Generation of Conductivity-Depth Pseudo-Sections from Coincident Loop and In-Loop TEM Data

P. K. Fullagar
Western Mining Corporation Limited
P.O. Box 57, St. Marys, S.A., 5042
Australia.

Abstract

A computationally-efficient transformation has been developed to convert coincident loop or in-loop TEM profiles to apparent conductivity versus depth pseudo-sections. The transformation is based on the depth to the maximum physical current induced in a half-space, not on attributes of abstract current filaments. Tests on both synthetic and field data indicate that these pseudo-sections provide a useful qualitative portrayal of conductivity structure, thus facilitating first-pass interpretation of TEM in mapping applications.

Key words: TEM, apparent conductivity, pseudo-section, mapping, inversion, interpretation

Introduction

With the increasing use of TEM as a mapping tool it is often desirable to present the data in the form of conductivity sections. Traditional apparent conductivity versus time pseudo-sections have their place, but their interpretational value is limited by the highly non-linear time-depth relationship. Inspired by the work of Nabighian (1979), a number of depth conversion schemes have been or are being developed for various types of TEM data, based on the diffusion rate of secondary current in a homogeneous or layered half-space, e.g. Raiche & Gallagher (1985), Macnae and Lamontagne (1987), Nekut (1987). A depth conversion procedure of this ilk for coincident-loop or in-loop TEM is described below. The procedure is novel insofar as it is based on the position of the physical current maximum in a half-space rather than on properties of abstract current filaments. Tests on synthetic data reveal that computed depth estimates are reasonably accurate. This is borne out in field data examples where structures inferred from conductivity-depth pseudo-sections have been confirmed by drilling.

Voltage-Time to Conductivity-Depth Transformation

A conductivity and depth are assigned to each TEM channel as follows: the conductivity is the conventional apparent conductivity σ_a and the assigned depth is the depth to the physical current maximum at the delay time in question for a half-space of conductivity σ_a. This approach is most closely allied to that proposed by Raiche and Gallagher (1985). However, whereas Raiche and Gallagher adopted the depth of maximum $|\frac{dB}{dt}|$ as their measure of penetration depth, the depth at which $|E|$ (and hence current) is maximum has been adopted here. For a horizontal current filament, $|E|_{max}$ and $|\frac{dB}{dt}|_{max}$ both occur in the plane of the filament, but for the distributed current system actually generated in a half-space, $|E|_{max}$ and $|\frac{dB}{dt}|_{max}$ do not occur at the same depth. The depth of $|\frac{dB}{dt}|_{max}$ corresponds approximately to the depth of the single filament which best replicates the observed magnetic field at the surface. This "equivalent current filament" with infinite current density must always lie below the maximum of the actual distributed current system. This is borne out by Nabighian's observation that the current density maximum for a rectangular loop (2:1 aspect ratio) migrates downward at an angle of 30° to horizontal, whereas the equivalent filament moves down at 47°. It may be concluded, therefore, that depths assigned according to $|\frac{dB}{dt}|_{max}$ will exceed those based on $|E|_{max}$. Hence the "penetration depths" derived by Raiche and Gallagher were excessive because they were more indicative of the "equivalent current filament" depth than of the penetration of physical current.

Coincident-loop TEM is well suited to apparent conductivity-depth transformation because apparent conductivity is unique. Physically, the uniqueness is a consequence of the fact that the decay is always monotonically decreasing for a simple conductive ground (Weidelt, 1982). Similarly, coil-in-loop TEM response is monotonically decreasing except at very early time. For readings with a small coil at the centre of a circular loop, it can be shown that the half-space decay is monotonically decreasing for

$$\tau = \frac{t}{\sigma\mu R^2} > 0.096$$

where t is delay time, σ is conductivity, μ the permeability, and R the loop radius. Since the response is almost constant for $\tau < 0.096$, coil-in-loop data can be uniquely transformed to apparent conductivity-depth form in all but pathological cases. More generally, whenever transmitter and receiver are separated, apparent conductivity is non-unique. Macnae and Lamontagne (1987), for example, attempt to overcome non-uniqueness in UTEM apparent conductivity with three-fold data redundacy.

Examples

The application of the $|E|_{max}$ transformation to theoretical coincident loop SIROTEM data is illustrated in Figures 1 and 2. The apparent conductivity curves provide a good qualitative indication of the true variation of conductivity with depth, even in the second case which exhibits "overshoot" (Raiche and Spies, 1981), causing a decrease in apparent depth with delay

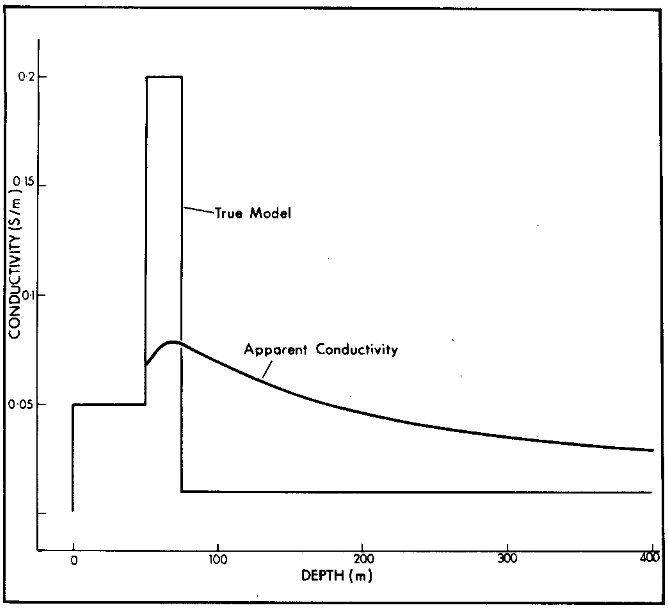

FIGURE 1
Layered conductivity model and the corresponding apparent conductivity versus depth curve derived from theoretical 200m coincident loop SIROTEM data. The apparent conductivity profile provides an accurate indication of the depth of the conductive layer.

time. Such "depth reversals" can be readily identified and removed; SIROTEM channels 9–18 (5.0 – 21.9 ms) have been rejected in Figure 2. Physically the spurious apparent conductivities and depths in this case are related to the effective confinement of current within the highly conductive surface layer.

An example of pseudo-section generated from 100m coincident loop field data is shown in Figure 3. Loops have

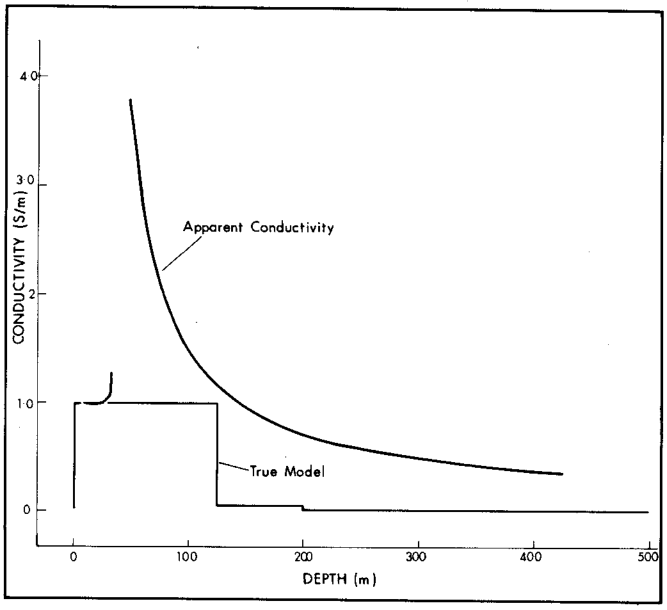

FIGURE 2
Layered conductivity model and the corresponding apparent conductivity versus depth curve derived from theoretical 800m coincident loop SIROTEM data. Channels 9-18 have been disregarded due to "overshoot" (Raiche & Spies, 1981). Interpolated, the conductivity-depth values for the retained channels provide a strong indication of high conductivity near-surface.

been read every 50m. The objective in this case was to map the unconformity surface between cover sediments and the Archean. Drilling results confirm the basic topography defined by the pseudo-section. The different rates of diffusion in conductive and resistive ground are reflected in the apparent depths assigned at early times along the profile.

The conductivity-depth transformation casts raw data into a convenient form for presentation and initial interpretation, but is not an inversion technique in the strict sense. The distinction is illustrated in Figure 4, where the apparent conductivity curve is plotted against a model generated via 1D inversion of the same 200m coincident Sirotem loop decay (27 channels; 0.5 – 80 ms). No geological validity can necessarily be ascribed to inidividual layers in the model. The apparent conductivity profile is consistent with the inversion model, insofar as it defines a low-high-medium variation over the first 150m, and is similar in shape to the average conductivity versus depth profile (Figure 5) derived via Backus-Gilbert (BG) resolution analysis (Fullagar, 1983). Since the BG average conductivity curve provides an indication of the conductivity variations actually resolved by the data, its similarity to the apparent conductivity profile augurs well for the utility of the $|E|_{max}$ transformation. "Ground truth" in the form of a geological log from a hole drilled on the edge of the loop indicates transported sand and residual clays in the first 48m, underlain

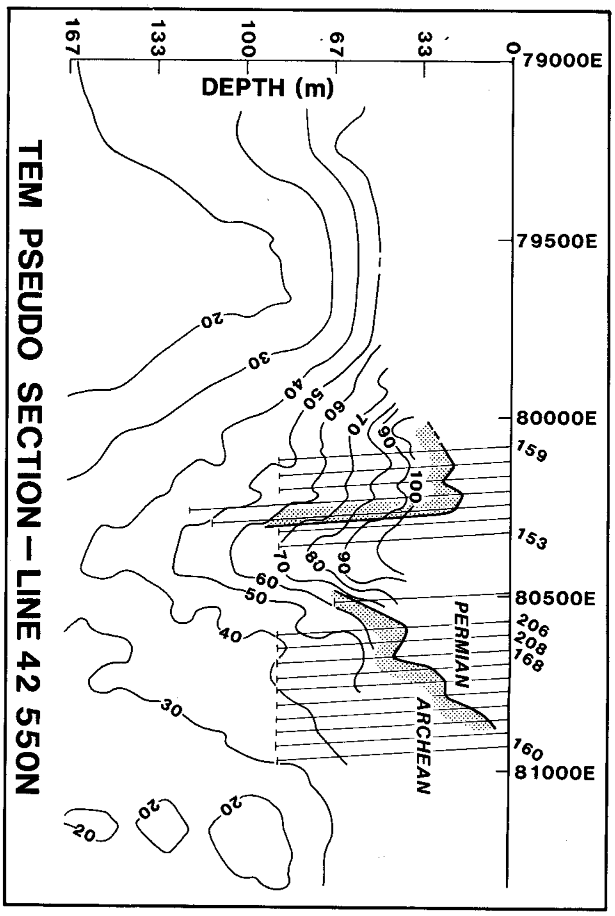

FIGURE 3
Conductivity-depth pseudo-section for 100m coincident loop SIROTEM field profile. Contour interval is 10 milli S/m. Examination of the section suggests a trough containing sediments, centred at 80400E. This was subsequently confirmed via percussion drilling (holes 153–159, 160–168, 206, 208). The unconformity surface is indicated with shading.

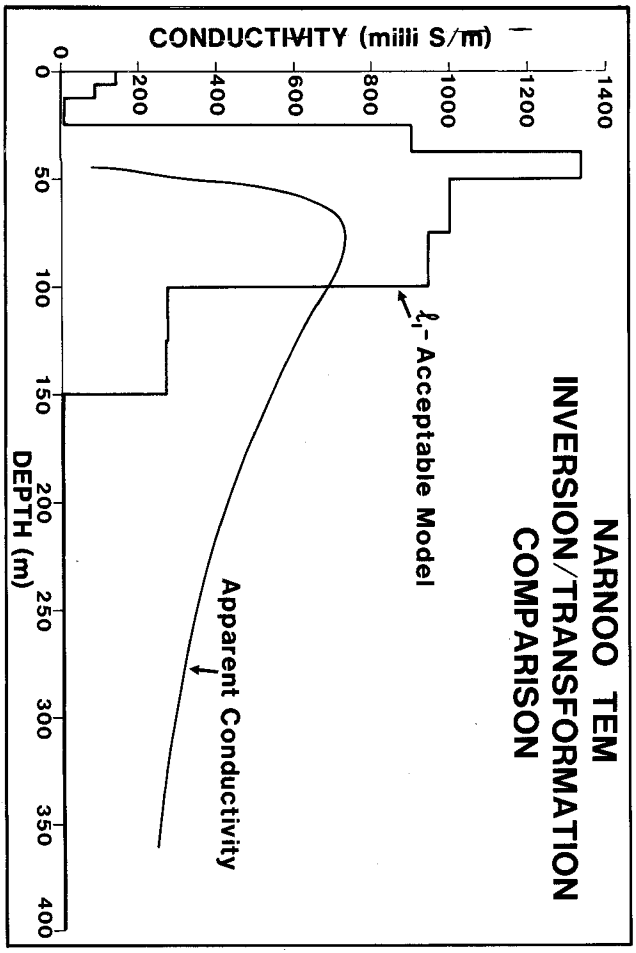

FIGURE 4
Comparison between a conductivity model constructed via inversion and the corresponding apparent conductivity profile for 200m coincident loop SIROTEM field data. The two representations of conductivity structure are qualitatively consistent.

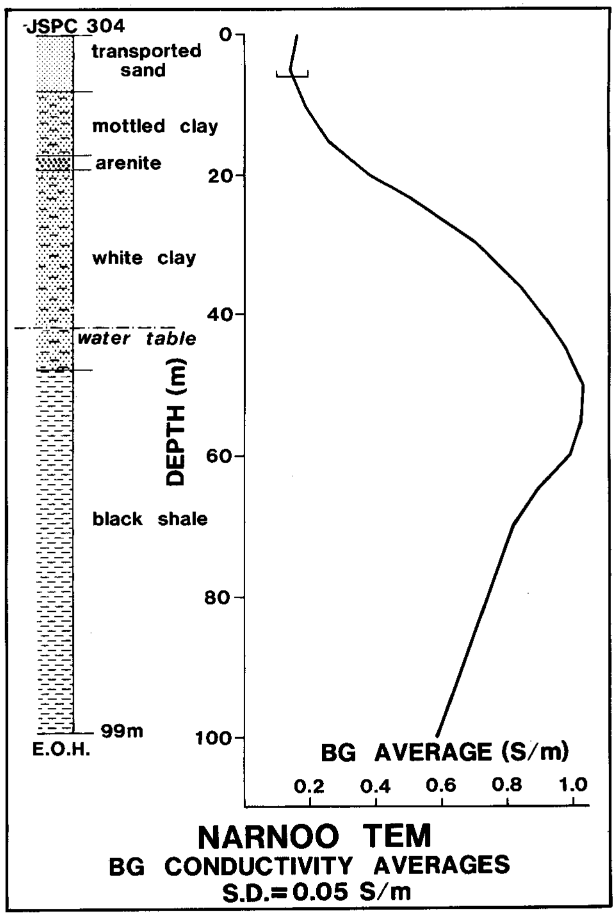

FIGURE 5
Backus-Gilbert (BG) conductivity averages with standard deviation 0.05 S/m (error bar) for the model in Figure 4; note similarity to the apparent conductivity is attributed to saline groundwater in weathered shale.

by a black shale (saprolite) zone extending to EOH at 99m (Figure 5). Saline groundwater was encountered at 42m. Thus the conductivity maximum near 55m is presumably related to saline groundwater in porous, permeable weathered shale.

Conclusion

A computationally-efficient transformation has been developed to convert coincident loop or in-loop TEM profiles to apparent conductivity versus depth pseudo-sections. Tests on both synthetic and field data indicate that these pseudo-sections provide a useful qualitative portrayal of conductivity structure, thus facilitating first-pass interpretation.

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