A comparative study of conventional arrays of resistivity prospecting with differential arrays

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Abstract: The second vertical derivative of gravity and magnetic potential are widely used in geophysical prospecting because of their better resolving power. In electrical prospecting these derivatives are not in use in spite of the fact that the derivatives can be directly measured in the field. The electrical prospecting offers a unique possibility to obtain the derivatives of potential in the field, in a desired direction which can be used for the computation of resistivity values. But most of the systems proposed for higher derivative measurement in sounding employ more than two source electrodes and current with high intensity which are difficult to work with.
Hence, Murali *et al.* (1980) and Murali and Sharma (1982), have suggested a simple differential array for obtaining the second derivatives of potential both in the lateral and vertical directions. In this paper an attempt is made to test the level of accuracy of this differential array. The theoretical two layer dipole curves and the differential array field curves are compared with one another for the same ρ_2/ρ_1 ratio. It has been shown from the results that this system is capable of detecting even very small changes in thickness of layers and it yields useful data over two layered media. It has been proved that this system is superior over the other configurations.

INTRODUCTION

Geophysical methods measure natural or induced physical phenomena in the earths crust and interpret the results to obtain information on the subsurface. The use of higher derivatives of potential and in particular the second derivatives is widely prevalent in geophysical prospecting (Bhattacharya and Patra, 1968). They are known to be capable of high resolving power permitting not only a fine discrimination between different subsurface bodies but also in the estimation of body parameters.

Derivative measurements in electrical prospecting, particularly the resistivity method, are not as widely used as in other geophysical methods. Numerous techniques have been proposed for the measurement of potentials in the resistivity method. When only two electrodes are employed (AM) only the potential because of the applied current is measured. In the Wenner configuration, (AMNB) a known current is passed through the two extreme electrodes and the potential difference is measured between the two inner electrodes. If one of the current electrodes (say B) is removed and placed at a far-off distance, the array changes to a three electrode array (AMN) and even here the potential difference is measured. In the Schlumberger configuration (AMNB, AB >> MN) the potential gradient is measured by virtue of the placement of electrodes.

Dipole-dipole array differs from the above mentioned configurations due to its capacity for second derivative measurements. A comparison (Keller and Frischeknecht, 1966) of the three types of sounding curves (Wenner, Schlumberger and Polar dipole) is shown in Figure 1 and 2 for two cases; a conductive slab over an insulating substratum (Fig. 1), and a resistant slab over a conducting substratum (Fig. 2). For the first case (Fig. 1) the apparent resistivity curve obtained with a dipole array differs from those obtained with the other two types of arrays in that for some spacings, the measured resistivity is lower than the overburden resistivity. The curve obtained with the dipole array shows the most abrupt transition from the resistivity for the overburden to the asymptotic behaviour.

For the case of a resistive overburden resting on a highly conductive substratum (Fig. 2), the apparent resistivity curves do not approach a linear asymptote, but rather the slope increases continually as the spacing is increased. The apparent resistivity curve obtained with a dipole array descends most rapidly. Both the curves for the Schlumberger and Wenner arrays depart uniformly from the value for the overburden resistivity but the curves for the dipole array first rises to a maximum valve of apparent resistivity which is 2% higher than the overburden resistivity, and then decreases.
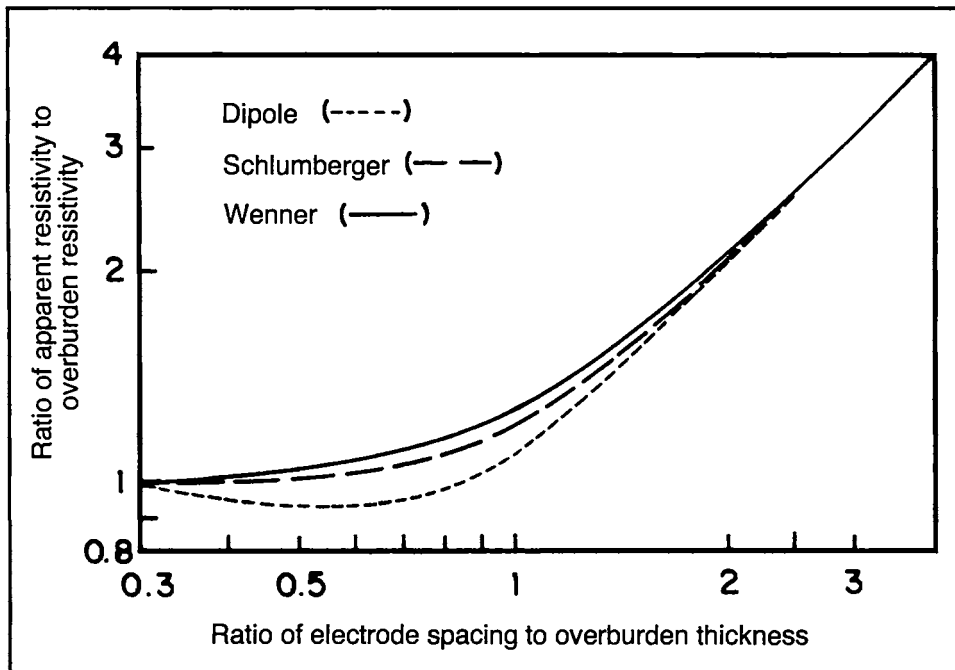
Figure 1. Comparison of resistivity sounding response over a resistive basement (after Keller and Frischeknecht, 1966).
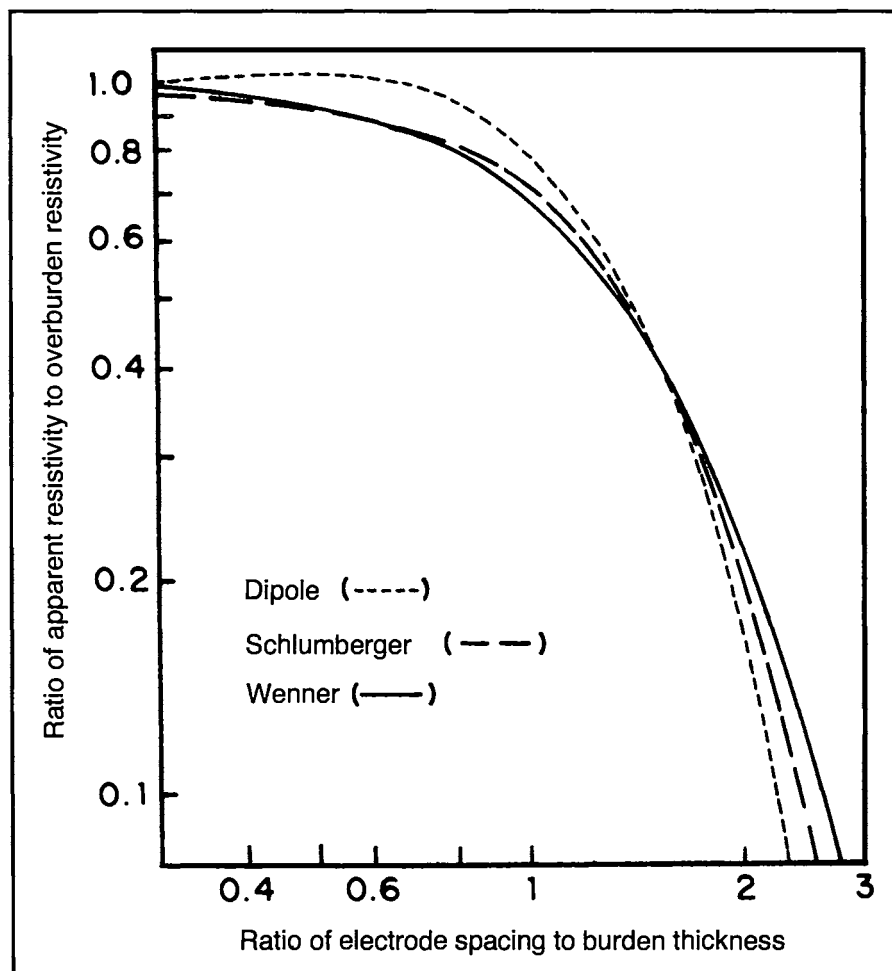

Figure 2. Comparison of resistivity sounding response over a conductive basement (after Keller and Frischeknecht, 1966).

Hence, from the above comparison it clearly emerges that, the resolving power of a dipole sounding is much greater than that of conventional sounding. Another advantage of the dipole sounding is the possibility of sounding on a curved profile. Because of the fact, that the dipole sounding is independent of the azimuth, it is not necessary for the centres of all the dipoles to lie on the same straight line and the dipoles may be conveniently located.

Inspite of the above mentioned advantages, there are quite a good number of reasons which make it difficult to obtain the field data for the dipole system. These are:

(i) Data acquisition with the dipole system is both time consuming and a laborious process.

(ii) The power required for a dipole sounding is larger than that required for a conventional sounding.

Hence, in order to overcome this difficulty of obtaining the resistivity measurements with dipole-dipole set up, a few methods exist in resistivity prospecting literature, for conversion of resistivity sounding curves from other configurations (Wenner, Schlumberger, Two-electrode etc.) to dipole-dipole configuration. Some authors address the problem to numerical solution of the differential equation connecting the two configurations, few others have suggested linear filter techniques, while some forward a numerical method based on regressional analysis (Sengupta and Banerjee, 1992).

But, the disadvantage in the numerical method based on regressional analysis is that the field data can't be used just as it exists. The resistivity values are required at closer electrode spacings. This means that even while collecting the data special attention must be given to the electrode spacings if the resistivity values obtained are to be converted to dipole set up values which is again time consuming.

DIFFERENTIAL ARRAYS

In these circumstances, the resistivity values obtained by using higher derivatives of potential are much useful. Even though, it is accepted in geophysical prospecting that higher derivative measurements are generally useful in increasing the resolution, even though in resistivity prospecting higher derivatives can be measured in the field and hence are more reliable and accurate unlike other geophysical methods where they have to be generally calculated from the measured potential values using finite-difference technique, VES methods do not take advantage of higher derivative techniques.

Alpin (1936, in Zohdy, 1969) was the first to propose an electrode configuration for the measurement of derivative. He suggested the use of two pairs of current electrodes along with a single pair of potential measuring electrode displaced in a straight line to give a 'AMNB' set up. Weyl (1967, in Szaramiec, 1972) proposed a new measuring technique which he called a tripole field technique, using three current electrodes and a pair of potential electrodes.

Zohdy (1969) proposed an array by modifying Alpin's array to measure transverse and longitudinal resistivity. By modifying Alpin's array, Szaraniec (1972) also suggested an array where four potential and two current electrodes were used (Fig. 3). Even though, the differential sounding curves of Al'pins array and Szaraniec's array do not differ from each other, Szaraniec's array, however has numerous good points simplifying the field procedure like:

(i) the application of one current circuit and one electric generator.

(ii) the total length of the cables being smaller.

(iii) possibility of carrying out bilateral differential sounding etc.

These arrays have been used by various workers to solve some specific problems. But most of these system proposed for higher derivative measurement
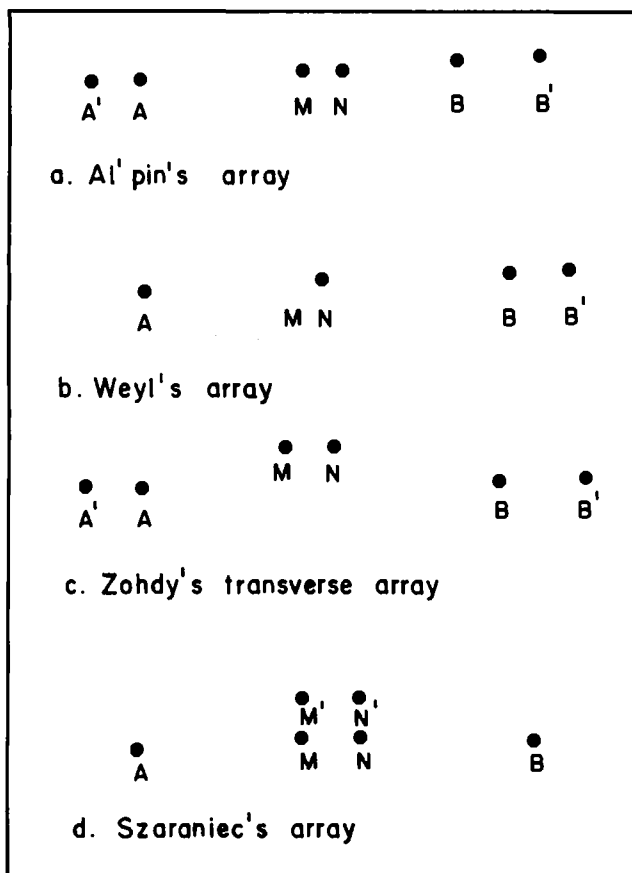

Figure 3. Various differential arrays.

in sounding employ more than two source electrodes and also current of high intensity which are difficult to work with.

Hence, Murali *et al.* (1980), Murali and Sharma (1982) have suggested a simple method of obtaining the second derivatives of potential both in the lateral and vertical directions. In this array without any additional current electrode being installed, a third electrode is placed centrally between the existing potential electrodes of the Schlumberger arrangement for obtaining second horizontal derivative and another pair of electrodes perpendicular to it for obtaining the second vertical derivative (Fig. 4). This array has been used in the groundwater exploration for its field applicability.

Whenever the derivative of a field is calculated using the differential array the magnitude obtained in the form of derivative is reduced and this has been the main reason why some of the workers are sceptic about their utility in the field. But the range of the signal increases even though the magnitude of the signal (as derivative) is small and hence it becomes easier to pick out anomalies due to objects of smaller geometrical and physical parameters. The only difficulty which may be encountered is the enhancement of the background noise. In areas where such noise enhancement is noticed a suitable filter can be developed and used to refine the data.

In order to confirm the field applicability of this derivative system, field work was carried out in sedimentary terrain around Madras. In a chosen area, where even the conventional methods of obtaining the resistivity data like Wenner, Schlumberger etc. failed because of the low variation in the magnitude of the incoming signal it was proved that the derivatives could be measured with this differential array with a good degree of accuracy. The data obtained in this area correlates very well with lithology data from the bore well which was drilled.

DISCUSSIONS

In this paper, an attempt is made to test the level of accuracy of this differential array and to prove its superiority over the other configurations. The theoretical two-layer dipole curves and the differential array field curves are compared with one another for the same ρ_2/ρ_1 ratio. For a two layered earth, the responses over a resistive basement ($\rho_2/\rho_1 = 9$) and the responses over a conductive basement ($\rho_2/\rho_1 = 1/9$) are compared and the results of this study are discussed below.

1. Perpendicular Dipole; Radial Dipole and Horizontal Derivative Systems

The apparent resistivity curves for the above types differ from one another to a slight extent; comparing the horizontal derivative curve (Fig. 5a) with the perpendicular dipole (Fig. 5b) and radial dipole curves (Fig. 5c) it is seen that these two curves (in Fig. 5b and 5c) have been shifted to the left. Among these three curves, the perpendicular dipole curve shows smaller variations in resistivity for the same electrode spacings. This implies that for smaller ratios of resistivity, the perpendicular dipole curve will be even much gentle, so that the variations in resistivity are not distinct. The curve obtained with the horizontal derivative system (Fig. 5a) shows the most abrupt change in resistivity among the three from which it is borne out that horizontal derivative system possess higher resolution.

2. Parallel Dipole and Vertical Derivative Systems

Comparing the vertical derivative curve (Fig. 6a) and the parallel dipole (Fig. 6b) it is seen that in both the curves, for few electrode spacings, the measured resistivity is lower than the top layer resistivity for a conductive top layer. Similarly, for a resistive top layer, the measured resistivity is
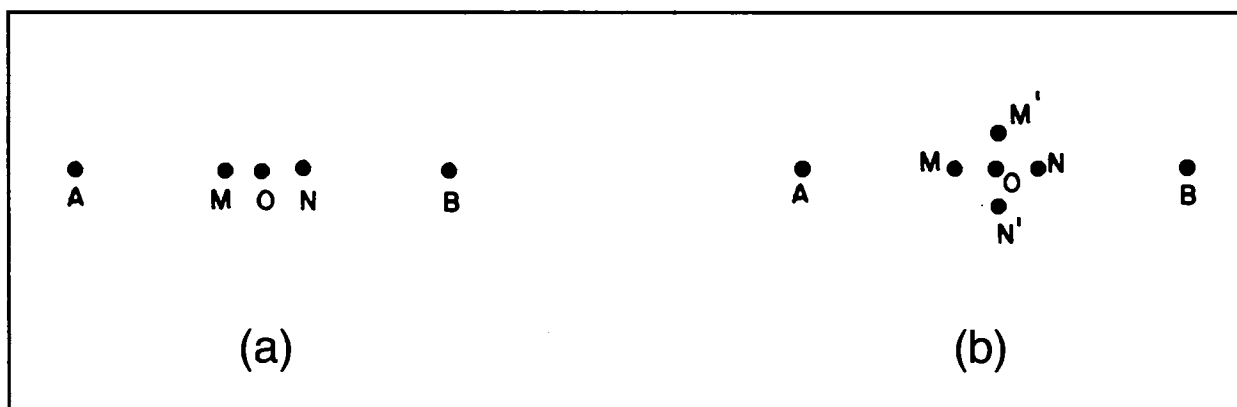

Figure 4. Differential array for measuring (a) Second Horizontal derivatives and (b) Second Vertical derivatives (after Murali *et al.*, 1980; Murali and Sharma, 1982).
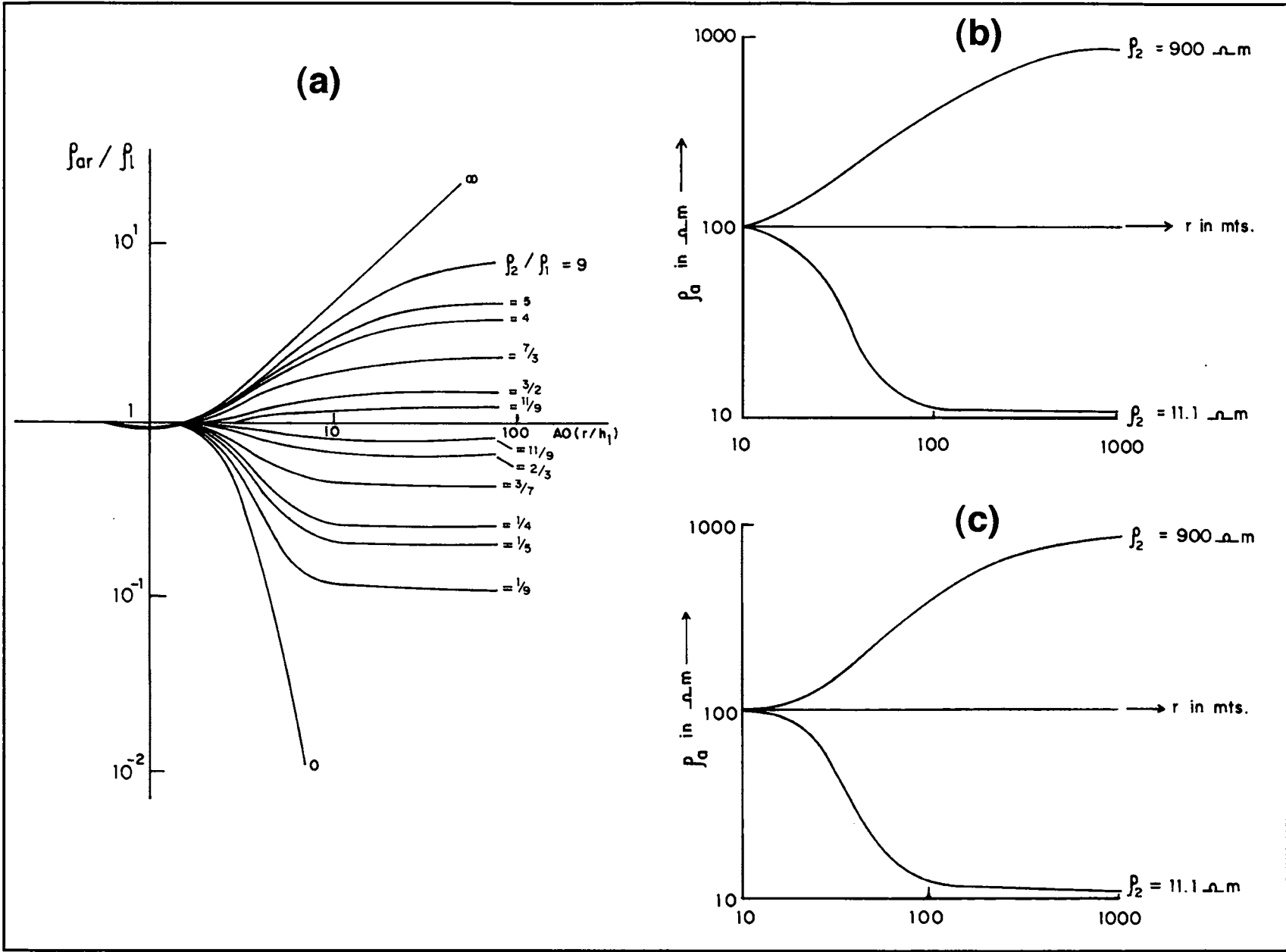
Figure 5. Response over a two layered earth having ρ_2/ρ_1 as 9 and 1/9 using (a) Horizontal Differential array, (b) Perpendicular Dipole array and (c) Radial Dipole array.
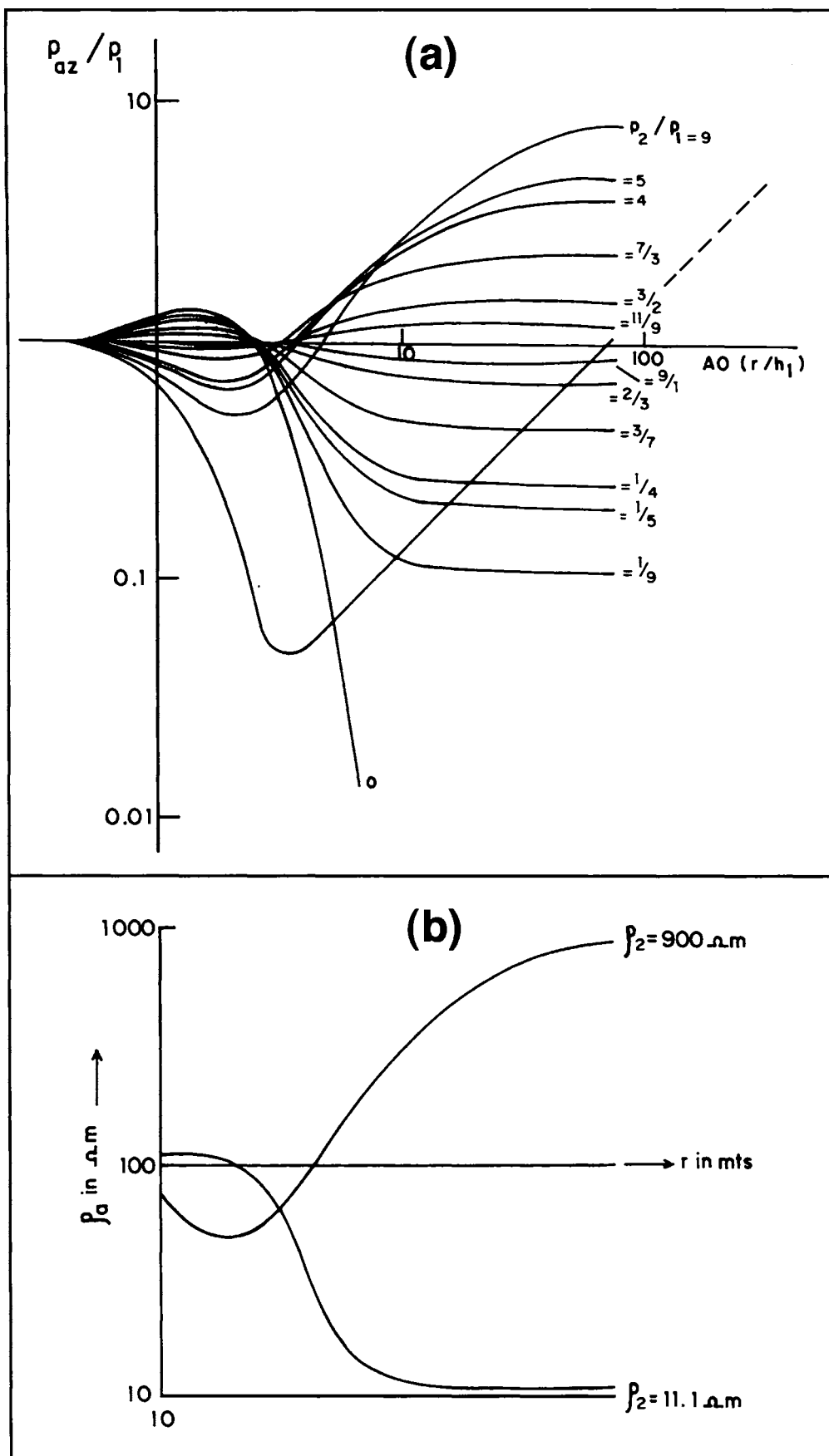
Figure 6. Response over a two layered earth having ρ_2/ρ_1 as 9 and 1/9 using (a) Vertical Differential array and (b) Parallel Dipole array.

greater than the top layer resistivity. But, even here, the difference between the measured resistivity and the top layer resistivity is greater/maximum in the case of derivative systems (Fig. 6a).

Additional point to be noted here is that in the case of dipole curves, for a resistive overburden the cross-over point of all the curves, do not coincide; they are just clustered. But, in the case of derivative system curves the cross-over point of all the curves coincide. This makes it possible to use a thumb-rule for finding the thickness of first layer.

3. Horizontal Derivative and Vertical Derivative System

On perusal of the horizontal derivative (Fig. 5a) and vertical derivative curves (Fig. 6a) it can be noticed that when the second horizontal derivative is used, the sounding curves show only a smooth variation from ρ_1 to the asymptotic value (equivalent to ρ_2), whereas for the second vertical derivative ρ_a becomes less than ρ_1 for small valves of x/h and then it increases to reach the asymptotic valve where $\rho_a = \rho_2$, for positive valves of reflection coefficient (K_{12}) (i.e. $\rho_2 > \rho_1$). The converse happens when the value of K_{12} is negative (i.e. the case when $\rho_2 < \rho_1$).

With the vertical derivative curves it can be seen that the ρ_2 curves are steeper and the final value reached (asymptote) is always nearer the true value of ρ_2. Also this asymptote is recorded for smaller AB/2 (half current electrode spacing) values in comparison to other conventional arrays. By virtue of the larger change in ρ_2 with any variation in h it is possible to match the field curves with the master curves more accurately resulting in a more precise determination of h or ρ_2. Hence, from the above discussion it is clear that derivative system suggested by Murali *et al.* is superior over the other configurations for a two-layer earth which in turn implies that at other geometries also this differential arrays will be best suited.

CONCLUSION

From the results presented above, it may be concluded that:
1. Differential sounding system proposed by Murali and Sharma (1982) yields useful data over two-layered media.
2. Small variations in resistivity contrast or thicknesses may be detected reliably with the help of this system.
3. The field measurement can be carried out without involving much effort by moving only the current electrodes and keeping the potential measuring electrodes constant in the same place (similar to Schlumberger method). It will be relevant here to note that much more effort and time are required for obtaining data at close AB/2 intervals using the normal Schlumberger soundings if these data are to be converted to Dipole-Dipole configurations using the method based on regressional analysis.
4. The vertical derivative curves have a distinct form which makes it possible to use empirical relationships for finding the thickness of the first layer.
5. Derivative values can be measured with a good degree of accuracy and reliability in the field using these differential arrays.
6. With the help of the master curves, it is possible to interpret these differential resistivity data quantitatively.
7. It is possible to measure the second derivatives directly in the field with the help of a differential amplifier system without much difficulties or compromise for accuracy.
8. In some cases, because of the way in which potential differences are measured, negative derivatives yield negative resistivity values. Even though, negative resistivity values at the first glance are absurd, this feature is actually an added advantage because, when resistivity curves are drawn using this array's measurements, some such resistivity undershoots can never be missed and these shoots always yield useful information about the presence of thin overburden underneath.

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