SVERIGES GEOLOGISKA UNDERSÖKNING

SER. C. Avhandlingar och uppsatser. N:o 327.

ÅRSBOK 17 (1923) N:o 8.

ELECTRICAL PROSPECTING IN SWEDEN

BY

K. SUNDBERG, H. LUNDBERG and J. EKLUND

With 8 Plates

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STOCKHOLM 1925
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Errata et addenda.

Page 13	line 10:	that,	Read:	whether
» 17	» 15:	values of a and c,	»	values of l = a and c
» 30	» 12:	single-phased,	»	not alternating

Pages 61 and 63:

Malånäset. Two new ore-bodies have been discovered in 1925. At *Österbäcken* drill holes struck a long but narrow arsenic-silver-gold ore under 15 metres of sand. The south-western part of the *Bjurliden* indication was proved to correspond to an ore-body of pyrite, pyrrhotite and blende.

Page 68:

Boliden. The average composition of the ore of the two drill hole sections Nos. 6 and 8 is 2.6 % Cu, 6 % As, 35 gr. Ag, 8.4 gr. Au and 34 % S, whereof 28 % arsenic ore with 17 % As, 3 % Cu and 15 gr. Au, and 72 % pyritic copper ore with 2.6 % Cu, 33 gr. Ag, 5.3 gr. Au and 37 % S. Boliden is thus a very large gold occurrence and perhaps the largest known arsenic ore of the world. Production will start in 1926.

253568. S. G. U. Ser. C, N:o 327. K. Sundberg, H. Lundberg and J. Eklund.

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Preface.

In the Year Book of the Geological Survey of Sweden for 1922 there was published a paper by Hans Lundberg, entitled "Practical experience in electrical prospecting". This treatise contained a brief description of the results then obtained in Sweden in perfecting the electrical prospecting methods to usefulness in practice.

During the last few years, in the course of work carried out for the Geological Survey of Sweden as well as for the Centralgruppens Emissions-aktiebolag, Ltd, of Stockholm, much labour has been devoted to the further development of the electrical prospecting methods and to the gathering of experience concerning their effectivity when dealing with complicated geological relations in nature. The many and in part important ore deposits that have been discovered during this work thanks to the electrical methods show that these methods are now quite necessary aids for the successful prospecting of non-magnetic ore-bodies that do not outcrop.

It has, then, been deemed appropriate to publish an revised account of these methods that have been developed in Sweden, and so much more as the paper of 1922, quoted above, is now out of print. The report of the electrical methods is worked out by the mining engineers Hans Lundberg and K. Sundberg, which before all others in Sweden have the merit of having developed these methods to practical usefulness. It has been found appropriate to give also a short account of other geophysical prospecting methods (magnetic, gravimetric, seismic, etc.), which it under certain conditions may be of advantage to use together with the electrical measurements.

Experience of how necessary careful and detailed geological surveys are for the obtaining of reliable results calls also for an account of the geological works carried out in connection with the geophysical investigations. The geological parts are written by Mr. J. Eklund who from the first beginning has taken part in the work of the Geological Survey in the district in question.

Stockholm 1925.

Axel Gavelin.

Introduction.

When prospecting for ores, the geophysical methods have become of ever increasing importance in recent years. These methods are based upon the fact that the physical properties of the ores differ from those of the surrounding rocks. The methods are electrical, magnetic, seismic or gravimetric, according as they are based upon the respective electrical, magnetic, elastic and gravimetric properties of the ores, i. e. essentially upon their electrical conductivity, magnetic permeability, modulus of elasticity and specific gravity compared with the corresponding properties of the surrounding rocks.

The main condition for finding an ore-body by means of electrical prospecting is that the electrical properties of the ore — with most of the methods hitherto invented, the electrical conductivity — differ considerably from those of the surrounding rocks. Table I (page 8) shows several determinations of the electrical conductivity of some rocks and ores. It is to be seen that ores with a metallic lustre, such as chalcopyrite, pyrite, galena, magnetite, graphite etc. are much better conductors than ordinary rocks. Ores of this kind are, therefore, likely to be found by means of electrical prospecting.

For such prospecting a *geological survey* is first made, in order to limit the area where the ore is likely to be found, and thereafter the electrical investigation is planned. First the most suitable method should be chosen, and the working program in general decided upon. The decisive factors in this respect are the electrical properties of the ore to be prospected for and those of the surrounding rocks, the structure, thickness of the overburden, sequence of the strata, the soil, climatic conditions etc. To be able to estimate the influence of these factors and consequently to plan the electrical investigation, it is, of course, necessary to have as complete a knowledge as possible of the *theory of the electrical methods*. Then comes the *field work*. Under complicated circumstances, *auxiliary methods* are used besides the electrical ones. When the investigation is finished, the *interpretation of results* follows, and the points are determined where excavations ought most suitably to be made. After completion of the excavations, the *practical results* are seen. We shall, therefore, discuss the subject under the following headings:

1. Geological preliminary survey.
2. Theory of electrical prospecting methods.

3. Practice of electrical prospecting methods.
4. Auxiliary methods.
5. Interpretation of results.
6. A few practical results.

These chapters have been written by us as follows: Mr. Sundberg has worked out the theory and practice of electro-magnetic and auxiliary methods, Mr. Lundberg everything concerning the potential methods, and Mr. Eklund the geological parts.

We take the occasion to express our thanks to Dr. A. Gavelin Director of the Geological Survey of Sweden, as well as to the directors and officers of the Centralgruppens Emissionsaktiebolag, for placing material at our disposal and for assisting us in our work also in other respects.

Stockholm, December 1924.

The Authors.

Geological preliminary survey.

Electrical prospecting must always be carried out in conjunction with a geological survey of the area to be investigated. The purpose of this survey is to limit the investigation area and to contribute to the interpretation of the electrical indications.

For limiting the area no general rules can be given. However, it should not be made too small, partly because the exact outlines of an ore-bearing district can seldom be determined solely by means of a geological survey and there is a risk of valuable ores occurring outside the investigation area, and partly because it is desirable, for intrepretation of the indications, that part of the neutral surroundings be included in the investigation.

Owing to experience gained in the course of investigation, the limits of the area must often be altered, partly because orebearing zones may prove to be in a direction other than that expected from the geological survey, and partly because no electrical indications may be obtained from areas suspected of being ore-bearing.

The geological survey for an electrical investigation is, on the whole, carried out in the usual way. Special attention ought, however, to be given to such circumstances as are of importance for the electrical investigation. Consequently, the geological map of the area should not be drawn in too small a scale, preferably not below 1 : 10,000, unless the structure of the area is particularly simple or, as in moraine-covered districts, the small number of exposures would render a large scale illusive. It is obviously unsuitable to have too great a disproportion between the scales of the geological and the electrical maps, the latter being drawn, as a rule, on scales of 1 : 800 to 1 : 4,000.

In making the geological survey it is of great importance that the electrical conductivities of the rocks be examined, and that all conductive rocks are entered on the geological map as exactly as possible. If the area is covered by deep moraine and a direct mapping of the conductive formations is therefore impossible, the moraine should be examined, and all boulders of conductive rocks discovered marked out on the map.

Besides ores and disseminations, the most frequent of the conductive rocks are graphitic and pyritic slates, basic eruptive rocks containing a good percentage of titano-magnetite or pyrrhotite, and in metamorphic terrains, poor sulphide disseminations (fahlbands) and iron formations containing magnetite and specularite (see table I).

Table I.

The electrical resistance of some minerals, rocks and ores.

	Ohms per cm³
1. Pure minerals:	
Calcite	$5.0 \cdot 10^{14}$
Quartz	$3.8 \cdot 10^{11}$
Mica	$1.5 \cdot 10^{10}$
Serpentine	$2.0 \cdot 10^{4}$
Blende (non-ferrous)	$1 \cdot 10^{8}$
Siderite	$7.1 \cdot 10^{3}$
Marcasite	10.0
Chalcopyrite	1.0
Molybdenite	0.8
Magnetite	0.6
Specularite	0.4—0.8
Graphite	0.03
Pyrite	0.02
Pyrrhotite	0.01
Galena	0.003
2. Rocks:	
Granite	c:a 10^{11}
Aplite, Ofoten, Norway	$> 50 \cdot 10^{6}$
Greenstone	c:a 10^{8}
Diabase, Kellogg, Idaho, U. S. A.	$308 \cdot 000$
Garnet-amphibolite, Ofoten, Norway	$3.2 \cdot 10^{8}$
Leptite, Striberg, Sweden	$> 50 \cdot 10^{6}$
» , Persberg, »	$> 50 \cdot 10^{6}$
» , banded, Utö, Sweden	$> 50 \cdot 10^{6}$
»	$6.0 \cdot 10^{6}$
Sandstone	c:a 10^{11}
Limestone	c:a 10^{11}
» , Persberg, Sweden	$50 \cdot 10^{6}$
»	$42 \cdot 10^{6}$
Micaschist	c:a 10^{9}
» , Ofoten, Norway	$> 50 \cdot 10^{6}$
Quartzite	c:a 10^{11}
Sericite-quartzite, Kristineberg, Sweden	$> 50 \cdot 10^{6}$
3. Rocks with disseminated conductive minerals:	
Norite with pyrrhotite, Sudbury, Canada	5
Limestone with chalcopyrite	$16 \cdot 10^{6}$
» » magnetite, Dannemora, Sweden	$68 \cdot 000$
Graphitic slate, Ofoten, Norway	13.3
» » whith pyrrhotite, Ofoten, Norway	0.5
Pyrrhotitic dissimination, » »	2.7
Graphitic slate, Storstensberget, Malånäset, Sweden	350
Slate with pyrrhotite	53.0

	Ohms per cm^3
Slate with pyrrhotite	6.0
Sericite-quartzite with streaks of pyrite, Kristineberg, Sweden	68.000
Sericite-schist with pyrite, Ofoten, Norway	$3.5 \cdot 10^6$
Quartzite with pyrite, » , »	$4.2 \cdot 10^4$
4. *Ores:*	
Spatic iron ore	c:a 10^8
Brown haematite ore	c:a 10^8
Specular iron ore	100—10
Magnetite ore	100—1
Titano-magnetite, Fatmomakke, Sweden	1900
Chromite, Fatmomakke, Sweden	120.000
Zincite, Franklin Furnace, U. S. A.	28
Blende ore, non-ferrous, Missouri, U. S. A.	$> 50 \cdot 10^6$
» » Joplin, »	$> 50 \cdot 10^6$
» ferrous	18.0
Blende-galena ore, Galena, Ill, U. S. A. parallel with banding	$>$ 0.1
» » » » » » perpendicular banding	36.000
» » » » » »	16.000
» » » Vindelgransele, Sweden	1350
Galena ore	c:a 1
» », Galena, Ill., U. S. A.	0.8
» », Joplin, U. S. A.	$<$ 0.1
Polybasite, Tintic, Utah, U. S. A. parallel with banding	0.1
Polybasite, Tintic, Utah, U. S. A. perpendicular banding	400
Silver ore, Tintic, Utah, U. S. A average type	2500
Conglomerate with native copper, Houghton, Mich., U. S. A.	0.2
Native copper, Jerome, Ariz., U. S. A.	$<$ 0.1
Cuprite, » » »	0.1
Chalcocite ore, » » »	3.1
» », Butte, U. S. A.	5.7
Chalcopyrite ore Jerome, Ariz., U. S. A.	10.5
» »	c:a 0.1
» »	2.0
» »	0.2
Cubanite (chalmersite), Fierro, N. Mex., U. S. A.	6850
Pyrite ore, Björkåsen, Norway	66.5
» », » , »	8.5
» », Bjurliden, Malånäset, Sweden	10500
» », » » »	2000
» »	250
» »	50
» »	30
» »	c:a 0.1
Pyrrhotite	7.0

Whether a rock is a good conductor or not, can often be ascertained by macroscopic or microscopic examination, but the safest way is by means of direct determination of the resistance. As a general rule, it can be said that the conductivity of a rock is increased in proportion to the percentage of opaque minerals with a metallic lustre contained in the rock. However, the structure of the rock is also of great importance, because the conductive resistance of a rock containing streaks and veins of conductive minerals is very low in the direction of the streaks, while a rock where the conductive minerals are distributed as isolated grains is often a bad conductor, in spite of containing a large percentage of conductive ore-minerals. Owing to their structure, graphitic and pyritic slates thus are generally good conductors, at least in one direction, while, on the other hand, rocks containing granular sulphide disseminations and basic eruptive rocks only occasionally are good conductors, in spite of containing large percentages of sulphides or titano-magnetite (figs. 1 and 2).

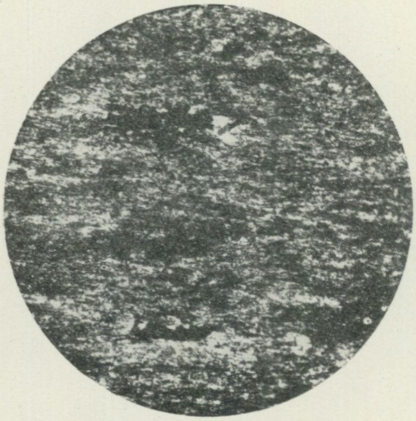


Fig. 1. Black slate with graphite (black dust) and pyrrhotite (large black areas). Saxå field, Sweden. × 10.

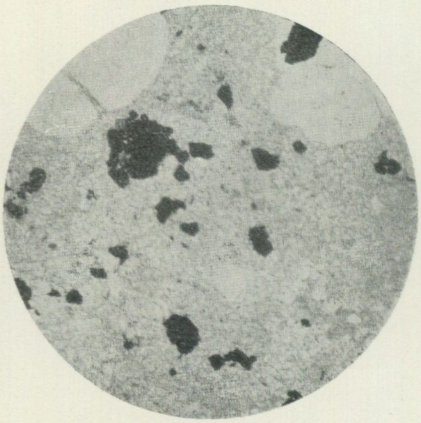


Fig. 2. Quartz-porphyry with disseminated pyrite. Bogärde, Skellefte district, Sweden. × 10.

The safest way, however, is to make direct resistance tests. Fig. 3 shows a simple apparatus for this purpose. The samples are inserted between the plates A and B. To get a better contact, a layer of tinfoil is placed between the sample and the plates. The resistance is then determined by means of a Wheatstone's bridge. For reasons stated above, determinations of resistance should always be made in different directions of the samples.

In the choice of samples certain precautions must be taken. They must be taken from fresh, unweathered rocks, as otherwise the conductive ores may have been wholly or partly dissolved or transformed into a non-conductive mineral as limonite. The rock should also be saturated with moisture, or the value of the conductivity will be too low, for, as a rule, the rocks are saturated with moisture already quite near the surface of the earth. Table II and III gives a few examples of the variation of conductivity according to the percentage of moisture.

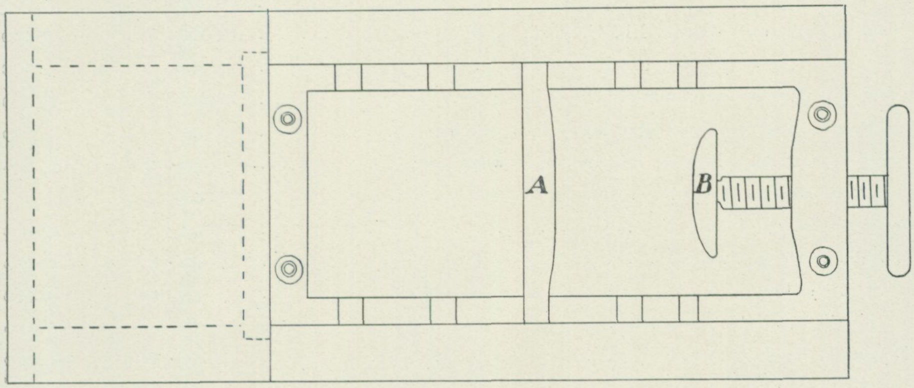


Fig. 3. Apparatus for testing electrical resistance of rocks and ores.

Table II.

(The specific resistance of water used W ca. 10 ohm/m³.)

Material.	Percentage of water	W ohm/m³
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
»	10.0	156
»	13.5	84
»	17.3	60
Clay	4.4	1,450
»	6.8	345
»	9.2	150
»	13.4	73
»	16.1	50
»	28.0	16
»	45.0	14.5
»	58.6	14.1

Table III.

	Ohm/cm³ Dry	Moist
Pyrite ore, Bjurliden, Malånäset, Sweden	2,000	1,400
» », », », »	10,500	6,000
Blende-galena ore, Galena, Ill., U. S. A.	16,000	1,500
» » », Vindelgransele, Sweden	1,350	300
Chromite, Vilhelmina Mountains, Sweden	120,000	30,000
Graphitic slate, Storstensberget, Malånäset, Sweden	350	50
Sericite-quartzite, schistose, Kristineberg, Sweden	$> 50 \cdot 10^6$	385,000
D:o with streaks of pyrite, », »	68,000	—
Diabase, Kellog, Idaho, U. S. A.	308,000	20,000
Leptite, Striberg, Sweden	$> 50 \cdot 10^6$	680,000
», Persberg, »	$> 50 \cdot 10^6$	310,000
», banded, Utö, Sweden	$> 50 \cdot 10^6$	1,000,000
Dolomite, Persberg, Sweden	$> 50 \cdot 10^6$	370,000
», », »	$> 50 \cdot 10^6$	550,000
Limestone, Dannemora, Sweden	68,000	40,000

In economic geology at the present time the electrical properties of minerals and rocks may be considered of great importance, and it is suggested that in all geological mapping of ore-bearing districts attention also be paid to the electrical properties of the ore and rock minerals. Ore and rock samples should then be collected, sufficient in number and size to facilitate a complete examination of the physical characters.

The conductive rocks are mostly easily traced and mapped in the field, owing to the fact that they are often rusty from weathered pyrite or blackened by graphite.

Great care should be bestowed upon the tectonic conditions, especially the form of the ore-bodies and the depth at which they are expected to be found. If the strike of the ore-bodies is in a certain direction, for instance if the ores are conformably interstratified in schistose or stratified rock, or form parallel veins, the direction of the strike ought to be determined, as, in this case, the electrical observations can be made at greater intervals along the strike than across it, without any risk of missing an ore-body. This will save much time and work.

In connection with the geological survey, the overburden, weathering and water-saturation should be observed. For regions under cultivation character and depth of the soil can usually be found in the land-surveying maps; should there be no such maps, the geologist will have to draw a soil map, if required. As to the weathering it is of importance to ascertain whether the upper parts of the ores are oxidized or leached.

In examining the water conditions, the elevation of the water table should especially be located, and observations should be made as to the moisture or lack of moisture in the rocks situated above this surface. Only in very arid countries is the soil quite dry to any great depth.

Theory of electrical prospecting methods.

To get an idea of the practicability of the different electrical methods, it should be ascertained which factors are essential for determining the results, when using a certain method. In this case, as well as in similar ones, the best way to carry out such examinations is to idealize mathematically simple cases, whereby certain equations are obtained. Then laboratory tests are made on a small scale, in order to ascertain whether these equations can be applied also under more complicated conditions, and finally the results arrived at in practical work are compared with the laboratory tests and the equations. In this way it is proved that the factors have the same effect in all three cases. If they have not, an investigation must be made in order to find out which of the factors decisive in practice have been overlooked or considered of too small importance.

The electrical prospecting methods can be divided into two principal groups, potential methods and electro-magnetic methods. Potential methods were tried as early as about 1830. These methods are based upon the investigation of the distribution of the potential in an electrical field by tracing equipotential curves or measuring differences in potential between different points. Electro-magnetic methods were tried for the first time probably in 1909. The direction and intensity in an electro-magnetic field are investigated.

Potential methods.

By applying a potential difference between two points in the ground, an electrical fileld is generated in the earth. In many cases the ore-body itself also generates a polarisation current in its surroundings.[1]) By direct observation of the potential at a number of accessible spots on or

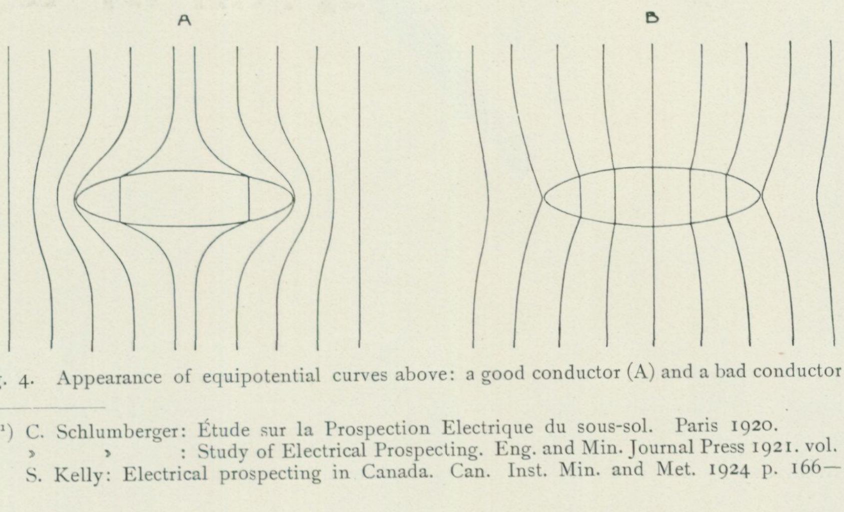


Fig. 4. Appearance of equipotential curves above: a good conductor (A) and a bad conductor (B).

[1]) C. Schlumberger: Étude sur la Prospection Electrique du sous-sol. Paris 1920.
» » : Study of Electrical Prospecting. Eng. and Min. Journal Press 1921. vol. 111.
S. Kelly: Electrical prospecting in Canada. Can. Inst. Min. and Met. 1924 p. 166—187.

below the surface of the earth, the distribution of the potential in this field can be investigated. It is simplest, however, to study surfaces of equal potentials. Curves of equal potentials can be traced on the ground to indicate exactly the outcrop 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. The illustration (Fig. 4) shows the appearance of the curves with a good conductor, A, and a bad conductor, B. Sometimes it is advisable, especially for determining the position exactly, to study the distribution of the potential along a profile line above an ore-body. Fig. 5 shows such a potential profile above an ore-body discovered by means of potential methods.

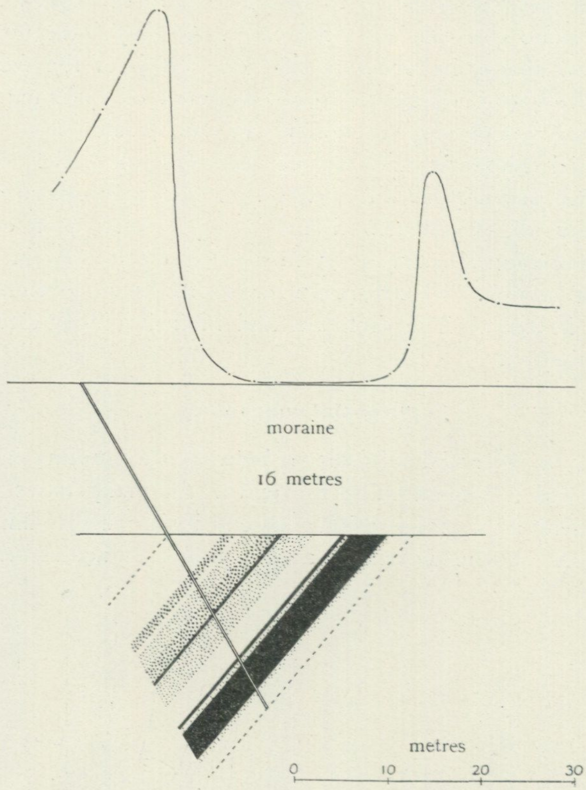


Fig. 5. Potential profile and drill-hole section. Bjurfors, western ore-body. (Ore black, impregnations dotted.)

In order to examine which factors have the greatest effect, when using electrical potential methods, we imagine an ore-body in the shape of a conductive ball placed in a medium of infinite extension traversed by a constant current in a certain direction (fig. 6). Here the potential V_s at an arbitrary point P is, as shown by Maxwell

$$V_s = V_p - \frac{k_1 - k_2}{2k_1 + k_2} \cdot \frac{a^3}{r^3} \cdot V_p$$

where V_p = the normal potential P, i. e. the potential if there were no ball,
k_2 = the specific resistance of the ball,
k_1 = the specific resistance of the surrounding medium,
a etc. refer to corresponding letters in the figure.

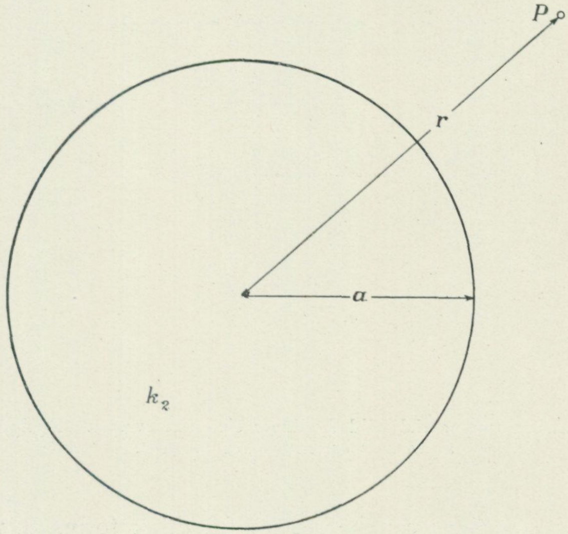


Fig. 6.

The alteration of the potential caused by the ball at the point P is consequently

1) independent of the scale, inasmuch as V is constant if $\frac{a}{r}$ is constant. From this follows that, in this case, a laboratory test on a small scale gives the same result as an investigation on a large scale, if $\frac{k_1 - k_2}{2k_1 + k_2}$ has the same value in both cases, i. e. if the ratio between the specific resistance of the ball and that of the surrounding medium is the same.
2) practically independent of whether the ball is a fairly good conductor or a very good one, as compared with the surrounding medium. For if the ratio between the conductivities of the ball and the surrounding medium is fixed at 100 in one case, and at 1,000,000 in the other, the factor $\frac{k_1 - k_2}{2k_1 + k_2}$ is 0,493 and 0,500 respectively, i. e. the alteration of the potential is only 1,4 % larger in the latter case than in the former.
3) inversely proportional to the cube of the distance from the centre of the ball, i. e. the distribution of the potential rapidly decreases when the distance from the ball is increased.

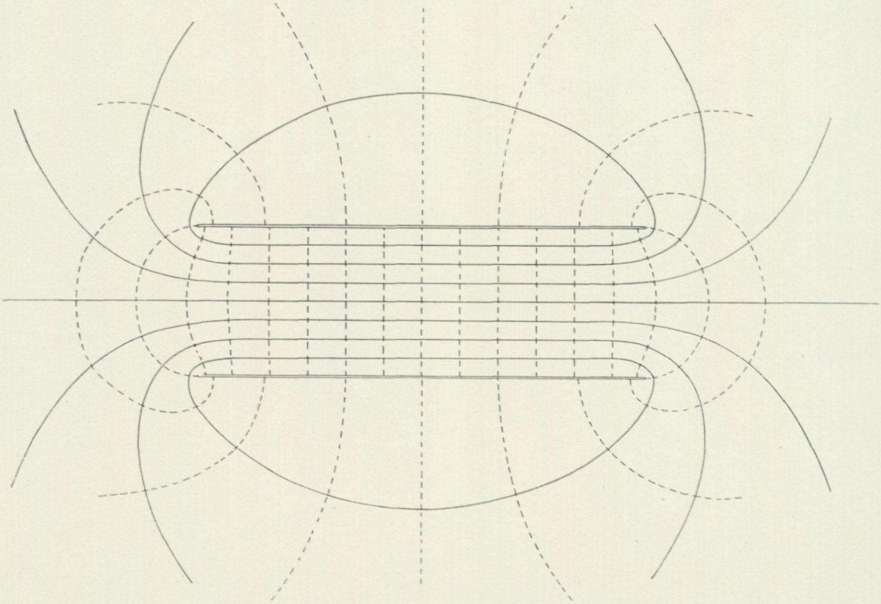


Fig. 7. Appearance of superficial field by linear electrode system. Equipotential curves, as well as current curves (dotted).

As analogous equations can be set up for other forms of the conductor, the following statements can be applied to the equipotential methods, and have also been confirmed by tests on a small scale and by field investigations:

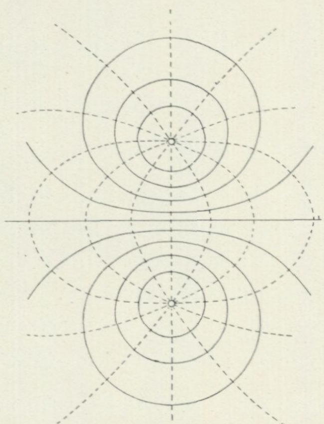


Fig. 8. Appearance of superficial field by polar electrode system. Equipotential curves as well as current curves (dotted).

1) Laboratory tests on a reduced scale give the same results as field work, if materials of the same electrical conductivity are used in both cases.
2) Practically the same distribution of the potential — i. e. the same electrical indication — is obtained, whether the conductivity of the ore is ten times or several million times higher than that of the surrounding rocks, from which follows, on the one hand, that the method is very sensitive and, on the other hand, that the electrical properties of the ore cannot be judged from the indication.
3) The strength of the indication decreases rapidly, when the depth of the cover increases.

The potential methods became generally

adopted in connection with introduction of linear electrodes according to the system Lundberg-Nathorst (fig. 7). Only polar electrodes had previously been used (fig. 8).

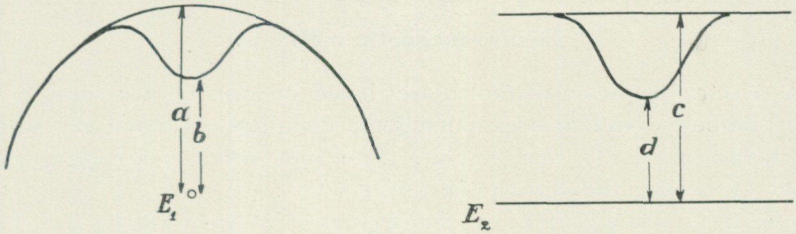


Fig. 9.

By using linear electrodes, a more homogeneous electrical field is obtained than with polar electrodes, and the interpretation of the results is thereby facilitated. The alterations of the potential caused by the ore are also much greater — and consequently the indications stronger — if linear electrodes are used. To exemplify this, the distribution of the potential has been calculated for both polar and linear electrodes at the same di-

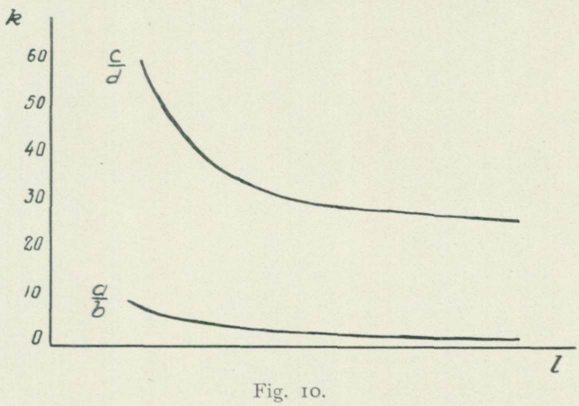


Fig. 10.

stance above an ore-body of infinitely good conductivity compared with the surrounding rock, and of considerable extent horizontally. For this purpose, the normal potential at different distances, l, from the respective electrodes is calculated, as well as the potential, V_s, obtained above the ore-body in this special case. For different values of l, (fig. 9) the ratio, k, has then been calculated between the values of a and c respectively, for which the normal potential V_n has the same value as the potential V_s above the ore-body, and $l = b$ and d at the point in question, viz.: $k = \frac{a}{b}$ and $\frac{c}{d}$ respectively. The greater the fall of the potential caused by the ore-body, the greater is, of course, the value of k. Fig. 10 shows the result of this calculation, from which is to be seen that much higher values of *k*, and consequently stronger indications are obtained, when linear electrodes are used instead of polar ones.

Electro-magnetic methods.

The electro-magnetic methods are based on causing a current to flow in an ore-body, and than examining the disturbances in the electro-magnetic field caused by this current. The methods can, according to the manner of causing the current, be divided into:

1) methods in which current is caused to flow in the ore-body *inductively*, i. e. by means of closed cables insulated from the ground,
2) methods in which current is caused *galvanically*, i. e. by means of wires connected with the ground; in this case an electric current is, likewise, caused inductively by the cables to the points of contact with the earth,
3) methods in which current is transmitted *capacitively*, i. e. by means of open wires, which are insulated from the ground, i. e. antennae. These methods also include »wireless» or »radio» methods.

The disturbances caused by the ore-body can be investigated:

1) by direct reading, in which case the strength of the electromagnetic field is read off at every point of observation;
2) by comparative readings, in which case the strength of the electro-magnetic field at a certain point is compared with that of the field at another point.

The methods which Sundberg has elaborated involve different combinations of these principles, which form the bases of the groupings given above. According to the methods in question, current is thus caused in the ore-body either inductively, galvanically or capacitively, or by a combination of these procedures, and the electro-magnetic field is investigated either directly or comparatively.

In the case of an *inductive* supply of current, the circuit on the ground (the primary circuit) forms together with the ore-body a short-circuit transformer, the secondary circuit of which is the ore-body. In order to indicate the position and outline of the ore-body, an examination is made of the course of the electro-magnetic field generated by the current in the ore-body (the secondary field). To begin with, it is therefore necessary to comprehend which factors determine the course of the secondary field. Let AB (fig. 11) be the primary circuit, CD the secondary circuit — the ore-body, and suppose that both are circular. It can then be proved that the following equation is obtained:

$$V_S^A = \frac{R \cdot r^2 \cdot 2\pi \cdot v \cdot M}{l^3 \sqrt{\frac{4k^2 \cdot r^2}{d^4} + 4\pi^2 \cdot v^2 \cdot L^2}} \cdot V_P^A$$

where V_P^A = primary field at point A,

V_S^A = secondary » » » A,

R, r, l, d = the distances shown in the figure,

k = the specific resistance of the ore circuit,

v = the frequency,

M = the reciprocal inductance between the primary and secondary circuits,

L = the inductance of the secondary circuit.

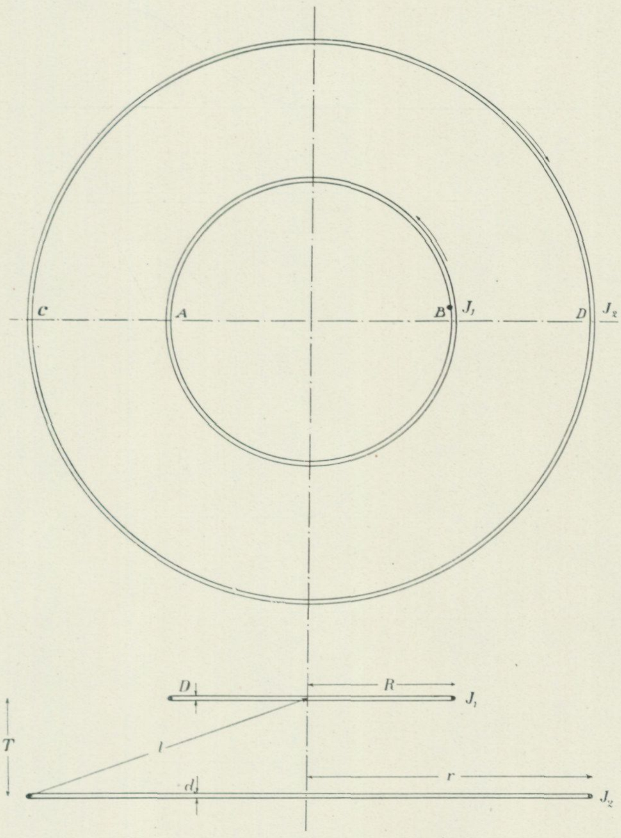


Fig. 11.

The secondary field thus depends on the dimensions and reciprocal positions of the primary circuit and the ore-body and on the frequency, as well as on the resistance of the ore-body, k, and permeability, μ, (as M and L are functions of μ).

A further examination of the equation proves:

1) that the strength of the secondary field is not independent of the scale, but that the electrical and magnetic properties of the »ore circuit» must

be altered in a definite proportion to the alteration in the scale provided that the same secondary field, i. e. the same electrical indication, is to be obtained in both cases;

2) that the strength of the secondary field is greatly dependent on the electrical and magnetic proporties of the »ore circuit» (L and *k*), for which reason the strength of the indications varies with the properties of the material composing the ore-body;

3) that the strength of the indications decreases slightly, in proportion to the depth of the ore,

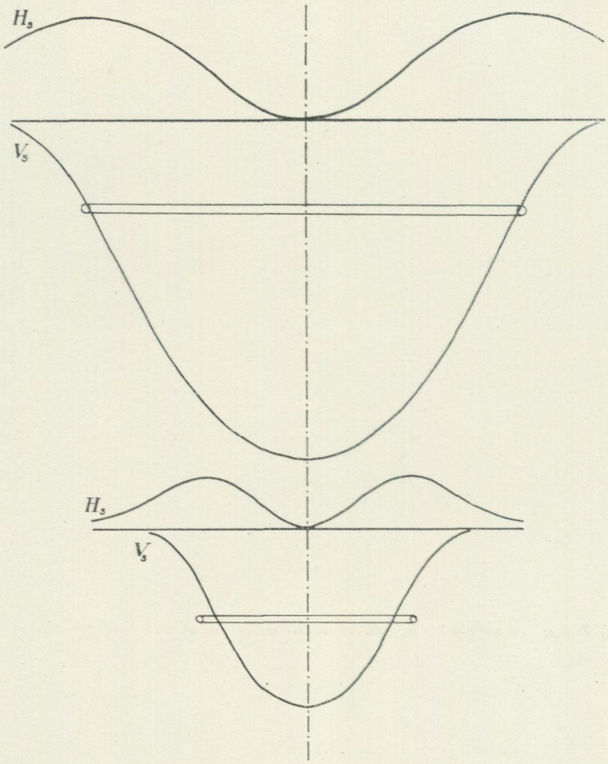


Fig. 12. Horisontal (H_s) and vertical (V_s) components of secondary electro-magnetical fields.

4) that it is possible to determine the specific resistance and the permeability of a material, if the secondary field be determined at different frequencies.

As analogous equations apply to other forms of the conductor, and the above facts have been proved by laboratory tests and field work, the above propositions are generic. Concerning the possibility of determining the electrical and magnetic properties of a material, in the case of an inductive supply of current, i. e. the possibility of carrying out *qualitative* investigations, it may be pointed out that these methods are not yet much

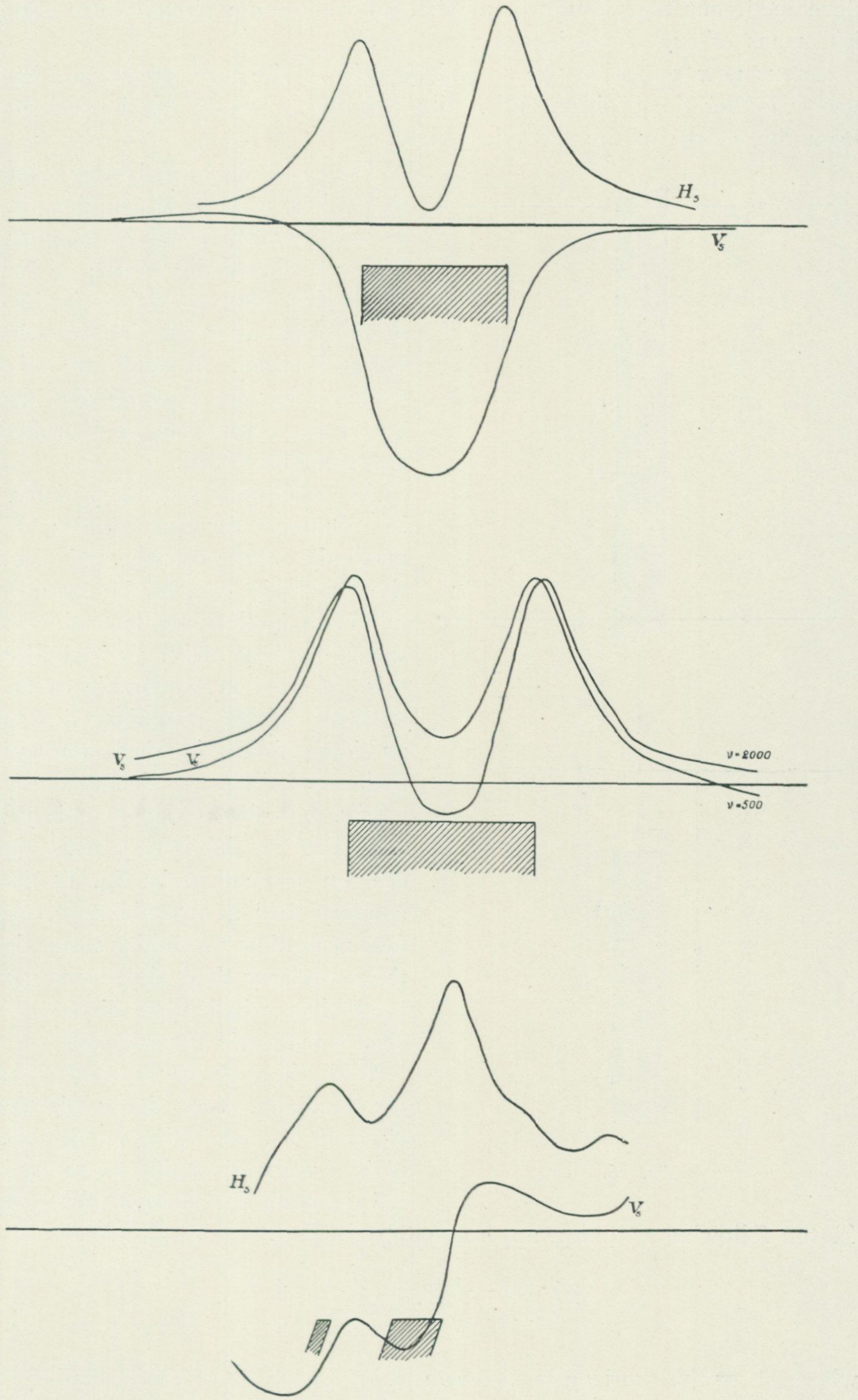


Fig. 13—15. Horisontal (H_s) and vertical (V_s) components of secondary electro-magnetical fields.

developed, but that results of a practical value have already been obtained by means of such investigations.

Let us now return to the secondary field of the »ore circuit» and investigate whether the position and outlines of the ore-body can be determined from the course of the secondary field.

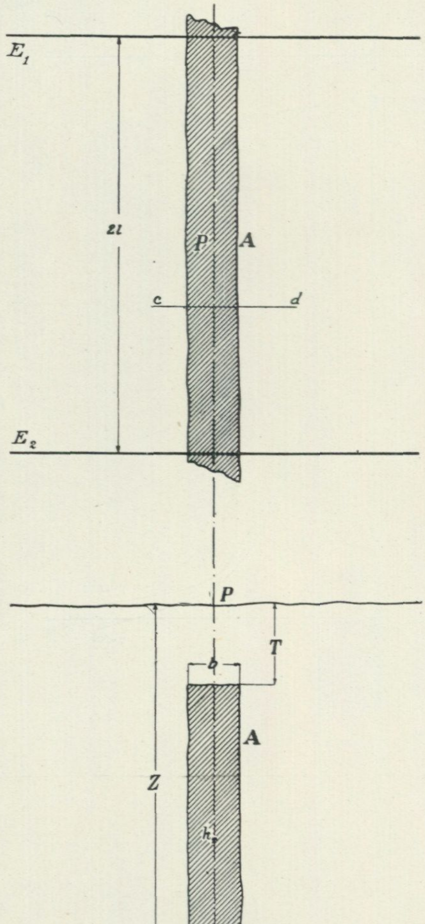


Fig. 16.

The secondary field at an arbitrary point has a vertical component, V_s, as well as a horizontal component, H_s. Fig. 12 shows the course of V_s and H_s in this case, as well as in the case of the diameter of the »ore circuit» being doubled. It ought to be quite evident that the position and diameter of the circuit can be indicated by the secondary field.

As analogous secondary fields will be obtained for any outline of the ore-body, the position and form of the ore-body can, in the case of the inductive method, be determined from the secondary field. In addition to this, at least in favourable cases, the strength of the secondary field gives an idea of the electrical conductivity and permeability of the ore.

Fig. 13 shows the secondary field according to laboratory tests carried out on a small scale, fig. 14 the secondary field at two different frequencies according to similar tests, fig. 15 the secondary field above two parallel ore-bodies, which were discovered by electro-magnetic investigation.

With the *galvanic method* are used, for example, two linear electrodes, E_1 and E_2, according to fig 16. If *A* is a vertical lamellar ore-body located beneath the surface at the depth *T*, the following equation approximately applies:

$$H_s^p = \frac{2b \cdot (k_1 - k_2)}{\pi^2 \cdot l \cdot k_2} \cdot {}^e\log \frac{Z\sqrt{l^2 + T^2}}{T\sqrt{l^2 + Z^2}} \cdot H_p$$

where H_s^p = the horizontal component (at point P) of the secondary field raised as a result of the current in the ore,

H_p = the strength of the electro-magnetic field at P, if there were no ore-body,

l, b, Z, T = the distances shown in the figure,

k_1 = the specific resistance of the surrounding rock,

k_2 = » » » » » ore.

Besides the geometric dimensions, the quota between the resistance of the rock and that of the ore thus determines the strength of the secondary field.

A further discussion of the equation, as well as laboratory tests and field investigations, prove

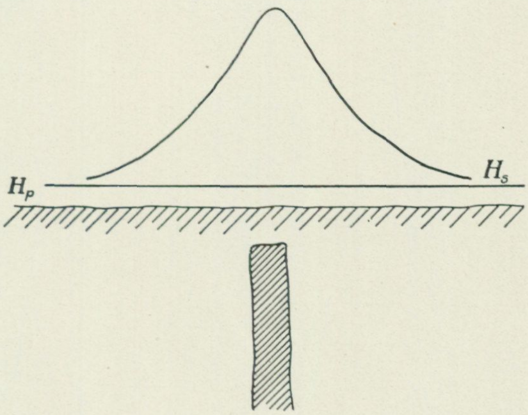


Fig. 17.

1) that the strength of the secondary field is independent of the scale, and laboratory tests therefore give the same results as field investigations, if only materials of the same conductivity are used in both cases,
2) that the method is very sensitive, in as much as indications are obtained also from relatively bad conductors; and in connection therewith the electrical properties of the conductors cannot be determined from the strength of the indication,
3) that the strength of the indication decreases at a relatively slow rate at a greater distance from the ore, i. e. when the depth of the cover increases.

If the value of H is calculated at different points along the line *c—d*, for $l = 500$, $b = T = 10$, $Z = 100$, $\frac{k_1}{k_2} = 1000$, the values indicated by fig. 17 are obtained, i. e. a pronounced maximum is obtained above the ore-body. The position of the latter is hereby determined.

Fig. 18 denotes the value of H above two parallel ore-bodies, according to investigations carried out in the field.

Capacitive methods.

Finally, as regards the theory of the *capacitive*, especially the »wireless» or »radio» methods, the equation drawn up by J. Zenneck[1] for the transmission of electro-magnetic waves in different media can be directly applied. According to a method devised by Sundberg, the position of the ore-body is traced by means of a movable receiving antenna, by gauging the strength, J, of current received from a stationary transmitting station. Besides depending on the distance from the transmitting station, J, also depends on the specific conductivity and dielectric constant of the sub-

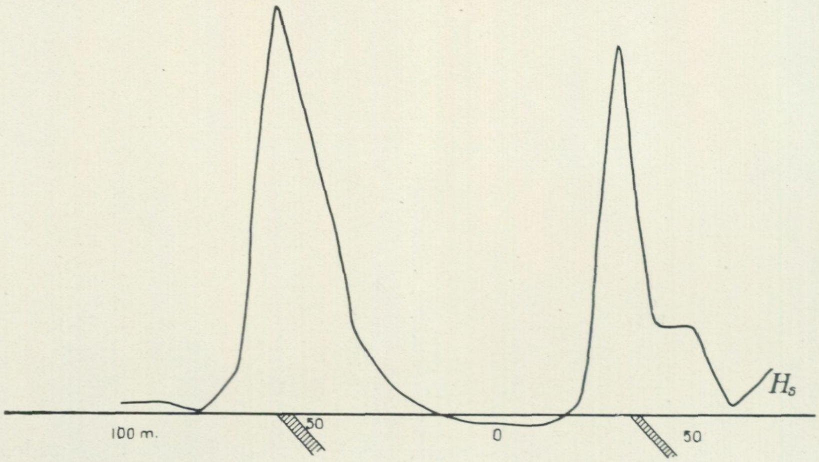
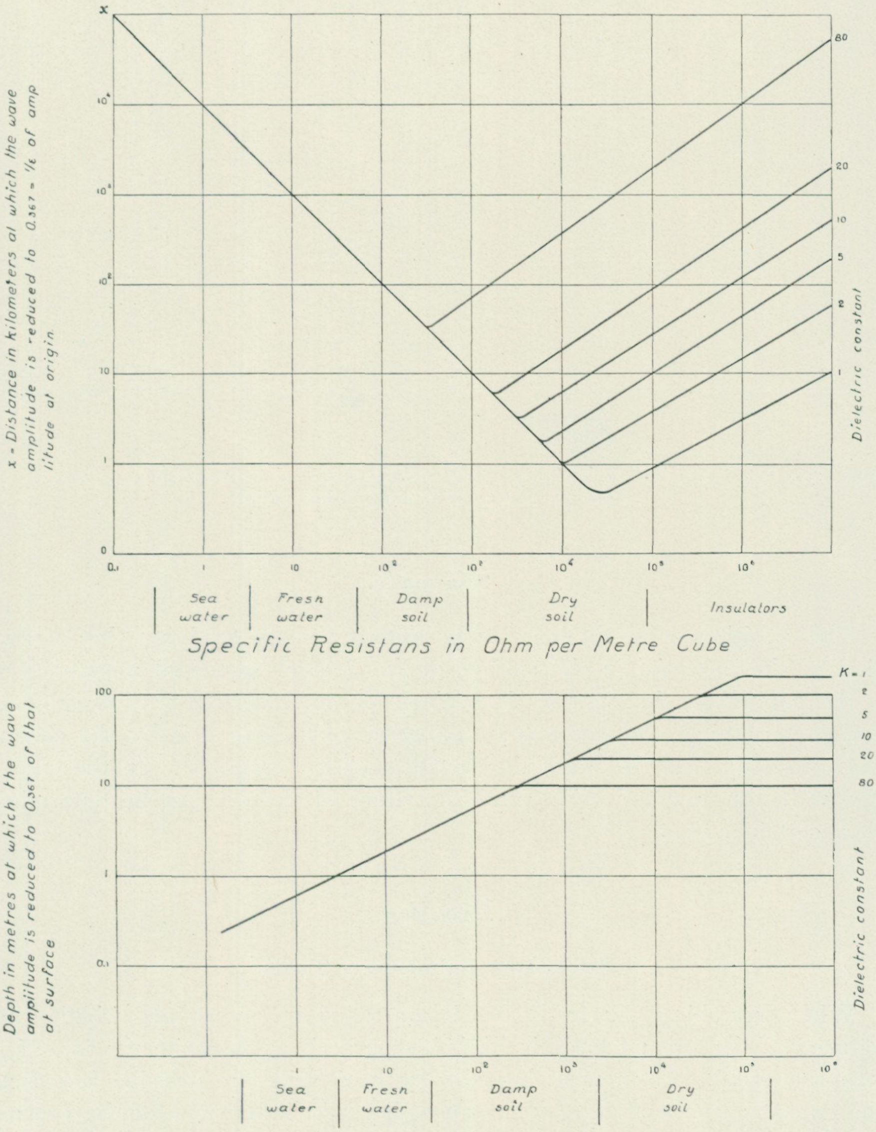


Fig. 18. Horisontal component of electro-magnetical field above two parallel ore-bodies.

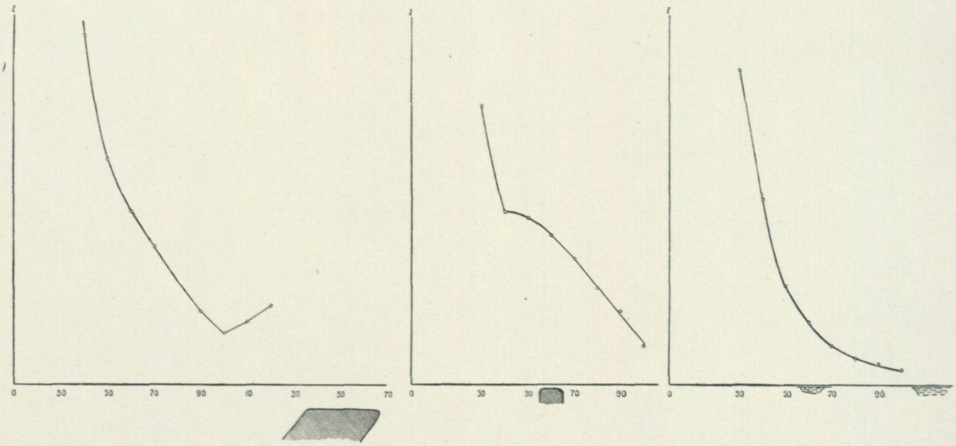
terranean material, as shown by fig. 19, taken from Zenneck. The conductivity of the soil, even when only slightly damp, is so strong that at least short electro-magnetic waves are rapidly absorbed, so that at a slight depth the energy is only a fraction of what it is on the surface. This is evident from fig 20, which is also taken from Zenneck. It is therefore unlikely, except in dry districts, that the position of deeply situated ore-bodies can be determined by electro-magnetic waves transmitted from a point on the surface of the ground. The fact that shallow ore-bodies can be detected by means of a »wireless» or »radio» investigation, even in wet districts, is shown by investigations carried out by Sundberg above known ore-bodies in Central Sweden. In a total of 22 investigations, distinct indications were obtained in 17 cases, indistinct indications in 3, and none in 2. As will be seen from figs. 20 and 21 taken from these operations, the ores make their presence known by the current in the recei-

[1] Annalen d. Physik, Vol. 23, 1907.



Figs. 19—20. Reduction of amplitude of electro-magnetic waves above and in different medias.

ving antenna, increasing in front of, and decreasing behind, the ore-body. Fig. 22 shows that by these investigations water did not cause indications, probably because the electrical properties of the water in these cases are scarcely discernible from those of the soil. In comparison with other electro-magnetic methods the »wireless» ones are at present of no importance. It is probable, however, that they will be of greater importance in the future.



Figs. 21—23. Reduction of intensity of electro-magnetical waves above ores and water. (Distances in metres from transmitting station).

Summary.

The position of ore-bodies can be determined by studying the distribution of the potential in the surface of the ground (potential methods).

By supplying the current *inductively* or *galvanically* into an ore-body and determining the secondary magnetic field generated by the current, the ore-body can be located (electro-magnetic methods). In the case of the inductive method, the physical nature of the ore can be determined to a certain extent.

Practice.

Preceding Laboratory Tests.

When searching for ore-bodies it must first be ascertained whether the nature of the ore minerals is likely to be such as to make the investigation successful. From what has already been said, the decisive factors are the specific conductivity, the permeability and inductance of the ore and of the surrounding rocks, i. e. the *electrical* and *magnetic properties* of the ore and the rock, which properties therefore should be examined. In addition to this, the geological conditions, such as the structure, the sequence of strata, the depth to the ore-bearing horizont, the extension of the ore-bodies etc., determine if the electrical investigatigation is at all possible. Further, the method of investigation which should be adopted as most suitable must be ascertained. In doubtful cases a laboratory investigation can be made on a small scale, under conditions analogous to those expected in the field. The field-work should therefore be preceded by work in the laboratory, as this is by no means insignificant, such as tests of the physical properties of the ore and rocks, as well as examination of model ore-bodies. This part of the work as well as other laboratory investigations has chiefly been carried out by E. D. Lindblom, graduated E. E.

How to determine the specific resistance of an ore or a rock has previously been described (page 10).

In order to judge the possibility and expediency of supplying the current inductively when prospecting for a certain type of ore, an examination of the electrical properties of the material in question is made by placing a small spool on a tolerably plain surface of the sample in question and sending an alternating current of a certain frequency through the spool. The currents thus induced in the sample cause an apparent change in the ohmic resistance and the inductance of the spool, from which the electrical and magnetic properties of the secondary field are then derived. Table III shows the result of some investigations of this kind.

Table IV.

	Frequence I		Frequence II		Frequence III	
	Rel. damping	Rel. change in inductance	Rel. damping	Rel. change in inductance	Rel. damping	Rel. change in inductance
Conglomerate with native copper, Mich., U. S. A.	0.76	0.89	0.68	0.88	0.39	0.84
Cuprite, Ariz, U. S. A.	0.94	0.49	0.87	0.96	0.74	0.89
Chalcocite, Butte, U. S. A.	0.78	1.00	0.63	0.99	0.98	1.01
Chalcocite, Långban, Sweden	0.67	1.43	0.92	1.06	0.96	1.05
Pyrite ore, Bjurträsk, Sweden	0.77	1.00	0.36	0.85	0.39	0.93
Pyrrhotite, Sudbury, Canada	0 82	1.03	0.37	0.94	0.46	0.93
Pyrrhotine-norite, Sudbury, Canada	0.52	0.96	0.39	0.96	0.91	1.02
Graphitic slate with pyrrhotite	0.98	1.02	0.98	0.99	0.78	1.00
Braunite, Långban, Sweden	0.99	1.44	1.05	1.12	—	—
Titano-magnetite, Fatmomakke, Sweden	0.92	2.87	1.19	1.42	0.94	1.20
Magnetite, Fierro, N. Mex., U. S. A.	0.81	3.00	1.10	1.10	0.88	1.28

Field work.

Using the potential method according to Lundberg, the investigation is carried out in the following manner: Two bare metal wires, electrodes, 300 metres to 1½ kilometres in length, are laid out on the ground at approximately the length of the electrodes from each other. The electrodes are grounded at suitable points, and connected with each other and a generator by means of an insulated cable. The current used is single-phased, alternating current with a constant frequency. As a source of current storage batteries or a generator are used.

For tracing equipotential curves a searching circuit is used consisting of two searching rods (iron rods fitted with insulated handles) and connected to an insulated line attached to a telephone. One of the searching rods is placed at the point *a* (fig. 24) and the other alternately at, say, points *b*, *c* and *d*. Let us now suppose that the 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*; *a* and *c* thus are of the same potential. Several other points c_1, c_2, c_3 at the same potential as *a* are traced in a similar manner. If these points are mapped and joined up, an equipotential curve is obtained. In this way other curves are traced, and all are marked out on the ground and mapped by means of a transit and stadia rod.

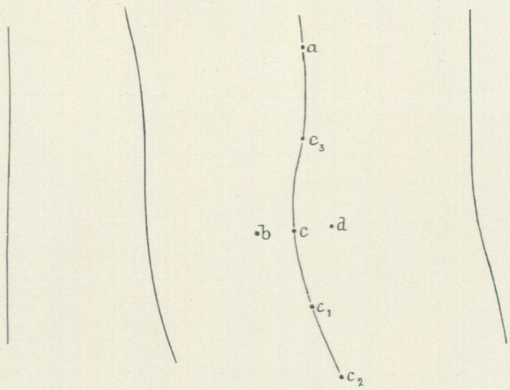


Fig. 24. Tracing of equipotential curves.

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 each other, say 30 to 150 metres, depending on the geological conditions.

In cases where the sensitiveness of the telephone is not sufficient, an amplifier can be used to strengthen it. If the course of the equipotential curve shows disturbances, several new curves must be traced in places between those already traced, so that as clear and detailed a knowledge as possible may be otained of the position and outline of the conductor.

In mapping the equipotential curves, attention is usually paid to certain topographical and geographical details, such as lakes, swamps and rivers, shafts and trenches, and also objects and rocks likely to disturb the electrical field, such as power and pipe lines and the geological conditions.

The time required for the survey mostly depends upon the topographical conditions, the soil, the vegetation and the climate, but as a rule, 3 to 8 kilometres of equipotential curves can be traced per day per observer. The staff consists of one observer, one surveying assistant and four unskilled hands. Fig. 25 reproduce a photograph of field investigations.

Using the electro-magnetic methods according to Sundberg, investigations are made in the field regarding the secondary field caused by the ore-bodies and other conductors. The observations are generally made at points marked on lines staked or cut on the ground, but they can also be made at arbitrary points, the positions of which must then be specially surveyed. As a rule, a preliminary investigation is first made along lines 50 to 75 metres apart at right angles to the general direction of the strike. In doing so, the course of the vertical component of the secondary field is investigated. This investigation is intended to determine the approximate position of conductive bodies. A prepared area of 1 sq. kilometre is, as a rule, investigated in about three days by two men, in which case five unskilled hands are required. The indications are then examined in detail, and in doing so, the observations are made along lines 10 to 25 metres apart and the points of observation are more frequent than in the reconnaissance. In making the detailed investigation, the horizontal, as well as the vertical, components are read off. In cases of steepdipping strata one set-up is, as a rule, required in order to distinguish the position of the hanging-wall of the conducting body, and another set-up to distinguish the foot-wall. The result of these detailed investigations are then put together on a map, the outlines of the conductor being obtained by connecting the various points of the boundary lines. As a rule, it has been possible to determine the outlines of the conductors to within a few metres, even when the over-burden has exceeded 20 metres. The method has not yet been tested in the case of deeper ore-bodies, but there is no reason to suppose that the results will be less accurate by any appreciable extent for greater depths, if conditions in other respects are favourable.

Fig. 25. Field work, potential method.

Fig. 26 reproduce a photograph of field investigations. Both in 1923 and 1924 surveys have been carried out in the north of Sweden throughout entire winters, at times at a temperature of 40° degrees below zero.

Fig. 26. Field work, eloctromagnetical method.

Magnetic, seismic and gravimetric methods.

It has already been pointed out that the electrical methods are by far the most important for prospecting purposes. But the other geophysical methods, i. e. magnetic, seismic and gravimetric, are often used as auxiliary to the electrical methods. Except in prospecting for magnetic ores, these auxiliary methods are not used before the electrical investigations are finished.

The well-known *methods of magnetometric surveying* need not be dealt with in detail in this article. Perhaps it ought to be pointed out that the magnetic methods are strictly to be regarded as a special case of the electro-magnetic ones, i. e. the case of the electro-magnetic primary field being single-phased.

Besides the Thalén-Tiberg and Thomson-Tahlén-Sundberg instruments, a most sensitive one has been used also here in Sweden, the Schmidt local-variometer. This instrument was made by A. Schmidt in 1914,[1] and consists of a magnetic needle placed horizontally in a brass cover, resting on two

[1] A. Schmidt: »Ein Lokalvariometer für Vertikalintensität», Potsdam 1915.

quartz edges and moving easily round a horizontal axis. In the middle of the needle a mirror is fastened, and vertically above the mirror is a system of lenses with eye piece and ocular scale. When using the instrument, the displacement of the reflected scale in proportion to the fixed one is studied, and in this way the deflexion of the needle is obtained, and consequently also the component of the magnetic field. Correction is made for temperature, daily magnetic variations etc. Each observation takes about 10 minutes, and the strength of the magnetic field is obtained to within about 0.0003 Gauss, or about 0.15 % of the horizontal component of the terrestrial magnetic field. Thus the instrument is 20 to 30 times as sensitive as an average Tiberg balance and about 5 times as sensitive as a good Thomson-Thalén instrument.

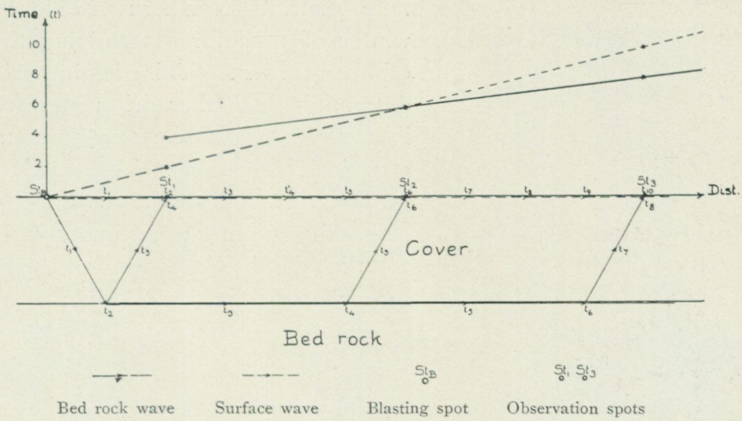


Fig. 27.

The Schmidt balance has been used for examinations to determine whether the electrical indications were magnetic, i. e. probably caused by magnetite or pyrrhotite. In several cases magnetic indications have been obtained with this instrument over ore-bodies where no deviation of the Tiberg magnetometer has been discernible.

The principle of *seismic*[1] methods is to be seen from fig. 27. At a point on the surface St_B a dynamite cartridge is fired, thereby causing elastic waves to emanate in all directions from the said point. By means of a seismograph placed at a certain distance, St_1, from the blasting spot, record is made of the time, *t*, which has passed from the moment of firing to the moment when the first wave sets the seismograph vibrating. The time *t* is observed for different distances, St_n, between the seismograph and the blasting station. If the elasticity of the medium beneath the surface is homogeneous, *t* will evidently be proportionate to the distances,

[1] Seismos A. G.: Mitteilung I und II.
H. Reich: Stahl und Eisen 1921.

and the ratio $\frac{St_n}{t}$ be the speed of the elastic waves. If, on the other hand there are several layers, 1, 2, 3, each with a higher elasticity than the overlying layer, the elastic waves in the medium 2 will have a greater speed than those in 1, etc. At a certain point between the seismograph and the blasting station, the waves passing through medium 2 will consequently arrive before the waves passing directly through 1. This is noticed from a change in the quota $\frac{St_n}{t}$, when the distance St_n is increased. By determining this point, the thickness of medium 1 can be determined, as well as the speed of the elastic waves passing through medium 2.

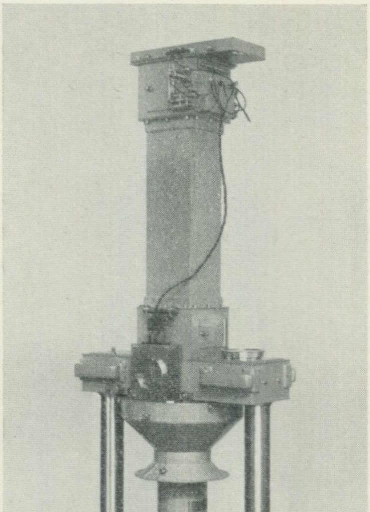


Fig. 28. Eötvös torsion balance.

Seismic methods were used in the Skellefte district (Northern Sweden) in the winter of 1923 for determining the depth of overburden. This is important for determining whether drilling or trenching is preferable for the examination of the electrical indications. The depth of overburden thus indicated has proved to correspond, within approximately 1 meter, to the depths later on ascertained by means of drilling or digging.

Tests for determining the physical properties of the bed rock from the speed of the elastic waves passing through it, have not been successful. This may, however, be due to the fact that the elastic properties of the different rocks and ores have not been sufficiently studied.

Besides the magnetic methods, the *gravimetric* or gravity methods[1] are the principal auxiliaries of the electrical methods. For gravimetric investigations the so-called torsion balance is used, by means of which the English physicists Mitchel and Cavandish determined the weight of the earth as early as in the 18th century. About 1900 the Hungarian Eötvös utilized the torsion balance for practical geological investigations and gave it a special construction suitable for this purpose. The Eötvös apparatus, as designed by him, is, on the whole, even used nowadays, although certain improvements have been made (fig. 28).

[1] H. Gornick: Verein Deutscher Eisenhüttenleute 1921.
Stephen Rybar: Economic Geology 1923 p. 638—662.
H. Shaw and E. Lancaster-Jones: Mining Magazine 1925 Jan. p. 18—25, Feb. p. 86—92.

From a platinum wire hangs a scale-beam with arms of equal length and loaded on both sides with equal gold weights (about 30 grams). One weight rests directly on the beam, while the other hangs at one end of a platinum wire, the other end of which is fastened to the beam. In consequence of this arrangement, the force of gravity is not equal on both weights, i. e. the gravity endeavours to turn the beam. This torsion is read off, and from the degree of torsion it is, of course, possible to determine the turning moment, i. e. the difference of the horizontal component

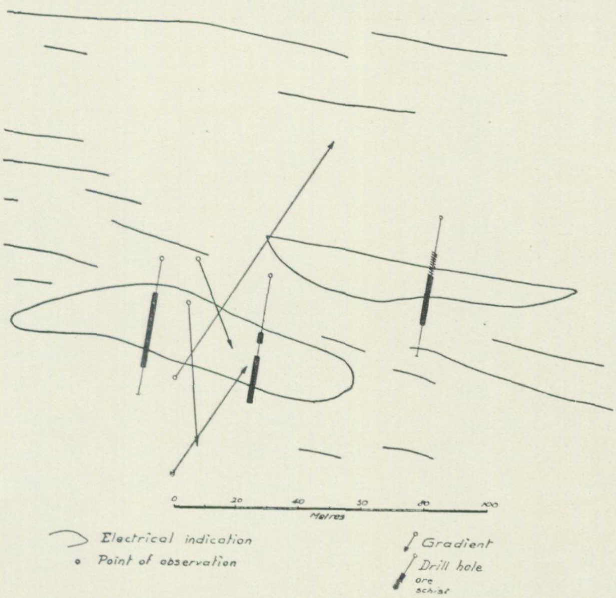


Fig. 29. Gravimetric measurements above an ore (Mensträsk).

of the gravity at the two points where the weights are hanging. For different positions of the beam in the horizontal plane, different turning moments are obtained, and the turning moment has its maximum value when the beam is at right angles to the direction in which the difference between the horizontal components of the gravity for the two points is greatest. Thus it is evident that, with a sufficient number of observations, it can be determined in which direction the change in the horizontal component of the gravity is greatest, as well as the amount of this change. For this purpose five observations are necessary at each point; this number has been reduced to three double observations by making a double instrument. Thereby is a check reading obtained at every point. The registration of the observations is made photographically. In one day it is, as a rule, possible to make two, and in favourable cases, three series of observations, i. e. observations at two and three points. The result of the observation at a certain point is obtained in the form of a gradient showing the direction in which the rate of increase of the horizontal component of the gravity is greatest in the case of vertical movement, as well as the extent of this deflexion. Fig. 29 shows the result of a gravimetric investigation above an ore-body.

Interpretation.

The Swedish electrical methods distinguish themselves from earlier methods by giving the exact outline and position of the conductor. If the geology of the district is known, it is therefore often possible to determine from the form, extension and position of the indications whether they are caused by ores, disseminations, graphitic slates or basic dykes.

Graphitic slates and iron formations generally occupy distinct, widely spread horizons in the formations, and always follow the general strike and dip of the country. Indications caused by slates are therefore as a rule, long, continuous and regular, and of greater dimensions than are likely to be caused by the ore-bodies prospected for. There are cases, however, especially in strongly folded strata, where the slates are torn and divided into a series of short lenses. The indications obtained from such rocks are puzzlingly like ore-indications and may lead to useless drillings and excavations without avail, if the question cannot be solved in another way.

When the ore-bearing formation is not covered by moraine, alluvium or other strata of younger date, most slates and dykes are likely to outcrop at the place where the indication has been obtained, provided that the dip is not too low. The cause of the indication can be ascertained at once by a simple geological survey, or, in districts already surveyed, by a comparison with the geological map.

If the prospecting area, however, is situated in once glaciated terrains, it renders the interpretation of the indications more difficult. The covering moraine is often so deep and watery that a direct investigation encounters great difficulties. Moreover, these terrains usually are rich in swamps and lakes. In such cases effective assistance is rendered by boulders in the moraine. If the moraine, on examination at a distance from the electrical indication in the direction of the glacial transport, shows an abnormal abundance of a certain conductive rock, dissemination or ore, the indication is certainly caused by this rock, dissemination or ore. Such an investigation, however, is not always successful, for instance in cases where the moraine has been carried a long way and does not contain any boulders from the immediate neighbourhood. If, in the vicinity of the indication, the moraine is covered by a lake, swamp or sand, the direction of the glacial transport is followed to a place where the moraine is not covered. The moraine sometimes can be reached by means of digging. The greater the distance from the indication, however, the rarer the boulders, and reliable information is not likely to be had from moraine examinations further than one kilometre from the indication.

It has been said before that electro-magnetic investigations sometimes give valuable information concerning the physical properties of the material causing the electrical indication. With the technique now developed, it is, as a rule, possible to ascertain by means of qualitative investigation whether an electrical indication is caused by

1) a solid conductor, containing no considerable amount of non-conductive rocks,

2) a banded conductor,

3) a magnetic conductor.

In the first place, conductors of the first kind naturally invite to further investigation.

In many cases a magnetic investigation is a great help in the interpretation of an indication, especially in metamorphic terrains, where magnetite and pyrrhotite commonly occur.

Graphitic slates and »fahlbands» often contain small quantities of strongly magnetic pyrrhotite which give as strong indications as pure magnetite ores, although containing but a small percentage of iron. However, the pyrrhotite is generally irregularly scattered in disseminations, veins or bodies, which gives the magnetic indication a »disturbed» appearance with small and very strong indications separated by rather weak parts. An iron formation, on the other hand, usually gives a uniform magnetic indication.

In conjunction with electrical prospecting, gravimetric investigations have been carried out in northern Sweden, with a view of ascertaining whether an electrical indication was caused by ores or graphitic slates, i. e. by a material the specific gravity of which is higher than, or about the same as, that of the surrounding rocks. It is a fact that black slates have almost the same specific gravity as other rocks, while a compact ore has a much higher specific gravity than black slates, as well as leptite and other rocks. These gravimetric investigations have led to satisfactory results, above larger ore-bodies even under a cover of more than 15 metres (fig. 29). However, great inconvenience is caused by the fact that even a rather small ridge in the bed rock covered by sand or moraine, especially when the overburden is shallow, gives indications that cannot be distinguished from those given by ores. It certainly is an unfortunate incident if a conducting slate is situated on such a ridge, thereby causing the electrical and gravimetric indications to coincide. Such cases have occurred (fig. 30).

By comparing all the data secured in the above way or otherwise, the indications obtained by means of electrical investigation can be divided up into such that are caused by non-metalliferous conductive rocks and such that ought to be more thoroughly investigated by means of excavation or drilling, either because they are likely to contain ore, or because knowledge of their contents can not be obtained in any other way. In such cases, the advantages of electrical investigations are evident. As it is possible to determine the position of the conductor to within a few metres,

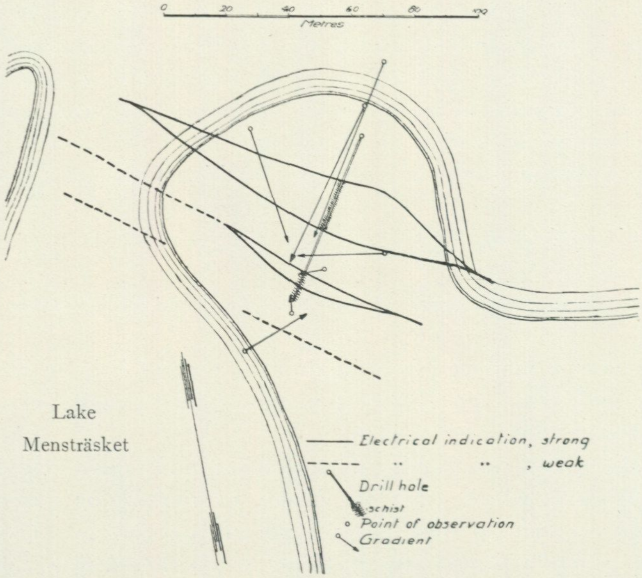


Fig. 30. Gravimetrical indication obtained on a covered ridge in the bed rock (Mensträsk).

there is practically no risk of passing the ore without finding it by drill-holes or shafts. Exploration works in non-ore-bearing rock can also be reduced to a minimum, because the indication shows the position of the uppermost part of the ore, which can therefore be reached directly by one vertical drill-hole. For steep-dipping ore the thickness can be determined by means of a short, inclined drill-hole through the upper part of the ore and thus extensive drilling at a great cost avoided.

Practical results in Sweden.

Four ore-bearing districts of importance can be distinguished in Sweden (Fig. 31). Two of them have been known from ancient times, viz. northern Lappland or Norrbotten, which is chiefly an iron ore district (Kiirunavaara, Gellivare etc.), and central Sweden or Bergslagen, containing both iron and sulphide ores. The ores in these districts have been found either directly, when outcropping, or by means of compass, most of them being magnetic. The compass has been used for prospecting purposes in Sweden for more than 250 years. Only recently has electrical prospecting been used in these districts, chiefly with the object of discovering new ore-bodies in fields where mining has been carried on since ancient times.

The other two ore-bearing districts, the Skellefte district and the Västerbotten mountains of southern Lappland, have been discovered in later years essentially by means of the electrical prospecting method in conjunction with geological investigations. They contain almost exclusively sulphide ores. The Skellefte district is the larger and more important of these two ore-fields, and will be dealt with in detail in the following.

The Skellefte district. (Plate 1.)

History.

Prospecting in the Skellefte district was started about 1900, when the arsenopyrite in numerous veins of quartz was discovered to be auriferous. About ten deposits spread over the whole of the district were made objects of extensive trenching and blasting. However, the deposits were always too small for profitable mining operations although the arsenopyrite often contained high values in gold. The work therefore ceased about 1908. In searching for gold, signs of other ores — especially pyrite — had, however been found in the form of boulders in the moraine. In one case, Sandlidberget, the mother lode itself had been found. The most important discovery of ore-boulders, at Bjurfors, caused an extensive search for the mother lode. Not less than 500 metres of trenches, as well as four shafts, were dug, but without success. As shown later on, the ore proved to be two kilometres from the place where these works were carried out. This shows best how small were the chances of discovering such moraine-covered ore-bodies, before the introduction of electrical prospecting, and

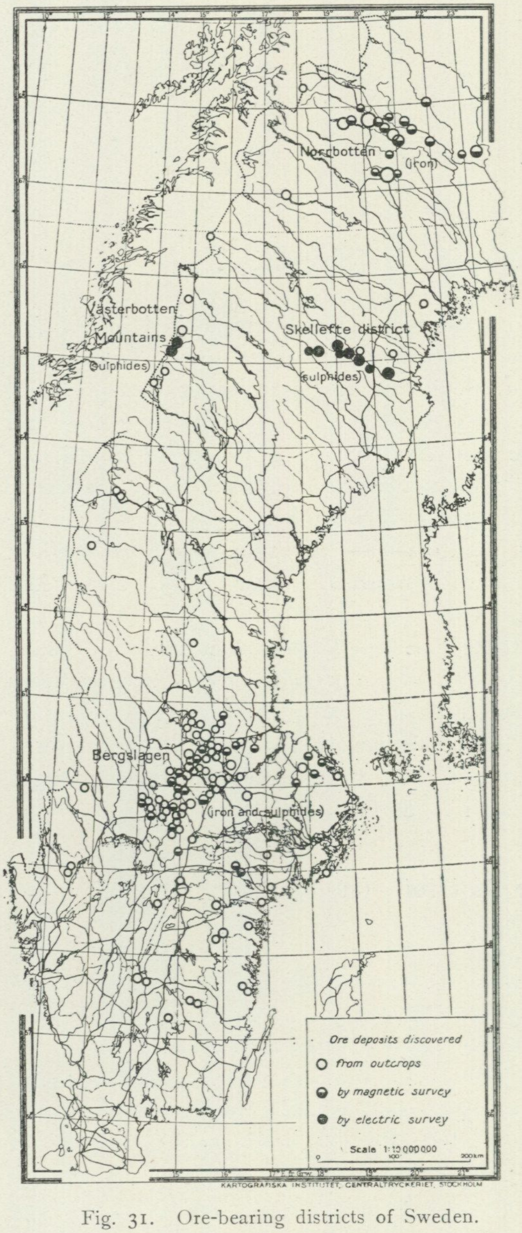


Fig. 31. Ore-bearing districts of Sweden.

how hazardous all prospecting must be. As no paying ore had been found (at that time the pyrite of Sandlidberget was considered of no value), these works ceased at the same time as the prospecting for gold.

On account of the high prices of metals during the war, and the scarcity of most raw materials such as pyrite and copper caused by the blockade, the interest of the prospectors was once more turned to the Skellefte district. In 1918 an examination was made by several mining engineers and geologists, and the Sandlidberget, Bjurfors and Kristineberg ore-fields were considered worth further investigation. Complete exposure of Sandlidberget was effected by means of trenches, which struck five ore-bodies, together containing 1,300 sq. metres of pyrite ore. At Bjurfors and Kristineberg electrical prospecting with equipotential methods was carried out for the first time in this district, on the initiative of the Centralgruppens Emissions A.-B. At Bjurfors no indication was at that time obtained, as the investigations covered but small areas, none of which was orebearing. At Kristineberg two ore-bodies were located. By means of further electrical investigations in 1919 the whole of the Kristineberg ore-field was discovered in less than one month. Eight trenches were made, five of which struck ore, two disseminations and one a rich but narrow stripe of pyrite. The advantage of electrical prospecting was so evident in this case, that it gained ground at once in Sweden.

In the following year, 1920, the Geological Survey of Sweden (Sveriges Geologiska Undersökning) and the Centralgruppens Emissions A.-B. started a more thorough geological examination of the Skellefte district, in conjunction with electrical investigations. It was a great undertaking. While the previously investigated areas comprised no more than a few hectares, or one sq. kilometre at the most, several hundreds of sq. kilometres were now to be investigated, the ore-bearing part of the Skellefte district being some 4,000 sq. kilometres.

In 1920, the work was carried out exclusively with the potential method, and the distances between the electrodes were small (about 250 metres). No ore-bodies were found, and the work consisted essentially in preparations for the future investigations. Ore-boulders were found at Bjurfors, Örträsk, Bjurträsk, Gissträsk, Maurliden, Udden and Bredselet, showing that the ores were widely distributed throughout the district.

In 1921 the known ore bearing district was considerably extended by the discovery of boulders at Svanfors, Dalliden, Skansberget, Braxträsk, Bjurliden, Mensträsk, Rakkejaur, Näsliden, Vindelgransele and Kuorbevare. This extension of the area to be investigated, however, required most of the staff for the geological survey, and only two ore-bodies were located, Bjurträsk (Slåttermyran) and Rakkejaur. The squares used for equipotential investigations had been increased to 1 sq. kilometre, and an amplifier had been used. In this year electro-magnetic methods were also tested for the first time by the Centralgruppens Emissions A.-B.

In the following year, 1922, only few additional promising places were found, but those previously known were more thoroughly investigated by means of electrical prospecting. In the early summer ore were struck at Näsliden by the Centralgruppens Emissions A.-B., and in the autumn at Bjurliden and Bjurfors by the Geological Survey of Sweden. The electromagnetic method had been developed so as to be of practical value, and in the equipotential method the amplifier came into frequent use. In the winter of 1922—1923 the Mintrop seismic method was tested at Mensträsk and Braxträsk, and for the first time extensive investigations were carried out in winter (by Centralgruppens Emissions A.-B.)

In 1923 the investigations were continued along the same lines as before, and in the winter of 1923—1924 the Centralgruppens Emissions A.-B reached the ore-bodies beneath the lake Mensträsket, by means of drill-holes.

In 1924 exposures were made of the Vindelgransele ore-bodies by the Geological Survey of Sweden, and of the Braxträsk and Boliden ore-bodies by the Centralgruppens Emissions A.-B. This company also discovered new ore-fields at Granbergsliden and Petikträsk. In the same year, the Centralgruppens Emissions A.-B. started exploitation of auriferous arsenopyrite at Holmtjärn (Granbergsliden).

Geology. (Plate 1.)

The Skellefte district comprises an area of supercrustal Archean formations intruded and folded by granites. It extends from the Gulf of Bothnia about 160 kilometres westwards. An area of granite separates it from the Stensele district where, however, no ores of importance have yet been found.

The oldest rocks of the district belongs to the leptite formation, the main ore-bearing formation of Sweden. It corresponds to the Keewatin of North America.

The leptite formation consists almost exclusively of volcanics (lavas, breccias and ashes). Acid rocks dominate. Only in the upper part of the formation there are some layers of limestone and slate. With regard to the degree of metamorphism the acid volcanics are named hälleflinta (dense), leptite (fine-grained) or gneiss (medium to coarse-grained).

Conformably above the leptite formation rests »the black slate series». This consists of dark, schistose hälleflintas, black pyritic and graphitic slates, grey slates, greywackes and greenstones. There are also some minor layers of conglomerate with pebbles of slate, quartzite and greenstone but no granites.

The leptite and slate formations are intruded and folded by an Archean granite, the Jörn granite, which corresponds to the »Ur-granites» of Southern Sweden and the Laurentian granites of North America. As in Southern Sweden this granite has caused extensive metasomatical alterations in the leptite formation resulting in the formation of sericite- and chlorite-quartzites, chlorite-schists or skarn-rocks (Ca-Mg-Fe-silicate masses). These alterations extend over hundreds of sq. kilometres and are accompanied by ore deposition.

The intrusion of the Jörn granite and the folding were immediately followed by a serie of conglomerates and greywackes named the Vargfors formation. Its post-granitic age is indicated by numerous pebbles of the Jörn granite. The Vargfors formation corresponds to the Kalevian of the Finlandian and the Temiskaming of the Canadian geologists.

The Skellefte district is bounded in the south of a large area of a very coarse, porfyritic granite, the Revsund granite. This belongs to the Serarchean group of Southern Sweden and corresponds to the Algoman granites of Canada. It has caused intense metamorphism and folding of the older rocks resulting in the formation of veined gneisses, gneissic granites and amphibolites. The Skellefte granite is the aplitic phase of the Revsund granite. The geological position of the Arvidsjaur granite, which occupies large areas to the north-west, is not quite clear. It resembles the Revsund granite.

The ores of the Skellefte district are of five different types.

1. Large sulphide lenses in metasomatically altered parts of the leptite formation.

2. Sulphide lenses in »the black slate series».
3. Quartz-veins containing auriferous arsenopyrite.
4. Chalcopyrite-fahlbands in the gneisses.
5. Calcite-veins with galena and fluorite.

Only the first two items are of commercial value.

The ores consist of pyrite, pyrrhotite, chalcopyrite, zinc-blende and arsenopyrite. They are often auriferous. Galena is remarkably rare. Boulangerite ($Pb_3Sb_2S_6$) on the other hand, is rather common, although not yet found in compact ore-bodies. The different types of ore are generally well separated from each other.

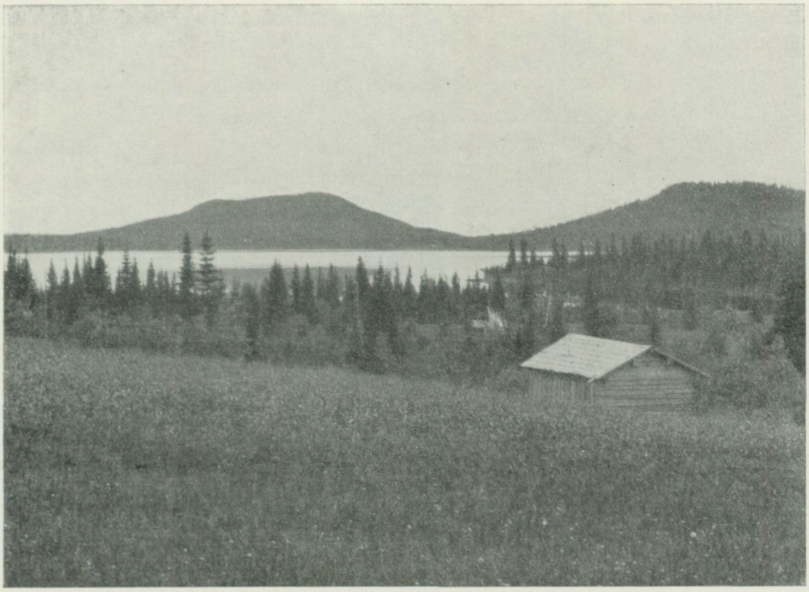


Fig. 32. View from the central part of the Skellefte district (Mensträsk).

The ores form lenses of different sizes and are lying conformably in the schistose rock. The length varies usually from 40 to 600 metres, and the width from 5 to 30 metres. A poor pyrite ore body is as much as 80 metres wide. The whole district is covered by quaternary deposits; moraine, swamps, fluvio-glacial sand and gravel and below 210 to 230 metres above the sea level also sand and clay deposited in the sea of the great Ice-age. Only occasionally the bedrock is exposed in small outcrops often not larger than some tens of sq. metres. In areas of several sq. kilometres there is sometimes no outcropping at all. It is easily understood that there is but slight chance of the ores showing in one of these outcrops and in fact it has not happened more than twice. This is the chief reason that these ores have not been discovered until now, although the district has been inhabited since the 16th century. It was only by the electrical prospecting methods that a means was found for the discovery of these covered ores.

The surface consists of: moraine 68 %, sand 7 %, swamps 20 %, lakes 5 % and outcropping rock < 1/2 %. The average thickness of overburden is 7 to 8 metres, but it often increases to more than 20 metres, especially in the valleys.

There is a great number of lakes in the district. As the ores, of course, can be situated also beneath the lakes, only such prospecting methods could be used that act also above water and are not influenced by same. This proved to be the case both with the electro-magnetic methods and the potential method, and investigations have been carried out by means of these methods from boats, as well as on the ice. To the present time 800 hectares of open water have been investigated in the Skellefte district, and four ore-bodies have been discovered beneath lakes.

Geological survey and electrical investigation.

The geological survey of the Skellefte district, the structure of which was previously almost unknown, has consisted in reconnaissance mapping, detailed investigation, and determining of such areas that are likely to be ore-bearing and should therefore be subjected to electrical prospecting.

The purpose of the reconnaissance mapping has been to examine, in broad outline, the structure of the district, and especially to distinguish the ore-bearing formations from the granite and gneiss areas that are not ore-bearing. At the same time observations were made as to the composition of the moraine and the direction of the glacial transport.

In the reconnaissance mapping, the first signs of ores were generally obtained through discoveries of boulders of sulphide-ore in the moraine or outcroppings of such metasomatic alterations of the rocks as accompany the deposition of ores.

Detailed geological survey was then directed towards the areas suspected of being ore-bearing. If it was proved thereby, especially through discovery of rich ore boulders, that ore was likely to exist, the next steps taken were to fix the boundaries of the area that ought to be investigated electrically.

In carrying out the electrical investigation, the area was first made the object of a reconnaissance, which, as a rule, started from a definite sign of ore, for instance a boulder or an exposure of ore-bearing rocks. In the former case the area was investigated in the direction of the glacial-transport from the boulder towards the supposed mother lode; in the latter case the direction of the strike of the rock was followed till indications were obtained. As the ores were usually confined to certain zones of a considerable extent, the indications obtained were followed in the direction of the strike until they definitely ended. In following indication zones in this manner, discovery has been made of several ore-bodies that were otherwise quite hidden and did not make their presence known in any other way, for instance by boulders (see the western ore-body of Mensträsk (plate 4), the copper ore of Bjurfors (plate 5) and Boliden (p. 67).

The reconnaissance was carried out in large squares of $^1/_2$ to $1^1/_2$ sq. kilometres. As the ore-bodies lay conformably bedded in the rocks and the strike was generally known, the reconnaissance lines could be laid out at fairly large distances from each other, without any risk of passing important ore-bodies. This enabled the reconnaissance to be carried out with great speed. The purpose of the reconnaissance was essentially to locate indications or indication zones. The detailed investigation, on the other hand, aimed at determining the form, and especially the width, of the indications obtained and determining points suitable for drilling or trenching, sometimes also determining the structure of the ore (quality investigation), the depth of the overburden etc.

The electrical prospecting was, as a rule, combined with a magnetic investigation, and in certain cases also with a gravimetric or seismic investigation.

By comparing all the data obtained, and in the manner earlier described, the indications were divided up into positive and probable ore indications, slate-indications, and indications of which nothing definite could be said. Only the ore-indications and the most important of the uncertain indications have been further examined by drilling or trenching.

The Vindelgransele Ore-field.

At Vindelgransele in the western part of the Skellefte district some boulders of pyrrhotite, pyrite and zinc-blende were discovered in 1919.

When the district was geologically mapped in 1921, the area was examined and mining claims were taken. In 1922 a magnetic reconnaissance was made with a view of locating the mother lode, which, owing to the high percentage of pyrrhotite of the boulders, was supposed to be magnetic. A strong compass indication was obtained 200 metres to the NNW. of the boulders. In the spring of 1923 a thorough magnetic investigation was made, and some pits were dug at the places where the indications were strongest. All of them struck black slate with veins of pyrrhotite. As the magnetic investigations did not give a satisfactory result, electrical prospecting was carried out by means of the potential method. In the immediate neighbourhood of the boulders some strong indications were obtained, as well as a strong indication zone 200 metres to the north, where the strike was from east to west.

Beneath 1 to 4 metres of moraine two small ore-bodies were exposed in the former zone; in the latter nothing was found but black slate containing a large percentage of pyrrhotite. The western ore-body consists of cupriferous pyrrhotite, the eastern one partly of high grade pyrite (on

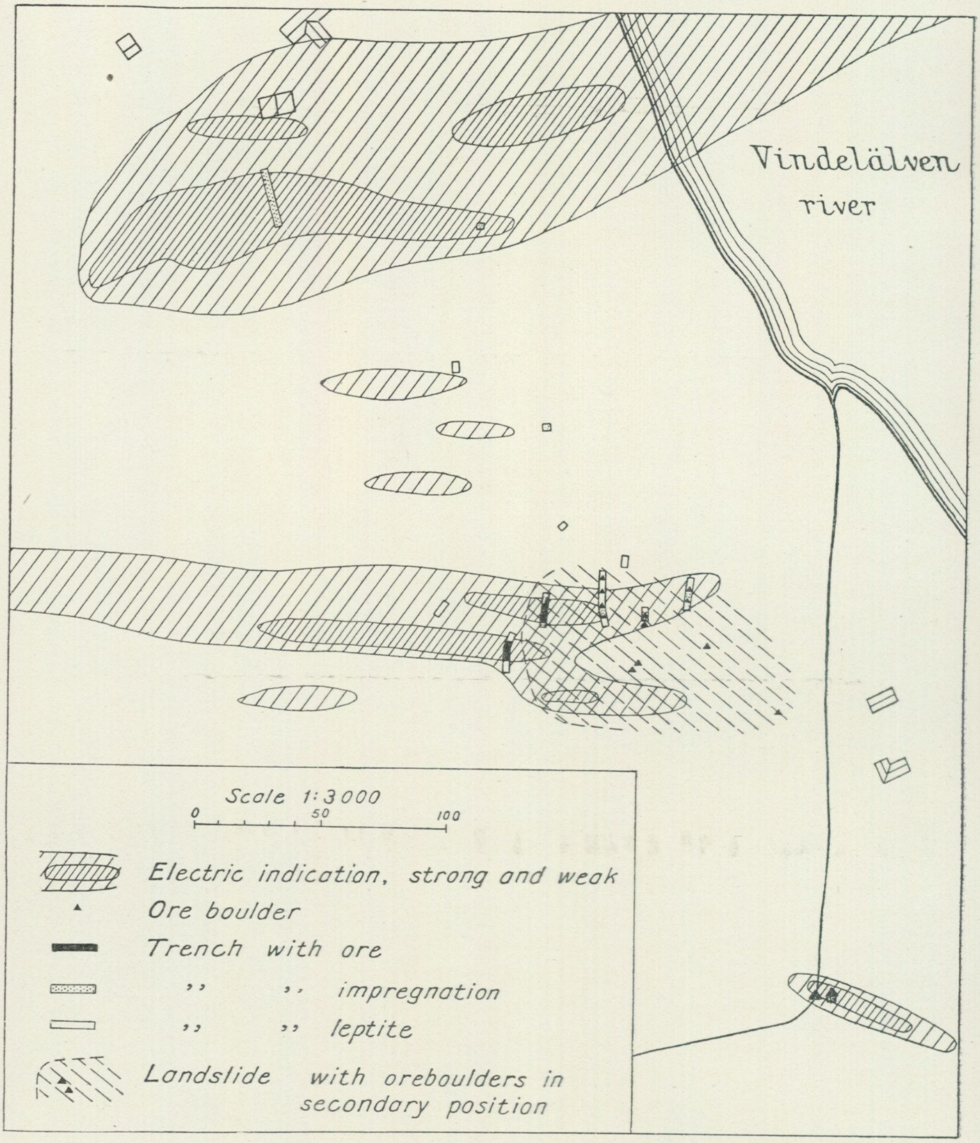


Fig. 33. The Vindelgransele ore field.

an average 47.5 % S) and partly of plumbiferous zinc-ore containing up to 39 % Zn. The widest exposure is 10 metres, and the horisontal area of the ore-body is most likely about 300 sq. metres.

As seen from Fig. 33 the agreement between indications and ores is very good. The indications have been constructed from three series of investigations.

The Kristineberg Ore-field. (Plate 2.)

The occurrence of ore boulders at Rävliden, west of Kristineberg (Fig. 36) 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 pyrite had been noticed.

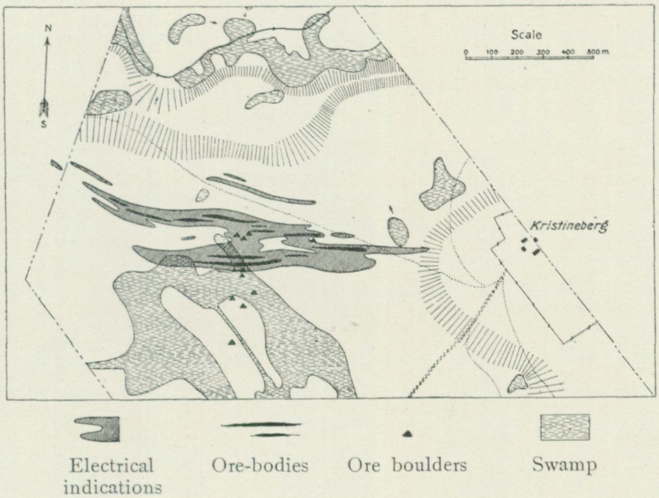


Fig. 34. Situation map of Kristineberg.

During the scarcity of pyrite in 1917, mining claims were located to cover the boulders. Mining experts who were consulted considered 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 north of the boulders as well as in their immediate neighbourhood (the exploratory workings marked in black on the electrical map, plate 2). No ore was found.

In October 1918 a small preliminary electrical investigation was made by the Centralgruppens Emissions A.-B. It immediately became evident that the general strike was from east to west, and that the bed rock contained several conductors. As the result of these investigations, one spot was pointed out as being favourable for making an opening, and 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 around the boulders.

The rock around and within the ore-field is composed of sericite-quartzite, chlorite-quartzite and chlorite schists. The distribution of these rocks (see geological map, plate 2) is very irregular, but this does not appear to affect the ores. The entire country-rock is slightly disseminated 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 IV, contain 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 ore so far developed is about 5,000 sq. metres. The probable total area is about 6,500 sq. metres. The width 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 investigation was carried out with the electrodes 160—200 metres apart. Only 5—8 curves were traced in the electrical field between the electrodes. No measurements were 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 (plate 2), equipotential curves, as well as the interpretation of the result in strong and weak indications, being also denoted.

If this map may 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 disseminations (the ends of indication I, the indication east of III and IV, the weak indications in the middle of the field and the large indication farthest to the north), and also by long bands of pyrite 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 indication which has been closely examined has been readily assignable to an ore, a narrow stripe or a dissemination.

The Näsliden Ore-field.

In the summer of 1921 some 20 boulders of pyrite were found at Näsliden in the parish of Malå. Here the search for boulders was rather difficult, because the greater part of the moraine was covered by swamps and mossy and morassy woods, which concealed the boulders. However, it was possible to locate a narrow trail of boulders (Fig. 35). In a reconnaissance, carried out in 1922 by the Centralgruppens Emissions A.-B. by means of electro-magnetic methods, two indication zones were obtained. Each of them was examined by means of a drill hole. Nothing but black pyritic slate and pyrrhotite was found. In the spring of 1923, electrical qualitative investigations were made, and as a result of same a hole was drilled, which struck ore immediately.

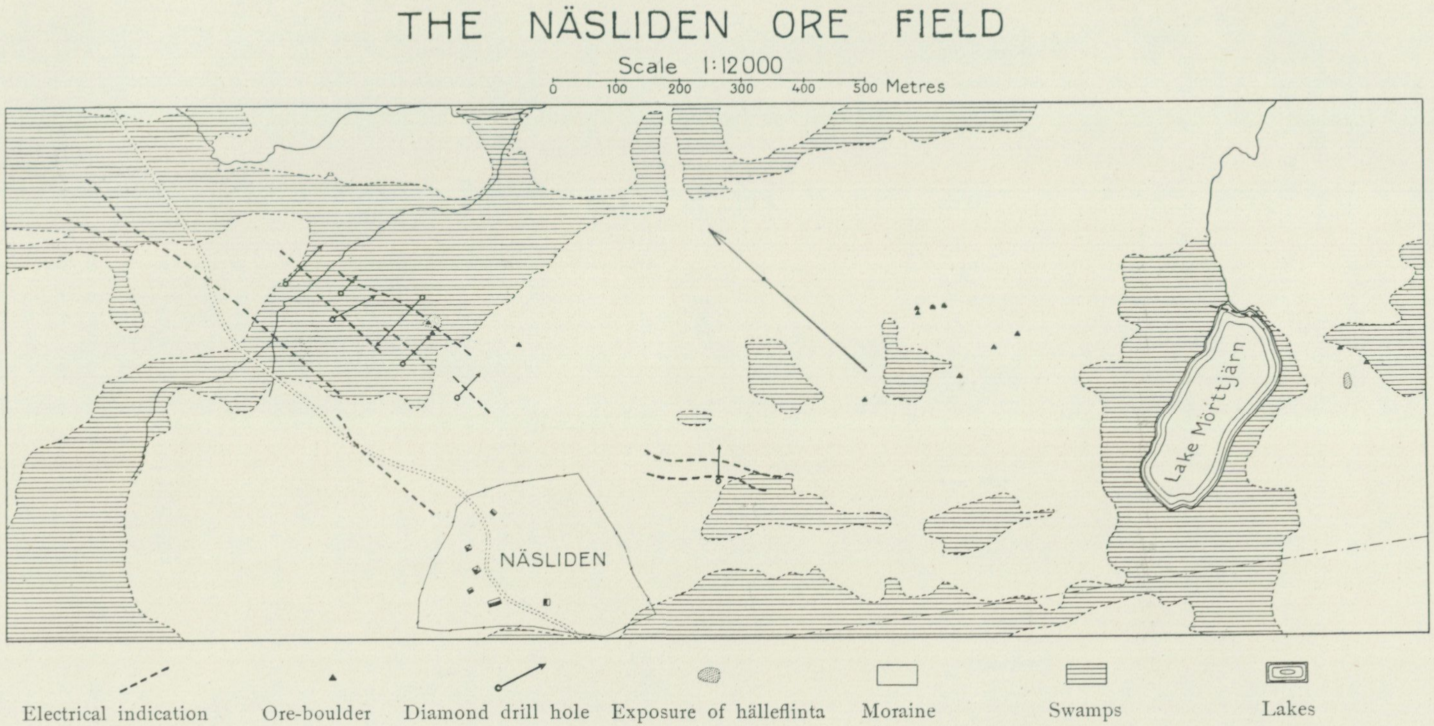


Fig. 35. Situation map of the Näsliden ore field.

The indication was examined later by means of four more drill-holes, all of which struck one or more ore-bodies.

The surrounding rock consists of highly sericitic hälleflinta with large phenocrysts of quartz. Black slate containing pyrrhotite often occurs in this ore-field, which evidently forms a small anticlinal ridge in a large area of slates.

The depth of the overburden varies from 2 to 15 metres. Only two outcrops are known in this district. A large part of the area is covered by swamps, and most of the ore-bodies lie beneath the swamps, which, however, had no effect on the prospecting.

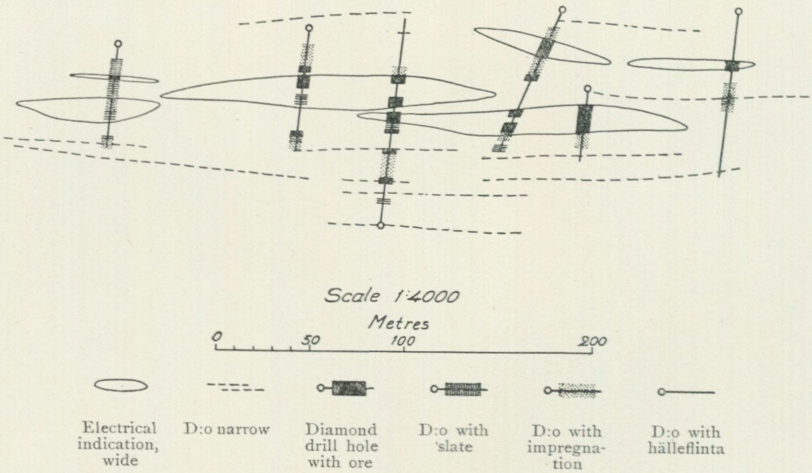


Fig. 36. The Näsliden ore field. Electrical indications and known ore-bodies.

From Fig. 36 the indications and ore-bodies are seen to agree very well. As a rule, the drill-holes have struck ore on the stronger indications. Although bands of black slate are numerous in this ore-field, only one drill-hole has exclusively struck slate.

The ore-bearing area is 3 to 4,000 sq. metres. The width of the lenses varies between 3.5 and 16 metres, and their length between 75 and 125 metres. The dip is almost vertical. The ore consists of pyrite containing chalcopyrite, pyrrhotite and magnetite. An analysis of the cores proves that the percentage of sulphur varies between 20 and 39 %, with an average of 35 %. The percentage of copper is mostly less than 1 %, but amounts to between 2 and 3,5 % in occasional sections.

The Rakkejaur Ore-field. (Plate 3.)

In the autumn of 1921, a large number of boulders containing arsenopyrite, pyrite, chalcopyrite and boulangerite were found one kilometre to the north-west of Rakkejaur farm in the parish of Malå, as well as an important limonite formation in a small tarn. (Fig. 38.) The overburden being rather slight in part of the field, it was possible to expose the ore at three places. In 1922 the Centralgruppens Emissions A.-B. made a thorough investigation by means of electro-magnetic methods, as well as by three drill-holes and a number of trenches. In 1923 and 1924 the exploration work was continued.

The ore-bodies are of widely varying sizes: the main pyrite ore-body is 450 metres long and up to 80 metres wide, and there are also small lenses of arsenopyrite only some tens of metres in length and a few metres in width. Owing to this fact, as well as the geological structure in general, the electrical investigation of this field has been rather difficult. The ores are to be found in the foot-wall of a band, 200 metres thick, of highly schistose sericitic and porphyritic hälleflinta. This band is bounded on both sides by tuffites and graphitic black slates with disseminated pyrrhotite, the conductivily of which rocks is occasionally very good.

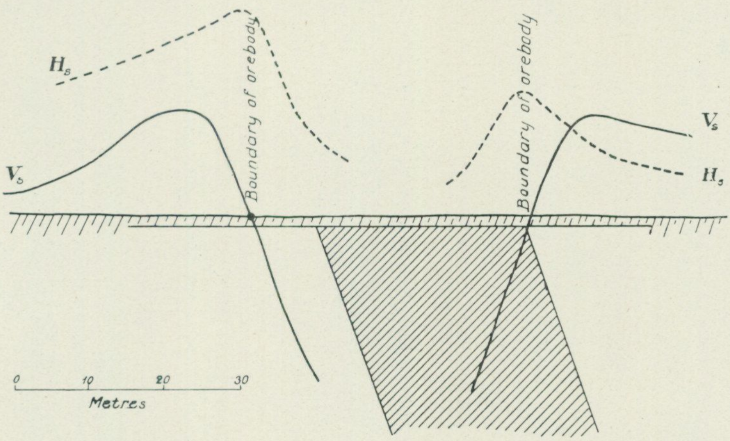


Fig. 37. The Rakkejaur ore field. Intensity profiles. V_s vertical and H_s horisontal component of intensity of the secondary field. Ruled area, known ore.

The hanging-wall slate has caused a strong electrical indication running parallel with the ore-bodies, but not in contact with them. The foot-wall slate, on the other hand, is adjacent to the ore. In spite of the fact that the difference between the conductivity of the ore and the black slate is rather small, it was generally possible to determine their outlines to within a few metres, when supplying the current galvanically and inductively (plate 3). Fig. 37 shows the secondary fields obtained in investigations along a profile line above the ore.

The agreement between the ore-indications and the outlines ascertained by means of drilling must be considered as good, in view of the size of the ore-body. Smaller disagreements may also be due to an irregular dip, whereby the projection of the outlines from the drill-hole to the surface of the bed-rock may not always be quite correct.

Most of the ore (more than 15,000 sq. metres) consists of a relatively

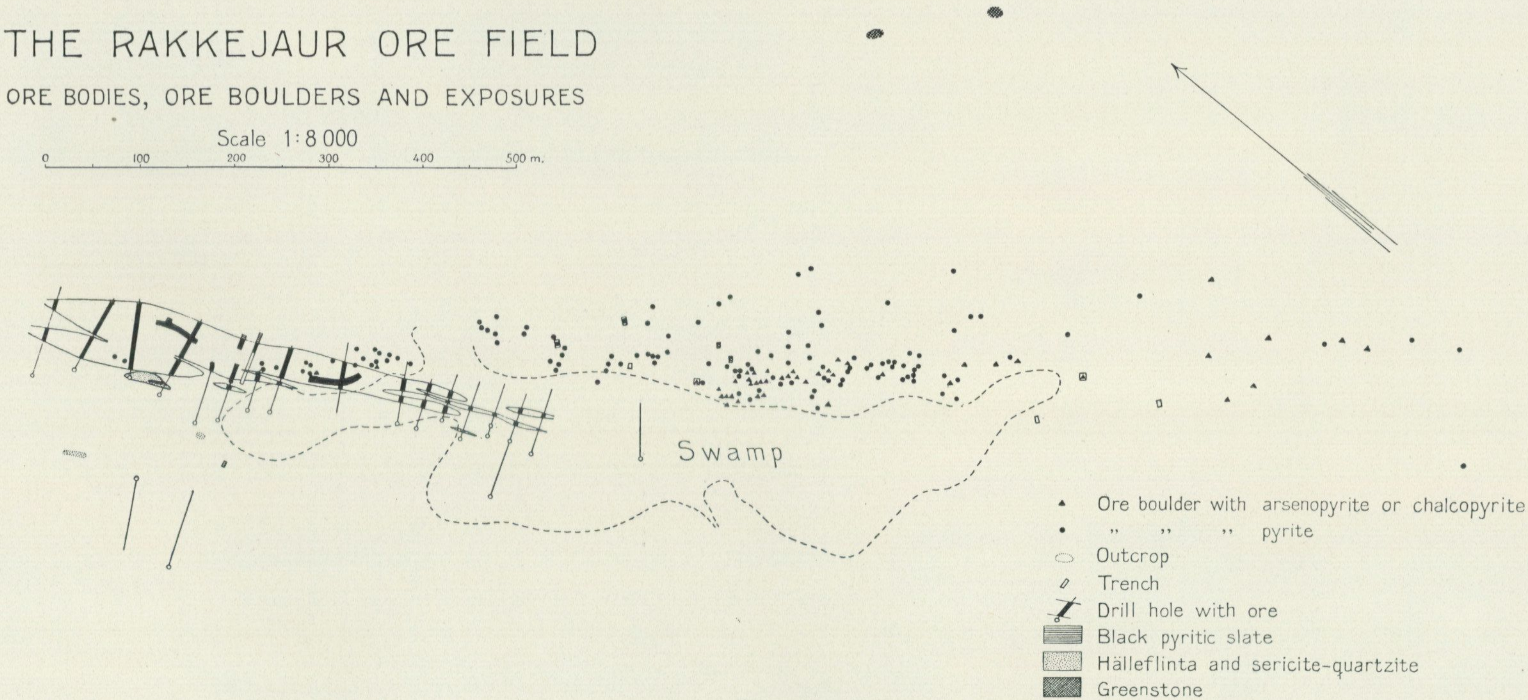

THE RAKKEJAUR ORE FIELD
ORE BODIES, ORE BOULDERS AND EXPOSURES
Scale 1:8 000
0
100
200
300
400
500 m.
Swamp
Ore boulder with arsenopyrite or chalcopyrite
" " " pyrite
Outcrop
Trench
Drill hole with ore
Black pyritic slate
Hälleflinta and sericite-quartzite
Greenstone

Fig. 38.

poor, streaky breccia of pyrite and pyrrhotite, containing 28 to 30 % S. In this breccia are bands of richer pyrite, as well as a copper ore-body of 1,000 to 1,500 sq. metres, containing 2.5 % Cu. In the hanging-wall and in the southern part of the ore-field are several smaller lenses of cupriferous and auriferous arsenopyrite, containing 10—25 % As, 2—6 % Cu, and 3—20 grams Au per ton. These lenses together are about 1,000 sq. metres

The overburden varies from some decimetres to 10 metres. The large pyrite ore-body is mostly covered by moraine, the arsenopyrite ore-bodies on the other hand, lie beneath a swamp.

The Mensträsk Ore field. (Plates 3 and 4.)

The first discoveries of ores in the Mensträsk field were made in 1921. They consisted partly of boulders, partly of an outcrop a poor breccia of pyrite. In 1922 and 1923, a great number of new boulders were found. Electrical prospecting was started in 1921, but not until the winter of 1923—1924 were the first ore-bodies struck by drill-holes, after the investigation of large areas by means of electrical methods.

The ore-deposits of the Mensträsk ore-field are situated around and beneath the Mensträsk lake.

The local topography is entirely predominated by the big lake. In most cases the islands and points in the lake are probably terminal moraines. The surrounding country is rather flat, consisting of forest-clad moraine and large swamps with a great number of lakes (plate 4). The overburden varies usually between a few metres and 20 metres. Examination of the bed-rock by means of digging is generally impossible.

As is to be seen from the map (plate 4) there are but few exposures of the rock in the middle and most important part of the field. Furthermore, a rather considerable area is occupied by the lake. It is therefore impossible to draw a detailed geological map based only on the natural exposures. Some idea however, is, obtained from the moraine and analogies with surrounding areas that are better exposed.

The Mensträsk ore-field consists chiefly of quartz-porhyritic or brecciated hälleflintas, and some unimportant beds of greenstone. Small layers of limestone exist, especially immediately to the south of the lake. Layers of grafitic, rusty slate are rather common, especially in the ore-bearing zones, but as a rule, they are small and divided into lenses. Larger layers of slate exist in the immediate vicinity of the lake both to the north and to the south, as well as in the eastern part of the field.

Most of the ore-bodies of the Mensträsk field occur in two zones lying in a direction from WNW to ESE. The principal zone passes beneath the lake and continues in an easterly direction towards the eastern end of the field, and has further been traced through the whole of the Malånäs field (plate 5), a total length of not less than 25 kilometres. The other zone is situated to the north of the lake, and has also been traced through the entire field. Besides, there are some smaller zones in different parts of the field, the most important of which is to the south of the lake, and where at one spot near the rapids Kvarnfallet at the outlet of the Mensträsk lake, blasting has been done in a pyritic breccia. The northern part of the area, on the other hand, is non-ore-bearing.

It is seen from the map, plate 4, that a considerable number of boulders have been found in the Mensträsk field. The swamps and lakes have been great obstacles in search for boulders, breaking up the fan-shaped areas of boulders, who cannot be traced beneath swamps and lakes. Most of the boulders have been discovered by means of digging and have not been found in the surface of the moraine. The most important trail of boulders

Fig. 39. The frozen lake Mensträsket. Reindeers on the ice.

originates from the main ore zone. A great number of boulders that cannot be attributed to the known ore-bodies show, however, that there must also be other, scattered ore-bodies in this field.

The ore-bodies hitherto found at Mensträsk are situated partly in graphitic slate, disseminated with pyrrhotite and ironpyrite, the electrical conductivity of which is relatively high, and partly in the contact between such slate and hälleflinta.

In this district six ore-bodies have so far been found, all of them situated in the main ore zone, four beneath the lake (plate 3), and two immediately east of the lake (plate 4). However, the investigations are not yet (1925) finished, and further ore-bodies are likely to be discovered. The horisontal area of the ore-bodies so far proved amounts to 5,cco sq. metres.

The four ores beneath the lake forming lenses of up to 20 metres in width, consists chiefly of pyrite (more than one half high grade ore containing 40 % S) but also of copper ore of which there is one lense of some 900 sq. metres with an average of 2.5 % Cu. and 35 % S, and another of at least 300 sq. metres with 3,8 % Cu. There are also some arsenic and zinc ore. As a rule, the ores are somewhat auriferous (4—6 grams per ton, occasionally more).

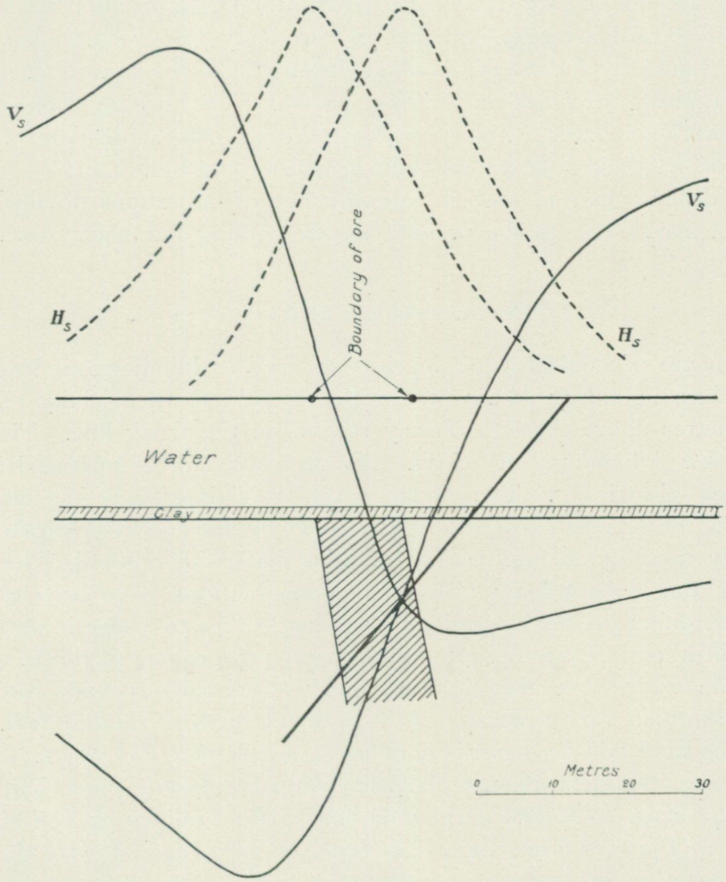


Fig. 40. Mensträsk ore field, western ore body. Intensity profiles and diamond drill hole. Legend see fig. 37 p. 49.

The electrical investigation has covered an area of almost 50 sq. kilometres, and a great number of indications have been obtained, with a total length of not less than 25 kilometres. Most of them are, however, likely to have been caused by black slates of a very high conductivity, which are frequent in this field. As it has, of course, been impossible to examine all these indications by drillings, extensive work has been devoted to detailed and qualitative electrical investigations, in order to distinguish, as far as possible, the indications caused by ores from those caused by slate. The number of electrical observations carried out in this district amounts therefore to about 150,000. For differentiating the electrical indications, gravimetric investigations have also been made.

For geological and electrical reasons, the area beneath the Mensträsk lake, shown in plate 3, was considered to be the principal ore-bearing area. The investigations were started in November 1923 when the lake was frozen (fig. 39) and in January 1924, or less than three months after the beginning of this electrical investigation, the first ore-body (the western one in plate 3) was found by means of diamond drilling from the ice. Fig. 40 shows the secondary field and a drilling profile. The drilling was continued throughout the entire winter, with the results shown in plate 3. In the spring of 1925, the eastern ore-bodies were discovered.

The drilling carried out in consequence of indications obtained in the northern zone have, to the present, struck nothing but black slate.

The Malånäs Ore field. (Plate 5.)

The name of »Malånäset» comprises an area 18 kilometres in length from the eastern boundary of the Mensträsk ore field to the vicinity of Udden, 8 kilometres above Kusfors railway station on the trunk line. The area is only a few kilometres in width. About 40 square kilometres have been examined electrically. The Malånäs ore field is one of the large areas that has been most completely examined by the electrical methods. As not only most of the ore-bearing electrical indications, but also the greatest part of those caused by slates and disseminations, have been examined, this area offers greater possibilities than any other to judge in detail of the possibilites and difficulties of the electrical prospecting methods. To this is to be added the fact that the composition, thickness and moisture of the overburden vary a great deal in different parts of the ore field. Therefore, this field will be described more in detail than the others.

The ore boulders in the Malånäs field are the only ones that at quite an early stage attracted great attention. The boulders on the hill »Bjurberget» at Bjurfors farm, were discovered in 1902, and in 1903 the mother lode was searched for by extensive, but fruitless, digging and blasting in the vicinity of the boulders (vide Fig. 46). The ore boulders at Slåttermyran were discovered in 1903, those at Örträsk, however, only in 1920, those at Bjurliden and Svanvaken in 1921, and those at Örträskgraven in 1922.

Bjurfors is one of the first places, where electrical prospecting was tried. As early as 1918 a small equipotential investigation was made around the boulders by the Centralgruppens Emissionsaktiebolag but no result was gained as the prospecting was not extended to where the mother lode is now known to be.

In 1920 the prospecting was continued by the Geological Survey of Sweden. A mapping of the boulders showed that the mother lode was to be found north of the river Malån under the large sand plain Malånäsheden. This was investigated electrically, but as no indication was obtained 1 kilometre north-west of the last boulders, the investigation was transferred to Norrliden, where, in the direction of the glacial-transport of the boulders, a pyrite dissemination had been found outcropping. A distinct indication was obtained, which was inspected by trenching, but only a poor pyrite breccia was found.

In 1921 Slåttermyran, south Norrliden, and some other places were investigated. In the following year, the electrical survey was extended most considerably, and the whole southern ore zone from Norrliden to Bjurliden was investigated (see plate 6). Only then were the mother lodes of the Bjurfors and the Bjurlid boulders found, the former by diamond drilling, the latter in a test shaft.

In the years 1923—1924 the electrical investigations were continued all over the Malånäs ore field so that this ought soon to be completely investigated. At the same time all favorable electrical indications were examined by excavations or drillings, an undertaking that proved very extensive because only little guidance could be had from geological investigations.

As regards configuration and overburden, three areas can be distinguished, viz.: —

1) The area above the upper limit of the glacial sea to the north and west. The overburden here is generally 3 to 10 metres, outcrops are rather rare, and the area is covered to a large extent by large swamps and some small lakes.

2) The valley of the river Malån and the surrounding sandy-plain (Malånäsheden), lying below the limit of the glacial sea. The overburden here is generally very deep, 10 to 30 metres, at several places even more, and consists to a large extent of extensive sand-plains. Outcrops are completely lacking, so that no sufficiently detailed geological maps of the underlying ore-bearing rock could be made before the electrical survey and drilling, especially as the moraine is covered by sand to such an extent that no guidance could be obtained from investigations of the moraine. Two lakes (Örträsket and Örträsktjärn) are situated within the area. The swamps are small, and in summer this area is very dry, especially on certain ridges of sand (old dunes) where it may be 10 metres or more to the ground water table.

This area is one of the best proofs of how little influence moisture has upon the results of the electrical investigations. In spite of the greatest contrasts in moisture, from lakes, rivers and swamps to dry sand-plains and sand-ridges, the equipotential lines did not at a single spot show any distinct deviation that could be definitely ascribed to differences in the moisture of the ground. An instance is shown by Fig. 41.

3) The area south of Malån. The overburden here is generally slight, and exposures are numerous. The geology of the bed-rock can therefore be studied rather easily. One of the ores occurring here, Bjurträsk, even

crops out of the moraine. There are several large but shallow and broken swamps in the district (Slåttermyran, Snåttermyran).

The rocks consist, in the western and northern parts, of hälleflintas, in the southern and eastern parts, of leptites and amphibolites. A large slate area begins to the south-west, and the western part of the hälleflint area is also divided by a synclinale of slate. Small layers of slate, which are nevertheless very troublesome when making the electrical investigation, are found all over the ore field except in the eastern part. From Bjurberget and eastwards the area is bounded by Revsund granite and to the north by the conglomerates and graywackes of the Vargfors-formation.

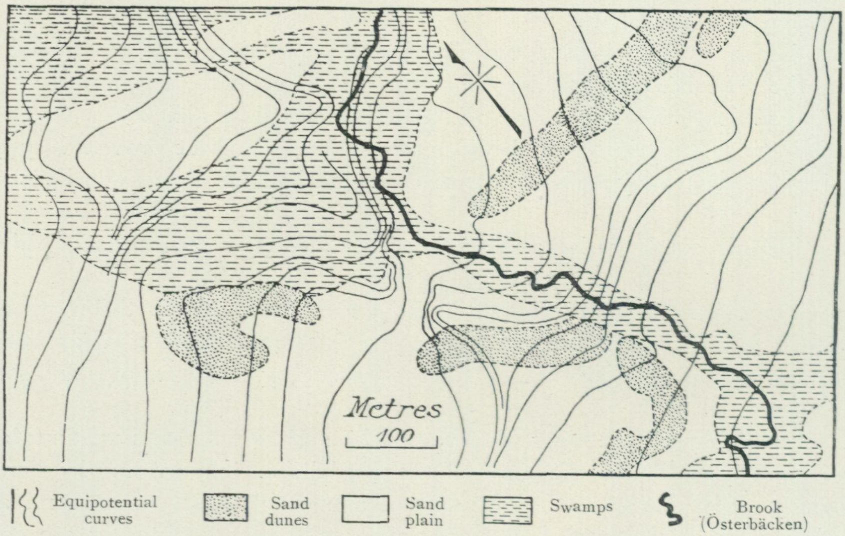


Fig. 41. Map showing the slight influence of differences in moisture of the soil on the trend of the equipotential curves. Österbäcken, Malånäset.

Two ore-bearing zones can be distinguished in the Malånäs field, of which the southern one has been traced throughout the field, the northern one, so far, up to only 4 kilometres.

Six ore-bodies have so far been laid bare, all of them in the southern zone: the Bjurfors field with three ore-bodies, and also Bjurliden, Bjurträsk, and Snåttermyran. In the northern zone no ores have yet been exposed, but to judge from boulders there exist at least an arsenic and pyrite ore at Österbäcken and some small bodies of pyrite farther west.

The ores lie direct in leptite or amphibolite, who are metasomatically altered next to the ores into chlorite-quartzite, chlorite-schist, and antophyllite- or biotite skarn. In the eastern part of the field, between the southern ore zone and Malån, there are considerable altered areas (sericite- and chlorite-quartzite) without any ore concentrations to speak of, but in parts strongly disseminated with pyrite.

The strike in the field is rather regularly WNW—ESE, only at Rutselet there seem to be some foldings worth mentioning. The dip is almost vertical in the northern zone; in the southern zone southerly with an amount varying from 70° in the western part to 45—50° in the central part and 35—40° in the eastern part. The southern zone at least has a pronounced linear structure, the direction being 30—40° towards WSW.

Bjurfors (Plate 6). The Bjurfors indications are four, the eastern, central and western ones, and a small indication just west of the latter. Besides these there are signs of a very weak indication immediately north of the east indication. All the surroundings are quite neutral, the nearest indications being 700 metres distant to the east and 1 kilometre to the west. The indications are therefore most pronounced. The overburden consists of sand and swamps partly the bottom of an old lake (Lapptjärn), and has a depth of 5 to 9 metres in the east, and 16 to 20 metres in the west. There are no ore boulders, nor anything else on the surface betraying the presence of ore.

The eastern indication has been checked by four drill holes and a test shaft, disclosing a slightly S-shaped ore lens about 200 metres in length and, on an average 15 metres in width. The average dip is 47° S.

The ore consists of chalcopyrite, pyrite, and pyrrhotite in quartz, and chlorite, and contains, on an average, 4 % Cu and 30 % S. It has only a low content of gold and silver.

The surrounding leptite and amphibolite are strongly altered into chlorite- and sericite-quartzite some tens of metres from the ore. Towards the foot-wall the ore is disseminated, and a small lens of solid sulphide is even found there. This is clearly seen from the electrical indication which, especially in the middle, has a considerable bulge on the foot-wall side.

Fig. 42 shows in profile the variation of potential across the ore-body and a drill hole through the ore.

The central Bjurfors indication has been examined by one drill hole. The indication suggests a short but broad ore lens. The drill hole also penetrated a very broad ore body (plate 6) divided by a horse into two parts, the first of which is a poor, pure sulphur pyrite, the other a rich but zinc-bearing pyrite with a band of pure blende.

The western indication suggests a long, narrow ore-body. Three holes have been drilled. They have shown a narrow pyrite—pyrrhotite ore immediately surrounded by disseminations. The westernmost drill hole possibly reached the end of a small western indication, for in the lower part of this drill hole a strong dissemination of pyrite was struck. Fig. 5 (page 14) shows a potential profile of the eastern drill hole.

The Bjurfors ores are somewhat magnetic, the western ore, however, very slightly so. This was discovered, however, only after the electrical investigation and the drilling, and was of no assistance in the discovery of the ores.

The area west of the Bjurfors ores. The first indication discovered in the Malånäs field was then so called Norrlid indication 1 kilometre north-west of the Bjurfors ores. As the overburden was slight, it was examined by a number of trenches. It proved to be caused by a poor pyrite breccia of no value but of a distinct ore type. The sulphur percentage was at the east end, 13 %, at the west, 18 %. A certain percentage of precious metals, 3 grams Au and 25 grams Ag per ton, was worthy of note.

The indication could be followed, weakly, about 1 kilometre to the west, where it ran out into a schist area. A trench there showed only black slate in which were disseminated pyrrhotite and graphite.

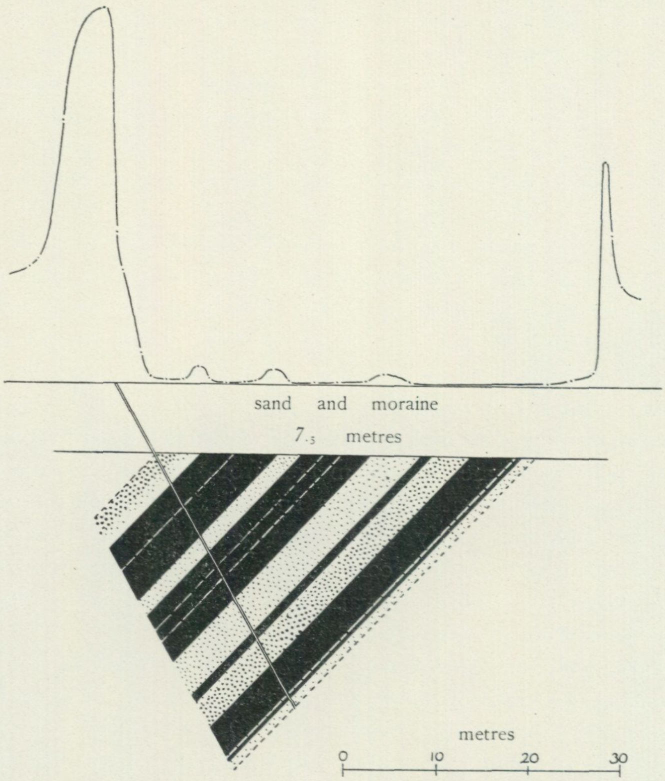


Fig. 42. Bjurfors ore field, eastern ore-body. Potential profile and diamond drill hole. Black, copper ore; heavy dotted, strong ore dissemination; thin dotted, lean dissemination.

2 kilometres west of the Norrlid indication, at the hill Storstensberget, was found an isolated indication of about the same form as the Bjurfors copper ore but somewhat larger. It was situated in the direction of the glacial-transport of a big boulder of pyrrhotite and blende weighing 16 tons (the Svanvaken boulder), but in spite of several diggings in the moraine no ore boulders were found in the vicinity. The indication was explored by a drill hole but showed only dark pyrrhotite-disseminated hälleflinta and black slate of good conductivity.

1 kilometre west of Storstensberget were found several long, narrow,

regular indications, which could be followed on to the Mensträsk field. The mere form of these indications indicated that they were caused by slate, and diggings in the moraine showed only schist boulders and no ore. Nevertheless the indications were examined in two prospecting pits under 5 and 11 metres of moraine respectively. Both of them showed a schistose pyrrhotite-disseminated hälleflinta which generally accompanies the black slate. The bottom of the moraine consisted chiefly of slate boulders. The indications were slightly magnetic.

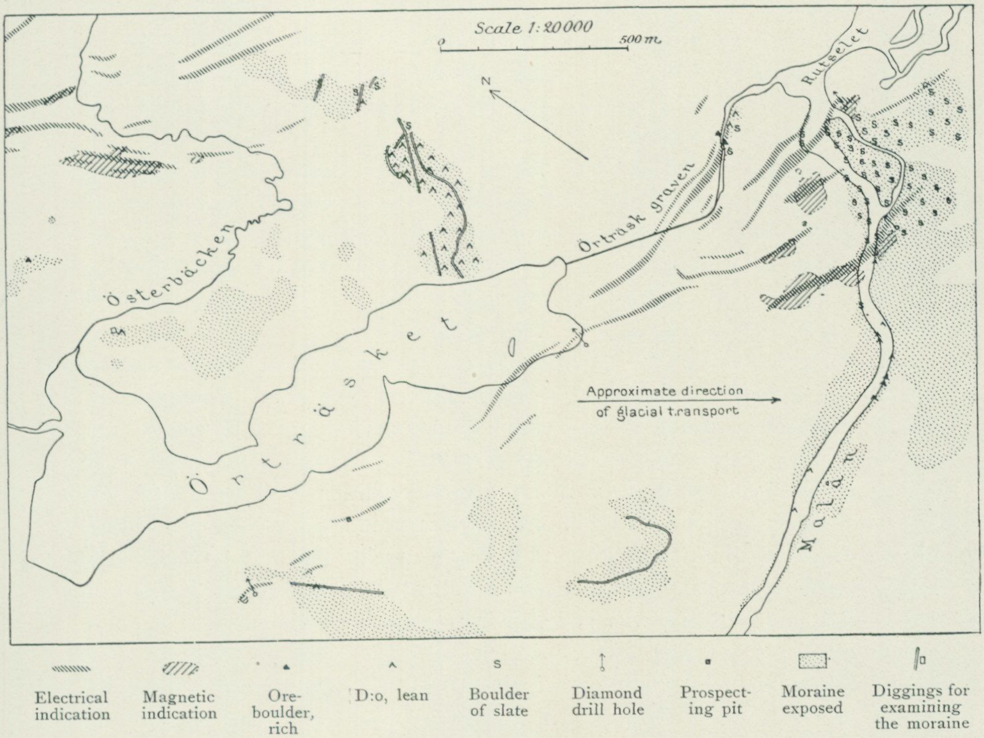


Fig. 43. Map showing the prospecting conditions in the heavy covered area between Bjurfors and Bjurliden, Malånäset.

The area between Bjurfors and Bjurliden. (Plate 6.) Between Bjurfors and Bjurliden, especially around and just west of Rutselet, there are a great many indications chiefly divided between two zones, a southern one, in which the Bjurfors and Bjurlid ores are situated, and a northern one. Besides these there are some indications at the so called Örträskgraven.

The conditions at these indications are very unfavourable for investigation (Fig. 43). Though some of the indications, on account of their lengthened regular form, were suspected of being caused by slates, this could not be definitely proved either by examining the moraine, as it was covered by deep sand, or magnetically, as the indications were partly non-magnetic. Only the indications close to Rutselforsen could be eliminated as due to slate on account of numerous big slate boulders and the magnetic qualities of the indications. As the overburden was very heavy and partly water-bearing (gravel), the indications could have been examined only by drilling.

Of the small group of indications nearest to Bjurfors (Åkergruvan) two indications hare been examined, those farthest east and farthest west. The latter was magnetic, the others not. The eastern indication was examined by a pit which reached, beneath 4 metres of sand and moraine, a schistose hälleflinta slightly disseminated with pyrrhotite and arsenopyrite. The western indication, which was drilled, showed chlorite-quartzite disseminated with pyrite. It may possibly contain some small stripes of solid ore but it is not a slate indication.

At the southern end of Örträsket, a hole was drilled in the long regular indication. The drilling showed graphitic slate strongly banded with sulphur pyrite, but very little pyrrhotite. The indication was not magnetic, whereas this was the case with the indications farther east (south-east). At the other side of Rutselet the indications ceased. A drill hole there showed slate and so did a drill hole farther west.

Immediately west of the Bjurlid ore, in the same zone, there were some indications which, on account of their position and their similarity to the Bjurlid indication, could be suspected of containing ore. However, no ore boulders were known that could be derived from these indications with the exception possibly of a poor blende-pyrite boulder, nor were any definite slate boulders known. Three holes were drilled, therefore, two in the indication nearest to known ore, and one at Rutselforsen. All of them showed black pyritic slate, that of the eastern indication not very strongly mineralized, while the western was strongly graphitic and pyritic.

Bjurliden. (Fig. 44.) At Bjurliden, in 1922, a small complex of electricat indications was obtained which it was considered might possibly be caused by the mother lode of the numerous boulders found some hundred metres farther south (vide Plate 5). The indications are in parts strongly magnetic.

The rock, which consists of leptite with small bands of amphibolite, is covered by moraine and sand, in the east to a thickness of 9 metres but in the west of only one metre in parts.

Ore has been found in two places at the largest indication, partly in a test shaft 14 metres deep, partly in a drill hole. It consisted of iron pyrite and some zinc ore. However, the type of ore of which numerous boulders consist, i. e. a strongly blende-banded pyrite, has not yet been found. But the western part of the indication is still unexamined. A trench at the western end of the indication showed disseminations of blende and galena.

The immediate surroundings of the ore consist of sericite-(biotite-)quartzite and chlorite-(biotite-)andalusite-skarn. The small indications in the foot-wall were caused by poor disseminations.

A small indication some hundred metres south of Bjurliden was examined by trenching but showed only a dissemination of pyrite.

The Crown Forest of Southern Malånäset. In the southern part of the crown forest Malånäset have been found a great many indications chiefly divided into five groups (vide Plate 5).

The rock consists of leptite and amphibolite in numerous, alternating layers. Black slates are absent, whereas there are several rather important zones of metasomatically altered rocks with pyrite disseminations (sericite-quartzite, chlorite-quartsite, and amphibole skarn) which cause large indications.

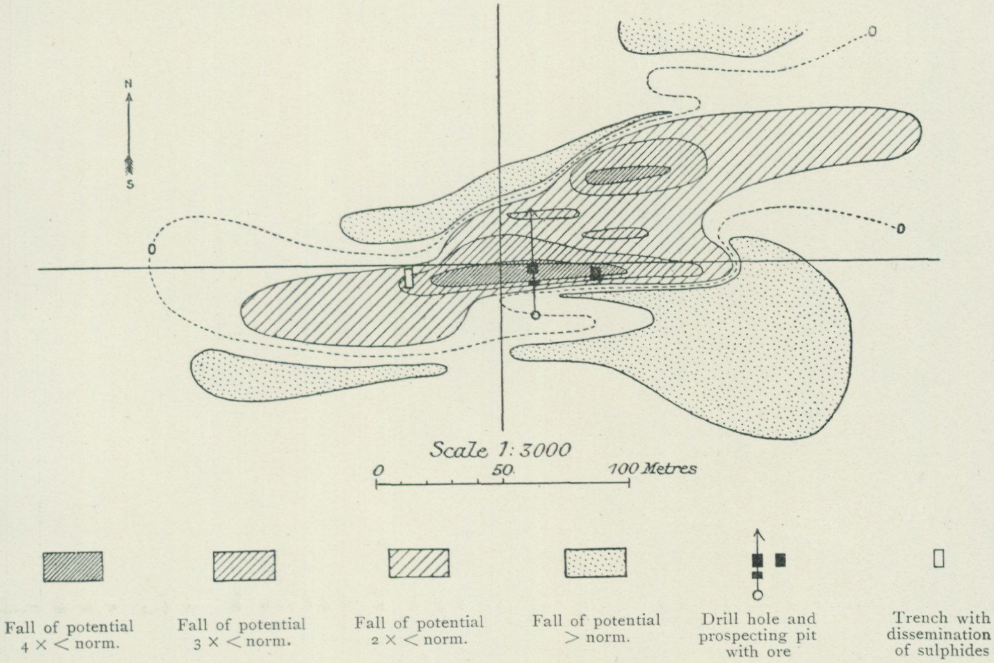


Fig. 44. The Bjurliden ore field, Malånäset. Isanomaly map of the potential fall constructed from the equipotential curves.

The covering of soil is generally slight, and outcrops are numerous. It is therefore easy to determine the minerals causing the indications by digging when they do not outcrop.

The most important group of indications is the southern one, which is the eastern continuation of the main ore zone of Malånäset. Four indications are found, viz. Bjurträsk, western and eastern Näverliden, and Snåttermyran.

The Bjurträsk ore was located in 1920 by a magnetic and geological survey, and an ore outcrop was discovered. In 1921, an electrical investigation was made to determine the extension of the ore, and the ore was then uncovered completely. The agreement between the form of the ore-body and the electrical indication was rather good, though only a few equipotential lines had been traced (Fig. 45).

The ore consists of two adjacent lenses. The northern one contains nothing but pyrrhotite, the southern and larger one pyrite as well (in its western end). The ore area is about 650 square metres, its greatest width

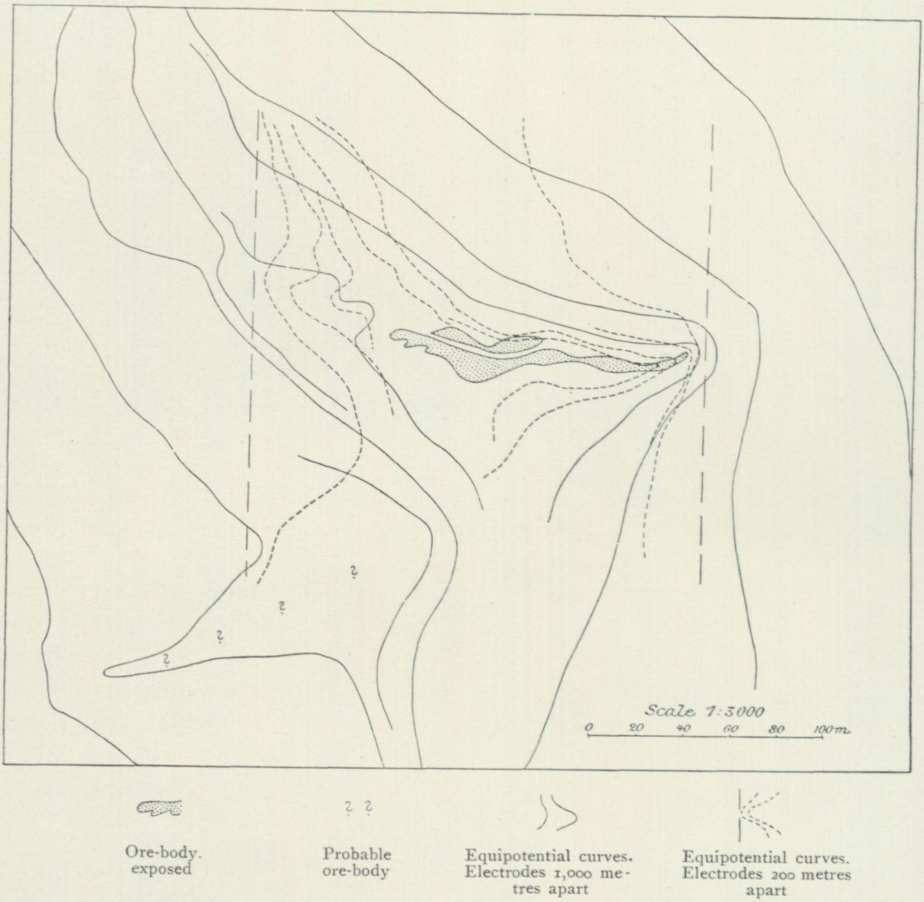


Fig. 45. The Bjurträsk ore field, Malånäset. Equipotential curves and ore-bodies.

being 9 metres. In the immediate neighbourhood the leptite and the amphibolite are altered into chlorite-quartzite, chlorite-schist, and amphibole skarn.

The western Näverlid indication contains no ore, only chlorite-quartzite in which pyrite is slightly disseminated. The eastern Näverlid indication has not been closely examined.

The Snåttermyran indication has only been incompletely examined by a test shaft and a trench. The overburden is 2 to 4 metres deep. Water from the swamp made the examination difficult. In the test shaft at the eastern end of the indication was found only chlorite-quartzite with veins of zinc-blende, whereas the trench showed compact ore of more than 4 metres in breadth. The ore consists of pyrite and pyrrhotite, poor but plumbiferous.

Just north of the main ore zone, long, continuous indications were obtained. To judge from outcrops and exposures made by digging, they were caused by sericite-quartzite in which pyrite is disseminated. The indications at Upper and Lower Brännan were examined by digging. The former was caused by amphibole skarn slightly disseminated with sulphides, the latter by a dissemination of chalcopyrite in schistose chlorite-quartzite.

The Northern Zone. The indications in the northern zone can be divided into three groups: the Kotjärn indications to the west, the central indications, and the Battmyr and Österbäck indications to the east.

The Kotjärn group contains several long, narrow indications. As the overburden is slight and the outcrops numerous, it is easily seen that they are caused by black slate in part strongly magnetic, with pyrrhotite and sericitic hälleflinta disseminated with pyrite.

The central indications consist of some small, lenticular indications. By digging (2 to 6 m. moraine) it has been shown that four of them are caused by pyrite-disseminated sericitic hälleflinta and some black slate. The two eastern indications are probably due to the same causes, judging from boulders. Two boulders of rich pyrite indicate also the existence of compact ore, but there is every sign that this is of very inconsiderable dimensions.

The Battmyr and Österbäck group contains several large indications (vide Fig. 41, page 56), but none of them has yet been examined, because the rock is covered by deep sand. Judging from boulders, the indications at Österbäcken are caused by sericite- and sericite-biotite-quartzite which is strongly pyrite-bearing. The boulders of arsenic-zinc-ore and pyrite-ore at Örträskgraven very likely originate from the same indication. The numerous boulders of black slate at the same place have probably come from the so-called Örträskgrav indications, because such boulders are quite absent from the moraine farther to the north-west.

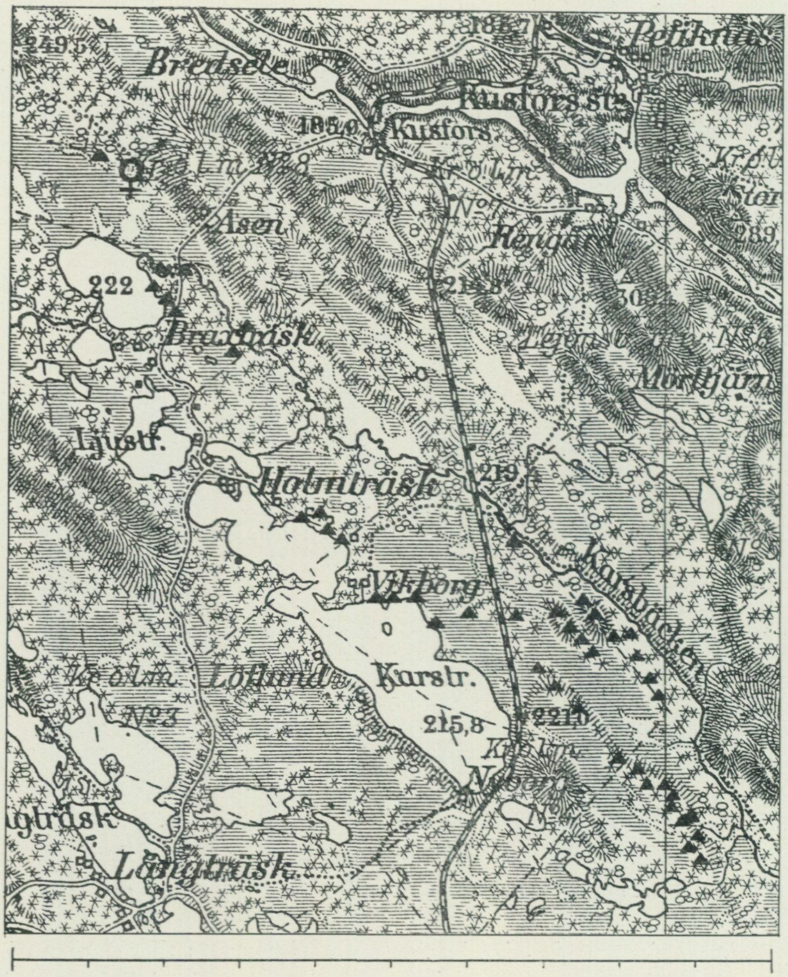
Some indications just north of the northern zone have not been investigated.

The Area South of Bjurfors. South of Bjurfors there are no indications until Svanvaken and the western slope of the hill Bjurberget are reached. The only exception is a weak indication which was prospected by drilling in 1922. The drilling showed sulphur pyrite impregnating in amphibolite.

The Svanvak indication, which lies close by the Svanvak boulder (page 56), is very weak. It has only been investigated gravimetrically. No excess of mass was indicated.

The Bjurberg indications run from where the brook Bjurbäcken join the river Malån, to far up on to Bjurberget, where they are cut off by granite.

They are very broad and in parts strongly magnetic, as these slates generally are, with irregulary varying intensity. The indications are also caused by contact-metamorphic black slate strongly disseminated with pyrrhotite, pyrite, graphite, and occasionally also richly with arsenopyrite (non-auriferous). The slates crop out in several places.



kilometres
Scale 1 : 100 000

Fig. 46. Situation map of the Braxträsk ore field showing ore-boulders (▲) and their mother lode (♀).

The Braxträsk Ore Field. (Plate 3.)

In the summer of 1921 some boulders of sericite-quartzite with pyrite were found at Vikborg near Braxträsk (Fig. 46). Geological investigations showed that there was a large area of metasomatically altered, ore-bearing rocks. The almost absolute absence of outcrops made it impossible to define the boundaries of the area. An investigation by the potential method was made in 1921 and gave some indications in the western part of the area, which were partly prospected by diggings, but only disseminations of pyrrhotite were found. In 1922, investigations were made by electromagnetic methods, but no strong indications were obtained. In the same year some further poor ore-boulders were discovered. In the spring of

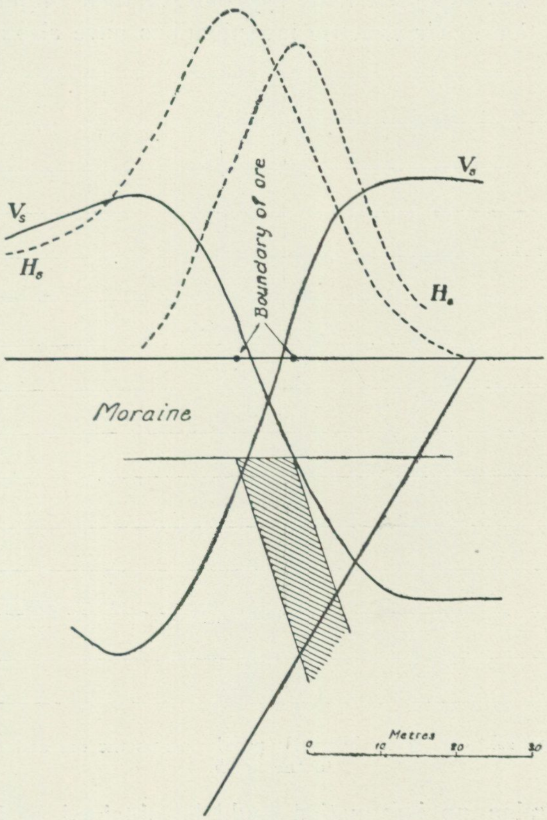


Fig. 47. The Braxträsk ore field, eastern diamond drill hole. Intensity profiles. Legend see fig. 37, p 49.

1923, a diamond drill hole was bored at Vikborg on the electrical indication which, though very weak, was considered to be the most promising one on account of its relation to the position of the boulders. The hole showed only granite-gneiss disseminated with magnetite and pyrrhotite. In 1923, search for boulders and geological investigations were carried on systematically, resulting in the discovery of some further ore-boulders, partly with chalcopyrite. It was then ascertained that the ore was likely to be found north of the area previously prospected, and therefore this suspected area was subjected to a survey in the autumn of 1923, and good electrical indications were recorded. As a black slate had previously been found immediately north of the indications, there was some doubt as to whether the indications were caused by ore or schist, but the qualitative electrical investigations showed that the indications were caused by a non-schistose conductor of relatively poor conductivity. A magnetic survey showed that the indications were non-magnetic, whereas the ground north of them was magnetic. As the boulders had only contained pyrite and chalcopyrite, it was supposed that they derived their origin from the non-magnetic indications. Gravimetric investigations gave also a positive result.

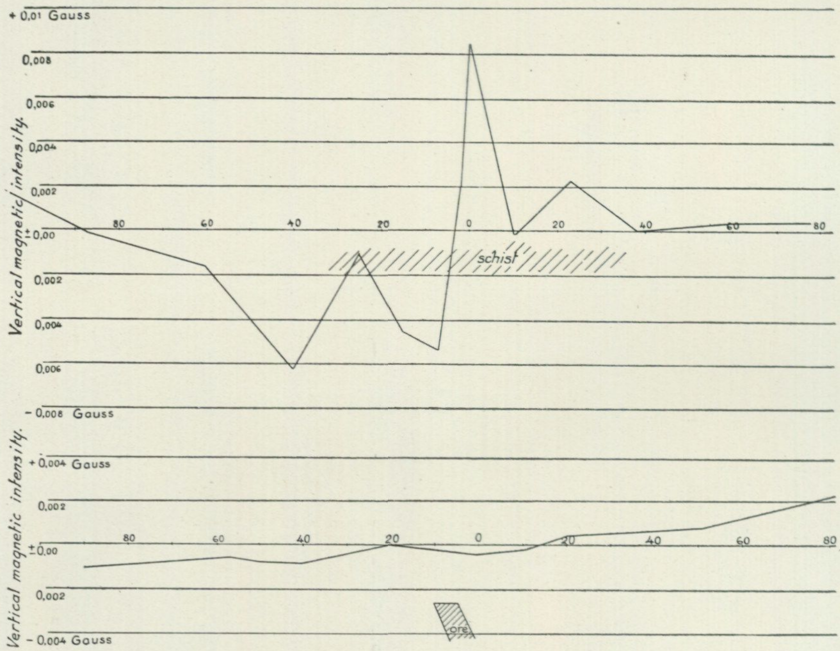


Fig. 48. The Braxträsk ore field. Magnetic profiles across the ore and the conductive slate to the north.

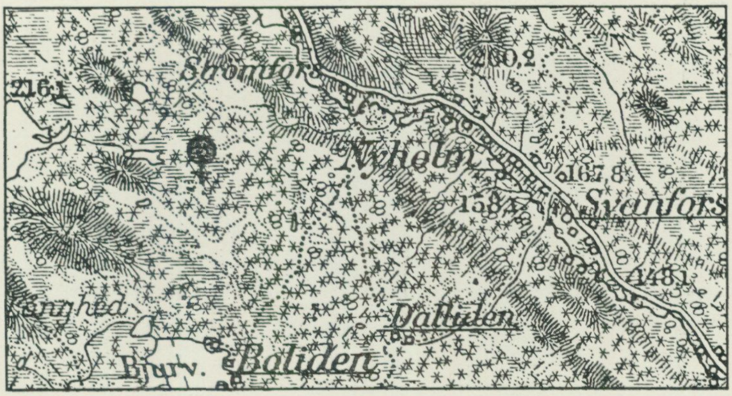
From the moraine no information could be obtained, as it in the neighbourhood of the indications consisted exclusively of material that had been transported from a comparatively great distance.

Two holes were drilled on the indications, in the summer of 1924, and both gave ore almost exactly within the indicated boundaries (vide plate 3). The ore is a poor, partly cupriferous pyrite in sericite-quartzite. The ore body seems to be 1,000 to 2,000 square metres in area. The overburden, moraine, is 9 to 13 metres thick.

Plate 3 shows the result of the electrical preliminary and detailed investigations, and of the boring. Fig. 47 shows the secondary field along the eastern hole and the boundary points of the hanging- and foot-walls fixed by examination of the secondary field. Fig. 48 shows the result of the magnetic survey along the same profile and of the slate north of the ore.

The Boliden Ore-field.

In the summer of 1921 several boulders of rich pyritic ore were discovered at Svanfors and Dalliden. On account of those and other discoveries of boulders, geological and electrical investigations were made in the area which the map fig. 49 comprises. It was then found that there probably was an ore-bearing zone in the hälleflinta just north of its boundary against the great slate area in the south (Plate 1). In the absence of outcrops the position of the ore-bearing zone could not be exactly determined by geological investigations alone. Electrical measurements were therefore made, starting with some ore boulders at the village of Boliden, and following the direction of the glacial transport (approximately northwest) until indications probably belonging to the ore zone were struck. They



Scale 1 : 100 000.

Fig. 49 Situation map of the Boliden ore field (♀).

were then followed eastwards in the direction of Strömfors and Nyholm. It was now shown that the most noteworthy group of indications, situated 2 1/2 kilometres north of Boliden, did not belong to any known ore boulder, nor was there any outcrop that showed the nature of the indications. However, as the qualitative electrical investigations indicated the existence of solide ore, the indication group was subjected to an examination by means of diamond drilling.

The first bore-hole, which was made in the northern indication, only showed an impregnation. But the second hole, which was made in the southern indication, gave an auriferous, arsenic-copper ore with bands of pyrite. The position and width were almost entirely in agreement with the electrical indication. A new hole was now drilled 50 metres farther west. This also gave rich arsenic ore, 4—5 metres wide.

The original investigation had indicated that the large southern indication was divided up into several small indications immediately east of drill-hole No. 2. However, as the profile lines measured lay obliquely across the strike of the ore, it might be supposed that this division into smaller indications was only apparent and was due to the difficulty in interpreting the electrical profiles.

The coordinate system was therefore altered and a new measurement made of the southern indication. It was now shown that the indication continued eastwards and that even the main and by far the greatest part was situated east of the second drill-hole.

These indications were now tried with the diamond drill holes nos. 4, 6, 7, 8, 9, 10, and 11. Of these, all except the easternmost one (no. 10) encountered solid ore of the same general character as that found with holes nos. 2 and 3. The width of the ore in the various drill hole sections were the following:

Hole no. 4	14 metres	Hole no. 8	30 metres
» » 6	>28 »	» » 9	20 »
» » 7	10 »	» » 11	28 »

This ore body is probably a continuous lense of about 600 metres in length and 10,000 sq. metres in area. It is in the main made up of rich pyrite ore with a varying percentage of copper and some gold and for the rest of rich arsenic and copper ore with high values in gold.

The rock in the district consists of leptite and amphibolite partially metasomatically altered into sericite-quartzite. The strike is E—W, the dip 85° S.

The rock is covered with moraine, swamps and some small lakes. There are no outcrops. The depth of the overburden varies between 7 and 18 metres. The bed-rock cannot therefore be examined by means of trenching. No ore boulders from the deposit are, as has already been mentinoned, known. Thus as the ore has no surface indications and is not magnetic either, it will be easily understood that it could only be discovered by electrical prospecting methods.

The Boliden deposit is therefore a very important find. Its discovery must be considered to be the most outstanding result yet attained with the electrical prospecting methods and, for the rest, one of the most remarkable finds of ore that has been made in recent years.

The Västerbotten Mountains.[1] (Fig. 31 and 51.)

It is known that the range of mountains in Scandinavia, upheaved in Caledonian time, contains a great number of ore-deposits, especially of pyrite and copper. All such deposits as were known and of any importance however, were situated on the Norwegian side of the border. But

[1] A. Högbom: De geologiska förhållandena inom Stekenjokk-Remdalens malmtrakt. English summary. Sveriges Geologiska Undersökning, Ser. C, N:o 329.

as the ore-bearing rocks at several places extended into Swedish territory, the Geologically Survey of Sweden started prospecting work in 1918 in conjunction with geological mapping of the most promising of these areas, viz.: the Tärna and Vilhelmina mountains in the county of Västerbotten. At the same time prospecting work was carried out by private persons in these same areas and in the Frostvik mountains to the south of the Vilhelmina mountains.

In 1918 two considerable ore-bodies were discovered at Stekenjokk and Tjåter, and in the following year one more at Remdalen. At the same

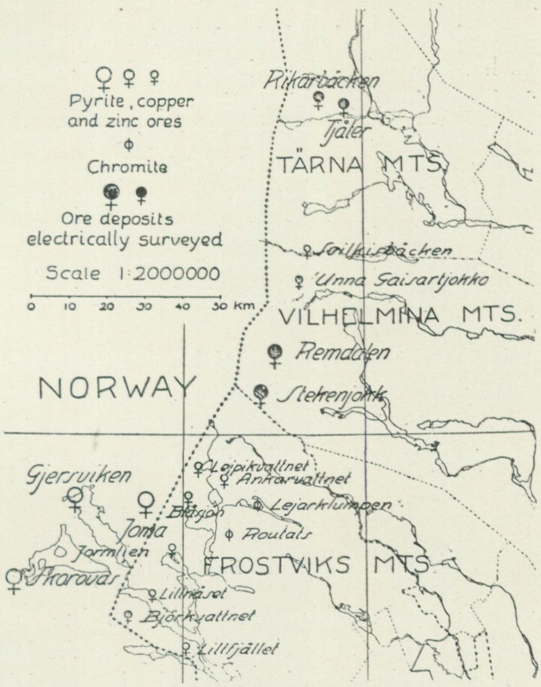


Fig. 51. Situation map of the ore-bearing part of the Västerbotten mountains.

time smaller ore-bodies were found in the Frostvik area. The Tjåter and Frostvik deposits were discovered by their outcroppings, and exclusively examined by trenches; but at Stekenjokk and Remdalen, where the ore-bodies were drift-covered and the evidence of their existence was boulders in the moraine, electrical prospecting methods were used.

The electrical investigations at Stekenjokk and Remdalen were carried out at a time when the electrical prospecting methods were but little developed and, above all, only little experience had been gained on which the interpretation of certain indications could be based. At Remdalen, where the conditions were simple, this fact did not matter so much, but at Stekenjokk great difficulties were met with, as the structure is rather complicated and great quantities of conductive graphitic slates occur together with the ores. The investigation was carried out with the potential method, using telephones without amplifiers and a hand-driven generator as a source of current. In order to make the strength of the current in the earth sufficient to allow the equipotential lines to be traced without the use of an amplifier, the distance between the electrodes had to be small. Nevertheless, it was often impossible to trace the equipotential lines except in the immediate vicinity of the electrodes. The electrical maps were therefore very difficult to interpret, owing to short, often discontinuous and scattered equipotential lines, and could not fully be utilized for the diamond drilling in 1920.

A later attempt to interpret the Stekenjokk investigation on the basis of further experience has proved that an interpretation is not at all impossible. Especially the ore-indications appear distinctly.

The above investigations were carried out by the Geological Survey of Sweden in 1919 and 1920. In 1924 the Centralgruppens Emissionsaktiebolag renewed investigations in the Tärna mountains. Tjåter was investigated electro-magnetically, and the indications traced in the field. At the same time another deposit was discovered somewhat to the west at Rikarbäcken, and mining claims were located. This deposit was indicated by a large number of boulders.

The ores in this district consist essentially of zinciferous pyrite and, in part, also of chalcopyrite (Stekenjokk, Remdalen), zinc ore (Tjåter, Jormlien) or magnetite (Unna Gaisartjåkko), generally occurring as greater or smaller, flattened lenses in slate, schistose greenstone or in quartzitic and sericitic granulite.

The Stekenjokk ore field. (Plate 7.)

The discovery of the Stekenjokk ore-deposit was due to boulders being found in the moraine. Soon after the discovery of the boulders, an outcrop was found in a brooklet passing through the ore-field. As the ore was otherwise entirely covered by moraine, sand, swamps and small lakes, and the geological conditions were evidently very complicated, an electrical investigation was instituted, with a view to getting an idea of the extent of the ore-body and the places where holes ought to be drilled.

The rock of the ore-field appears to consist of three layers, first granulite, then the ore-bearing zone, and then greenstone and grey slate. The ore-bearing zone, which is between 20 and 30 metres thick, consists of alternating bands of small-grained pyrite with an average of 35 % S, 5.6 % Zn and 1.2 % Cu, quartzitic copper-ore with an average of 2 % Cu, 23 % S and 2.8 % Zn, black graphitic slate and quartzitic and sericitic granulite.

The ground is strongly folded along axis usally having a shallow dip towards the SSW. The outcrop of the ore-bearing zone is therefore rather irregular and the flat-laying ore-bodies covers large areas. This hampered the electrical investigation considerably as the equipotential lines could not be traced there without an amplifier the subjacent ore-flats absorbing all of the current. (Fig. 52.)

In the central part of the ore-field the thickness of the overburden is not more than a few metres, but in the northern part, beneath a sandy

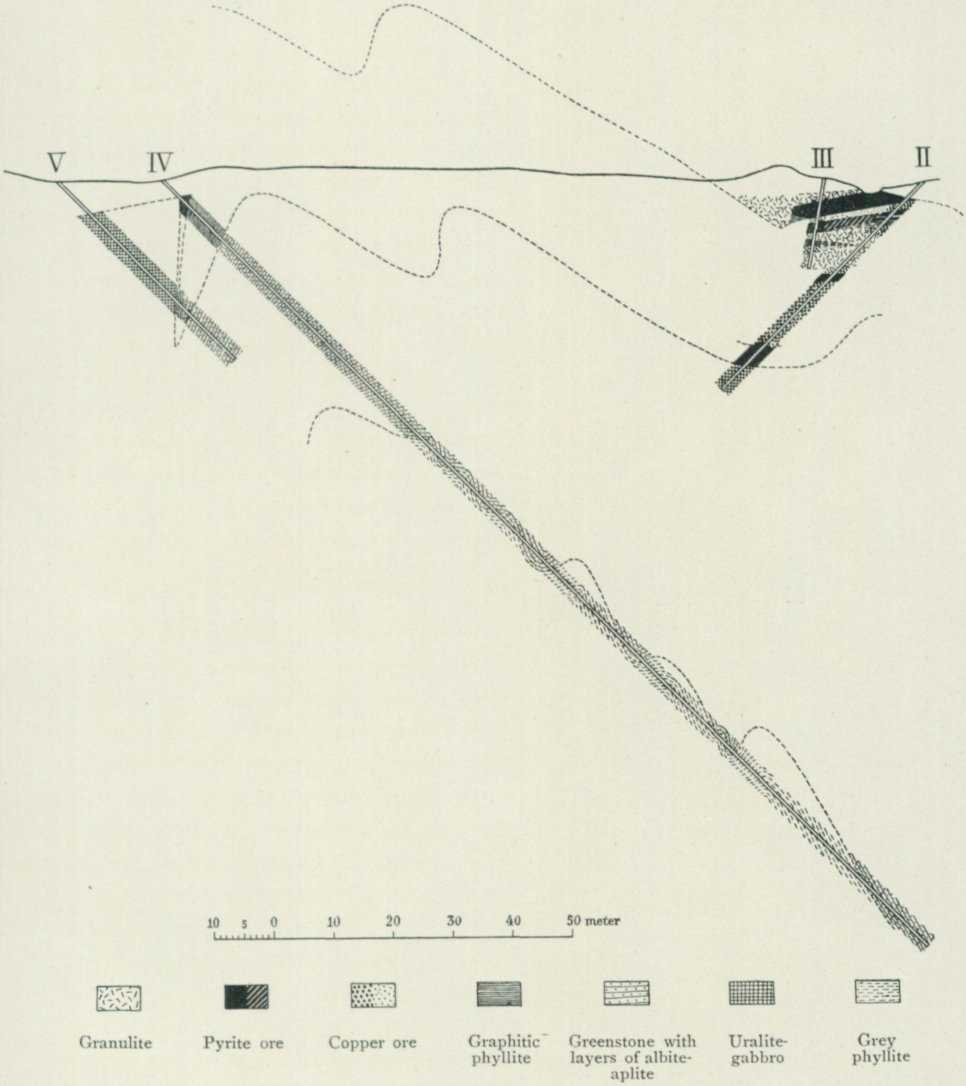


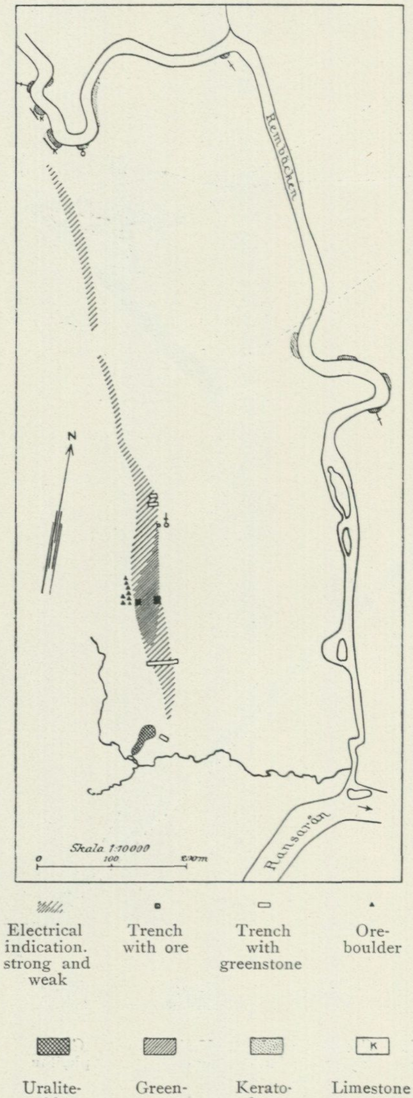
Fig. 52. The Stekenjokk ore field. Profile across the main ore outcrop.

delta plain deposited in an ancient lake dammed up by the ice, it is probably between 10 and 20 metres.

The variations in the structure of the overburden had no influence on the course of the equipotential lines, and distinct deflections were not obtained even above the lakes or swamps.

The extent and results of the electrical investigation are seen from Plate 7. $1^1/_2$ sq. kilometres have been investigated. As is to be seen, the indications are divided into three groups, the central area, the western indications and the northern indications.

In the central area three stronger indications are discernible. Two of them have proved to be ore-bearing when drilled and excavated. From the third one, which is electrically very distinct but has not been thorougly examined, the numerous boulders immediately to the northwest of the indication are supposed to originate. For the rest, and especially in their extensions towards the south, north and southwest, the indications (as a matter of fact rather weak) are likely caused by graphitic slate. To judge from drilling and excavations, the same kind of rock is probably the cause of the zone of indications passing through the western part of the ore-field.



Pig. 53. The Remdalen ore field. Electrical indications and exposures.

The Remdalen ore field. (Fig. 53.)

The Remdalen ore-field was discovered owing to boulders being found in the moraine in 1919. Soon afterwards the mother lode was located by means of electrical investigations, and the ore was laid bare in the indication.

The rock consists of uralite-gabbro and schistose greenstone accompanying the former. The ore, consisting partly of pyrite banded with zinc-blende (37 % S, 8 % Zn and 0.9 % Cu) and partly of cupriferous pyrrhotite (2.8 % Cu, 39 % S and 1.3 % Zn) forms a big lense in the schistose greenstone.

The structure is not clearly known but the dip of the folding axes is rather low, and the ore-body is supposed to pitch along them in a northernly direction.

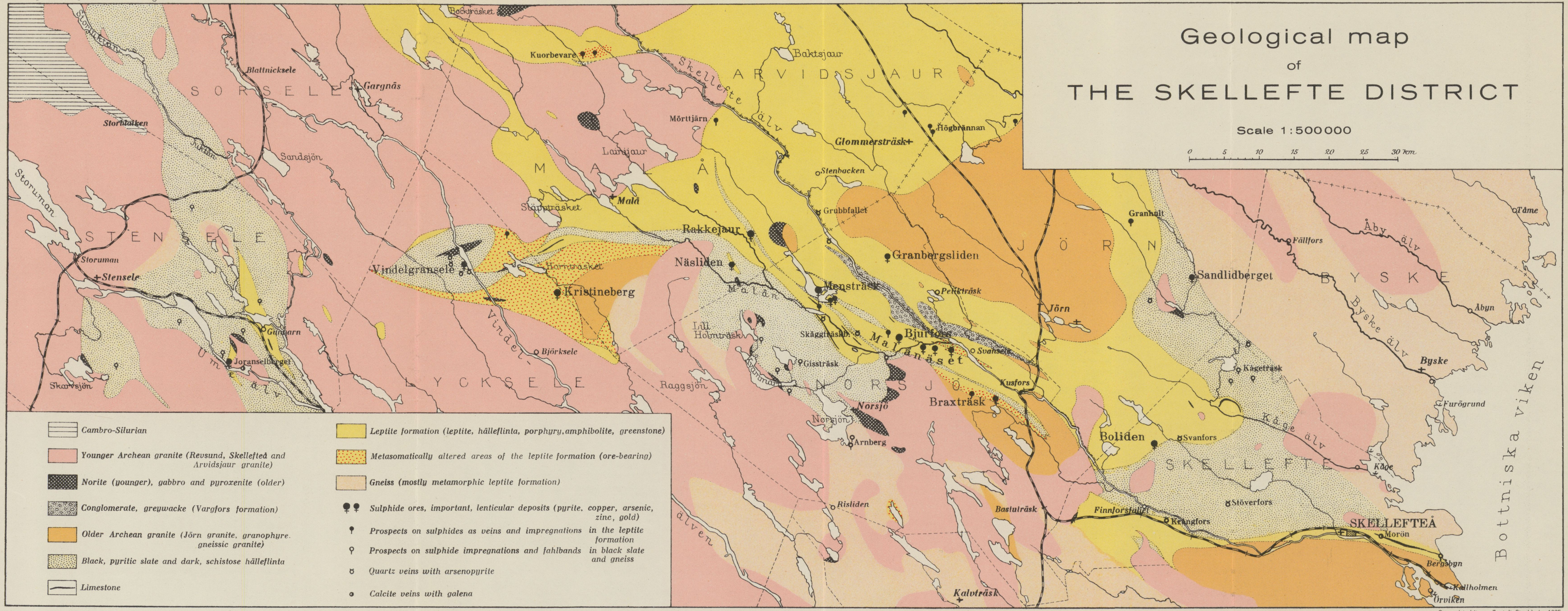
Everywhere in the ore-field the rock is covered by moraine and deposits of ancient glacial lakes, to a depth of several metres.

The electrical investigation covered an area of 1 kilometre in length and

250 metres in breadth (25 hectares). The result was a regular indication, with one small interruption in the northern part. In the southern part of the indication, in the vicinity of the boulders, a stronger indication was clearly discernible within the larger one. On this indication, the ore has been exposed in two places. The exposures in the weaker part of the indication have shown nothing but greenstone, and no boulders have been found in this part of the ore-field. In all probability, the indication is caused by the continuation along the pich of the same ore-body which does not reach the surface of the bedrock.

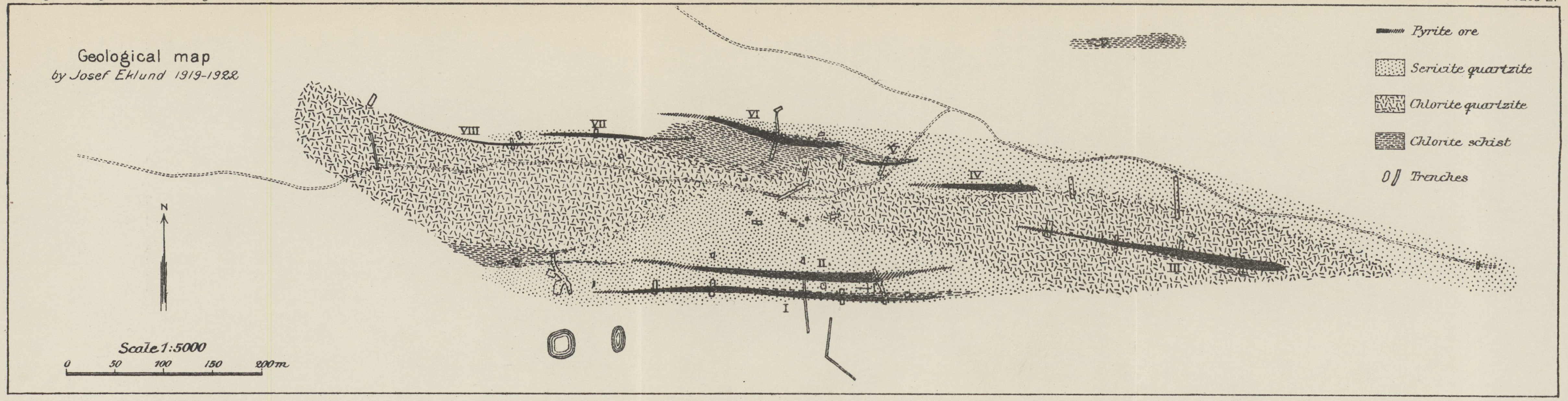
Explanation of some Swedish and Lappish names on the maps

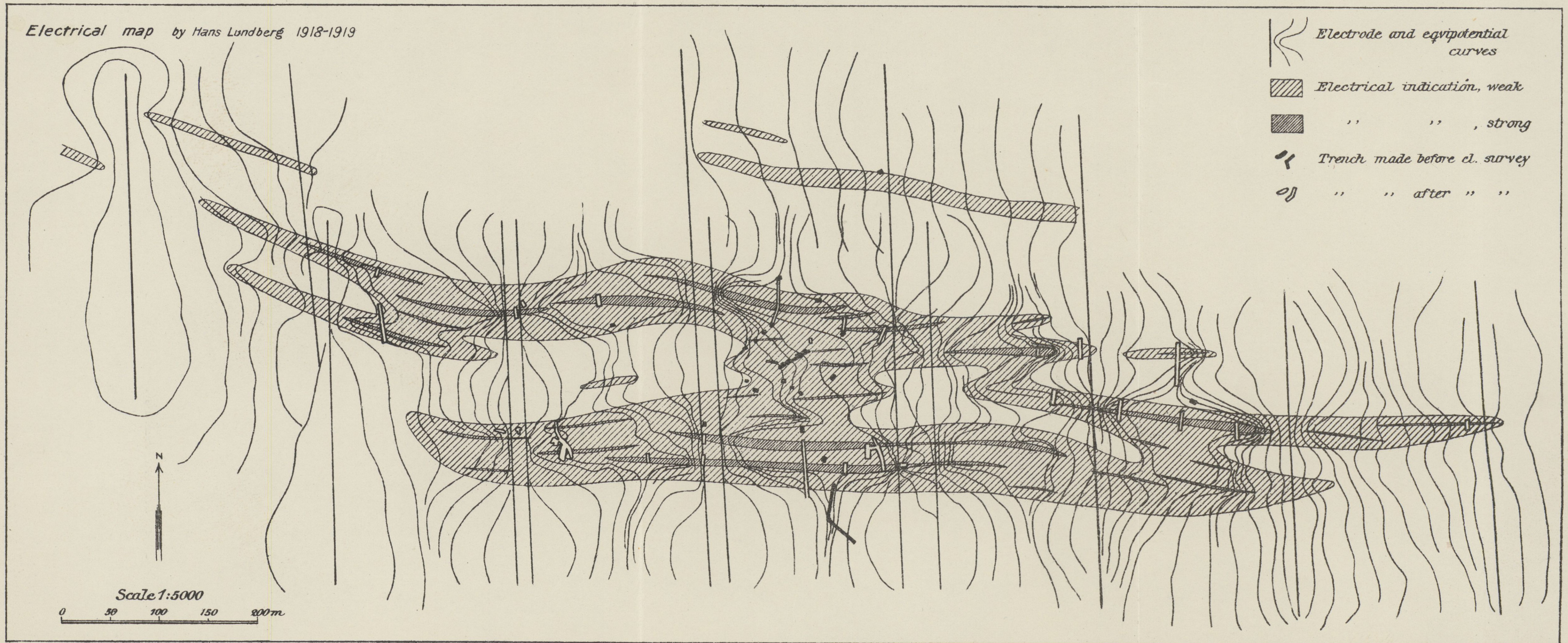
å	= river, small	myr	= swamp
älv	= » large	näs	= point
bäck	= brook	sel	= slow-flowing part of a river
berg	= rocky hill	sjö	= lake
by	= village	tjärn	= tarn
fors	= rapids	träsk	= lake
jaur (lappish)	= lake	vare (lappish)	= hill
lid	= driftcovered hill		



Generalst. Litogr. Anstalt Stockholm 1925

THE KRISTINEBERG ORE FIELD





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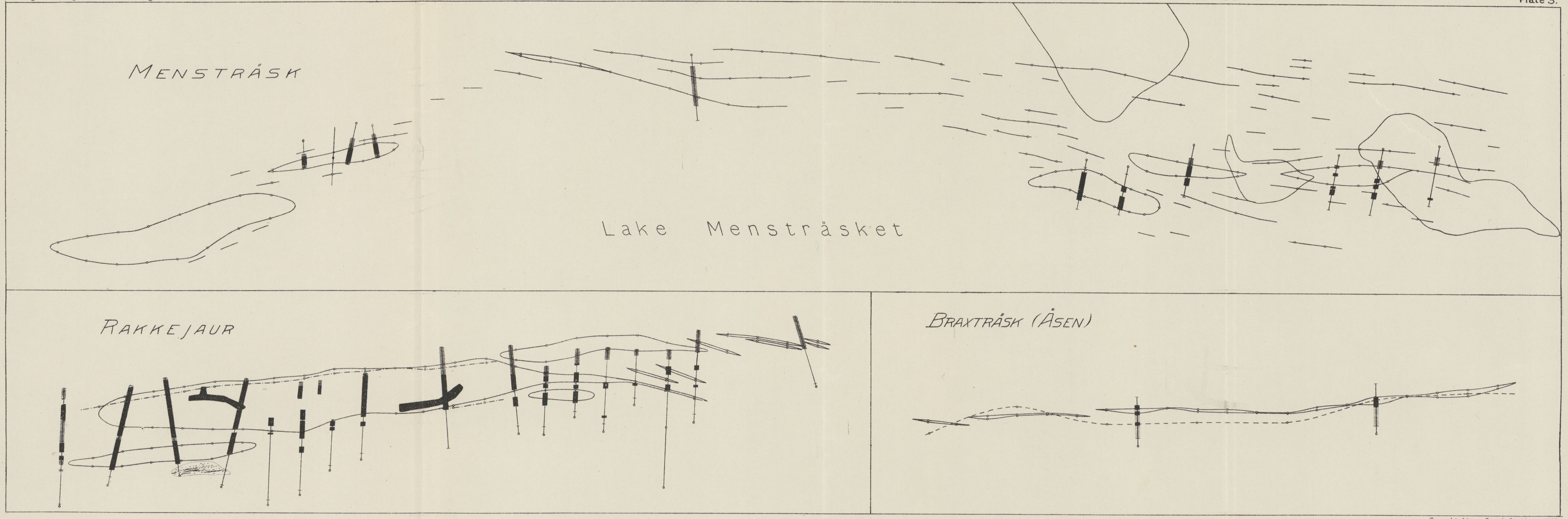

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Indication obtained by detail investigation in field applied in inductive manner
" " " reconnaissance " " " " " "
" " " " " " " galvanic "
Points determined

Scale 1:3000
0 50 100 200
Metres

Diamond drill hole with ore
" " " " impregnation
" " " " black pyritic slate
" " " " hälleflinta and sericite-quartzite

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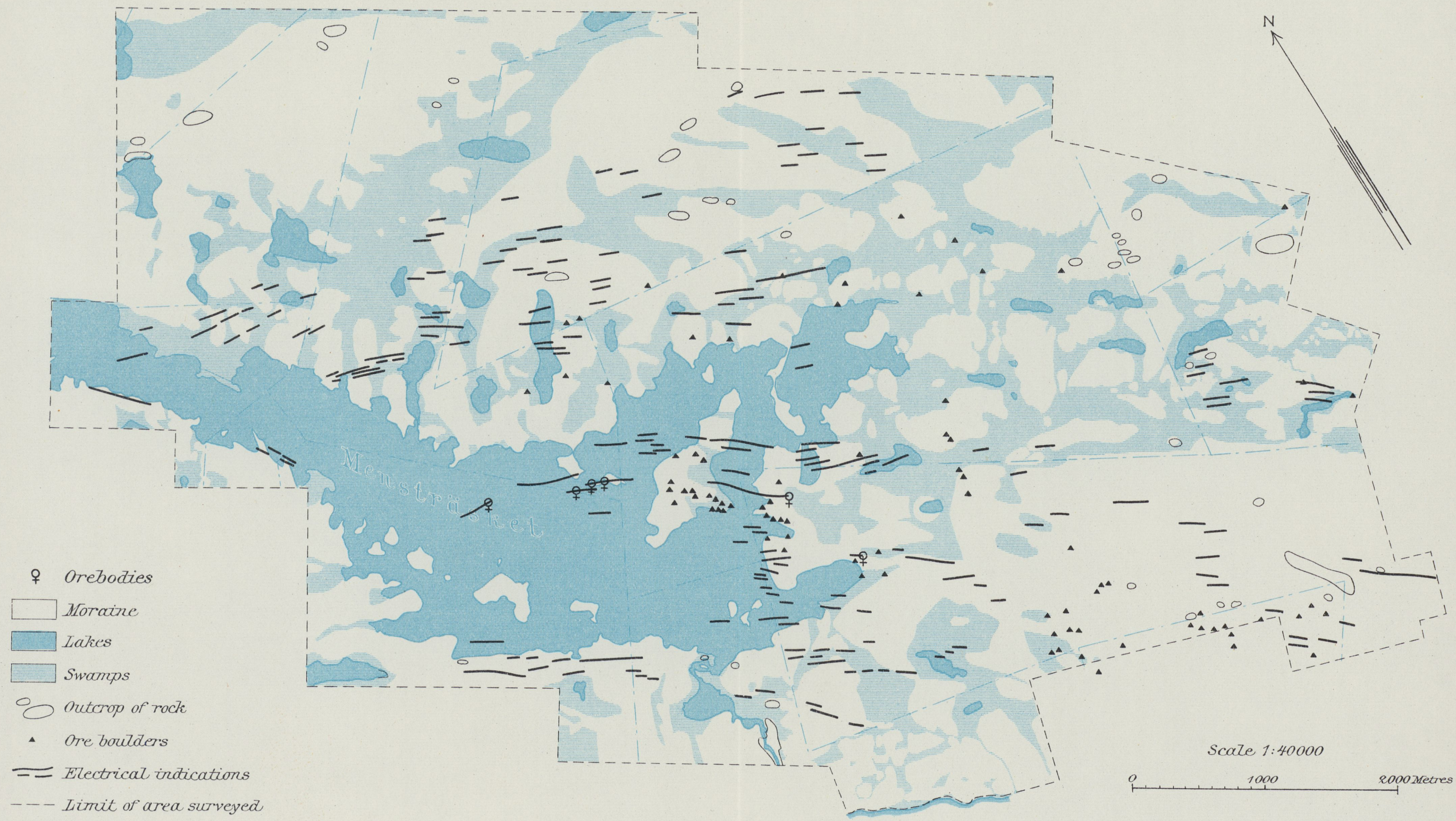
THE MENSTRÄSK ORE FIELD

Plate 4



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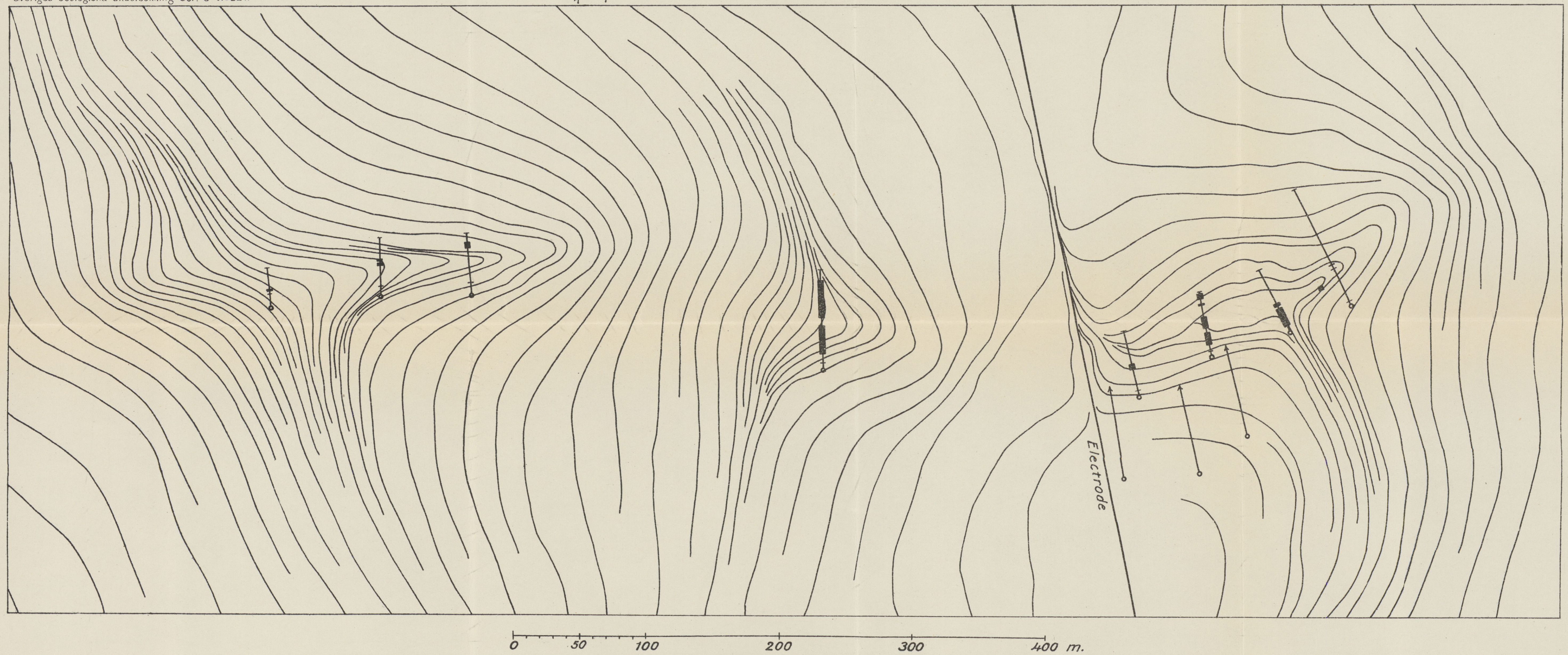
THE BJURFORS ORE FIELD

Equipotential curves and drillings



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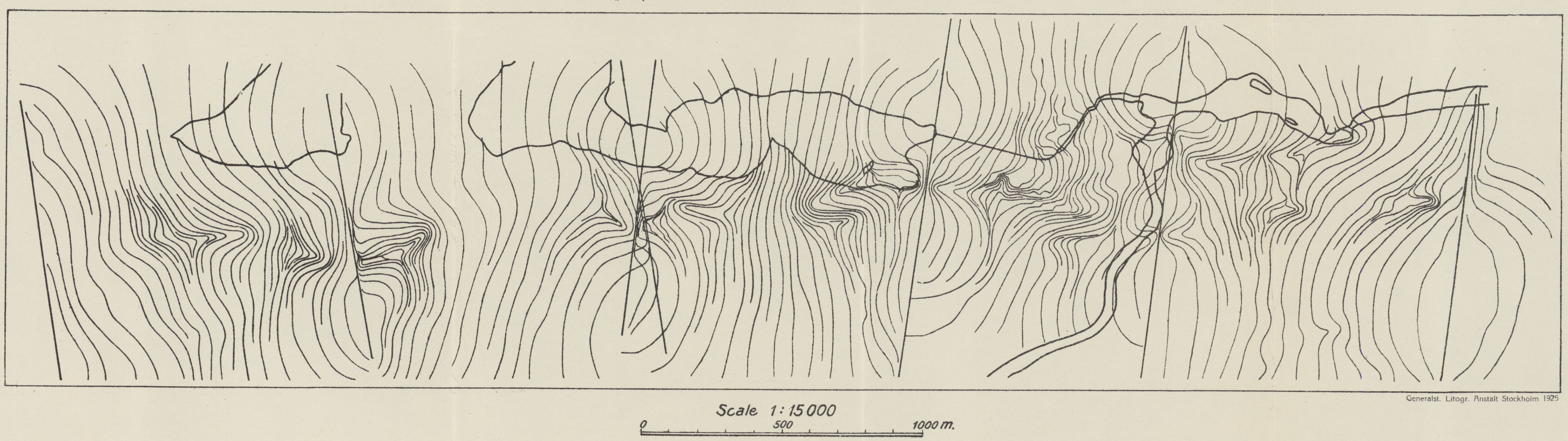
The electrical survey between Bjurfors and Bjurliden

Equipotential curves and electrodes



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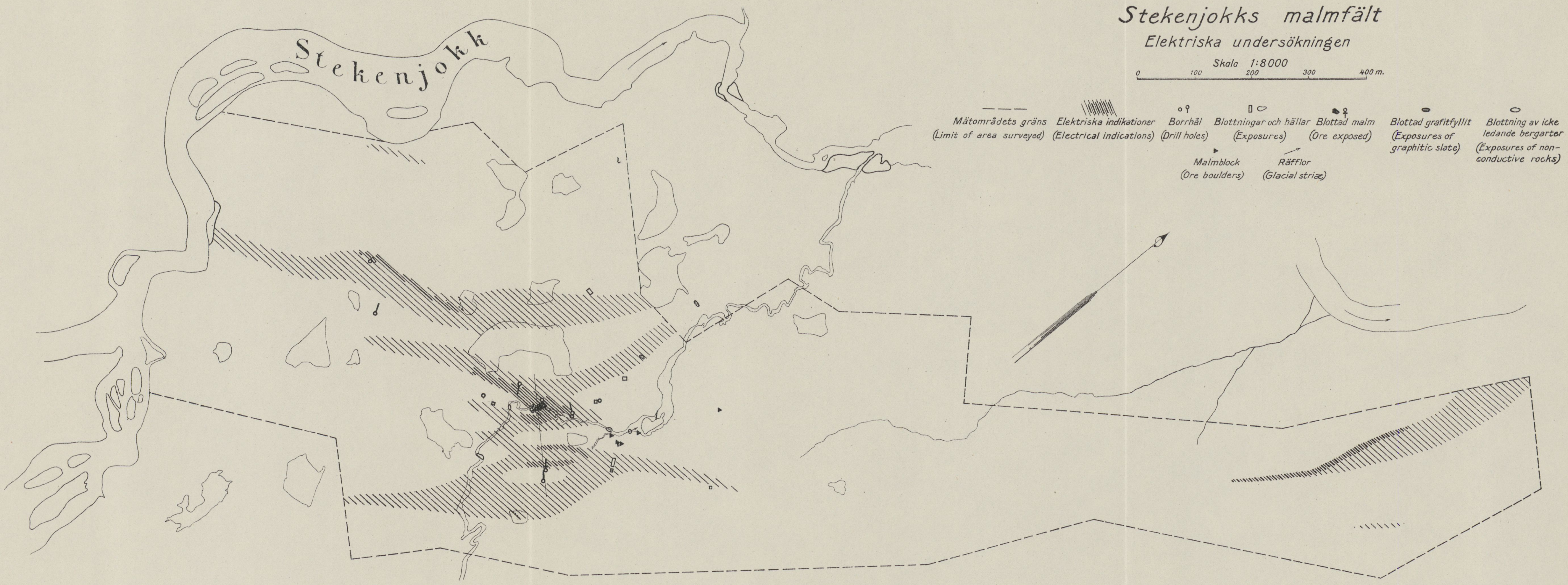

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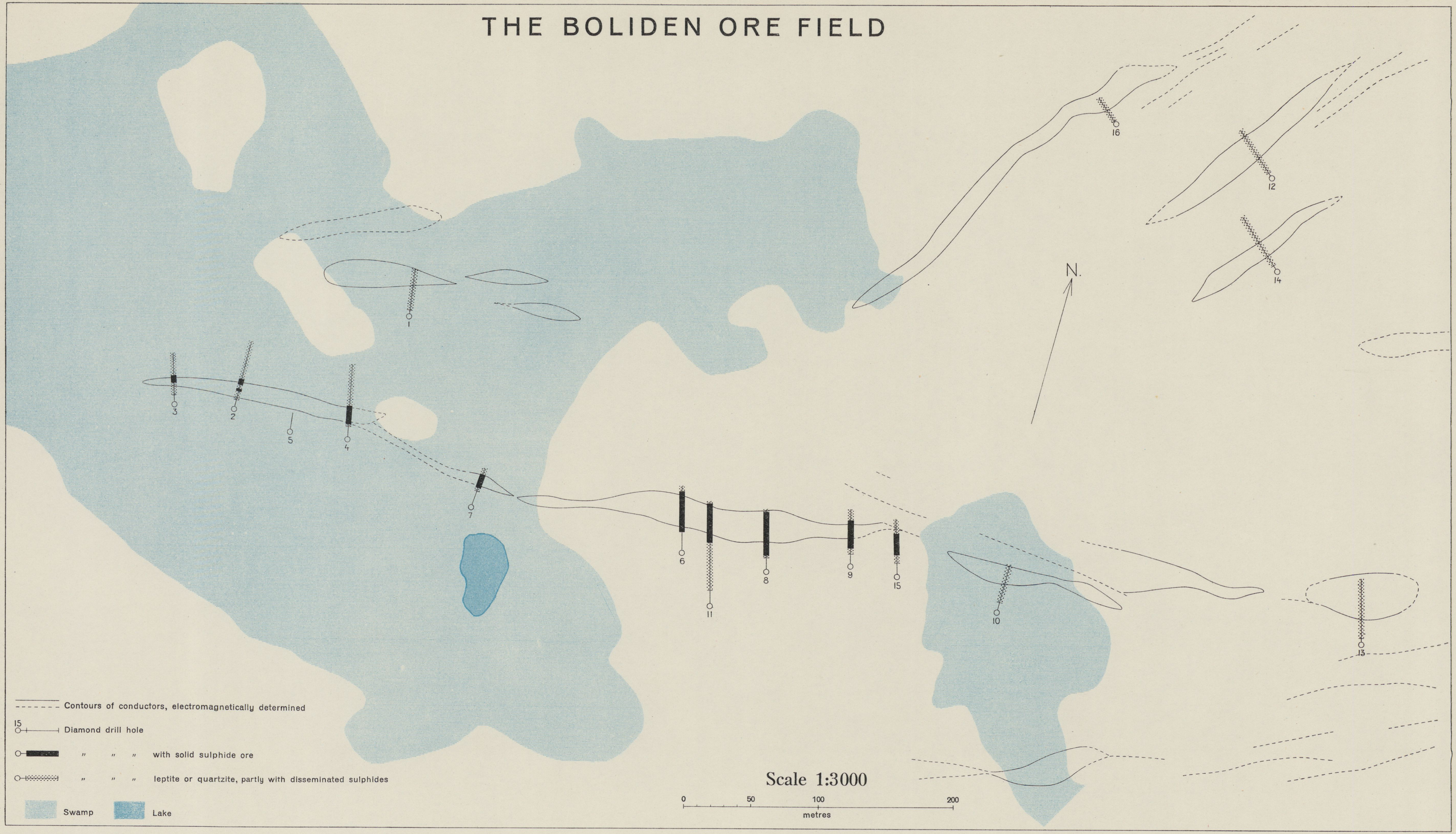

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