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The first official recommendation to establish exploration geophysics in institutions in Australia: providing some insights into the status of exploration geophysics worldwide up to 1927

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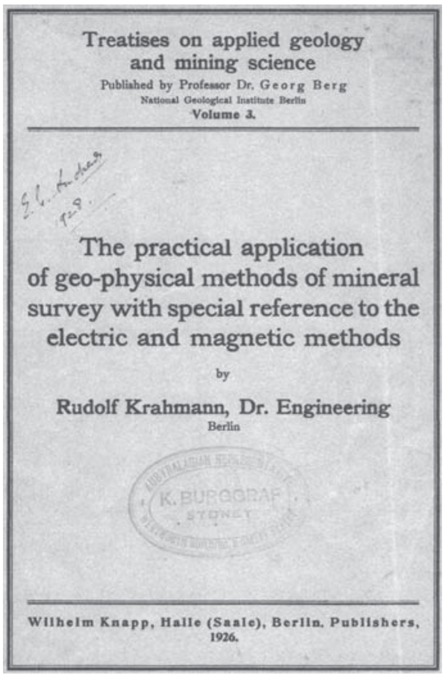
In 1927, E. C. Andrews, then Government Geologist to the N.S.W. Dept. of Mines, titled his contribution to the Department's Annual Report for 1927, 'Preliminary Report on Geophysical Prospecting for Ore Bodies' (Andrews 1928). In it he makes some general comments about the value of geophysics; describes the methods of geophysical prospecting that had come to his attention by then; their manner of use and costs to survey; suggests their applicability to Australian conditions and makes recommendations for their adoption in NSW and Australia, generally. Alan Day in his comprehensive review of the development of geophysics in Australia (Day 1966) claimed that '**official** interest in this new technique' (of geophysics prospecting) was aroused by this time and Andrews 'investigated geophysical methods while overseas in 1927 and reported favourably, **recommending the institution of geophysical facilities** by the New South Wales Geological Survey'.[1] It was in this report by Andrews (1928) that these recommendations were made and it is therefore an important source document in relation to the formal establishment of geophysical exploration in NSW and Australia, generally.[2]

As to Andrews' overseas travel, his biography by G. P. Walsh (1979) informs us that in 1908, 'Earnest Clayton Andrews' travelled to the USA and also visited Canada, England and Europe. At that time very little exploration geophysics was known but in 1927, according to Walsh (1979), 'he gave the Silliman lectures at Yale University'. By this time several methods were in routine use and it is likely that it was only during this later visit that he learned about the geophysics on which he reported.

In 1965, in my one year as a geophysicist in the NSW Geological Survey, I was fortunate to save a copy of Andrews' report, possibly his own copy, from being discarded. In addition, I was also able to retrieve a 3-page, typed occasional paper entitled 'Electrical Prospecting' signed by Andrews and dated 5/3/1925 (more on that later) and some reprints of papers and a company booklet, each apparently belonging to Andrews as they have his name and a date in 1928 handwritten on them. All were published in 1926 or 1927. Figure 1 is an illustration of the front cover of one such reprint showing the 'ownership' marking. The authors of the papers are prominent geophysicists of the period. As some are published in the USA, Andrews may have acquired these during his visit there in 1927. The company booklet is from 'Elbof' Geophysical Co. Ltd., a German contractor, and shows that they had offices in various countries including one at 6 Dalley Street, Sydney (Figure 2). These papers are all listed in the References and distinguished from other references by special notation. It is clear that this is where Andrews obtained much of the material for his report as parts of them are marked up, presumably by him. In themselves, they give further insight to the state of the profession at this time.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The practical application of geo-physical methods of mineral survey with special reference to the electric and magnetic methods

by

Rudolf Krahmann, Dr. Engineering
Berlin

K. BURGGRAF
SYDNEY

Wilhelm Knapp, Halle (Saale), Berlin, Publishers, 1926.

Fig. 1. *The front cover of Krahmann (1926) showing 'E. C. Andrews 1928' and also the stamp of K. Burggraf, the 'Elbof' agent in Sydney.*

One reprint authored by Krahmann (1926) and published in Germany has an oval stamp on the front cover with 'K. Burggraf, Sydney' in the centre and around the perimeter, 'Australian Representative. Wentworth Building, 6 Dalley Street' (see Figure 1). In the 'Elbof' booklet, Burggraf is listed as the Sydney representative of the 'Elbof' Company (see Figure 2). This suggests to me that Andrews might have been given this copy of Krahmann's not easily obtainable paper, by Burggraf.

Because of the interesting insights that Andrews' report gives into the status of exploration geophysics at the time,

[1]Here, 'geophysical prospecting' is distinguished from observatory geophysics and regional surveys conducted by Nuemayer and others from 1860.

[2]As Section 7 of his report is titled 'Application to Australian Conditions', Andrews was thinking of applications not only in NSW.

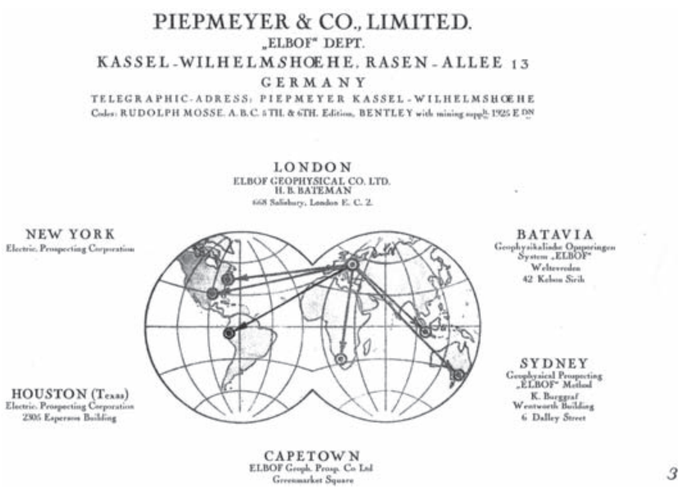

Fig. 2. *Page 3 of Elbof (1927) listing an office in Sydney with K. Burggraf the representative.*

including its practice and some famous practitioners, and his recommendations for its establishment in Australia, I have, in the following, discussed the parts of most historical interest and in some cases quote verbatim from the report. Where appropriate, I also quote from the reprints that were in his possession, for further clarification. As the report has no figures, I have included some illustrations relevant to the time taken from some of the other papers Andrews possessed and other sources.

Andrews' report has the following section headings: 1. General; 2. Sources of Information; 3. Brief Statement of Processes; 4. Prices of Apparatus; 5. Costs of Geophysical Surveys; 6. Patents Covering the Methods; 7. Application to Australian Conditions; and 8. Conclusions and Recommendations.

In section 1, '*General*', Andrews proves to be a true geologist in not wanting to give geophysics all the credit with his very first two sentences: 'The various geophysical aids to prospecting, as at present known, **do not furnish royal roads** to the detection of commercial ore deposits. They merely furnish clues to, or indications of, the existence of certain masses of material in the field of operation which are relatively conductive or non-conductive'. Andrews is, in this instance, referring only to electrical methods and he goes on to explain how 'non-commercial material (such as "graphite schist") may yield extremely "favourable" [geophysical] indications'. Here, at least with electrical methods, Andrews is alluding to their inability to discriminate economic ore from worthless minerals on the basis of electrical properties. With regard to the use of other methods 'whether gravitational, electric, magnetic, seismic, or sonic', he still only allows that 'all that can be discerned by the geophysicist in this connection is that an ore-body…exerts a disturbing influence...'. After further enlargement on this theme with more examples, he concludes, 'that the assistance of the geologist is **indispensable**' and '...it is the province of the geologist to interpret the indications from the knowledge of the associated geology'. 'He [the geologist]…most materially, assists in giving definite form and colour to the final picture'. The indispensability of the geologist is repeated two times here and altogether five times in the report. One could say that he is not exactly making a strong case for the use of geophysics. He goes on, 'Each does excellent service in his special sphere'. However, 'neither [physicist nor geologist] can be expected **to spring full grown** into the other's work'. These days there is not this strict division and a good geophysicist will take account of the geology in his or her interpretation. Andrews does concede that while '**great skill** is needed in the continuous adjustment necessary ... for the proper evaluation of the various ...indications'. Is this some praise, at last, for the work of the geophysicist?

After some 650 words so far on this general theme, Andrews feels obliged to provide yet another analogy and for 300 more words describes the great value of the geologist in the construction of a 'hydro-electric power scheme', with no mention of geophysics. It is puzzling as to why this is in a report on geophysical prospecting for ore-bodies. He then goes on to suggest another analogy, '…the analogy of **sounds or of languages** is not inapplicable to the case of this geophysical work'. Then he refers to the 'peculiar sounds produced in his [the geophysicist's] head phones', and 'It is the province of the geophysicist, in electrical methods, …not to confuse **the roaring of a power-line**...with the **whistle of the ore body**…'.[3] Then, 'He [the geophysicist] proceeds to interpret these languages, but it is **the geologist** who interprets the ambiguous phrases and **the more difficult sentences**'. So the geologist comes to the rescue again.

Andrews finishes this section acknowledging that 'the accompanying report…is not complete, having been prepared by a geologist possessing **a slight acquaintance only** with mathematical and physical principles'.

Section 2, '*Sources of Information*'. Here, Andrews lists the 'names of the companies and individuals **interviewed** in connection with this geophysical enquiry'. The 'interviews' could have been conducted by correspondence and perhaps in preparation for his visit to the USA. Alternatively, all but one of the contacts could be found in the USA at this time so he could have met them there in 1927. 'Mr D. Mouchketov' from the 'Geophysical Survey of Russia' is unlikely to have been interviewed in Russia given the difficulty of international travel at the time (see Historical Context below). It is possible that he was also visiting the USA when Andrews was there. In Section 5 of his report, Andrews states: 'In south-western Wisconsin **which was visited by me**…'. He makes no mention in the report of his travelling anywhere other than to Wisconsin. However, there are also three references in the report (in Sections 4, 5 and 6) in relation to seismic, of further information (to do with prices and patents) being obtained 'after a visit to Oklahoma and Texas'. It is not clear if this trip is intended to be made later by Andrews or by another person.

Andrews' list is as follows:

i) Representatives of the 'Swedish American Prospecting Corporation', including 'H. Lundberg' ('H' being 'Hans'), no doubt of the 'Lundberg method' of Surface Potential referred to later, and 'Sundberg', most likely Karl Sundberg who Andrews later attributes to employing the Induction method he describes;
ii) 'Mr E. L. DeGolyer', said here by Andrews to be using gravity and seismic methods for locating salt domes in

[3]Andrew's biographer (Walsh 1979) says he 'never lost his youthful and schoolmasterly habits: in his papers, often prolix, he used apt classical allusions, once felicitously likening the geologist to "Antaeus of old, who must draw strength from continual contact with the Earth"'.

Oklahoma and Texas.[4] Also, according to Barton (1928) (one of the reprints I retrieved as belonging to Andrews), DeGolyer was President of Rycade Oil Corporation when a survey by Rycade discovered the Nash salt dome in Texas using the Eötvös torsion balance, in 1924. This is usually accepted as the first discovery of an oilfield by any geophysical method. Also, according to Barton (1928), DeGolyer was President of Amerada Petroleum Co. when the torsion balance was used to map structure on the oilfields in Oklahoma; [5]

iii) 'the Physical Exploration Corporation', including 'Messrs. M. Mason (President Chicago University), L. B. Slichter' and others.[6] One of the other publications I retrieved with Andrews' report was a reprint by Dr Max Mason (Mason 1927) from which it would appear Andrews gained much of his information, particularly about the magnetic and induction methods;

iv) 'Messrs A. L. Day and F. Wright of the Carnegie Geophysical Laboratory.' 'F. Wright' is presumably the Dr Fred Wright referred to later in Section 4 – Prices, in relation to a new type of gravity meter. Apart from this reference to Dr Wright, Andrews made no further mention of the Carnegie Geophysical Laboratory (CGL), which is one of the six research departments of the Carnegie Institution of Washington (CIW) created in 1905 and still very active today, concerned with research in the earth sciences. Another of the six departments of the CIW, the Department of Terrestrial Magnetism, was founded in 1904, originally to map the geomagnetic field of the Earth. The CIW made regional and observatory type magnetic measurements in Australia from 1906 to 1920. Day (1966) gives a detailed account of these surveys, which were not intended for purposes of prospecting.[7] This may be why Andrews did not refer more to the CIW.

v) 'Messrs E.G. Leonardon, Sherwin F. Kelly and Hoover representing the Schlumberger Electrical Prospecting Methods.'[8] Note that this is not actually a company but there was the Schlumberger Company of France (founded by Conrad and Marcel Schlumberger) which according to Day (1966) took out patents in Australia (see Andrews' Section 6 below);

vi) 'Mr D. Mouchketov… Director of the Geophysical Survey of Russia'. Mouchketov is referred to later, in the section on Prices of Apparatus, then as 'Dr.' Mouchketov.

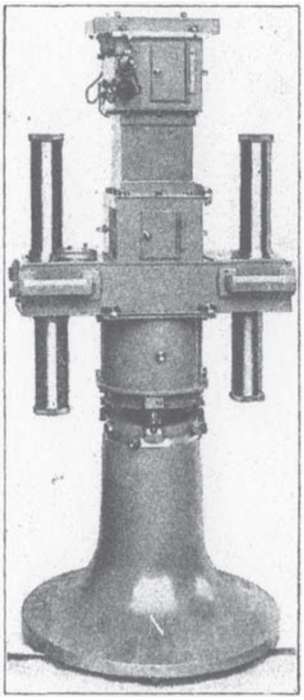

Fig. 3. *One type of torsion balance. (From Elbof (1927), p. 34).*

Section 3, '*Brief Statement of Processes*' is by far the largest section of the report in which Andrews describes seven exploration geophysical methods he knew to be available at the time. In the first, the '*Gravity Balance Method*', he describes the Eötvös torsion balance, first invented by Lorand Eötvös in 1890 and which was in routine use in the 1920s. Figure 3 is an illustration of one of the many versions of a torsion balance. Figure 4 shows a torsion balance in its housing to minimise

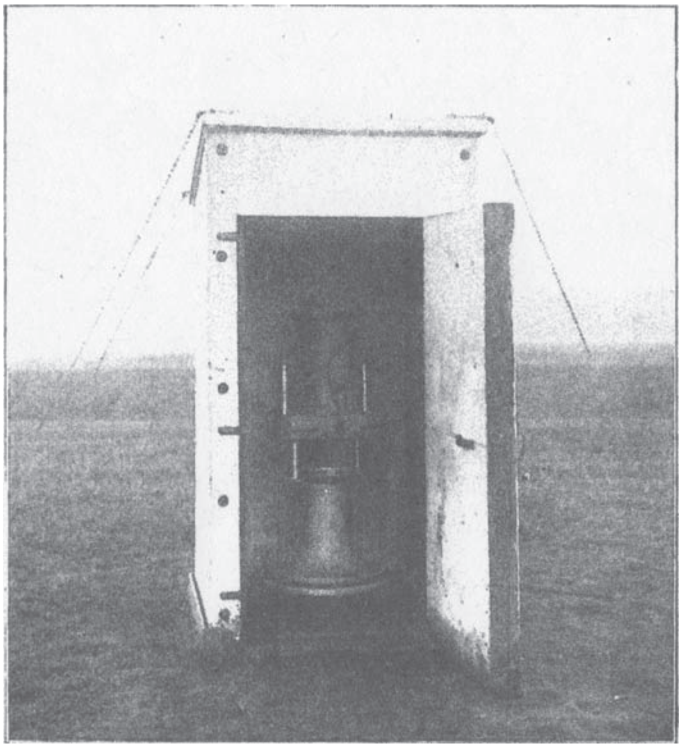

Fig. 4. *A torsion balance in a housing to protect it from atmospheric fluctuations particularly of temperature. (From Elbof (1927), p. 36).*

[4] Clark (1999) claims that DeGolyer imported an Eötvös Torsion balance into the US for his company's use in 1924 and financed the formation of Geophysical Service Inc. (GSI).

[5] DeGolyer received the inaugural Honorary Membership of the SEG in 1930. Also in that same year, Donald Barton was the first President of the SEG and he received the SEG Honorary Membership award, posthumously, in 1940.

[6] Louis B. Slichter was awarded Honorary Membership of the SEG in 1959.

[7] At times some of the regional observation points were noted as being very anomalous, such as at Mt Magnet, W.A. which were then attributed to banded iron. For a colourful account of the CIW's use of camels in the desert and some excellent old photos, see Morrison (2005).

[8] Both Leonardon and Kelly subsequently published papers in the transactions of the Am. Inst. of Min. Metal. Engs. (AIMME) Transactions; Leonardon (1932) on electrical methods applied to problems in civil engineering and Kelly (1932) on a uniform expression for resistivity.

temperature changes during a measurement which usually takes 6 hours at each site.[9] Andrews states that 'the balance appears to have been successful in Texas and Oklahoma in the location of oil domes under great horizontal plains.' However, 'In areas of rough topography and in areas also containing only relatively **small ore bodies** under deep cover… the balance could not be expected to be very useful'. This is a reasonable conclusion by Andrews given that a) the balance was extremely sensitive to changes in topography in its proximity (within a radius of 100 m and more) and b) the relative insensitivity to small bodies.[10] Not surprisingly then, the torsion balance lost favour in the mid 1930s to the faster-to-read and easier-to-use suite of gravity meters as we know them today. Indeed, Andrews might have sensed this as he mentions two new types of gravity meter under development in his Section 4 on Prices of Apparatus. (More detail on this later.)

The next two processes, '*Seismic Method*' and '*Sonic Method*', Andrews states 'for the purpose of this report… may be considered together', apparently since they both involve 'a charge of explosive' ('Sonic' is synonymous with 'Acoustic', being sound waves with a higher frequency than most seismic waves). Andrews deals with these two methods together throughout the report; however, it is more likely that the sonic waves for sub-surface exploration are generated by mechanical vibration, for example, a 'sledge hammer' (Heiland 1968, p. 959). Mason (1927), whose paper Andrews follows a lot, does also deal with these two methods together. Mason claims that 'the acoustic method – which is, broadly speaking, the study of echoes reflected by ore bodies from incident sound waves – early proved rather disappointing'. In this, the shortest section of all methods described, Andrews alludes to the two method's 'ready application' in Texas and Oklahoma 'where salt domes occur more or less regular in shape'. However, he is here, I believe, suggesting their unsuitability in areas of intense structure, or 'many irregularities', as might occur around ore-bodies.

In the '*Self Potential Method*' Andrews gives a reasonable description of the, by now, well accepted process whereby the existence of currents flowing in ore bodies makes this method useful for their detection. In practice, the 'apparatus used consists of two electric cells on separate staffs, the two being connected by a wire, and one of the portable staffs carrying a potentio-meter with sensitive galvanometer'. Figure 6 is an illustration of the typical electrodes used in this period. Here he adds some history: 'Messrs, R. W. Fox and W. C. Henwood, in Cornwall about 1830, are reported to have been the first to investigate this method, while Carl Parus [sic] of the United States Geological Survey is reported to have employed it in 1882 at Comstock Lode'.[11]

The fifth method is called '*The Surface Potential Method*', a term not familiar to me. It is better known as the 'equipotential method' consisting of establishing an electrical field between ground contact electrodes and mapping distortions in the electric field due to anomalous conductivity. Andrews refers later in this section to the 'distortion of the **equipotential curves**'. Mason (1927) used this term 'surface potential' to involve the injection of current and observing 'the nature of the current distribution at the surface'. In his 3-page paper on electrical prospecting which I retrieved, Andrews describes, at some length, this 'equipotential' method using input electrodes and 'a telephone' to determine the null point between two search electrodes. He starts the paper with: 'The literature of prospecting for ore bodies by electrical methods is becoming quite voluminous, dating from 1907 onwards'.[12] As examples of its applicability he quotes at length from the 1922 Year Book No.16 of the Geological Survey of Sweden. This was all known to Andrews before he wrote his 1927 report.

First, Andrews briefly describes what he calls the 'Schlumberger method' whereby, 'current may be sent into the earth at two points by means of metal spikes or electrodes', but this is all he says specifically of this method here. Later in the section on Patents it is then referred to as the 'Schlumberger Process'. Mason (1927) also only says that 'Professor Schlumberger made creditable contributions to the study of artificial current distribution at the surface as influenced by ores'.

Andrews then describes the 'Lundberg method' where 'the current is passed into a great loop or coil, from which metal spikes or electrodes carry the current into the earth. In this method an area may be marked out, say 3,000 feet by 2,500 feet…occupied by two wires or extended electrodes, grounded at intervals'. (These are more or less exactly the words Mason (1927) used to describe the method he attributes to 'Hans Lundberg'.) Andrews continues with 'The occurrence of a definite conductor within the area examined is detected readily by the…points of minimum sound as detected in the head telephones used by the operators'. While he doesn't mention how the current is generated, later in the section on Prices to do with the Surface Potential method he refers to 'apparatus for production of **kilowattage**' [sic]. Krahmann (1926) in his paper, a copy of which was owned by Andrews, describes these two methods as 'the "Iso-Potential" method' and using 'a sensitive voltmeter connected between two searcher sondes' (electrodes).

After listing six conductive minerals and 11 poor or non-conductive ones, Andrews reintroduces the indispensability of the geologist to 'make a commercial interpretation of the **physicist's** observations' and to distinguish the worthless responses from an ore deposit, 'because the **geophysicist has not the wherewithal** to distinguish the conductive characteristics of these various occurrences'.[13] The indispensability of the geologist mentioned here for the fourth time, is also given prominence in the final conclusions. These

[9]Other illustrations of equipment and practice at this time are in Rayner (2007).

[10]Many such examples of the unsuitability of the method for ore-bodies are given in Barton (1928) which are heavily marked up in Andrews' copy.

[11]'Parus' is certainly a misspelling of Barus as Mason (1927) has it correctly as C. Barus who, as I know, published a paper 'On the electrical activity of ore bodies', (Barus 1882).

[12]The second sentence (from indistinct old typing copy) gives some famous names: 'The name of Professor C. Schlumberger Chief Inspector of Mines for France, Mr. G. Bergstron , Geological Survey, Sweden, H. Lundberg, H. Nathorst, and S. F. Kelly United States, are prominent in this connection'.

[13]Andrews uses 'physicists' interchangeably with 'geophysicists' and if there was any distinction in his mind, the physicist is usually mentioned in connection with the use of equipment and its operation and the 'geophysicist' more with interpretation of the observations. Sometimes Andrews recognised mathematics as being involved together with physics.

mentions are always accompanied by even more references to the inabilities of the geophysicist. So far he is not making a good case to recommend the inclusion of geophysics in the search for ore-bodies. Yet, he then refers to the ability of this method 'to detect the dip and strike of sediments underlying alluvium….and to locate faults', that is, structure as well as ore-bodies. And, 'Herein, there lies a great future for suballuvial and **submarine** geological surveying'. This is the only mention made of marine operations and it is not expanded on. However, he is now making a very important observation of 'the possibilities of **geological surveying by geophysical** methods when the various methods are employed together'.

It is intriguing that Andrews made no reference to the 'Resistivity method', where, by measuring the strength of the current as well as the potential difference, the physical property of conductivity is determined. Nowhere in the report is the term 'resistivity 'or indeed 'apparent resistivity' mentioned. Yet, this four-electrode method of resistivity prospecting was described as early as 1912 by Conrad Schlumberger (1915) and by Frank Wenner (1915), the latter being popular in the USA where Andrews might well have heard of it. There are cases of the use of the resistivity method before 1928 of which Andrews may have heard. For example, in 1925, Rooney and Gish (1927) carried out some resistivity depth soundings near Watheroo Observatory, W. A. Very soon after Andrews wrote his report, the resistivity method saw rapid growth and especially the theory and methods of interpretation (see Postscript).

The sixth method is '*The Induction Method*', the non-contact method using alternating electromagnetic fields. Andrews states that 'This method is "reported" to be the outcome of the early work of H. R. Conklin, and others…'. As Mason (1927) mentions H.R. Conklin as deserving 'credit, both for the early recognition of the possibilities of this method and for contributions toward its practical development', this is likely to be the 'report' Andrews refers to. To date I have not been able to find a reference for Conklin. Andrews attributes its use to 'Sundberg of the Swedish American Prospecting Company [as does Krahmann (1926)] and by the Physical Exploration Company'. As this method does rely on listening to specific frequencies of fields in headphones, Andrews strangely describes the frequency 'usually of 1,000 cycles per second with an acoustic effect somewhat resembling the whistle heard at times **at a peanut stand**' [?]. 'Higher frequencies giving sounds somewhat resembling **a sparrow chirp**'[14]. Figure 5 is an example of the receiving equipment for the Inductive method at the time.

The seventh method is '*The Magnetic Method*', in which Andrews states 'This method appears to give great promise indeed in geological surveys. One State geological survey, at least, in the United States, namely, Wisconsin, has

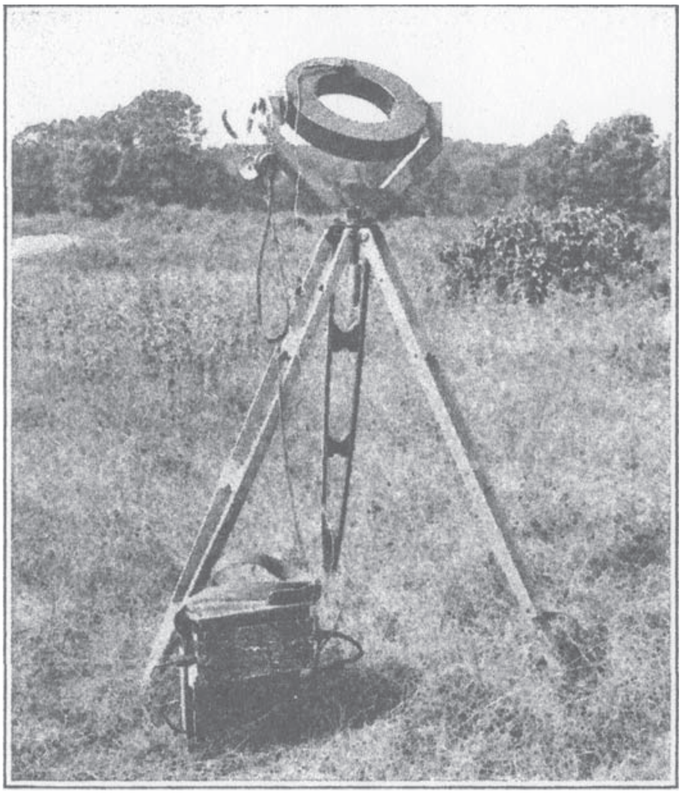

Fig. 5. *An example of the receiving equipment for the inductive method. (From Mason (1927), fig. 6).*

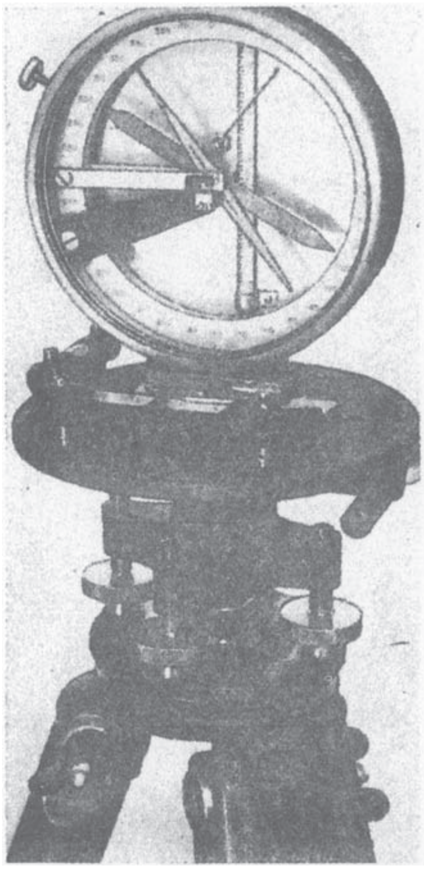

Fig. 6. *A Hotchkiss superdip. (From Heiland (1968), fig. 8–27).*

[14]In a similar way, Mason (1927) was not averse to anthropomorphising, claiming that 'If, then, the fundamental procedure is to shout down questions in the hope that an orebody will hear and answer back to us, it is clear that a large part of the expert's study must relate to the kind of questions best suited to the **temperament and intelligence of orebodies**'. [!] Also, 'In other cases…the ore is **too polite** to talk unless spoken to, and we therefore have to stimulate it with an individual field'. And, 'One must know in what language the ground will speak, how to distinguish the **Chinese of the surface soils from the Greek of the ore**'.

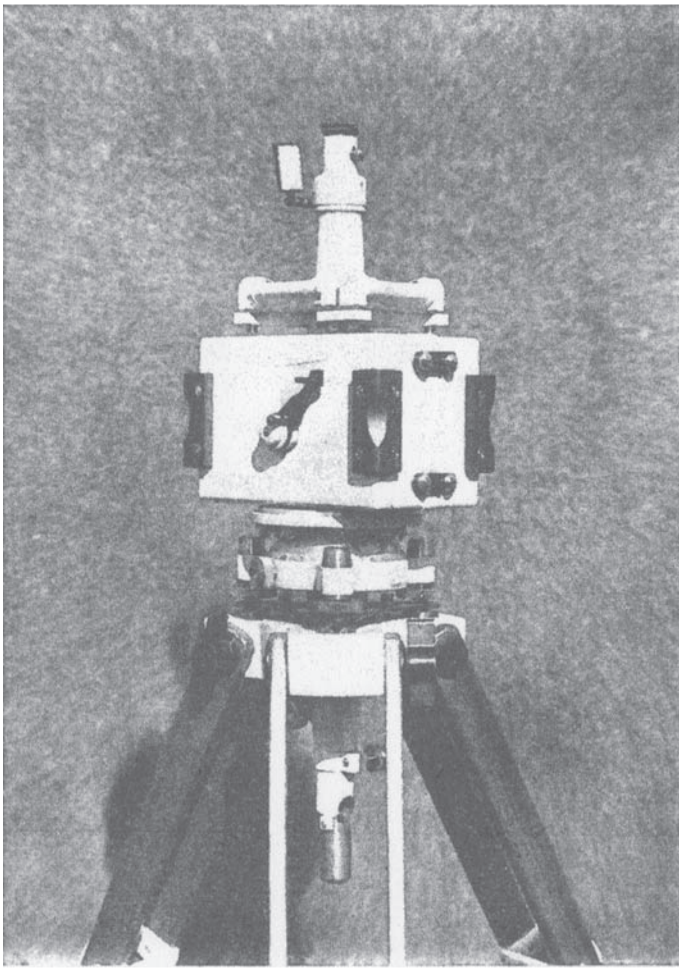

Fig. 7. *A Schmidt vertical balance magnetometer. (From Lewis and Blazey (1930), fig. 126).*

accomplished, and is accomplishing, splendid work by this method'. Only later, in Section 5, does Andrews reveal, 'In south-western Wisconsin, **which was visited by me**...'. He then describes three types of 'magnetic instruments' in use in the United States, namely, 'the Gurley Dip-Needle (with the Hotchkiss release), the Hotchkiss Needle and the Magnetometer. Of these the Gurley Needle is, by far, the simplest form, the Hotchkiss Needle being much more sensitive, but requiring much greater skill in its use'. Figure 6 is an illustration of the Hotchkiss superdip. 'The Magnetometer, of approved make, both of vertical and horizontal type, such as the **Askanie** [sic] balance made in Berlin, is extremely useful but very sensitive, and requires great skill and experience in the interpretation of the field observations'. As for 'Askanie', a misspelling he appears to have gained from Mason (1927), he is no doubt referring to Askania magnetometers, otherwise known at the time as 'Vertical and Horizontal Variometers' (Krahmann 1926 and Elbof 1927) or magnetic balances designed by Prof. Schmidt of Potsdam (the 'Schmidt Vertical Balance') in 1915 and manufactured by Askania Werke A.G. of Berlin. Figure 7 shows a typical Schmidt vertical balance.

Andrews has thus listed the three types in order of increasing complexity and skill required to use them. Apart from mentioning next the 'various magnetometers such as the Askanie [sic] and the Gepege' as needing 'Much greater care and skill…. with the employment of these delicate instruments.', he makes no further reference to magnetometers but rather more on dip-needles and their application to distinguishing various rock types, 'In skilled hands'. It would appear that he understands these better than magnetometers. Of course, dip needles had been in use as early as 1640 to map magnetite in Sweden (de Beer 2011). Andrews, later in Section 4 – Prices, refers to their poor sensitivity of 'about 5 x 10^{-2} Gausses' [sic] or 5,000 nT, whereas the sensitivity of the magnetometers 'is very great as it is down to down to 10^{-5} Gausses'. In fact, they had a sensitivity of about 10 nT and were in use for about 40 years. I have not previously known of the 'Gepege' magnetometer but once again, Andrews may be benefiting a little too much from his reading of Mason's 1927 paper who, in describing his Figure 2, illustration of 'Two types of portable magnetometers', states 'one is the Askanie [sic] balance, the other the Gepege', with no further mention of the Gepege. Later in Section 4, Andrews states; 'The Askanie and Gepege are in common use' and gives an address of where to obtain the Askanie but not the Gepege. In his section on the magnetic method, Mason (1927) states 'The pocket dip needle **of the geologist** has found increasing application in the rapid and cheap survey…', but 'where increased accuracy and sensitivity are desired, field instruments are now available which far surpass, in reliability, speed, and accuracy, those of a dozen years ago'. The more sensitive fluxgate magnetometer (0.2 nT) is yet to make itself known, at least to Andrews, having only been invented in Germany in 1928.

It is noted that Andrews did not include the *Radiometric method* in his list of methods. It was used at the time, but may be not much earlier and seemingly was not so well established. It is briefly described in Krahmann (1926), one year before his report. Krahmann gives only three references to the method, the earliest in 1910 and others in 1920 and 1921. The 'Elbof' booklet (Elbof 1927) owned by Andrews, also includes 'Radio-Activity Investigations' and gives one case study in Kahla, Germany.

Also, both Krahmann (1926) and 'Elbof' (1927) list another method which Andrews also doesn't mention, that of *Geothermics*. This method was very successful in South Africa in the early 1920s in predicting the temperature level in the deep mines of the Witwatersrand (de Beer 2011) and it is surprising if Andrews had not heard of it. Indeed, he made no mention at all of the growing use of geophysics in southern Africa in the early 1920s as reported by de Beer (2011).[15]

In Section 4, '*Prices of Apparatus*', Andrews comments on the costs of all the methods listed above and in some cases, gives more details on the equipment required. However, he prefaces this with 'Several of the processes are covered by patent, and for these the apparatus is prepared as it is needed by the companies interested'. He claims that the Sonic & Seismic, Self-Potential, Surface Potential, Inductive methods and the Hotchkiss needle were all patented, but not the Gravity and Magnetic methods. Here I was hoping to see at least a comparison of the prices for each method, even though they would be 1927 prices, but due

[15]Apart from geothermics, de Beer (2011) reports on 'a flurry of electrical prospecting activities' taking place from around 1925 largely to locate gold reefs, including by Conrad and Marcel Schlumberger and in the Zambian copper belt by Broughton-Edge (who later directed the IGES trials in Australia). Andrews was apparently unaware of this activity in Southern Africa otherwise he would surely have used it to support his recommendations.

to the patenting issue, Andrews gives prices for the 'Oertling Balance [a type of torsion balance], £900 in London'; 'Eötvös Balances £800 to £1,000 in U.S.A'; 'The Gurley needle with Hotchkiss release' – $25 (only, even then) from Gurley in New York, and the magnetometers: Askania type – $560 in Europe and about $900 in the USA.[16] To these prices, duty and transport costs would be added.

In this section 4, Andrews gives not only prices but some further detail on the type of instruments, their weights in some cases, some relative sensitivities in the case of magnetometers as we have discussed above, and also how they were used in the field. For some instruments, he gives detailed names and addresses from where they may be purchased. Here, he again mentions Dr Mouchketov, from Russia, who claimed to be perfecting a smaller, lighter and cheaper gravity balance than those from Hungary. Even more interesting I find, is reference to a Dr Fred Wright (most likely the 'F. Wright' of the CIW in Sect. 2) 'designing a tungsten wire, coiled in the form of two hollow cones which is designed to take the place in part at least of the gravity pendulums. In this method, however, the total pull of gravity is recorded whereas in [Balances], the variations alone in gravitational attraction are recorded'. Is this the beginning of the 'zero-length spring' invented by Lucien LaCoste in 1932 and of the gravity meter we now know was soon to replace the slow and laborious torsion balance?

Section 5, '*Costs of Geophysical Surveys*', commences with 'It is not customary to find surveys conducted with the use of one method only with exception of magnetic surveys such as those carried out by the Wisconsin Geological Survey', whereupon he gives some examples of combined methods. Not much of the rest of this section is of lasting historical interest as Andrews outlines courses and training sessions available from the companies and institutes active at the time as mentioned in Section 2. This section is divided into three sub-sections, the first being 'Wisconsin Magnetic Survey (Gurley needle)'. Even in those days, students were being used (exploited?) by their universities, such as the reported case of a 'raw student' in Wisconsin 'For the first month he receives **no pay** but transportation and subsistence costs are found'. The second sub-section entitled 'Gravimetric, Sonic and Seismic Surveys', referring to salt domes, is where he states: 'General costs will be supplied later **after the Oklahoma and Texas areas have been examined**' (by Andrews or whom?). The third sub-section is entitled 'Costs by the Schlumberger, the Swedish-American Prospecting and the Physical Exploration Companies', and he first examines the costs of the 'Schlumberger process', by supposing an area like Broken Hill with the nature of the area supplied by Andrews and costs prepared by E. G. Leonardon of the Schlumberger Co. of New York. A list of individual costs is provided including the 'Trip return **from New York** for one or two observers'! Travel was presumably by ship. No other useful comparisons of costs are given in the rest of this section.

Section 6, '*Patents Covering the Methods*', gives some of the patents current at the time. The only ones applying to Australia are, the 'Schlumberger process' patented in Australia in June 1913 (#9,378) and May 1914 (#13,132) and patents that Andrews attributes to 'The Swedish-American Process – The Lundberg Process and the Sundberg Process', and those covering Australia, with no dates, are #11,438 and #10,535. Day (1966) states these last two patents were taken out in 1913 by the 'Electrical Prospecting Company of Sweden (ABEM)'. Once again, Andrews says that information on patents for the 'Sonic and Seismic' methods will be obtained 'after a visit to Oklahoma and Texas'. He does not say by whom and when.

In Section 7, '*Application to Australian Conditions*', Andrews considers the application of geophysical methods to Australian conditions but not before another cautionary first sentence: 'Geophysical methods as applied to prospecting for ore deposits…only during quite recent times that they may be said to have conquered many of the initial difficulties'. He then examines two broad categories, first, 'Oil, Gas and Coal' and second, 'Other Minerals'. For oil he nominates 'The Greater Roma District' where he suggests applying every method he described previously, and 'the Tertiary rocks and sediments of southern Victoria and South Australia…' [where] 'there have been many assertions that these areas are oil bearing'. Thus Andrews was not only thinking of New South Wales. His suggestion of the potential of the Roma district certainly proved to be very prescient. As for coal, 'The coal measures of the Hunter River Basins appear well adapted to the….self-potential, surface-potential, inductive, and magnetic processes'. The 'magnetic processes' are presumably included for the interbedded 'lava flows'.

In 'Other Minerals' Andrews nominates, not surprisingly, the 'Broken Hill District' for '…various modified forms [?] of the electric and magnetic methods…'. Exactly what these modifications are, he does not say. He reveals here that electric methods would be appropriate as 'galena, the principal lode mineral, is a good electrical conductor'. Other areas nominated are 'The Greater Cobar District' (again no surprise here), 'The Lake George District' (could he be thinking of Woodlawn?), 'The west coast of Tasmania' (outside NSW again and once again, showing good foresight) and 'the Great Artesian Basin' generally. Interestingly, he confesses that 'The question of prospecting for **the gutters of deep leads** is occupying my attention' (this will be referred to by me again below) but, 'Much depends on the amount of conductive material (pebbles) occupying the gutter and the **relative** conductivities of these as compared with those of the (usually) hard bed rock'. Here he recognises the necessity for a difference in physical properties. He concludes this section with '…the several areas mentioned above will serve to illustrate **the advisability of securing geophysical methods in New South Wales and Australia at an early date as an aid to geological survey and to mining generally**'. Now (one might say, 'at last') he has made his case for geophysical methods to be adopted generally.

More specific recommendations and how Andrews thinks they should happen are given in the final section, '*Conclusions and Recommendations*'. However, he begins this section by once again reverting to the very first sentence of his report '…there is no royal road to prospecting, or to surveying**,** by geophysical methods', except that this time he has added 'surveying' as he now recognises the possibility of using geophysics for geological surveying as well as for direct search. It is as if he is understanding more as he writes his report. And yet again, for one final time, '…it is coming to be seen more and more how **indispensable are the geologist's services in the *interpretation* of the geophysical notes**…'. More importantly, the next sentence is; 'This class of work is taught in various

[16]Andrews makes no further mention of the Oertling Balance of which one was used by the IGES and is now on display in the National Museum of Australia. Read more on this in Rayner (2007). Also, Andrews may have mixed pounds and dollar symbols wrongly here.

colleges in Europe, and…has already been commenced in the United States, as at Golden, Colorado', thus recognising that courses at universities are required. The next short sentence, on its own, is 'It appears advisable also to introduce **it** into New South Wales and into Australia generally'. One presumes that the vague word 'it' is referring to the 'work' [of geophysical prospecting] but is he also including in his recommendation the teaching of it in universities in Australia? I feel that he knew it would be necessary here too. This aspect of the recommendation has not been suggested before by Day (1966) or others. There is support for this possible additional recommendation later on in his closing sentences where he once again mentions 'University geologists'.

Andrews then splits his specific suggestions for further action into two cases, 'New South Wales alone' and 'Australia Generally'. For New South Wales, 'In this case it would appear advisable to send a man of promise **and address** [?] to the United States at least, where so many leaders in geophysical methods are assembled, to learn the various processes, especially the gravimetric and the magnetic, and to visit various areas in which the several methods have been found to be especially applicable'. Has Andrews favoured gravity and magnetics perhaps because he has said before that these two methods are taught at 'Colorado Mining College at Golden'? Has he not specified any other methods, such as the inductive method because he didn't know of their being taught in the USA? Judging from his own 1925 paper on 'Electrical Prospecting' he may feel he knew this method well enough; also the self potential method is simple and he didn't have confidence in the seismic method for ore-body detection.

In the second case of 'Australia Generally', '…it appears advisable, as a preliminary, to obtain a report from some accredited person or persons as to the nature of the methods and progress made therein generally in the United States and in Europe.' Andrews doesn't say who might provide this report but he says that 'The Director of the Bureau of Mines in the U.S.A.' has been preparing one to which he has not had access. And then; 'This report…could be presented to a conference of Federal, State and University geologists, together with representatives of the **Federal Council of Science and Industry**'. First, note that Universities are included and not just Surveys. Also, the Council he refers to was the precursor of the CSIRO, only just formed in 1926.

Day (1966) claims 'Andrews' report…[contributed] to an approach by the Australian government to the Empire Marketing Board in 1927 concerning geophysical surveys'. A subsequent proposal that an extensive trial of the principal methods take place led to the formation of '**The Imperial Geophysical Experimental Survey' (IGES)**, in 1928. This is another exciting story well documented by Day (1966) and entertainingly described by Rayner (2007).

It is perhaps no coincidence that only two years after Andrews' recommendations were published, the first geophysicist was appointed to the NSW Dept. of Mines. This was J. M. Rayner, whom Day (1966) states was 'the sole geophysicist in permanent government service in Australia at the time'. Rayner was seconded to the scientific staff of the IGES in 1929.[17] With regard to my inference that Andrews was also recognising the need to have courses in exploration geophysics in universities, according to Day (1966), 'a University undergraduate geophysics course was not established until 1950' when Sydney University appointed as lecturer Dr H. I. S. Thirlaway, a graduate of Cambridge, to 'develop teaching and research in geophysics, both fundamental and applied'.

[17]Interestingly, the first report of many that Rayner was to publish (Rayner 1931) was on magnetic surveys over basalt-covered deep leads at Gulgong, the very 'gutters' that were occupying Andrews' attention as he stated in his report. A lot of interesting information about Jack Rayner is given in Rayner (2007).

Postscript

Just at the time Andrews was writing his report in 1927, radical new developments in geophysical instrumentation were beginning to appear and many of the methods he described were to become out-dated just a few years later. His 'magnetometers' or Variometers were soon replaced by the more sensitive fluxgate magnetometers, gravity meters of the type we use today were in routine use in 1929 and the torsion balance was no longer competitive by the mid-1930s (Clark 1999), the surface potential method was even at the time being replaced by the resistivity method (for example, Schlumberger (1915) and Wenner (1915)) and induction methods were to blossom into many variants and improve with better electronics (no more headphones!). The theory and interpretation of methods was also developing rapidly from the early 1930s. For example, from my own research in electrical methods, Tagg (1930) as one of his many papers over 30+ years, published on theoretical considerations of the resistivity method, Roman (1931), in one of many papers over 30 years, published on the computation of tables for determining the resistivity of layers, Kelly (1932) published on a uniform expression for resistivity, and Slichter (1933) on interpretation. Many other papers followed throughout the 1930s.

Historical context

It is interesting to consider the historical context of Andrews living in Sydney in 1927. One major change to life-style just beginning at the time was the growth of aviation which was then in its infancy. In 1919, the Smith brothers, Ross and Keith, had flown from London to Darwin in just under 28 days. Soon after, the continent was traversed by air from north to south and from east to west. In 1927, Charles Kingsford Smith and Charles Ulm circumnavigated Australia in what was then, only 10 days, before becoming the first team to cross the Pacific from San Francisco to Brisbane in May 1928.

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