Stratigraphic mapping applications of TEM

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Introduction

While the TEM method has been mainly applied to base metal exploration, it has been increasingly used for stratigraphic mapping over the past few years. In particular, the technique may be applied to the delineation of saline soil layers, coal seams and oil shale deposits, and the detection of conductivity anomalies occurring in association with oil and gas deposits.

To permit more accurate inversion of the TEM response of near-surface layers, the measurement time range of SIROTEM has been extended earlier by one decade to 49 μs. The interpretation of data is carried out with the CSIRO-AMIRA one-dimensional inversion program, GRENDL.

The early-time SIROTEM system

The early-time TEM system developed at CSIRO consists of a new front end for SIROTEM, and measurements may be made with standard or early-time channels. The delay times and corresponding window widths for the two modes of operation are listed in Table 1. Data are sampled in time intervals of 49 μs, and then summed into channels which consist of one or more of these samples. This time resolution represents an eightfold increase compared to that of 392 μs used for the original SIROTEM sampling scheme. The first block of five channels has a width of 49 μs, and this width doubles for consecutive blocks of five channels. This provides a quasi-logarithmic time scale extending to approximately 20 ms at channel 32. Within the region where the early-time and standard SIROTEM sampling schemes overlap, the high density of narrower early-time channels permits a more accurate measurement of the shape of a rapidly decaying transient response.

The early-time SIROTEM system was initially tested with an analogue modelling system by using it to record the response of 50 mm diameter coincident loops over a uniform half-space modelled by a cube of aluminium measuring 30 cm on a side. With a scale factor of 2257, this corresponds to measuring the response of a 0.16 Ωm half-space with 100 m coincident loops. In the time range of approximately 0.1-1 ms, the response follows a $t^{-0.97}$ decay (where t is the delay time). This is close to the expected early-time decay of t^{-1}, as demonstrated in Fig. 1. At late delay times of about 50-100 ms, the response approaches a $t^{-5/2}$ decay, as expected theoretically (Fig. 2). Figure 3 shows an example of measurements of the transient response made with an early-time and a standard SIROTEM at a local test site with 100 m coincident loops. In the common time range of the two systems, the decay rate measured with the early-time SIROTEM is close to that measured with standard SIROTEM, while the amplitude is about 30% lower than that of standard SIROTEM. More accurate calibration since this field test has reduced the difference between the two modes of operation to less than 8%.

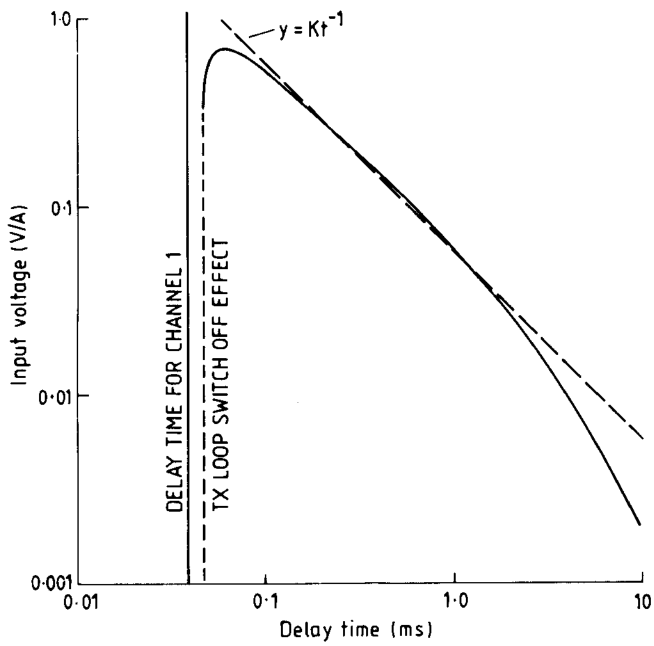

Fig 1 The transient decay curve measured in the laboratory using early-time SIROTEM to record data from 50 mm diameter coincident loops on a half-space modelled by an aluminium cube.

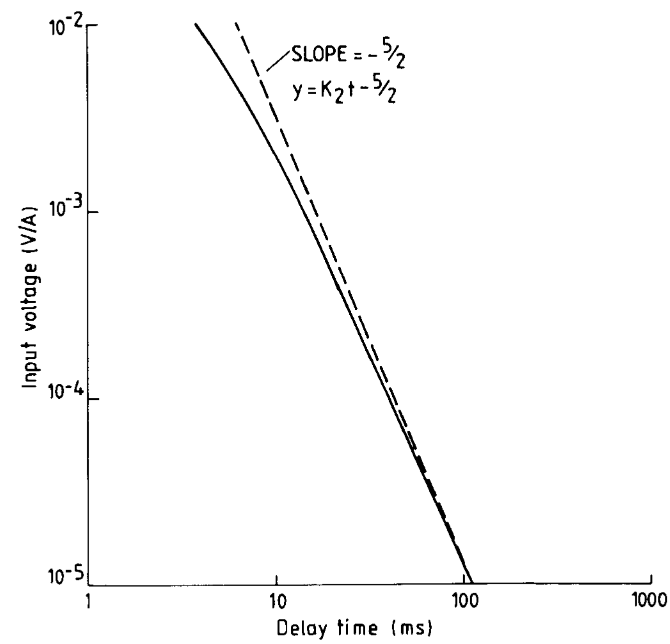

Fig 2 The transient decay curve measured at late delay times in the laboratory using standard SIROTEM to record data from 50 mm diameter coincident loops on a half-space modelled by an aluminium cube.

Stratigraphic modelling

The early-time SIROTEM improves the detection of the response of poorly-conducting but economic orebodies. The response of these may have reached noise level by about 1 ms, and would be detectable only in the earliest time channels of standard SIROTEM. Measurements with early-time SIROTEM may also be used for the mapping of 5-10 m thick shallow-dipping layers at depths of about 10-30 m. This application may be used for a number of different sounding problems such as the mapping of coal seams, oil shales, saline soil and groundwater, and for geoengineering.

To investigate what additional information on the geoelectric section of the ground may be obtained from early-time TEM measurements, mathematical modelling has been carried out assuming a one-dimensional stratified earth model. A number of such models has been run to test the effect of loop size, the depth and thickness of the buried layer, and the resistivity contrast between the layer and host rock. The CSIRO-AMIRA restricted programs CLRTEM and GRENDL have been used for this modelling. For each model, a forward calculation was made with program CLRTEM to generate the TEM response at each of the early-time delay times listed in Table 1. Random noise was added to the calculated voltages, which were then inverted with program GRENDL. Results of this study show that the early-time TEM measurements enable the depth to a buried layer and the resistivity of the covering layer to be resolved more accurately. In some cases, more accurate values of the thickness and resistivity of the buried layer may be obtained.

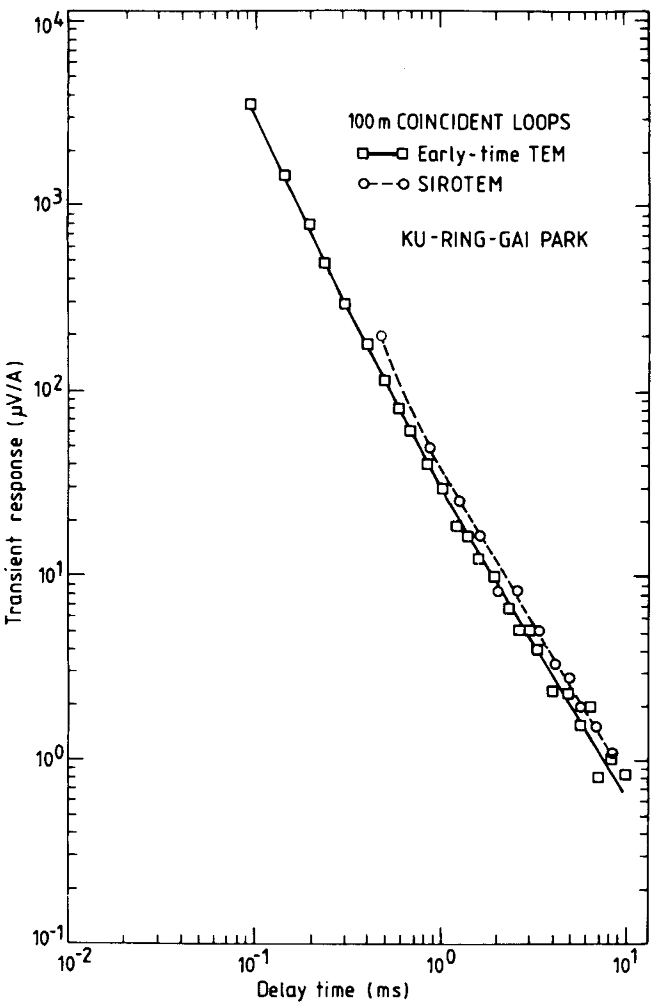

Fig 3 Comparison of the measurement of the 100 m coincident loop TEM response at a local test site with standard and early-time SIROTEM.

Table 1 Delay times and window widths for standard and early-time SIROTEM.

Channel	Standard SIROTEM Delay time (ms)	Standard SIROTEM Window width (ms)	Early-time SIROTEM Delay time (ms)	Early-time SIROTEM Window width (ms)
1	0.487	0.392	0.049	0.049
2	0.879	0.392	0.098	0.049
3	1.271	0.392	0.147	0.049
4	1.663	0.392	0.196	0.049
5	2.055	0.392	0.245	0.049
6	2.643	0.784	0.319	0.098
7	3.427	0.784	0.417	0.098
8	4.211	0.784	0.515	0.098
9	4.995	0.784	0.613	0.098
10	5.779	0.784	0.711	0.098
11	6.955	1.568	0.858	0.196
12	8.523	1.568	1.054	0.196
13	10.091	1.568	1.250	0.196
14	11.659	1.568	1.446	0.196
15	13.227	1.568	1.642	0.196
16	15.579	3.136	1.936	0.392
17	18.715	3.136	2.328	0.392
18	21.851	3.136	2.720	0.392
19	24.987	3.136	3.112	0.392
20	28.123	3.136	3.504	0.392
21	32.827	6.272	4.092	0.784
22	39.099	6.272	4.872	0.784
23	45.371	6.272	5.660	0.784
24	51.643	6.272	6.444	0.784
25	57.915	6.272	7.228	0.784
26	67.323	12.544	8.404	1.568
27	79.867	12.544	9.972	1.568
28	92.411	12.544	11.540	1.568
29	104.955	12.544	13.108	1.568
30	117.499	12.544	14.676	1.568
31	136.315	25.088	17.028	3.136
32	161.403	25.088	20.164	3.136

Field results

RESISTIVE LAYER

Murdoch (1982) has carried out an extensive study of the mapping of coal deposits with electrical methods. Results of this work indicate that fresh coal is a very poor conductor. In its weathered or altered state, the coal is gradually reduced to a wet or moist ash, containing a significant quantity of clay minerals and hence is often fairly conductive. In general, therefore, a fresh coal seam would not be expected to be directly detectable by TEM, but it may be possible to map the coal measures in which the seams occur, as these could be more conductive than the host rock. King (1985) quotes values of 0.01 Ωm for the resistivity of cindered coal, compared to 1000 Ωm for fresh coal, and presents examples of the detection of cindered coal seams at depths of ~350 m using surface TEM soundings. Dodds and Henderson (1981) have demonstrated the application of SIROTEM to the mapping of coal and oil shale deposits. They conclude that because variations in apparent resistivity of about 1 Ωm could be detected, the TEM method enables subtle variations associated with subcrop and fault zones to be mapped accurately. Such small variations in the apparent resistivity could not be detected with the DC resistivity method because they were obscured by the electrode contact noise of ~2-5 Ωm.

One test survey of early-time SIROTEM has been carried out over coal deposits in the Hunter Valley. Micrologs in coal blast holes indicate that the near-surface coal measures are a factor of 2–3 times more resistive than the host rock. From preliminary data analysis, a value of ~20 Ωm is obtained for the host rock resistivity, and therefore the resistivity of the coal seam lies between ~40 and 60 Ωm. Theoretical modelling shows that the thickness and resistivity of this coal seam cannot be resolved with the TEM method. As discussed by Raiche *et al.* (1983, 1985), the direct current (DC) sounding method is more sensitive to resistive layers than the TEM method. Where both TEM and DC sounding data are available, joint inversion of the TEM-DC data produces more accurate values of the model parameters than separate inversion of either the TEM or DC data.

CONDUCTIVE LAYER

SIROTEM soundings have been made at a groundwater-producing site in central Spain with 50 m coincident loops at two stations ~500 m apart. DC soundings made eight years previously in this area indicated the presence of resistive layers to a depth of ~60 m over a more conductive layer with a resistivity of ~20 Ωm. The apparent resistivities derived from the SIROTEM data decrease with delay time at both stations. A superparamagnetic response (Buselli 1982) would be a possible cause of this behaviour, but the environment is such that near-surface superparamagnetic (SPM) material is not expected in this area, and a t^{-1} decay which is characteristic of an SPM response is not observed.

When the TEM data from the two stations are inverted, the results show a conductive layer at a depth of (124 ± 4) m at one station and (130 ± 4) m at the other. The resistivity of this layer is (1.1 ± 0.01) Ωm at the first station, and (0.29 ± 0.05) Ωm at the second. These results are interpreted as indicating that an incursion of saline water has occurred at depth following continual pumping of the groundwater over the eight years following the DC sounding.

Acknowledgments

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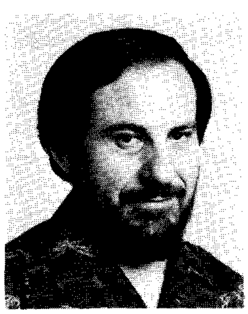

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