The use of Cole–Cole impedances to interpret the TEM response of layered earths

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Commonly used TEM (transient electromagnetic) sounding equipment such as Sirotem and EM-37, which measure the response of the earth 0.05–50 ms after source current turn-off, are usually considered to be high frequency devices whose voltage response should not be significantly affected by induced polarization effects. Thus inversion and forward modelling procedures usually assume real electrical resistivities. This implies that the Hankel transform of the time-domain layered earth impedance function, F(λ), is strictly non-negative, a property which can be used to stabilize and speed up model calculations. Thus, in the case of horizontally layered structures, excited by coincident loop or in-loop configurations utilizing ramp function turn-off, the TEM voltage decay curve must be of one sign (by convention, positive). A more general result (Weidelt 1982) showed that the TEM decay curve had to be of one sign for the coincident loop response to any physically reasonable, frequency independent distribution of electrical resistivity and magnetic permeability.

In fact, a number of TEM surveys carried out in Australia have observed negative responses for coincident loop and in-loop configurations; for example, Spies (1980). In most cases, the decay curves are initially positive, swing negative, and then asymptote to zero (Fig. 1).

Using Cole–Cole impedances with realistic values of chargeability frequency dependence and time constant it is possible to calculate model decay curves which are very similar to observed decay curves (Fig. 2). In this case F(λ) is positive for small values of λ and negative for large λ. The resulting IP process has a longer time constant than that of the EM inductive process. Thus, at 'early' times, the EM inductive process is dominant and the decay curve is positive. Whether or not the curve turns negative depends upon how resistive the earth is. For relatively conductive terrains, the decay curve is attenuated at 'late' times but remains positive as shown in Fig. 3. For resistive terrains the IP response can dominate the late time EM response, causing the negative portion of Fig. 2.

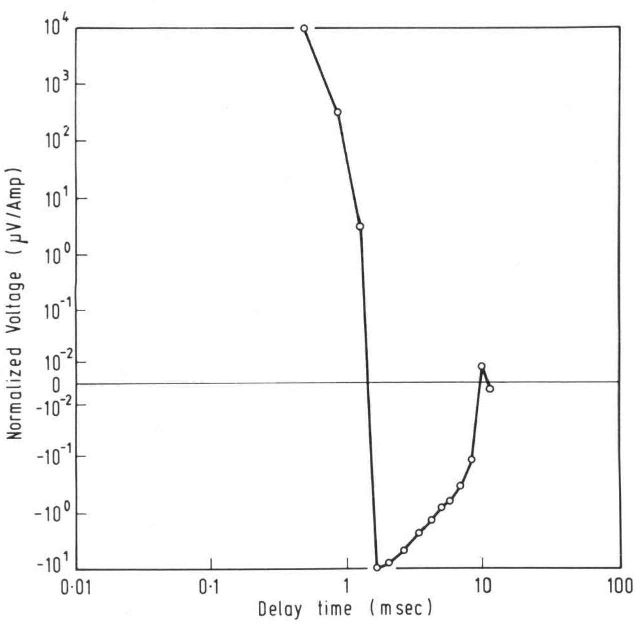

Fig 1 Field decay curve.

	Resistivity (Ohm-metres) R	Thickness (metres) h	Time constant (seconds) Tau	Frequency dependence c	Chargeability (Volts/Volt) m
1/2 SPACE	125·0	NA	0·0001	0·5500	0·4600

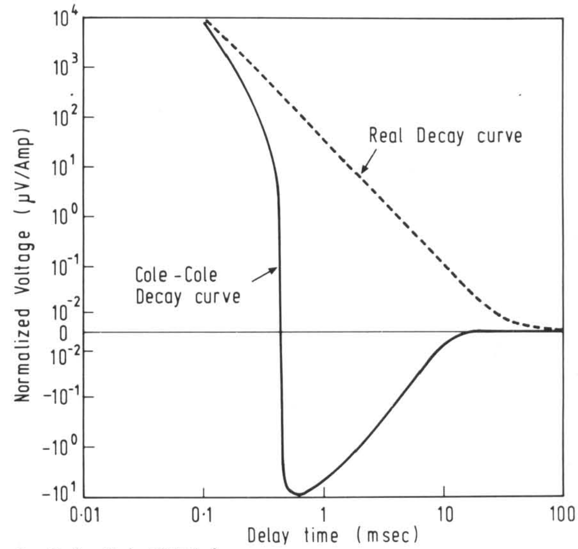

Fig 2 Cole–Cole TEM decay curve.

	Resistivity (Ohm-metres) R	Thickness (metres) h	Time constant (seconds) Tau	Frequency Dependance c	Chargeability (Volts/Volt) m
LAYER 1	160·0	50·0	0·0	1·0	0·0
LAYER 2	160·0	76·0	0·0061	0·30	0·416
BASEMENT	160·0	NA	0·0	1·0	0·0

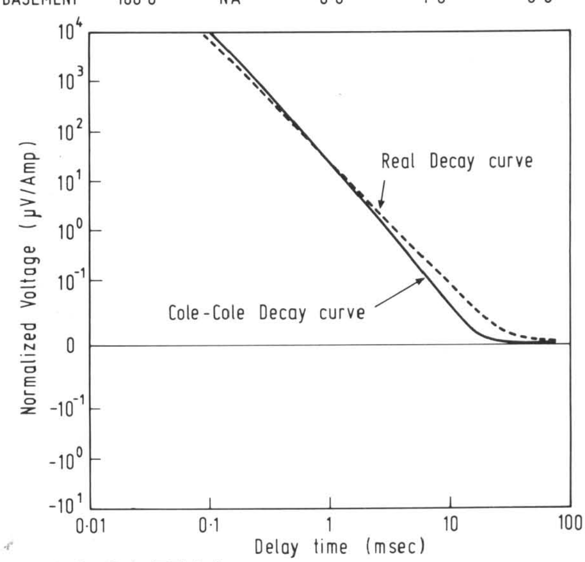

Fig 3 Cole–Cole TEM decay curve.

	Resistivity (Ohm-metres) R	Thickness (metres) h	Time constant (seconds) Tau	Frequency Dependence c	Chargeability (Volts/Volt) m
LAYER 1	100·0	10·0	0·0	1·0	0·0
LAYER 2	1000·0	60·0	0·003	0·16	0·4600
LAYER 3	1000·0	1000·0	0·0	1·0	0·0
BASEMENT	100·0	NA	0·0	1·0	0·0

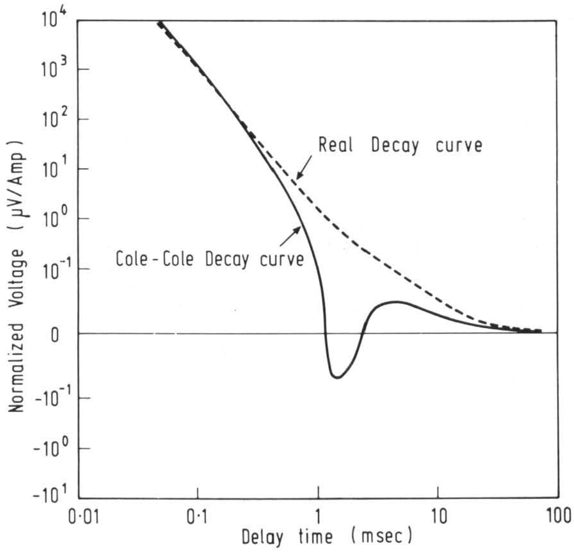

Fig 4 Cole–Cole TEM decay curve.

INVERTED SECTION	COLE-COLE SECTION
RES 1 = 142 OHM-M ; H1 = 88M	RES1 = 160 ; H1 = 50 ; TAU = 0 C = 1 ; M = 0
RES2 = 211 OHM-M ; H2 = 503M	RES2 = 160 ; H2 = 76 ; TAU = 0·0061 C = 0·3 ; M = 0·416
RESB = 1259 OHM-M	RESB = 160 ; TAU = 0 C = 1 ; M = 0

Fig 5

An interesting variation occurs in the case of a shallow polarizable layer in a resistive terrain containing a deeply buried conductive layer. For the model shown in Fig. 4, the TEM 'smoke ring' reached the conductive layer after the IP effects began to dominate the response. The late time EM inductive response was strong enough to cause a second positive branch in the decay curve. In practice, this effect is difficult to separate from instrument noise.

The fact that IP processes can significantly affect TEM data, without actually causing negative transients, presents a problem for layered earth inversion based on purely real resistivities. For example, an inversion of the data shown in Fig. 3, which ignored Cole–Cole parameters, produced the three layer model shown in Fig. 5 with a standard error of 2.7% and an average predicted residual error of 3.4% — in short, an apparently good inversion. The only clues that something was amiss were some rather strange correlations between model parameters. As a check, an inversion was performed on the model data from the non-Cole–Cole model which recovered the original model reasonably well.

All of the figures in this abstract were based upon coincident loop geometries. For TURAM geometries negative effects can be due to a mixture of geometrical and IP causes.

The conclusion is that the already difficult tasks of TEM modelling and inversion will have to assume a further degree of complexity when used to interpret data in areas where IP effects may be present.

References

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Weidelt P. (1982), 'Response characteristics of coincident loop TEM systems', *Geophysics* **47**, 1325–1330.

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The geophysics of the Olympic Dam discovery

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The central southern part of South Australia was one of a number of areas considered favourable for economic deposits of copper mineralization by WMC geologists in 1974 (Fig. 1). This area was far too large to be explored in detail. The process of ground elimination and target selections required the use of all the available geological and geophysical information.

The geological model was that of a sediment hosted copper deposit where the metal source was considered to be a thick pile of continental tholeiite basalt lavas; mobility was to be provided by hydrothermal fluids active during metamorphic alteration processes. This was translated into a geophysical model which consisted of a magnetic anomaly caused by the tholeiitic basalts and a gravity anomaly related to a horst block within the main basaltic mass. The object was to identify this situation within the geological province using the regional gravity and magnetic data.

Samples of Roopena Volcanics (of Willouran age) considered to be similar to the source rock, were obtained from exposures at Roopena Station and Depot Creek both close to Port Augusta. Measurements of magnetic susceptibility and density were made and compared to the same parameters measured on samples of Marinoan rocks (Whyalla Sandstone, Tregolana Shale, Corraberra Sandstone, Arcoona Quartzite, Tent Hill Formation). The susceptibility contrast was variable and related to the degree of alteration of the basalt samples, but a density contrast of 0.3 gms/cc was established with a greater degree of credibility.

The regional magnetics were first assessed with the object of locating a basaltic pile of sufficient thickness, lateral extent,

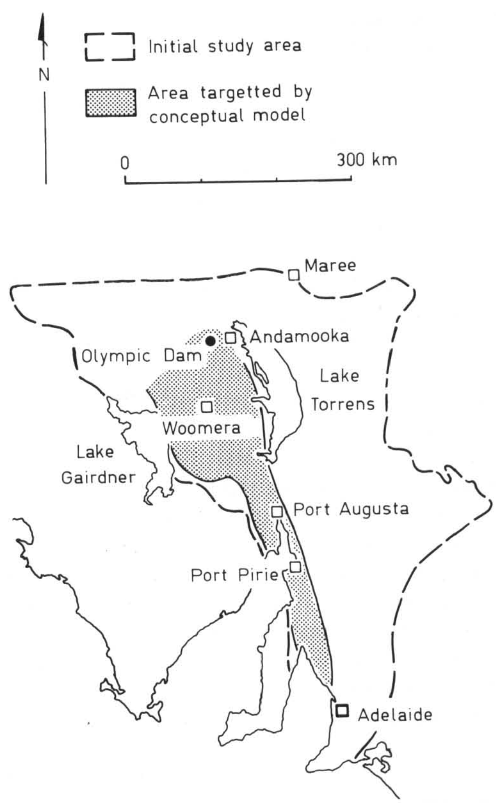

Fig 1 Location of Olympic Dam copper deposit and initial study area.