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Transitional layering effects on electrical resistivity measurements for detection of 3D contamination plumes in the subsurface

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One of the simplest model assumptions, for the interpretation of resistivity profiling data for detection of a subsurface contamination plume, is to consider the plume as a three dimensional (3D) body in a layered structure with each layer having a constant resistivity. However, in reality, resistivities of the layers may vary continuously with depth. This may be due to differential weathering of the surface layer especially in areas subjected to tropical and subtropical conditions. A layer, in which resistivity (or conductivity) changes with depth in some continuous fashion, is called a transitional layer.

A typical example of a transitional layer is a weathered granite or basalt layer of gradually increasing freshness with depth. In general, any weathered zone in hard rock areas, where the degree of weathering diminishes with depth, represents a transitional layer. Transitional cases can also be seen in variable permeability and salinity of overburden as well as groundwater situations. Often where the geological section is approximated by horizontal layers, the boundaries between the layers are commonly assumed to be sharp. However, in reality these boundaries are not sharp but are mostly transitional in nature.

A particularly interesting transitional case occurs in deep basement layers of the Earth's crust, where increasing temperature can be associated with continuously increasing conductivity. Another field example is a fissured geological formation (e.g. limestone), which forms a transitional layer due to any phenomenon that alters continuously the physical status of the fissures. In this case, the increasing pressure in the deeper zones because of the increasing load and the gradual filling of fissures with

other materials such as clay, loam, sand and water can be two important reasons for this continuous variation of the resistivity with depth. Transitional layers can also be seen in coastal areas where the diffusion of saline water from the sea into fresh water produces a region with continuously variable salinity in the vertical direction.

The theoretical formulation of the resistivity problem in a layered earth with transitional layers has been presented in a number of publications. In general, the authors of these publications have used mathematical relations and boundary conditions to obtain a rigorous solution for the electrical potential in a transitional zone in which the resistivity (or conductivity) varies with depth in accordance with a specific function. This resistivity (or conductivity) function has been considered mainly to be of exponential, linear, or generalised power

variation with depth. Unlike many authors who considered a type of change (e.g. linear) with depth for the conductivity of a transitional layer in a layered earth, authors of new papers mainly considered a layered earth model with a transitional layer in which the resistivity changes linearly with depth. The reason is that the linear change of the resistivity with depth seems to be a far more common occurrence than the linear change of the conductivity with depth. In general, the layered earth model contained an arbitrary number of homogeneous layers and transitional layers. Nevertheless, the solution of the problem for the case of resistivity variation with depth is the same as for the case of conductivity variation with depth. Some other authors gave apparent resistivity expressions for a multi-layered earth with an arbitrary transitional layer having exponentially varying conductivity.

Previous publications concerning transitional layers have investigated the problem of a layered earth model without considering a 3D body (e.g. a subsurface contamination plume) embedded in it. In this regard, an interest from the detectability point of view of the resistivity profiling method is to consider a 3D contamination body under a transitional cover. For this, first relevant mathematics for a 3D body embedded in a layered earth with a transitional layer will be derived, and then some numerical examples will be presented. The model studied in this paper consists of a transitional layer in which resistivity or conductivity varies exponentially with depth. In numerical examples, the effect of transitional overburden layers on the detectability of 3D bodies from the apparent resistivity profiles using different electrode configurations such as the Wenner and Schlumberger arrays will be investigated. Through numerical examples it is shown that the resistivity profiling method using conventional resistivity methods is hardly capable of detecting anomalous bodies. However, some techniques will be presented that enhance the detectability of the 3D body by this method. It is concluded that the detectability of a 3D body under a transitional overburden layer in some layered earth situations (e.g. an electrically conductive body under a transitional overburden of decreasing resistivity with depth) using the conventional apparent resistivity profiles is worse than under a homogeneous overburden layer.