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Geophysical Prospecting Methods

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Abstract.—The article gives a brief account of the historical back ground in the development of Geophysical Prospecting methods and explains the fundamental basis for their application. The progress of work carried out in India is reviewed. The scope for future work in the different fields of application, *viz.* Oil Exploration, Mining, Water supply and Engineering investigations is outlined, drawing attention to the special conditions in India for using the recent methods of aeromagnetic and marine geophysical exploration. Finally, some suggestions are put forward regarding the ways and means of tackling the various problems.

1. *Introduction.*

After learning the use of metals, man began treading untrodden ground to look for the deposits from which he could win the ores and process them for use. At first he was content to take what came across accidentally. In the long history of exploration and discovery of mineral deposits, the so-called "chance finds" have had their heyday. The location of a good number of mineral deposits has for a long time become possible only by a closer study of the surface indications available for direct observation. Even the old time prospector was not merely a man of adventure; he had good powers of observation, and was intelligent and practical enough to note the correlation between soil, vegetation, topography, and the rock formations favourable for the occurrence of mineral deposits. However, where surface indications were not obliging, the lure of gaining knowledge of the hidden deposits has been strong from a long time.

In order to locate concealed deposits, various methods have been tried—some of them like the devining rod and pendulum,[1] without any rational or scientific basis; but others have proceeded on one or the other of the physical properties associated with the minerals sought for. At least, as far back as 1640 the compass was used in the search for iron ores in Sweden; in 1815 was the first study of the electrical phenomena associated with ore deposits at Cornwall by Robert Fox; in 1818 was introduced the pendulum for precise measurements of variations in the gravitational field by H. Kater; and in 1855 the possibility of using seismic methods in the study of subsurface structures was suggested by Robert Mallet. Numerous workers in the different parts of the world began to develop sensitive and portable instruments and methods of measurement by which indications concerning the subsurface materials could be found.[2] Improved techniques of measurement and apparatus continued to follow from time to time, and gradually by the early quarter of this century, the knowledge gained by workers in different fields came to be systematised into what is known as "Geophysical Prospecting" methods. Also, advancement in other aspects of the study of the globe on which we live came to be integrated into a definite science, Geophysics—or the science of the Earth.

The two World Wars caused terrible destruction of materials. In order to carry out the reconstruction programmes following these wars, and to keep pace with the pressing needs for industrial development all over the world, there has been a great urge for the location of minerals of one type or the other. If prosperity is to be kept up, more deposits of minerals should be found by intensive exploration on a scientific basis. The two wars themselves have, in a way, provided the impetus needed for the special research and design of geophysical instruments. During World War I, a sound ranging technique was developed to locate the position of enemy guns. Soon after, vigorous attempts were made to design instruments for seismic prospecting which played such a prominent part in the discovery of oil, and which continues to be the leading method for that purpose even at the present day. During World War II, airborne magnetic detectors were designed and successfully used for the location of enemy submarine. Further improvements effected soon after the war, produced the fine instruments for aeromagnetic exploration which have now made rapid surveys of blanketed and inaccessible regions a practicable operation. Many other improvements concerning the subsurface exploration for civil engineering and other allied problems were also brought about during these years. The various methods adopted in geophysical prospecting are dynamic—the techniques, instruments, and interpretation of the measurements being continually under change and development. However, the fundamental principles, or the basis for the application of the various methods in operation, are well established.

Geophysical prospecting may thus be defined as prospecting for mineral deposits, or determination of geological structures, by appropriate measurements of the physical properties of rock formations. It may also be said to be the art of applying physical sciences to the study of composition and structure of the layers of the earth that are sufficiently shallow to be exploited by man. As a special science, it takes a place between geology and mining engineering.

2. *Fundamental basis of Geophysical Prospecting methods.*

In looking for concealed mineral deposits or geological structure, we have to study only the "distance effects" produced by the bodies saught for. As there are large variations and contrasts in the physical properties of rocks and minerals, we may, by appropriate instrumental devices and methods of operation, measure the field of force due to these substances composing the earth crust at any given place. From the indications or anomalies noticed by such measurements we may be in a position to decipher the subsurface geology. For instance, the variation in the properties of materials caused by density, magnetic susceptibility, electrical conductivity, etc., could be made use of to measure the fields of force present naturally, or obtained under artificial energising conditions. Thus, the basis for the use of the magnetic method is the variation in magnetic susceptibility; for the gravitational method a variation in density, for electrical methods a variation in electrical conductivity, and for seismic methods a variation in velocity of the elastic waves. In the first place, the subsurface structure, or mineral deposit can be geophysically located only in such cases where detectable differences in the physical properties (like those mentioned above) exist, as contrasted with those of the surrounding medium. The detectability depends upon the composition, shape, size and depth of the body, or the structure sought for, in comparison to its surroundings. The sensitivity of the instruments of measurement is also important. The latter factor can, of course, be controlled by practical technique and human ingenuity to which, we may say, there is no natural limitation. More and more delicate instruments of precision to measure (or detect) differences of a lesser and lesser magnitude, are being constantly put forward from time to time, so much so that one may be inclined to think that almost any of the hidden deposit or structure could be discovered with appropriate and sensitive instruments. Unfortunately, this does not hold good: conditions encountered in the ground are often complex and involved. Therefore, an unequivocal solution of the problem becomes impossible in many cases due to several disturbing factors, and no increase in the accuracy of the measurements may then be of any more help. The point may be explained with the help of a specific example: Differences in density of rock formations produce variations in the force of gravity. The usually observed acceleration due to gravity varies on the earth's surface by about half-a-percent. Much the greater part of this variation is due to the ellipticity of the earth and the change in the centrifugal force from the equator to the pole. The residual part, which indeed is ascribable to geologic formations, or structures, may be of the order of 1 in ten-thousand. Smaller bodies cause even smaller variations. Instruments are now available to measure accurately 1/100-millionth part of the total field. Comparatively speaking, it may be said that in a weight of about 3000 short tons of a block of rock the subtraction or addition of even 1 ounce becomes detectable with the instrument. Even so, we may not be able to distinguish between bodies possessing a large density contrast, if they are not favourably situated. For, the gravity values are affected in a larger magnitude, by the altitude, latitude, the distant topography, and the local terrain to such an extent that proper corrections, sufficiently accurate for such extremely precise measurements, become impossible in rugged country. Therefore, instruments of greater precision in themselves would not materially help to detect bodies concealed amidst surroundings which constitute a complicated set of conditions.

Normally speaking, the geophysical measurements do not give direct evidence as to the existence of any mineral or rock formation of a specific type. On the other hand, the geophysical surveys are carried out as an indirect aid in prospecting. For instance, magnetic anomalies may be due to bodies of magnetite, pyrrhotite, specular hematite, or some of the manganese ores,—but no direct evidence can be found in the magnetic measurements to distinguish between these minerals when they are concealed. The anomalies could, however, be usually outlined and the limits of the bodies or formations carrying such minerals, be delineated in the field, despite the fact that considerable thickness of overburden may exist. The location of oil, gold, and several other workable mineral deposits rests on an even more indirect basis. Oil is located by mapping the hidden geological structures, which, from experience gained in many parts, show that they are expected to be favourable for the accumulation of oil. There is no indication at all about the existence or otherwise of the oil itself in these structures outlined geophysically; the matter could be known only by drilling. Similarly, gold which occurs in quartz veins is usually present in such minute quantities or proportion that no physical reactions due to the metal itself are obtainable, even with the most delicate and sensitive instruments that could be devised. However, it often turns out that auriferous quartz veins may be successfully prospected for and located by the electrically high resistive anomalies found over the quartz veins.[3] Or again, gold in placer channels may be located indirectly by tracing magnetic anomalies due to black sands in which the association of gold has been established in one part in the area.[4] In South Africa, the geological studies on the Reef area in the Rand field resulted in outlining an eighteen-mile westward extension of ore bearing structures, through magnetometrically tracing the shale beds occurring in known stratigraphic relationship to the ore-bearing conglomerates.[5] Some shafts there have already reached the gold bearing horizons, and an impressive record of extension of the auriferous formation in the Rand area has been produced by the application of magnetic methods, although gold itself possesses no distinctive magnetic susceptibility. Instances of many such spectacular discoveries of ore may be cited from Sweden, Canada, Australia and various other parts of the world. In a number of the instances, even the tracing of such structures as shear zones, fault-planes, geological contacts, etc., by one or the other of the geophysical methods, has led to the location of valuable mineral deposits.

We might, therefore, say that most of the geophysical methods aim at not so much on the direct discovery of the ore bodies as on the location of physical anomalies in the ground which are usually, but not exclusively, associated with mineral deposits or geological structures. An anomaly connected with the large structures in the oil field is detected by suitable technique and interpreted definitely but most of the ore deposits form very much smaller features. The anomalies in the latter cases are usually of a localised character and may be complicated by several factors depending upon the geological conditions. Interpretation will, under such circumstances, become extremely difficult.

However, it is well to bear in mind that in geophysical prospecting we get only "indications". But what the causes are for those indications can be found only by putting in trial pits, trenches, shafts, adits, cross-cuts, bore holes, or such other suitable means of direct 'probing' into the material. All that the geophysical methods claim to do is simply to sort the ground in terms of physical properties and locate the spots at which the aforesaid direct 'probing' into the material could be done with justification or reasonable chance of success.

3. *Progress in India.*

Several papers[6] have been published during the last two or three years furnishing valuable accounts of the progress made in geophysical prospecting in India. The scope for further work has been also discussed in a few of these papers. While those particularly interested on the question of geophysical prospecting in India would profit much by referring to these papers, a general summary is presented here including all the latest progress—together with some of the writer's own ideas on the scope and plans for the future work.

From the available records it is learnt that the first Indian prospecting by geophysical methods was undertaken as far back as 1923 when, even in Europe or America, the application of such prospecting methods had not been proved to be definitely successful. The first geophysical survey sponsored by Burmah Oil Company Ltd., in 1923-24, used a torsion balance. By observing gravity anomalies it confirmed the existence of an anticline, indicating clearly the summit position of structure.[7] Unfortunately, the test well which was drilled failed to show up any oil. During 1927-29 Mr. N. K. Bose carried out a large number of Torsion Balance measurements in North Western Punjab for ascertaining the subsurface structure beneath the alluvium.[8] Again, the Burmah Oil Company had some trial measurements by electrical resistivity in Assam early in 1936, which gave evidence of an anticline concealed by alluvium near Digboi.[9] It is reported that the subsequent drilling done there showed substantially the correctness of the structural evidence given by the resistivity survey. It is also known from published records that during the years immediately which preceded World War II, the Burmah Oil Company not only planned a great extension of geophysical surveys in India and Burma, but also had contracts with some of the American and English companies for large scale geophysical exploration.[10] Part of the work by seismic and gravimetric methods was under progress. At the outbreak of war, the work had to be suspended owing to the restrictions imposed by Government then on purely exploration programmes. After the close of the war, the Company again resumed some geophysical exploration mostly in parts which now lie in Pakistan.

Apart from Burmah Oil Company, a few private companies in India had engaged the services of foreign geophysical parties in the exploration for sulphide ores and gold. The prospects which have been so examined by those foreign parties are: (1) the copper belt in Singhbhum, (2) the copper indications near Nellore, (3) the exploration for auriferous quartz lodes to the north of Kolar Gold Fields and (4) in Hyderabad on the Hutti Gold Field. With the exception of the last two,[11] there are no published accounts of these surveys.

Some of the State Governments in India have carried out geophysical prospecting operations on a small scale, and except in the case of Mysore, published records of either the methods used or the results obtained are not available. In Mysore, electrical resistivity and self-potential methods have been successfully applied to the location of pyrites and graphite.[12] Some problems on ground water have also been investigated by resistivity methods. During 1944, the bedrock conditions in the Godavari river for the Ramapadasagar project,[13] and also in the Gandikota gorge near Cuddappah for the Penner project, were investigated by electrical resistivity methods and some useful results were obtained which helped the engineers in the selection of Dam sites.

During 1945, Mr. B. L. Gulatee of the Survey of India carried out gravimetric and magnetic surveys to test their applicability in the location of manganese ores in the Central provinces.[14]

The Geological Survey of India organised a Geophysical Section under the guidance of Dr. G. Dessau. Since its organisation in 1945 this Section has been carrying on investigations by using electrical and magnetic methods. Some account of the work carried out by this Section has already been published elsewhere.[15] Amongst the important results obtained in these surveys may be mentioned : (1) The tracing of the boundary hidden by alluvium between the Gondawanas and the Archaeans near Kamptee. (2) The location of Manganese ore deposits near Tirodi in C. P. by magnetic prospecting. This work specially has been very successful and given a number of indications of manganese ore bodies which were hidden. Some of the pits which have been put down for testing the indications have brought to light deposits of manganese ore at depths of 6″ to about 40′ below the surface. (3) Surveys by self-potential methods have been carried out near Athmalik in Orissa for the location of graphite. Two out of the strong indications obtained there were trenched, and graphitic schists found below 10 to 15 feet from the surface, although it is not yet known whether the deposits are commercially important. All these three surveys were carried under Dr. Dessau's directions while he was Geophysicist in the Geological Survey of India. (4) In the field of water supply investigations, surveys have been carried out under the guidance of Dr. Ermisch by electrical resistivity methods in Rajputana (Jodhpur and Bikaner States) and also in some of the Deccan Trap areas near Bombay. While the conditions in Rajputana proved unfavourable for solving the problem, in the case of the survey in Deccan trap region some interesting data have been obtained. Another survey during the last season led by Mr. L. N. Kailasam was in Berar to demarcate the fresh and saline water zones. This latest survey especially has given valuable information by indicating potable water, by resistive anomalies, amidst the saline areas which are highly conductive. Also, additional information on the thickness of the fresh water zones has been obtained and the results show that even in the fresh water belt saline water occurs at a depth of about a hundred feet from the surface.

4. *Scope in India*—In order to appreciate the possibility in the use of geophysical methods we may group them into 3 fields of application : (1) oil exploration, (2) mining and (3) engineering and watersupply investigations. Further, we may briefly note the feasibility in the methods of prospecting from the Air, and also from ships over water-covered areas.

(1) *Oil exploration*—When we take into account the vast area covered by alluvium in India where some of the Tertiary formations appear to be concealed, it looks as if there is ample scope for the application of geophysical methods in order to obtain a knowledge of the sub-surface geological structure. But the chances of finding any large number of oil sources are by no means comparable to those in U. S. A., Iran and other countries. Dr. Wadia in several of his articles has already given a clear account

of the areas in which geophysical investigations may be fruitful.[16] The Burmah Oil Company have been investigating considerable tracts in Assam. If we exclude this, there are two more regions which require examination as soon as possible. The first of these is near the Gulf of Cambay on the West Coast where some of the Tertiary rocks are probably concealed under water or under recent formations. The alluvial covered area in the north-eastern part of Gujarat require careful investigation. The other zone is in sub-Himalayan range round Nainital. There are possibly several other areas on the eastern side of India wherein geophysical exploration would be needed to find out the concealed structures in the Tertiaries. All these investigations require a systematic set up. Geophysical exploration for oil stands on an entirely different footing, bearing little in comparison with the application in the mining and other fields. It is a highly specialised technique involving the use of elaborate equipment and highly trained personnel. Enormous sums of money are required for the instruments, field equipment, laboratory, operating charges, and other investments. In U. S. A. and other countries exploration for oil constitutes almost an "industry" by itself, backed by the oil business with substantial funds. Whether or not such work should be undertaken by Government agency is a matter of policy. But if we have to organise a unit in India, even on a modest estimate, an investment of at least 15 lacs of rupees for instruments and equipment will be required. The operational costs might range from 2 to 3 lacs for a year, depending upon the extent of the survey programmes to be undertaken. Under the present conditions such a scheme of exploration for oil appears to be beset with many difficulties. There are several questions to be carefully considered before any definite organisation can be established. Nevertheless, a step has already been taken by the Geological Survey of India to tackle a regional problem, preliminary in the exploration for oil even with the limited equipment available at its disposal, although it must be said that nothing more than a reconnaissance has been done now. During the last field season, magnetic surveys for obtaining information on the geological structures covered up by recent formations in Saurashtra, were carried out by Dr. S. L. Banerjee. Observations at nearly 4000 stations have been obtained covering a region of 10,000 sq. miles. Some interesting results are noted, and the survey data appear to indicate a wide magnetic low region between two highs in the neighbourhood of Borsad and Baola. The interpretation of these anomalies in terms of geological structure is still under study. However it appears necessary to continue this survey work with a closer network of stations in the anomaly zones, together with supplementary observations by gravimeter as soon as possible. Orders for the purchase of a gravimeter from Askania-Werke have already been placed, and it is likely that the instrument may become available to us within the next few months. The question of procuring seismic equipment is also under consideration, and when it is obtained, we might be in a position to carry out some amount of detailed surveys on a limited scale.

(2) *Mining.*—There will be more or less a steady demand for geophysical investigation in the mining field in India—and this demand may be expected to increase somewhat in relation to the increasing industrialisation of the country. Exploration for sulphide ores by electrical methods would naturally be looked upon as the most feasible. As far as the writer could see from the available references, the occurrence of ores of copper and lead have been listed at more than a hundred localities in this subcontinent. How many will prove to furnish workable deposits is not known. There are extensive tracts, as in Khetri (Rajasthan), Garimenapenta (Nellore), Chitaldrug (Mysore), Sikkim, Garhwal, and many other areas wherein surface indications of copper ore are abundant. Once upon a time, India had a flourishing copper industry, though judged from the modern standards, the output of those mines could not have been large. The possibility of the occurrence of massive sulphide ores at these places is recognised by geologists and mining engineers. These localities have to be geophysically examined in great detail to see if indications are available of any large bodies of

ore concealed either in association with the old workings or in adjacent places where geological conditions are favourable. It is also possible that further exploration round about Zawar in Udaipur by geophysical investigations might prove helpful in locating more of lead and zinc sulphide ores deposits.

If the sulphide ore minerals are not concentrated as to form a continuous body, we may fail to obtain sufficiently strong and clear indications. Also, there may be cases where disseminations of the ore offer a continuous path for the current so as to produce strong reactions simulating those due to solid ore. Therefore the electrical method would have to be used with proper geological control, and the help of trenching, shafting, or drilling may have to be called in frequently for aiding in the interpretation of the indications even during the course of the geophysical survey. Such a co-ordinated method will be helpful in focussing attention quickly on valuable property and eliminating useless ground. There may be several areas with indefinite gossan-like material, distributed in various parts of the mineralised belts. By surface observations alone it will not be possible to say which of them are likely to lead into a sulphide body in depth. By the application of one or more of the geophysical methods, we might be able to obtain helpful additional information for locating the spots below which the chances of finding ore bodies are increased.

In prospecting for iron and manganese ores, magnetic method can be applied. Although there is no urgent necessity for the location of iron-ore deposits in India by geophysical methods, cases may arise for locating rich magnetite deposits in a few areas, and investigations of that type could be easily taken up. As regards manganese ores also, it is likely that the magnetic method could be successfully used in several areas to locate hidden deposits—as is being done in Tirodi, C. P. A reconnaissance magnetic and electrical survey in the alluvial territory near Ramtek and other places where sub-surface formations may contain manganese ores but are covered up, has been suggested recently by Dr. West as a worthwhile exploratory investigation.

Some of the Pyrolusite ores in other parts of the world have been noted to give rise to spontaneous polarisation currents and it is likely that surveys in some of the fields may be applied to locate Pyrolusite. As regards Graphite, which is usually a good conductor, the electrical method would be highly suitable. In some areas the presence of uneconomic bodies of graphitic schists would cause serious confusion in interpreting the electrical indications, as they may be mistaken for sulphide ores, but with geological control a proper interpretation may still be possible.

In respect of the other minerals like Coal, Chromite, Bauxite, etc., the location of the deposits would form a more or less specialised geophysical investigation. Each case would have to be considered in detail with respect to the nature of the associated minerals and the contrasting properties expected in relation to the medium in which the deposit is enclosed. Successful interpretation of the geophysical data in those cases could be made only if there is a favourable combination of the geological and mineral association.

The exploration for radio-active minerals, more especially those of uranium and thorium, can now be carried out by means of portable Geiger-Muller Counters, and these investigations are now under the direction of Dr. D. N. Wadia. Portable radio-active detectors are being constructed under the direction of Dr. H. J. Bhabha at the Tata Institute of Fundamental Researches, Bombay.

There is one other way in which geophysical methods can be effectively employed: that is in underground workings, shafts, tunnels, etc. Valuable information may be gained on the location of the ore-lodes, or important structural features like shear zones, and fault planes. Sometimes, it may be possible to get indications of an ore-body, which may be close by, but which has been missed in cross-cutting or shafting or in the bore-holes by sub-surface geophysical measurements.[17]

Conditions of stress and instability and failure of ground in mines and other workings, or subsurface structures may be investigated by acoustic or modified seismic methods. Some progress has already been made in U. S. A. and Canada on such methods[18]. There is considerable scope for research work in such specialised fields in India also and a suitable programme of investigation with the co-operation of geologists, mining engineers, and geophysicists may be productive of useful results.

(3) *Engineering and Water Supply Investigations.*—The problem arising from the need for determination of depth to bed-rock, water table, etc., will have to be taken up as and when occasions arise. The geophysical technique has to be adopted to suit the particular problem, and no general procedure can be laid down for the operating conditions. Each of these investigations will have to be tackled with due consideration to the particular set of conditions associated with the problem. Electrical, seismic, and very occasionally, magnetic methods will be applicable. In the solution of some of the problems connected with civil engineering, such as construction of highways, bridges, tunnels, dams, etc., the services of the geophysical methods are likely to be called in on a larger scale than till now. Many Irrigation and Highway projects are being investigated in India. After we obtain a suitable seismic equipment, it will be possible to make a fuller contribution to study the sub-surface problems in these projects.

(4) *Prospecting from the air.*—Geophysical measurements are possible not only on the land surface or on water, or in underground workings and boreholes (sub-surface), but also from the air, high above the ground surface. Geophysicists have recognised the advantages of making surveys of the gravitational and magnetic variations by flights in air. The writer has discussed elsewhere[19] the question of aeromagnetic surveys in India. The advantage of air-borne surveys are that measurements are made rapidly, even over the remote, inaccessible areas, especially in swamps, lakes, deserts, jungles, and mountainous tracts. The air-borne measurements also effectively eliminate, or at least minimise, the interferences caused by rails, pipes, and other disturbing factors met in the ground surveys in some areas. We may also add the further advantage of studying a particular indication or anomaly, at different altitudes and thus obtaining valuable additional data for interpretation. The problem of instruments suited to this type of measurement had not been solved. During the last war, the development of Magnetic Air-borne Detectors made it possible to devise similar instruments suitable for geophysical surveys. The helicopter type of aircraft[20] is also now being used for geophysical measurements. Helicopter has great manoeurability as it could fly at very low altitudes. Its speed is less and a given point could be reached at a given moment. It is also possible to keep hovering at a point, ascend or descend vertically over a fixed point. It is also capable of landing in small clearings—all of which go to make it an eminently suitable vehicle for geophysical observations.

Although some success has already been achieved in the practical application of the magnetic prospecting from the air, and increasing attention is now being paid to the question of expanding surveys over larger territories in U. S. A., Canada, Australia, Africa, and other parts of the world, we must not fail to note the special conditions in India for the use of this method. The aerial instruments can be effectively used only for large scale or reconnaissance surveys where the geological formations sought for contain minerals of fairly high magnetic susceptibilities. There is no doubt that there are some large areas of forest, and inaccessible hilly and mountainous tracts, and other types of blanketed ground in India where air-borne magnetic surveys may probably furnish some useful indications of iron-ore deposits, or possibly of certain types of sub-surface geological structures. The location of iron-ores in such blanketed tracts will be of no immediate benefit. As regards the location of possible structures for oil, the scope and the limited chances of success in India has already been stressed elsewhere in this paper. The question of cost of aero-magnetic surveys for India will also have to be viewed from the proper perspective. In advertisement and technical pamphlets, furnished by foreign companies, one finds tempting comparisons of cost on the basis of what the ground surveys would cost as an alternative, and evidences are put forward to show that the economy in the adoption of air-borne surveys is about a tenth of the ground surveys. This comparison is true no doubt in appropriate cases, but it should not be thought that the aero-magnetic surveys, as such, are cheap or inexpensive. For operations in countries outside U. S. A. the contracting party will have to pay all the expenses of moving the plane, survey equipment, crews, etc., and meet, in addition, the operational costs, living expenses and all other incidental charges of the working crews, over and above the contracting fees. The total cost may work up to many lacs of rupees, and by spending all that money we are not likely to obtain results which are of any immediate use. The air-borne device cannot dispense away wholly with the measurements on ground surface, which will have to be carried out anyhow, for obtaining greater details over selected anomalies. Moreover, we are not equipped for detailed prospecting and drilling to test the indications of the Aerial Surveys. In the present context of the country, it would therefore be far better to intensify and expand greatly the ground surveys, procuring the less costly instruments and training the personnel. We can turn out a great deal of surveys in the ordinary way without having to drain heavy amounts in foreign exchange. Ground work would take proportionately much longer time than aero-magnetic surveys. As we are not likely to be ready for detailed prospecting or drilling, for some years, the time factor involved in ground surveys is of not much consequence.

5. *Prospecting Over Water.*—Although geophysically prospecting areas covered over by water is similar to that of any other blanketed ground, there are certain special aspects in practical application which need some emphasis. Usually, the measurements over water are carried out in suitable rafters, boats or ships, depending upon the place of investigation, *i.e.*, whether in rivers, lakes or the sea. Of course, recently Airborne Megnetometric Surveys have also been carried out over the sea with radio-navigation controls. For most investigations, however, the towing of the vessels in water causes oscillations, disturbing the stability of the instruments. Many improvements in the type of vessels for the special purpose and in the design of suitable instruments have been effected in recent years to enable fairly accurate and reliable measurements in gravimetric and seismic methods to be obtained—though difficulties continue to limit the usefulness of observations in, or over, water regarding the other methods.

In order to explore for petroleum sources, marine seismic studies of tide lands and coastal shelves are making considerable progress in several regions—as for instance, in the Gulf Coast of U. S. A., East Indian Archipelago, the Persian Gulf and the Caspian Sea.[12] A survey and mapping of the coastal shelf arround the Indian Peninsula by gravimetric, magnetic and seismic methods will have to be taken up some time or other in order to obtain information on the sub-surface geological features and to assess the economic possibilities. There have been marine transgressions and regressions during the late Palaeozoic period and after, on the east coast especially, and it is desirable to obtain information on the nature of the undersea beds along the coastal margin not merely by direct sampling, but having recourse to seismic methods. Such geophysical measurements on the sea should naturally be coupled and integrated with other aspects of Oceanographic researeh. Otherwise, financially, any scheme of geophysical prospecting on the sea might become so costly that no practicable organisation could materialise in India. Although no certain prospects of any direct economic gains following such geophysical prospecting programmes can be held out, it must be realised that the untold wealth which may lie within the waters and the bed of the seas surrounding us, will have to be surveyed on a more or less co-ordinated basis, keeping in view the possibility that we may have to operate on such resources eventually. Therefore, in laying out the plans for oceanographic surveys in India, the question of using geophysical methods require careful consideration and expert guidance.

Occasionally some cases will arise for minor specialised geophysical investigation over the rivers or other inland water covered portions in connection with mineral prospecting, or for engineering geology, in certain areas. During the geophysical investigation of the Rampadasagar area an attempt was made by electrical resistivity measurements to get an estimate of the depth to bed rock over the water course engaging three boats. Although this was done purely on an experimental basis, the practicability and usefulness of such measurements were demonstrated by the results noted later from the actual drilling operations at the site by the Engineers.[22]

Conclusion.

In the foregoing an attempt has been made to explain the fundamental basis for the application of geophysical prospecting methods, and to furnish a brief account of the work done in India. The scope for future work has also been outlined in somewhat general terms to give the reader an idea of the extent to which the methods are likely to be serviceable. Apart from the Burmah Oil Company, there is no private organisation at present in India which is sponsoring any geophysical survey work. The Central Provinces Manganese Company have been getting their property surveyed by the Geophysical Section of the Geological Survey of India, and very likely a few more private companies may call for such surveys. However, the initiative for further progress in the various fields will continue to be the responsibility of Government departments.

The problems to be geophysically solved will have to be viewed under three categories: the Regional, the Local, and the Special. Regional problems are those that constitute a systematic examination of large areas covered by alluvium, or other kinds of overburden. Whether it be for oil, or for sulphide ores, several hundreds to thousands of squre miles will eventually have to be covered in India with close network of stations or grids. These are long range programmes and suitable schemes will have to be prepared.

As regards the local problems, *i.e.*, the investigations in certain specified areas where the occurrences of ore have already been noted, or in areas where extensions of known ore bodies have to be traced into the adjoining ground, such items can continue to form a routine in yearly programme of the Geological Survey of India, a system of priorities being adopted according to urgency for the development work.

Lastly, the special problems relate mostly to the water supply and engineering questions, or certain other investigations proceeding with a limited objective, and extending over comparatively small areas, to secure a particular type of information or experimental data.

With regard to the local and specialised problems, the Geophysical Section of the Geological Survey of India is now equipped only for magnetic and electrical methods. The equipment for gravimetric and seismic methods may be obtained in a year or two. The Geophysical Section has also to procure some equipment by way of transport for conducting the surveys as a self-contained unit. The training of the personnel will also take some more time. However, with the continued progress in procurement and training within the next 2 or 3 years we may be able to attain a position when we could tackle almost all the local and specialised problems. But separate co-ordinated plans will have to be prepared and considered in order to deal with the regional problems.

The study of the Physics of the Earth, or Geophysics, although slow in obtaining a recognition, has at the present day assumed an important role in agriculture, commerce, navigation, and mineral development. Many improvements in methods of attacking the problems in these various fields have been introducd within the last two decades. It is only by an all-round appreciation of the improvements effected in the several branches of geophysical study that a properly balanced progress could be maintained, avoiding duplication of effort, or over-specialisation. The instruments and techniques of observation in the various branches of Geophysics have a certain similarity of pattern and fundamental basis,—although the objectives in each of the fields are different. The common ground for co-operation happens sometimes to be wider than is usually realised. With the formation of the Central Board of Geophysics in India, it has become possible to bring together the various workers and to interpret their knowledge and experience for the benefit of all. The coming years may, therefore, be hoped to bring in more fruitful results to the country.

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