Processing of Magneto Telluric Sounding Data for Pseudo Depth Sections

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Summary

Very broad band of natural magneto telluric (MT) signal with signal penetration determined by the skin depth provides MT method capability to probe shallow and deep features equally well albeit with decreasing resolution as the depth increases. We used a new processing scheme involving second derivative of the apparent resistivity curve to enhance the effects of thin conducting layers in continental crust at different depths which are otherwise masked in conventional resistivity pseudo sections. Since the second derivative of apparent resistivity curve exhibits a peak/ trough for each interface, the configuration of an interface can be easily marked in a seismic-like plot of these data. Analyses of synthetic data over three different models, viz., Deccan Trap, India, Rhine Graben-Black forest region, Germany and a fold belt demonstrate the potential of the scheme developed.

Introduction

The natural-source magnetotelluric (MT) method records signal in a very wide band of frequencies, e.g., frequency as large as ~20 KHz to period as long as ~50000 seconds with the measurable frequency band increasing rapidly. The Audio MT (AMT) method, records signal in audio range (~20 KHz- 10 Hz), and is being used for geothermal and mineral exploration. It is also a very effective tool for detecting economic (electrically conducting) mineralization zones at depths greater than 500 m. (Chouteau et al.,1997). At lower frequencies, the MT method has found widespread applications in delineating deep structures and determining the physical properties of the continental crust, lithosphere and the upper part of the asthenosphere.

The MT technique has a unique advantage in depth probing over all other geophysical methods due to the phenomenon of characteristic attenuation (skin depth). But, the resolution decreases with depth due to the intrinsic 'low pass' character of the earth the filter. Thus, one can use the same processing, analysis, modelling and inversion tools to tune MT data for any depth of interest. Although the MT method is an integrating method, like potential field methods, it does not suffer from intrinsic non-uniqueness. Two uniqueness theorems were established as early as the 1970s (Weidelt, 1972) for the case of perfect data from an 1D layered earth in which the conductivity varies with depth. Equivalent uniqueness theorems for conductivity varying with depth and in one lateral direction (2D case) have also been shown to exist (Jones et al., 1987). Accordingly, non-uniqueness in MT is associated with error, insufficiency and sparseness of observed data. Further, Jones et al., (1987) addressed the issues of resolution and uniqueness of the MT method by demonstrating that *a priori* information (data) or joint inversion can constraint otherwise poorly-posed problems.

Recently, Xiang (1997) used the greater resolving power of second vertical derivatives, to resolve the presence of a thin resistive layer sandwiched between two conducting layers from the observed MT apparent resistivity data.. We extend the idea for elucidation of deep crustal structures over three typical situations in continental crust, viz. (i) Deccan Trap, (ii) Rhine Graben-Black forest area and (iii) a typical fold belt. We simulated the MT responses over these situations using 2D forward modeling and computed the second vertical derivative to prepare pseudo depth sections. These depth sections clearly brings out the structures which were masked in apparent resistivity sections.

Theory

Second derivatives of observed potential field data have been used extensively to enhance weak signals masked in presence of strong regionals/ interferences (Blakely, 1995) although, such processings are not commonly performed on MT data. There are several schemes to compute second derivatives from a set of observed data. We used the following formulation.:

$$\mathbf{s} = \mathbf{G}\mathbf{d} \tag{1}$$

where
$\mathbf{s}^T = [s_1, s_2 ..., s_{n-2}]$ represents the second derivative,
$\mathbf{d}^T = [d_1, d_2 ..., d_n]$ is the logarithm of the observed apparent resistivity data.

and

$$\mathbf{G} = \begin{bmatrix} -1 & 2 & -1 & 0 & 0 & \dots & 0 \\ 0 & -1 & 2 & -1 & 0 & \dots & 0 \\ 0 & 0 & -1 & 2 & -1 & \dots & 0 \\ \vdots & & \ddots & & & & \vdots \\ 0 & 0 & \dots & & -1 & 2 & -1 & 0 \\ 0 & 0 & \dots & & 0 & -1 & 2 & -1 \end{bmatrix}.$$

has a dimension (n-2) x n.

The second derivative of, an MT apparent resistivity data plotted against frequency/ period on log-log scale possess the following general properties:

(i) It is positive at a point where the 'curve' concaves up.
(ii) It is negative at a point, where the 'curve' concaves down and
(iii) it vanishes at an inflection point where the 'curve' has a transition from concave up to concave down or vice versa.

Thus, the total number of peaks and troughs in a second derivative profile indicates the number of interfaces in the subsurface.

Examples

We considered three typical resistivity structures over continental crust and computed apparent resistivity at multiple sites using finite element algorithm of Wannamaker (1989). Subsequently, we used equation (1) to compute the second derivative of the apparent resistivity curve.

Deccan Traps

About 250,000 km^2 of the Western peninsula of India are covered with fissure erupted basaltic magma and the region is referred to as the Deccan Traps. The Deccan Traps is electrically conducting but highly heterogeneous and overlies relatively more conducting mesozoic sediments prospective for hydrocarbon accumulation. The heterogeneity of the trap results in large scale scattering of propagating seismic waves posing a great challenge to conventional seismic method in mapping these sediments. MT method can map the sediments because these have resistivities higher than the traps. We considered a conceptual model (Singh et al., 1984) of the area with the resistivity and the thickness of trap assumed as 50 ohm-m and 1.2 km respectively (Figure 1a). The salient feature of this model (Table 1) is that, the thickness of the trap is kept fixed with the trap/sedimentary boundary horizontal whereas the thickness of the sediments increases from 1 km in the northern end to 5 km along the southern end corresponding to a slope of 1:3 for the interface separating the sediments from the basement. The apparent resistivity was computed over 25 stations at equal intervals along a 15 km long profile for frequency range 0.01- 667 Hz. Figure 1b shows the pseudo depth section in which the apparent resistivity data is plotted against the logarithm of frequency. It could be seen that neither the presence of the sediments nor the dip of the basement surface could be seen clearly in this pseudo depth section. We now display in figure 1c the second derivative of the apparent resistivity data in the form of a pseudo depth section using a variable area plot. It is interesting to note that Figure 1c not only indicates the presence of two interfaces, but it also displays the slope of the interface properly, viz., the shallow interface is horizontal and the deeper interface, i.e., the basement surface is dipping towards south.

Rhine Graben-Black Forest Region

We selected the electrical structure in the Rhine Graben- Black forest region, Germany (Strack et al., 1990) Wihelm et al., 1989) to compute the (MT) apparent resistivity over 20 stations at equal intervals along a 40 km long profile for frequency range 0.0001 Hz to 80 Hz. Rhine Graben has around 1.0 km thick sediments but no mid-crustal conducting zone. On the other hand, Black forest region has a thin (~ 1km) mid crustal conducting zone at around 12 km depth but is devoid of sediments at the surface (Figure 2a). The crustal resistivity is 1000 ohm-m while the upper mantle resistivity is about 10 ohm-m. The moho is reported at 38 km The apparent resistivity section

Table 1: Parameters of a conceptual model depicting resistivity structure in Deccan Trap

Layer	Apparent Resistivity (Ohm-m)	Thickness (Km)
Trap	50	1.2
Sediments	10	1.0 – 5.0
Basement	20	Half space

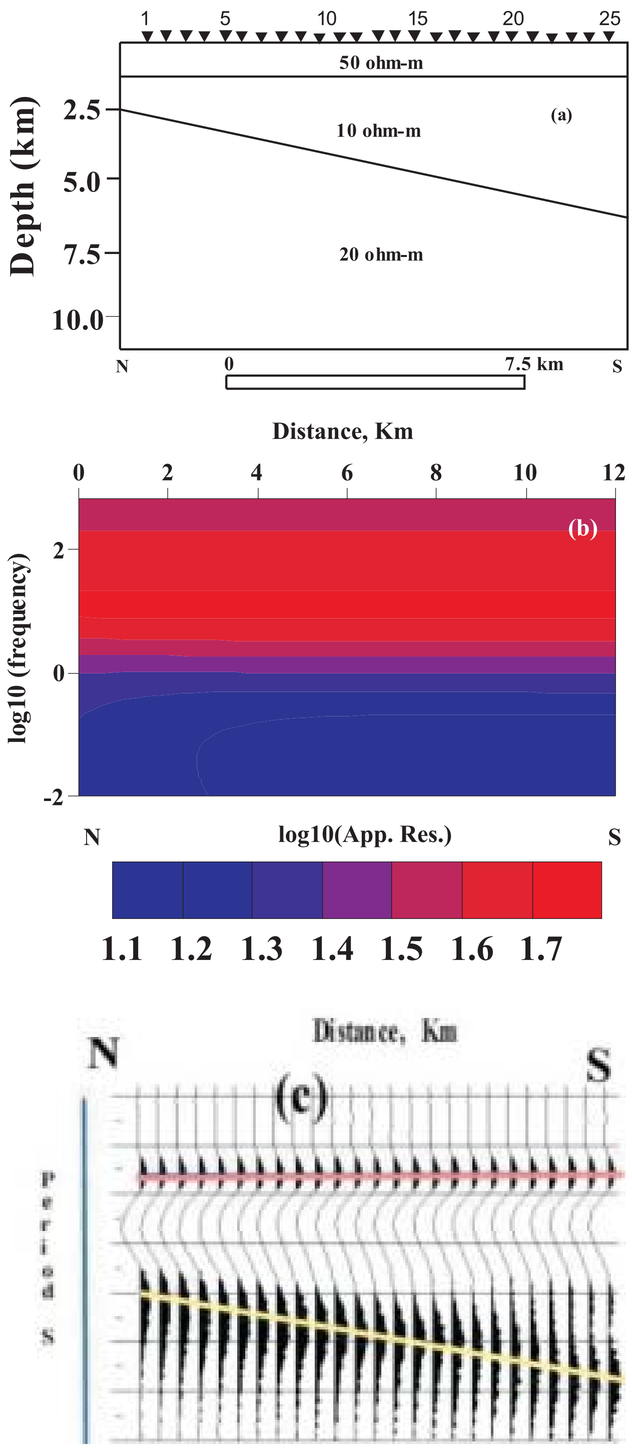


Fig. 1: (a) Section showing resistivity variation with depth over Deccan Traps, (b) Apparent resistivity pseudo depth section and (c) corresponding second derivative pseudo depth section.

(Figure 2b) indicates the presence of a 2D feature at around 17 km from the left end of the profile (Rhine Graben). However, the feature, present throughout the depth section,

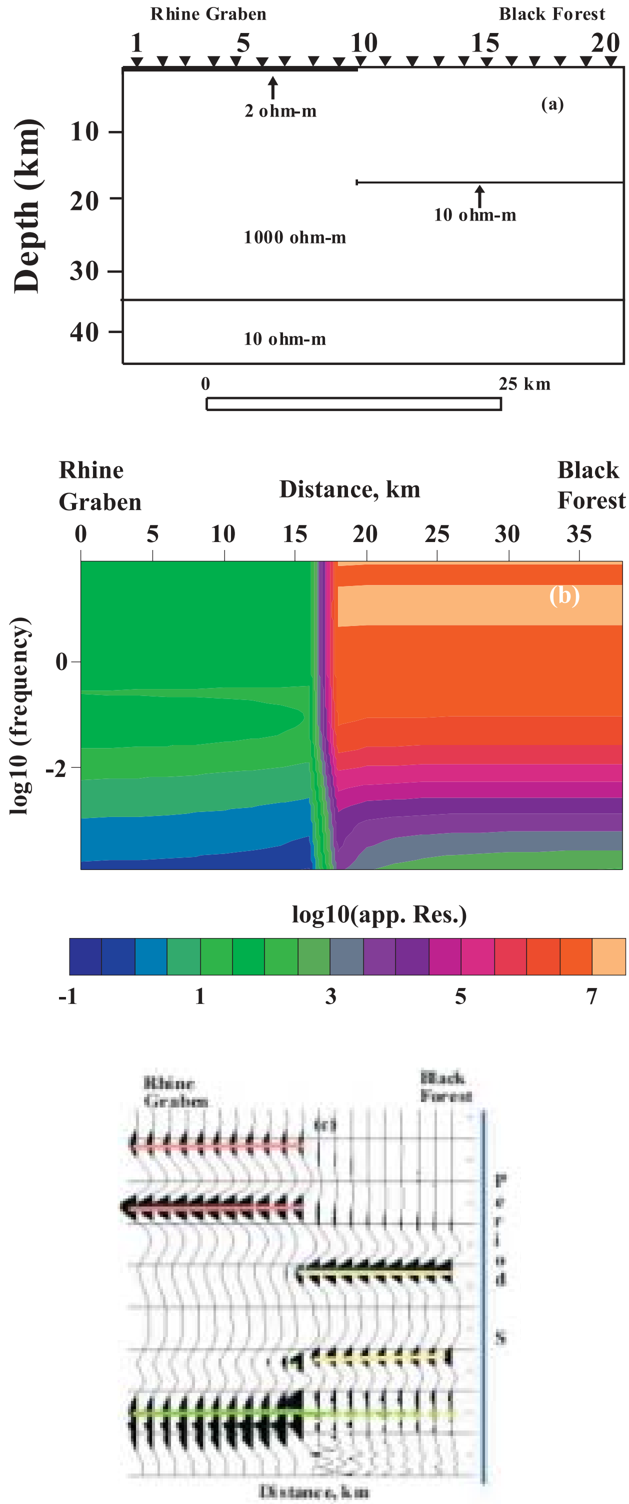


Fig. 2: (a) Section showing resistivity variation with depth over Rhine Graben-Black forest region, Germany, (b) Apparent resistivity pseudo depth section and (c) corresponding second derivative pseudo depth section.

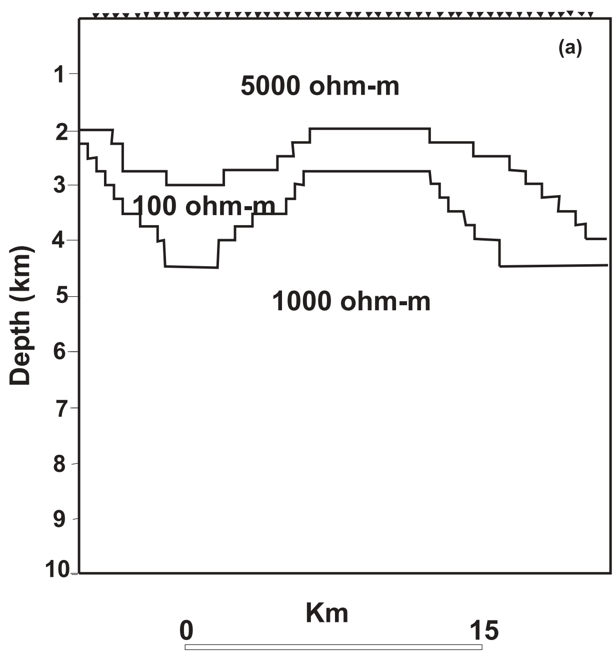
appears as a vertical contact rather than a thin mid-crustal conducting zone. The second derivative pseudo section (Figure 2c) demarcates all the three interfaces along the entire profile, as expected. It could be further seen that the moho is better resolved below the Rhine-Graben than below the Black forest due to the absence of the mid-crustal conducting zone which attenuates the long period signals..

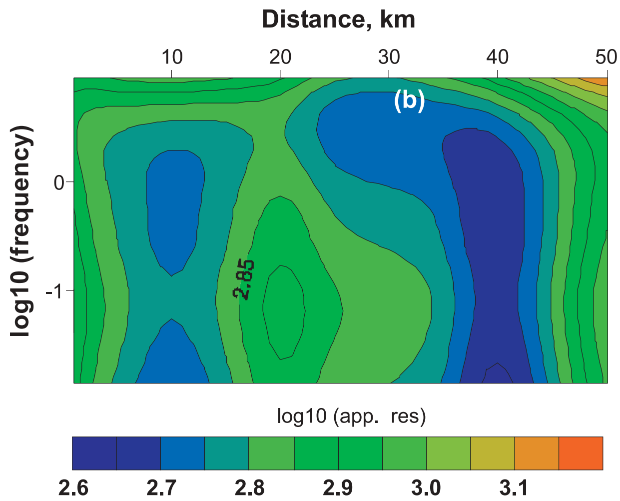
Fold Belt

We further simulated a folded structure which is commonly observed in the continental crust.. A 50 km long profile was considered. MT stations were selected at an equal interval of 500 m. The upper crust was considered to possess a resistivity of 5000 ohm-m, the fold belt of relatively low resistivity 100 ohm-m and the half space of 1000 ohm-m (Figure 3a). The fold belt is not visible in the apparent resistivity section (Figure 3b). The second derivative pseudo depth section (Figure 3c) clearly brings out the structure in the fold belt.

Conclusions

We used the higher resolving power of second derivative of observed MT apparent resistivity data to elucidate crustal structures in three different situations in continental crust and displayed the second derivative of the apparent resistivity as variable area plot. These plots look very similar to seismic sections so that interfaces separating two distinct layers could be mapped easily. We





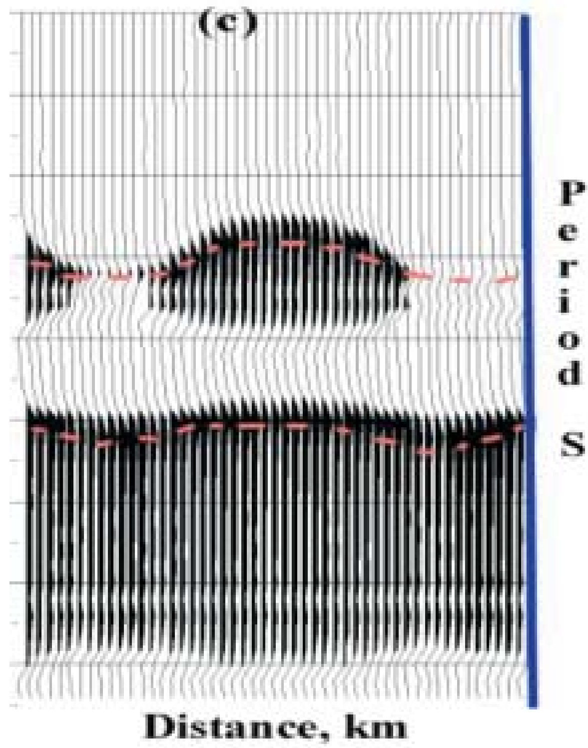


Fig. 3: (a) Resistivity section over a fold belt, (b) Apparent resistivity pseudo depth section and (c) corresponding second derivative pseudo depth section

used finite element method to simulate MT data over 2D structures over three models, viz. (i) Deccan Traps, (ii) Rhine Graben- Black Forest area and (iii) Fold Belt. The second derivative pseudo sections clearly bring out the presence of Mesozoic sediments under the Deccan Trap as well as the dip of the basement surface in the selected model. The presence of a thin mid-crustal conducting layer in the

Black forest region and sediment infill in the Rhine Graben could also be resolved. The decreased resolution of moho in the Black forest region is due to attenuation of long period signals by the mid crustal conducting layer. The fold belt of relatively low resistivity has also been resolved by the use of second derivative apparent resistivity section. We emphasize that we have not used any *a priori* information or constraints of any sort to derive the results. Further, the simulation of the data was from 2D modeling so that the pseudo sections presented are truly 2D in nature and are different from ‘stitched sections’.

On the basis of the above novel results we advocate the use of second derivative of the apparent resistivity data instead of apparent resistivity data to extract subsurface electrical properties. This concept may further be extended in alleviating the challenging static shift problem. We note that high quality data is required for analyzing second derivatives as noise present in the data get amplified in the process of computing derivatives.

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