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Self Potential Modeling

from Primary Flows

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ABSTRACT

A new method for the calculation of self potentials (SP) based on induced current sources is presented. The induced sources are due to divergences of the covective current which is driven, in turn, by a primary flow, either heat or fluid. Numerical modeling utilizing this method has been implemented using a two dimensional transmission surface algorithm. When the primary flow is driven by the gradient of a potential, joint modeling of the primary flow and the resultant SP is possible with this algorithm.

Coupled Flows

The general equation for coupled flows can be written (Marshall and Madden, 1959; Nourbehecht, 1963)

$$i = \dagger_j L_{ij} X_j, \tag{1}$$

where the fluxes $_i$ (charge, matter, heat, etc.) are related to the various forces X_j (gradients of electric potential, pressure, temperature, etc.) though the coupling coefficients ("conductivities") L_{ij}. For many practical applications of coupled flows, we are concerned with secondary electric current flows and potentials which are driven by some other primary flow. When the effects of the secondary electric potentials on the primary flow are small, the primary flow equation is decoupled and the resulting equations are

$$1 = -L_{11} \tag{2}$$

and $J_{Total} = \quad _2 = -L_{21}$ (3)

where $_1$ is the primary flow (solution flux, heat flux, etc.), L_{11} is the primary conductivity (permeability, thermal conductivity, etc.) and is the primary potential (pressure, temperature, etc.), J_{total} is the total electric current, L_{21} is the cross coupling "conductivity", is the ordinary electrical conductivity and is the electric potential. The decoupled primary flow problem (equation 2) can be solved separately and used in the solution of the electrical flow problem (equation 3). Starting with equation 3, we note that the first term is a "convection" current driven by the primary flow and the second term is the usual conduction current driven by the gradient of the electric potential. Using this approach, we can write equation 3 as

$$J_{Total} = J_{conv} + J_{cond} \quad (4)$$

where $J_{conv} = -L_{21}$ (5)

and $J_{cond} = -$ (6)

If no <u>external</u> current sources are imposed and we have DC conditions (i.e. ¶/ t = 0), then the total current is divergenceless ($\cdot J_{Total} = 0$) and

$$\cdot J_{cond} = - \cdot J_{conv} = \cdot (L_{21} \quad) = L_{21} \cdot \quad + L_{21} \quad (7)$$

Thus there are sources (non-zero divergence) of conduction current wherever there are gradients of the cross coupling coefficient parallel to the primary flow (flow perpendicular to boundaries) or wherever there are sources of the primary flow. The sources of the conduction current given by the right-hand side of equation 7 can then be used to determine the resultant electric potential, . This procedure has been implemented with a two-dimensional transmission surface algorithm.

Model Studies

The interaction of a point source of primary flow with two vertical interfaces is shown in figure 1. Figure 1a shows a plan view of the normalized surface potential for a point source of heat flow in the center of a dike with non-zero coupling coefficient ($C = L_{21}/$). The positive portion of the anomaly over the dike is elongated in the strike direction while the negative portion is elongated perpendicular to the dike. Figure 1b shows the surface potential for a point source of fluid flow. In this case the negative monopolar anomaly is elongater perpendicular to strike.

Simple model studies, such as these, illustrate the variety of self potential anomalies due to different sources and geometries. They also show how variations in the model parameters affect the form and magnitude of the anomaly.

Field Example

The Monroe Red Hill (Utah) geothermal system is an example of deep circulation along a fault zone that has been relatively well studied (Mase et al, 1978). A limited SP survey over the Red Hill area showed a modest anomaly of dipolar form that correlated reasonably well with certain features of the electrical resistivity anomaly ad delineated by dipole-dipole measurements. Figure 2 shows the physical properties model and the location of the thermal sources. The main features are a steeply dipping fault separating the volcanics on the east (20$m) from the alluvium on the west. The heat source distribution in the model represents the circulation of hot water up the fault and horizontal leakage into the alluvium. The temperature distribution from these sources is shown in figure 2b; also shown are the observed temperatures at 25m increments, for four drillholes along the profile (Mase et al, 1978). The drillhole temperatures have been corrected for the mean temperature and the thermal gradient (15°C/km) which are not represented in the model calculations. A comparison of the observed and calculated SP anomalies are shown in figure 3. The comparison is reasonably good although it should be noted that the observed anomaly is not exactly symmetrical about the centerline. The cross coupling coefficients in the model are all larger than those typically reported in the literature, which seems to be a common problem (Fitterman and Corwin, 1981; Corwin et al, 1980). However, it should be noted that most samples reported on in the past were relatively unaltered material and the effects of elevated temperatures on the cross coupling coefficients are not well known.

References

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Figure 1. Contours of surface voltage (x, y plane, z = o) for point sources and a dike. (a) Point temperature source (b) Point pressure source.

Figure 2. (a) Physical properties used tomodel the data at Red Hill. (b) Comparison of the observed and calculated temperatures at Red Hill.

Figure 3. Comparison of the observed and modeled SP anomaly at Red Hill. Model properties in figure 15a.