The Inversion of Magnetotelluric Data and the Elimination of Topographic Effects Through Modeling

(A comparison of 1-D and 2-D Inversion Models)

This study applies to all magnetotelluric data, whether they are collected as Controlled Source Audio-frequency Magnetotelluric (CSAMT), Natural Source Audio-frequency Magnetotelluric (AMT) or as lower frequency Magnetotelluric (MT) data. Models shown in this study are based on AMT frequencies. TM-mode and TE-mode AMT results are compared and discussed.

Rough topography may cause severe distortion in imaging based on AMT data acquired with the electric field oriented perpendicular to geologic strike, ie. TM-mode data [1-3]. Topographic peaks create high-angle conductive distortion while topographic valleys create high-angle resistive features in TM-mode AMT data. Topographic distortions will be carried through to produce high-angle conductive or resistive artifacts in inversion models unless the imaging procedure accounts for the distortion. **SCSINV** 1-D resistivity-depth images are affected by 2-D topography, while **SCS2D** 2-D inversions with models including a topographic profile do not.

TE-mode magnetotelluric data, with the electric field oriented parallel to geologic strike, is distorted less by 2-D topography than is TM-mode data. However collecting TE-mode is generally impractical when collecting closely spaced data along survey lines oriented perpendicular to geologic strike. Continuous AMT production is optimized when electric-field dipoles are positioned along survey lines to collect TM-mode data. In contrast, aligning electric-field dipoles perpendicular to survey lines to collect TE-mode data is time consuming (and expensive). As a result, most closely sampled AMT data are collected in the scalar TM-mode. Consequently, this paper focuses mostly on the effects of topography upon the interpretation of TM-mode AMT data, although some TE-mode results are included.

The starting point for the comparison is to produce a test data set with known geology and topography. The forward modeling program **EM2D** produced synthetic field data for the two idealized geologic sections shown in Figure 1. The second step of this comparison is the **SCSINV** inversion program, which produces an image stitched together from a series of 1-D models based on a layered earth, and shown as a “flat” earth projection with the vertical scale being depth. The third step of this comparison is the **SCS2D** inversion program, which produces a 2-D image that successfully eliminates the effect of topography when inverting these synthetic AMT-mode magnetotelluric data.

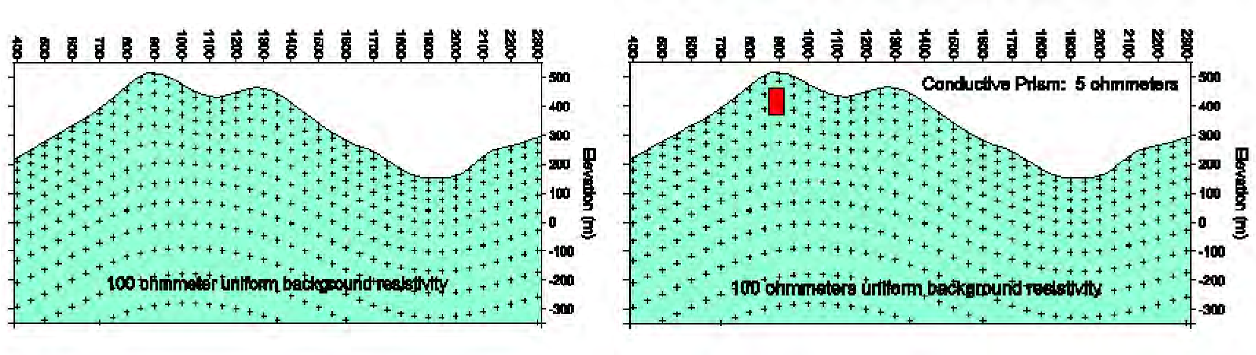

Figure 1: Topographic Profile

Model cross-sections used to produce the synthetic TM-mode Cagniard apparent resistivity and impedance phase pseudosections shown in Figures 2 and 3.

Topography for this example is taken from an actual field project in Papua, New Guinea. It is instructive to compare this AMT study, and compare results with a Zonge paper titled "Two-dimensional Inversion of Resistivity and IP Data with Topography", which is based on synthetic data using the same topographic profile.

The Zonge **EM2D** 2-D forward model was used to synthesize the AMT data shown in Figures 2 and 3, based on the topographic profiles and idealized resistivity sections in Figure 1. These resistivity model sections represent "known" geology. On the right panel of Figure 1, the small conductive prism (in red) represents a near-surface geologic target. **EM2D** is able to synthesize TM–mode and TE-mode AMT data for arbitrary 2-D resistivity model sections.

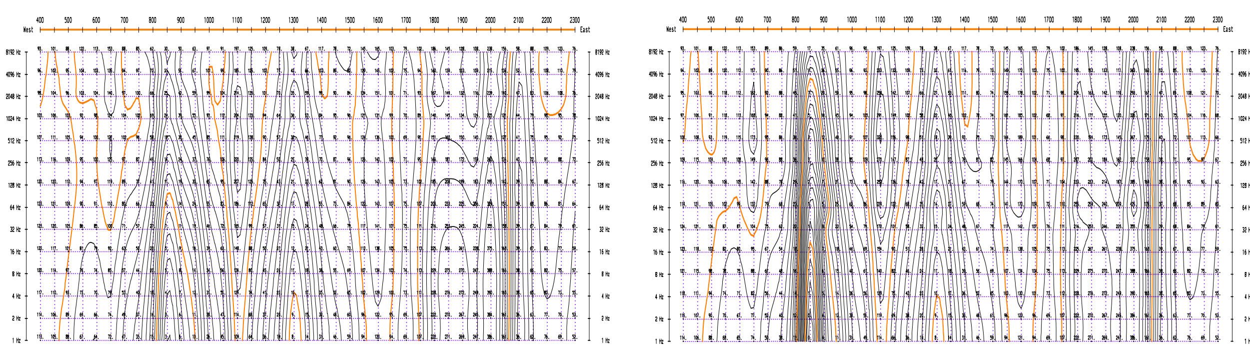

Figure 2: Cagniard TM Resistivity Pseudosections

Synthesized TM-mode Cagniard apparent resistivity pseudosections show strong correlation with topographic "peaks" and "valleys", obscuring the near-surface conductive prism located on the right panel. The vertical axis is frequency, from 1 Hz at the bottom to 8192 Hz on top.

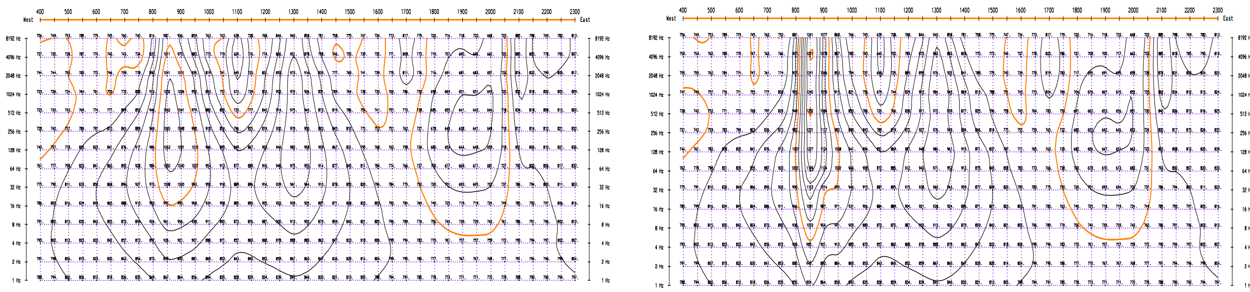

Figure 3: TM Impedance Phase Pseudosections

Synthesized TM-mode Cagniard impedance phase pseudosections also show strong correlation with topography. The impedance phase response to topography only in the left panel indicates that apparent resistivity sounding curves can be distorted by topographic effects, not merely offset by a constant multiplier (static shift).

The one-dimensional **SCSINV** inversion process assumes a flat earth with layered geology under each site. **SCSINV** inversion of the test data set produces images with high-angle conductors under peaks and high-angle resistors under valleys (Figure 4). The intensity of the distortion is proportional to topographic profile curvature. Responses associated with topography are clearly seen on the left image with the high-angle resistive feature (shaded in blue) coincident with the valley centered on station 1950. High-angle conductive features (shaded in red and yellow) are located under topographic peaks at stations 900 and 1300. Conductive and resistive features, imaged on Figure 4's left panel, are artifacts generated by topographic effects and these features are also imaged on the right panel. In comparing the left and right panel images, it would be difficult to reliably predict the presence of the conductive prism beneath station 900 based on 1-D modeling alone.

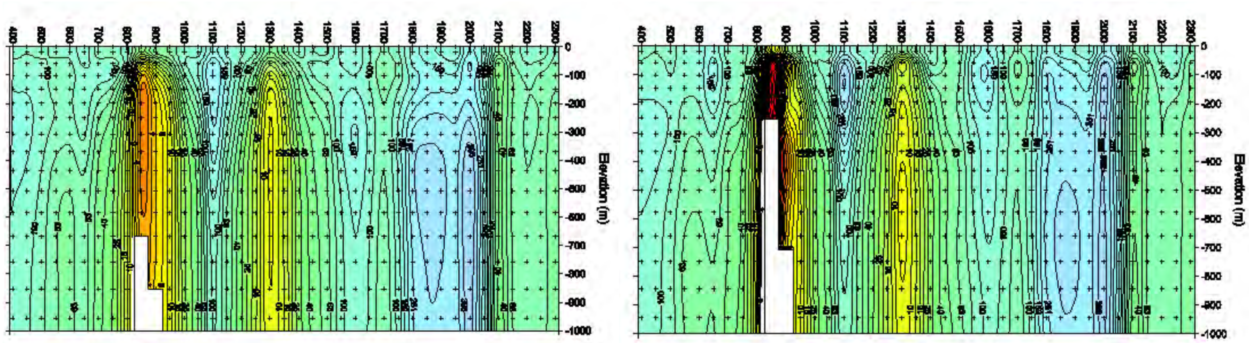

Figure 4: SCSINV 1-D Inversion Model

Inversion of the synthetic test data with the 1-D inversion program SCSINV does not account for topographic effects and produces images with residual artifacts. As SCSINV assumes a layered geologic half-space, TM or TE mode data are treated in the same manner.

Figure 5 shows images created using 2-D imaging without topography. These are 2-D inversion models without the benefit of terrain corrections. Although the two-dimensional inversion program **SCS2D** is able to model high-angle features and geologic edged contacts, without topographic corrections these images are distorted. Using TM-mode AMT data it would be difficult to predict the presence of the conductive prism below station 900 from the images in Figure 5, where topographic effects effectively mask the conductor.

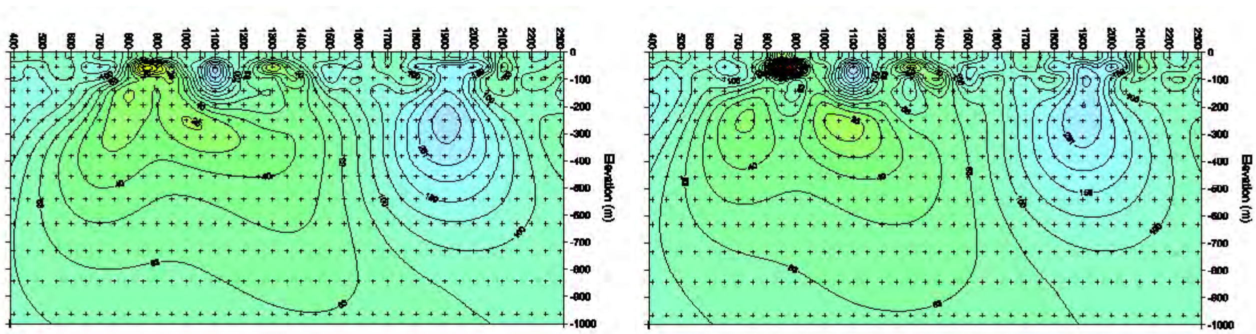

Figure 5: TM-mode SCS2D 2-D Inversion Model Without Topography

Images generated by the 2-D inversion of TM-mode AMT data without including topography in the model.

The 2-D images shown in Figure 6 easily identify the conductive prism from the original model sections used to create the synthetic data set.

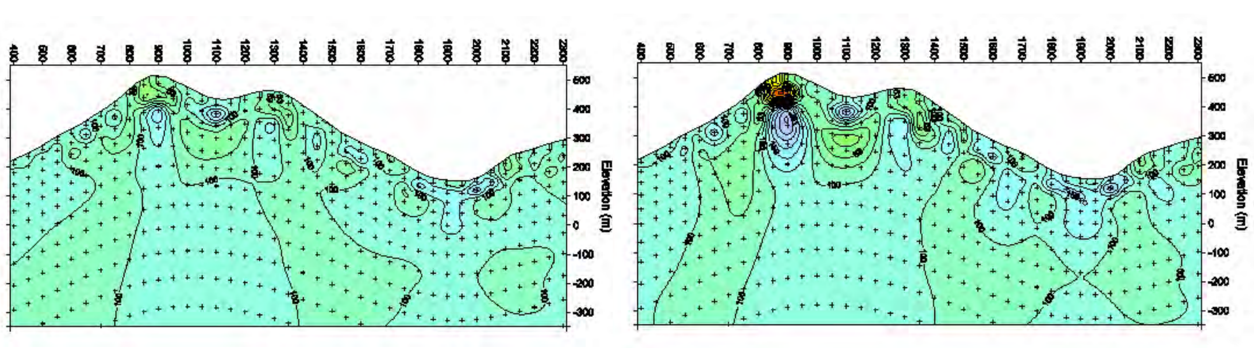

Figure 6: TM-mode SCS2D 2-D Inversion Model With Topography

Images generated by the 2-D inversion of TM-mode AMT data with topography included in this model. 2-D inversion of TM-mode data with topography does a better job of recovering the original geologic section.

Clearly the **SCS2D** 2-D inversion program (Figure 6) images the conductive prism below the peak centered below station 900 on the right panel in Figure 2. Conductive and resistive artifacts related to 2-D topography are minimized. While this case study shows that the **SCSINV** 1-D inversion may be unreliable in identifying geologic features in steep terrain, experience shows that this 1-D inversion may be more sensitive than 2-D imaging when mapping near-surface features that may be thin and steeply dipping. In practice, reviewing both **1-D** and **2-D** imaged sections is recommended, as differences between the **1-D** and **2-D** modeled sections may provide additional insight useful for interpretation.

Nevertheless, **SCS2D** 2-D imaging successfully removes much of the ambiguity in interpreting TM-mode AMT electromagnetic data, such as collected with controlled source CSAMT and natural source AMT surveys. **SCS2D** 2-D imaging has been found especially useful when imaging TM-mode data collected in severe topography, and equally important, when the influence of surface geology on the resolution of deep features is critical.

The **EM2D** forward model is also able to produce TE-mode AMT data. When these TE-mode scalar data are imaged with the **SCS2D** inversion the conductive prism is clearly imaged.

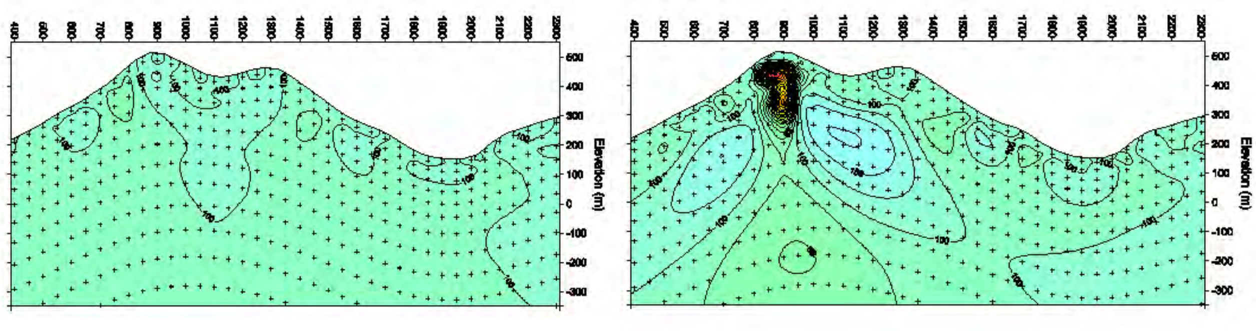

Figure 7: TE-mode SCS2D 2-D Inversion Model With Topography

Images generated by the 2-D inversion of the synthetic TE-mode data with topography included.

When collecting AMT data in a decidedly more complex 3-D topographic environment, it may be useful to selectively include TE mode data in 2-D inversions to help resolve ambiguities in identifying resistive or conductive geologic targets. Topographic ridges generate TM-mode apparent resistivity lows and weak TE-mode apparent resistivity highs, while the resistive response of subsurface geologic features is unchanged. The combination of TM and TE data with opposite topographic effects may help conclusive identification of geologic features versus topographic artifacts where survey lines cross ridge tops or valley bottoms.

In this discussion, the ability to use the **SCS2D** inversion of TM-mode data to effectively identify conductive and resistive targets in rough terrain is demonstrated. This is practical to the explorationist because logistics for the acquisition of scalar TM-mode CSAMT or AMT data are very efficient, especially when continuous coverage is required. In some cases, the more complex collection of tensor AMT data can be selectively employed where survey needs justify the added cost. If available, TE-mode data can be combined with TM-mode data and inverted to a single resistivity image. **SCS2D** 2-D inversions with topography of either TM-mode, or combined TM & TE data, minimize the problem of image artifacts due to topographic effects.

*Note: **EM2D**, **SCSINV** and **SCS2D** are all modeling software developed and marketed by Zonge. These modeling software are routinely used at Zonge for the interpretation of Controlled Source Audio-frequency Magnetotelluric (CSAMT), Natural Source Audio-frequency Magnetotelluric (AMT) and lower frequency Magnetotelluric (MT) data. Additional information about these software programs can be obtained from:*

Zonge International

3322 East Fort Lowell Road, Tucson, AZ 85716 USA
Tel: (520) 327-5501 Fax: (520) 325-1588 Email: zonge@zonge.com

References Cited

[1] Ku, C.C., Hsieh, M.S., Lim, S.H., 1973, The topographic effect in electromagnetic fields, Can. J. Earth Sci., v10, p645-656

[2] Reddig, R.P., and Jiracek, G.R., 1984, Topographic modeling and correction in magnetotellurics, presented at the 54th Ann. Internat. Mtg. Soc. Explor. Geophys., abstracts and biographies, 44-47.

[3] Wannamaker, P.E. and Stodt, J.A., Rijo, L., 1986, Two-dimensional topographic responses in magnetotellurics modeled using finite elements, Geophysics, v51, p2131-2144.