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MODELING SELF-POTENTIAL (SP) DATA IN THE ABRAHAM AND MEADOW-HATTON GEOTHERMAL SYSTEMS

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self potential, SP, fluid flow, field data acquisition, modeling

PROJECT BACKGROUND AND STATUS

Ross et al. (1993) collected SP data at Abraham and Meadow-Hatton Hot Springs, two of the largest thermal spring systems in Utah. In this paper, these data were modeled to determine upflow zones and source characteristics using a numerical code.

PROJECT OBJECTIVE

SP has long been a promising method for geothermal exploration because the measured anomalies are directly related to subsurface heat and fluid flow. The technique has not been widely used because of uncertainties in data quality and the lack of interpretation methods. As part of our research effort in SP we are examining data collection issues and have developed interpretation techniques that are suitable for small computers. The two case studies below present examples of SP data interpretation.

RESEARCH RESULTS

Numerical Modeling of SP Anomalies

Computer code SPXCL calculates the electrical potential anywhere in a two-dimensional medium from thermal or pressure (flow) sources. It is the latest modification of a code written by Sill (1983). The two-dimensional model requires input of three sets of physical properties for every mesh point. The location and strength of the flow sources must also be specified. The resulting voltages, pressures, and temperatures can be used to fit field observations (see Wilt et al, 1996).

Information on the permeability distribution, resistivity structure, and cross-coupling coefficients are gathered to begin constructing a model. These are either known from site studies, or estimated from previous experience. Source characteristics are based on hot springs flow data or educated guesses. The code allows either a point or a finite line source. Data is interpreted via iterative forward modeling. That is, a model consistent with the known geology and hydrology is input and then iteratively modified to fit the SP voltages and/or pressures and temperatures. Each forward model requires less than one minute to compute on a Sun workstation.

Case 1: Abraham Hot Springs

The thermal springs that issue at Abraham have temperatures as high as 87°C and flow rates up to 140 l/s. The hot springs lie 6 km east of Fumarole Butte, a Quaternary eruptive center that formed a broad basalt apron known as Crater Bench. A north-northwest trending fault within Crater bench probably provides the vertical permeability for geothermal flows emanating at Abraham Hot Springs.

A total of approximately 22.0 line-km of SP data were collected in 1991 and 1992 (Ross et al., 1993). Figure 1 is a map of the Abraham Hot Springs area showing SP contours in millivolts and data collection points. The contours show a general trend of negative values to the west of the fault and positive values to the east. The smoothed SP contours, overlaying the raw data in Figure 1, were used in the two-dimensional modeling.

To model a data set with SPXCL the geologic structure must be approximately two-dimensional and the data must be smoothed to remove short wavelength anomalies related to near-surface sources. For Abraham Hot Springs we applied a rough hand-smoothing of the data to accentuate large-wavelength anomalies and selected a profile (A-A'), perpendicular to the predominant NW-SE structural trend, for application of the 2-D model.

Our SP model, based on published geology and geophysics is shown in Figure 2 (Mabey and Budding, 1987; Oviatt, 1991).Two layers of Quaternary basalt overlay the alluvial sediments. These layers represent the basalt apron that makes up Crater Bench. The lower layer, weathered basalt mixed with Quaternary alluvium, is 75 m thick. The upper "fresh" basalt layer has virtually the same properties as the weathered basalt, except for a lower permeability due to less fracturing. The vertical unit, consisting of highly fractured basalt and alluvial sediments, is coincident with the fault and represents the passage for fluid to ascend.

A point pressure source was placed at a depth of 200 m near the contact of the vertical conduit and the alluvial sediments. The source strength was given as 300 l/s, about twice the observed flow rate at the surface. Physically, this point source represents the onset of open fractures.

Although the depth required for heating the fluids, suggested by Ross et al. (1993), is about 3 km, the actual source from which fluids are released from a high pressure conduit to a lower pressure layer in the subsurface is likely much shallower. A likely scenario is that geothermal waters are circulated by convection to an area of highly fractured rock. The high permeability of the fractured zone causes a decrease in pressure. This area is designated as the source location in the model. The flow then ascends along the fracture zone, encounters the basaltic overburden, and travels laterally until it discharges at the surface.

Our model is consistent with the known geology at Abraham Hot Springs, but it is clearly not unique; for this reason we did not strive for an exact fit to the observed data. We discovered that the model was most sensitive to changes in the source depth and strength and to a lesser extent changes in the permeability and resistivity of model units. The location and strength of the source in relation to the fractured zones also played an important role for aligning the dipolar anomaly correctly with the observed SP data.

Case 2: Meadow-Hatton Hot Springs

Meadow-Hatton is located in the eastern Black Rock Desert, in the Basin and Range province of western Utah. Hatton Hot Springs issues from the edge of a 2 km long, northeast trending travertine mound with a temperature of 63°C and a flow rate of 0.1 l/s. Meadow Hot Springs, located 8 km northwest of Hatton, experiences variable flow rates, from no discharge to significant discharge.

Figure 4 is a map of the area with SP contour lines in millivolts and data collection points; the hand-smoothed SP data used in modeling is superimposed. The field studies by Ross et al. (1993) show three coherent anomalies with amplitudes of –70 to –120 mV located 300 to 1000 m north of Hatton Hot Springs, suggesting a possible upflow zone. No significant anomalies were observed at Meadow Hot Springs. Our smoothed profile, located across the voltage anomaly, indicates two adjacent negative anomalies reaching –50 mV.

The geologic model for Meadow-Hatton is shown in Figure 5. The dome of mixed alluvium and travertine is about 20 m high and extends laterally 600 to 900 m. Thermal fluids rise along fractures within the dome which cut valley fill sediments. Two pressure sources (190 l/s and 200 l/s) are located at 200 m depth each on the outside contacts of the conduits.

Figure 6 shows the fit of the observed and model-generated data. Like the model for Abraham Hot Springs, the highly negative anomalies (–50 mV) measured require large subsurface flow rates. The model suggests that geothermal waters, brought up from deeper convection, may have migrated laterally in the permeable travertine layer to outflow at Hatton Hot Springs where minor seeps occur, and probably northwest beneath conductive soils, to the Meadow-Hatton pools area. Although, at present, neither hot springs system produces significant discharge, the travertine mound indicates that there was significant flow in the past. The SP models suggest a high flow rate exists today but most of it remains subsurface.

CONCLUSIONS

We have shown through these two studies at Abraham and Meadow-Hatton Hot Springs that models consistent with known geology can locate the source depth, strength, and location. As with any geophysical technique though, SP modeling does not come without limitations. The solutions derived are restricted to a point or line source, the code cannot account for three-dimensional variations, and the solution is not unique. However, given enough background information, a model can be constructed that is both accurate and realistic.

FUTURE PLANS

We plan to continue our research in SP along several fronts. We are continuing to work on data collection schemes to improve reliability and isolate sources of noise. We are also improving our computer codes and developing better documentation for wide acceptance. In particular we are working on the following tasks.

An operations manual for program SPXCL is presently being written and the code will be modified for use on a PC. (Note that an older version of SPXCL, is available for PC through the U.S. Army Corps of Engineers, Wilt and Butler, 1990).

The main stumbling block to effective use of numerical modeling is the knowledge of SP coupling coefficients. Very little reliable data on this physical property is known and little new data is being acquired. We are presently working with Dr. Dale Morgan at MIT, the only active researcher in this area, to assemble known data and outline future needs.

INDUSTRY INTEREST AND TECHNOLOGY TRANSFER

There is considerable new interest from geothermal developers in using SP and applying our two-dimensional modeling algorithm to field data. We have distributed our computer code to TransPacific Geothermal Inc. of Oakland Calif and to Geophysica of Golden Colo. We are presently examining SP data provided by Oxbow Geothermal.

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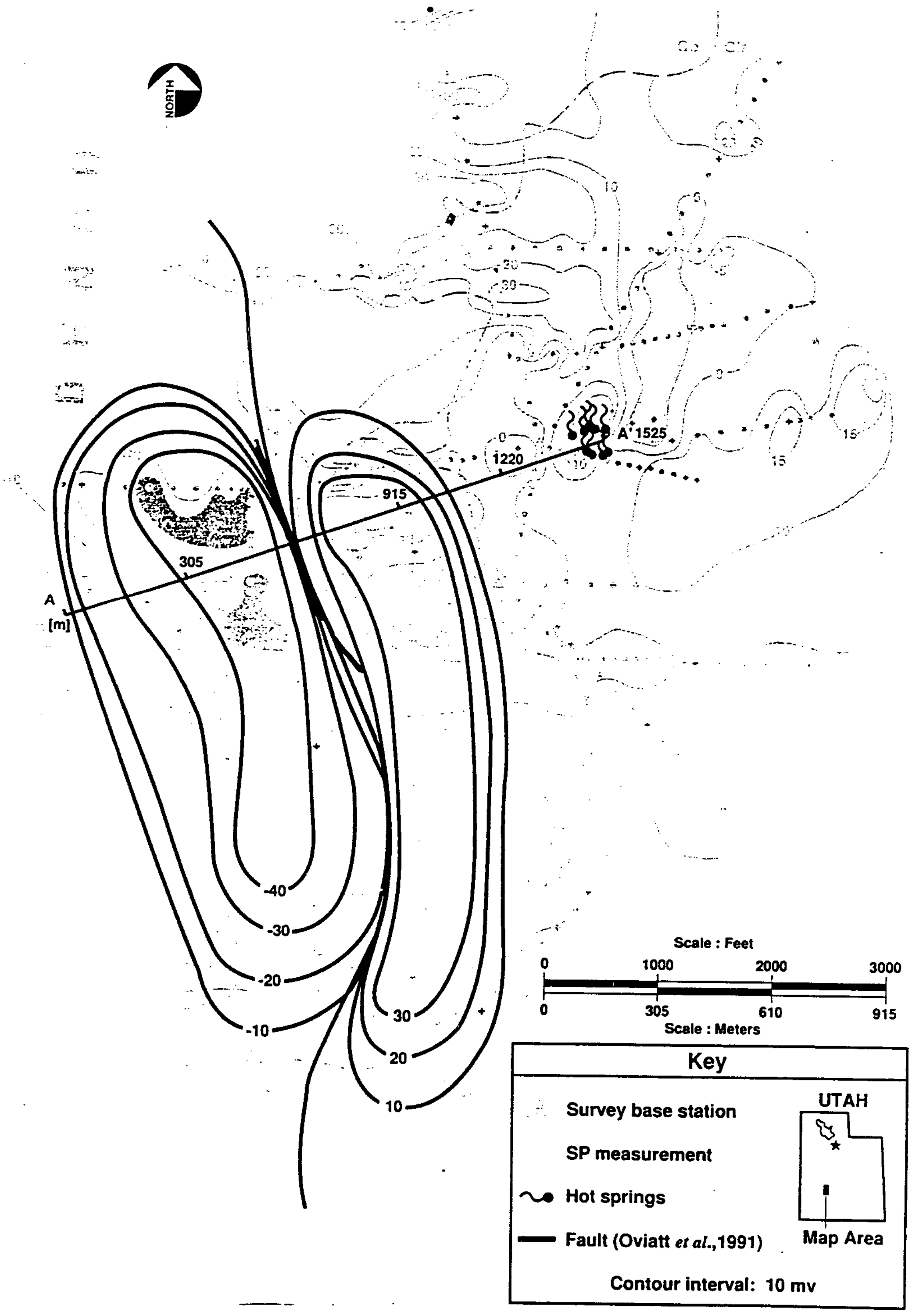


Figure 1. Abraham Hot Springs raw and smoothed surface voltages. The contour interval is 10 mV. Profile line A–A′ is used in modeling the data.

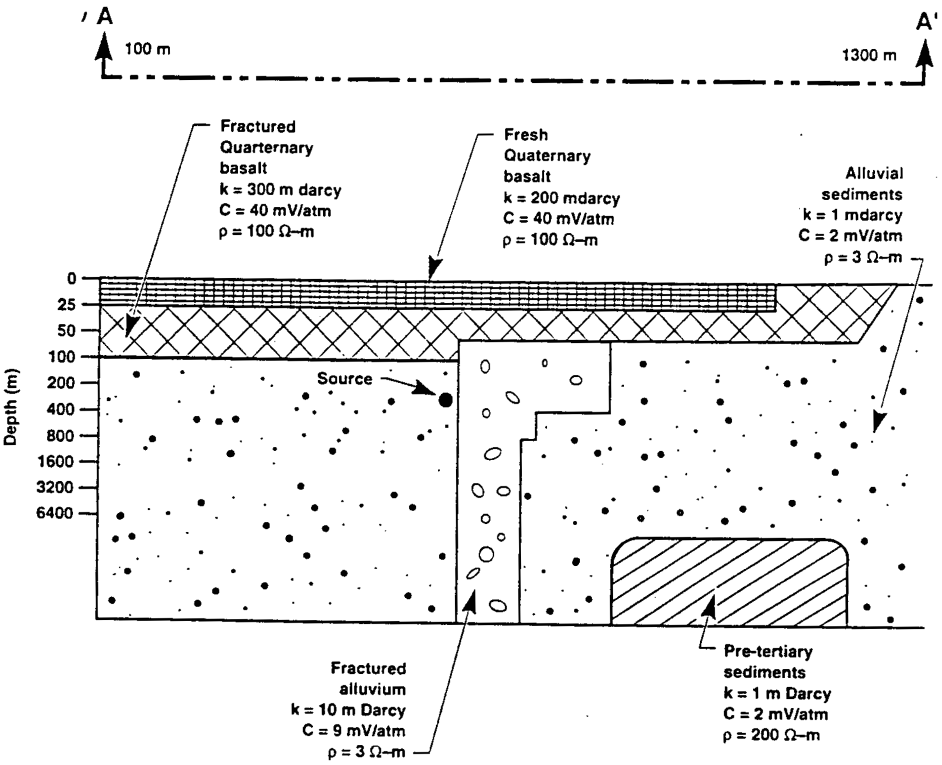


Figure 2. Model used in the SP interpretation.

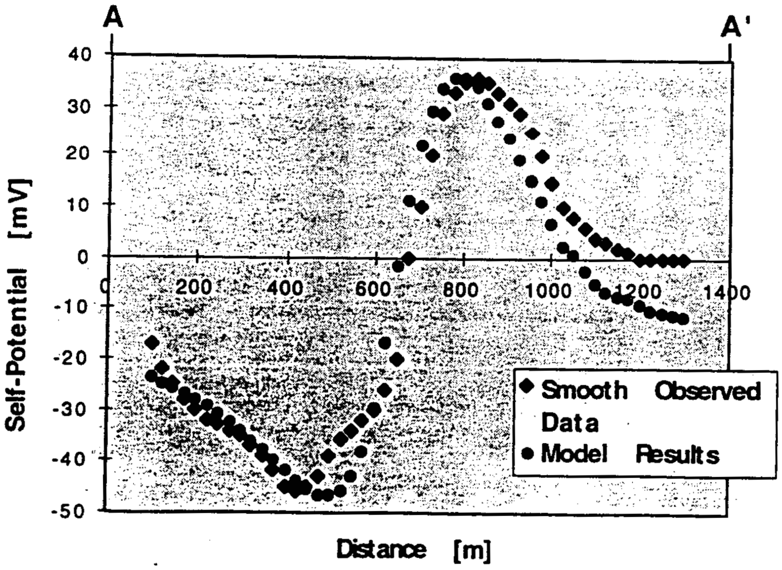


Figure 3. Plot of surface voltage values generated from the model compared to the smooth observed values.

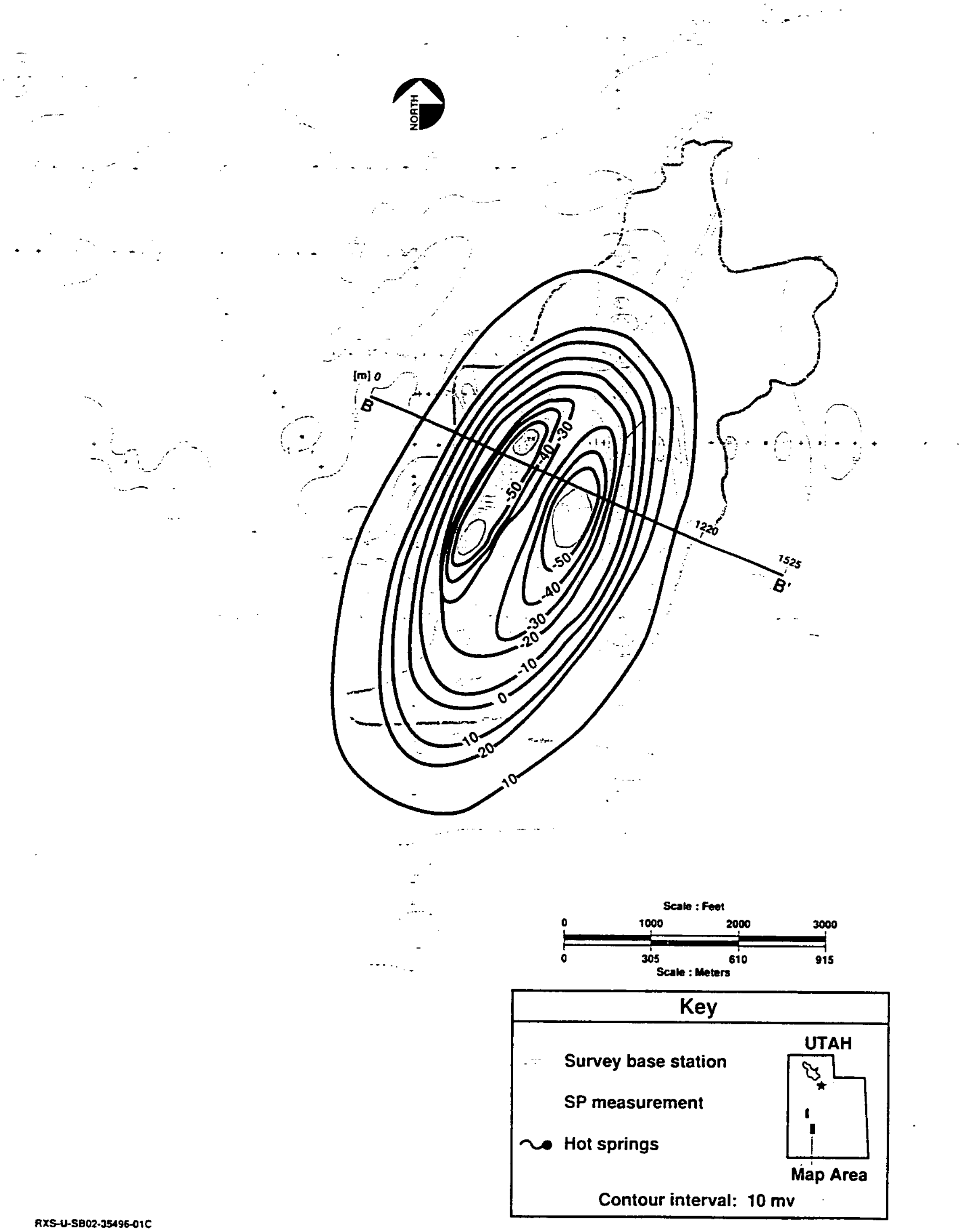


Figure 4. Meadow-Hatton Hot Springs raw and smoothed surface voltages.

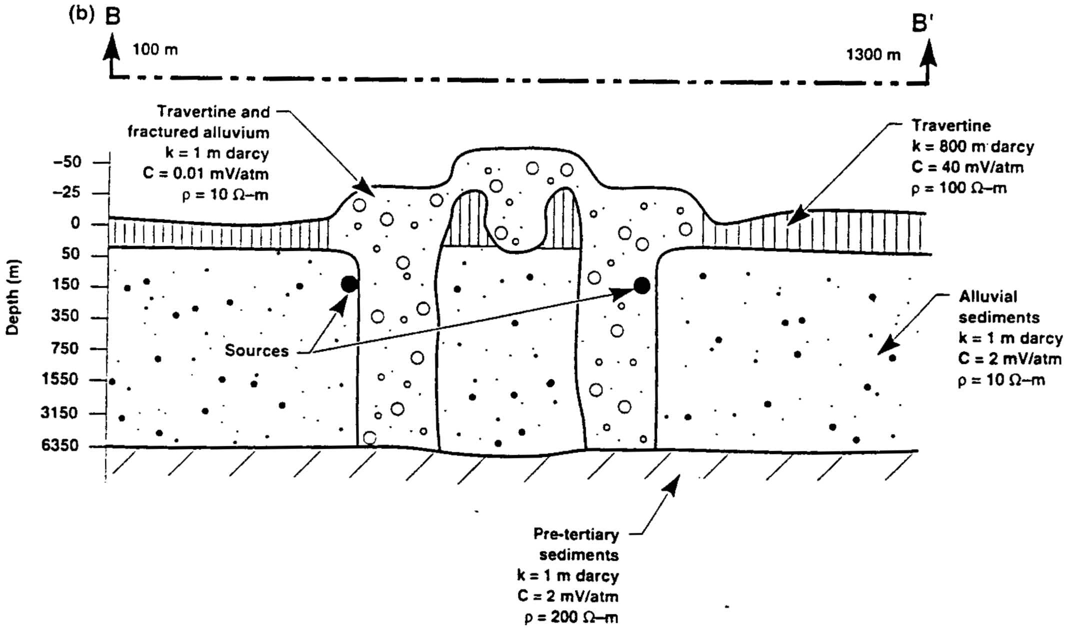
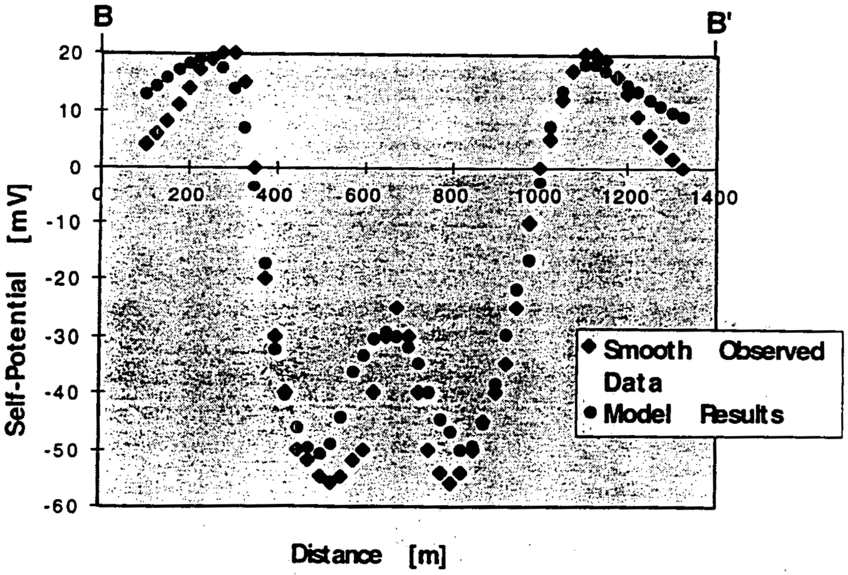


Figure 5. Model used in the SP interpretation.



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