ABSTRACT

Mathematical models of one and two dimensional borehole direct current resistivity problems were simulated to study the relative merits and demerits of focused (seven electrodes) and unfocused (two and three electrodes) arrays of electrodes.

Earth models, considered for forward model simulation, have been broadly divided into three main categories. First two of the models are one dimensional and the third one is two dimensional in nature.

In the first part of one dimensional modeling, electrical responses are computed along a vertical profile and across a horizontal layer embedded in a homogeneous and isotropic full space. In this case perturbation potentials are computed using the method of electrical images and the principle of superposition. Two electrode system (TES, normal log), three electrode (lateral log) and seven electrode (SES, a modified version of laterolog 7) configurations are used to compute the apparent resistivity profiles. This modified version of laterolog 7 (LL7) differs from the conventional LL7 in the sense that auxiliary current electrodes are assumed to be unshorted and bucking currents are fed through two different circuits. The detailed expressions for the perturbation potentials for different positions of the current and potential electrodes are given in the chapter 2 and in the Appendix A. Variable geometric factor and variable bucking current and focusing current ratios are used to compute apparent resistivity for SES. Computed apparent resistivities, for no borehole condition, are then compared to assess the merits and demerits of different electrode arrays. Results are given with identical tool length to compare the relative performance under same environment. It is observed that SES has better resolving power than two electrode system for all the bed thicknesses. Therefore, for surface geophysics d.c. resistivity profiling, SES may turn out to be a better array than two electrode system (TES) so far as resolving thin

vertical dykes and veins are concerned. The ratio of the bucking current and focusing current can be recorded as a log for delineation of the bed boundaries. The current ratio is directly proportional to the resistivity contrasts of the shoulder and the target beds. For a very thin target bed lateral log response appears to be better than those of both two and seven electrode systems for no borehole condition. Bucking current/focusing current ratio and geometric factor vary sharply near the bed boundaries.

In the next phase, one dimensional d.c. resistivity forward problem is solved assuming axial symmetry with cylindrical co-axial layers depicting different zones, generally develop, surrounding the borehole. Computations are done neglecting the effect of planar horizontal beds or shoulder beds and assuming the infinite extent of the target bed. Unlike computation of borehole profiles or logs, as done in the previous 1-D model, borehole sounding resistivity departure curves are computed with step wise increase in the array length to observe the radial characteristics of the different configurations. Analytical solution of the potential problem satisfying Laplace and Poisson equation are solved by the method of separation of variables and Frobenius extended power series. Invaded zone is assumed to be a transitional zone with variable resistivity along the radial direction. Cylindrical co-ordinate system was chosen to solve the problem of cylindrical symmetry. Spline interpolation technique has been introduced for fast and accurate computation of kernel function. Results are given in a dimensionless form for convenience. Model responses with and without transition zone as well as for different parametric values are presented to show the sensitivity of the borehole sounding forward model curves.

Since the multi channel single run logging is practically possible, the author proposes for reintroduction of the borehole sounding with ten to twelve data points for accurate estimation of the true resistivity of the uncontaminated zone. Existing geophysical approaches for determining the important parameters like true resistivity of formation (R_t) or diameter of invasion (D_i) have some limitations. These limitations come from the gross inadequacy of data. This point can be taken care of if borehole sounding is done. Resistivity departure or forward model curves are presented for normal (TES), lateral and Seven electrode (SES) configurations for three layer and four layer problems. Three layer problem simulates borehole mud, uniform resistivity invaded zone and uncontaminated zone where as four layer models simulate borehole mud, flushed zone, transitional or fixed resistivity invaded zone. One five layer model is presented to show the effect of the mud cake on the electrologging devices. Resistivity departure curves are compared with those already available for simpler models. Borehole sounding forward model curves are presented to show the degree of departure in the apparent resistivity for models (i) with and without invaded zone, and (ii) fixed resistivity and variable resistivity invaded zone. It has been proposed that borehole sounding and solution of inverse problems can give reasonably well estimation of these parameters. Inverse modeling is tested here with synthetic data and one set of 1-D ridge regression inversion model data has been presented.

In the final step of the forward modeling, finite difference method is used to solve for problem which have both horizontal and cylindrical interfaces. The problem becomes more acceptable in view of actual setup when inhomogeneous invasion is included in the structure. Apparent resistivity values in the presence of borehole mud, flushed zone, transitional invaded zone as well as fixed resistivity invaded zone and model without invaded zone and horizontal shoulder beds are computed for the geometry that is radially symmetric around the borehole axis. The efficient and accurate forward model response calculations are achieved by using gradually expanding grid system with two dimensional central difference average resistivity scheme for rectangular grids. Proper ordering of nodal elements and direct solution comprising of L-U decomposition and forward-backward substitution are used to solve the large sparse conductivity coefficient matrix. The finite difference solutions are verified with analytical solutions for relatively simpler one and two dimensional models. The FD mesh was improved till the match is excellent. The effects of shoulder bed resistivity, mud resistivity, transitional invaded zone resistivity, target bed resistivity and thickness are studied. Series of 2-D forward model curves are presented for different variable parameters and keeping all other parameters fixed. It is qualitatively demonstrated how increase in mud conductivity can reduce the sensitivity of the departure curves. Sensitivity of the departure curves on target bed thickness is also presented. It seems that shoulder bed resistivity along with the mud resistivity and target bed thickness have distinct and substantial influence on sensitivity in the resistivity departure curves.

Resistivity departure curves and their relative sensitivities at different electrode separations for different factors give an insight about the electrode separations required for optimum information hunting. It is observed that when electrode separation is three times the bed thickness, shoulder or adjacent bed effect masks the information from other zones. Lateral log response appears to be the sharpest of the three configurations studied. shoulder bed effect starts appearing in lateral log response when the bed thickness is nearly three times the electrode separation. This figure is roughly twelve times for the normal and eight times for the SES.

Detailed nature of the two dimensional resistivity forward model curves or departure curves are presented for transitional invaded zone, fixed resistivity invaded zone and no invasion zone as an aid for solving 2-D inverse problems. It has been proposed that multi channel single run borehole sounding is a better approach to estimate the true resistivity of the uncontaminated zone and the diameter of invasion.

In the presence of a borehole, the nature of variation of bucking current/focusing current ratios and geometric factor change significantly. Changes in the current ratios do not restricts their variations in the zones adjacent to the boundaries. but varies continuously. Even in the presence of borehole mud, the current ratio logs will demarcate the bed boundaries.

Advantage of focusing, as has been shown for SES with no borehole condition, vanishes with the introduction of the borehole mud. Effect of bypassing of current through saline mud in a borehole and conductive shoulder bed towards reducing the sensitivity of the apparent resistivity responses are qualitatively demonstrated. It is demonstrated that SES is more affected due to bypassing effect of the current than TES. Unfocused two electrode and three electrode responses are better than SES. For relatively conductive borehole mud when both TES and SES show flat responses, lateral log shows the presence of the bed. It reflects the presence of conductive flushed zone and invaded zone and do not reflect the resistive uncontaminated zone. Lateral log device has a domain of superiority over others. For models with conductive target and resistive shoulder beds, the SES response is marginally better than TES. It appears from 2-D modeling that bypassing effect of current in a borehole with conductive mud is more for focused device than for an unfocused device.

KEY WORDS : BOREHOLE DIRECT CURRENT RESISTIVITY MODELING, 1-D/2-D PROBLEMS, LAPLACE/POISSON EQUATION, METHOD OF SEPARATION OF VARIABLES, FROBENIUS EXTENDED POWER SERIES, FINITE DIFFERENCE METHOD, NORMAL, LATERAL AND SEVEN ELECTRODE RESPONSES, TRANSITIONAL INVADED ZONE, BOREHOLE SOUNDING/PROFILING, FORWARD MODEL CURVES, FOCUSED/UNFOCUSED SYSTEM.