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# Time domain EM comes to Australia: the early history of the MPPO-1

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Australia, with its extensive ancient and weathered terrain, has long been a testing ground for geophysics. The Imperial Geophysical Experimental Survey (I.G.E.S) carried out 18 months of fieldwork in Australia during 1929–30 'for the purpose of conducting thorough trials of the principal geophysical methods to determine their practical value and limitations under a variety of geological conditions' (Broughton Edge and Laby, 1931). Between 1935 and 1940 the Aerial, Geological and Geophysical Survey of Northern Australia (AGGSNA) used the latest aerial, geological and geophysical techniques to map and explore remote areas of Northern Territory and Queensland, and this led to the establishment of the Bureau of Mineral Resources, Geology and Geophysics (BMR) in 1946. For more than half a century Australia has proved a challenging and fruitful frontier for testing the latest geophysical technology.

Magnetic, gravity and electrical methods were widely used and well understood, but electromagnetics (EM), which worked so well in Scandinavia and Canada, continued to confound and disappoint when brought to Australia. These EM systems operated in the frequency domain, and measured the in-phase and out-of-phase response referenced to the transmitted primary sine wave. Operating at relatively high frequencies, and suitable for the highly resistive shield areas of Canada and Sweden, traditional EM systems were severely hampered by the thick conductive weathering that covered much of Australia and rendered the systems mostly ineffective.

That was until 1970–71, when two Australian geophysicists independently visited the USSR to learn of new techniques that had not yet reached the West[1]. The intrepid travellers, Hugh Rutter of Western Mining Corporation (WMC) and Elmer Sedmik of the BMR, reported back to their respective organisations about a new technique, transient electromagnetic (TEM), which might solve the problem of how to explore beneath Australia's regolith.

Canadian Tony Barringer, who attended a scientific conference in Russia in 1965 where he heard about the MPPO-1 (Les Starkey, pers. comm.), preceded Hugh and Elmer. Barringer was intimately familiar with time domain EM, having conceived the airborne INPUT (Induced pulse transient) system in 1956 while working for Selco Exploration. He tried to purchase an MPPO-1 instrument but to no avail – export of the MPPO-1 to non-communist countries was prohibited until the late 1960s.

Meanwhile, Newmont Exploration Ltd had been working on the theory of inductive transient techniques from as early as 1951, and had successfully tested their first Newmont EMP (EM pulse) system consisting of a large transmitter loop and roving receiver in Cyprus and South Africa. This large-loop system was brought to Australia in 1976 and remained in use until the mid-1980s.

These new techniques were developed and used under the strictest secrecy, lest companies lose their competitive edge, and little information permeated into the outside world.

Back in Australia, the sole agent with a license to sell Russian instruments, such as the MPPO-1, was Jack Zonnerville of the Industrial and Scientific Supply Company. Orders were delivered on six monthly intervals, with much paperwork involved. The first MPPO-1 unit to arrive in Australia was for Geotechnics (Les Starkey, pers. comm.). The unit ordered in 1969 was destroyed by fire in transit in Holland or Belgium, and a new order was finally received in 1971. Field tests were conducted over known ore bodies in the ensuing months. Western Mining staff were so impressed with the results that they bought two systems. Other companies purchasing an MPPO-1 included LA Richardson and Associates in the early 1970s. Aquitaine Australia Minerals Pty Ltd tested an MPPO-1 at the Steeple Hill massive sulphide deposit, 100 km east of Kalgoorlie (Gunn and Brooke, 1978).

## The arrival of the MPPO-1 at the BMR

When I arrived at the Bureau of Mineral Resources, Geology and Geophysics (BMR) in 1970, as a new cadet in the Metalliferous Branch (along with Peter Gidley, Ian Hone and Jovan Silic), my supervisor Elmer Sedmik told me that my job would be to take charge of a new EM system from Russia, mysteriously called the 'MPP0-1', which would arrive in the following year. I sat down to read all that I could on transient electromagnetics, starting with the classic 1967 booklet by Velikin and Bulgakov, loosely translated as 'Inductive electrical prospecting by the method of transient processes with combined source and receiver' (Figure 1). 'MPP' stood for 'Metod perekhodnykh protsessov', translated as 'method of transient processes'. The '0' referred to the single loop configuration. Later models MPP-3, MPP-4 involved separate source and receivers, including down-hole versions.

The BMR's MPPO-1 arrived in April 1972. The BMR technical officers set to work to try and understand the electronics so that

[1]Reports of developments in USSR geophysics had begun to reach the West in the late 1960s, e.g. via George Keller in the introduction to Van'yan et al. (1967) and via a U.S. Exchange Delegation (Keller et al., 1966). Keller's report focused on Van'yan's deep long-offset TEM sounding, and the US delegation was petroleum oriented.

they could upgrade components and conduct repairs if necessary. The transmitter was powered by expensive but effective 6V rechargeable silver-zinc batteries housed in a small box (Figure 2). This unit proved to be quite reliable, with replacement batteries readily available in the West.

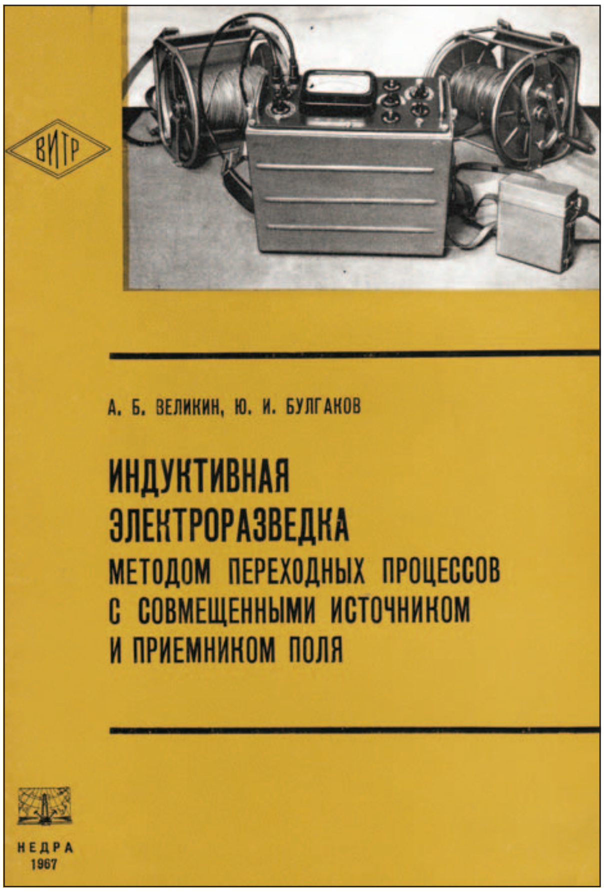


**Figure 1.** *Cover of booklet by Velikin and Bulgakov (1967), with a photo of the MPPO-1 receiver (centre) and transmitter (right). The breast-mounted cable reels contains wire used to make square loops ranging from 10 m to 200 m square.*

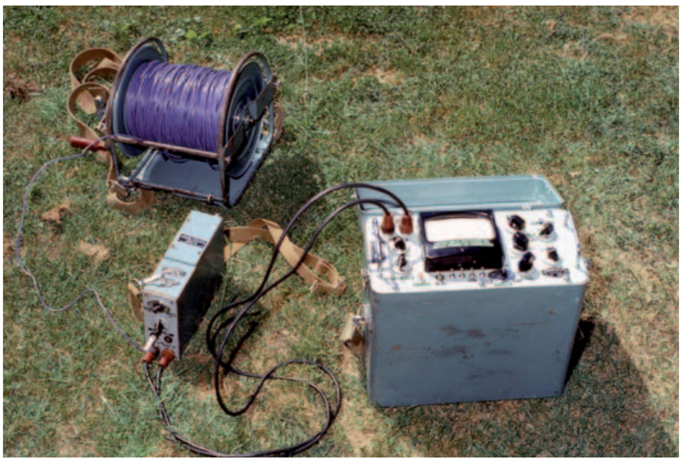

**Figure 2.** *MPPO-1 transmitter pack (lower left) and receiver unit (right). The main settings on the receiver are selection of transient decay time (bottom left) ranging from 1 ms to 15 ms, amplification (mid-right), and two settings of noise damping (bottom right). The transmitter sends 20-ms wide rectangular pulses at the rate of 18 Hz into the combined transmitter/receiver loop.*

The main receiver unit was more difficult to reverse engineer. The most complex aspect of the MPPO-1 was that the same loop of wire was used for transmitting and receiving. A 2-amp, 20-ms wide square waveform was transmitted into a loop of wire laid on the ground and abruptly terminated in a few tens of microseconds. The circuitry was then switched to a sensitive set of amplifiers, which recorded the voltage in the same loop of wire induced by the decay of secondary currents from the earth. Quite sophisticated electronics is required to measure microvolt-level signals in the same wire loop that a few microseconds earlier was subject to hundreds of volts in back-EMF generated as the transmitter current was terminated.

The circuitry contained a number of unique features. Seven rechargeable cylindrical nickel-cadmium battery packs provided power to separate parts of the receiver circuitry to prevent ground loops and cross-interference. Russian transistors were quite leaky by Western standards, but their performance was boosted by ancillary circuits that counteracted their inherent limitations. Each time the BMR technicians attempted to 'improve' a component or part of circuitry they marvelled at the skills of the original designers in making the instrument work so well. Indeed, no other manufacturer has been able to replicate a functional system that uses a single loop of wire for transmitting and receiving. One addition the BMR technicians did make was to add two early-time channels of 0.57 ms and 0.79 ms. WMC added a box on the side with additional circuitry which could utilise higher voltage batteries, and thus higher transmit current, and increased the number of time windows (Figure 3).

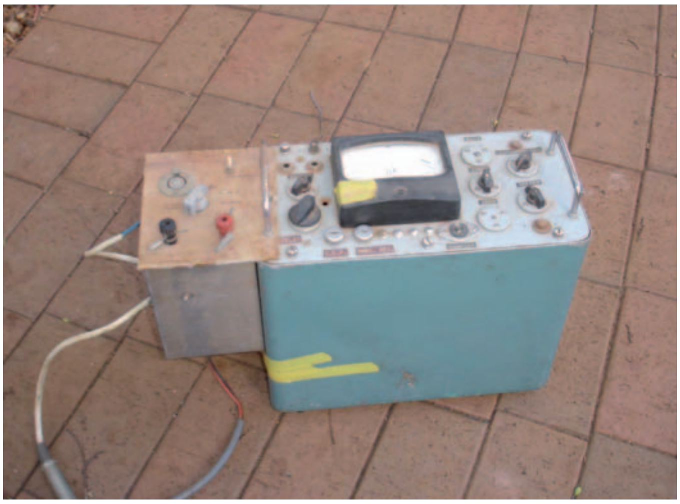

**Figure 3.** *MPPO-1 modified by WMC with larger battery pack to provide higher transmitter currents. This instrument now resides in the ASEG Museum (courtesy John Coggon).*

## First field tests

The BMR conducted its first field campaign using the MPPO-1 in Northern Australia from August to October 1972 (Figure 4). The areas selected for test surveys included iron deposits at Tennant Creek and conductive shale and gossan at Rum Jungle, Mary River and Cloncurry (Spies, 1974a). These surveys tested loop sizes from 10 m to 200 m in a variety of terrains, with comparisons with other techniques.

The 1973 field season returned to Rum Jungle and Mt Isa/Cloncurry (Hone and Spies, 1974). These investigations included

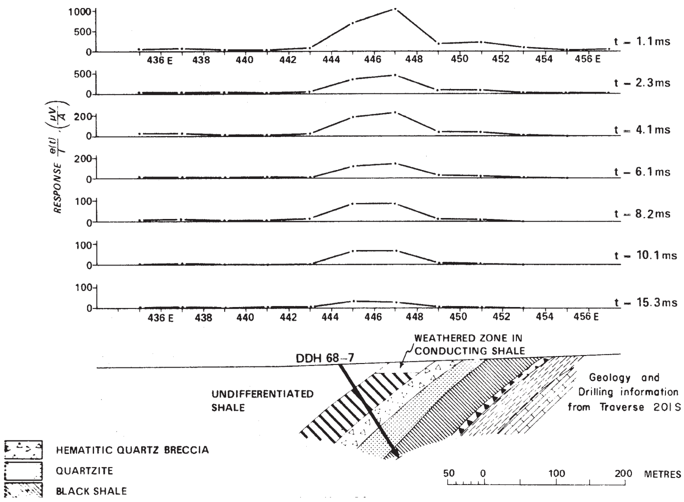


**Figure 4.** *First BMR MPPO-1 results, 1972 in the Rum Jungle, Mt Minza area, showing a strong anomaly over a dipping black shale. Note the high data quality.*

depth sounding using different loop sizes, and trials of a figure-of-eight configuration ('dual loop'), to enhance the response of vertical conductors and reduce that of horizontal conductors. At Cloncurry anomalously small or negative responses were recorded over conductive shale. It was postulated that these responses could be caused by IP effects. The sign reversals were subsequently replicated by a prototype SIROTEM instrument.

## Elura – A prime geophysical test site

The Elura zinc-lead-silver deposit was discovered by Electrolytic Zinc Company of Australasia (EZ) at the extremities of an aeromagnetic survey (Davis 1980). Following drilling to confirm the viability of the deposit, EZ made the area available to the BMR and other parties who carried out an extensive series of surveys with a wide variety of techniques between 1974 and 1979. The MPPO-1 instrumentation was the first TEM trialled at Elura, in December 1974 (Hone, 1976), and 'the results were encouraging'. In contrast, other EM methods tested over the deposit in early years, including airborne INPUT and ground Crone (loop-loop) PEM, gave disappointing results (Davis, 1980). Extensive EM surveys were carried out between 1974 and 1979, these surveys included detailed comparisons between the MPPO-1 and SIROTEM, PEM and others.

A comparison of MPPO-1 data over the Elura deposit from the 1974 survey and a SIROTEM profile in 1978 (Figure 5) clearly shows the advantages of the modern technology, with much longer averaging times and sferics rejection.

The ASEG convened an Elura Symposium in 1980 and published a comprehensive set of papers in a special issue of *Exploration Geophysics* (Emerson, 1980).

Elura presented a unique opportunity to test a range of TEM instruments with different loop configurations, including small multiturn loops, separated loops and dual loops. Anomalous responses could be tested and retested, with loops raised off the ground, or transmitting and receiving loops displaced by varying distances. These tests led to rapid advances in the understanding that viscous magnetisation due to maghemite in the soil could adversely affect TEM readings with combined transmitter and

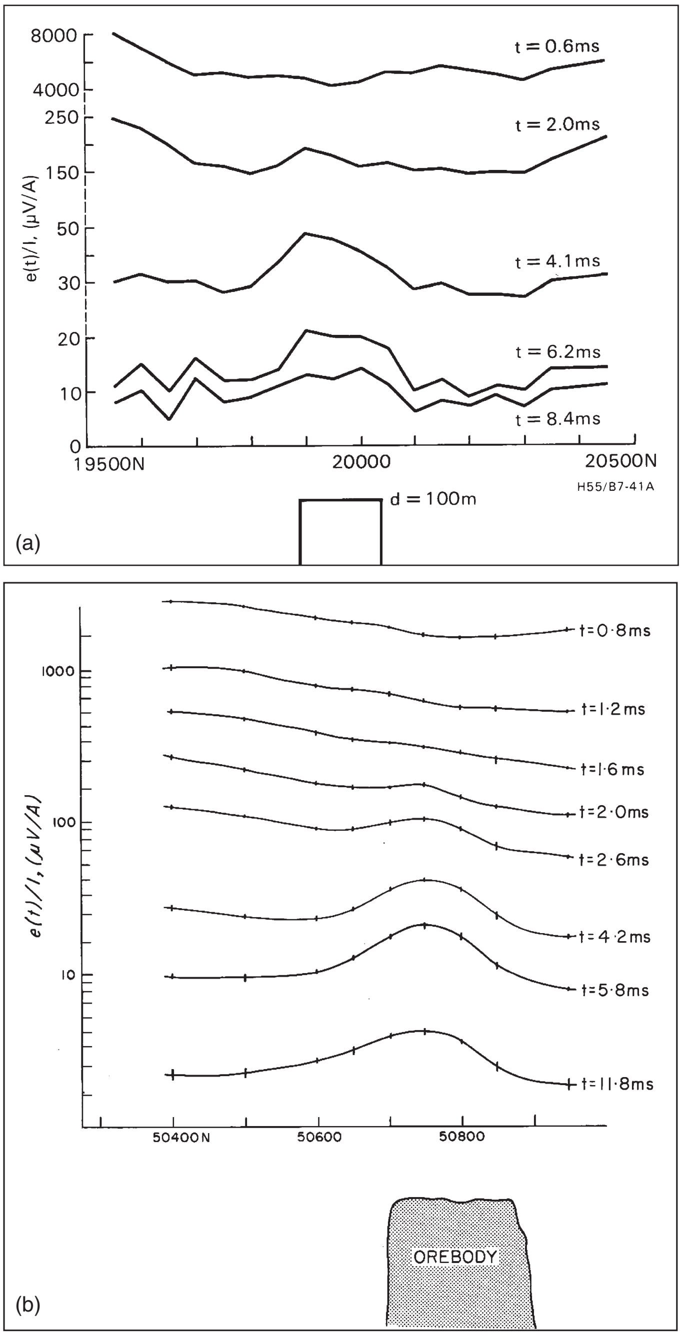


**Figure 5.** *Comparison of MPPO-1 (1974) (a) and SIROTEM (1978) (b) results over Elura (Spies, 1980). The orebody is evident at sample times later than 2 ms.*

receiver unless large loop sizes or displaced receiving and receiving loops were used, as described later in this paper.

## WMC's Benambra VHMS discoveries

The volcanic-hosted massive sulphide (VHMS) deposits at Woodlawn and Captains Flat in NSW led Western Mining Corporation (WMC) to explore for comparable deposits in the Lachlan Fold Belt in Victoria in the late 1970s. Regional aeromagnetic and radiometric surveys, followed by helicopter EM, ground geochemistry, magnetics, IP and Crone shoot-back EM were carried out in the Benambra area, but exploratory drill holes failed to intersect significant mineralisation (Rajagopalan and Haydon, 1999).

WMC knew that TEM was likely to be more effective than IP in detecting massive sulphides, but difficult terrain condition delayed their use. Failure with IP, dip-angle EM and airborne EM prompted WMC to re-evaluate the use of TEM. In 1977–78, WMC carried out field trials of the MPPO-1 in the Benambra area and found the rate of ground coverage to be better than expected, and quality of the data was encouraging.

Supervising geophysicist Don Esdale ran an MPPO-1 survey with 50 m loops at the Wilga prospect. A strong early-time anomaly was detected 150–200 m from the nearest geochemical anomaly and previous drillholes (Figure 6). Drilling of the MPPO-1 anomaly intersected 25 m of massive sulphides assaying 4.1% copper, 0.46% lead, 7.28% zinc and 31 g/t silver.

A larger 100 m loop was used for discovery of the Currawong deposit in 1979 (Figure 7). The availability of the SIROTEM system in the early 1980s allowed WMC to change from 100 m loop MPPO-1 surveys to 200 m loop SIROTEM surveys, increasing the depth of exploration. Later, the Geonics EM37 system and borehole EM were also used. The Wilga and Currawong zinc-copper orebodies are the largest base metal deposits discovered in Victoria.

WMC's MPPO-1 results from the Yilgarn Block are briefly described by Coggon (1978).

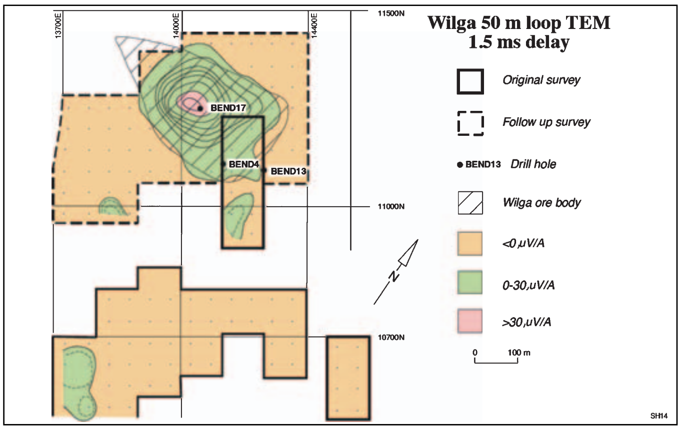


**Figure 6.** *Wilga 50 m loop, 1.5 ms. Selected drillholes and outline of the Wilga orebody (Rajagopalan and Haydon, 1999).*

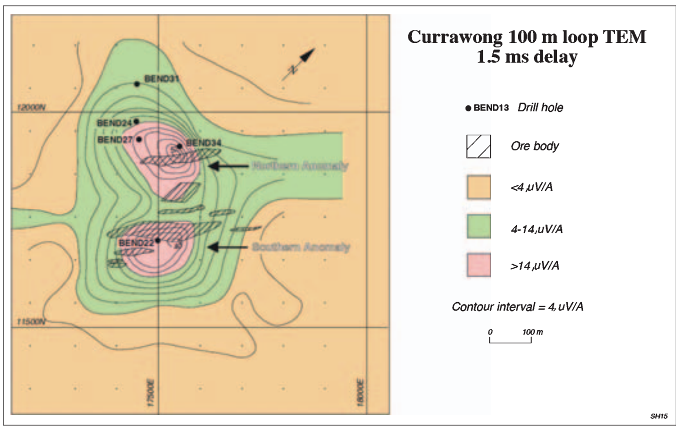


**Figure 7.** *Currawong 100 m loop, 1.5 ms. Selected drillholes and outline of the Currawong orebody (Rajagopalan and Haydon, 1999).*

## Depth sounding

In addition to profiling for exploration, early studies with the MPPO-1 investigated the potential of TEM for depth sounding. Lee and Lewis (1974), amongst others, derived expressions for calculating layered-earth responses for TEM systems, and it was known that the depth of investigation increased with sample time according to the diffusion equation, rather than the loop size.

For instance, it was understood from theory that with the 20 ohm-m overburden present at Elura, the orebody at a depth of 70 m should be first visible at 2 ms. However, loop-loop TEM systems detected an anomaly at much earlier times. Grid coverage revealed the presence of a shallow north-south surficial conductive zone in the soil, which was the cause of the loop-loop anomaly. Theoretically it should have been possible to detect Elura with a small multiturn loop, but the TEM response obtained with this geometry was found to result in unexpected 1/t decay at late times. This anomalous response was later found to be caused by viscous magnetisation in the soil.

Further depth sounding experiments with MPPO-1 equipment were carried out at Pooncarie and Pirlta in western NSW in a test TEM survey conducted jointly by BMR and Macquarie University in November 1975.

The depth sounding experiments led to development of two-layer master curves for field interpretation (originally an internal CSIRO report; later published as Raiche and Spies, 1981). As quantitative interpretation methods advanced, it became easier to distinguish between true inductive responses that could be used for depth sounding, and anomalous responses due to viscous magnetisation and IP effects, particularly with smaller loops.

## Model studies

Between field seasons, starting in 1973, the BMR's MPPO-1 was used extensively in scale model studies in BMR's basement to aid field interpretation. Multiturn loops ranging from ½ cm to 15 cm diameter were connected to the MPPO-1. A travelling carriage slowly moved the loop over the model and the output fed to a chart recorder (Figure 8). Models included Woodlawn and Gubberah Gossan with different loop geometries (Spies,

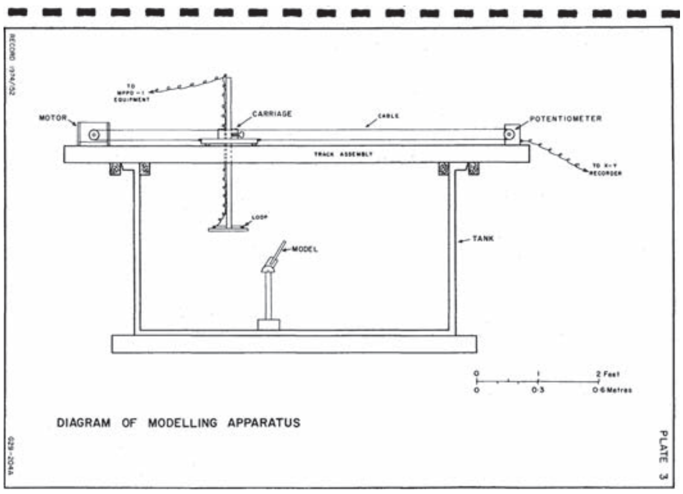


**Figure 8.** *Model setup at BMR using MPPO-1 (Spies, 1974b).*

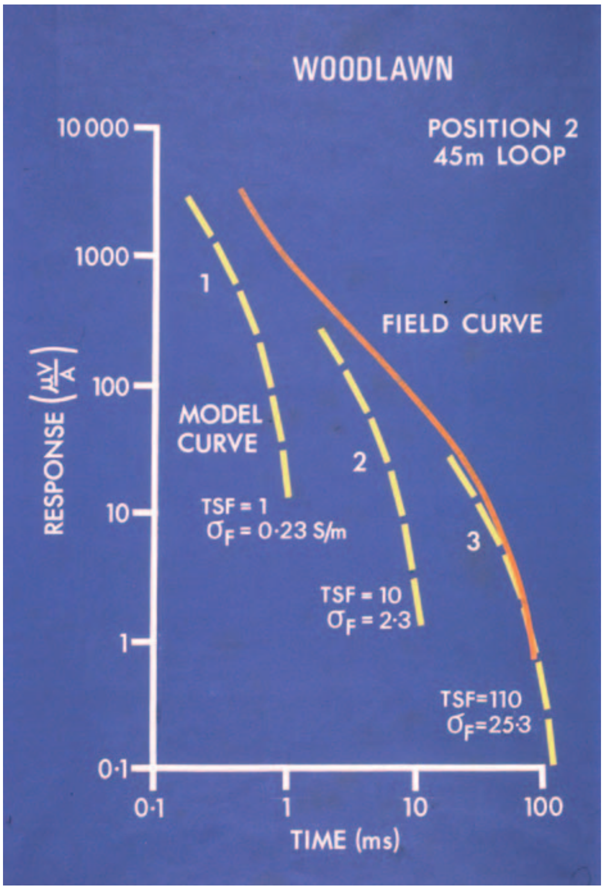


**Figure 9.** *Model and field results from Woodlawn. The average conductivity of the orebody was inferred to be 25 S/m (Spies, 1979).*

1974b, 1976) and tabular and dipping plates with the dual loop configuration (Spies, 1975).

Figure 9 shows a TEM decay curve obtained over the Woodlawn orebody with a 45 m loop (field curve) and data measured over a graphite model of the orebody (model curve). Using TEM scale modelling relations (Spies, 1977) with a time scaling factor (TSF) of 110, the average conductivity of the orebody was interpreted to be 25 S/m.

## Other uses of the MPPO-1

Unexploded ordnance (UXO) presents a major problem in much of the world. The BMR was approached by the Commonwealth Department of Construction to see whether TEM could be used to detect UXO at the old Majura Field Firing Range area, Gungahlin, ACT, which was to be developed as a police drivers training centre. The MPPO-1 was tested here, as well at Holsworthy near Sydney, using small multi-turn loops over a series of buried shells and compared with gradient magnetometers (Hill, 1978).

The dual-loop configuration referred to earlier was also tested in an attempt to cancel out the ground response. The tests demonstrated that in many areas magnetic methods were overwhelmed by variations in the magnetic properties of the soil, whereas TEM was relatively insensitive to changes in magnetic susceptibility in the subsurface and could successfully detect UXO to a depth of up to 1 m (Figure 10). (A note to the

**Figure 10.** *Ordnance detection with small multiturn loops, Port Botany.*

reader: These tests should have suggested to any entrepreneur the potential of TEM metal detectors for gold fossicking and treasure hunters, a market currently worth over $200m pa. Airport security screening is now a $5b market)!

## The rise of SIROTEM

Inevitably, Aussie knowhow and ingenuity challenged the scientists and engineers at CSIRO to develop a fully digital version of the MPPO-1 using modern electronics and digital signal processing. The rise of SIROTEM is expertly reported by Henderson (2014). The CSIRO Division of Mineral Physics, under the leadership and vision of Dr Ken McCracken, started investigations soon after the MPPO-1's arrival in 1972, and launched an AMIRA-funded project in 1975. Early SIROTEM prototypes were compared with the BMR's MPPO-1 in Cloncurry in 1974, and later at Woodlawn and Elura. Competition between the BMR and CSIRO was intense but friendly, spurring a decade of advances in TEM instrumentation, modelling, inversion and regolith petrophysics, as well as dozens of publications in peer-reviewed journals and a handful of higher degrees.

Perhaps the best ongoing legacy of the MPPO-1 is that it is still the only ground TEM instrument designed to use a single wire loop for transmitting and receiving. The single loop setup was efficient to use in the field – no separate receiver to put in the centre of the loop, and no second loop wire.

## Acknowledgements

This paper drew on the memories and contributions of valued colleagues; Roger Henderson, Jock Buselli, John Coggon, Les Starkey, and Kim Frankcombe, for which I am most grateful.

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## Biography

**Brian Spies** has held senior research and management roles in the mineral, petroleum and environmental sectors in Australia and the USA, including Chief Research Scientist at CSIRO and Director of Physics at ANSTO. His current research interests include the nexus between water, energy, climate change and the Australian economy. Recent publications include 'Sustainable water management: Securing Australia's future in a green economy' (ATSE), and 'The science and politics of climate change' (*Proc. Royal Soc. NSW*).

Brian has a degree in physics and geology from the UNSW and a PhD in geophysics from Macquarie University. He is a Fellow of the Australian Academy of Technological Sciences and Engineering (ATSE) and the Royal Society of NSW, and in 2003 was awarded the Australian Centenary Medal for his services to Australian geosciences. He is past-president of the ASEG and past vice-president of the SEG.