Fast representation of dipole-dipole geoelectrical data with pseudosections for regional surveys

Mauro Giudici
Università degli Studi di Milano, Dipartimento di Scienze della Terra, Sezione di Geofisica, Milano, Italy

Abstract
I propose a fast method for constructing pseudosections of apparent resistivity from geoelectrical data collected for deep studies with continuous polar dipole-dipole arrays. Once a vertical section is fixed, each value of apparent resistivity is assigned to a point on the section and finally pseudosections are obtained by interpolation. This allows the geophysicist to represent a large amount of data in a fast and simple way, to perform a qualitative interpretation and to facilitate the quantitative interpretation.

Key words *electrical sounding – dipole-dipole methods – apparent resistivity – deep sounding – data processing*

1. Introduction and description of the method

The objective of this paper is to evaluate if and how the techniques of geoelectrical data representation used for shallow prospecting (Reynolds, 1997) can be adapted to the characteristics of geoelectrical data acquisition for large-scale deep studies. The goal is to represent all the collected data in a pseudosection of apparent resistivity (ρ_{app}), with a fast process, in a format which is easily intelligible even by an inexpert final user.

The acquisition of dipole-dipole data for geoelectrical deep surveys usually consists of some vertical electrical soundings with Continuous Polar Dipole-Dipole (CPDD for short) arrays (Alfano, 1974, 1980). The simple formulas to obtain pseudosections of ρ_{app} from data acquired with multi-electrode systems for shallow exploration cannot be applied in a straightforward way to data acquired with CPDD arrays. In fact, the basic differences are the different length of the current and potentiometric dipoles and the asymmetry of the array. Moreover, since deep soundings are often performed in areas with complex topography, field conditions prevent from maintaining a polar disposition of the electrodes and the soundings are not perfectly aligned along a profile.

The first attempts at the construction of pseudosections used backprojection techniques, based on the function that describes the elementary contribution to the electrical signal (Roy and Apparao, 1971; Barker, 1981) and corresponds to the so called Frechet's derivative or sensitivity coefficient in the literature on inverse problems (see, *e.g.*, McGillivray and Oldenburg, 1990). These techniques have not led to satisfactory results and require further work, for instance, following the suggestions of Cosentino *et al.* (1998).

Mailing address: Prof. Mauro Giudici, Università degli Studi di Milano, Dipartimento di Scienze della Terra, Sezione di Geofisica, Via L. Cicognara 7, 20129 Milano, Italy; e-mail: Mauro.Giudici@unimi.it

An alternative approach is to determine a point in space where each value of ρ_{app} is assigned and then to interpolate the three-dimensional data set. Since software packages for two-dimensional interpolation are very common and the data acquisition for deep studies is usually performed along profiles, which are approximately linear, I propose the following simplified procedure. Fix a vertical section and for each value of ρ_{app} determine the point of the section to which this value is assigned and then interpolate the two-dimensional data set.

Conventional methods of constructing pseudosections of ρ_{app} for shallow targets use data located on a regular and dense grid, whereas data collected for regional studies are sparse and often scarce. Moreover assigning a value of ρ_{app} to a single point is not correct, because this operation does not take into account the contribution to the signal from different regions. As a consequence of these two facts the interpolation of the data can introduce some artefacts.

1.1. *Determination of the point where the value of apparent resistivity is assigned*

Let us consider an array, as represented in fig. 1; fix a Cartesian co-ordinate system and denote the position vectors of the electrodes of the current (AB) and potentiometric (MN) dipoles with $\vec{A}$, $\vec{B}$, $\vec{M}$ and $\vec{N}$.

We consider a weighted average, $\vec{C}$, of these vectors given by

$$\vec{C} = \frac{1}{2}\left(\frac{\vec{A}+\vec{M}}{|AM|^2}+\frac{\vec{B}+\vec{M}}{|BM|^2}+\frac{\vec{A}+\vec{N}}{|AN|^2}+\frac{\vec{B}+\vec{N}}{|BN|^2}\right) \cdot \tag{1.1}$$

$$\cdot\left(\frac{1}{|AM|^2}+\frac{1}{|BM|^2}+\frac{1}{|AN|^2}+\frac{1}{|BN|^2}\right)^{-1}.$$

If the four electrodes lie at the surface of an horizontal terrain and if the array is symmetric, which is the case, *e.g.*, for Schlumberger or

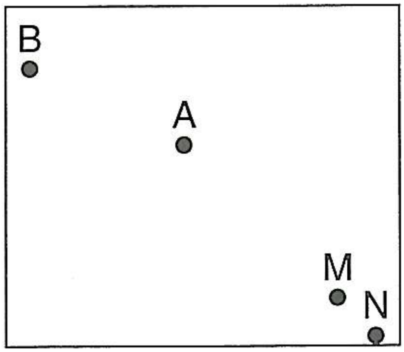

Fig. 1. Plane view of an array for measuring electrical resistivity.

Wenner array, then $\vec{C}$ corresponds to the centre of the array. On the other hand with asymmetric arrays the weight given by the inverse of the squared distance between the electrodes has the effect of moving $\vec{C}$ near electrodes that are close to each other.

The value of ρ_{app} obtained with a given array is assigned at a point, whose position vector $\vec{P}$ has the same horizontal components as $\vec{C}$, and the vertical component given by

$$P_z = C_z - d_e \tag{1.2}$$

where

$$d_e = c[(|AM|^\alpha + |BM|^\alpha + |AN|^\alpha + |BN|^\alpha)/4]^{1/\alpha}. \tag{1.3}$$

The values of the constant coefficients c and α have been assigned by comparing the values of d_e given by (1.3) with those of «effective depth» obtained for several arrays by Edwards (1977). In particular for $c = 0.26$ and $\alpha = -1$ a good match is found with the values of «effective depth» computed by Edwards (1977) for dipole-dipole arrays. Finally, the point $\vec{P}$ is located on the prescribed vertical section with a simple orthogonal projection.

I developed an original computer program using the FORTRAN 90 programming language and defining a module that includes all the standard operations on three-dimensional vectors so that the algorithm is implemented in the main procedure in a few lines and with a syntax similar to the analytical one.

2. Application to synthetic and real data sets

2.1. *Application to synthetic data*

The procedure described in the previous section is applied to plot the pseudosections for two data sets, which correspond to two synthetic simple geoelectrical structures, drawn in fig. 2a,b. Case A (fig. 2a) consists of a layer with average thickness equal to 200 m and resistivity equal to 1 Ω·m, separated by a dipping discontinuity from a deep bedrock with resistivity equal to 100 Ω·m; case B (fig. 2b) presents a vertical discontinuity between two half spaces with resistivities equal to 1 and 100 Ω·m respectively. The hypothesised acquisition scheme is common to both cases, is similar to the typical acquisition scheme used in real field works and is represented in fig. 2c. It consists of nine vertical electrical soundings with maximum length of the array equal to 2 km, but for two soundings with maximum length of the array equal to 10 km.

For each case I have computed ρ_{app} for CPDD arrays with numerical models and I have assigned the values to points at different depths, according to the procedure described in Section 1.1. The interpolation was performed with kriging (Davis, 1973). Several attempts were made with different analytical forms of the variogram. Here I show the results obtained with linear variograms with an anisotropy ratio equal to four. This choice means that the correlation length along the horizontal direction is four times greater than that along the vertical direction and induces a prominent horizontal correlation in the interpolated field of ρ_{app}.

Figure 3a,b shows the pseudosections of ρ_{app} for both cases; the values of ρ_{app} are represented

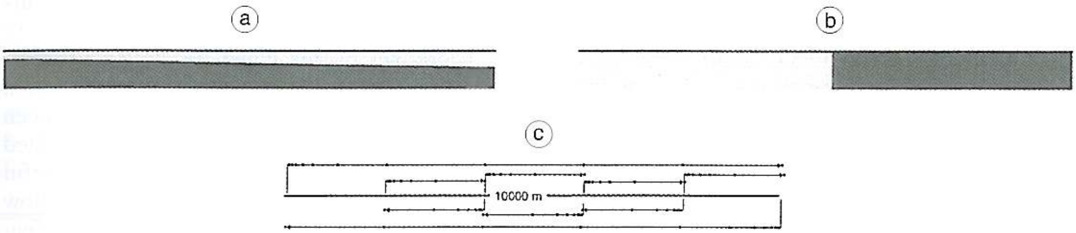

Fig. 2a-c. Vertical sections of the geoelectrical models (a) for case A and (b) for case B; light grey = 1 Ω·m; dark grey = 100 Ω·m. c) Scheme of data acquisition; thick horizontal line = ground surface; vertical lines = position of the centres of the potentiometric dipoles; horizontal arrows = direction and maximum length of the vertical electrical soundings; dots = position of current electrodes.

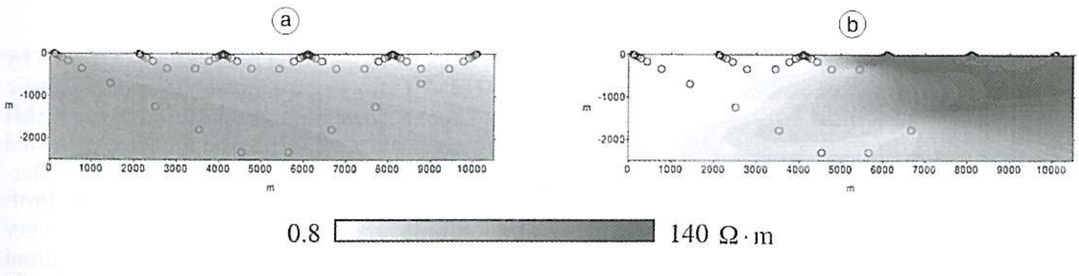

Fig. 3a,b. Pseudosections of apparent resistivity (a) for case A and (b) for case B. Circles show positions of the points where field data of apparent resistivity are assigned.

with grey levels corresponding to a logarithmic scale and the positions where field data are assigned are plotted with open circles. The results for case A (fig. 3a) show both a general increase in ρ_{app} with depth and a lateral variation which is related to the dip of the discontinuity surface. The results for case B (fig. 3b) show a clear lateral variation. The use of an anisotropic variogram enhances the appearance of layered structures; nevertheless fig. 3b, which corresponds to a vertical discontinuity, is satisfactory, because it shows the signature of lateral heterogeneity. This fact depends upon the sensitivity of dipole-dipole arrays to lateral variations which is still apparent in the final data representation.

2.2. *Application to field data from the Secchia river valley*

In fig. 4 I show the pseudosection of ρ_{app} obtained from a real data set which consists of five vertical electrical soundings performed with CPDD arrays along the valley of the Secchia river, south of Sassuolo (MO - Italy). From fig. 4, we observe that the average value of ρ_{app} is less than $10\ \Omega \cdot m$, with some heterogeneous areas both at surface, with alternating high and low values, and at greater depth with some localised conductive features. These remarks were confirmed by the geophysical interpretation, which was integrated with the results of data from some soundings approximately perpendicular to the profile of fig. 4.

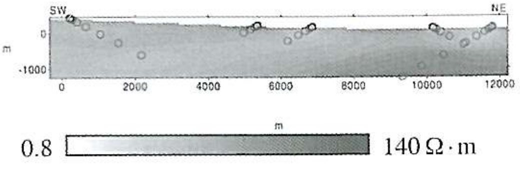

Fig. 4. Pseudosection of apparent resistivity for a field survey in the Secchia river valley (Italy). Circles show positions of the points where field data of apparent resistivity are assigned.

3. Conclusions and future perspectives

The pseudosections of ρ_{app} obtained with synthetic and real data show that the proposed method permits to map all the collected data together in a fast a simple way. I stress that pseudosections of ρ_{app} are preliminary data representations only and quantitative interpretation is needed for obtaining the real image of resistivity distribution in the subsurface.

The application of geostatistical techniques for the interpolation is very promising and is still worthy of research efforts. In particular geoelectrical data performs a kind of regularisation of the subsurface heterogeneous structure, in the sense that the ρ_{app} obtained with a given array depends upon the true resistivity distribution over a volume of the Earth. Therefore the ρ_{app} field filters the resistivity distribution in the subsurface; as a conclusion it is worth evaluating the dependence of the data correlation structure, quantified by the variogram, on the data acquisition scheme and on the true heterogeneity structure of the subsurface.

Moreover in this paper geostatistical interpolation techniques have been applied in a straightforward way and they have not been used to estimate the error on the interpolated values; such an estimate could be very useful both to plan new data acquisition and to allow the inexpert user to distinguish confident features from artefacts of the interpolation procedures in the pseudosections.

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