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FINAL REPORT

RESISTIVITY MEASUREMENTS BEFORE AND AFTER INJECTION TEST 5 AT RAFT RIVER KGRA, IDAHO

by

William R. Sill

September 1983

Work performed under Contract Number: DE-AC07-80ID12079

DISCLAIMER

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EARTH SCIENCE LABORATORY
University of Utah Research Institute
Salt Lake City, Utah

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TABLE OF CONTENTS

INTRODUCTION

Resistivity measurements were made prior to, and after an injection test at Raft River KGRA, Idaho. The objectives of the resistivity measurements were to determine if measureable changes could be observed and whether they could be used to infer the direction of fluid flow. Self-potential measurements were also made in conjunction with this test and the results of that study are reported in Sill (1983).

The injection phase of Test 5 consisted of the injection of water from well RRGP-3 into RRGP-5 at a rate of 9.5 L/S (150 gpm) for a period of 376 hours (Downs et al., 1982). The total volume of injected fluid was about 1.4×10^4 m^3. The injected water from RRGP-3 is more conductive (1.25 Ωm) than the reservoir water produced from RRGP-5 (4.0 Ωm). The large volume of conductive fluid injected into RRGP-5 during Test 5 provided the best opportunity to observe resistivity changes due to the displacement of presumably more resistive native fluids by the more conductive injected fluids. Although the volume of injected fluid is large, the distance it migrates from the borehole is strongly dependent on the geometry of the flow. For spherical spreading into a medium with 10 percent porosity the distance is only 35 m. On the other hand, if the fluid spreads out radially within a 1 cm fault zone with 50 percent porosity the distance traveled would be about 1 km (Sill, 1983). The preferred model resulting from the self-potential study contained a vertical fault extending from near the bottom of RRGP-5 (1400 m) to within 100 to 200 m of the surface. Depending on the thickness and the porosity, it is conceivable that the injectate could have displaced the native fluids in this fault zone, over a considerable distance.

RESISTIVITY DATA

Resistivity measurements were made using the casing of RRGP-5 as an electrode. During the measurements the wellhead was electrically isolated from the injection pipeline. A grounded casing acts as a transmission line which distributes the transmitted current along its length. When the frequency of the current excitation is low and the medium is homogeneous the distribution of current along the casing is uniform (Sunde, 1949). As the frequency increases, transmission delays along the line give rise to a non-uniform distribution of current. As a practical compromise a frequency of 0.125 Hz was chosen for the current source. At much lower frequencies telluric noise tends to degrade the voltage measurements and the time required to obtain an accurate measurement becomes excessive.

The transmitter used in these measurements was a Geotronics Model FT-20 and the typical transmitted currents ranged from 10 to 16 A. A Zonge Engineering Model GDP-20 receiver was used to make the voltage measurements for the resistivity calculations. The typical voltage amplitudes ranged from a few to tens of millivolts.

In order to estimate the errors involved in the measurements under typical field conditions, one station at a distance of 900 m from the well casing electrode was chosen for repeated occupation. Repeat measurements made on 5 separate days gave a standard error of about 2.5 percent. Since electrode locations were carefully marked, most of this error is attributable to small variations in the current control by the transmitter and small changes in the gains of the receiver amplifiers.

Resistivity measurements were made along six lines at 100 m station spacings. Measurements at each station were made on a pair of orthogonal 100 m dipoles. The direction of the electric field and the station locations are shown in Figure 1. As might be expected the electric field points more or less radially away from the casing electrode. Some significant deviations are present and these indicate the presence of some 2 or 3 dimensional effects. The amplitude of the total voltage differential at each station were used to calculate the apparent resistivity plan map in Figure 2. These calculations assume a uniform, vertical line source 1400 m long located at RRGP-5. The apparent resistivity varies from greater than 30 Ωm near the well (shallow penetration) to about 10 Ωm at the edge of the survey area (deep penetration). A slightly anomalous region is located along the E-W line in the vicinity of a cathodic protection system (Sill, 1983).

The resistivity model of Figure 3 was adapted from the self-potential modeling of Sill (1983). The apparent resistivity calculated from this model using a uniform line source along the casing is shown in Figure 4. The agreement between the calculated (Figure 4) and the observed (Figure 3) apparent resistivities is reasonably good.

After the period of injection, the resistivity survey was repeated and the observed changes (in percent) are plotted in Figure 5. Most of the changes are close to, or smaller than, the estimated standard error of the measurements (2.5 percent). The large change (44 percent) is close to the cathodic protection system and is probably a "cultural effect". The data suggest the possibility of a positive zone (apparent resistivity went up after injection) extending to the northeast which may be flanked on the north, west and south by a negative zone.

RESISTIVITY MODELS

The direction of the trend in Figure 5 is similar to that observed in the self-potential measurements made during this test (Sill, 1983). This suggests that a common source geometry may be involved in both the resistivity and self-potential changes. The self-potential model required a fracture zone extending from depth to within a few hundred meters of the surface. The fracture zone is indicated by the dashed line in Figure 3. The question is whether the movement of fluid of different salinity along this zone could produce the observed resistivity changes. Numerical modeling such as was used to get the results shown in Figure 4 is one approach to this problem. However, the numerical models usually produce results which have an accuracy in the neighborhood of a few percent and taking the difference between two model calculations to derive a change of a few percent is a risky procedure. Nevertheless, the two dimensional transmission surface algorithm was used in an attempt to study the changes produced by introducing a fracture zone of contrasting resistivity into the model of Figure 3. The fracture zone (25 m thick, infinite strike length) was made both more conductive (5 Ωm) and more resistive (20 Ωm) than the host (10 Ωm). The changes caused by the fracture zone in these two instances are shown in Figure 6 along two lines, one perpendicular to the fracture and the second over the fracture. For the conductive fracture zone (5 Ωm) the model results indicate a general decrease in apparent resistivity of a few percent. The resistive fracture model shows a tendency for positive deviations near and over the fracture and negative changes elsewhere. This latter pattern may be more in accord with the trend in Figure 5.

DISCUSSION

Most of the apparent resistivity changes observed after the injection phase of Test 5 are smaller than the estimated standard deviation of the measurements. However, the contour map of the changes suggest an anomalous trend to the northeast which is similar to the trend in the self-potential data. The numerical modeling of the resistivity data is marginal for changes as small as those observed but the results suggest that changes of a few percent could be expected from a fracture zone extending from depth to within 100 m of the surface.

ACKNOWLEDGEMENTS

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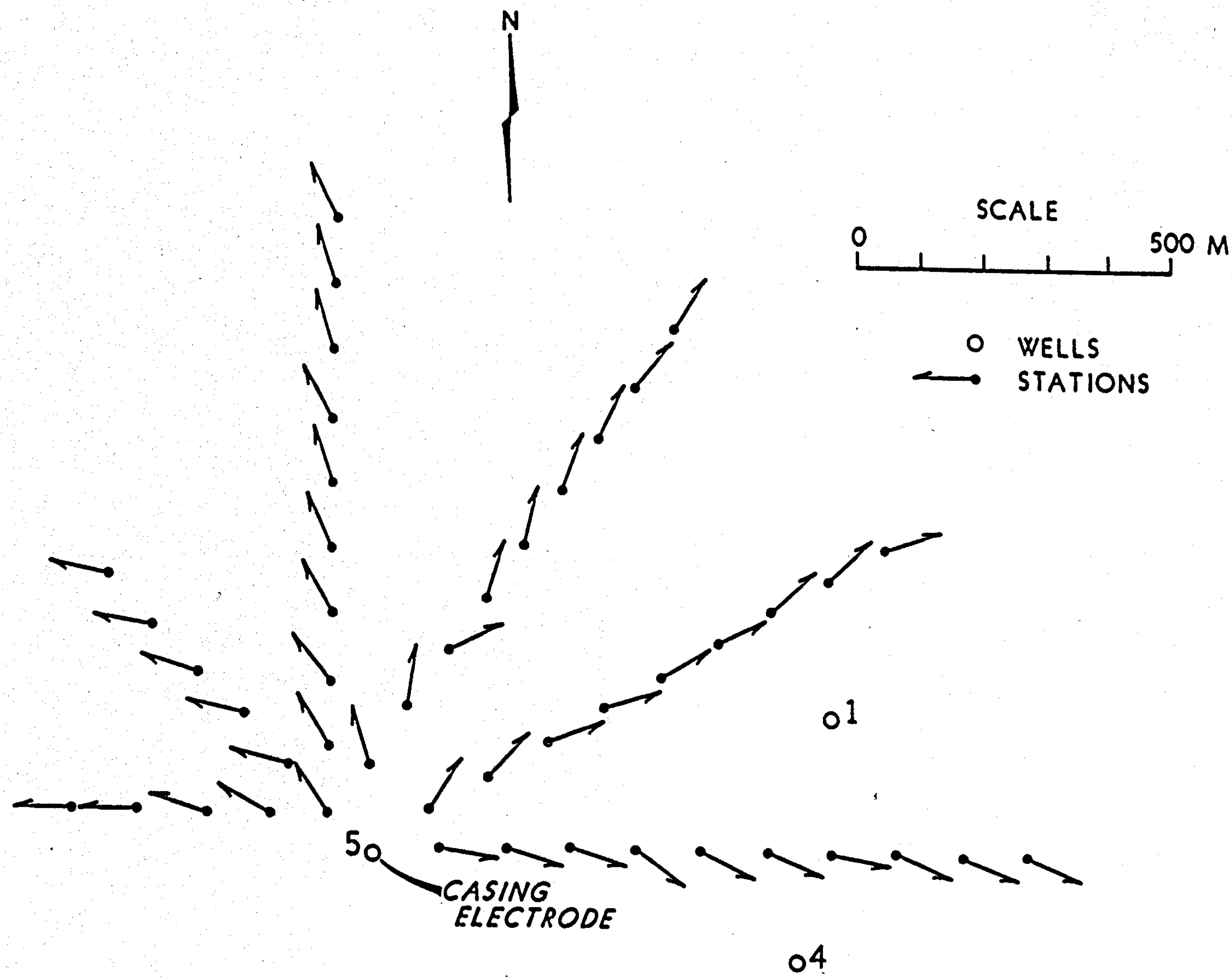
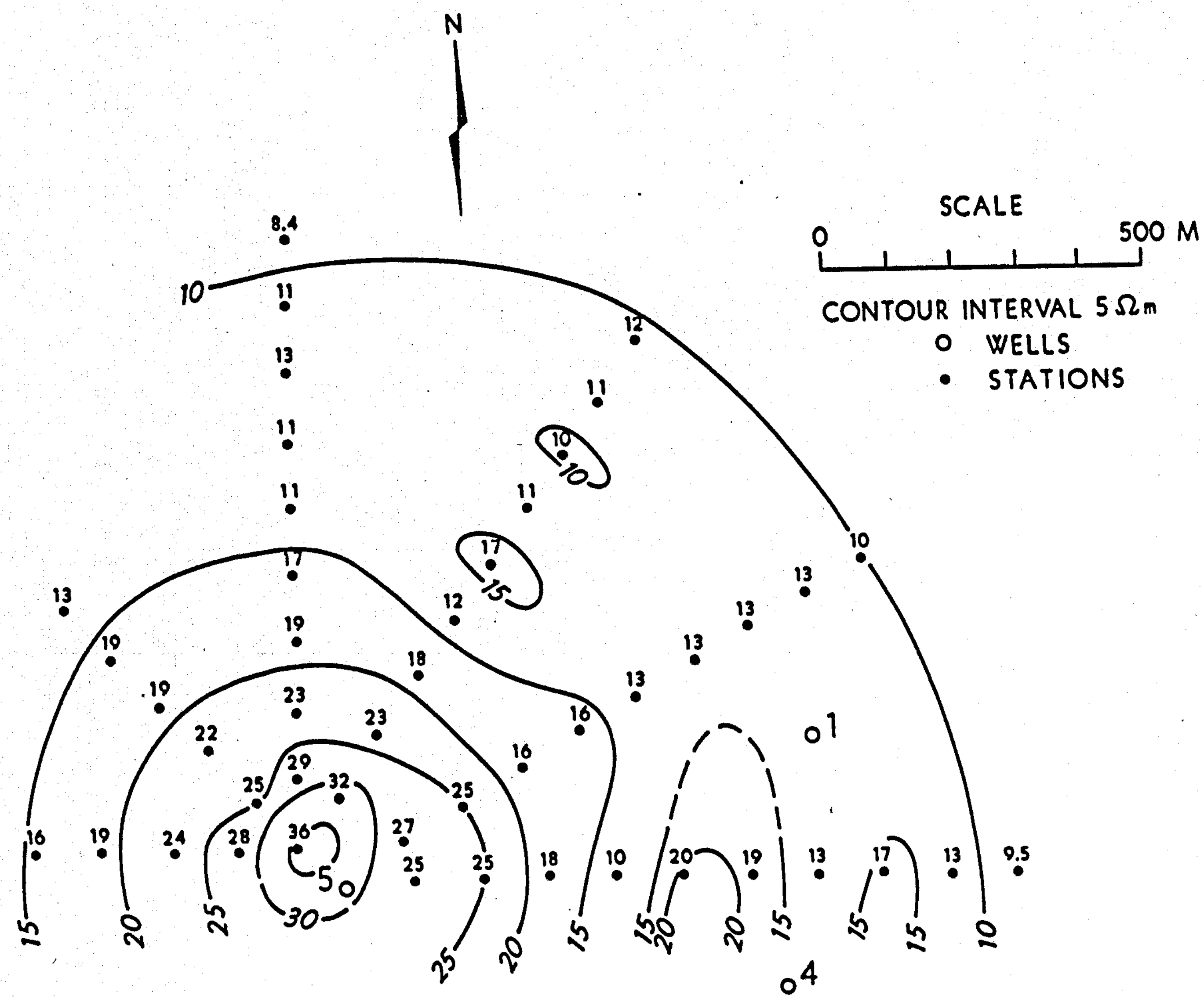
LIST OF FIGURES

Figure 1.

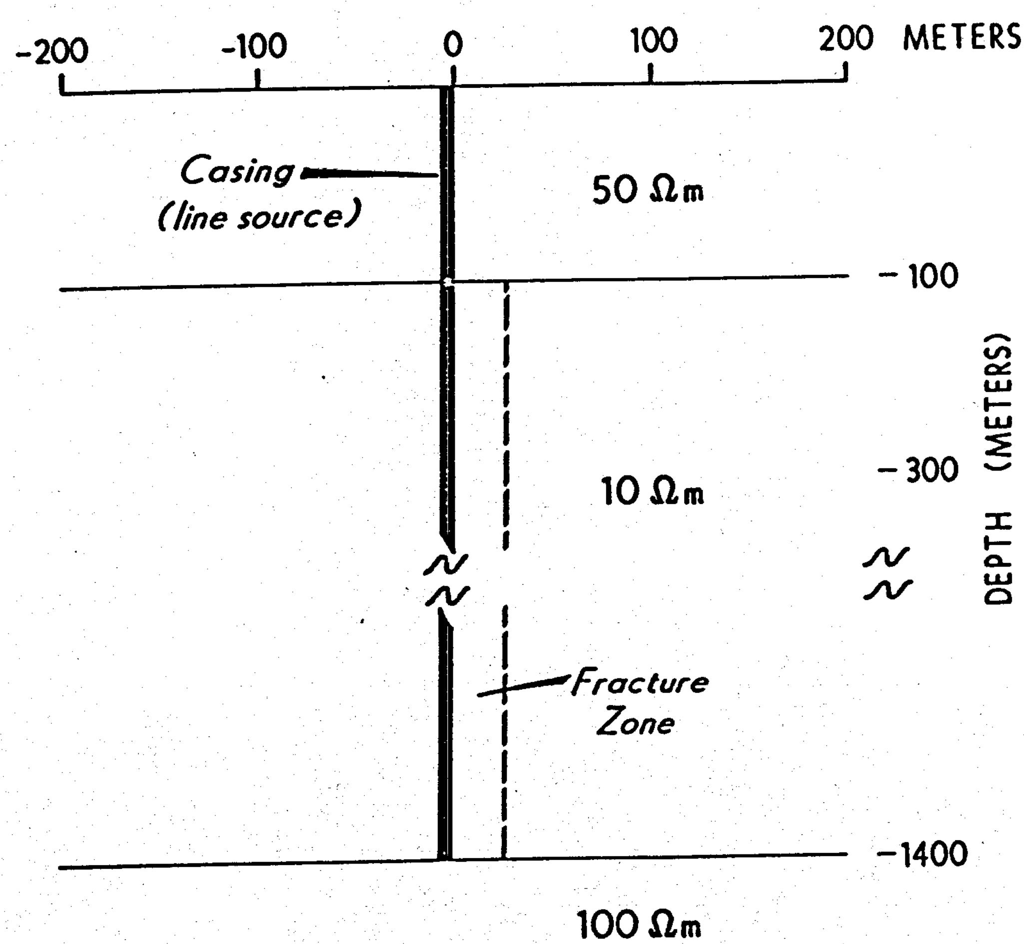


E FIELD DIRECTIONS - RAFT RIVER

Figure 2.

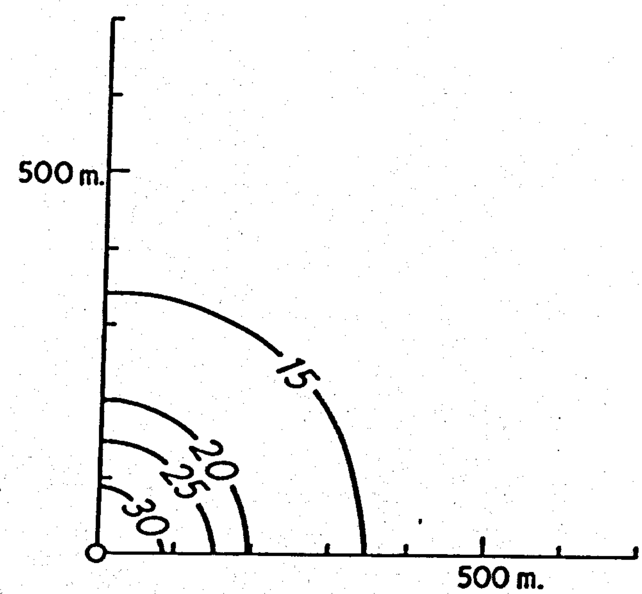


APPARENT RESISTIVITY - RAFT RIVER



RESISTIVITY MODEL

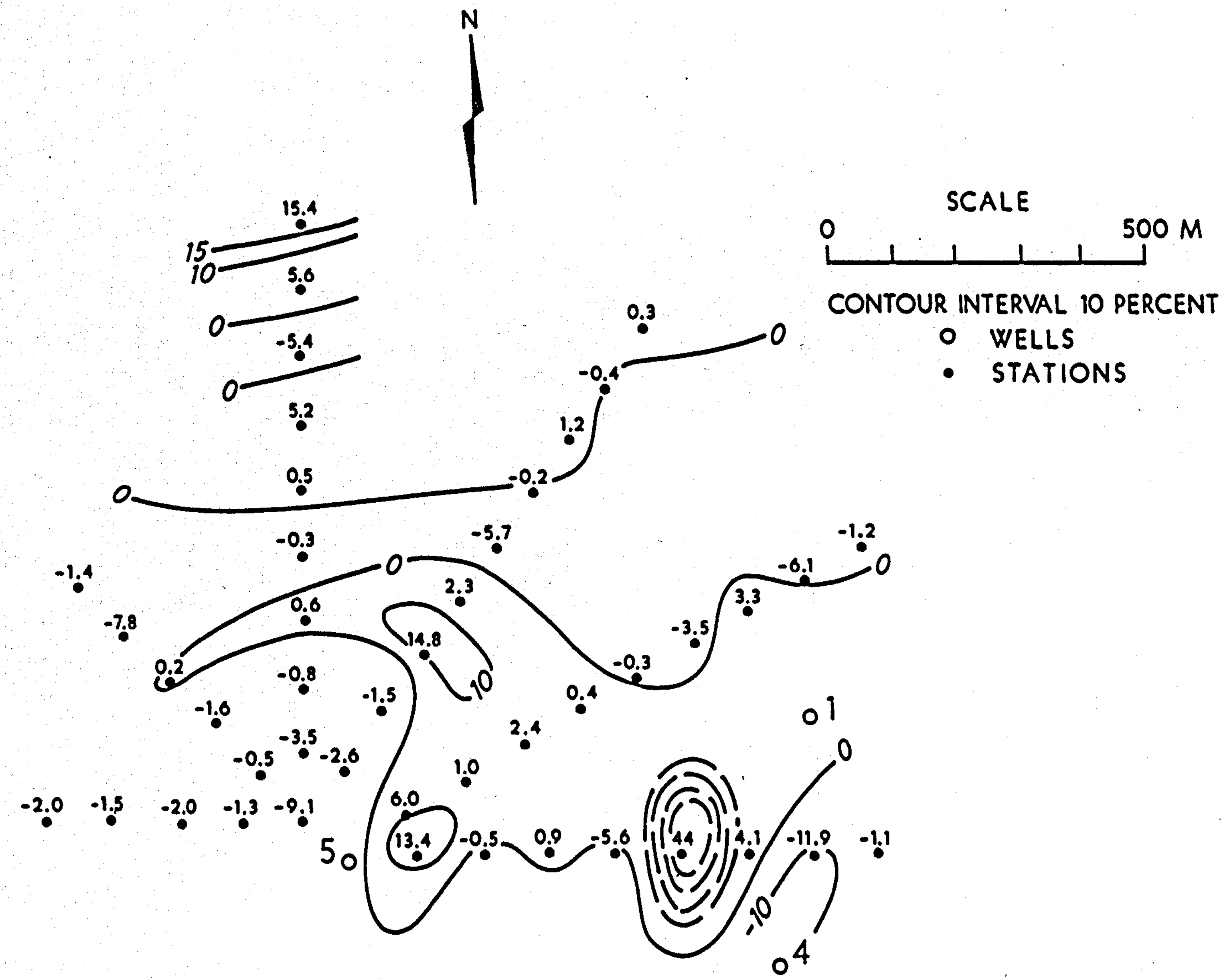
Figure 3.



CONTOUR INTERVAL 5Ωm.

MODEL APPARENT RESISTIVITY

Figure 4.



RESISTIVITY CHANGES - RAFT RIVER TEST 5

Figure 5.

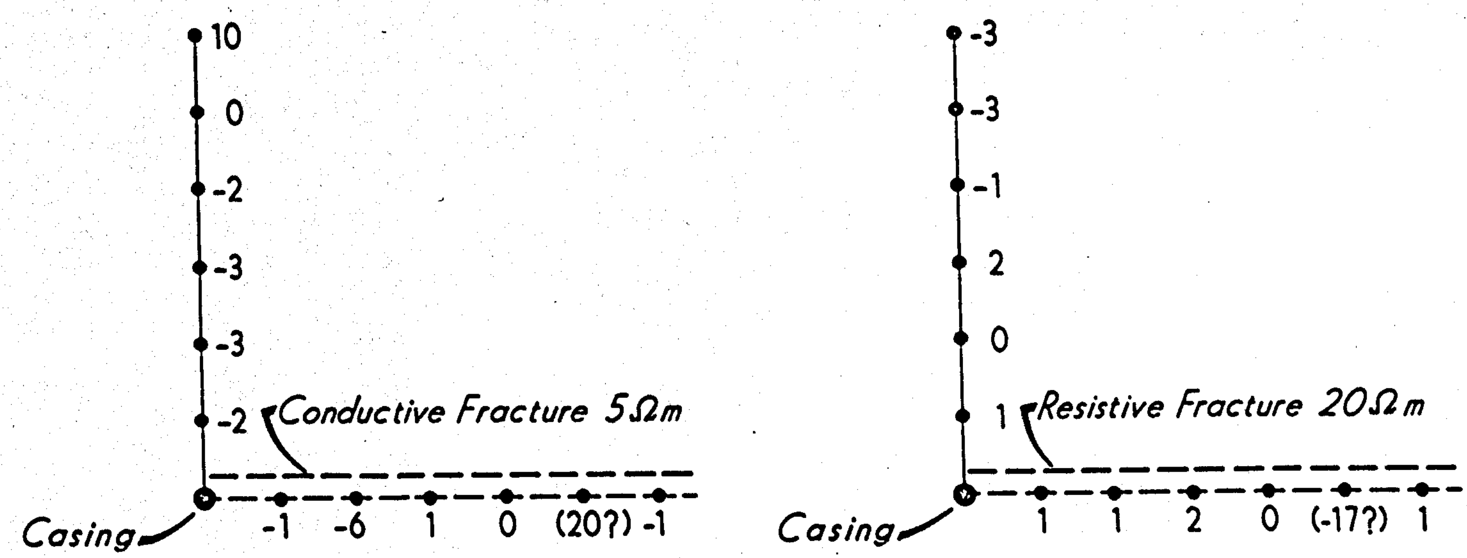


Figure 6.

CALCULATED CHANGES IN APPARENT RESISTIVITY IN PERCENT