New Approaches to the Application of High Sensitivity Temperature Logs for Detection of Groundwater Flow in Fracture Rock

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The use of temperature logging for identifying water flow through fractures in sedimentary rock has generally declined over the last several decades. The literature raises issues of low sensor resolution and cross-connected flow through the borehole as the major reasons. Although sensors resolution has improved to the order of 10^{-3} C° for almost two decades, the use of temperature logging has not experienced a significant increase in popularity based on number of publications.

This work outlines the fundamental limitations of the temperature technique and three methods to overcome these limitations and improve characterization of ambient flow in fractured sedimentary rock. First, cross-connected flow along the borehole has long been known to exasperate contaminant distribution; our study shows that vertical water movement through a borehole can mask important flow conduits thereby distorting the interpretation and lead to inappropriate design of multilevel sampling installations. Temperature logs collected in a removable polyurethane coated nylon liner are shown to avoid the impacts of cross-connected flow. Temperature measurements in temporarily sealed boreholes offer new insights regarding previously un-resolvable flow distributions in fractured rock systems while leaving the borehole available for other forms of testing and monitoring device installation.

Secondly, the existence of a boundary (recognized since the 1960’s) between shallow environmentally drive thermal variability (the heterothermic zone) and the stable uniform homothermic zone below is shown to define the limit of detection of flow in fractures by temperature profiling and create a variable assessment of flow within the upper zone. The active line source (ALS) method, the use of a heating cable to place the entire static water column of the lined borehole and its immediate vicinity into thermal disequilibrium with the broader rock mass is shown to provide two advantages. First, it eliminates depth limitations and second, both identification and qualitative assessment of ambient groundwater flow in fractures is improved throughout the test interval. The identification of many fractures or other flow conduits is supported by additional evidence concerning fracture occurrence, including continuous core visual inspection, acoustic televiewer logs and tests for hydraulic conductivity using straddle packers.

Finally a new device, the thermal vector probe (TVP) which measures the magnitude and direction of the temperature field within the borehole fluid is presented. Comparison of data collected under ambient conditions (thermal and hydraulic) as well during thermal recovery after active line source (ALS) heating demonstrate the repeatability of the results and the interrelationship between groundwater flow and the details of the thermal field.

The aspects of temperature logging historically limiting applicability for detecting and comparing flow through fractured rock are now consistently overcome. The high level of detail achieved in the data highlights the complexity of the system and offers opportunities for further refinement. The TVP and ALS technique applied in a lined borehole promise new insights into and potentially quantification of ambient groundwater flow through fractured rock.

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