Simulation of EMAP Responses in Three-Dimensional Environments

EM 2.5

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SUMMARY

Simulation of EMAP responses due to 3-D geoelectric models is carried out via an integral equation approach. In so doing, various kinds of structural complexity are considered as sources of static field distortion superimposed on the inductive signature of both 3-D and 1-D media. EMAP traverses are laid out directly over the outcropping distorting bodies or adjacent to them, and the magnetic field is sampled either at a single station or averaged from an array of magnetic stations to obtain an estimate of the primary magnetic field. Our study shows that if the static telluric distortion is due to confined bodies located within the spatial extent of the survey traverse (and not necessarily directly along it) then EMAP processing eliminates this distortion. However, proper evaluation of the inductive response due to 3-D targets may require more than one EMAP traverse. The vertical magnetic field can be a good indicator of inductive response due to bodies located off the traverse only in cases where this magnetic component has not been subjected to static distortion.

INTRODUCTION

ElectroMagnetic Array Profiling, or EMAP (Bostick, 1986, Torres-Verdín and Bostick, 1989 a and b) is a relatively new adaptation of magnetotellurics in which surface electric fields are sampled tangentially to a continuous survey traverse. Tensor impedance components along the EMAP traverse are computed from primary surface magnetic fields sampled either at a fixed reference station or estimated from an array of magnetic stations' (Figure 1.) Inference of the earth's resistivity distribution beneath the EMAP traverse is carried out from these in-line tensor impedance components in a two-step process: First, the impedance components are spatially low-pass filtered such that the filter width is adapted via a nonlinear iterative process driven by both apparent resistivity and frequency, and which is also a function of position along the traverse. Second, the low-pass filtered impedances are inverted into a resistivity section with simple existing techniques. Both of these steps can be refined and even tailored to the particular exploration problem; research is ongoing.

For their study, EMAP responses have been synthesized so far only from 2-D TM (electric field perpendicular to strike) impedances with encouraging results (Torres-Verdín and Bostick, 1989b.) This procedure is justified by the fact that the TM response of a 2-D earth is in some ways similar to that of a 3-D earth (Wannamaker et al., 1984, Torres-Verdín and Bostick, 1989 a), and the advantage is that model complexity can be expanded to levels only allowed by a 2-D simulation code within standard memory and computation time constraints. Most of the 3-D magnetotelluric simulation procedures published so far, either analytical or numerical, have a restrictive range of application and only a few of them are suitable to include both station density and frequency sampling required by EMAP in a milieu where shallow resistivity anomalies are commonplace. Among these procedures, we have preferred to use the integral equation formulation and thus have restricted ourselves to the analysis of confined resistivity anomalies whose lateral extent is limited by the computer memory available for the computations.

SIMULATION

The simulation study was carried out with an algorithm that allows outcropping bodies (Wannamaker et al., 1984), a feature particularly interesting to us. Figure 2 shows one of the several models discussed in this paper. An outcropping confined conductor (resistivity = 1 Ω-m) overlies a larger 3-D block (resistivity = 3 Ω-m); both of the 3-D blocks are hosted by a 1-D medium including only two layers. The upper layer's resistivity is 50 Ω-m and its thickness is 4 Km; the second layer is a semi-infinite conductive half-space (resistivity = 1 Ω-m.) Four different EMAP traverses were considered as illustrated also in Figure 2. Electric field responses at a sufficient number of points along each line were computed and dipole responses synthesized by numerical integration. The surface magnetic field was computed in this case only at the lines' midpoints and these values were used to calculate the tensor impedance components Z_{YX} and Z_{YY} from the formula

$$E_Y = Z_{YX} H_X + Z_{YY} H_Y , \qquad (1)$$

where in each case the Y-axis is parallel to the EMAP traverse and the X-axis is perpendicular to it such that the Z-axis points downward. Computations were performed at 13 different frequencies, evenly spaced in logarithmic fashion and spanning the interval 0.001 Hz - 1000 Hz.

Given that both magnetic field components H_X and H_Y are approximately average magnetic fields, i.e., primary magnetic fields for two normally incident and mutually perpendicular plane waves (one for H_X and one for H_Y), in equation (1) the tensor component Z_{YX} includes mostly the contribution from an incident plane wave with electric field parallel to the Y-axis (magnetic field parallel to the X-axis.) Additionally, due to the three-dimensionality of the model, the tensor component Z_{YY} describes a secondary cross-coupling term as part of the total electric field E_Y. These two terms bring about both inductive and static contributions into the composite electric field, and their additive interplay is governed by the frequency under consideration.

Analysis of static effects due to three-dimensional shallow resistivity anomalies into an otherwise 1-D or 2-D magnetotelluric response has been the subject of a number of studies (see for instance Bahr, 1987, and Groom and Bailey, 1989.) These works examine the influence of the telluric static distortion upon the impedance tensor and provide ways to characterize it so as to recover some of the characteristics of the background magnetotelluric response, but they are unable to determine the undistorted impedance values in the absence of additional information. Our simulation study is intended to shed light into an alternate way to eliminate this 3-D distortion effects via dense spatial sampling of the surface electric field.

RESULTS

Figure 3 is a gray-scale apparent resistivity pseudosection of the unfiltered EMAP impedance component Z_{YX} along line no. 3, which is offset 40 m with respect to the edge of the outcropping conductor (Figure 2.) Both sampling interval and dipole length are 50 m, and the EMAP traverse is 3 Km long. Notice the anomalously low apparent resistivity values introduced by the telluric static distortion due to the outcropping conductor. This distortion precludes proper identification of both the buried 3-D block and the conductive basement. At frequencies below 0.1 Hz, the 3-D block's own static effect adds to that of the outcropping conductor to further distort the inductive response of the conductive basement. Thus, this is a case of two distinct static effects acting at different frequency bands but overlapping at the low-frequency end of the central soundings. Figure 4 shows the Z_{YX} impedance phase component where all structural patterns are visible; this is so because in this model impedance phases respond purely to the induction process. EMAP filtering applied to the Z_{YX} impedances yields an apparent resistivity pseudosection where all three features become clear at different frequency bands (Figure 5.) The static field distortion due to the 3-D block has also been removed from the conductive basement's signature, and at frequencies higher than 100 Hz the 3-D inductive response of the outcropping conductor persists after the spatial filtering has been carried out. Evidently, in this frequency range the EMAP line senses the body as a 3-D feature but is unable to locate it correctly, and thus additional information is needed to attain this objective. The vertical magnetic field is a good candidate to help solve this problem if its own static distortion is previously removed. Clearly, the 3-D buried block is not strongly emphasized in the EMAP apparent resistivity pseudosection, and this is partly due to the fact that the EMAP traverse is close to the edge of the body.

That spatial electric field filtering along a line offset from the outcropping conductor can remove the conductor's telluric static effect may not be intuitively clear. However, recalling that the spatial filtering process of the traverse impedance components is a modified version of the integral

$$\int_{\Gamma} \vec{E} \cdot d\vec{l} \ ,$$

one can show that at low enough frequencies this line integral of the electric field, $\vec{E}$, will eliminate the telluric static component provided that the integration path, Γ, is long enough to reach points where the background field is essentially undisturbed. In cases where the resistivity anomaly is confined, the associated static field will also be confined and thus our results are correct if the EMAP traverse is sufficiently long to go through the spatial extent of the distorting field.

CONCLUSIONS

Our simulation study shows that EMAP filtering can remove the telluric static distortion due to confined resistivity anomalies provided that the survey traverse is long enough to go past the spatial limits of the distorting telluric field; this includes distortion due to bodies offset with respect to the traverse. However, proper recognition of a 3-D body may require additional spatial information of its inductive field response. We propose the use of vertical magnetic field measurements to help accomplish this objective only if their own static distortion effects are previously removed.

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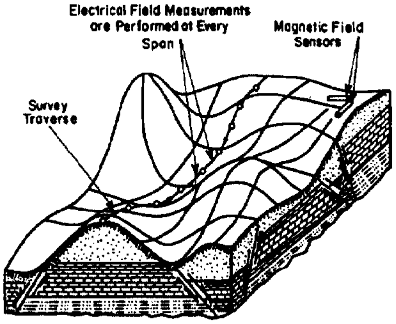
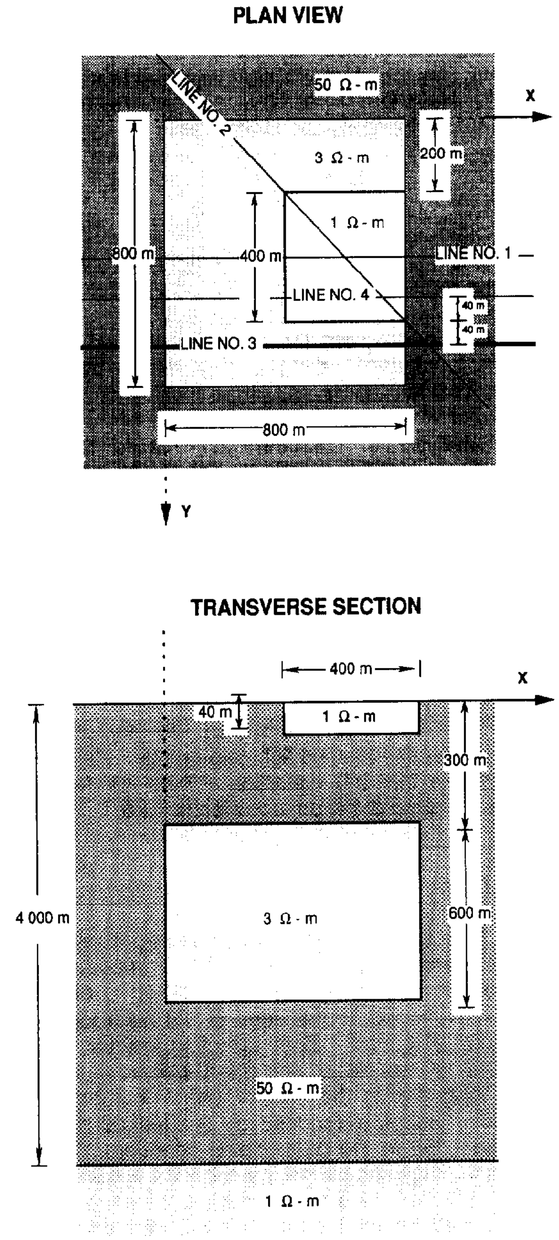


FIG. 1. Graphical description of the EMAP field procedure.


PLAN VIEW

TRANSVERSE SECTION

FIG. 2. Plan view and transverse section describing a 3-D model of our simulation study; 4 EMAP lines shown as well.

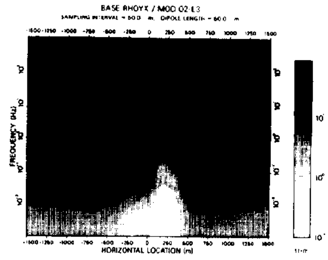


FIG. 3. Apparent resistivity pseudosection of Z_{YX} tensor impedance component along line 3 in Figure 2.

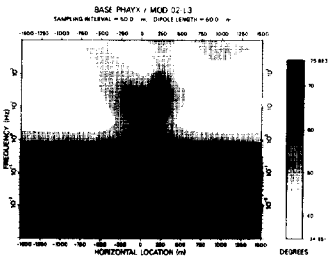


FIG. 4. Phase pseudosection of Z_{YX} tensor component along line 3 in Figure 2.

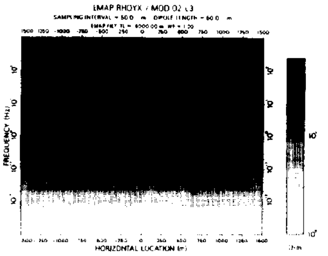


FIG. 5. Apparent resistivity pseudosection obtained by applying EMAP spatial filtering to Z_{YX} tensor component described in Figures 3 and 4.