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A BOREHOLE-TO-SURFACE DC RESISTIVITY EXPERIMENT

E. Gasperikova[1], W. Frangos[2], A.C. Tripp[1], and P. M. Wright[3]

[1] Dept. of Geology & Geophysics, U. of Utah, S.L.C., UT 84112
[2] Engineering Geoscience, U. of California at Berkeley, CA 94720
[3] U.of Utah Research Institute, 391 Chipeta Way, S.L.C., UT 84108

ABSTRACT

A DC resistivity borehole-to-surface survey of a complex geological area has been conducted by the University of Utah Research Institute. The purpose of the survey and subsequent interpretation has been to examine the efficiency of borehole-to-surface DC measurements in delineating strata in a region with good well control. This paper contains a progress report on this work.

INTRODUCTION

There have been a number of papers concerning borehole-to-borehole and borehole-to-surface electrical measurements. DC resistivity measurements using a combination of subsurface and surface electrodes are more sensitive to subsurface inhomogeneities than are arrays confined to the surface. The other advantage of these configurations is that they reduce the influence of near surface inhomogeneities. Asch and Morrison (1989) showed that in order to maximize the effectiveness of borehole-to-surface resistivity measurements, the downhole electrodes must extend below the target. The optimal depth depends on the distance between the target and the boreholes, and on the target size, shape, and conductivity contrast with the surrounding geology.

Many geothermal reservoir parameters, such as temperature, alteration and brine concentration, have a electrical conductivity expression. Unfortunately variation of these parameters at depth are obscured by near-surface geological noise. In this case, borehole-to-surface techniques should be useful for geothermal studies. However, field work in a geothermal environments involves particular logistic difficulties. Therefore proof of concept field studies should be attempted first in cool environment. It is our intention in this paper to discuss ongoing research involving a proof of concept borehole-to-surface field study.

GEOLOGY AND TARGET DEFINITION

A borehole-to-surface DC resistivity experiment was realized in Emery Co., Utah in the Ferron Sandstone Member (Figure 1). The Late Cretaceous (Turonian) Ferron Sandstone Member of the Mancos Shale is a well-exposed example of rocks deposited in a fluvial-dominated deltaic environment. The Ferron Sandstone has been the subject of numerous scientific publications and it is used as a reservoir analog by a number of petroleum companies (Nielson et al., 1992). The Tununk Member of the Mancos Formation underlies the Ferron and is composed of off-shore marine shale that thickens to the southwest documenting the subsiding foreland basin of the Sevier orogenic belt. The Ferron was deposited during an overall regression of the Cretaceous sea. A schematic cross-section showing the stacking pattern of the Ferron Sandstone is in Figure 2.

It might be possible to find significant natural gas sources in known reservoirs by developing a methodology to identify and predict reservoir heterogeneity. In pursuing this notion, the University of Utah Research Institute (UURI) investigated reservoir heterogeneity during 1989-1991 using the Ferron Sandstone as a study area. The conclusion of this project was it is not possible to determine the continuity and connectivity of reservoir seals or reservoir bodies on the basis of high resolution microscanner images, although reservoir heterogeneity in fluvial-dominated deltaic sediments is significant. This raises the question whether we can get any useful information about this area by doing a borehole-to-surface DC resistivity survey.

We analyzed borehole logs and identified a few conductive shale layers in the resistive sandstone formation. The thickness of those shale layers was only a few meters. The deepest shale layer was at a depth of about 80 m. Are we able to image the distribution of these conductive layers in a resistive surrounding, even if it is not a homogeneous one?

To get an idea of what kind of response we can get from these conductors in a resistive environment, we ran many test models using an algorithm written by Beasley (1986). The modeling showed that in order to resolve thin deep conductive bodies we need highly accurate measurements.

FIELD SITUATION

Two holes were drilled in this area, UURI-1 and UURI-2. The distance between these boreholes is about 500 m. Their depth is about 150 m. They are cased only for the top several meters. The following logs were collected: Natural Gamma Ray Spectrometry, Induction, Neutron/Density Porosity, and Formation Microscanner.

In order to realize borehole-to-surface field measurements it was necessary to develop a special down-hole current electrode. Downhole transmitter systems pose several design challenges. It is essential that current be introduced into the earth solely at the point of the downhole electrode in order to accomplish the assumptions of the data analysis. Furthermore, it is critical that the system function as intended, since failures tend to ruin both the geophysical equipment and the expensive drillhole. Accordingly, the cable must maintain its insulation in the rough environment of the drillhole walls and the downhole electrode must resist electrolytic corrosion during use, and do so without compromising the point-source nature of the current source.

The borehole-to-surface system uses a four-conductor armored logging cable and a specially designed downhole electrode adaptor, or DTA. The actual electrode may be either a piece of standard 3/4-inch threaded water pipe or a metallic rod secured by three set screws. Provision for replaceable electrodes allows using a size appropriate to a particular survey; for the Ferron work, we used a 5-foot section of iron pipe.

Two additional electrical properties of the cable system are important in safe operation: its resistance and inductance. Direct measurement of the resistance and inductance yielded values of 30 ohms and about 10 millihenries, respectively. Empirical evaluation of the cable characteristics during the field survey indicated that the goals declared above were well met. Operating at currents of 1 and 2 amperes for long periods, the coil showed no signs of warming, as observed by feeling the exterior and the steel axle. Isolation between the electrode and the cable armor was verified by measuring voltage between the armor and a surface electrode with the transmitter on and off. The difference was about 6 volts, while the transmitter output voltage was approximately 400 volts.

The area between the two boreholes (roughly 500 m x 500 m) was covered by measurements with different electrode configurations. There were three different setups of current electrodes A and B for each borehole. For UURI-1 these sets were
A_1 = [-467.5, 200.0, 0.0]
B_1 = [-21.53, 294.11, 0.0],
A_2 = [-467.5, 200.0, 0.0]
B_2 = [0.0, 0.0, 0.0], and
A_3 = [-467.5, 200.0, 0.0]
B_3 = [0.0, 0.0, 100.0],
while for UURI-2 they were
A_1 = [1077.5, 341.0, 0.0]
B_1 = [560.0, 265.0, 0.0],
A_2 = [1077.5, 341.0, 0.0]
B_2 = [582.31, -0.02, 0.0], and
A_3 = [1077.5, 341.0, 0.0]
B_3 = [582.31, -0.02, 100.0].

We took measurements with 50 m dipoles in two orthogonal directions, on a 50 m grid. A GGT-30 transmitter and a GDP-16 receiver from Zonge Engineering were used for this project. The field site was surveyed with a Pentax electronic distance meter to get precise position of current and potential electrodes.

DATA PRESENTATION

Figures 3 and 4 illustrate the resistivity distribution and character of the electrical field in this particular area. Figure 3 is the total apparent resistivity map for the UURI-1 [A_2, B_2] current electrode position, and Figure 4 is the total apparent resistivity map for the UURI-1 case when one current electrode is 100 m deep. These two maps are dissimilar. There is an order of magnitude difference in resistivity values in these maps. This suggests that we are seeing the influence of the deep conductive layer with our system configuration.

PLANNED WORK AND CONCLUSIONS

We have gathered a reasonable data set in this field experiment which shows evidence of resistivity variations with transmitter electrode depth. To analyze these variations precisely we need computerized interpretation. We are now in the process of modifying a multidimensional resistivity inversion algorithm to handle downhole electrode sources. Because we have multiple sources and an orthogonal set of potential dipoles in this project we will also evaluate the usefulness of tensor resistivity calculations. According to Bibby and Hohmann (1993) the tensor invariants, which represent averaged values of apparent resistivity, successfully eliminate "false" anomalies, which are a characteristic of single-source measurements. These invariants will hopefully define three-dimensional variations in electrical resistivity of strata.

ACKNOWLEDGMENTS

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REFERENCES

Asch, T., and Morrison, H. F., 1989, Mapping and monitoring electrical resistivity with surface and subsurface electrode arrays: Geophysics, 54, p. 235-244.

Bibby, H. M., and Hohmann, G. W., 1993, Three-dimensional interpretation of multiple source bipole-dipole resistivity data using the apparent resistivity tensor: Geophysical Prospecting, 41, p. 697-723.

Beasley, C. W., and Ward, S. H., 1986, Three-dimensional mise-a-la-masse modelling applied to mapping fracture zones: Geophysics, 51, p. 98-113.

Newkirk, D. J., 1983, Downhole electrode resistivity interpretation with three-dimensional models: M.S. Thesis, University of Utah, Salt Lake City, Utah, p. 141.

Nielson, D. L., et al.,1992, Evaluation of reservoir heterogeneity using the statistical curvature analysis technique: Final Report, Contract No. 5089-260-1855, UURI, Salt Lake City, Utah, p. 141.

Ryer, T. A., 1981, Deltaic coals of the Ferron Sandstone Member of the Mancos Shale: predictive model for Cretaceous coal-bearing strata of western interior: American Association of Petroleum Geologists Bulletin, v. 65, p. 2323-2340.

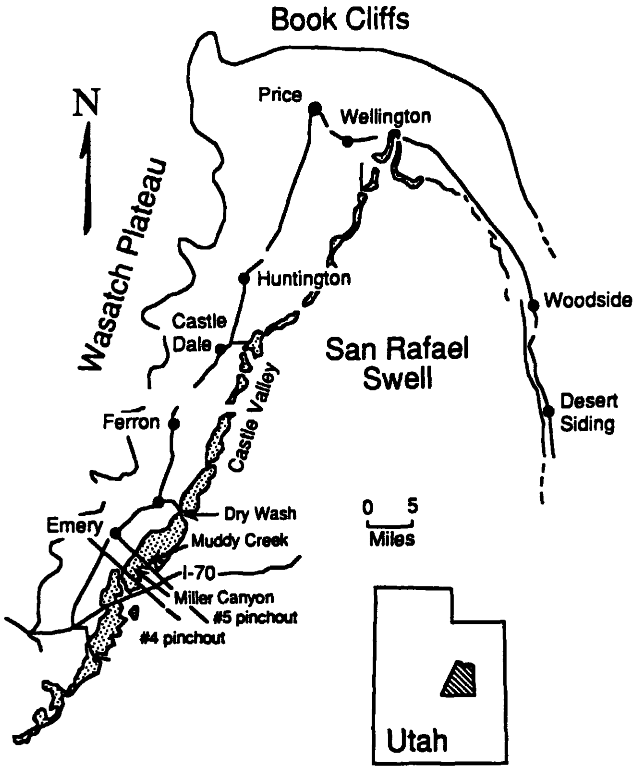

Figure 1. Location map and outcrop pattern of the Upper Cretaceous Ferron Sandstone Member of the Mancos Shale. Landward pinchouts of the #4 and #5 marine sandstones are from Ryer (1981a).

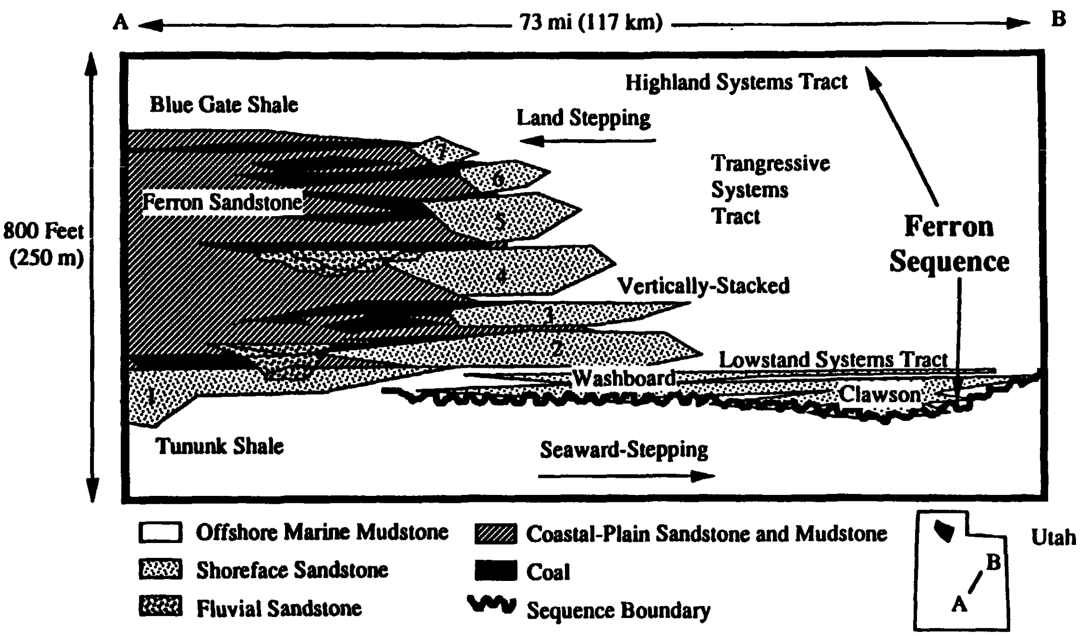

Figure 2. Schematic cross section showing the stacking pattern of the Ferron Sandstone. (Gardner, in prep.)

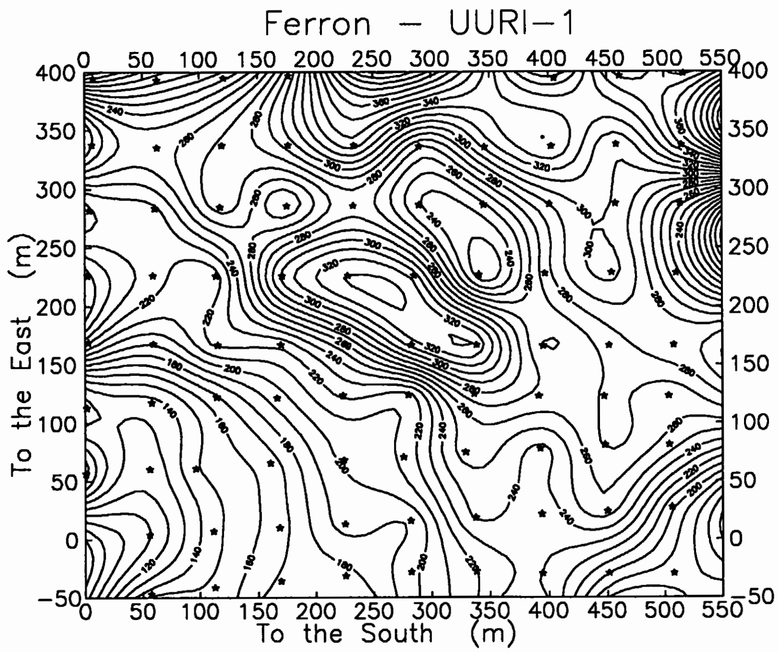

Figure 3. Total apparent resistivity map for the current electrodes A=(−467.5,200,0) and B=(0,0,0)

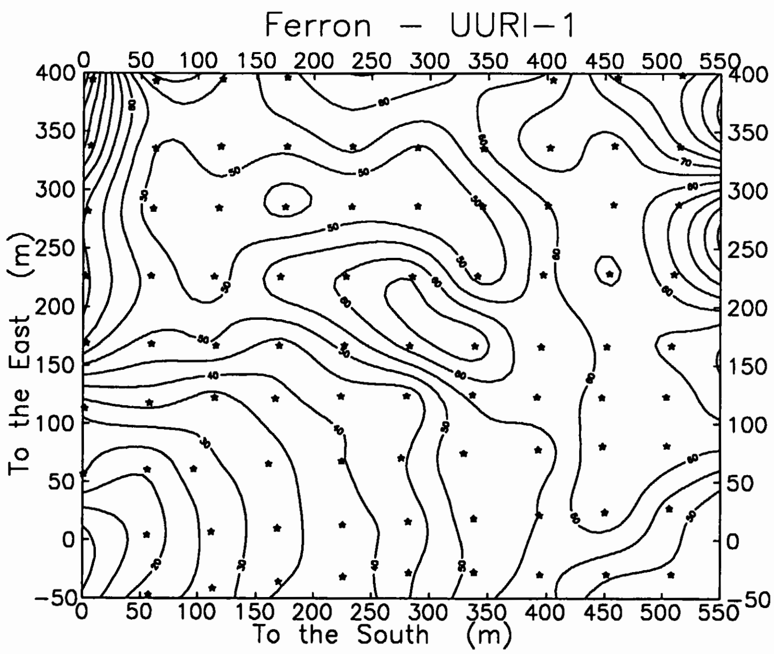

Figure 4. Total apparent resistivity map for the current electrodes A=(−467.5,200,0) and B=(0,0,100)