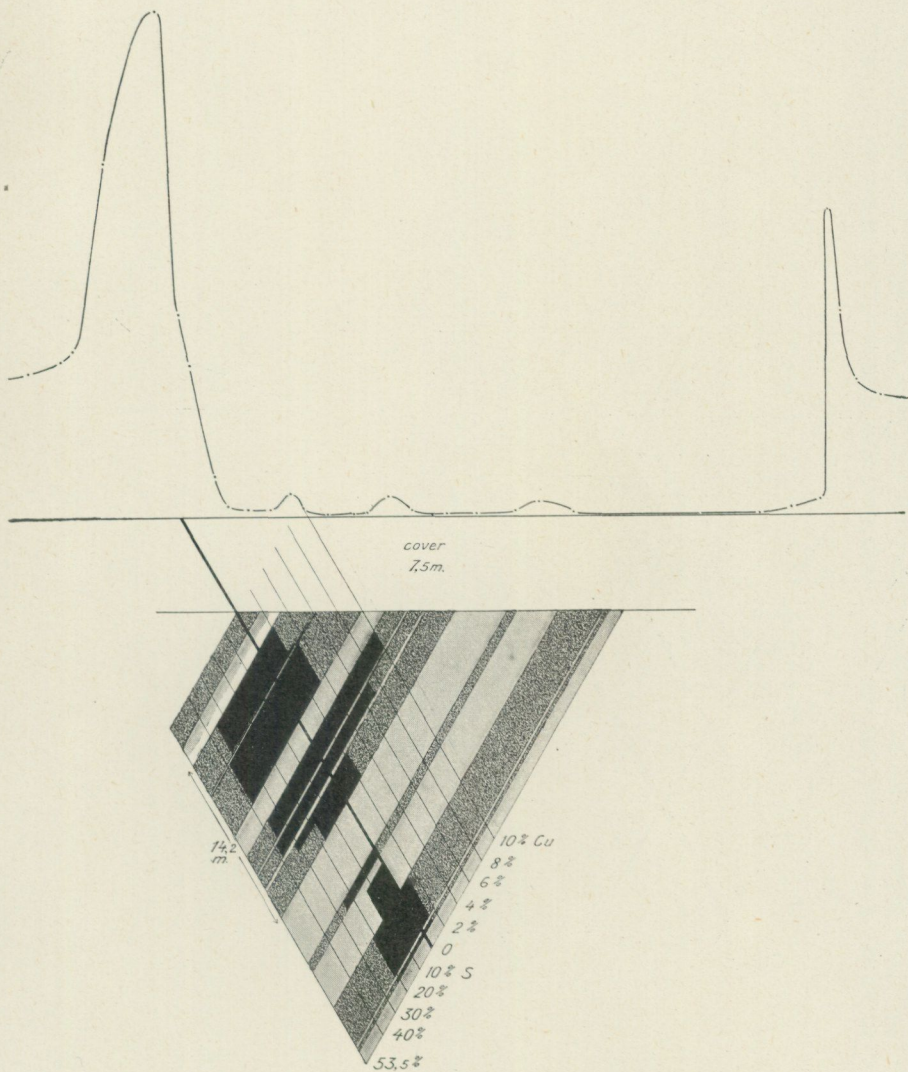


Fig. 15. Potential profile and bore-hole section Bf III.

A comparison of the bore-hole sections with the potential profile (Figs. 14, 15, and 16) also shows harmony.<sup>1</sup> The potential profile does not directly indicate the variations of the measured potential but *the fall of potential per unit of length*. Strong maxima are thus

<sup>1</sup> About one hour was spent in tracing each of these potential profiles.

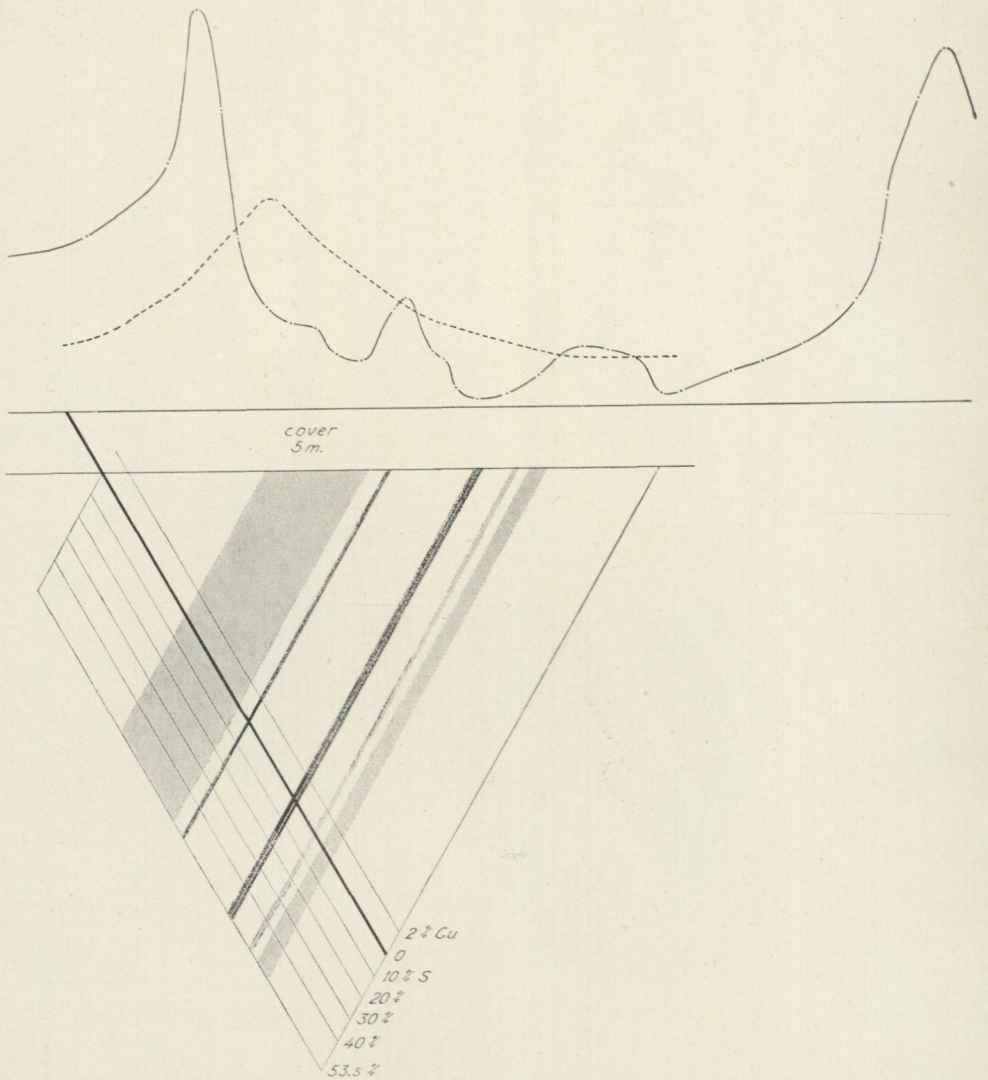


Fig. 16. Potential and intensity profile and bore-hole section Bf I.

obtained at the ore zone limits, and a distinct minimum above the ore itself.

Of the profiles, Bf I, and Bf III have been directly observed in the ground, while Bf II has been calculated from the equipotential curve map. Profile Bf I has not been observed immediately

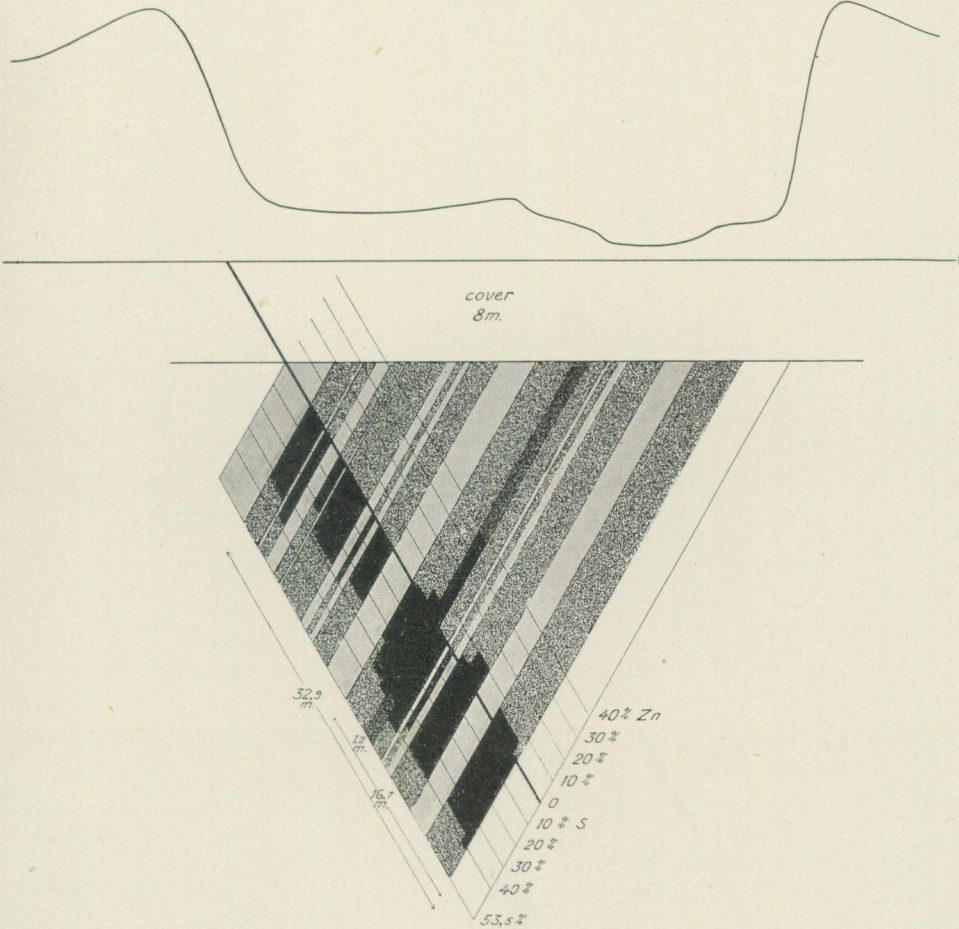


Fig. 17. Potential profile and bore-hole section Bf V.

above the bore profile, but 30 metres towards the broader part of the »indication».

It is quite clear from the profiles that the suspected area can be fixed within limits which within a few metres coincide with those of the ore

Profile Bf I also shows that broader parts of wall rock in the main ore zone cause great irregularity in the minimum area of the profile.

The central Bjurfors »indication» is only known by a bore-hole Bf V. The »indication» is rather short, 75—100 metres. The ore zone which, on the other hand, is the broadest one known in the Bjurfors field, is at least 32 metres wide.

The bore hole, drilled at an angle of 60°, first shows a rather poor

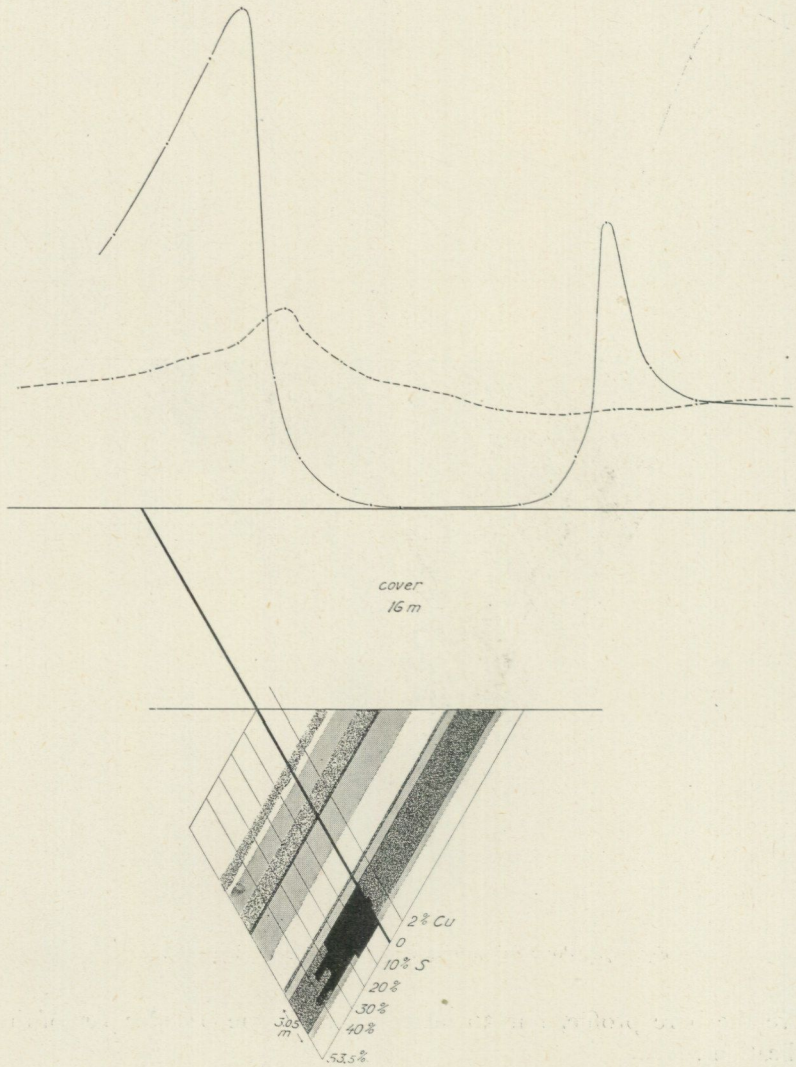


Fig. 18. Potential and intensity profile and bore-hole section Bf VI.

pyrite, free from zinc and copper, with numerous streaks of sericite-quartzite. Then amphibolite is reached with a rich ore zone corresponding to the middle of the »indication». The ore here chiefly consists of sulphur pyrite with 38—42 % S, containing some veins of zinc-blende, but free from copper. The sulphur pyrite, which, including a few small bands of wall rock is 16.6 metres broad, also contains a band of zinc-blende 1.2 metres broad, with 30 % of Zn. Below the

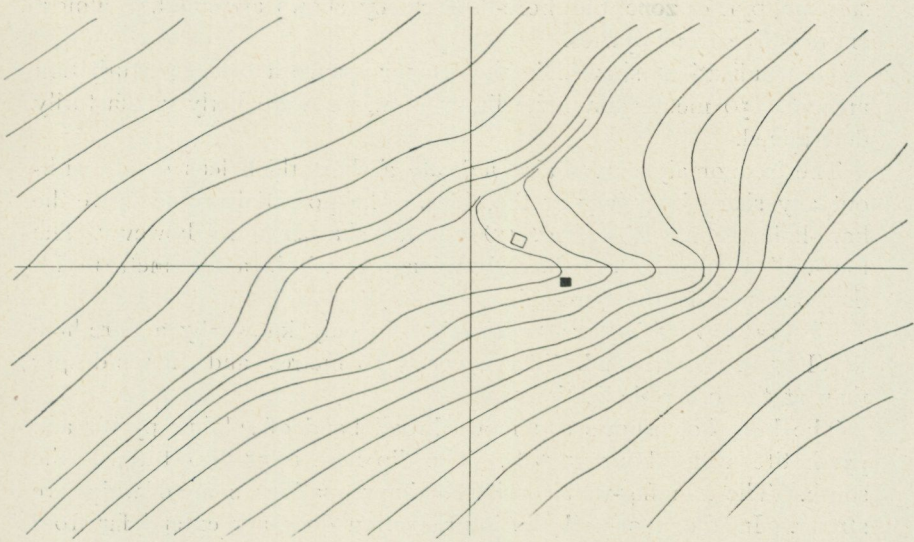


Fig. 19. Investigation of the Bjurliden »indication». Equipotential curves. Scale 1: 3000.

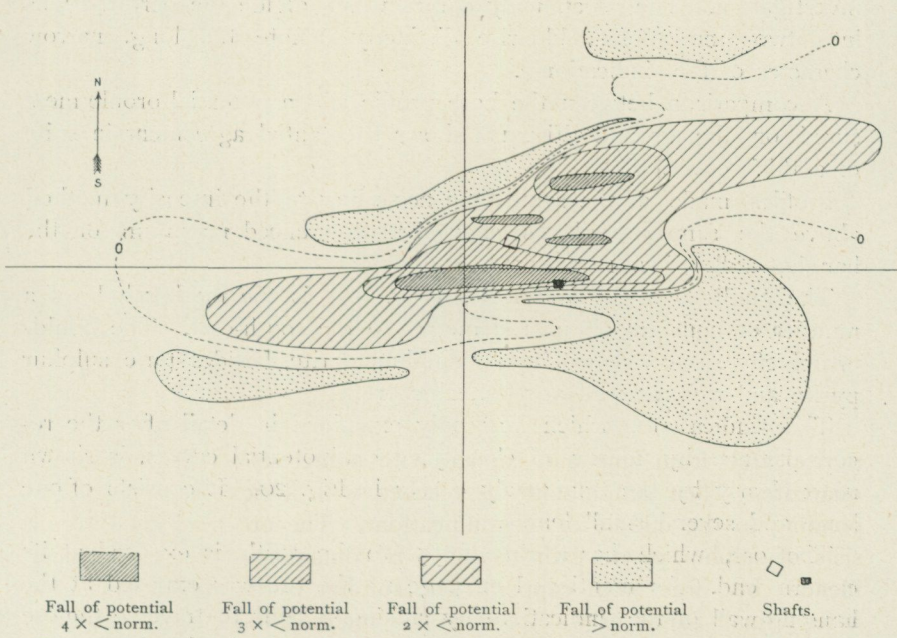


Fig 20. Investigation of the Bjurliden »indication». Isoanomaly curves. Scale 1: 3000.

sulphur pyrite zone the bore-hole chiefly shows amphibolite, almost entirely free from pyrites.

The »indication» showed in the reconnaissance a broad perturbation area ca. 150 metres long, the limits of which were fairly satisfactorily determined.

The isoanomaly curves also indicate a short thick lens of ore without any sharp boundary at the sides. The potential profile above the bore-hole (Profile Bf V, Fig. 17) indicates sharper limits, however. The foot-wall is distinctly indicated and agrees within a few metres with that observed in the bore-hole.

The western *Bjurfors* »indication» is only known by a bore-hole Bf VI at its eastern end. The cover is 16 metres, and thus is deeper than at the other »indications».

The bore hole shows a 3 metre broad band of sulphur pyrite and pyrrhotite with about 35 % S. The dip here is 55—60° towards the south. The hanging-wall consists of impregnations, some of which are strong. In the foot-wall the impregnation does not extend far from the ore. The deepest part of the hole shows leptite and, for the rest, more or less metamorphosed amphibolite.

In the reconnaissance the electrical »indication» gave a perturbation area 500 metres long. The »indication» itself was limited by a detailed investigation. The isoanomaly curves which divide the perturbations into two »indications», likewise distinctly denote the long, narrow character of the »indications».

A comparison between the bore profile and a potential profile measured on the ground (Fig. 18) shows substantial agreement in spite of a thick cover.

Profiles made at the same time according to the intensity method above the same bore-holes showed a pronounced maximum on the hanging-wall (Figs. 16 and 18).

The »indication» at *Bjurliden* (Fig. 19) is the mother lode of a number of boulders about 100 metres to the south-east. The boulders chiefly show rich zinciferous sulphur pyrite, besides pure sulphur pyrite and rich, as well as poor, zinc ore.

The »indication», which was only examined in detail after the reconnaissance by means of close-lying equipotential curves, is shown most clearly by the isoanomaly curves in Fig. 20. It consists of one large and several small lenses.

The ore, which has a dip of 55° to the south, is exposed at its eastern end. As mentioned on page 24 the ore was exposed at the hanging-wall of the »indication» by sinking a shaft to traverse the ore vertically. Rock was discovered in the shaft at a depth of 9 metres,

and the ore was discovered at a depth of 10 metres. This therefore shows a substantial agreement between the »indication» and the existing ore. The hanging-wall is composed of an inhomogenous biotitic skarn; below this there is 0.7 metres of poor zinc ore, then sulphur pyrite with 38—42 % S (free from zinc, copper and arsenic). The pyrite has been penetrated to a depth of 4.4 metres without reaching the foot-wall.

December, 1922.

*Geological Survey of Sweden.*

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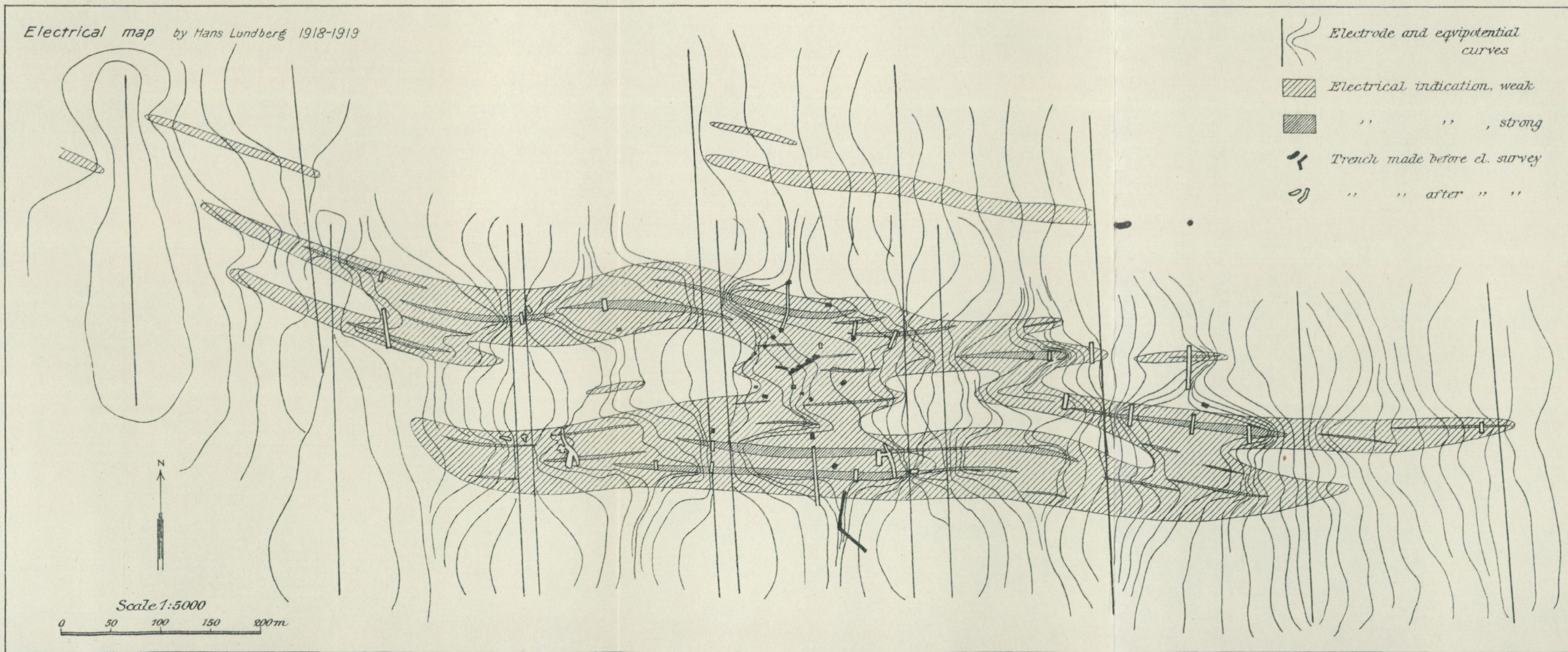
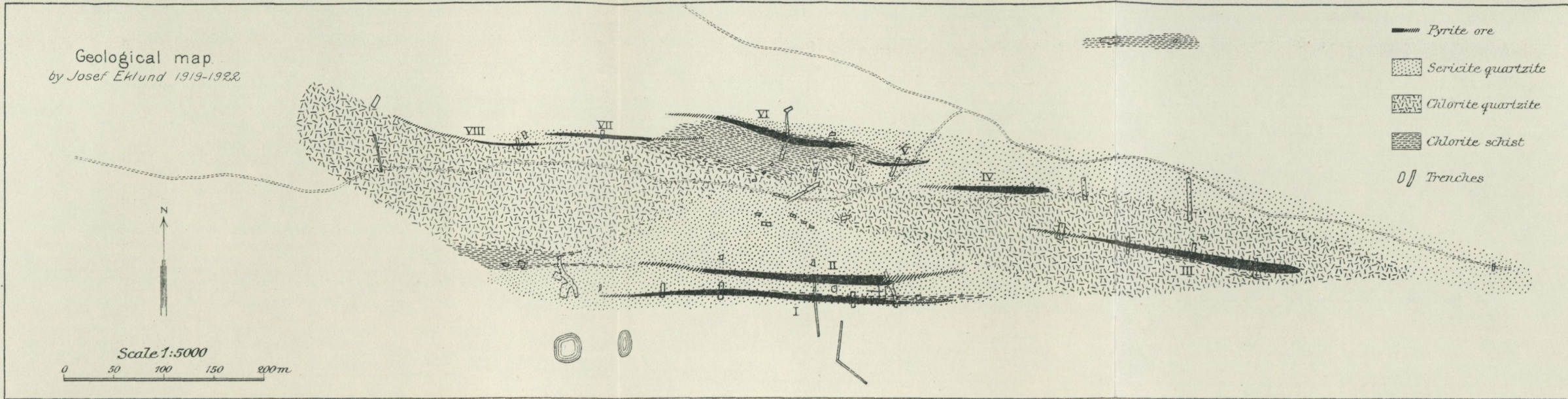
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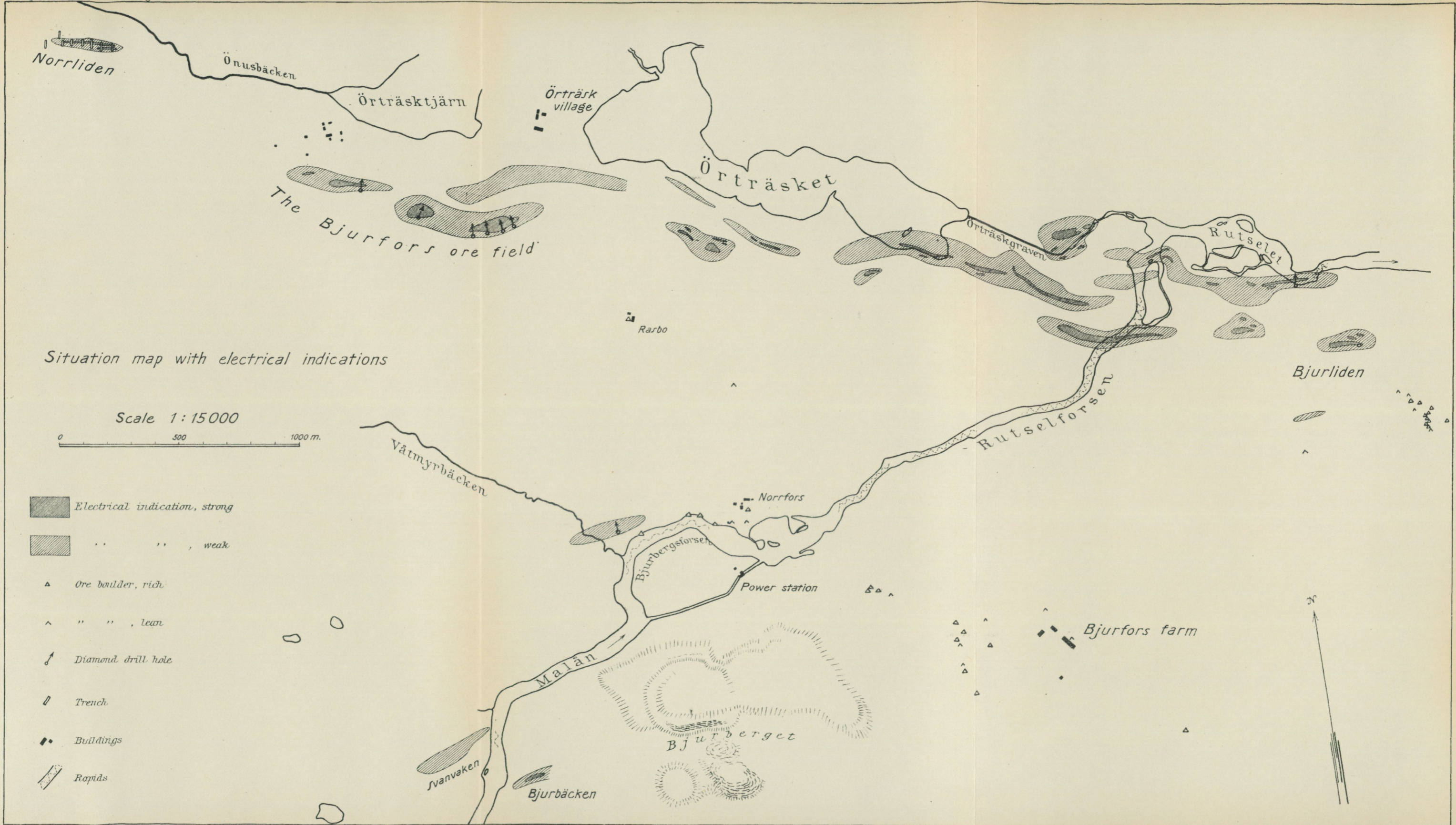
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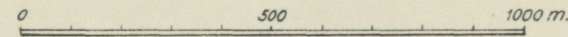
THE KRISTINEBERG ORE FIELD













Situation map with electrical indications

Scale 1:15000

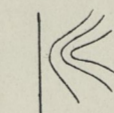


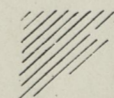
-  Electrical indication, strong
-  " " , weak
-  Ore boulder, rich
-  " " , lean
-  Diamond drill hole
-  Trench
-  Buildings
-  Rapids



*Electrical reconnaissance  
and detail maps*

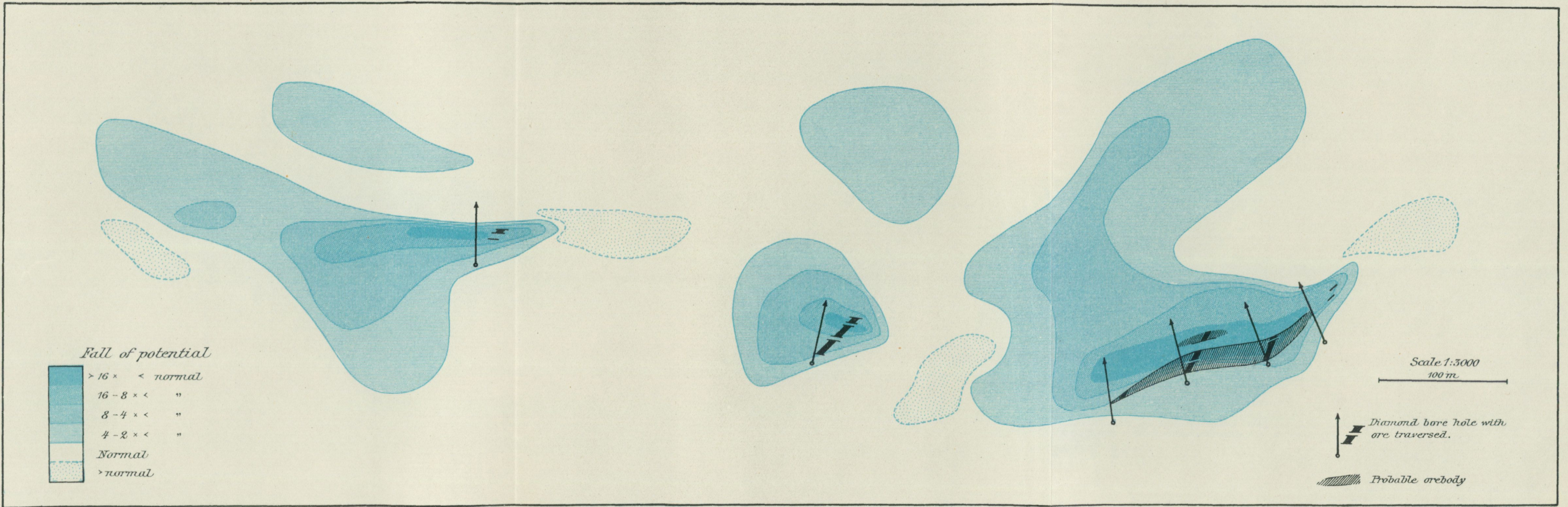
Scale 1:15 000  
0 500 1000 m.

 *Electrode and equipotential curves*

 *Disturbed areas*

# THE BJURFORS ORE FIELD

Anomaly map of the potential fall



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