E.M.B.6.

GEOPHYSICAL SURVEYING

REPORT OF A SUB-COMMITTEE OF THE COMMITTEE OF CIVIL RESEARCH

E·M·B

NOVEMBER, 1927

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PREFACE.

In January, 1927, Mr. H. W. Gepp, Chairman of the Australian Development and Migration Commission, submitted to the British Government a scheme for the geophysical survey of portions of Australia, embracing the electrical gravimetric and magnetic methods.

The scheme was referred by the Secretary of State for Dominion Affairs to the Empire Marketing Board who decided, as a result of preliminary examination, and in view of the fact that no Government Department could reasonably be expected to advise upon all aspects of the problem, to invite the Chairman of the Committee of Civil Research to set up a Sub-Committee to investigate the proposal.

A Sub-Committee was accordingly appointed in April, 1927, and in July, 1927, its Report was approved by the Committee of Civil Research, who recommended it to the consideration of the Empire Marketing Board.

The Board was satisfied that the investigations recommended by the Sub-Committee would be of benefit to many parts of the Empire and might be expected to further the marketing in the United Kingdom of raw materials produced within the Empire. They accordingly approached the Commonwealth Government of Australia, who agreed, at the Board's request, to assume the direct responsibility for the conduct of the proposed investigations on the understanding that, upon their completion, the information derived from them would be made available to the Board for communication to any other part of the Empire interested.

It will be seen that the Sub-Committee calculated that the total cost would not exceed £27,000, of which the Empire Marketing Fund should bear £13,500 ; but subsequent examination of the probable expenditure suggested that that figure might in fact be exceeded. Accordingly the Empire Marketing Board agreed to recommend that the allocation from the Empire Marketing Fund should not exceed a figure of £16,000, viz. up to £10,000 for the first year and up to £6,000 for the second year. The Australian Authorities agreed to match this contribution by a similar amount.

Steps are being taken to constitute the survey party, which will be under the leadership of Mr. A. Broughton Edge, M.B.E., B.Sc.

Empire Marketing Board.

November, 1927.

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COMMITTEE OF CIVIL RESEARCH.

SUB-COMMITTEE ON GEOPHYSICAL SURVEYING.

REPORT.

I.—INTRODUCTORY.

On April 5th, 1927, the Chairman of the Committee of Civil Research appointed a Sub-Committee to ascertain and report :—

(*a*) What recent developments, if any, have been made in the methods employed in geophysical surveying ;

(*b*) Whether these methods have as yet been fully tested on a large scale either individually or in combination ;

(*c*) If not, whether the proposals for a geophysical survey in Australia submitted by the Development and Migration Commission of Australia offer a suitable opportunity for testing such methods in the interests of Empire development generally ;

(*d*) If so, to submit recommendations regarding the composition, functions, duration and probable cost of the expedition that would be required for such a survey.

2. This Sub-Committee consists of :—

Lieutenant-Colonel the Right Hon. Sir Matthew Nathan, G.C.M.G. (*Chairman*).

Lieutenant-Colonel Sir Edgeworth David, K.B.E., C.M.G., D.S.O., F.R.S., Professor Emeritus of Geology, University of Sydney.

Colonel Sir Gerald Lenox-Conyngham, F.R.S., Reader in Geodesy, Cambridge University.

Colonel H. St. J. L. Winterbotham, C.M.G., D.S.O., Geographical Section, General Staff, War Office.

Dr. William McLintock, F.R.S.E., F.G.S., Curator, Museum of Practical Geology.

Dr. G. F. Herbert Smith, M.A., F.R.A.S., F.G.S., Assistant Secretary, British Museum (Natural History).

Mr. A. F. Hemming, C.B.E., Assistant Secretary, Committee of Civil Research, *Secretary to the Sub-Committee*.

3. In the course of our enquiry we have received great assistance from various technical witnesses who have submitted to us important evidence regarding the use of the various methods of geophysical surveying, particularly of the electrical and gravimetrical methods and of these and other methods in combination. We should further acknowledge the readiness with which Departments have furnished us with information whenever we have had occasion to apply for such assistance.

4. In preparing our Report we have thought it convenient to follow in the main the order in which the subjects dealt with are arranged in our terms of reference.

5. The section immediately following is accordingly devoted to a brief account of developments since the war in the methods employed in geophysical surveying. In this highly technical part of our Report we have tried to confine our description to general terms, and, as far as possible, to avoid entering into discussions on technical points.

6. We have thought it convenient, while dealing in this section with each of the various methods of geophysical surveying, to indicate the extent to which they have respectively been employed in the field, the various parts of the world where they have been tried, and the degree of success with which they have met in particular types of prospecting.

7. In Section III we have collected such information as we have been able to obtain regarding the combined use of two or more methods of geophysical surveying in a single area.

8. In Section IV we deal with the proposal submitted by the Development and Migration Commission of Australia for a geophysical survey at the joint charge of the British and Australian Governments of an area to be selected in Australia. In this section we have been mindful that this proposal was originally submitted with a view to increasing population in parts of Australia by opening up new areas for economic development. In Section V we submit our recommendations for the consideration of the Committee of Civil Research. These, with our principal conclusions, are summarised in Section VI.

II.—THE VARIOUS METHODS OF GEOPHYSICAL SURVEYING.

9. The methods to be considered are those dependent on properties of the minerals or structures to be surveyed which can be detected without direct access. These properties are gravity, electrical conductivity, magnetic attraction, and elasticity. Certain thermal properties that in some cases can be so detected have not at present any proved value for locating minerals or structures associated with them. The employment of geophysical methods is comparatively recent. Except for the use of magnetic measurements of which, particularly in Sweden, advantage was already taken by the middle of the 19th century in searching for deposits of iron ore, these methods were practically unknown until within the last twenty-five years. Their development, stimulated by the increasing possibility of working deep deposits and by the difficulty and cost of finding these by direct observation through borings or from shafts, galleries, etc., has taken place mainly in the last decade.

10. Geophysical methods can be used both *directly* to ascertain the presence, location, and bulk of bodies of ore through measurement of the distant effects of certain qualities inherent in them, and also *indirectly* in cases where such effects are not produced by the object sought for, but are created by other elements of the underground structure that have a regular correlation with this object. As an example of many such indirect applications of geophysical methods prospecting for petroleum may be quoted. Oil itself is only in the most exceptional circumstances directly indicated through the use of these methods. Indirectly, on the other hand, various geophysical methods can be used to locate petroleum deposits by determining the location and exact limits and profile of the salt-domes to the flanks of which experience shows the deposits to be tied.

(a) *Gravimetric Method.*

11. This is based on ascertaining from the surface of the ground, differences in the density of the underlying rock. This may indicate the structural features underground or the actual presence of minerals, provided they exist in quantities sufficient to exert measurable effect. The differences of density are indicated by variations in the attractive force of gravity and these are measured by a torsion balance, of which the original idea is associated with experiments carried out by the English physicist Cavendish at the end of the eighteenth century. The balance consists of a freely suspended beam that comes to rest in a definite position under the double influence of gravitational forces and of the twisting of the suspending wire. The balance in general use was designed for purposes of geodetic research in 1888 by the late Baron Roland von Eötvös, a Hungarian physicist, who at Arad in 1900 mapped out from the suıface all the subdrift structure of a portion of the Hungarian plain. The instrument presently came into general use for discovering underground formations or ore-bodies masked by superficial deposits, and has constantly been improved. Over 200 instruments are said to be now in use in nearly 20 different countries, and by a large number of oil-exploring and other companies. The instrument has not hitherto, however, been used in considerable numbers by British concerns.

12. In a balance survey made to locate a massive deposit the instrument has to be set up at a number of stations sufficiently close to one another to enable the area over which gravity disturbances occur and the positions of the maximum gradients to be accurately found. These gradients occur near the boundaries of the mass and a curve through their positions shows the extent of the deposit. This being known, the approximate thickness and the depth of the deposit can be calculated from the gradient observations. Even in the case of a horizontal body these calculations are cumbrous, and if the bed is inclined the difficulty is enhanced. Recent theoretical developments have, however, tended to facilitate the interpretation of results, and it is now claimed that a stage has been reached when it is possible to calculate the effect to be expected from any known body of whatever form, while in addition improved corrective formulæ have been introduced enabling observations to be extended to hilly country instead of being confined to the plains, as was the case until comparatively recently.

13. Plans were laid before us which showed the success that had followed the use of the gravimetric method at various mines on the continent of Europe. The survey by this method of the Hanigsen salt deposit in 1917, located the edges to within 50 to 100 metres, and showed that the western edge was nearer to the surface than the eastern edge and that the sides fell steeply. In 1919–21 the line of an important fault in Wiener Becken was located to the great service of the mining interests of that area. The question of the continuance to a reasonable distance of a lode at the Hanbugel iron ore mine was settled in 1921 by a gravimetric traverse at right angles to the known direction of the lode.

14. We were told that in 1925, results were obtained from a gravimetric survey of the Hodbarrow Iron Ore mine in Cumberland that indicated structure in a pronounced manner, and in addition the location and extent of a mass of iron ore embodied in subdrift lime stone. The effect of the latter had first to be computed and the necessary corrections made on account of it before the effect of the haematite could be ascertained and the confines of the deposit calculated. In spite of this, the boundaries of the ore deposit were located and the mass estimated at about 2,000,000 tons. The average depth below the surface of the deposit subsequently proved to be about 220 feet.

15. In the twenty years before 1924 only six salt domes were discovered in the Texas Gulf Coast Oilfield, but since the introduction of geophysical methods of prospecting (mainly the torsion-balance method) seven more have been found, five of which were discovered in the year 1925. Salt domes, or plugs, are usually found in association with accumulations of oil, of which they thus indicate the probable existence. The success of the torsion-balance surveys in the Gulf Coast has led to most of the available oil-producing land there being leased for further geophysical prospecting. We have seen before us the results of gravity surveys over two-oil-producing surveys in this region. These particular domes were not originally located by geophysical methods, their existence being known before the gravity surveys, but they served to show the type of result given by salt domes. This conformed very closely to that theoretically calculated.

(b) *Electrical Methods.*

16. These, as far as minerals are concerned, depend entirely on the electrical conductivity of the ore bodies as compared with the rocks containing them. The method most in use is to pass an electric current between two earthed electrodes and to trace the equipotential lines. These are refracted above the place where bodies of different conductivities meet, diverging above good and converging above bad conductors. In special cases an electro-magnetic method may be used. There are certain other systems, but all those that have been satisfactory require an engine-driven electrical generator as part of the field equipment. Contact with the ground at the surface is sufficient in all cases. The work is as precise as can be recorded with the style of survey that would normally be employed. The interpretation of results depends largely on the experience of the man doing the work. He must be alive to possible complications due to special geological conditions such as the

presence of graphitic zones or abnormal sub-surface water. Fortunately, these complicating factors are uncommon and as a rule are readily detected by experienced workers.

17. The methods have been successfully practised in *Germany* by the Elbof Company, and in Sweden in the course of work carried out for the Geological Survey and for the Central-gruppens Emissions-acktiebolag of Stockholm.

18. While the ores in two of the four mining districts of *Sweden*—those of Northern Lapland and Central Sweden—have been known from of old through outcrops or as the result of prospecting with the magnetic compass, those in two others—both in Southern Lapland—have been discovered in recent years through the electrical method of prospecting in conjunction with geological investigations. In one of these—the Skellefte district—prospecting by direct methods based on examination of moraine boulders had gone on from 1900 to 1908 without payable results. On the renewal of prospecting in this district, stimulated by the war prices of metals in 1918, electrical equipotential methods were tried, and in the four or five years following were developed so as to be of real practical value. So also in the other ore-bearing district of Southern Lapland—the Västerbotten Mountains—two ore-fields have been investigated since 1919 by electrical methods that have yielded excellent results. The Swedish ores so investigated have been almost exclusively sulphides of copper, arsenic, and iron, containing gold. The electrical investigation was in all cases preceded first of all by reconnaissance mapping to distinguish the ore-bearing from the other formations and then by a detailed geological survey to determine the boundaries of the area that ought to be investigated electrically. The squares for these investigations had been increased to one square kilometre and an amplifier employed. The electrical prospecting was as a rule combined with a magnetic investigation, and in certain cases gravimetric or seismic methods were used, but, except in prospecting for magnetic ores, these auxiliary methods are not employed until the electrical methods are completed. Seismic methods were used in the Skellefte district in the winter of 1923 for determining the depth of overburden, and the results so obtained proved to correspond, within approximately one metre, to the depths subsequently ascertained by means of drilling and digging. Gravimetric investigations have been carried out in Northern Sweden with a view to ascertaining whether an electrical indication was caused by ores or by graphitic slates, i.e. by a material of which the specific gravity is higher than, or about the same as, that of the surrounding rocks, and have given satisfactory results even with ore bodies at depths of over 40 feet.

19. One witness stated that he had personally seen the electrical method successfully employed for detecting gold-bearing pyritic ores in Sweden and other countries. His experience in one country, where there was an overburden of highly-ferruginous lateritic material and rotted gneiss, and the general conditions appeared to be similar to those found in many parts of Australia, showed that the electrical method could detect the position and extent of ore bodies to within a few feet. Working within a favourable district of about 20 by 3 miles in extent, he had by its means detected six to eight bodies of pyritic copper ore, the presence of which had since been proved by drills and shafts. He had subsequently obtained ten to fifteen other good indications

which there had not yet been time to confirm. As regards the original selection of this area, one small ore-body had been detected, as the result of local reports of copper stains, before he began his operations. The strike of that ore-body was known and he had proceeded to test from it east and west. The local geological conditions suggested that the mineralisation conformed with the general strike of the district. There had been no previous survey of the district, but he had prospected the ground electrically for 10 miles or so on either side of the known ore-body. Within eight weeks of the start of his work he had checked the first ore-body and detected four others. In this district, where there were lodes of low-grade ore (1 per cent.–5 per cent. copper), he considered that in cases where the thickness of overburden—alluvial material, or decayed rock—concealing an ore deposit did not exceed 200 to 300 feet (or possibly 400 feet, in the case of large pyritic ore bodies like those of Spain), the presence and approximate size of the upper part of such ore deposit could be ascertained, even at the above exceptional depth, by the electrical method. In such cases the deposits would vary from 5 feet to 60 feet in thickness, and from 300 feet to 400 feet along the strike. At present, this method, while it gives the width and length of the undergound outcrop of an ore-body, is not reliable to more than a limited extent for revealing the full additional depth to which such an ore deposit may descend ; but such supplemental information might possibly be gained by subsequent gravimetric survey or other geophysical methods. The electrical method was, however, in the witness's opinion, only suitable for the purpose of detecting sulphide ores of iron, copper, and lead and other minerals of good electrical conductivity, e.g. magnetite, graphite, haematite, zinc blende (ferrous), manganese ores, etc. In this area he had only employed the electrical method, as that appeared the most suitable for local conditions and gave results sufficiently precise for the location of shafts and drill-holes. In some districts, however, he agreed that other methods were more appropriate, while in others a second method would prove a valuable check on the results obtained by the first method employed. It is a matter for congratulation, however, if a district is found in which the local conditions will permit the useful application of a second method.

20. At the Britannia Mine in Canada, the position of bodies of massive chalcopyrite and pyrite, indicated at a depth of 200 feet by the electrical method, was subsequently confirmed by mine development, and similar results were achieved by this method in the case of the Walker Mining Corporation in California, which is quoted as typical of the successful application of geophysical survey to the location of mineral deposits in the United States of America. We did not, however, take any evidence of, or make further enquiry into, these applications in Canada and the United States.

(c) *Magnetic Method.*

21. As already stated, the discovery of the ores in two mining districts of Sweden—those of Northern Lapland and Central Sweden—was in part achieved by the use of the magnetic compass. Magnetic methods were formerly limited to strong magnetic ores, but are now applicable to the differentiation of igneous and sedimentary rocks and to the survey of salt deposits.

22. It is now being further used to a considerable extent in combination with the gravimetric method by the leading Oil Companies. There is in certain areas a connection between magnetic and gravimetric anomalies, and as the former may be observed with far greater facility and in less than one-tenth of the time required for the observation of the latter, it would be advisable in such areas to make a preliminary magnetic survey and to confine the subsequent gravimetric survey to areas in which anomalies had been found. The combination of the magnetic and electrical methods in the Southern Lapland mining districts has already been mentioned. By means of the magnetic method the salt ridges of Segeberg (Germany), the magnetic deposits of Berggieshübel (Saxony), and the basaltic rocks in the sedimentary and basaltic area of Babichtswald, near Cassel (Prussia), have been clearly defined. The only recent developments in the magnetic method reported to us have been two instrumental ones, viz. :—

(i) Improvement of the Bamberg Schmidt variometer to reduce the temperature corrections ; and

(ii) Introduction of a magnetic variometer by Oertling of London.

(d) *Seismic and Sonic Sounding Methods.*

23. Just as gravimetric methods of prospecting are based on the different densities of materials in the earth's crust and electrical methods on their varying conductivities, so seismic methods take advantage of their greater or less elasticity. A dynamite cartridge fired at a point on the surface of the ground causes elastic waves to emanate in all directions from the point, and by means of seismographs the times taken for these waves to travel various distances from the blasting point are recorded. Disproportion between these times and distances indicates want of homogeneity in the elasticity of the layers beneath the surface, and with a sufficiency of observations the thickness of the upper layer can be determined as well as the speed of the elastic waves passing through the layer below.

24. Reference has already been made to the use of seismic methods in the Skellefte district of Northern Sweden for determining the depth of overburden, and there has been some application, of which very little is known, of the methods by the Seismos Gesellschaft in Germany. During the last few years they have been employed in Mexico and the United States, notably in the Gulf Coast oilfields of Texas, and have been successful in locating structures of a pronounced character, e.g. salt-domes. There seems little doubt but that they will prove of considerable application to the discovery of underground oil structures, to the exploration of coal-fields, and possibly to water finding. Seismic methods may apparently be advantageously used as a preliminary to gravimetric or in combination with electrical methods. They have suffered hitherto from control by private interests and lack of publication of the methods used and results obtained. "Sonic sounding," or "echo," methods, based also on the differential elasticity of ore bodies on the one hand, and their containing rocks on the other, have, we believe, been tried to a very limited extent in Australia, but so far no results of the experiments have come under our notice.

(e) *Thermal Methods.*

25. Measurements at or near the surface of the earth of temperature generated within it by volcanic action, or by radio-activity, or of differences of temperature due to greater or less conductivity and absorption of heat by different substances, while they may be included in geophysical methods, have as yet no direct application to prospecting for minerals.

III.—EXTENT TO WHICH DIFFERENT GEOPHYSICAL METHODS OF SURVEYING HAVE BEEN EMPLOYED IN COMBINATION.

26. As stated in the preceding section, we have knowledge that in the prospecting for sulphide ores in the Skellefte district of Southern Lapland, the electrical method was as a rule combined with a magnetic examination, and in certain cases also with a gravimetric or seismic investigation, but that except in prospecting for magnetic ores these auxiliary methods were not employed before the electrical work was finished. Seismic methods were used for determining the depth of an overburden, and gravimetric to ascertain whether an electrical indication was caused by ores or graphite slates, i.e. by a material the specific gravity of which is higher than, or about the same as, that of the surrounding rocks.

27. We have also information of the combined use of the magnetic and gravimetric methods in Mexico, and of the use of the former as a preliminary to the employment of the latter method in the same country and in the United States.

28. Several geophysical methods have been employed concurrently for prospecting in other areas. Naturally, in a survey for oil the first line of attack by geophysical means attempted is the gravimetric method. This was, however, supplemented in the case in question by the magnetic method, which showed magnetic anomalies of a proved oil-bearing zone. In the present season the Company concerned are, we understand, trying the electrical method, with apparatus constructed in this country under the direction of their technical officers. Unfortunately, no information is at present available regarding the results obtained by the latter method. It is, however, worthy of note that on the advice of their expert staff the Company in question considered that the prospect of obtaining information of value in supplement to or in correction of, the results obtained by the gravimetric and magnetic methods was sufficient to justify the considerable outlay in money and time involved in trying out the electrical method.

29. A further occasion on which several methods have been employed in combination was brought to our notice by another witness, who stated that the whole of the area in this case was covered by glacial drift, and there was nothing on the surface to indicate the presence of minerals. Prospecting by geophysical methods had been started on an area of about two acres at an old lode which had been worked and abandoned 50 years before. Results at this point obtained by the torsion-balance and the electrical method agreed with one another. The survey was then transferred to a place where the probable presence of lodes had been indicated by the torsion-balance survey. The electrical and magnetic methods were employed, and confirmed the conclusions of that survey. A trench had then been cut down to the carboniferous

limestone until a mass of calcite veins had been found. The position was very promising and a shaft was being sunk. The witness considered it likely that lead and zinc sulphides would be found. The whole area was one where ordinary prospecting methods would have been too expensive to be profitably undertaken. The witness added that in the case of this particular survey the torsion balance had given better and more practical results than the electrical method.

30. Generally, it would seem that the electrical method is quicker in operation and simpler in application than the use of gravity instruments. A preliminary investigation by the former method sufficient to determine the approximate position of conductive bodies can be carried out over an area of a square kilometre by two skilled men with unskilled assistance in about three days. Further detailed investigations are, however, necessary before a map can be prepared showing the outlines of the conductor accurately to within a few metres. In the case of the gravimetric methods, accurate setting up of the instrument is necessary and a number of observations have to be made at each point. Practically, it is only possible to count on completing the observations at one station in a day. In using this method, care has to be taken to record every considerable natural or artificial projection above the surface of the ground within a certain distance of the points of observation and the corrections on account of such projections add intricacy to the necessary calculations. It has been stated to us that the electrical method is about ten times as rapid as the use of the gravity instrument. The magnetic methods are also comparatively rapid. The seismic methods seem to be suitable rather to the solution of a particular problem than for a general survey.

31. A comparison between the different methods as regards rapidity in carrying out the practical work and simplicity in the calculations involved to enable the results to be plotted is not, however, the basis on which the choice of methods can be mainly decided. This depends rather on the constituents of the rocks to be investigated and on the minerals they may contain. To ascertain these things there is required a general geological reconnaissance from which alone it will be possible to judge the most suitable geophysical method or combination of methods which should be employed in carrying out the survey. According to Dr. Richard Ambronn, whose "Methoden der angewandten Geophysik" is the most thorough account of these methods we have come across, "the task is at the outset one in which qualitative determination is geological, the geophysicist seeking to determine the quantitative conditions of the deposit."

32. Probably if the results of the geological survey show no particular reason for the employment of one method rather than another, that is to say, if the mineral or structure sought for has not magnetic properties, and has about the same variations in density and in conductivity from the rocks in which it occurs, the first method to employ in the survey would be the electrical one, as being more rapid in execution and simpler in application than the use of gravimetric instruments, but even in that case the use of such instruments might subsequently be applied, owing to their great accuracy, to checking or filling in important details of the survey.

33. But in this and other matters connected with the combination of geophysical methods we are satisfied that there is much to gain through an investigation which

will be concerned not only with getting information with regard to the minerals in a particular area, but also with adding to the knowledge of how generally to gain such information by geophysical methods under the very different conditions to be found in various economic deposits. We make this answer to the question contained in the second part of our terms of reference.

IV.—THE PROPOSAL SUBMITTED BY THE DEVELOPMENT AND MIGRATION COMMISSION FOR A GEOPHYSICAL SURVEY IN AUSTRALIA.

34. The scheme put forward by the Development and Migration Commission may be summarised as follows :—

(1) That a survey by geophysical methods of parts of Australia should be undertaken at the joint charge of the British and Commonwealth Governments.

(2) That each Government should contribute £25,000 towards the cost of the survey estimated by the Commission at £50,000.

(3) That the expenditure of the foregoing sum should be entrusted to the Development and Migration Commission.

(4) That the magnetic, electrical and gravimetric methods should be employed the necessary apparatus being purchased on the advice of the Anglo-Persian Oil Company.

(5) That, as regards staff and the training of staff, advantage should be taken of the facilities which the Commission understand the Anglo-Persian Oil Company are willing to offer.

(6) That the first place in which to try the methods referred to in (4) above should be the Western Australian Goldfields ; and that the apparatus employed should be standardised on the known Goldfields at Kalgoorlie and Wiluna.

(7) That, if the surveys produce successful results, a transport department should be organised ; and the auriferous areas attacked by a scientific staff, acting in co-operation with the State authorities, the transport department being responsible for supplies so as to enable prospecting to proceed without interruption.

(8) That drilling should be undertaken where considered desirable in suitable areas.

(9) That any valuable areas found should be secured on behalf of the two Governments and sold or otherwise treated as may be determined from time to time.

(10) That, as time and opportunity permit, other areas and other States (i.e. than Western Australia) should be systematically prospected until such time at least as private enterprise has undertaken or will undertake all necessary work at such speed as conditions demand.

35. The foregoing proposals were submitted by the Commission to the Oversea Settlement Committee, on the ground that a revival of gold and other mining in Australia would be of great benefit to the British as well as the Australian Government, and would lead both directly and indirectly to an expansion of trade, increased population, and later to more land settlement. It was expressly suggested that the survey should, in the first instance, be limited to Western Australia, where, in the opinion of the Commission, there was a large area of auriferous country that had been very poorly prospected and where also there were areas in which other metals, e.g. copper, tin and lead, had been found in payable quantities.

36. The Oversea Settlement Committee examined these proposals, but found that they were debarred by the provisions of the Oversea Settlement legislation from financial participation in such a scheme. It was subsequently referred to the Empire Marketing Board, at whose instance the present Sub-Committee was constituted.

37. Our terms of reference bind us to regard a possible survey by geophysical methods in Australia from an angle different from that of the Development and Migration Commission. The Commission proposed it in general as a possible means of stimulating migration from this country to Australia and, in particular, as a means of assisting the reorganisation and development of the Western Australian mine fields. We, on the other hand, are specifically instructed to consider whether the proposal put forward offers a suitable opportunity for testing the value of the various methods of geophysical surveying in the interests of Empire development generally.

38. We should like, however, at the outset to express our entire agreement with the underlying principle of joint action by Great Britain and the Commonwealth in the development of the great potential wealth of Australia. Our examination of the various methods of geophysical survey has convinced us that their introduction opens an important chapter in the history of prospecting. So far as the British Empire is concerned, surprisingly little use has been made of these methods, in spite of its great mineral resources and the wide areas that await prospecting. It is important here to observe that in the case of one method only, the gravimetric, has development been accompanied by corresponding publication in the scientific world of the scientific data obtained. It can justly be claimed that since its invention the history of the Eötvös torsion-balance has been that of a genuine scientific instrument. Full details regarding its construction and of successive improvements introduced have been published in the scientific press. The same is true in regard to improvements in the reduction of the observational data and the interpretation of the results obtained. No comparable scientific publications have been issued in regard to the other geophysical methods. In particular, the electrical method has throughout been treated by the companies employing it as a jealously-guarded secret trade process. In the result little information is available to the general scientific world regarding the methods employed in the use of this method, the apparatus required, the field operations, or the interpretation of results. We believe that this policy of secrecy is short-sighted, and that a full disclosure of the scientific facts would tend more than anything else to stimulate the natural development of this method of geophysical surveying, by placing it on a scientific footing similar to that of the gravitational method.

39. We are satisfied regarding the value of geophysical methods of surveying ; we believe that an extensive trial of the principal methods, accompanied by full publication of the scientific information and experience so acquired, would be of great interest and value to the Empire ; and we consider that the proposal of the Development and Migration Commission of Australia, modified in the manner proposed in the following Section of this Report, offers a suitable opportunity for testing these methods in the interests of Empire development generally.

40. Such a survey cannot, however, be considered as more than a hopeful experiment, and we consider, therefore, that in the first instance it should be approved for only a limited period. One year would probably not be long enough to enable the necessary amount of scientific data to be obtained. We, therefore, recommend that the proposed survey should be planned to last for two years, at the expiration of which period its continuance should be further considered.

V.—RECOMMENDATIONS.

(a) *The Selection of Sites to be Surveyed.*

41. The evidence that we have received satisfies us that there are large areas in Australia which are *primâ facie* suitable for trying out geophysical methods, but that these methods are not suitable for the purpose of carrying out a reconnaissance and the areas that can usefully be examined by their means are relatively small.

42. Probably it would be necessary to restrict any area to be surveyed to (say) twenty miles square, i.e. 400 square miles. In these circumstances it is apparent that the utmost care should be taken to select sites which for geological and geophysical reasons appear the most promising. We recommend, therefore, that in the first place the leader of the party, who we propose in paragraph 45 should be a geophysicist, should confer in Australia with the leading Federal and State geologists. The leader of the party, if previously unacquainted with Australia, would naturally have made a preliminary study of the geological literature of the principal mineralised areas in the Commonwealth, and by so doing would probably have been able to select a number of likely areas. The conference, we consider, should examine the possibilities of any areas that the Australian geologists might bring forward or that of the geophysicist might suggest, and should reach a preliminary decision on the area or areas to be surveyed.

43. The conference should be perfectly free to recommend areas for survey in any part of the Commonwealth, but, if two areas appeared on scientific grounds to be equally promising, regard should, we consider, be paid to the hope expressed by the Australian Government that the survey may lead to new opportunities for an expansion of population.

44. Before, however, orders were actually issued for the survey to be started in any area, we consider that the leader of the surveying party and the State (or Federal) geologist concerned should jointly undertake a more detailed reconnaissance (without geophysical instruments) of the area selected by the conference and should decide on the precise point of attack.

(b) *The Composition of the Surveying Party.*

45. Much of the success of the venture will depend on the character and qualifications of the leader of the surveying party. After careful consideration, we recommend that the leader should be primarily a geophysicist rather than a geologist, though he should undoubtedly have an adequate knowledge of geology. Further, we consider that as the electrical method of surveying will probably be the one most adapted for use in Australia, the geophysicist-leader should have a special knowledge of the electrical method and of electricity generally. If, however, he is to carry out his duties as leader of the party it will be necessary for him to acquire an adequate knowledge of the gravimetric, magnetic and seismic methods. In addition, he will need to have at his disposal the fullest available knowledge of the geology of the areas to be surveyed. We consider that this can best be secured by arranging in each area for the local State (or Federal) geologist to be available for consultation by the survey party in the field.

46. The leader would, however, have many duties in connection with the general supervision of the survey, the selection of sites, the preparation of reports, etc., that he would not himself be able to undertake the whole of the electrical survey carried out. We recommend, therefore, one member of the party should be a first-class honours graduate in electricity, who would be responsible for this part of the work under the general supervision of the leader. Similarly, we recommend that the party should contain a first-class honours graduate in physics and mathematics, who would be responsible to the leader for the gravimetric and magnetic surveys undertaken.

47. Both the electrician and the physicist recommended above would require the assistance of a surveyor in carrying out the surveys for which they were respectively responsible for assisting in the working out of the results obtained in the field. The smooth working of the survey would further be facilitated if there was attached to the party a physics laboratory assistant.

48. In addition to the above staff, there would need to be probably four labourers, two each for the electrical and gravimetric parties, a cook, assistants, etc.

(c) *The Personnel of the Party.*

49. In the preceding section we have sketched the composition of the survey party, and it remains to consider the method of securing the most suitable personnel. The most difficult problem will be to get a leader possessing the necessary technical and scientific qualifications. We have already expressed our view that he should be a geophysicist and should possess expert knowledge of the use of the electrical method. The number of such geophysicists is, however, strictly limited. It should be made perfectly clear to whomever this appointment is offered that, if he accepts, he will be under an obligation to report, at such times as the Government may direct, during the progress of the work, in full detail on the methods, apparatus and every part of the procedure, and, at its conclusion, to prepare the whole for publication.

50. As regards the physicist to undertake the torsion-balance survey, we recommend that this post should be held by an Australian, and that a suitable candidate should be selected by the Australian Government in consultation with the Department in this country administering the grant. We consider that immediate arrangements

should be made for the candidate so selected to come to this country for the purpose of undertaking an intensive study of the gravimetric method, and that the Department of Scientific and Industrial Research should be asked to provide for his training, in consultation with the Science Museum.

51. The electrician who will undertake the bulk of the electrical survey should also, if possible, be a first-class honours graduate in electricity. If, as we recommend, the leadership of the party is entrusted to a geophysicist possessing an expert knowledge of the use of the electrical method, the electrician would not need any additional training, as he would be able to work under the leader's instructions until qualified to work independently. It should be possible, in regard to this appointment also, to find a suitable candidate in Australia.

52. The remainder of the party, viz. the surveyors, laboratory assistant, labourers, cook and assistants, could all, no doubt, be engaged locally.

(d) *The Cost of the Proposed Survey.*

(i) *Staff.*

53. We estimate that a sum of £8,000 would be required to cover the salaries and wages of the above staff for one year.

(ii) *Equipment.*

54. Our recommendations under this head may be summarised as follows :—

Electrical apparatus.
One magnetometer.
Two torsion-balances, including the necessary huts, etc.
Two trolleys for the torsion-balances.
Level.
Miscellaneous instruments, books, stationery, etc.
Two one-ton motor lorries.
Camp equipment.

55. We estimate that the cost of the above equipment would amount to approximately £4,000. As regards the electrical method, little or no reliable equipment for this form of surveying is available on the market and anyone proposing to use this method would probably need to design his own apparatus. No difficulty will arise on this score if a geophysicist with expert knowledge of the electrical method is put in charge of the survey as he will be familiar with the apparatus required. We do not include in our estimate any provision for testing the seismic or other methods dependent on elastic properties, but the application of these should be considered in the course of the survey.

(iii) *Passages, etc.*

56. Provision will be necessary for the passage to Australia of the leader of the party and for the passage from Australia to England and back of the Australian physicist to be trained in the use of the torsion-balance at the Science Museum. It is difficult to forecast what other passages may be required, but we suggest that provision of £800 should be made for this heading. We suggest in addition an item of £400 to cover cost of travelling, etc., in Australia.

(iv) *Field Allowances.*

57. The cost of running the survey camp will depend on various factors, but, on the assumption that it will be met by the issue of Field Allowances, we recommend the insertion of an item of £2,000 for this service.

(v) *Summary.*

58. In addition, we recommend the provision of a sum of (say) £800 to cover the cost of any necessary items not included for any reason in the foregoing recommendations. Our estimate for the cost of equipping the party and for its maintenance for the first year may, therefore, be summarised as follows :—

	£
Salaries and wages	8,000
Equipment (including instruments, etc.)	4,000
Passages and travelling	1,200
Field allowances	2,000
Contingencies	800
	16,000

59. The cost of the survey during the second year we estimate as follows :—

	£
Salaries and wages	8,000
Field allowances	2,000
Travelling	400
Renewals and contingencies	600
	11,000

60. The total cost for a survey such as we recommend extending over a period of two years would, therefore, we estimate, be as follows :—

	£
Salaries and wages	16,000
Equipment (including instruments, etc.)	4,000
Passages and travelling	1,600
Field allowances	4,000
Contingencies and renewals	1,400
	27,000

(vi) *The Finance of the Survey.*

61. As regards the finance of the survey, we suggest that the Committee of Civil Research should recommend the Empire Marketing Board to make a grant of £13,500 for a geophysical grant, on the lines suggested in this Report, of areas to be selected in Australia, provided that the Australian Government accept the basis on which it is proposed to organise the survey and are willing to provide a like sum

to meet its cost. The grant should cover a two years' period, the amount required in the first year being £8,000, and that for the second year £5,500. We do not propose to deal with the detailed financial arrangements that will require to be made with the Australian Government, or with the steps to be taken with regard to any minerals of value that may be found in the course of the survey, as we consider that these matters are outside our terms of reference. If our proposals are approved, these suggestions will, however, require to be carefully considered by the Department charged with the administration of the grant, in conjunction with the Empire Marketing Board. Suitable arrangements will at the same time need to be made defining the responsibility of the leader of the party to the Commonwealth Government during the actual conduct of the survey in Australia.

VI.—SUMMARY OF RECOMMENDATIONS.

62. Our conclusions and recommendations may be summarised as follows :—

(*a*) That material progress has been made in recent years in the various methods of geophysical surveying.

(*b*) That a trial of the various methods on a large scale, individually and in combination, if accompanied by full publication of the scientific information and experience so acquired, would be of great interest and value to the Empire.

(*c*) That on geological and geophysical grounds Australia offers a suitable field for testing geophysical methods in the interests of Empire development generally.

(*d*) That a trial should, therefore, be made of these methods in Australia, and that it should be planned to last for two years, at the expiration of which period its continuance should be further considered.

(*e*) That as regards the selection of areas to be surveyed, arrangements should in the first instance be made for the leader of the party to confer with the various State and Federal Geologists, who should jointly select any area or areas that appear the most promising ; that before a survey is actually started the leader of the party, in conjunction with the local State or (Federal) Geologist, should examine the ground (without geophysical instruments) and should decide the exact point of attack ; and that for the purpose of each particular survey undertaken, arrangements should be made for the local State or Federal Geologist to be available for consulatation by the survey party in the field.

(*f*) That a sum of £8,000 should be provided for the salaries and wages of the survey party, which should be composed as follows :—

(i) One geophysicist to act as leader, who should have a special knowledge of the electrical method, and should undertake to report, at such times as the Government may direct during the progress of the work, in full detail on the methods, apparatus and every part of the procedure, and at its close to prepare the whole for publication.

(ii) One physicist to undertake the gravimetric and magnetic surveys ; this post to be filled by a selected Australian first-class honours graduate in physics and mathematics, who, during the period of the geological reconnaissance in Australia, should proceed to this country where the Department of Scientific and Industrial Research should be asked to provide for his training, in consultation with the Science Museum.

(iii) One Australian first-class honours graduate in physics who has specialised in electricity, to assist the leader in the electrical survey.

(iv) Two surveyors to assist respectively the physicist and the electrician, to be engaged locally in Australia.

(v) One physics laboratory assistant, to be engaged in Australia.

(vi) Four labourers, one cook, and other additional assistants, to be engaged in Australia.

(*g*) That the survey party should be supplied with the following equipment at an estimated cost of £4,000 :—

Electrical apparatus.
One magnetometer.
Two torsion-balances, including the necessary huts, etc.
Two trolleys for the torsion-balances.
Level.
Miscellaneous instruments, books, stationery, etc.
Two one-ton motor lorries.
Camp equipment.

(*h*) That, in addition to the foregoing, provision of £800 should be made for passages, £400 for travelling and £2,000 for field allowances, making a total (including salaries and equipment) of £16,000 for the first year. For the second year, provision would require to be made for salaries and wages, £8,000 ; travelling, £400 ; field allowances, £2,000 ; contingencies and renewals, £600 ; making a total of £11,000.

(*i*) That the Committee of Civil Research should recommend the Empire Marketing Board to make a grant of one-half of the cost of a two years' survey on the lines set out in recommendations (*e*) to (*h*) above, provided that the Australian Government accept the basis upon which it is proposed that the survey should be organised, and are prepared to provide a like contribution towards its cost.

(Signed) MATTHEW NATHAN.
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A. F. Hemming,
Secretary to the Sub-Committee.
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July 14, 1927.

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