Flowing-Fluid Electric-Conductivity Logging for Hydrologic Characterization of Fractured Rock

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RESEARCH OBJECTIVES

For the study of flow and transport in the subsurface, knowledge of flow zones and their hydraulic properties is essential. Boreholes drilled deep into the rock are often employed to determine this information. Coring and geophysical methods may be able to identify the fractures themselves, but they are unlikely to provide information on fracture flow properties. Straddle-packer pump testing yields fracture flow properties, but is very time-consuming and expensive. Flow-logging techniques are an attractive alternative—they are sensitive to fracture flow and are efficient to deploy in the field. The objective of the present work is to develop the theory for the multi-rate flowing fluid-electric-conductivity (FEC) logging method and demonstrate its application to field data.

APPROACH

The flowing FEC logging method involves the replacement of wellbore water by de-ionized or constant-salinity water, followed by constant pumping with rate Q, during which a series of FEC logs are taken. The logs can be analyzed to identify depth locations of inflow, as well as evaluate the transmissivity and electric conductivity (salinity) of the fluid at each inflow point. When the method is repeated with two or more pumping rates, a combined analysis of the multi-rate data allows an efficient means of determining transmissivity and salinity values of all inflow points—as well as their inherent (so-called far-field) pressure heads.

ACCOMPLISHMENTS

Flowing FEC logging was performed in Well DH-2, very close to the Japan Nuclear Cycle Development Institute's MIU (Mizunami Underground Research Laboratory) site in the Tono area of Gifu Prefecture, Japan. Well DH-2 is about 500 m deep; the upper 167 m penetrates tertiary sedimentary rocks, which unconformably overlie a medium-grained biotite granite of Cretaceous age that is weathered and highly fractured. Flowing FEC logging was repeated three times, using pumping rates of 10 L/min, 20 L/min, and 5 L/min. The suite of FEC logs for each pumping rate were matched (through trial and error) by varying feed-point strength and salinity. Feed-point salinity is constrained to remain the same for each pumping rate, whereas the variation in feed-point strength with pumping rate provides the basis for determining feed-point transmissivity and inherent pressure head.

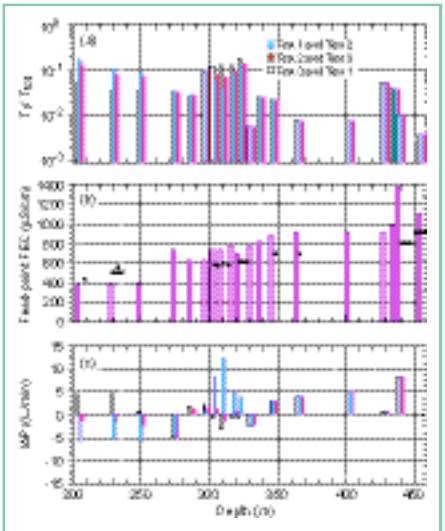

Figure 1. Results of multi-rate flowing FEC logging: (a) feed-point transmissivity normalized by total transmissivity of the borehole; (b) feed-point salinity (the black segments show independent salinity information, which was not used in the present analysis); (c) normalized inherent pressure head of feed-points (IDPi = 0 corresponds to the pressure head of the wellbore as a whole under zero pumping conditions).

Performing the flowing FEC logging method at different pumping rates has enabled us not only to estimate inflow strengths and salinities of hydraulically conductive fractures intersecting Well DH-2, but also to compare their transmissivities and inherent pressure heads (Figure 1). Moreover, using three pumping rates provides a consistency check on the analysis, supplying a measure of the uncertainty within the results. Comparisons against static FEC profiles and independent chemical, geological, and hydrogeological data provide further checks on the validity of the multi-rate flowing FEC logging-method results.

SIGNIFICANCE OF FINDINGS

Flowing FEC logging provides an efficient, affordable means of characterizing the hydraulically conductive features intersecting a borehole with high vertical resolution. Such information is invaluable for characterization of regional groundwater flow, design of nuclear waste storage facilities, remediation of subsurface contamination, and a host of other issues. Moreover, it can be very useful in conjunction with other subsurface site characterization activities, such as providing high-resolution monitoring during a tracer test, or providing ground truth at boreholes for crosshole geophysical imaging methods.

RELATED PUBLICATIONS

Tsang, C.-F., and C. Doughty, Multi-rate flowing fluid electric conductivity logging method. Water Resour. Res., 39(12), 1354 (10.1029/2003WR002308), 2003. Berkeley Lab Report LBNL-52518

Doughty, C., S. Takeuchi, K. Amano, M. Shimo, and C.-F. Tsang, Application of multi-rate flowing fluid electric conductivity logging method to Well DH-2, Tono Site, Japan. Water Resour. Res. (in press), 2005. Berkeley Lab Report LBNL-56479.

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