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The practical application of geo-physical methods of mineral survey with special reference to the electric and magnetic methods

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Rudolf Krahmann, Dr. Engineering

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Preface.

The present review of the practical geo-physical methods of mineral survey and their spheres of utility, is an elaboration and completion of two lectures, given by the author before a small circle at the thirtieth international meeting of rock-drilling engineers in Linz a. D. on the 14th of September 1925, and before a large audience at the International Congress of boring engineers at Bucharest on September 29th. 1925.

This elaboration contains nothing particularly new in the technical details, apart from the research work on electrical conductivity, concerning which little has yet been published in German literature. It rather has for its object the description, in a form easily comprehensible to the layman, of some of the underlying principles guiding the present development and application of practical geophysics, with a view to making the available information known in broader mining circles and explaining the principles of the methods.

With the same object in view the list of publications given in the appendix has been chosen separateley for each section. The work does not go into any discussion of the various disputed questions as to the advantages or disadvantages of individual methods and instruments, but deals more wirth information as to the utility and results obtainable by each of the methods described.

I am indebted for the kind supply of clichés, etc. to the firm Piepmeyer & Co. Departement „Elbof" of Marburg-Cassel (Illustrations Nos. 2 — 22 and Nr. 31); the Askania Werke A. G. Berlin (Illustration 24—30, 32, 33, 35 and 36) and the Gesellschaft für praktische Geo-Physik, Freiburg i. Br. (Illustration 34).

Berlin-Cladau, November 1925.

Dr. Engineer Rudolf Krahmann.

Chapter I.

Practical geo-physical methods of survey as a whole.

The most important recent progress and the future possibility of development in the discoveray and exploitation of useful mineral deposits lies in the first and last processes involved in mining operations; by which I mean on the one hand the final preparation of the raw-products mined, i. e. their concentration; and on the other hand the first step in any mining operation, viz. the prospecting survey, the most recent development of the latter being the application of geo-physical methods, which will be the subject of the following treatise.

Three factors have brought a rapid and already quite successful development to this branch of science. Firstly the almost revolutionary technical advances during the war, specially in the improved precision in all instruments; furthermore the necessity of increased supplies of minerals after the extraordinary consumption of raw materials during the war, and finally the general economic position, which in hardly any country permits the exploitation of ore beds by deep boring operations on account of the large capital required. Shortly, in other words, the discovery of mineral deposits necessitated cheaper and more comprehensive methods of investigation than drilling, which was often difficult and only gave results point by point. Here lies the practical problem with which applied geophysics have to deal.

In order to avoid misunderstanding which, as a practical geologist, I have all too often met with, I wish already here to emphasize that the geo-physical investigation c a n n o t take the place of deep borings in the discovery of mineral deposits, but they can and are only intended to point to the best localities for starting such operations in order to avoid futile boring.

Their economic necessity, and sole aim and object is to i n d i c a t e deposits, and not to e s t a b l i s h their presence.

The rapid and still young development of methods of applied geo-physics in spite of their already extensive practical application and considerable number has not yet been the subject of a thorough and comprehensive description of the various systems adopted or a critical estimate of the results obtained. It cannot yet be said when the several manuals and books now being written on the subject of applied geo-physics will be published. The literature hitherto available, consisting as it does of smaller or larger pamphlets describing seperate methods and instruments, is widely diffused and often of little value because of its one-sided propaganda. Above all, however, it contains only a very small percentage of references to investigations carried out up to date and an almost smaller fraction of information concerning actual experience. It is a great hindrance to the development of geo-physics, and also to the dissemination of objective information among broader circles, that there is no exchange of views regarding the experiences gained by the various methods. Another great obstacle is the fact that the parties for whom investigations are carried out nearly always require secrecy in regard to the results. For this reason it is often the best methods and the most valuable investigations which thus are kept secret even to the closest circle.

Furthermore within the scope of this treatise it is of course impossible, nor is it my intention, to give a full and exhaustive description or analysis of all the geo-physical methods of prospecting. I intend, rather, after a general review to give a more detailed description of two methods only, the electrical and the magnetic methods (particularly as the former method is still the least known), and for these methods a few recent examples of investigations will be quoted. Concerning other geo-physical methods only enough will be said to explain their method and compare them with the first named methods and also to show how they can be used for practical geological purposes.

While practical geological investigations up to the present time have chiefly been confined to ocular observations and deductions therefrom (apart from chemical, analytical and similar aids) it is the purpose of geo-physical surveys to record certain physical properties of subterranean matter by means of suitable instruments and thus to amplify the geological-mineralogical picture of an area surveyed and to correct and complete it. Following the methods hitherto in use, the geological knowledge concerning territory which has not been fully opened up is derived almost entirely from various observations on the surface, whereas the results of the geo-physical methods of investigation supply important supplementary information concerning the deeper regions.

A further improvement over the methods of examination hitherto in vogue, which in my opinion is even of greater and more promising importance and which as yet has never been expressed with sufficient clearness, lies in the fact that while previous investigations have chiefly related to separate analytical mineral surveys (minralogic, petrographic, palaeontologic or stratigraphic) in order to build up from these various observations an estimate as to the nature of the formation, the applied geo-physical methods work in the opposite direction, commencing with a non-analytical total diagnosis of the nature of sub-terranean formations and continuing by employing a combintion of the various methods and thus narrowing the diagonosis down to the localisation of a deposit; a much more synthetic method of procedure. In other words (although somewhat exaggerated) it may be said that a fundamental improvement lies in the fact that previous investigations of deposits are principally built upon the observation of certain parts of the deposit or lumps of ore isolated from each other, while the applied geo-physical methods build upon the observation of the aggregate geological formation and sections of territory in their entirety.

ua mau ke ea o ka aina i ka pono

The progress in geological practice is further emphasized by the possibility of selecting a particular subject for geological observation.

In the summary in the last chapter I will return to this question.

Up to the present applied geo-physics have more or less accurately succeded in establishing the following physical properties underground, specially with reference to their variation within a given territory examined.

1. Specific gravity, density or gravitation and their local changes.
2. Magnetism in horizontal and vertical directions and its intensity.
3. Electric earth currents or static electric properties as they appear, for insance, in the outcrops of many ore lodes.
4. Radio activity such as observed in large faults and in certain deposits.
5. Geo-thermic properties occuring as irregularities in the increase of temperature towards the centre of the earth.

While these properties can be ascertained by suitable instruments to be permanently present under the earth and observable at a distance, it ist necessary, in order to establish the following not less important properties, previously to produce artificially a particular condition by suitable means. These measurable properties thus brought about are:

6. Conductivity or resistance to artificially produced electric currents and their electric fields.
7. Permeability or reflectivity in regard to artificially produced electric waves.
8. Conductivity or reflectivity in regard to artificially produced acoustic (seismic) waves.

In practice, so far as utility and results are concerned, up to the present the following four methods of the eight mentioned have proved to give most satisfaction:

1. Measurements of density, specific gravity or gravitation.
2. Magnetic measurements.
3. Examination of electric conductivity and resistance.
4. Seismic measurements of the propagation of explosive waves.

The other methods of investigation are either limited in their utility to certain specific cases, as for instance the electric wave methods, radio-activity research, observation of temperature, or they have not been sufficiently developed in method for general use. This applies to measurements of spontaneous electric earth currents.

I shall now proceed with a more detailed explanation of the elextric, or, more exactly, the electro-magnetic conductivity method.

Chapter II.

Detailed description and practial results of the electro-magnetic conductivity method.

Investigations carried out by the electro-magnetic conductivity method depend upon the different resistances offered by the various minerals and rocks in the earth to the passage of an artificially produced electric current forced through the earth.

In order to obtain some idea as to the values involved in the measurements of electric resistance it may be mentioned that (according to various writers)[1]) the specific resistance „W" of one cubic centimetre is for:

silver	0,000 001 437	ohms
chemically pure water . , . .	9 400	„
ordinary glass	2 500 000	„
sulphur	3 430 000 000 000 000	„

A grouping of the more important ores, bitumens, coal, salts, and other useful minerals according to their specific resistance in „conductors" and „non-conductors" has been collated in the following table.[2])

Table I. Electric conductivity of the more important useful minerals.

Specific restistance per ccm.

„Conductors" below 250 kilo-ohms, above that **„Non-conductors".**

	I. Ores.	
All platium, gold and silver-ores	except	Red silver-ore, stephanite, polybasite and all other lead ores
Galena (1 Ohm ccm)		
Mercury and its fahl-ore (grey-copper)	„	Cinnabar
Red zinc-ore, franklinite, wurtzite	„	Zinc-blende, zinc-spar, willenite
All copper-ores	„	Bournonite, malachite, blue copper, tennatite
All iron-ores	„	Limonite and siderite
All manganese-ores	„	Hausmannite and rhodonite
All nickel-ores	„	Nickel arseniate and silicates
All cobalt-ores	„	Cobalt arseniate
Tinstone, cassiterite	„	Tin pyrites, squat
All bismuth-ores	„	Bismuthite and silicate
All arsenic-ores	„	Realgar and orpiment
Wolframite		All antimony and chrome-ores
Molybdenite		Wulfenite
All sulphide-ores, pyrites and magnetic pyrites		Sulphur aluminium-ores, sulphur, ukanium
	II. Bitumina and Coal.	
Hard Coal		Lignite
Anthracite		Asphalt, petroleum, gas

[1]) The more important publications on the subject of various methods of geo-physical investigations are mentioned in the appeodix, grouped in accordance with the arrangement of this text. I shall therefore, not in future refer to any publications.

[2]) A symposium of all the electric and magnetic properties hitherto found in minerals and rocks will later be published by the author elsewhere.

III. Salts.

Lyes and brine	All rock salt minerals

IV. Non-Metalliferous Minerals.

Graphite	Mica, asbestos, marble, corundum, kaolin (China clay), talcum, magnesite, gypsum, fluorspar, baryta, phosphorite (apatite), diamond, diamond clay, precious stones

V. Counter-Lodes (Gangues).

Gangue rocks are conductors when they contain larger proportions of graphite, pyrites, magnetite, salts, salt lyes etc.	Eruptive rocks	10^3 to 10^8 K-Ohm
	Crystalline shales	10^6 to 10^8 K-Ohm
	Crystalline sedimentary	10^8 K-Ohm
	Clastic sedimentary	10^8 K-Ohm

The first experiments in the practical geological utilisation of the difference in conductivity, just mentioned, in various rocks and minerals tock place about the year 1900. The method was given a further and more important development during

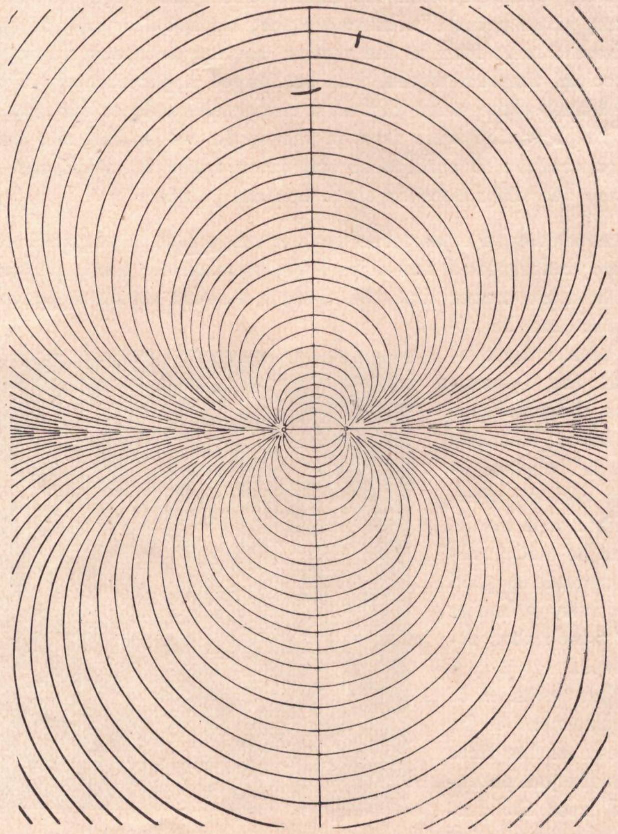


Figure 2. Normal course of lines of electro-magnetic force between two electrodes (earth-points) in homogeneous sub-soil.

the war by certain phenomena observed when listening in to enemy conversations by means of the wireless earth telephons, particularly by an Austrian engineer, Mr. N. Gella, under whose name this method is often described, and also by assistant professor Dr. H. Scheuble-Leoben. The theoretical foundation may be simply sketched somewhat as follows: If by means of two or more earth contacts used as electrodes, a fairly strong electric current is passed into and through the earth, then this current, in perfectly homogeneous ground (electrically speaking of perfectly even conductivity), will follow underground a course which, when plotted, has some similarity to that of the magnetic field. (Recall the well-known school experiment by which this field diagram is made visible by means of iron filings spread on a sheet of glass, under which a horseshoe or other magnet is placed.) The normal field of electromagnetic force, found by means of numerous laboratory experiments and, above all, by means of experiments in the open, covering several square kilometres, is reproduced in figure 2 below.

The lines of electro-magnetic force passing between one electrode and another, follow of course, not only the paths shown, but they flow in the same direction at every point between the lines drawn (which only serve to show the direction at any given point). Furthermore they do not flow only in the horizontal plane, but take the same form in the vertical section or in any sloping plane. The complete spherical diagram would thus be shaped approximately like concentric hemispheres of almost the same form as a rotary ellipsoid, or for instance a somewhat similar shape to the lines seen in the apple cut in half, the cut surface of wich would represent the surface of the earth while its stalk and flower ends would represent the electrodes or earth contact points.

It is now easy to understand that in the presence of particularly good or bad conductors underground the normal electromagnetic force-diagram would be deformed in such am maner that the electric current would endeavour to avoid dielectric bodies and be attracted by good electric conductors. From the appearance of these deformations, their concentration, intensity and position in relation to the electrodes and the electromagnetic field as a whole, deductions can be made concerning the particularly good or bad conductivity of bodies underground, which thus reveal themselves.

Another method of making this apparent is by plotting, instead of the lines of force, lines of equal potential, deduced from the former; i. e. lines connecting all points having the same

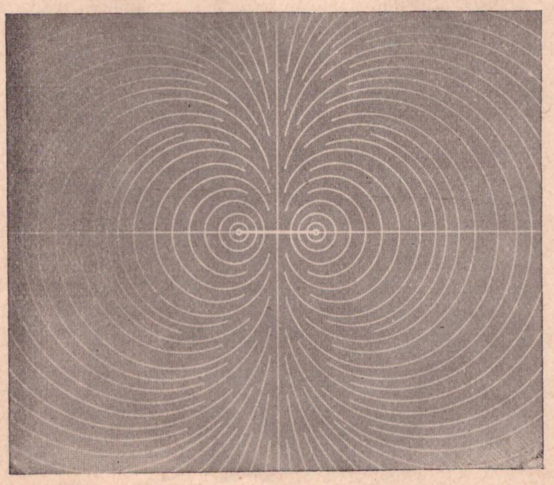


Figure 3. Normal course of electro-magnetic iso-potential lines between two electrode points in homogeneous sub-soil.

electro-magnetic potential (iso-potential lines) between which, therefore, no current flows. These lines are always perpendicular to the lines of force and accordingly show the same characteristics transposed at an angle of 90 degrees.

From this simple connection it will be seen that the equi-potential lines in any non-homogeneous sub-soil will show deformations corresponding to those indicated by the lines of force, which deformations will also be transposed by 90 degree. If, thus, in any territory examined, the equi-potential lines are found to be divergent (by comparison with their normal course) then this means that the same fall in potential will take place over a greater distance and, therefore, that the electromagnetic resistance is relatively less. Vice versa a concentration of equi-potential lines indicates a considerable reduction of conductivity or, which amounts to the same thing, increased resistance at this point. The apparatus, hitherto proved to be the best for these investigations, is shown in the following illustrations. (These instruments, especially the frame aerial receiver and the amplifier are specially manufactured by „Elbof", the electrical prospecting departement of the firm Piepmeyer of Cassel, who manufactures them for their own European and Overseas prospecting groups only, on the basis of their own very considerable experience. The manufacture is supervised by their engineer, Mr. Gella, who has already been mentioned.)

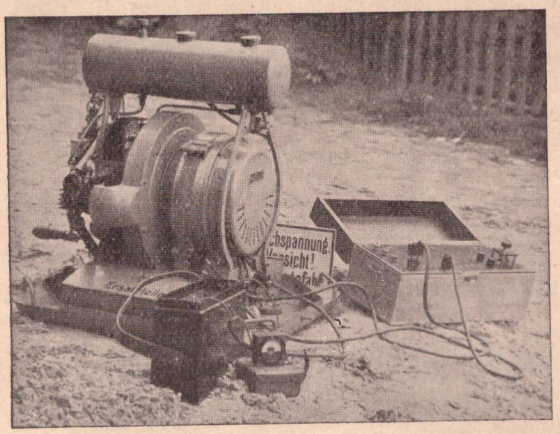


Figure 4. Bosch aggregate of about 1 KW capacity.

The generators for the production of the alternating current are either portable, independant aggregates consisting of a petrol engine and dynamo, of about 1 KW capacity, depicted in figure 4 and 5, or else a generator of $1^1/_2$ KW. capacity, driven by the engine of a motor car, used to carry also the other instruments and the personnel belonging to a prospecting group. This is shown in figures 6 and 7.

Finally for quite small areas accumulator batteries with buzzer transformers are used, as shown in figure 8.

Figure 5. The same used as a generator in the open.

Figure 6. Dynamo attachment with Cardon shaft 1,5 KW. capacity.

The actual apparatus for sending out the H/T current, which is included in figures 4 to 8, consists only of measuring instruments, switches, adjustable resistance and a Morse key.

In order to establish contact with the earth, simple iron rods about 18" long are used as electrodes, several being grouped at each point. Where necessary, concentrated hydrochloric acid is poured into the holes in order to establish better contact between the electrodes and the ground.

The receiving gear consists of a ring aerial (enclosed frame aerial) which contains a large number of wire coils wound in a special manner. It will be seen

Figure 7. The same used as a generator in the open.

from figure 9 and 10 that this ring can be turned round a vertical and a horizontal axis. (There is no directk contact between the receiver and the earth in the Elbof method in contrast to the electric prospecting method of the former

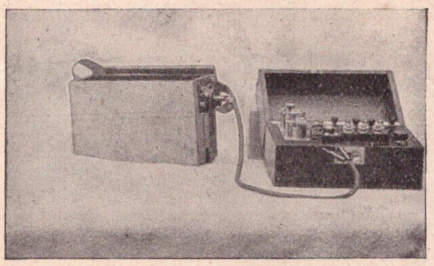


Figure 8. Accumulator transmitter with buzzer transformer.

Erda A. G. of Göttingen or die Gesellschaft für praktische Geophysik of Freiburg, „The sonde method" or the French and Swedish „equal-potential" methods of Schlumberger, and Lundberg and Nathorst.) In the centre of the receiver frame there is a graduated circle to facilitate the reading of the direction and also a clinometer to measure the angle of dip. The current induced in the receiver ring frame is passed to an amplifier shown in figures 11 und 12. This instrument is mounted on shock-proof suspension, can be regulated and consists of a multi-valve amplifier of special construction minutely adjustable to correspond with the transmission instrument. (Constructed at the „Elbof" instrument workshop at Marburg.) In this amplifier the current induced in the receiver is increased several thousand times before reaching the listening telephone, also illustrated.

Figure 9.

It is necessary, in order to arrive at conclusions with regard to the minerals present, that before each electric survey, tests of the conductivity of all rocks and minerals present in the area should be made. The necessary samples may be obtained from outcrops, borings or previous mining operations.

The tests are carried out before each investigation upon samples containing as nearly as possible their natural humidity. These tests are made with special instruments and in the manner indicated in figure 13. Although the measurements of specific resistance obtained with these instruments are neither exact nor very reliable (an improved method of testing is now being adopted) the method of preliminary testing has hitherto given all the necessary information. The measurements are sufficiently reliable, when carried out by a geologist with petrographic experience, to give him all the information he needs before commencing and electric survey.

Figures 9 and 10. The „ELBOF" receiving apparutus with induction coil (enclosed frame aeril) battery amplifier and telephone. On the right a Theodolite.

The method of survey is now as follows: immediately outside the territory to be examined, which must previously have been the subject of an accurate topographic survey, at some point found especially suitable for the purpose, the double earths are established, i. e. two bundles of earth-contacts are placed in the ground at an equal and fixed distance, generally 100 metres from a third bundle. These three contacts or electrodes are connected with the generator transmitter in such a manner that, by means of a switch, the current can be passed alternately between electrodes 1 and 2 or 1 and 3. In sending the signals each of these two terminal sets is distinguished by special Morse signs agreed upon. Now, the entire area is surveyed with the receiving instrument along parallel lines 15 to 70 metres apart (depending on wether the survey is of a special or a general nature) and in such a manner that along these lines at every 15, up to 70 metres the surveyor notes the direction of the lines of force. The local direction of the lines of force at any point is indicated by a maximum in the electro-magnetic inductivity, recorded by adjusting the ring aerial until a maximum sound is heard in the telephone attached to the receiving instrument with its amplifier. The direction to which the aerial points in the position of acoustic minimum corresponds to the direction of the electro-magnetic equi-potential line.

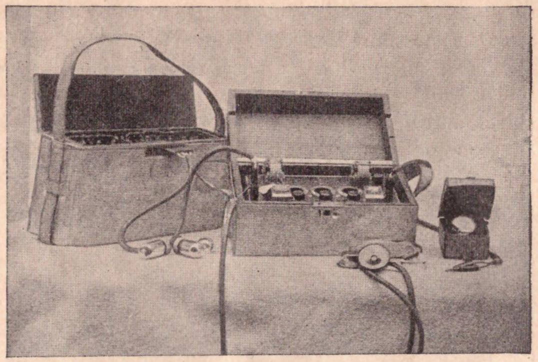
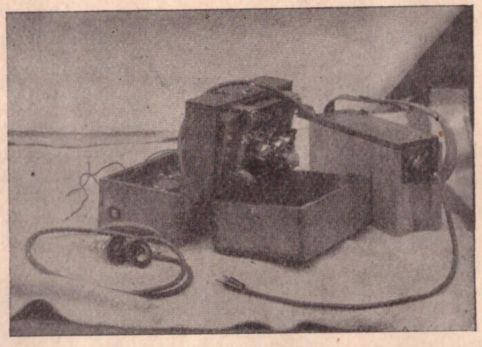


Figure 11.



Figures 11 and 12. „ELBOF“ amplifier with battery and telephone.

By inclining the receiver frame a maximum and a minimum of sound are similarly obtained, the angle of incline corresponding to the latter being noted. At certain signals or at agreed intervals of time, varying according to the territory and distance concerned, the current is passed into the earth through the second pair of electrodes and the direction and angle of the lines of force for this pair is then taken from the same receiver point before moving the instrument. In the immediate vicinity of the electrodes it is impossible to plot any lines as the electro-magnetic field of the generator and the earth wires cause disturbances. For specific cases, of course, some other arrangement of the electrodes than that described may be used.

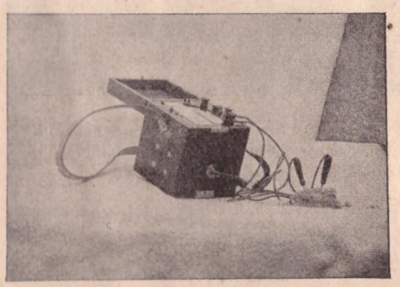


Figure 13. Investigation of electric conductivity of mineral samples.

The directions of the lines of electromagnetic force thus found, are plotted separately for each pair of electrodes on the topographical chart of the territory and from these plottings, by graphic interpolation, the complete electromagnetic field diagram for each pair of electrodes is drawn. For every survey, therefore, one obtains by using „double earths“ two entirely independant field diagrams. In nearly every case a further double earth is established, usually in a position opposite to the first earth, and with this as a basis a second survey is carried out over the same entire area surveyed. The taking up of four electromagnetic field diagrams from two different sides of the territory and at given angles to each other has been found to be necessary, as it may happen (which will be shown in later examples of surveys) that subterranean bodies of particularly good or bad conductivity, on account of an unfavourable position in relation to one or other of the double earths, may not be sufficiently sharply defined in a single diagram. The angles of dip are also treated separately in a similar manner and are used to indicate the depth of any deposit found.

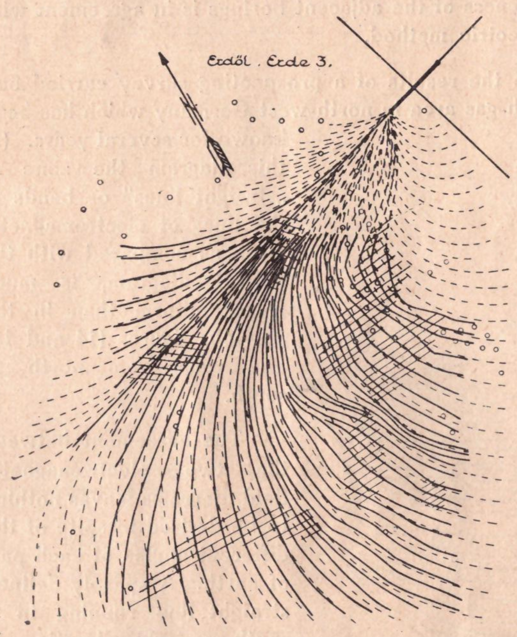


Figure 14. Electromagnetic survey of a Hannoverian oil district carried out on behalf of the Deutsche Petroleum A.G. of Berlin Electromagnetic field diagram of earth 3.

o———o = electrode couple supplying current.
— — — — = normal course of electro-magnetic lines of force in homogeneous sub-soil, for comparison.
———— = actual diagram of electro-magnetic lines of force found by survey.
||||||||| = areas promising oil according to divergences of the lines of force.
o o o o o = adjacent deep borings partly productive and partly barren.

In order to give an indication of the practical geological value of this method, I may be allowed to refer in the following to a few specially selected examples of completed surveys which have a bearing on oil prospecting, the most important mining question of today. These are a few of the most recent surveys on oil bearing territory carried out by the Piepmeyer („Elbof“) firm, of Cassel, already referred to. Unfortunately, as already indicated, I am not permitted in every case to give details concerning the position, locality and geology of the territories concerned.

The above figures 14 and 15 show the result of surveys and the divergences of lines of force in a Hannoverian oil district which was examined in the year 1925 on behalf of the Deutsche Petroleum A. G. of Berlin. On both figures the numerous divergences from the normal electromagnetic diagram are clearly seen and the „straight“ sections are easily recognisable. On a closer examination the agreement between the divergences in each diagram is quite clear in spite of the different angle of each pair of electrodes (earths) in relation to each other. The special difficulty in this particular survey was due to the fact that the subterranean formation was very much broken, which was already known through the deep-borings undertaken in the vicinity and which is reflected in the electric survey, visible on the diagram as irregularities of the „straight sections". The productiveness or non-productiveness of the adjacent borings is in agreement with the indications found by the electric method.

Figures 16 and 17 give the results of a prospecting survey carried out, also in the year 1925, on an earth-gas area in north-west Germany which has been known for several years. (In this diagram the zone of „straight lines" or bends in the lines of electromagnetic force as compared with the normal diagram, is much more uniform than in the previous figures (14 and 15) and runs from north to south.

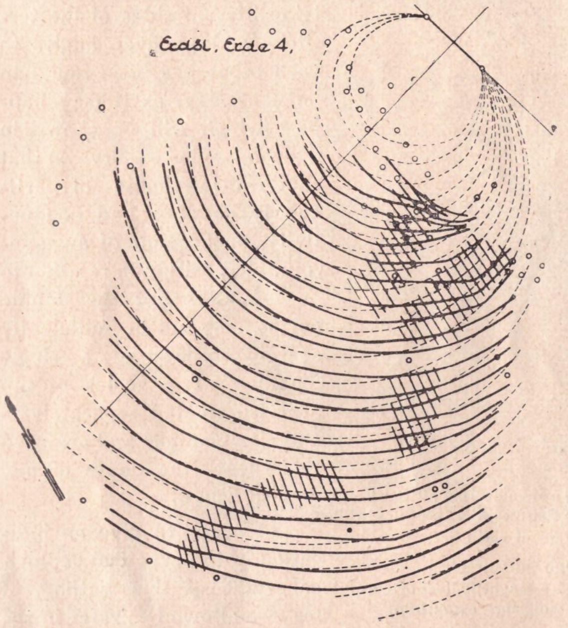


Figure 15. The same area. Electromagnetic field diagram of earth 4. (For comparison.) Signs as under figure 14.

The agreement between the two electromagnetic field diagrams leaves nothing to be desired in spite of the different angles of each pair of earth. A sparply defined straight line running in a south-westerly direction in figure 17, seen on one of the inner current lines, is, howevre, surprising, but it has nothing to do with the deeper subsoil, because the sharpness of these divergences immediately indicates the presence of a particularly good conductor at a shallow depth. Subsequent investigations showed that at this point lies the main pipe line carrying gas from the deposit to a large town near by. If one compares this diagram with figure 16, covering the same territory, the question arises as to why the gas main mentioned did not influence the latter field diagram. The answer is that without any knowledge of the existence of this pipe line, the electrodes in figure 16 were placed directly in line with it. Now, on the connecting line between the electrodes and along its prolongation, the symmetric centre, the current lines are normally absolutely straight. This is seen most clearly from the normal field diagram in figure 2. In figure 16, the pipe line at a small depth below the surface has prevented a divergence of the lines of force from their symmetric course, and as it has maintained the

symmetry, it gives the illusion of normal sub-soil.

In this connection I draw attention to my remarks about the choice of electrode earth-points and above all to the necessity of having at last a double set and preferably a quadruple set of current line diagrams, covering every area surveyed. These diagrams should be taken up from different angles and from opposite sides. In order to improve and to obtain more detail than hitherto in the plotting and interpretation of the lines of force, it is possible to express the measurements of the divergances in figures and then plot them in lines and areas of equal aberratin (the reasoning is here very simply indicated) which, in conncetion with topographic contour lines, isograms, isodynamies,etc., are more familiar to the eye.

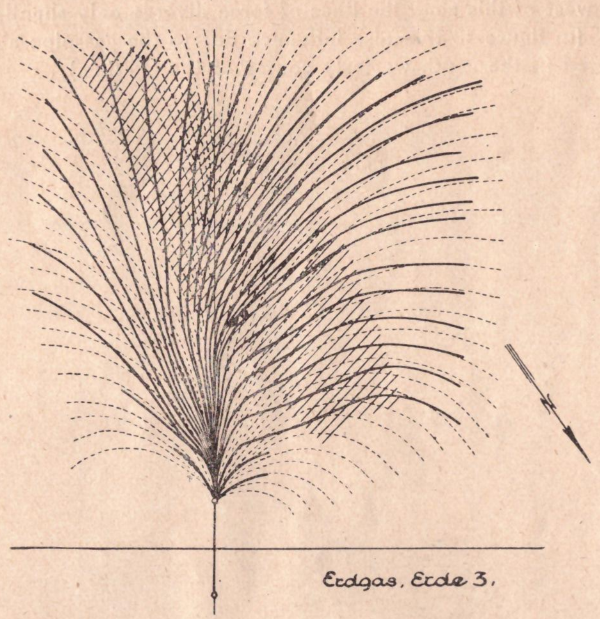


Figure 16. Electromagnetic survey of the North-German earth-gas fields. Electromagnetic field diagram for earth 3. (For explanation of signs see figure 14.)

A preliminary result of investigations only recently begun bv me, concerning other methods of depicting and interpreting the results of electric survey is shown in the following figures 18 and 19, which have been drawn on the basis of figures 16 and 17 and thus represent the results of the same transmission electrodes on the same gas-field, but by a different method of plotting.

In both illustrations three important maxima of divergence are noticeable in the north and south direction which are already known from the previous figures,

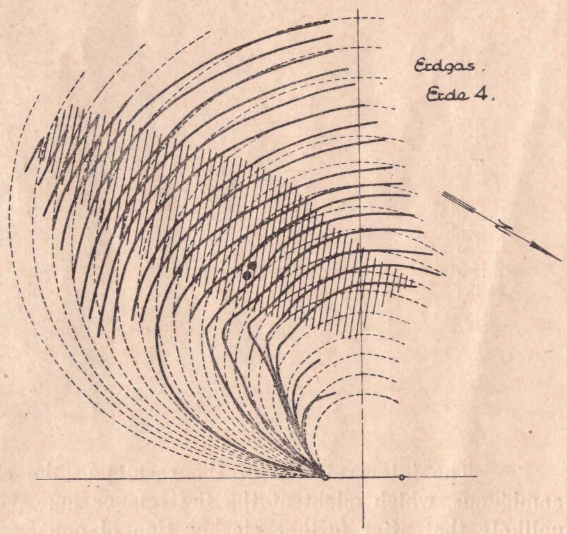


Figure 17. The same area Diagram of earth 4. (Signs see figure 14.)

while to the east and the west of this zone the lines of force diverge only slightly from their normal course. (In figure 18 the false influence due to the gas-pipe already mentioned is indicated in the south-westerly course of the O - line.)

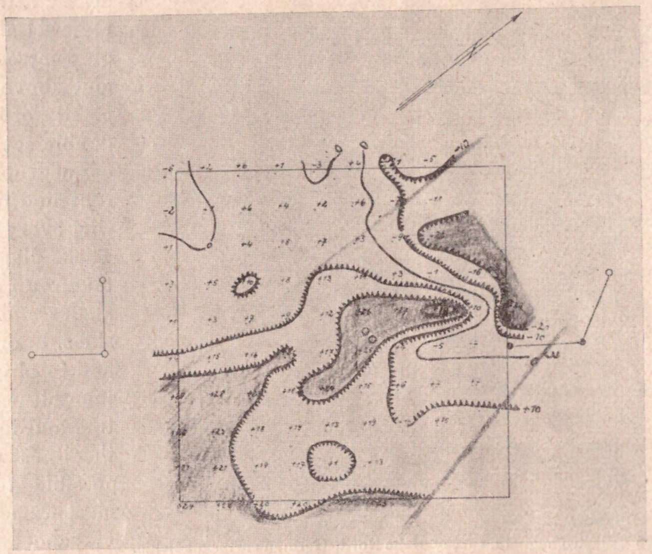


Figure 18.
Electromagnetic survey of Nord-German earth-gas-field.
Areas of equal line-of-force divergence observed for earth 3.

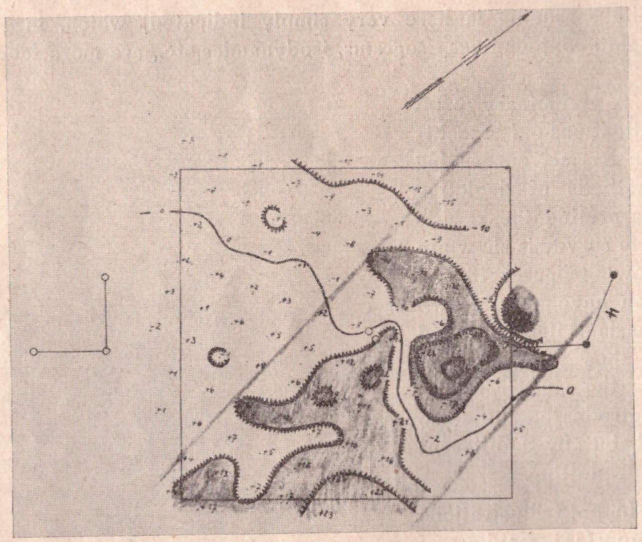


Figure 19.
The same earth-gas-field survey.
Area of equal divergence observed for earth 4.

The interpretation of the results of the electric survey is at least not ambiguous, which might at the first glance appear to be the case, and it is not unlikely that after further elarboration of one or other of the new methods of plotting it may be possible to draw contours following a desired profile line.

A feature giving special interest to the electric survey of the earth-gas-area just mentioned is that this area is part of a larger area which has been examined by all the known geo-physical methods. Thus the gravity measurements undertaken immediately south-west of the area which was electrically surveyed, indicate a salt ridge underneath the diluvial layer usually found in North-Germany. The magnetic-measurements, according to their author, Mr. C. Heiland, have established the varying level of the undulating boundary between the diluvial and the tertiary formations. The seismic measurements by Mintrop have failed, because deep borings undertaken after indications by this survey, to find a supposed salt ridge, were negative. The radio-activity investigations and measurements of the electrostatic potential, and finally the geothermic survey, obtained in the best cases only local results of no practical and of very small scientific value. I will return to these other geo-physical methods of survey in a later chapter. Another example of a survey carried out by the Elbof electric prospecting method, is shown in the following chart from an American ore-survey undertaken in the year 1924.[1])

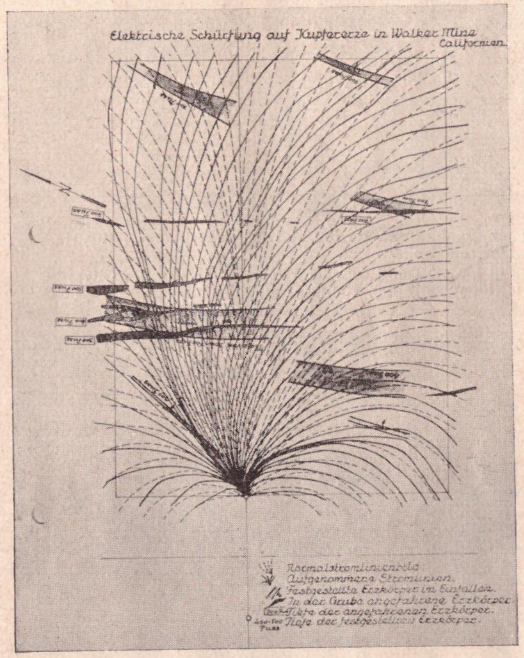


Figure 20. Electromagnetic survey of the Walker Copper Mine in California.

Normal lines of force. Surveyed lines of force.
Ore bodies found. Ore bodies explored in the mine.
Deep of the ore bodies found. Deep of the ore bodies in the mine.

Finally the following figures 21 and 22 which give another example of non-metalliferous mineral deposits, show divergences of current lines and interpretations of the results which agree with each other very well. The almost immediate vicinity of a particularly good conductor such as graphite alongside a specially bad conductor such as talcum, has produced usually sharp aberrations in the lines of electromagnetic force.

With reference to the information obtainable concering deposits it has been found in the fairly numerous surveys hitherto carried out, judging by the success or failure of the same, that the best objects for survey by the eletromagnetic line of force method are those where the mineral is either of good conductivity or where it has good insulating properties. The two extremes are, on the one hand oil and gas deposits and, on the other hand, ore-bodies.

1) Figure 20 is only one of four line-of-force diagrams. All four diagrams are of course made use of in calculating the results of the survey.

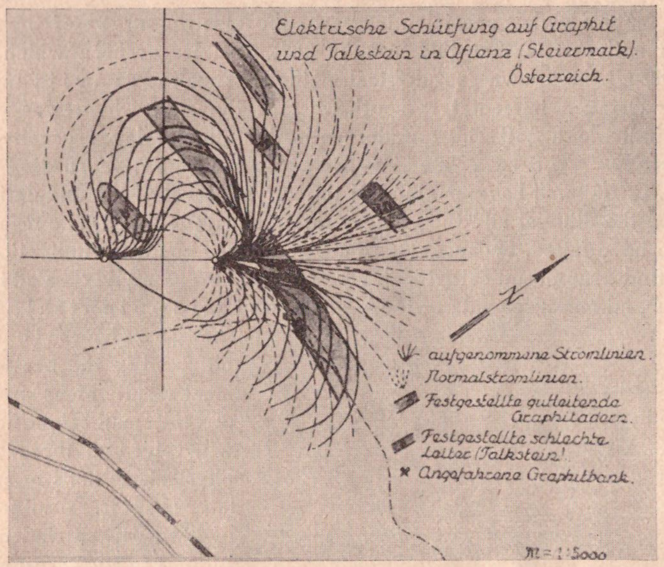


Figure 21. Electromagnetic prospecting for graphite and steatite at Aflens (Steiermark) Austria. Diagram No. 1.
Normal lines of force. Surveyed lines of force. Good conductor found (veins of graphite) Non-conducting material found (steatite). Lode of graphite mined.

Oil deposits, in all the surveys hitherto carried out, have been clearly indicated, even showing a direct so-called „screening" effect, i. e. behind any oil-bearing line in the territory examined no signals were heard in the receiving instrument in any position, although the distance of the receiver from the transmitter was only a fraction of the distance of 2000 metres otherwise normally covered by the transmitter.

Gas-deposits have hitherto shown proncounced „straight" sections in the surveyed lines of force, but not this peculiar screen effect. This is also easily explained by the compressibility of earth-gas and its much less independent occurance as a deposit.

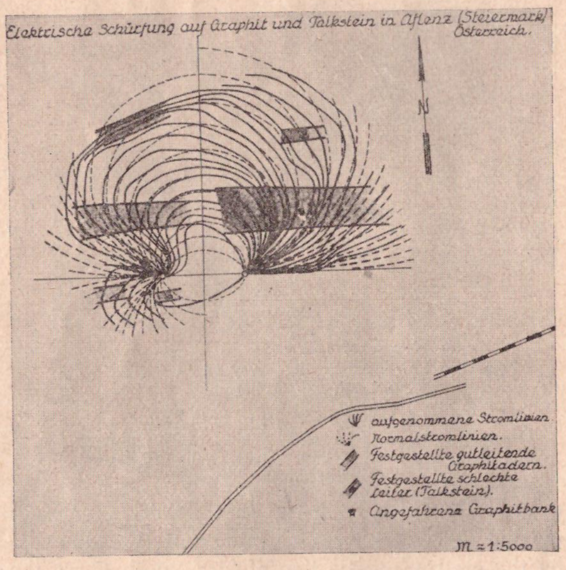


Figure 22. Electromagnetic prospecting for graphite and steatite at Aflens (Steiermark) Austria. Diagram No. 2.
Normal lines of force. Surveyed lines of force. Good conductor found (veins of graphite). Non-conducting material found (steatite). Lode of graphite mined.

Concerning the utility of this electromagnetic induction method, the most important indications (apart from geological conditions occasionally met with) are contained in the table Nr. 1, given at the beginning of this chapter, showing electric conductors and non-conductors among the useful minerals. Its special suitability for bitumen on the one hand and for ores on the other, and very particularly for sulphide ores, has also been referred to. Among the various classes of coal, anthracites, on account of their good conductivity, are easier to locate than lignites. The possibility of locating other useful minerals, especially non-metalliferous minerals, depends usually more upon the surrounding geological formation on the spot — particularly the electric properties of the rock in which they are found — than upon their own electric properties and can only be decided on for each individual case. Besides locating deposits it is, of course, possible with the electromagnetic induction method to locate also faults, intrusions and other geological phenomena so long as there is a certain minimum difference of conductivity between the various formations, which is seldom absent and in eruptive areas nearly always present.

In practice the survey of an area of one square kilometre covered four times, according to the nature of the territory requires an average of one to two weeks. For a general survey of larger areas an average time of 10 to 12 days will suffice for four square kilometres.

The principal advantage of this electromagnetic induction method (Elbof method) as compared with other geophysical methods later to be mentioned arises from the fact of the direct influence of the deposits themselves. The following description will show that the other methods give results more of geological and, above all, of tectonic (structural) importance than direct information concerning the deposit itself.

Before I leave this chapter, I have still to mention a few deviations from the „Elbof" method as described above, which is that mostly used.

The use of direct current instead of alternating current hat not been very successful, because earth currents (which I shall return to in the next chapter), local polarisation currents and subterranean humidity often give rise to considerable disturbances affecting the results.

Furthermore the so-called „Sonde" method of the former „Erda A. G." of Göttingen and the Gesellschaft für praktische Geophysik does not give much promise in regard to extensive development and use. This method differs from the „Elbof" or Gella method desribed by having as a receiver, instead of an induction coil (frame aerial), earth contacts or „sondes", similar to those used for transmission. It is obvious that with this direct reception of the current from the earth it will be almost exclusively the more superficial distribution of the current which will act upon the receiver, for which reason it is impossible to obtain results relating to any great depth. Furthermore this method, of course, entirely lacks any means of registering the depht, such as the „angle of dip" described under the „Elbof" method and also in the few instances where it has been used as compared with the Gella method, it has taken much more time for each receiving station because of the moving of the earth contacts, while finally, the greatest drawback of all is that each time the sondes are moved there will be a different contact resistance between the receiving sonde and the earth, for which reason

Elbof Method.

this method cannot give even approximately as accurate results as the other.

From foreign technical literature the method best known, apart from the „induction method" above described, would be the „Iso-Potential" method as described and used by the Frenchman Schlumberger and also by the Swedes Lundberger and Nathorst. These methods utilize, instead of point electrodes, mainly line electrodes for passing the current into the earth and between these electrodes there will be an approximately linear system of equi-potential lines, representing the „normal field" of the areas surveyed. In regard to the receiving apparatus these methods are rather similar to the Sonde method, as they use a sensitive voltmeter, connected between two searcher sondes. After the explanation, given in the beginning of this chapter, concerning the equi-potential lines and the method in which their course through particularly good or bad conducting sub-soil is expressed, and after the description of the searcher sondes just given above, it would appear unnecessary to go into details concerning these methods. Especially in Sweden quite good results have been obtained with the Swedish method under the peculiar local conditions which are especially favourable to electriy prospecting. For oil prospecting, the main field of utility of the „Elbof" method, these methods so far as I know have not yet been used, probably because of their insufficient penetration in depth.

Finally a new electro-magnetic method, the „Sundberg" method, from Sweden has recently appeared before the public, replacing the Lundburg-Nathorst method. Up to date, however, only Swedish ore-deposits (the Skelleftea field) have, so far as I am aware, been examined by this system. This method at present employs for the transmission induced current only (instead of earth contacts an insulated cable is used), and the receiver instrument, called a solenoid, consists of an induction coil very similar to the Scheuble-Gella frame aerial. The depth penetration of this method, however, according to the claims of the inventor, does not exceed 300 metres.

Chapter III.

Prospecting by means of electric waves and the measurements of electric earth currents or self-potentials.

Methods utilising electric waves and oscillations, which have been proposed by various inventors, depend upon a phenomenon rather opposite to that upon which the conductivity method mentioned above is based, viz: that good conductors of electricity are almost inpenetrable to electric waves and will reflect them or, vice versa, that non-conductors, the so-called dielectric materials are good conductors of electric waves.

On this basis various methods have been evolved and patented with the object of ascertaining the presence and position of ore-beds, ground-water, salt-ridge brines, etc., but none of them have emerged beyond the experimental stage or found any practical use such as that to which the four principal geo-physical methods have been put for some considerable time.

Parallel with the rapid development of wireless science much theoretical work has been put down on these methods. I will only mention a few names, such as Trüstedt, Leimbach, Löwy and Ambronn and the experiments in earth

telegraphy to which I have previously referred. Practically, however, the main difficulty for further development of this method seems to me to lie in the too frequent and too pronounced differences in the moisture of the sub-soil. In our latitudes, therefore, their utility will probably be limited to a few special cases, such as potash mining, and in southern latitudes to the often very important problem of sub-terranean water.

Still further backward in development and above all in practical and material results are investigations concerning the small but nevertheless existing electric earth currents, the frequently measurable polarisation currents, electric self-potentials, and whatever these electrical phenomena have otherwise been called. The first observations of this nature go back to the forties of the last century, to the work of Reich and Fox and tell us no more than that occasionally electric currents have been met with in ore-deposits, and point out that it may be worth while to continue these observations and to make use of the phenomenon forthe re-discovery of lost or broken lodes of ore. Since then similar observations have frequently been made and published, but unfortunately it is still impossible to co-ordinate them and systematize them for purposes of further development.

Personally I regard further investigations in this direction as quite promising, but I except from them results less in regard to geo-physical prospecting and discovery, than rather important additions and possibly also alterations to our present theories concerning the origin of ore-deposits.

I assume that later the electrolytic processes will play a part in our genetic theories which cannot yet even be grasped. A digression on this theme would, however, exceed my subject. My intention was only to point out at a suitable opportunity the possibility of also theoretic-scientific development which is opened up by the advances in practical geo-physics.[1])

Chapter IV.

Description and examples of the magnetic intensivity survey.

Magnetic investigations were first carried out in Skandinavia on the enormous magnetite deposits found there and the method of their use was there developed. For some considerable time now, beginning with quite simple instruments, the boundaries of the magnetic deposits there have been established very successfully. Only recently, in the last year or two, the instruments and their theoretical principles have been much improved, thus greatly extending the utility of these magnetic surveys.

The practical geological basis of this method lies in the varying magnetic properties of rocks. Those which reither have any magnetism of their own, nor are capable of concentrating to themselves the magnetic field lines, are described as diamagnetic and they rather diffuse, or turn away the magnetic lines and thus produce magnetic minima. Paramagnetism or magnetic susceptibility are the terms used for describing the property of locally condensing the lines of earth magnetism, or concentrating them and thus producing magnetic maxima. Finally the third degree of magnetic susceptibility is the ferromagnetic condition, which we shall

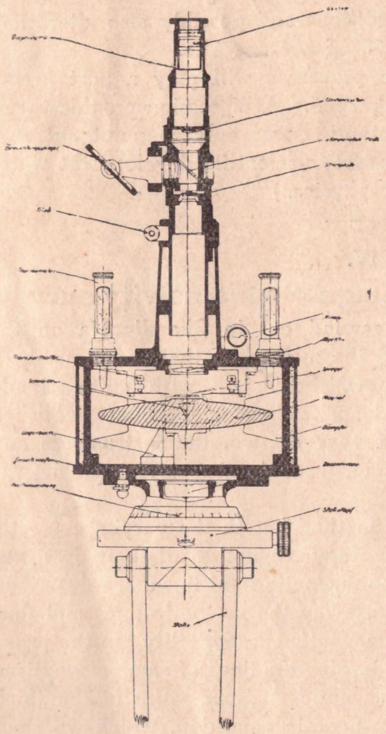
1) I hope shortly to be able to publish further articles on this subject in the „Zeitschrift für praktische Geologie".

shortly describe as self-magnetism (inherent magnetism). A few data concerning the magnetic properties, only intended as a basis of comparison, have been collated in the following table[2]):

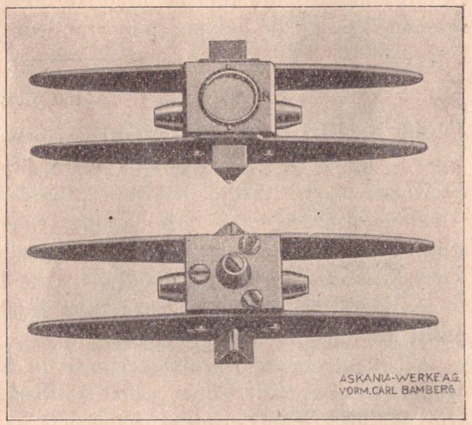
According to Stutzer, Gross and Bornemann, the magnetic susceptibility per unit of volume is, for:

Quartz	0,9·10⁻⁶	Augite (pyroxene) .	133,13·10⁻⁶
Calcspar		Limonite	219,61 „
Fluorspar		Arsenical pyrites . .	236,82 „
Baryta		Wolframite	240,89 „
Sulphur	0,80·10⁻⁶	Chromite	244,51 „
Dolomite	0,91 „	Psilomelan	286,06 „
Galena	2,63 „	Siderite	231,45 „
Magnesite	3,00 „	Red Manganese ore (dialogite) . . .	379,90 „
Pyrite	4,54 „	Rhodonite	457,48 „
Marcasite	5,43 „	Serpentine . about	2 535,— „
Graphite	8,00 „	Spekularite . . „	3 215,— „
Anchorite	23,55 „	Magnetic pyrites . „	7 018,— „
Chalcopyrite	32,15 „	Titanic ironstone „	30 740,— „
Malachite	34,41 „	Franklinite . . „	35 640,— „
Azurite	39,85 „	Magnetite . . . „	97 350,— „
Hornblende	122,66 „		
Pyrolusite	127,69 „		

Table 23. The magnetic properties of a few useful minerals and rocks.



The magnetic field is at every point of the earth physical-characterized by the direction and intensity of the magnetic force. The direction in the horizontal plane is called the declination. In Central-European



Figures 24 — 25. Local variometer for measurements of magnetic vertical intensity, (the Schmidt field-balance) manufactured by the Askania Werke of Berlin; next to it, seperately, the balanced system of magnets seen from above and from below.

2) A summary of all the electric and magnetic pr perties hitherto found for minerals and rocks will shortly be published by the author elsewhere.

latitudes a magnet in free suspension will adopt a position of about 65 degrees inclination towards the north.

In order to establish and make use of local peculiarities, the most suitable condition to observe is not the direction, but the intensity of the magnetic force. In both hemispheres of the globe the local changes in vertical intensity are subjects for observation and in the area around the magnetic equator, also the variations in horizontal intensity.

The methods of observing variations in intensity in either direction, are very similar, in regard to both the instruments and the methods employed and I will, therefore, in the following confine myself to the survey of vertical intensity which is almost exclusively employed in these latitudes and local deviations therefrom due to the varying magnetic properties, indicated above, of the different types of rock in the sub-soil. Here again exceptional cases may occur in the form of magnetic fields arising from the earth-currents already referred to, for which the rocks of the sub-soil are only indirectly responsible, as they arise more from chemical changes. Furthermore local anomalies sometimes occur due to spontaneous magnetisation caused by lightning etc.

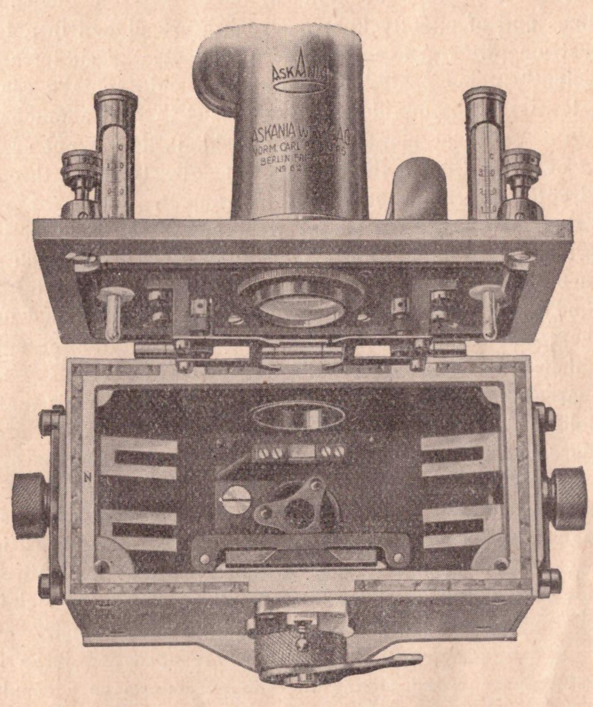


Figure 26. Local voriometer for the measurement of magnetic vertical intensity, manufactured by the Askania Werke of Berlin, part view of interior.

The instrument as manufctured by the Askania Werke of Berlin and designed by professor Adolf Schmidt[1]), for these vertical intensity surveys, is in spite of its great sensitiveness, almost the simplest and most easily handled of all geophysical appliances.

In figure 24, there is, on a stand adjusted exactly horizontally, a case which may be turned in a horizontal direction containing a compensated double magnet shown in figure 25. This magnet is suspended upon a quartz prism resting on a quartz foundation and mobile, not like a compass in a horizontal direction, but

1) Even in Sweden, the country where magnetic survey originated these Askania instruments are preferred.

only in the vertical plane. Placed on the case is an optical instrument throught which the indicator of the balancing system of magnets may be seen in order to observe its angle with the horizontal when at rest. The reading is taken from a scale fixed inside the optical device. The same scale serves as an indicator, being projected by means of a ray of ligth entering the instrument from one side and reflected in a mirror attached to the system of magnets. Viewed from above this reflected image is seen alongside the fixed scale, and the divergence of the reflected image from the fixed scale is read off and gives a direct indication of the angle of dip of the magnet. Should this divergence be so great that the movable image should go beyond the limits of the fixed scale then auxiliary magnets of various sizes and of exactly known strength are placed in a telescopic tube beneath the instrument. By means of these magnets the subterranean magnetic field is sufficiently compensated to make it possible to take readings. To these the field intensity of the auxiliary magnets must then be added or substracted in calculations.

Measurements with the Askania instrument are taken at least three times at every station in the east to west direction and three times in the west to east direction, turning the entire instrument. From these six readings the average value is taken. The exact west and east direction is adjusted by means of a detachable graduated circle. Simultaneously with each measurement the temperature of the instrument must be read from thermometer fixed inside it and also the time of observation must be precisely noted. Based upon the indication of time the results from each station are corrected after the entire investigation has been finished in accordance with the observations of the magnetic variations at the nearest magnetic observatory. The reason for this is that variations in the magnetic field of the globe, caused by sun spots, etc. must of course be eliminated. If there is no magnetic observatory anywhere near the area surveyed, which would frequently be the case in colonial work, then it is necessary to work with two instruments by the so-called chain method, or else an instrument with an automatic registration device must be kept in a stationary position.

The observer must of course, just as the entire instrument, be absolutely free of iron and he must also carefully examine the vicinity of each selected station for iron objects and chose its position accordingly.

In order, finally, to discover so-called jerks in the registration of the instrument arising during the measurements as a result of knocks or too sharp variations of temperature, and to be able in the later calculation to equalise them as far as possible, measurements must be taken at several control and auxiliary stations every day, so that the stations suveyed day by day are well linked together.

On one quare kilometre, all according to the object of the search and the local geological conditions, there will be from 30 to 300 stations. I would, however, reckon with an average of 100 stations plus 20 repeat stations, the magnetic survey of which would teke about five days, depending of course on the territory. Including calculations and estimates one could reckon with about a week. From this it will be seen that the magnetic method is a fairly rapid and, therefore, cheap method of survey.

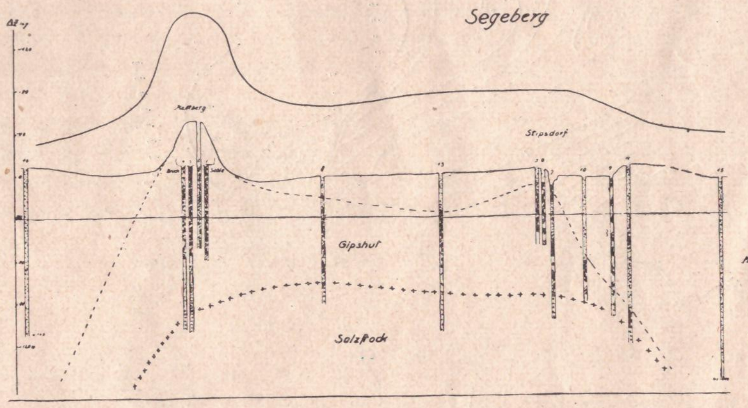
The evaluation of magnetic measurements is arrived at by the multiplication of the scale value of the instrument by each station's result, after the latter has been corrected for temperature and magnetic variations. The station values

Figure 27.
Iso-anomalies of magnetic intensity above the north-west German salt ridge at Segeberg.

Segeberg
Z - isanomales 1921 . 5
[measured, reported and interpreted by C. Heiland 1922.
scale: 1 : 25000
union: 1 · 10^{-5} cgs
station: · 75
Drilling:
○ - 35 founding gypsum or salt (number of depth = superior of the gypsum)
○ - 800 without success (number = depth of the drilling)
v: - 25 to - 50 y
v: - 50 to - 75 y
v: - 75 to - 100 y
v: - 100 to - 125 y
v: - 125 to - 150 y
calcaire cropping out

The deepness of the drillings are not reduced to n. n.

thus found expressed in γ ($1\,\gamma = 0.000\,01$ C. G. S. units) is entered on the chart, and stations having the same value are connected with each other by lines. Thus isodynamic lines of vertical intensity are recorded. If these isodynamic lines are reduced according to the socal average value of the earthmagnetism, then one obtains iso-anomalies which often are described by the sign $\triangle$ Z. I will now proceed with a few examples of surveys.



Figur 28. Magnetic profile through the salt ridge of Segeberg and vicinity

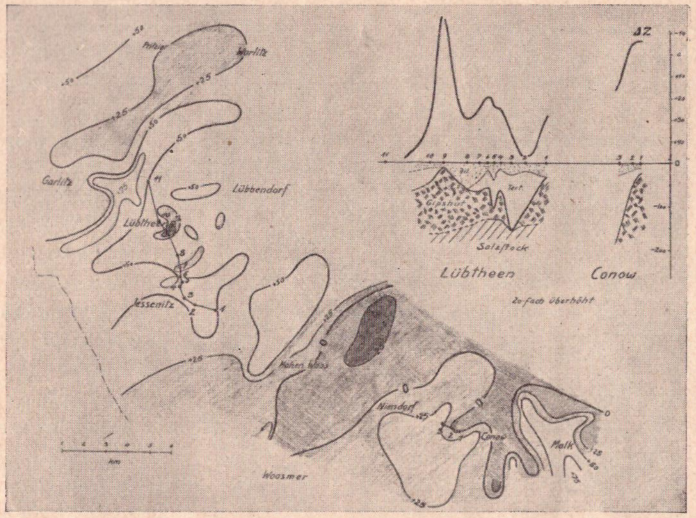


Figure 29. Iso-anomalies of magnetic vertical intensity in the Mecklenburg salt ridge of Lübtheen-Conow.

Figure 27 shows the distribution of the strength in the magnetic field over the magnetic field over the north-west German salt ridge at Segeberg, which manifests itself as a magnetic minimum because the rock salt has a smaller magnetic susceptibility than the rocks surrounding it, which always contain traces of iron. Figure 28 shows the same territory in profile. The rise of the △ Z curve indicates, according to the scale on the left, a diminution of the magnetic properties.

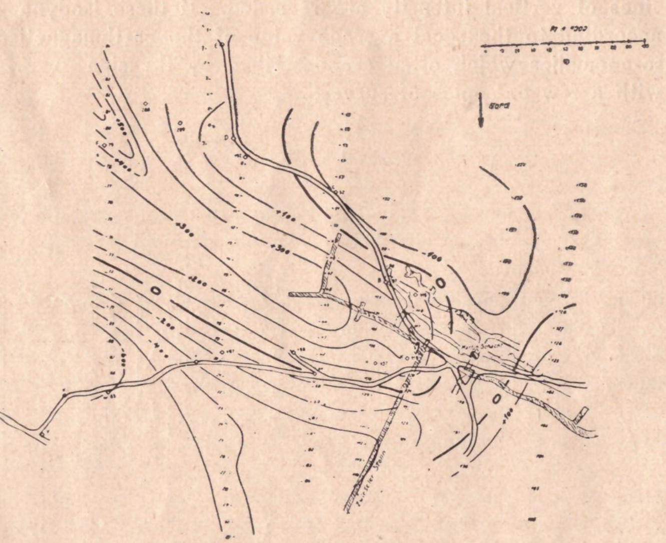


Figure 30. Iso-anomalies of magnetic horizontal intensity in the magnetite deposit at Berggieshübel, Saxony.

Figure 29 shows by the same method the result of one of the first larger magnetic surveys in Germany, carried out by Schuh in the area of the Mecklenburg salt ridge.

Figure 30 shows the magnetic anomalies of the Saxon magnetite deposit at Berggieshübel, where the difference in magnetismus between the orelode and the gangue amounts to 1.100 γ. It is worth noting that at this deposit also an electro-magnetic „Elbof" survey was carried out, giving results whose agreement with the magnetic survey was quite surprisingly good and which have later been confirmed by mining operations.

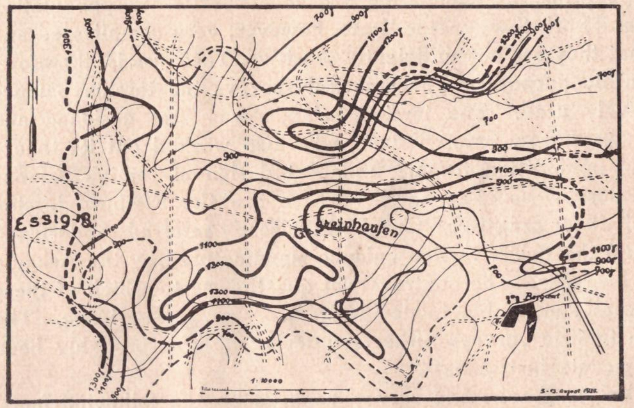


Figure 31. Isodynamic lines of magnetic vertical intensity in the basalt rocks of Habichtswald near Cassel.

Finally the last figure No. 31 shows pronounced magnetic anomalies in the tertiary sedimentary and basaltic area of the Habichtswald near Cassel. This territory, comprising an area of more than two square kilometres, was surveyed by myself on behalf of Elbof, Cassel in August 1925 in order to complete the geological chart. Measurements were taken from 120 stations plus 25 repeat and control stations in seven days[1]).

The practical utility of the magnetic mine survey is thus, as will have been seen from the examples given, by no means, as formerly, confined to ferromagnetic deposits. Even the small difference in permeability between salt rocks and gangue is easily distinguished with the new instruments, provided, however, that the salt ridge is not covered with too excessive a layer of tertiary and diluvial matter. Personally, in tracing the course of the isodynamic lines or iso-anomalies, I see such wide possibilities of confirming, completing and correcting, in short of increasing our geological knowledge, that I believe that the magnetic survey will very soon be added to every geological chart.

From the rapid and exact method of this survey, it is obvious that the other geo-physical methods of survey, particularly the electro-magnetic, would benefic by the use of the magnetic survey in confirmation of their results. In addition, however, there are many practical geo-physical problems which it is possible to solve in a satisfactory manner by means of the magnetic survey alone.

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[1]) For details see Rudolf Krahmann „Magnetic survey" of Habichtswald near Cassel in completion of the geological chart. „Zeitschrift für praktische Geologie" January 1926, part. 1.

Chapter V.

The nature and utility of the specific gravity survey. Gravity Method.

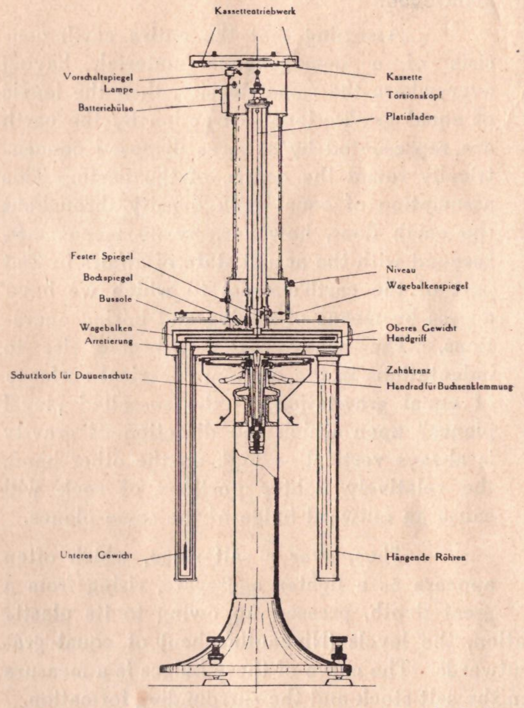
Local variations in gravity have previously been established by measuring divergences from the perpendicular of a plumbline or else by means of the Sterneck pendulum apparatus, by comparing the local period of pendulation with a second pendulum. Both these methods are, however, very complicated and another drawback is that they are not sufficiently sensitive. Their use is, therefore, limited to purely scientific purposes. For practical surveys the torsion balance is now almost exclusively used. The torsion balance was first designed and used by the Hungarian professor, Baron Eötvös, who also worked out its theory in considerable detail. In addition to this Budapest design of torsion balance two or more German designs soon appeared. These are the Freiburg torsion balance of the Gesellschaft für praktische Geophysik, already referred to, designed by professor Hecker, and the Berlin torsion balance manufactured by the Askania Werke by professor Schweydar. The controversial question as to which of these three designs is the best I am unable to decide from my own experience. The greater part of all gravimetric surveys hitherto untertaken have probably been carried out with the Ascania instruments.

The principle of the gravimetric survey depends on the following facts: a beam bearing exactly the same load at each end, is suspended on an exceedingly sensitive platinum-iridium wire of 0,04 mm diameter, 50 cm long.

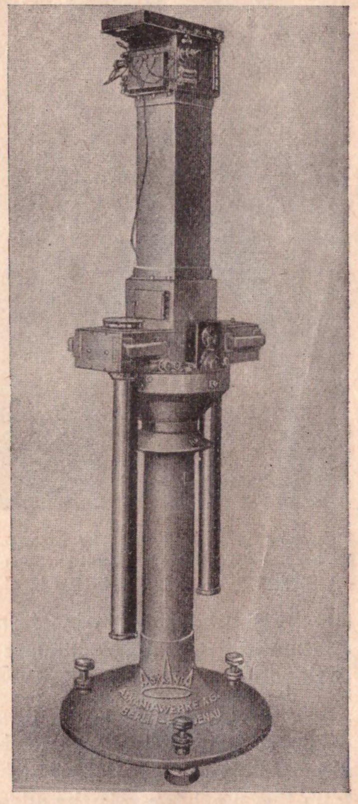
If this instrument is placed in the neighbourhood of a particularly heavy or dense mass, then the latter, so long as it lies in the direction of the beam or in a direction perpendicular to it, will exert no turning force on the beam, although perhaps the entire suspended system may be slightly attracted by the mass. If, however, the mass of gravity is situated in neither of these four horizontal direction but in a horizontal direction at an angle to either of them, then the suspended system will, like a magnetic needle, endeavour to turn with the nearest end of the beam towards the mass of gravity and this turning movement will continue so far as permitted by the torsion resistance of the wire by which it is suspended. It is for this reason that the wire has to be so very sensitive.

Now, if this instrument is placed on level ground which shows no excess of mass or deficiency of the same, in the immediate neighbourhood, and if we turn the upper end of the suspended system, the so called torsion head, so that the entire system is turned at a certain angle, then the beam will turn with it to exactly the same angle. If, however, in a certain direction there is an excess of gravity, for instance a mountain, then the fixed angle to which the torsion head has been turned will not be the same as that indicated by the beam. The latter will turn in advance of the torsion head if the adjustment of the torsion head brings one end of he beam towards the direction of the mountain, and it will lag if the same end of the beam is moved away from the mountain by turning the torsion head. What is measured, therefore, is the difference of angle between the torsion head after turning and the angle indicated by the beam.

The most important improvement introduced by Eötvös is that instead of having weights either end of the beam at the same height, one of them is suspended on a second wire in a position 60 cm. deeper than the other. This latter wire is, unlike the suspension wire, of no importance to the actual functioning of the suspended syestem. Owing to the different levels of the weigths, however, the sensitiveness of the entire instrument is increased in a definite way and in a certain direction. In order that as many readings as possible may be taken in a given period and to overcome the drawback of the long time required before the system comes to rest after the turning of the torsion head (about one hour for each adjustment) the instrument is now always designed as a double balance, so that there are two complete, entirely independent, balance systems side by side in the same casing, with the lower weights at opposite ends. Furthermore, the turning movement is no longer carried out by hand but by a clock work, which avoids shocks to the suspension by the otherwise uneven movement of turning by hand, and above all the actual measurement is carried out automatically. Thus the reading of the angles is accomplished by a completely automatic photographic registration device, at any rate in the German models. Finally there is a triple



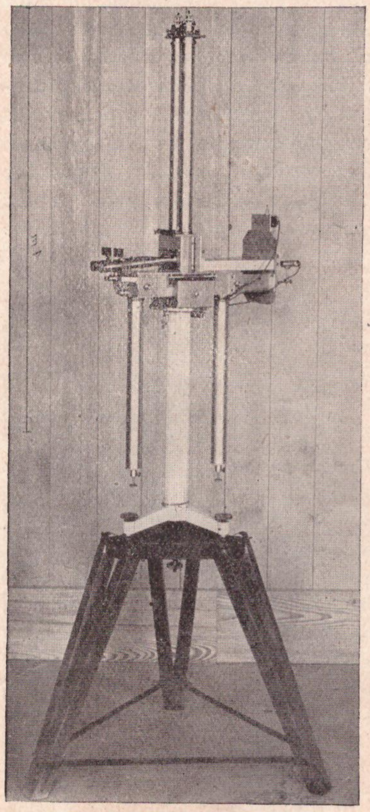
Driving gear for cash-box, reflector, lamp, case for battery, reflector fixed, reflector of boussole, compass, beam, apprehension, corb for protecting, lower weight, cash-box, head of torsion, thread of platin, level, reflector of beam, upper weight, grip, wreath of cogged wheel, wheel for pressing the boxes, hanging tubes.



Figures 32 and 33. Torsion balance by professor Schweydar, Askania Werke Berlin.

metal tube covering the suspension system, which protects it from changes of temperature and which gives instrument its external appearance. By means of these devices it has at last been possible to obtain an accuracy of $1:10^{-9}$ C. G. S. units, which corresponds to one billionth part of the force of gravity.

While figures 32 and 33 show the Berlin torsion balance design, the following figure 34 shows that of professor Hecker, the Freiburg torsion balance, as used by the „Gesellschaft für praktische Geophysik" of Freiburg. This Company also manufacture the instrument for sale. The Berlin balance is heavier and more expensive; it has a photographic registration device above the torsion head. The Freiburg balance has this arrangement at one end and opposite it is a visual scale.



Figures 34. Torsion Balance by professor Hecker „Gesellschaft für Praktische Geophysik", of Freiburg in Breisgau

In order now to describe the use of a torsion balance for geological purposes and to explain its results in the simplest manner, the following consideration must first be mentioned.

Assuming that the entire earth consists of a homogeneous material, having everywhere the same density, then the levels of equal gravitational attraction by the earth are represented by spheres disposed concentrically round the centre of the earth. This assumption of equal rock density throughout the earth does, however, by no means correspond with the actual state of affairs in that part of the carth's crust to which we have access by means of mining and boring operations. The heavy rocks will give rise to indentations in the original spherical surfaces of equal gravitation — the so-called „level planes" upon which the direction of gravity is always vertical — and, on the other hand, the relatively lighter portions of rock will cause an outward bulge of the same planes.

Thus, over a salt ridge, which often appears as a lighter aggregate, rising from a great depth, pressed up owing to its plasticity by the heavy covering formation, the levels (Niveauflaechen) of equal gravitation will show marked bulges outwards. The curve of these bulges is a measure of the difference in density between the salt stock and the surrounding formation.

If, now, I place the torsion balance over the centre of an imaginary circular salt ridge, then I will not be able to observe any turning force, in whichever direction I may turn the beam by moving the torsion head. The further awayget from this point towards the edge of the salt ridge, however, the more pronounced will the distortion be. What the torsion balance thus indicates is the bend or curve of the levels of equal gravitation, which over small areas are normally almost flat. The results of these measurements are plotted on the chart of the area as gradients for each station in such a manner that the direction of the gradient represents the direction of greatest attraction by denser formations or, which amounts to the same, the direction of the sharpest courve in the level of equal gravitation. In plotting, attention is given also to the length of the gradients which is plotted proportionate with the force of attraction.

Beyond the limits of the salt ridge, once more above rocks of fairly even density, the station gradients will no longer assume any distinct divergence of direction or length. The following figure 35 once again explains by means of curved le vels of equal gravitation, how the turning force arises.

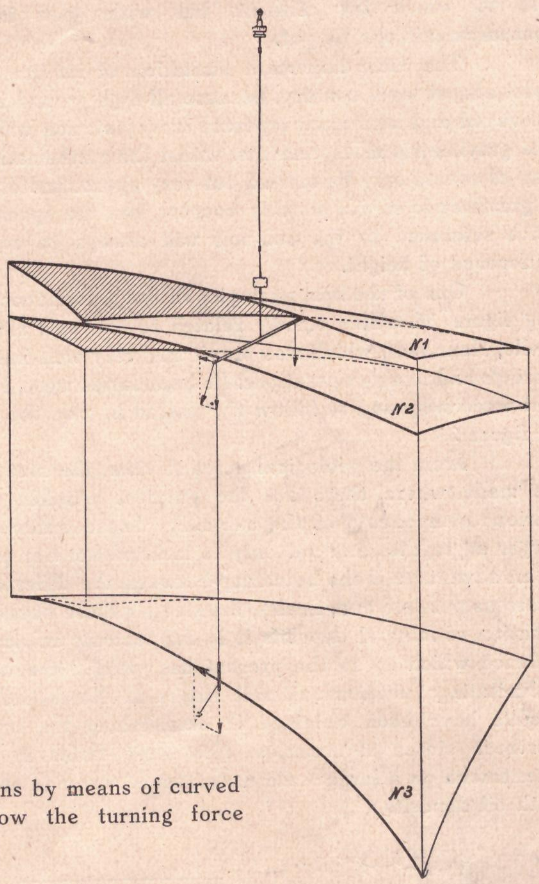


Figure 35. Diagrammatic illustration showing how the turning force arises with a curve in the levels o i equal gravitation.

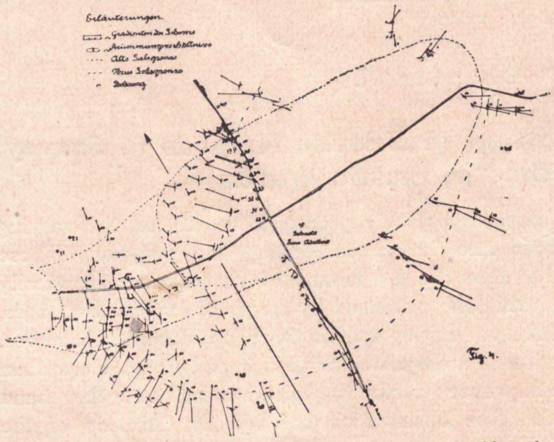


Figure 36 Results of gravimetric survey of the salt ridge of Oldau-Hambühren, near Celle, Hannover. („Exploration" G. m. b. H., Berlin.)

From this much simplified explanation of the principles and use of the torsion balance (in practice the torsion balance itself, its method of use and the calculation of the results are at once the most difficult, the slowest and the most sensitive of all geophysical instruments and methods). I repeat, from this principle of operation it is easy to recognize the best use to which the difficult, but with good instruments exact, gravimetric measurements can be put.

The most important limitation of its use is the necessity of flat, or at least almost level country, because all high ground in the vicinity of the area to be surveyed and near each seperate survey station will naturally affect the results of the gravimetric measurements, whilst the mathematical elimination of these factors can of course only be carried out very approximately. It is possible for me to make a gravimetric survey in hilly country, but the special interpretation of the results with reference to the sub-soil will always be more uncertain with increasing difference of height.

One of the best examples of the gravimetric survey is shown in the following figure 36. This survey relates to the salt ridge of Oldau-Hambühren near Celle, Hannover, which was previously very well known through a large number of borings and mining operations. Its boundaries were, however, not accurately known, but were supposed to follow the dotted line on the special geological chart shown in figure 36.

From the geological point of view, the best use of the torsion balance can be made where there are the greatest possible differences in density in the various components of the sub-soil. These differences must of course relate to larger aggregates and not only to isolated heavier pieces of rock. Furthermore it is an advantage if the boundary between the different materials underground is as sharp as possible and, finally, the steeper these boundaries are, the better. For the location of mineral deposits it is the tectonic information supplied by the torsion balance which up to the present has yielded the best results in discovering and delimitating subterranean salt ridges in North-Germany, while especially good results have been obtained in establishing the presence of salt domes in the northern states of America, also large faults in Mexico and similar tectonic phenomena on a large scale underground, such as are of importance in connection with oil deposits.

Chapter VI.

The Nature and Application of Seismic Methods of Survey. (The Method of Elastic Waves.)

Seismic investigations depend for their geological results on the varying elasticity of the different rocks and lacers comprising the sub-soil. These differences of elasticity can be observed by means of earthquakes (originally arising in the natural way), now artifically produced by means of explosive charges, the waves of which are transmitted at varying speeds through different substances. In soft friable rocks the vibration is transmitted with a speed of no more than 400 metres per second; in hard primary rocks the speed is on the other hand about 4000 metres per second. This observation has led Dr. Mintrop of the firm „Seismos" G. m. b. H. of Hannover to a practical method of investigation. Based upon the seismic theories and the large amount of the research material available from the numerous seismological stations and above all upon the fundamental work of Wiechert, practical results have by this method been obtained principally by making use of curved lines expressing the time of transmission.

In homogeneous sub-soil the graphic picture of the distance-time curve of an explosive wave would be expressed by a straight line. If, however, we assume that there are differences of elasticity in the rocks then this line will show breaks, whose projection on the surface of the earth will represent the lines of faults or other boundaries between the various rock-formations.

In practice there are still further complications of all kinds, such as reflected waves, overtaking waves, varying amplitudes, transversal waves, etc. etc. I must, however, confine myself to merely indicating such factors (in the absence of any experience of my own, or any practical geological literature, giving information concerning this geophysical method) and I can only add that there is already a substantial amount of research material for the calculation of all these factors.

The principal utility of the seismic method is that of establishing the thickness of covering layers of loose types of rock overlying the older primary formation, or salt ridges, etc. Furthermore it is of use in discovering concealed faults, the locating of deeper-lying parts and thus establishing the presence of saddles, basins, troughs and answering other similar questions dealing with the subterranean tectonic structure.

In other quarters work has been proceeding with the object of utilising, instead of seismic waves, acoustic waves in a similar manner for geophysical survey, but the results and the development of this method do not appear to have reached beyond the experimental stage. At any rate, there is no information published or otherwise available, concerning any practical results achieved by this method.

Chapter VII.

Geo-Thermic and Radio-Activity Surveys.

Concerning the measurements of temperature as a geophysical method of survey, I can say all I have to say very shortly. The so-called normal geo-thermic range of depth, i. e. the fact that on the average the temperature of the crust of the earth increases by 1° C. for every 32 metres towards the earthcentre is generally kown. Formerly one was satisfied with this purely scientific statement until it was established by repeated comparisons in various deep-borings that on reaching the vicinity of certain types of deposits the temperature increases at shorter intervals than 32 metres. Up to the present this has been found in the vicinity of salt ridges, many petroleum deposits, coal seams of certain types and certain oxidisible ores, for instance pyrites, etc. Unfortunately the research material available up to date is still incomplete and the natural laws covering the phenomenon are not yet clear enough to enable us to make use of the range of temperature measurements for geological purposes. The preliminary results may perhaps be formulated in this manner that a normal increase of temperature by no means indicates the absence of any deposits sougth for, but that a divergent range of temperature in combination with the geological results of borings may give valuable indications.

Finally I would like to say a few concerning investigations of Radio-activity from which Dr. Ambronn hopes to find points towards the solution of the question of the divining-rod. A truly objective view of this, always hitherto and perhaps for ever, subjective phenomenon has, however, not yet been obtained in this way and for the present the problem of the divining-rod has only been enriched by a new possibility.

The measuring instruments for the investigation of Radio-activity are relatively simple. An electrometer is placed over the air issuing from the ground, or over the substance to be tested, whose rate of discharge is inversely proportional to the emanation capacity of the material in question. A strong emanation increases the conductivity by ionisation and accelerates the discharge of the electrometer.

Dr. Ambronn has tried two methods of carrying out these investigations. In one instance he takes a sample of air from a handboring about one meter deep in order to investigate its emanation capacity and draws the conclusion that with increasing emanation a fault or a lode may be present.

Personlly, however, I believe that frequent casual occurances in the continuous decomposition of the uppermost layers of the earty and consequent differences in emanation of the same will often, to say the least, cause disturbances in the results obtained.

The other method, which I regard as more promising, is to test the radio-activity of bore-hole samples. When some day numerous and comprehensive series of such bore-hole investigations are available, which at present they are not, then it may be possible to draw up, in a similar manner to the temperature measurements, (perhaps also in reality akin to these?) although much ore easily, a well-controlled bore-hole profile showing radio-activity, which will probably give indications of some practical value. At present, however, there is not enough research material available for comparison.

I would finally point out that these exact radio-activity investigations have probably no connection at all with the socalled Pastor's „Radio-Emanation", concerning which the information at present available is so unclear and complicated that it is impossible to give a considered judgement concerning it, the more so as the inventor, Pastor, has been unapproachable.

Chapter VIII.

Concluding Synopsis.

From the preceding description it is seen clearly enough how close is the connection between all these methods of survey and the sciences of geology, mineral structure and mining theory as a whole, in short with the „Practical geology". The basis and the premises of each seperate geophysical method are derived from the methods and morphology of the above mentioned sciences. If a question arises from this connection, then the answer also belongs to it. Just as the physical instruments and methods are aids to the study of geophysics, including meteorology and similar sciences, so the practical geophysical investigations are aids to the study of geology and mining.

The developments of all these methods clearly show this. Wherever any of them has presumed to work entirely independantly, from the purely physical point of view, without the cooperation of geologists, or — which was still more frequently the case, in fact in the beginning quite usual, — wehre a client ordered a particular method of survey with a view to testing it, without disclosing any geological or mining facts or previous information, thus forcing such a method into an independant position which is not natural to any of these methods of survey; in nearly all such cases failure and disappointment has been the result. The individual methods are not to blame for this, but only those persons who prevented or ignored a geological basis for the work and who thought only from the physical point of view. At the present stage of development the most important geophysical methods of survey are; of the direct methods the gravity method and the magnetic measurements, and of the indirect methods the electric and seismic measurements. The electric wave methods, temperature, rario-activity and earth-current investigations have as yet not been sufficiently developed and tested for general use.

It is impossible to draw limits for the sphere of utility of each seperate method because the geological complexity of any territory would make it idle to exclude one or other from consideration. In this connection I refer again, as in the beginning, to the technicality of the preparatory concentration. Just as the methods of concentration must be chosen seperately for each case on account of the physical properties of the ore and raw material to be treated, just in the same way must the geophysical method of survey be specially chosen from case after the same principle of the greatest physical difference, with due regard to local geophysical conditions. The problems of preparatory concentration and of applied geophysics have thus at least in regard to the gravimetric and electric methods a common foundation, namely mineral physics. A close exchange of views concerning this problem between geophysical experts and concentration experts (between the experts dealing with the first and the last operations involved in mining) has not yet been even thought of but is hereby most emphatically recommended.

Finally a few additional notes will be summarised. In almost every case the electric method of survey gives direct results and knowledge concerning the deposit, especially in regard to oil prospecting, while the other three principal methods, particularly, however, the gravimetric and seismic surveys, give more indirect results which are more of tectonic importance. The electric and seismic methods of survey are somewhat similar in that they are very suitable for preliminary surveys of large, previously unknown, areas, while the gravimetric and magnetic measurements cannot be carried out on such broad lines. In regard to the costs of the investigation and the time required, the gravimetric (torsion balance) and seismic surveys are the most expensive, while the electric survey costs much less and the cheapest of all is the magnetic survey.

With progressive development of the geophysical methods of surveys they will become more and more important from the practical point of view (especially for the mine owners) and they will no doubt be given increasing consideration in the mining laws of the different countries. It is to be hoped that the development of these methods, now in their infancy, will not lead to such unsound conditions as were attached to the rapid expansion of the deep-boring methods. This will to a great degree depend upon the consideration given to this new branch of mining science in the laws of the seperate countries at an appropriate moment. It is characteristic that the first reference to geophysical methods of survey may be found in the new Russian mining laws. (Decree concerning the interior of the earth, (mineral wealth) and its exploitation; 30th Iune 1925).[1])

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[1]) See Zeitschrift für Bergrecht, vol. 65, pages 137 and 450 and the journal „Petroleum" of 1. July 1921, vol. 20, No. 19. Page 906.

Para. 6. „The search for useful minerals, which only consists in surveying the surface of the territory, the production of maps of the area, the collection of samples of minerals, the execution of geological magnetometric, electric and other surveys which do not require any excavation, is allowed everywhere without special permission."

Pary. 10. „The exclusive right to undertake prospecting excavations within the boundaries of certain areas can also be granted to persons who give geological and other reasons which point to the probability of the presence of the mineral mentioned in the application."

Chapter IX.

Literature-Index.

In the order in which the seperate methods of geophysical surveys have been discussed in the preceding chapters the following list will enumerate some books of reference. Owing to the fact that the existing geophysical literature from both the physical and the geological point of view already includes many hundred works, the purpose of the following list is (just as the whole treatise) only to give particulars of a general character.

1. Geophysical survey methods as a whole.

Ambronn, R. Die Anwendung physikalischer Aufschlußmethoden im Berg-, Tief- und Wasserbau. (The application in physical surveys in mining-, shafting- and well-sinking.) Jahrbuch d. Hallischen Ver. z. Erforsch. d mitteld. Bodensch. Volume III. No. 2. p. p. 21—49.

Glockemeier, G. Welchen Nutzen bringen die geophysikalischen Untersuchungsmethoden den Bergbautreibenden? „Metall und Erz". (What profits are derived by mine-owners from geophysical methods of survey?) 1924 Vo. XXI. No. 8 and 9. p. p. 165—173 and 189—202.

Heiland, C. Das Erdgasvorkommen von Neuengamme im Licht geologischer Forschung. Dissertation Hamburg 1923 und geologisches Archiv 1924. (The earth-gas deposits of Neuengamme in the ligth of geological and geophysical survey.)

Koenigsberger, J. Die Verwendung geophysikalischer Verfahren in der praktischen Geologie. (The application of geophysical methods in practical geology.) Zeitschrift für prakt. Geologie 1922. Volume XXX. No. 3. p. p. 33—41.

Reich, H. Angewandte Physik im Bergbau und in der Bohrindustrie. (Applied physics in mining and deep-boring industry.) „Pumpenbrunnenbau, Bohrtechnik". 1925. Volume XXI. No. 5—8 p. p. 151—155, 191—193, 227—231 and 263—267.

Zeitschrift für angewandte Geophysik. Herausgegeben von Dr. Ambronn. (Periodical for applied geophysics, edited by Dr. Ambronn.) Berlin 1922. Bros. Bornträger.

Zeitschrift für Geophysik. (Periodical for Geophysik, edited on behalf of the German Geophysical Society by O. Hecker-Jena, E. Wiechert-Göttingen and G. Augenheister-Göttingen). Braunschweig, 1924.

2. **The electromagnetic conductictivity method and the equipotential and sonde methods,** are dealt with in, among others,the following works:

Beijerinck, F. Ueber das Leitungsvermögen der Mineralien für Elektrizität. (Concerning the electric conductivity of minerals.) Yearbook for mineralogy geology and paleontology. XI. Vol. 1897, p. p. 403—474.

Gella, N. Elektrische Bodenforschung in Amerika. (Electrical earth surveys in America.) „Die Umschau". Vol. XXIX. No. 3., 1925.

Koenigsberger, J. Verwendung von elektrischem Strom in der Erde für die Zwecke der praktischen Geologie. (The use of electric current in the earth for the purpose of practical geology.) „Geolog. Rundschau". Vol. XIV. 1923 p. 164 f.

Lundberg-Nathorst. Practical experience in electrical prospecting. Sveringes Geologiska Undersökning. Series C. No. 319. Yearbook 16, 1922, No. 9.

Meier, O. Elektrische Schürfmethoden und ihre Anwendung in Schweden. (Electric methods of prospecting and their application in Sweden.) Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins. 1925, p. p. 217—221.

Petersson, W. Das Aufsuchen von Erzen mittels Elektrizität. (The search for minerals by means of electricity.) „Glückauf" 1907 p. p. 906—910.

Schlumberger, C. Etude sur la prospection electrique du sous-sol. Paris 1920.

3. **Prospecting by electric waves and electric self-potentials** are treated, among others, by the following:

Leimbach, G. Elektrische Schwingungen zur Erforschung des Erdinnern. (Electric vibrations for the exploration of the sub-soil.) „Kali", 1913 p. p. 433—441 and 1914 p. p. 157—161.

Same as above. Zeitschrift des Vereins deutscher Ingenieure. (Periodical of the association of German engineers.) 1914, p. p. 1298—1300.

Löwy, H.-Leimbach, G. Eine elektrodynamische Methode zur Erforschung des Erdinnern. (An electrodynamic method for the exploration of the sub-soil.) Physikal. Zeitschrift, 1910, p. p. 697—705.

Same as above. Systematische Erforschung des Erinnern mittels elektrischer Wellen. (Systematic exploriation of the sub-soil by electric waves.) Zeitschrift für praktische Geologie, 1911, p. p. 279—288.

Trüstedt, O. Ueber Erzsucher mittels Elektrizität. (Concerning ore-prospecting by electricity.) Journal for practical geology, 1912, p. p. 159—162.

Electric self-potentials are dealt with among others by:

von Cotta. Erzlagerstättenlehre. (Science of ore-deposits.) 1859. Vol. 1 p. p. 238, 243.

Fritsch, K. von. Ueber die Mitwirkung elektrischer Ströme bei der Bildung einiger Mineralien. (Concerning the action of electric currents in the formation of certain minerals.) Dissertation, Göttingen, 1867.

Kelly, S. F. Experiments in electrical prospecting. Eng. a. min. J. P. 1922, p. 623 f.

Reich. Versuche über elektrische Ströme auf Erzgängen. (Experiments with electric currents in ore-lodes.) Karstens Archiv XIV, 1840, p. p. 141—158.

Strombeck, A. von. Ueber die von Herrn Fox angestellten Versuche, in bezug auf die elektromagnetische Aeußerung der Metallgänge. (On the experiments made by Mr. Fox with reference to electromagnetic phenomena in metal lodes.) Karstens Archiv, Vol. VI, 1833, p. p. 431—438.

Wells. Electric activity in ore-deposits. U. S. Geol. surv. bull. 548, 1914.

4. **Magnetic special surveys** are dealt with by, among others:

Dahlblom, Th. Ueber magnetische Erzlagerstätten und deren Untersuchung durch magnetische Messungen. Aus dem Schwedischen übersetzt von P. Uhlich, Freiberg, 1899 (Graz und Gerlach). (Concerning magnetic ore-deposits and their exploration by magnetic measurements.) Translated from Swedisch by P. Uhlich. Freiberg, 1899.

Haalck, H.-Brinkmeier, C. Erdmagnetische Untersuchungen am Salzstock der Burbacher Achsenzone bei Wefensleben. (Earth-magnetic prospecting on the saltridge in the Burbach axial-zone at Wefensleben.) Zeitschr. f. angew. Geophysik. Vol. 1. No. 4. 1923, and „Kali" 1923, No. 16.

Heiland, C.-Duckert, P. Beschreibung, Theorie und Anwendung einer Neukonstruktion von Ad. Schmidts Feldwage. (Description, theory and application of an new design of Ad. Schmidts field balance.) Zeitschr. f. angew. Geophysik. 1924. No. 10.

Heiland, C. Die bisherigen Ergebnisse magnetischer Messungen über norddeutschen Salzhorsten. (The results of magnetic measurements on North-German saltridges.) Journal of the German geological society. Vol. 76. 1924. Nos. 5—7, p. p. 101—111.

Krahmann, R. Magnetische Untersuchungen im Habichtswald bei Cassel als Ergänzung der geologischen Kartierung. (Magnetic prospecting in Habichtswald near Cassel in completion of geological cartographic survey.) Zeitschrift f. prakt. Geologie. 1926. No. 1.

Moll, E. Erdmagnetische Vermessung der Gegend von Rostock und Warnemünde. (Eearthmagnetic measurements in the Rostock and Warnemünde districts.) Braunkohlen- und Brikett-Industrie. 1923. p. p. 125—128, und p. p. 176—179.

Nippoldt, A. Magnetische Aufnahme des Südost-Harzes mittels Ad. Schmidts Feldwage. (Magnetic survey of the south-east Harz by Ad. Schmidts field balance.) Tät.-Bericht d. pr. Meteor.-Inst. f. Jahr 1917—1919. Berlin 1920. p. p. 90—100.

Reich, E. Magnetische Messungen in Oberschlesien. (Magnetic measurements in Upper Silesia.) Yearbook of the Prussian Geological National Institute. 1925. XLIV. p. p. 319—342.

Schmidt, Ad. Ein Lokalvariometer für die Vertikalintensität. (A local variometer for vertical intensity.) Tät.-Bericht d. Preuß. Meteor. Inst. f. d. Jahr 1914, Berlin, 1915. p. p. 109—134. also the same source, Berlin 1916, p. p. 87—106.

Schuh, F. Magnetische Messungen im südwestlichen und nordwestlichen Mecklenburg als Methode geologischer Forschung. (Magnetic measurements in south-western Mecklenburg as a method for geological survey.) Mitt. a. d. Mecklenburg. geolog. Landesanstalt, XXXII. Rostock 1920 und XXXIV. Rostock 1923. Vergl. „Kali" 1921, p. p. 231—234.

Stutzer, F.-Gross, W.-Bornemann, K. Ueber magnetische Eigenschaften der Zinkblende und einiger Mineralien. (On the magnetic qualities of native sulphide of zinc and of some other minerals.) „Metall und Erz" 1918, p. p. 1—8.

5. **For the gravimetric surveys (torsion balance)** the following works are considered to be the most important:

von Boekh, H. Der Nachweis von Brachyantiklinalen und Domen mittels der Eötvösschen Drehwage. (Information on brachyanticlinals and domes by using the Eötvös torsion balance.) Petroleum XII. 1917. No. 16.

von Eötvös, R. Bestimmung der Gradienten der Schwerkraft und ihrer Niveauflächen mit Hilfe der Drehwage. (Establishing gradients of gravity and their level planes by using the torsion balance.) Verh. d. XV. general conference of the international earth-measurements in Budapest. 1906. Berlin 1908, p. p. 387—395.

von Eötvös. Geodätische Arbeiten in Ungarn, besonders über Beobachtungen mit der Drehwage. (Geodetic surveys in Hungary, particularly on observations made with the torsion balance.) Verh. d. XVI. general conference of the international earth-measurements, London 1909. p. p. 319—350.

Gornick, H. Die Drehwage und ihre Anwendung zu praktischen geologischen Untersuchungsarbeiten. (The torsion balance and its application for practical geological surveys.) Ver. deutsch. Eisenhüttenleute. Erzausschuß-Ber. 2. 15. XII. 1921.

Heiland, C. (The utility of the torsion balance in the field.) Die Brauchbarkeit der Drehwage im Felde. Zeitschrift f. Instrumentenkunde. 1925, p. p. 89—95.

Koenigsberger, J. Feststellung der Grenze und Tiefenlage überdeckter Salzstöcke mit der Drehwage nach Eötvös. (Determination of extension and depth of covered salt ridges with the Eötvös torsion balance. „Petroleum" 1924. p. p. 723—725.

Schumann, R. Ueber die Leistungen der Eötvösschen Schwerewage. (On the utility of the Eötvös torsion balance.) „Bergbau und Hütte", VI. 1920. p. p. 1—4.

Schweydar, W. Die Bedeutung der Drehwage von Eötvös für die geologische Forschung nebst Mitteilung der Ergebnisse einiger Messungen. (The importance of the Eötvös torsion balance for geological prespecting with description of the results of some measurements.) Zeitschrift für prakt. Geol. 1918. p. p. 157—162.

Schweydar, W. Die photographische registrierende Eötvössche Torsionswage der Firma Carl Bamberg (Askania) Berlin. (The Eötvös torsion balance with photographic registration, of the firm Carl Bamberg [Askania]). Zeitschrift f. Instrumentenkunde 1921, No. 6. p. p. 157—183.

Schweydar, W. Ueber Fortschritte bei Feldmessungen mit einer Drehwage nach Eötvös. (Progress of measurements made with the Eötvös torsion balance.) Zeitschr. f. Instrumentenkunde, 1923, No. 10, p. p. 308—311.

6. **The method of seismic surveys,** is treated in:

Mintrop, L. Ueber künstliche Erdbeben. (On artificial earthquakes.) Intern. Kongreß, Düsseldorf 1910. Abtl. IV. Vortrag No. 14.

Reich, H. Elastische Bodenwellen als Hilfsmittel zur Aufsuchung von Lagerstätten. (Elastic earthwaves as indications in prospecting for mineral deposits.) „Stahl und Eisen" 1921. p. p. 547—548.

Reich, H. Versuch einer Anwendung der Seismometrie auf die Geologie. (Experiments with the application of seismometry for geological purposes.) Yearbook of the prussian geological Inst. 1921. XLII, 1923, p. p. 697—722.

Seismos association. Mitteilung der I. Erforschung von Gebirgsschichten und nutzbaren Lagerstätten nach dem seismischen Verfahren. (Information on the exploration of rock formations and useful deposits according to the seismic method. Seismos G. m. b. H. publication.) Hannover 1922.

7. **The geothermic surveys**, are treated amont others by:

Duncker, E. Ueber die Wärme im Innern der Erde und ihre möglichst fehlerfreie Ermittlung. (The heat in the interior of the earth and its possible precise measurement.) Zeitschr. f. prakt. Geologie. 1896, p. p. 417—433.

Johnston, J.-Adams, L. H. (Elektrische Temperaturmessung). Electric temperature measurements. Economic Geology XI. 1916, p. p. 741.

Koenigsberger, J. Ueber Messungen der geothermischen Tiefenstufe, deren Technik und Verwertung zur geologischen Prognose und über neue Messungen in Mexico, Borneo und Mitteleuropa. (Measurements of geothermic depth intervals, their methods and use for geological prognosis, and certain recent measurements in Mexico, Borneo and Central Europe.) Yearbook for min., geol. and pal. XXXI, Beilage-Band 1911, p. p. 107—157.

8. **Radio-activity measurements** are treated among others by:

Ambronn, R. Die Anwendung physikalischer Aufschlußmethoden im Berg-, Tief- und Wasserbau. (The application of physical methods of prospecting in shafting, deep-drilling and well-sinking.) Yearbook of Hall. Assoc. 1921, Vol. III. No. 2, p. p. 41—45.

Gockel, A. Radioaktivität der Gesteine. (Radio-activity in rocks.) Yearbook f. Rad. VII. No. 4. 1910.

Hirschi, H. Bestimmung der Radioaktivität von Gesteinen. (Determination of radioactivity in rocks.) Vierteljahrsschr. Nat. Ges. Zürich 45, of 20, November 1920.