Some snapshots from fifty years of geophysics

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SUMMARY

A person lucky enough to have worked in different aspects of geophysics in Australia over the last fifty years is sure to have a treasure trove of rich memories. Australia has the great good fortune to be a whole continent within one national boundary, and to be a marvellous laboratory for geophysical methods. The developments in geophysics which have taken place in Australia have been based, and have indeed been possible, because of strong rigorous traditions existing in mathematics, physics and geology.

A perspective to the present state of geophysics is obtained be re-visiting various geophysical experiences over fifty years. The path followed commences with trigonometrical surveying (which allows the fifty years time span!) and progresses through various aspects of magnetic and electromagnetic measurements. Part of the journey takes place on land, some is airborne, and some is by sea. Developments in electronics, and computers, have made geophysics a rapidly-developing and exciting subject.

The last fifty years of exploration work in Australia have taken place against the proving and acceptance of continental drift, plate tectonics and mantle convection. It has therefore been a time of remarkable intellectual stimulation and activity, of the widest possible importance to humankind.

Key words: geophysics, Australia, history, magnetism

INTRODUCTION

The history of geophysics in Australia began with the first European explorers, who were concerned with the measurement of basic geophysical quantities, such as the Earth's gravitational and magnetic fields (Day, 1966). By the first half of the twentieth century, Australia had been recognised as a possible happy-hunting ground for the new methods of exploration geophysics, as witness the account of the Imperial Geophysical Experimental Survey (IGES) in the book by Broughton Edge and Laby (1931). World War II (WWII 1939-1945) was followed by major advances in technology and science, and particularly in the realisation of a nuclear age. The author came into geophysics in the mid-1950's, as scientists of many nations were keen to collaborate globally and peacefully, for example in the International Geophysical Year (1957-1958). Early in 1957 the author was awarded a cadetship in geophysics by the Australian Atomic Energy Commission (AAEC), wishing at that time to foster the discovery of uranium ore in Australia, and working for that purpose with the Bureau of Mineral Resources, Geology and Geophysics (BMR). The geophysics arm of the BMR was in Melbourne, and the senior personnel had strong links with the IGES of some 25 years earlier (Wilkinson, 1996). Fifty years of geophysics is claimed on the basis that early in 1955, while a secondary school student on summer holidays, the author worked with a trigonometrical survey team in western Tasmania. The measurement of the Earth, and the determination of its shape, is perhaps the most fundamental geophysical pursuit of all.

With the financial self-sufficiency that the AAEC cadetship offered, the author took himself to the University of Sydney, and enrolled there in science. Undergraduate studies in Physics, Mathematics and Geology led to majoring in the first two, followed by an honours year in the Department of Geology and Geophysics, with a thesis supervised by Alan A. Day on "Radioactivity of some common rock types". Samples were measured with a Geiger counter and a scintillometer. A novel aspect of the work was to use nuclear emulsions, obtained from the Physics Department where they were used in stacks to study cosmic ray activity, to trace and record the emissions from any radioactive particles in polished rock surfaces, which were placed against the emulsions for periods of days. Other teachers noted for geophysics at the University of Sydney included Keith Bullen and Bruce Bolt of the Applied Mathematics Department, and their visitors such as Harold Jeffreys and Jack Jacobs.

SURVEYING AND TURAM (TASMANIA, 1955 – 1958)

Summer holiday employment in western Tasmania comprised two seasons with the Tasmanian Lands and Surveys Department, and then two with the Rio Tinto Mining Company, carrying out exploration work. Regarding the former, surveying was by theodolite, log books were written in pencil, and basic calculations done by mental arithmetic. Radio contact between parties tens of km apart was sporadic, and some signalling between mountain tops was achieved by solar reflectors. The experience of camping high in Tasmanian mountains, and getting to the peaks in time to commence theodolite observations in clear early morning air, presented the survey crews with scenes of unforgetable splendour, even if (though it was summer) at times one felt rather cold (Lilley, 1955).

The first season with Rio Tinto comprised ground geological reconnaissance, and the second (1957-58) comprised mainly TURAM work over particular prospects. The Swedish ABEM Turam gear had vacuum tubes as the basis of its circuitry, and worked at two frequencies (440 Hz and 880 Hz from memory). A full field crew comprised four people, as the equipment moved along a traverse: one each to carry the leading and trailing horizontal coils, an operator of an electronic box who judged a null on earphones by adjusting a balance between the two coils, and an assistant who made entries in a log book. The transmitter line was laid out at the start of a survey, and a generator in the line switched on. The activity described took place in typical thick Tasmanian bush, in remote places. Line clearing was a major part of the work, and helicopter transport to the survey camps was new, and made a huge difference to what could be done. I remember particularly sitting in a wet tent among tussocks of grass, with rain coming down outside, endeavouring to solder cable-breaks at plugs. The soldering iron was electric and basic, and running off a car battery which was rapidly going flat! The scene was a world away from modern electronics.

AEROMAGNETICS (BUREAU OF MINERAL RESOURCES, 1961 – 1963)

Three years in the BMR were a marvellous experience. It was the days of the DC3 aircraft VH-MIN (the BMR fleet had also included VH-BUR and VH-RES). Aeromagnetic surveying had been commenced less than ten years earlier (Wilkinson, 1996). The culture of the BMR in those days was to introduce methods into Australia very often by building the equipment at the BMR laboratories and workshops in Footscray, Melbourne, and this pioneering work was carried out by a team of highly skilled and versatile people. There was also much equipment in evidence which was surplus from WW2 and adapted for geophysics, such as the airborne fluxgate magnetometers themselves, and aerial survey cameras. During this period the BMR trained a whole generation of Australian geophysicists, and recruited many from England.

The DC3 generally carried out surveys at 500 ft altitude, with survey lines spaced one mile apart. The pilots navigated visually from mosaics of aerial photographs prepared for them, and an aerial camera in the plane recorded its path (ingeniously on an endless strip of photographic film), so that this path could be plotted accurately afterwards, again on an aerial photograph mosaic. The plane also carried scintillometers, at two levels: one in the plane, and a second in a "bird", towed behind the aircraft on a cable. Part of the mythology of the airborne group concerned a plane coming in to land still trailing the bird, which was later recovered from a sandhill near the airport.

In 1962 and 1963 BMR was involved in the development and test flying of a new magnetometer, a proton-precession instrument. This magnetometer, trailed in a bird, was fitted to the BMR Cessna aircraft (VH-GEO). This aircraft had previously been used for scintillometry only, as the fluxgate equipment had been too heavy for this light plane. Test flights were from Moorabin Airport, Melbourne, and then the first trial surveys, where the idea was to match (or improve upon) the detail available in ground magnetometer surveys, were carried out in Cobar, 1963 (Goodeve and Lilley, 1963). A similar method in the same area later revealed the Elura deposit (Emerson, 1980).

MAGNETOMETER ARRAYS (AUSTRALIAN NATIONAL UNIVERSITY, 1970's)

After some five years overseas in Canada and England, as a graduate student and post-doctoral fellow respectively, I returned to Australia, to the Australian National University as a Research Fellow, following Everett and Hyndman (1967) in their studies of natural electromagnetic induction in the Earth. The motivation for the work was that natural electromagnetic induction could indicate regions in the Earth of high electrical conductivity, which might in turn indicate places of abnormally high temperature. In particular I inherited from Jim Everett and Roy Hyndman, and used at first, a set of portable magnetic observatories in the form of proton-precession magnetometers with bias coils wound on spherical formers, of different diameters so that the coils nested to save space. It was a new development that the proton precession magnetometers had a digital output, which was recorded on punched paper tape, and so amenable to computer analysis.

D. Ian Gough came from Canada on a sabbatical visit, and brought with him his array of 25 magnetometers (Gough and Reitzel, 1967). These instruments had been developed to be an economical way of setting up an array of what were essentially portable magnetic observatories. They ran off car batteries, which would last three weeks. They recorded on film, which was a step backwards, but in discrete dots (every minute), which we set up systems to digitise. Their reliability when buried and left remotely was a result of the simplicity of their design, and an important advantage. The idea was to observe magnetic disturbances simultaneously over a region, and detect conductivity structure from recurring features in the patterns of the magnetic fluctuations. Their use in Australia, in two array experiments, discovered major electrical conductivity structures, and contributed significantly to understanding the physics involved in the electromagnetic induction process (Gough et al., 1974; Bennett and Lilley, 1974).

We serviced the instruments by light plane, which proved to be an excellent mode of transport in Australia over the inter-station distances of typically 150 km. We also built a set of three basic telluric recorders to use with the Gough-Reitzel instruments, and so made some of the first long-period magnetotelluric soundings in Australia (Tammemagi and Lilley, 1973). These recorders ran off car batteries, and recorded by ink trace on paper chart. They needed servicing every three days.

Ian Gough agreed to our workshop copying his instrument, and we then had the benefit of a set of 21 instruments of our own (Lilley et al., 1975). This set was a workhorse for reconnaissance observations in Australia for over a decade (Woods and Lilley, 1979). In Tasmania, Dudley Parkinson and students were working in parallel, with a set of fluxgate instruments, and followed up early indications, from an array study around Bass Strait, of the Tamar Conductivity Anomaly. Similarly, in South Australia, Francois Chamalaun and Antony White were developing, and using, fluxgate instruments. Applied source-field methods were investigated as a means of studying conductivity anomalies, and the regional structure in which they occurred (Constable et al., 1981). The ANU set of magnetometers was also used internationally, in India in 1979-80 (Arora et al., 1982).

For some time in Australia the simultaneous telluric observations lapsed, not only because they needed more field support (cables laid out on the ground are vulnerable to being chewed; even in the most uninhabited-looking places, cattle and kangaroos come by!). But also, because it was obvious that they were strongly affected by local distortion from which the magnetometer data were relatively free. This matter of local distortion, and its correction, has continued to be a major topic in magnetotellurics, and practical experience has stimulated theoretical enquiry (e.g Weaver et al., 2000).

SEAFLOOR MAGNETOTELLURICS (1980's)

The International Association of Geomagnetism and Aeronomy has a Working Group on Electromagnetic Induction in the Earth, which has run a very successful set of biennial workshops since 1972. Contacts made at these workshops led in 1983-84 to collaboration with Jean H. Filloux of Scripps Institution of Oceanography, a pioneer in the geophysical technique of seafloor magnetotelluric observations. A traverse of instruments was established across the Tasman Sea, with ship-time contributed by the Royal Australian Navy, which supported the experiment with two voyages of its purpose-built oceanographic survey ship the HMAS COOK (Filloux et al., 1985: Ferguson et al., 1985). Where the traverse met continental Australia it was continued inland with Gough-Reitzel magnetometers. Antony White also joined in this experiment with a continental shelf magnetometer, and in various ways the 1983-84 experiment set a basis for further research.

The Tasman data set was something new for Australia, and stimulated the use of new techniques in interpretation (Heinson and Lilley, 1989). There was supporting evidence for an asthenospheric layer beneath the Tasman seafloor at depth order 100 km, which was highly electrically conductive as a consequence of being partially molten. Induction at the coast line of New South Wales with the Tasman Sea was further investigated with more detailed magnetometer observations down the continental slope (Kellett et al., 1988).

MOTIONAL EM IN THE SEA, AND ON LAND A RETURN TO QUEENSLAND (1990's)

The observations with the Filloux instruments on the floor of the Tasman Sea had recorded a variety of oceanographic phenomena (Bindoff et al., 1986). Whereas the basic magnetotelluric signals were caused by changing electric currents in the ionosphere and beyond, the oceanographic signals were due to motional induction. The mechanism was that of the seawater, a good electrical conductor, moving through the steady main magnetic field of Earth.

One such phenomenon recorded was the passage southwards of a strong warm-core ring (or eddy) in the East Australian Current. Not only were the motional induction signals clearly evident in the electrical observations, but they were also clear in the magnetic data. The latter observations were unexpected, and new. They were due in part to the layer of sediment on the floor of the Tasman Sea, which conducted leakage currents.

These observations stimulated a search for the motional induction magnetic signal down through the ocean column, where it should be at a maximum. It was realised that the problem of orientating a magnetometer traversing the ocean column could in part be met by using total-field magnetometers (an echo of earlier aeromagnetic experience), as a total-field magnetometer measures changes in the direction of the Earth's main magnetic field, which is known.

Thus an instrument was designed and used comprising a total-field magnetometer which was lowered to the deep sea floor and hauled up again by ship's winch. There was also the option of traverse down by free-fall, and free-float up again when a ballast mass was jettisoned by a release receiving an acoustic signal. A research cruise of RV FRANKLIN supported successful profiling in the East Australian Current. The instrument was also floated at the sea surface to record the signals due to the motional induction of ocean swell. In another experiment, a set of three-component magnetometers was sited in a line underneath the Antarctic Circumpolar Current in the Southern Ocean, in a bid to monitor its transport by the motional induction signal generated. All four instruments were recovered but not all had functioned correctly; the experience may be the basis for a further foray into that topic in the future.

The task of mapping the major electrical conductivity features of the Australian continent had been advanced by the Australia Wide Array of Geomagnetic Stations (AWAGS) of Chamalaun and Barton (1993). To clarify the position of the conductivity structure in Queensland, a magnetometer study in two arrays was carried out there in 1995, laying the basis for a detailed magnetotelluric traverse across the conductor in 1997 (Wang et al., 1997). The combination of reconnaissance by magnetometer array, and detailed study by magnetotelluric traverse, proved to be effective in refining knowledge of the conductivity structure, which may mark a major suture in the Australian continent.

Finally, bringing together a number of the topics mentioned above, work was initiated to explore the possible application of aeromagnetic cross-over misfit data to give information on natural electromagnetic induction (Hitchman et al., 2001). The principle explored is that the time-varying part of the magnetic field, in a region being covered by aeromagnetic observations, will be less spatially uniform in the vicinity of a conductivity structure. An increase in cross-over misfit may result, leading to an indication of the presence of the conductivity structure, and its possible mapping.

CONCLUSIONS

The period described has been shared by a whole generation of Australian geophysicists, who will each have their own set of memories. The individual memories will be different, as an attraction of geophysics is that it is so varied. However there should be some common themes, a major one being the stimulation between field observations, theory, and numerical modelling. Another theme will be the benefits of collaboration and discussion with colleagues, not only in one's home institution but also at local, national and international meetings of the ASEG and other societies. A third theme will be the stimulation and excitement of working in one's own speciality in geophysics, while the amazing developments of the last half-century in "whole Earth" geophysics have taken place.

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Reviewing fifty years of geophysics brings memories of colleagues from around Australia and the world. In a subject like science which should be coldly objective and impersonal, the warmth of the human dimension experienced when one actually comes to do science is a marvellous bonus, and profoundly rich. My gratitude goes to the many mentors and collaborators who have shared geophysics with me over fifty years, and continue to do so.

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