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The level of knowledge about exploration geophysical methods in Australia prior to the Imperial Geophysical Experimental Survey (IGES), 1928–30. Part 2

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Introduction

In Part 1, published in *Preview*, **189**, pp. 42–49, nine sources of knowledge about exploration geophysics in Australia before the IGES were identified and examined individually and generally. In Part 2 details about the knowledge of the particular methods revealed by the sources are discussed. As in Part 1, descriptions of instrumentation are not included as the instruments, in any case, are mostly obsolete.

Sources available before IGES

The nine sources available to the author, which describe exploration geophysical methods available in Australia before 1929, are, in chronological order and abbreviated form:

[1] Andrews, March 1925.*
[2] *Western Argus* newspaper, December 1925.
[3] Krahmann, 1926 *(Andrews' copy dated '1928').
[4] Elbof Geophysical Co Ltd, 1927 *(Andrews' copy not dated).
[5] Sub-Committee (for Geophysical Surveying) of the Committee of Civil Research, November 1927 *(Andrews' initials on cover).
[6] Gepp et al., June 1927.
[7] Mason, December 1927 *(Andrews' copy dated 21 05 28).
[8] Barton, February 1928 *(Andrews' copy dated 21 05 28).
[9] Andrews, 1928.*

*Denotes copies originally held by E. C. Andrews and now retained by the author.

The content of these sources is considered by individual geophysical method.

Methods

Magnetic method

The magnetic method was not discussed in Andrews (1925), the *Western Argus* (1925) or Barton (1928). The Sub-Committee (for Geophysical Surveying) of the Committee of Civil Research (1927), hereafter referred to as the "Sub-Committee", states that the magnetic method was an exception to the belief that "employment of geophysical methods is comparatively recent" because it was used in *"the middle of the 19th century in searching for deposits of iron ore"*, particularly in Sweden. After initially being used only on magnetic ores, "Magnetic methods …are now applicable to the differentiation of igneous and sedimentary rocks and to the survey of salt deposits".

Krahmann's (1926), chapter on magnetic intensity commences with "Magnetic investigations were first carried out in Skandinavia [sic] on the enormous magnetite deposits found there…", unfortunately with no dates. He goes on to say, "Only recently, in the last year or two [i.e., 1924 or 5]…theoretical principles have been much improved". Four examples of case studies, in Germany, with intensity contour plots ("isodynamic lines") are shown, one acquired in 1922 and interpreted by C. A. Heiland[1]. One of the examples given in Krahmann, 1926 (Figure 1) shows "pronounced magnetic anomalies in the Tertiary sedimentary and basaltic area". Three of Krahmann's (1926) examples are also used by the Sub-Committee (1927), and two by Gepp et al. (1927).

In the chapter on "Magnetic Surveys" in Elbof Geophysical Co Ltd (1927), hereafter referred to as Elbof (1927), magnetic susceptibilities are listed and then five German examples are given (all different from those of Krahmann, 1926); three on iron ore deposits, one on a salt ridge indicated by a magnetic low, and another to map the depth and thickness of oil bearing chalk. Gepp et al. (1927) has four pages, on "Magnetic" (sic). The techniques and equipment are referenced to Heiland (1926) and also to Krahmann (1926), the latter suggesting that Gepp et al. (1927) may have seen a copy of Krahmann (1926).

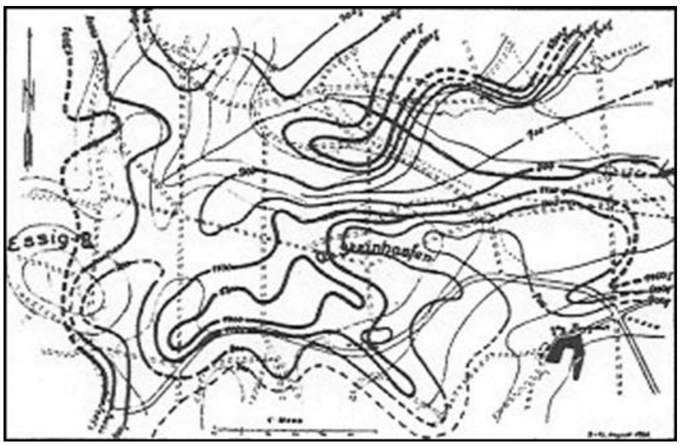

Figure 1. *"Isodynamic lines" of vertical magnetic intensity over basalt near Cassel, Germany, surveyed by Krahmann in 1925 (from Krahmann, 1926, Fig. 31).*

[1]Heiland, who was later to become Professor of Geophysics at Colorado School of Mines, authored many papers and a seminal textbook; *Geophysical Exploration* (Heiland, 1940).

The Sub-Committee (1927) further states "Magnetics are also used *in combination* with gravity as it takes ….less than one-tenth of the time required… of the latter". Also, magnetics are being used "in combination with the gravimetric method by the leading Oil Companies" and in combination with electrical methods "in the Southern Lapland mining districts". A general conclusion is that the magnetic method is quick and well able to complement the results of other methods.

Only one small magnetic survey was conducted in Australia before the IGES; see Part 1.

Gravity method

This method was not applied in Australia before the IGES. It was discussed by all sources except Andrews (1925) and the *Western Argus* (1925).

While the Eötvös torsion balance was first tested in the field in 1891 (Szabo, 1998), it was not used for prospecting until some years later. Broughton Edge and Laby (1931, p. 136) offer an example of what may be one of the *earliest applied geophysics uses* as, "Schweydar, in 1917, carried out the first torsion balance survey in Germany over a salt dome…". It is noted by the Sub-Committee (1927), somewhat pointedly, that "the original idea" of the torsion balance is based on "experiments … by the English physicist, Cavendish" in 1797.

Krahmann (1926) concludes that the torsion balance instrument "*is at once, the most difficult, the slowest and the most sensitive of all geophysical instruments*". "The most important limitation…is the necessity of flat, or at least almost level country". Krahmann (1926) notes that the "mathematical elimination" of high ground that disturbs results "can of course only be carried out very approximately". Mason (1927) claims, however, that "the effect of near-by surface irregularities [is] computed and corrections made therefore". Andrews (1928) claims that correction for topography "requires a considerable knowledge of mathematical principles".

Regarding interpretation, the Sub-Committee (1927) claim that "the approximate thickness and the depth of the deposit can be calculated", although "cumbrous". "Recent theoretical developments have however, tended to facilitate the interpretation…and it is now claimed…*it is possible to calculate the effect to be expected from any known body of whatever form"*[2]. Gepp et al. (1927) in their section on "Gravitometric" (sic) quote entirely from other sources (in particular, Shaw and Lancaster-Jones, 1925) and add nothing to the more interpretational aspects described above. Mason (1927) has concerns for the method's use in *mining environments* where topography and structural complexity will be prominent, thus, "… the success of the Eötvös balance in such districts as the oil fields of Texas cannot be duplicated in most mining regions". This caution is repeated by Andrews (1928).

Regarding petroleum exploration, Krahmann (1926) acknowledges, "especially good results have been obtained … [on] salt domes in the northern states of America, also large faults in Mexico…such as are of importance in connection with oil deposits". The Sub-Committee (1927) also refer to the use of the torsion balance method in Texas, USA, where in 1925 alone, five new salt domes likely to be associated with oil deposits were found. Only six were discovered without the use of geophysical methods in the previous 20 years.

Generally, the Sub-Committee (1927) state; "The instrument has not hitherto, however, been used in considerable numbers by *British concerns*". One instance, at an iron-ore mine in Cumberland in 1925, was described with satisfactory results. Also, they report that the method was used in Northern Sweden to determine if the electrical indications were due to ores or graphitic slates (by their different densities).

The most recent and authoritative source for this method is Barton (1928), the subject being the Eötvös torsion balance only. There was no indication from any of the other sources, apart from E C Andrews, who held a copy, that they had read this paper. Barton (1928) quotes numerous examples of its use in the USA, including over salt domes in Texas, on faults and a granite ridge, and he proposes its use in *mapping geology*. The gradients over the Nash Dome, discovered in 1924 and generally quoted as *the first discovery of an oilfield by any geophysical method,* are illustrated in Figure 2. The use of the torsion balance in mining is dealt with in only five short sentences, including: that the "Colorado School of Mines and the U S Bureau of Mines are cooperating in some experiments … in mining problems in Colorado".

Unfortunately the torsion balance had a limited future. The early 1930s saw the rise of the spring gravity meters, which were a lot easier to use.

Electrical methods

These methods, of one type or another, were referred to by all sources except Barton (1928), whose only subject was gravity. The report in the *Western Argus* (1925) epitomises the commonly expressed belief in the value of the electrical methods: "In prospecting for ore bodies, the methods…have

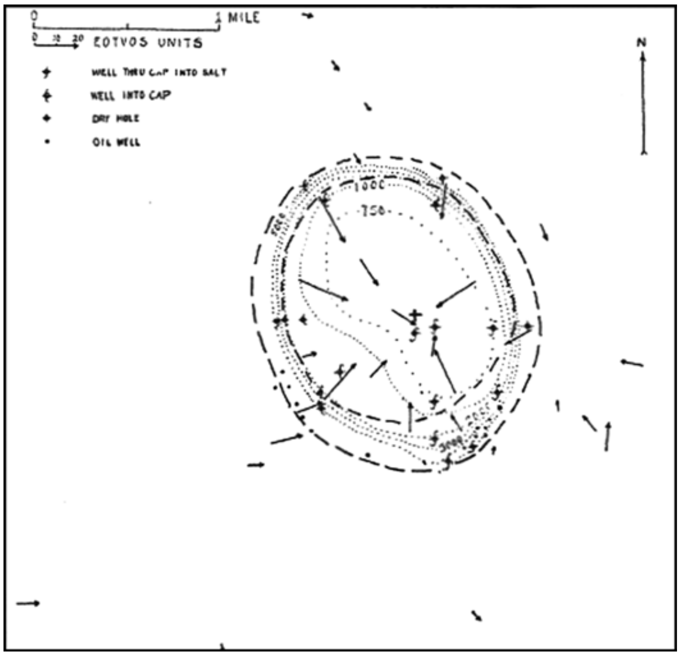

Figure 2. *Eötvös gravity gradients (the arrows representing intensity and direction) over the Nash Dome, Gulf Coast, Texas. The dashed lines show the interpreted limits of the dome at two depth levels, the outer at 4–5000 feet deep (from Barton, 1928, Figure 9).*

[2]No support is given to this bold statement by references, but they could be referring to such work of Shaw and Lancaster-Jones (1922) and (1925); two Englishmen based at the Science Museum, London.

proved most successful". They have also "been subject to the most energetic …work, especially in Sweden".

The electrical methods described by the sources were the 'Equipotential method' (with contact or non-contact receivers) available since the early 1900s, the 'Inductive method' (with or without a grounded source) since 1921, and the 'Self-Potential' method practiced as early as 1830. The 'resistivity sounding method' was mentioned only by Elbof (1927). See more on this below.

(a) Equipotential method

All sources, except Barton (1928), described the use of the equipotential method. Current passed into the ground through point sources develops a field of which the equipotential lines can be mapped using 'search' electrodes or coils. Figure 2 in Part 1 illustrates the basis of this method. Distortions in the normal pattern are attributed to the presence of anomalous conductivity.

Andrews (1925) in his informal paper titled "Electrical Prospecting" only described the equipotential method and with AC current, "preferred by most experimenters" (although "Schlumberger was inclined to favour the application of direct current"), point source current electrodes and two "search" electrodes with an intervening "telephone". Later, Andrews (1928) called this method the "Surface Potential Method" (as did Mason, 1927) with two variations, 'the Schlumberger method', with point sources, and the 'Lundberg method' when line sources are used. Figure 3 is a schematic of the method's use with line electrodes and illustrates how equipotentials may be disturbed by anomalous conductivity. Andrews (1928) also noted the potential of this method to *map structure.*

As an example of "the striking results which may be obtained by means of electrical prospecting", Andrews (1925) refers to "the discovery of the Kristine Berg [sic] Ore Deposits in Northern Sweden" and references Yearbook No. 16, 1922 of the Geological Survey of Sweden (without any author(s)). Krahmann (1926) also refers to this same Yearbook with the reference as "Lundberg-Nathorst" (1922). Gepp et al. (1927) also refer to the Kristineberg deposit and their figure 9 illustrates a particularly good result of the use of the method in this field.

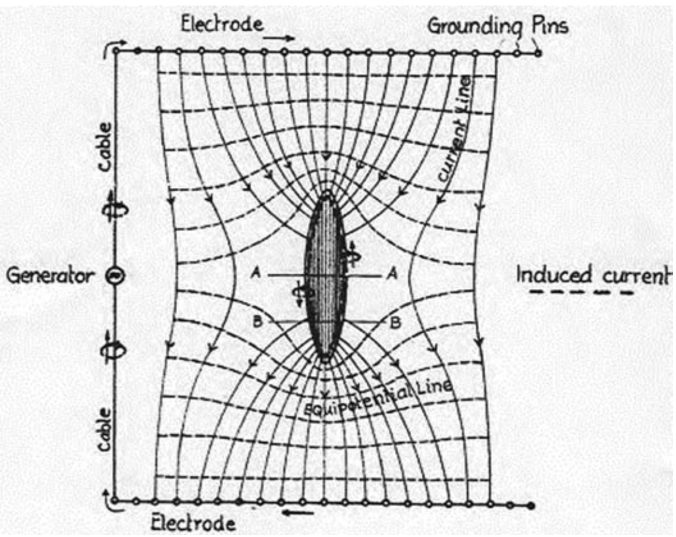

Figure 3. *The distortion of the equipotential field by anomalous conductivity when using line (Lundberg type) source electrodes (from Lundberg, 1929, Figure 3a).*

Another variant of the equipotential method is that which Krahmann (1926) calls the 'Elbof' technique using grounded AC current input, and non-contact, 'search coil' receivers. Figure 4 shows the Elbof type of receiver apparatus. He believed the Swedish methods, of using contact receiver 'sondes', limited their ground penetration and therefore rendered them not so useful for oil exploration, which is "the main field of utility of the 'Elbof' method". Following a detailed description of all elements of the method, Krahmann (1926) gives four case studies acquired by Elbof Geophysical Co., including one at a copper mine in California, USA, surveyed in 1924. Elbof (1927) provides six

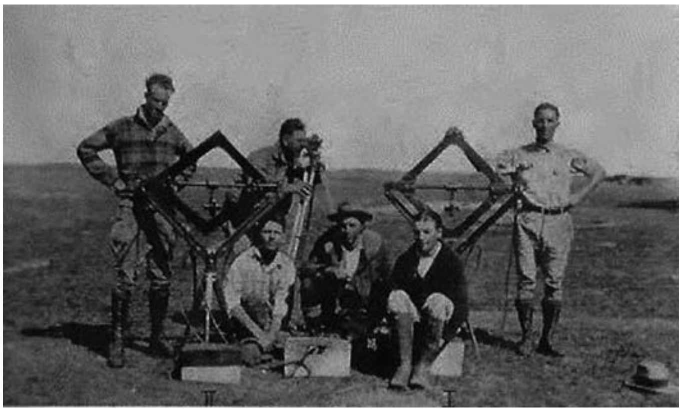

Figure 4. *The non-contact receiving apparatus used by Elbof (from Elbof, 1927, p. 9).*

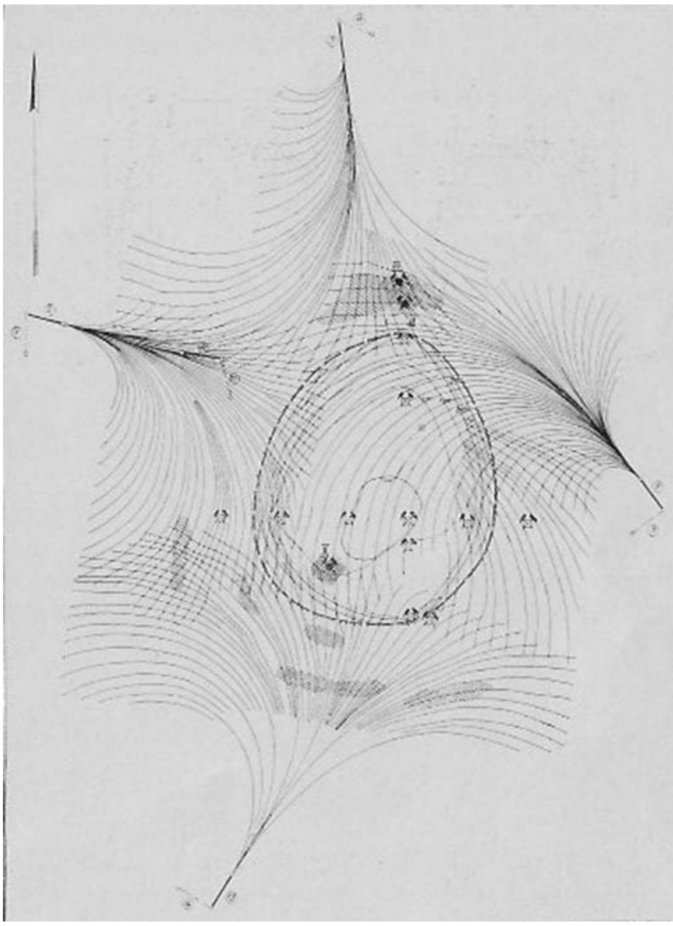

Figure 5. *The "Elbof"-type equipotential method showing four of the 14 current dipoles used over a salt dome in U.S. A. (outlined) with areas of divergence 'hachured' (from Elbof, 1927 p. 15).*

case histories illustrating the use of the Elbof style equipotential method with good diagrams, including diagrams of metalliferous deposits in Quebec, Canada and Germany and oil and gas deposits in Texas and Germany. Figure 5 shows deviations over a salt dome (outlined) in the USA resulting from fourteen separate current dipoles (only four are shown for clarity.)

As well as the distortions in the equipotential fields giving the size, shape and strike of the target body or bodies, for Elbof (1927), the depth to sub-horizontal bodies is separately given "by the 'sounding method' originated by Schlumberger". This is the one exception in all the sources where depth sounding is mentioned, and in this case using the Schlumberger array.

Eblof (1927) also refers to employing "particular apparatus" for work underground. Mason (1927) refers to surveying underground as an application for methods in general.

The equipotential method was used by the IGES, but soon after that its value was superseded by the resistivity method's ability to obtain more quantitative conductivity and depth information.

(b) Electromagnetic method

This method is described in all sources except Andrews (1925) and Barton (1928).

The *Western Argus* (1925) acknowledges the source of their information on the electromagnetic method as a paper by Hans Lunberg (sic), (possibly Lundberg and Nathorst, 1922) and report that "the main development occurred in 1921 when Karl Sundberg, a Swedish mining engineer, began to experiment with a number of their methods". They had been used "with good results since 1922 in prospecting in Sweden and Norway" and in particular, in the "Skelleftea district" of Sweden[3].

Krahmann (1926) at the end of his chapter on the electromagnetic method, states "Finally a new electro-magnetic method, the 'Sundberg' method from Sweden has recently appeared…. replacing the Lundberg-Nathorst method". He indicates that it uses induced transmission by insulated cable and an induction coil receiver.

Mason (1927) also describes a truly electromagnetic method distinguished by non-contact loop transmitters using AC, and the measurement of the secondary magnetic field using coil receivers. He credits H R Conklin with its development[4]. Andrews (1928) has "The Inductive Method" as a separate section with a similar description to Mason (1927), employing a vertical "triangular" source coil (several meters high) and an "induction coil" receiver.

(c) Self-potential method

This method is described in Krahmann (1926), Gepp et al. (1927), Mason (1927) and Andrews (1928).

Figure 4 in Part 1 illustrates the principle of this method; that of observing natural potentials due to some oxidizing ore bodies. This method is generally reported as being first demonstrated by R W Fox in 1830 in mines in Cornwall (Fox, 1830). Morrison (2004) includes one of Fox's many results. In 1882, Carl Barus, a physicist with the U.S. Geological Survey, greatly improved the viability of the method using non-polarising electrodes.

Krahmann (1926) deals briefly with "electric self-potentials" and expresses reservations about their use in prospecting, rather than their use "concerning the origin of ore-deposits". He gives Kelly, 1922 as one of his references. Gepp et al. (1927) call this method, strangely, "the Schlumberger method" and rely for its description on a long extract "from a paper by Sherwin H. [should be 'F'] Kelly…" and references Kelly, 1926[5]. Mason (1927) describes the self-potential method as expounded by "Mr Kelly", shows the result over a nickel body at Sudbury, and compares it favourably with results obtained earlier by S F Kelly on the same target (Kelly, 1922). He also states, "The best early work …was done by Carl Barus in 1822 at the Comstock Lode". Ninety years after Fox worked underground, directly on ore, Kelly was the main exponent of the practical surface method.

Capacitive coupling

The *Western Argus*, 1925, no doubt from Lundberg as its source, describes three different ways of causing current to flow, namely; inductively, galvanically and capacitively. Gepp et al., 1927 also mention capacitive coupling, in this case, via a "wire antennae suspended over and insulated from the ground".

It is intriguing to see capacitive coupling referred to as early as 1925, as there is no reference to its use at that time by Lundberg, or others. The author's earliest knowledge of capacitive coupling being employed is in Russia in 1978 (see Timofeev et al., 1994).

(d) Resistivity method

As we see from a) above, the only source to mention the resistivity method was Elbof (1927) to obtain the additional dimension of the depth to a body revealed by an equipotential field. Not even Mason (1927), the most advanced source in other ways, referred to it and consequently neither did Andrews (1928), who followed Mason (1927) closely. However, we know from Part 1 that Rooney and Gish (1927) carried out resistivity surveys in Western Australia from 1923. Henderson (2013, p. 43) reminds us that the four-electrode method to obtain resistivity was developed even earlier by Frank Wenner in 1915.

It would seem that a big leap was made from the scant knowledge of this method in the sources to that of the IGES Report (Broughton Edge and Laby, 1931), which devotes a special section to the "Resistivity Methods", separate from other electrical methods[6].

In summary, all these electrical methods were being used in Europe and the USA before the IGES (in the case of self-potential from 1830 and electromagnetic methods from 1917).

[3]The famous Boliden mine, described in detail by Gepp et al. (1927) is in this Skelleftea district and Kristineberg (as named by Andrews, 1925 and Gepp et al., 1927) is also close by.

[4]Conklin was with the U S Bureau of Standards at the time. Actually, Van Nostrand and Cook (1966) claim that Conklin developed the method from 1917 and that Sundberg's method from 1922, was based on Conklin's work.

[5]This naming of it as the Schlumberger method may relate to the Mason (1927) statement, "About 1913 Prof. C. Schlumberger, of Paris, revived interest in the self-potential work …which contributed much to the knowledge of this method".

[6]The technique to measure resistivity by Gish and Rooney, based on the four-electrode method after Wenner, with improvements, became well known as the "Gish – Rooney" method.

They were not being used in Australia, except for the use in Western Australia of the resistivity method by Americans, Rooney and Gish (1927) and an equipotential survey at Broken Hill in 1927 (Day, 1966–1967).

Acoustic methods

Krahmann (1926), the Sub-Committee (1927), Mason (1927) and Andrews (1928) only very briefly referred to acoustic methods. Gepp et al. (1927) dealt more extensively with these methods, thought to have a poor future by the others.

Mason (1927), for the purposes of geophysics, defines acoustic methods as "broadly speaking the study of echoes reflected by orebodies (sic) from incident sound waves". Note his bias to hard-rock applications. The media for such waves can be air, water or earth, and they are in the audible range.

Krahmann (1926), in a one-page chapter on 'Seismic' methods in general, appears unenthusiastic about acoustic waves "…work has been proceeding… but the results do not appear to have reached beyond the experimental stage. Further, "…there is no information published or otherwise available, concerning any practical results achieved by the method".

Gepp et al. (1927) in a short chapter on 'Sound Vibration', where they make no distinction between 'acoustic' and 'seismic' methods, describe as one of "two important methods"; the "Fessenden Method"[7]. This method consists of generating sound waves in water using oscillators and microphones and relies on "putting down shafts" to detect anomalous transmissions between four shafts filled with water. Figure 6 is Figure 1 from Gepp et al. (1927) and illustrates the method[8]. Gepp et al. reference Heiland (1926) for this method and give no indication

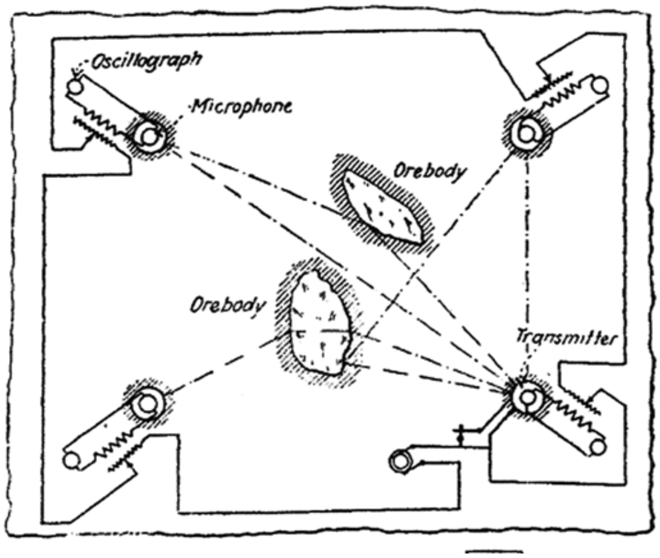

Figure 6. *A plan view of the Fessenden acoustic method showing the four shafts, oscillators, microphones and oscillographs used (from Gepp et al., 1927, Figure 1).*

[7]One of the SEG Awards is the Reginald Fessenden Award; "for a specific technical contribution to exploration geophysics" and it has so far been awarded to two ASEG Members, Derecke Palmer in 1995 and Keeva Vozoff in 2009.
[8]This diagram is from Figure 1 of Fessenden's 1917, USA patent #1,240,328 (Lawyer et al., 2001).

of its use. The method may have been too hard to arrange and little use was made of it subsequently. Mason (1927) states, "The acoustic method…early proved rather disappointing". This method was referred to by the IGES report (Broughton Edge and Laby, 1931, pg. 195) in only one sentence "Fessenden attempted practical exploration in America in 1913, … he used the sonic sounder and a sonic receiver".

The Sub-Committee (1927) make the surprising statement; "Sonic sounding" or "echo" methods…..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". The author is not aware of any such experiments. Nor is it clear whether the Sub-Committee is referring to the Fessenden method that Gepp et al. (1927) highlighted.

The acoustic method was not used by IGES, and the author does not believe that it has been used in Australia subsequent to the IGES.

Seismic method

This method was referred to by Krahmann (1926), the Sub-Committee (1927), Gepp et al. (1927), Mason (1927) and Andrews (1928). As simplified by Gepp et al. (1927), this method generates "artificial earthquakes" detected by "a very sensitive seismometer".

Krahmann (1926), in one page on the seismic method, notes the physical basis which "has led Dr Mintrop of the firm 'Seismos' of Hannover to a practical method of investigation".

Seismos G. m. b. H. of Hannover was the company of Dr Mintrop, a pioneer of seismic prospecting who, according to Lawyer et al., (2001), "filed in 1919, for a German patent entitled, "Method for Determination of Rock Structures'. He … set up….Seismos Limited in 1921". According to Barton (1929), Mintrop started experimenting with early seismographs during WWI. "By 1921, he had demonstrated the potential of the method…" and "In …1923 Mintrop's method was introduced in Mexico by the Royal Dutch Shell". Also, "The discovery of several salt domes late in 1924 by a troop (sic) of Mintrop's "Seismos" company… gave great impetus to the method".

Krahmann (1926) also discusses the use of 'distance-time curves' to determine "the thickness of covering layers" and the detection of concealed structures is explained; for which "there is already a substantial amount of research material for the calculation of these factors". The Sub-Committee (1927) conceded only that "….the thickness of the upper layer can be determined as well as the speed of….the layer below". They also indicate that in conjunction with electrical methods; "Seismic methods were used in the Skellefte district [of Northern Sweden] in the winter of 1923 for determining the depth of overburden…" with close accuracy compared to drilling. For Gepp et al. (1927), "Mintrop's Method" (sic) is the other one of their "two important methods" and their description is attributed to "Heiland, 1926". They also refer to its use in Sweden.

As none of the sources have any illustrations of the seismic method in operation (admittedly, at a time when photos were not readily produced, as now), Figure 7a–c reproduced from Rieber (1929), illustrate the level of practice at the time.

Figure 7. *(a) "Receptor (geophone) being lowered into place" (from Reiber, 1929, Figure 3). (b) "A typical field party" (from Reiber, 1929, Figure 4). (c) "Dynamite truck firing a charge" (from Reiber, 1929, Figure 2).*

The seismic method was not used in Australia before the IGES. Part of the reason for this lack of use was the recognition that such methods were not as suited to the detection and delineation of ore-bodies, so much as they are for mapping relatively flat lying strata - especially that containing oil and gas fields. Mason (1927) states, "the difficulties in [the seismic methods] are of a serious nature". "In the neighbourhood of most orebodies the rock conditions are complicated by fracture zones, by faults or folds and, in general, by many irregularities". Andrews (1928) made this same observation (about the "irregularities") in what was by far the shortest description of the various methods dedicated to the "sonic and seismic methods" in his report.

The influence of IGES on the seismic method in Australia

The seismic method is a second instance (along with the resistivity method) of the rapid development of a method in Australia due to the instigation of the IGES. The big gap in knowledge between what was known of the seismic method in Australia before the IGES, and that subsequently published in the IGES report, is exemplified in the introduction to the report (Broughton Edge and Laby, 1931); "During these early preparations in London the testing of seismic methods by [IGES] was thought to be impracticable, since neither experienced operators nor the necessary equipment could be secured". However, "following on their war experiences of seismic methods, the late Professor J. A. Pollock, F.R.S. (one of designers of the first gravity meter, see Henderson, 2015) and Major E. H. Booth of Sydney University had, for some years, been carrying out experiments…very similar to that now being employed in geophysical investigations."(Broughton Edge and Laby, 1931, p. 3). Consequently, Major Booth consented to act as a consultant to the IGES for the seismic method.

Radiometric method

The author can find no reference to the use of the radiometric method in Australia before the IGES, nor was it used as part of the IGES. The only two sources that discuss this method, namely Krahmann (1926) and Elbof (1927), indicate that the method was in its infancy.

Krahmann (1926), in his Chapter VII "Geothermic and radio-activity surveys", which is only one page long, describes the measurement of radioactive gas emanations from soil at a depth of one meter, and "the radioactivity of bore-hole samples", which "I regard as more promising". Elbof (1927) in Chapter V "Geo-thermic and Radio-activity Investigations", claims the method enables faults and fissures to be located. Figure 8 is a radioactivity profile, across a faulted trough in Thuringia, Germany from Elbof (1927). No date is given. The faulted edges of the trough are clearly indicated by anomalous radioactivity[9].

This method has become, since the late 1940s, very important in the direct detection of uranium and in mapping geology and, in that respect, is very complementary to magnetic and gravity methods. Just as with regional magnetics, entire continents are now being mapped with radiometrics.

Geothermal method

Krahmann (1926) acknowledges anomalous temperature gradients with depth "in the vicinity of salt ridges, many

[9]The Geiger-Muller tube, which made the measurement of radioactivity so much more practical in the field, was not invented until 1928. Thyer (1979) reports that probably the first use of a 'Geiger counter' ("built in in the Physics Department of Adelaide University") was *by himself*, at Mt Painter, South Australia, in 1944.

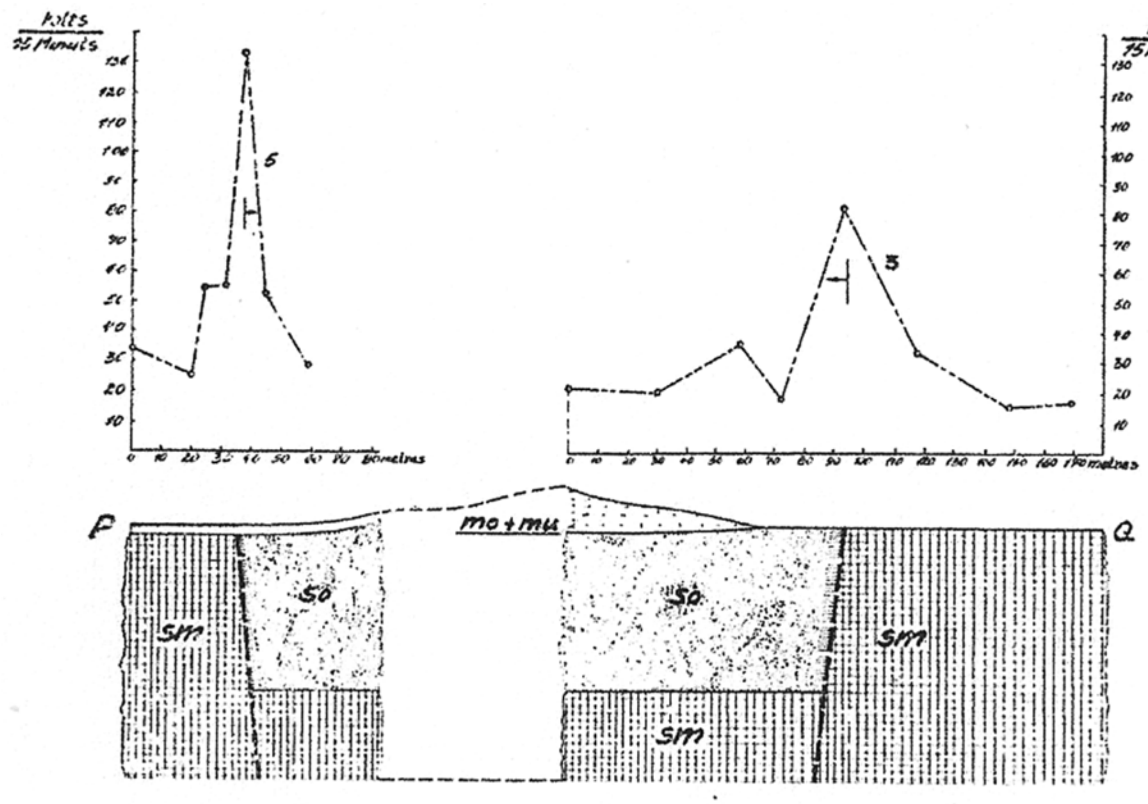

Figure 8. *A 'radio-activity' profile over faults in Thuringia, Germany of Volts/time (from Elbof, 1927, p. 41).*

petroleum deposits, coal seams of certain types and certain oxidisible ores….". However, he believed the science was "not yet clear enough to enable" its use for "geological purposes". In addition to repeating these anomalous situations, Elbof (1927) add the anomalous gradient due to radioactive minerals. The Sub-Committee (1927) only states, "[Thermal methods] have as yet no direct application to prospecting for minerals".

Geothermics was also not practiced before or during the IGES, in contrast to its use in the deep mines of Witwatersrand, South Africa from 1911 (de Beer, 2011). However, much more recently, "hot rocks" have become very popular in Australia as a source of geothermal energy.

The secrecy of companies

Krahmann (1926) and the Sub-Committee (1927) referred to what they regarded as the unhelpful secrecy surrounding the practices of some private companies.

Krahmann (1926, Ch. I, p.6) decried the lack of information on geophysical methods in general, and claimed that a "great obstacle is the fact that the parties for whom investigations are carried out nearly always require *secrecy* in regard to the results". The Sub-Committee (1927)] states that, contrary to the case of the gravit*y* method of which "Full details….have been published in the scientific press…", "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 this case I assume they are referring to companies like Elbof. With regard to seismic methods, "They have suffered hitherto from control by private interests and lack of publication of the methods used and the results obtained". For example, "very little is known, of the methods by the Seismos Gesellschaft in Germany"[10].

E H Booth, consultant to the IGES for seismic methods, made a similar claim as to the prior knowledge of seismic methods in his Presidential address to the Royal Society of NSW (Booth, 1938); "Up to this, [the time of the IGES] although certain scientific papers were available, the procedure and theoretical methods of interpretation,…were mysterious (sic) as they were applied by private companies which preferred to keep their methods *secret*".

To some extent this secrecy could be a result of companies not wanting their rivals to know about their proprietary techniques.

Exploration geophysics in South Africa before the time of the IGES

Johan de Beer in his comprehensive paper on early exploration geophysics in southern Africa (de Beer, 2011) reveals how magnetic, gravity, electrical, seismic and geothermal methods were all used in that region from the mid-1920s, some by geophysicists we know about from the 'sources'. The earliest use of mining geophysics in southern Africa was said, by de Beer, to be a geothermal survey reported in 1911; as indicated in 'Geothermal Method' earlier.

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[10]Broughton Edge and Laby (1931) suggests that a major aim of the IGES was to address this paucity of information, particularly with electrical methods. With regard to seismic, "This branch …was entirely in the hands of certain geophysical companies".

The first practical electrical surveys started in 1925 "by the Electrical Prospecting Company from Stockholm". Electrical methods were suggested for the gold reefs of the Witswatersrand, in 1926 by "Conrad and Marcel Schlumberger of France, and Karl Sundberg and Helmer Hedström of Sweden"… "In 1925 and 1926, the British geophysicist Arthur Broughton-Edge (sic) conducted experimental geoelectrical surveys in the Northern Rhodesian (now Zambian) Copper Belt"[11]. In 1929, "self-potential and mise-à-la masse surveys" were conducted[12]. Refraction seismic surveys were conducted in 1927–8 and magnetic surveys were "carried out on an ad hoc basis" before the 1930s. Gravity surveys were not reported until later. In 1930, Rudolf Krahmann (See 'Krahmann in Australia (and South Africa, briefly)' in Part 1) arrived in South Africa and became famous for his magnetometer surveys, which resulted in more than twelve gold mines.

Why was there such poor knowledge in Australia before 1928 about exploration geophysical methods being practiced in Europe and north America?

Was the remoteness of Australia a factor? The distance to Australia from Europe and north America is of the order of 20 000 km and transport by ship, as experienced by E C Andrews in March, 1928, took two months. Regular air services were not available until later and, even so, were very expensive. The first radiotelegraph linking Australia to Europe started operation in April 1927, and the first radiotelephone in April 1930.

Apparently this remoteness was not as much a factor in South Africa, where geophysics was more advanced than in Australia before the IGES (see preceding section). Were connections better through the continent of Africa, at least for the British?

The well-known phrase "tyranny of distance" may be appropriate in this case. In the preface to his book of that title, Geoffrey Blainey (1968) states; "…most parts of Australia are at least 12,000 miles from western Europe, the source of most of their people, equipment, institutions and ideas". All this is very true of the science of geophysical exploration in the mid-1920s. Certainly there was no local development and manufacture of geophysical equipment at this time, or indeed for several decades later; E C Andrews was only just urging for the introduction of geophysical prospecting in institutions in 1928 (Henderson, 2013) and very few new ideas could be nourished when formal lectures on the subject did not start until 1949.

Edgar Booth, in his Presidential address to the Royal Society of NSW (Booth, 1938), acknowledged the value of the IGES to Australian geophysics, nevertheless, he alluded to the "temporary collapse of the economic system (the Depression) in the last year of the survey…". Had it not been for this, Booth was sure that the impetus of the IGES "would undoubtedly have resulted in the establishment of maintained training centres in our universities". Why then did this take nearly 20 years?

[11]Here de Beer (2011) makes the surprising statement that "Broughton-Edge is regarded as the father of exploration geophysics in Australia", which can only be through his association with the IGES. The author is not aware of this claim being widely recognised.

[12]The method of Mise-à -la-masse, which involves inserting current into a conductor resulting in electrical potentials around it, was not mentioned in any of the Australian 'sources' nor was it employed by the IGES.

Another more technical reason for the late introduction of exploration geophysics to Australia could be the lack of outcrop, particularly when compared to countries like Sweden that had rich outcropping ore-bodies such as Boliden (referred to in detail by Gepp et al., 1927). Also, thick, conductive regolith was difficult to penetrate with electrical methods; the primary methods used for metalliferous targets.

Whilst Australians had a poor knowledge of exploration geophysical techniques prior to 1928, the IGES prompted a rapid expansion of interest and activity. Australian exploration geophysicists are now renowned throughout the world and have been responsible for notable advances in geophysical instrumentation.

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