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FLUID FLOW MONITORING BY VERTICAL ELECTRIC PROFILING METHOD IN OGACHI HDR SITE, AKITA PREFECTURE, JAPAN

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ABSTRACT

Hydraulic fracturing experiments for making a man-made reservoir have been conducted on HDR project by CRIEPI since 1986.

The Vertical Electric Profiling (VEP, hole-to-surface) method of the geotomography has been applied to monitor fluid-flow behaviors during massive hydraulic fracturing operations.

Self potentials (streaming potentials) and charged potentials (apparent resistivities) were continuously observed at multiple stations on the ground surface before and during pumping operations for estimating fluid-flow front and fracure extents.

The injected fluid-flow was continuously imaged as a function of time with a personal computer on the Hot Dry Rock site.

INTRODUCTION

Various geophysical explorations using boreholes have been applied to the problem of detecting the subsurface fluid flows. The most productive geotomography methods of fluid-flow detection include hole-to-surface and hole-to-hole seismic transmission, hole-to-hole electromagnetic transmission and hole-to-surface (the mise-à-la-masse) resistivity surveys. An early application of the mise-à-la-masse method is described by Conrad Schlumberger in reference to the exploration of ore deposits. This method utilizes a buried point source within the target, and the other current electrode is set in a distant away from the target body.

In a similar practical approach to geothermal investigations, we adopted a steel casing pipe as one current electrode (a line source) in a manner which allowed direct detection of fluid-flows surrounding the injected borehole (hydraulic fracturing well) on the Hot Dry Rock Project in Japan.

VERTICAL ELECTRIC PROFILING (VEP) SURVEY

The Vertical Electric Profiling (VEP) survey was carried out in Ogachi area as shown in Figure 1, by using a hydraulic fracturing well in order to monitor fluid-flow behaviors during pumping operations in related to HDR project.

The injected fluid flow was continously detected and monitored with multiple stations on the ground surface surrounding the hydraulic fracturing well by the digital recording system based on a personal computer (NEC 9801) on the site.

The field survey has been conducted in Aug. 1st Sept. 6, in 1991 during 20 runs of massive hydraulic fracturing operations at Ogachi HDR site of CRIEPI, Akita Prefecture, Japan.

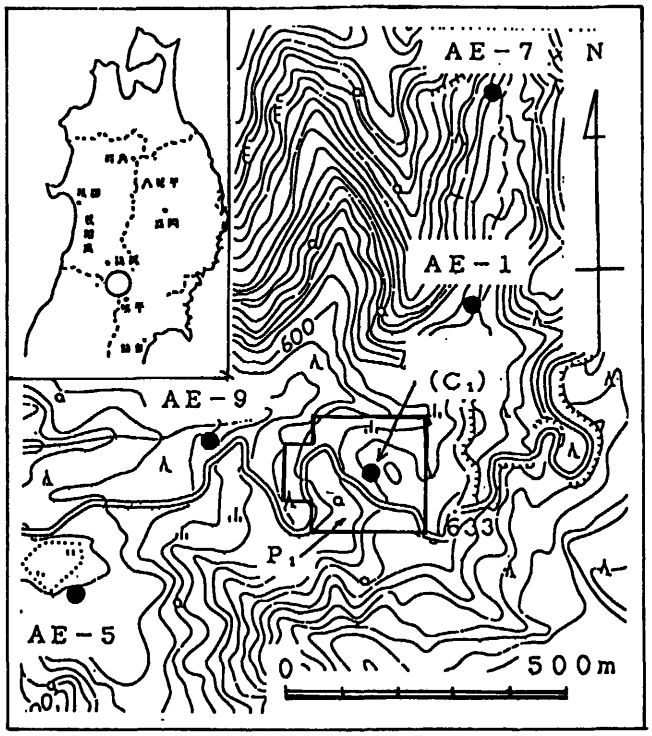


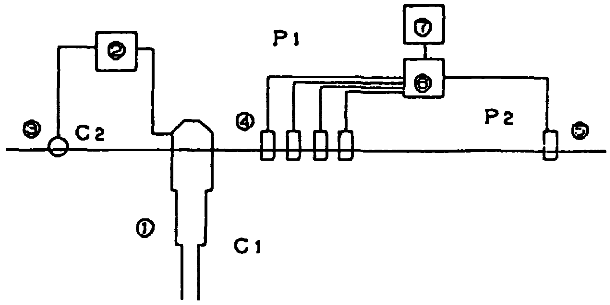
Figure 1. Location map of Ogachi HDR site in Japan.

Figure 2 shows the electrode array used for the VEP survey in the area. A current electrode C1 is connected to the wellhead of a casing pipe of hydraulic fracturing well. The well is earthed into the resistive formations (200 ohm-m) to 1000m depth.

The distant earthing electrode C2 is taken 2 km apart from the well, while the potential electrode P2 is set 2 km in the opposite side of C2 from the well. The potential electrodes P1 were set in a grid form with 25 m separations as shown in Fig.3.

The monitoring surveys were continuously carried out before and during each pumping operation.

A commutated electric current of 16 A intensity which has a frequency of 0.1 Hz is introduced into



① Current Electrode(Casing Pipe) ② Generator + Transmitter
③ Current Electrode (Fixed) ④ Multiple Potential Electrodes
⑤ Potential Electrode (Fixed) ⑥ Hybrid Recorder (120 ch)
⑦ Personal Computer (note type)

Figure 2. VEP electrode configuration.

the earth through a casing pipe of the well and the resulting voltages and self potentials on the ground surface are simultaneously measured by the digital recording system of 120 channels receivers.

The self potentials (streaming potentials) and charged potentials (mV/A) surrounding the well can be quickly monitored at 2 sec interval over all potential electrodes and visualized on the CRT of a personal computer during massive fracturing operations with the present computer-controlled system on the HDR site.

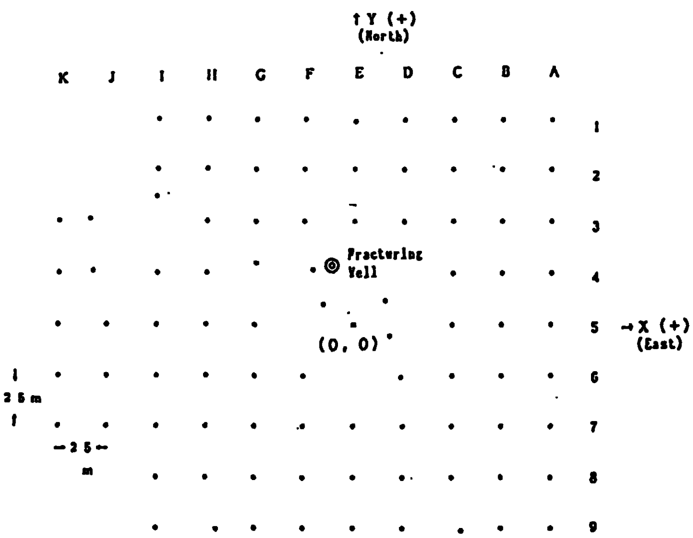


Figure 3. Potential electrode array for FFT survey.

FLUID FLOW TOMOGRAPHY (FFT) SURVEY

Fluid flow tomography (FFT) surveys have been conducted by using a casing pipe of the fracturing well in order to trace the extension of fractures around the injection well.

Figure 4a shows the self potential values with time on the CRT of a computer during the period of 13:56 to 14:45 on August 9 at all stations surrounding the well. Figure 4b shows a detailed time series data observed at station H4 located in 50 m west from the fracturing well.

The drastic change of SP value occur around 14:15 from 60 mV to 90 mV (50% change) during the injection of fluid by hydraulic fracturing operations.

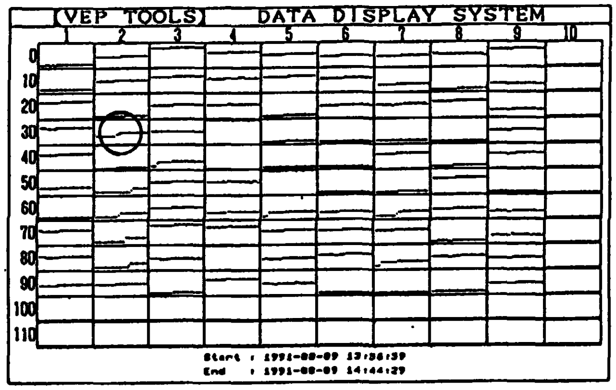


Figure 4a. SP variation with time on the CRT at all stations surrounding the well.

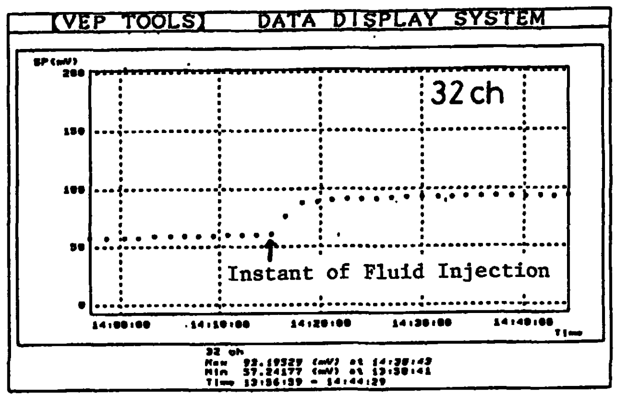


Figure 4b. A detailed time series data observed at potential electrode, H4.

Figure 5 shows the SP variation with a time slice between 14:00 and 14:18 observed during a massive hydraulic fracturing operation.

Anomalous positive zones of SP are observed with NW - SE direction and extend to NE direction in the surveyed area. This trend shows a good agreement with the geometry of major fractures estimated by the acoustic emission (AE) survey carried out in a larger area as shown in Figure 1.

Figure 6 shows an example of apparent resistivity changes obtained by comparing with two data on 20 Aug. and 21 Aug. in 1991.

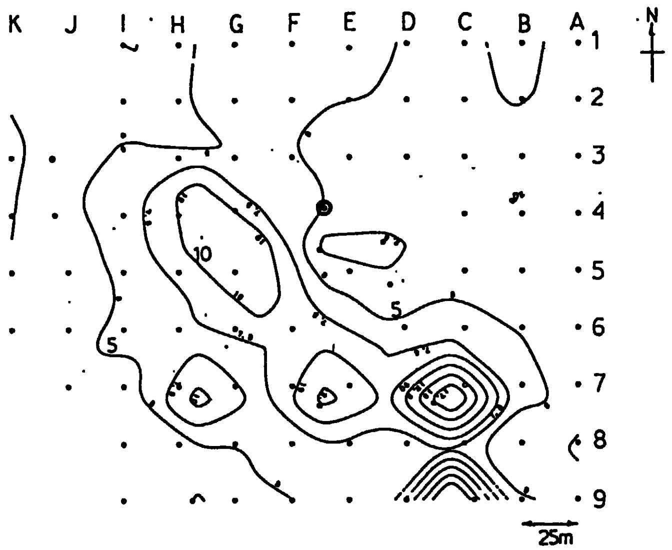


Figure 5. Residual values of self potentials between 14:00 and 14:18.

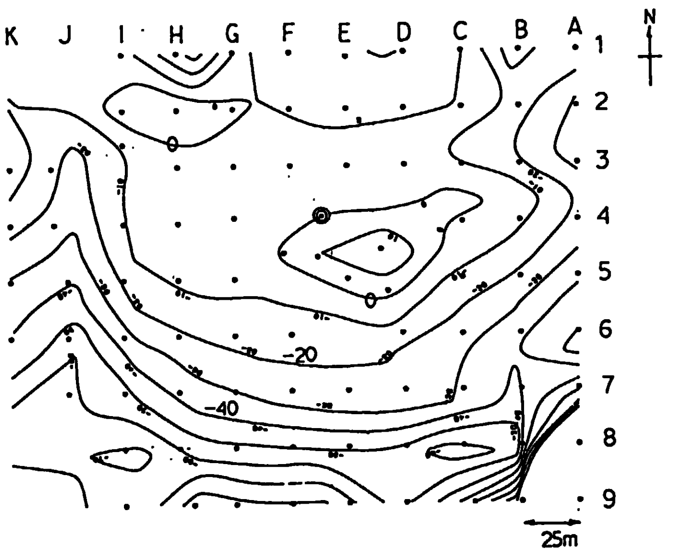


Figure 6. Daily change of apparent resistivity distribution between 20 Aug., and 21 Aug., in 1991.

Apparent resistivity values surrounding the well decreases as a function of time because a large amount of conductive water were injected into more resistive formations by the massive hydraulic fracturing operations in this area.

CONCLUSIONS

Fluid flow monitoring survey has been conducted by the VEP electrode array on Ogachi HDR project. Charged potentials (mV/A) and self potentials (mV) can be simultaneously measured with 2 sec interval of time over 120 stations surrounding the hydraulic fracturing well with a computer-controlled data acquisition system on the site.

(1) Fluid flow fronts were imaged by the use of self potentials (streaming potentials) as a function of time during massive fracturing operations.
(2) The fraction of the injected fluid could be imaged by the apparent resistivity changes by comparing datasets as a function of time.

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