A Multilevel Monitoring System Provides New Insights into a Bedrock Aquitard in Southeastern Minnesota

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ABSTRACT

Aquitards are an important control on recharge and contaminant transport, yet are relatively poorly understood compared to aquifers, particularly in fractured rock such as that of the Cambrian St. Lawrence bedrock aquitard of southeastern Minnesota. To better understand the properties of bedrock aquitards, we initiated a project that included the construction of a multilevel system (MLS) with numerous ports for monitoring a borehole that spans the St Lawrence Formation in the eastern Twin Cities Metropolitan Area.

The open borehole penetrated about 100 ft of bedrock and ambient flow conditions prior to MLS installation were dominated by strong downflow (~60 gal/min) from the lower Jordan Sandstone to the upper Tunnel City Group, bypassing the intervening St Lawrence Formation. Information from an extensive suite of borehole geophysical logs and packer tests guided construction of the MLS, which includes 14 ports for discrete interval fluid pressure measurements and water sampling, and six ports for higher capacity pumping. Hydraulic head measurements collected since installation of the MLS in November, 2012 reveal that a head difference of ~50 ft from the top and bottom of the open hole is mostly expressed as distinct, large deflections across four thin (<10 ft) intervals in the lower Jordan Sandstone and St Lawrence Formations. Meyer et al. (2008) documented similarly abrupt shifts in the Paleozoic bedrock of Wisconsin, and suggested they may reflect poor vertical connectivity of fracture sets in adjacent geomechanical and (by definition) hydrogeologic units. Our outcrop observations of fractures in bedrock of southeastern Minnesota are consistent with such an interpretation: vertical fractures commonly are stratabound within discrete mechanical units. Analysis of water chemistry from our Minnesota MLS is ongoing, but initial results show variability between units defined by head deflections. Additionally, there is some evidence that water from discrete fractures may differ in some chemical parameters from water sampled largely from matrix.

Highest intergranular permeability

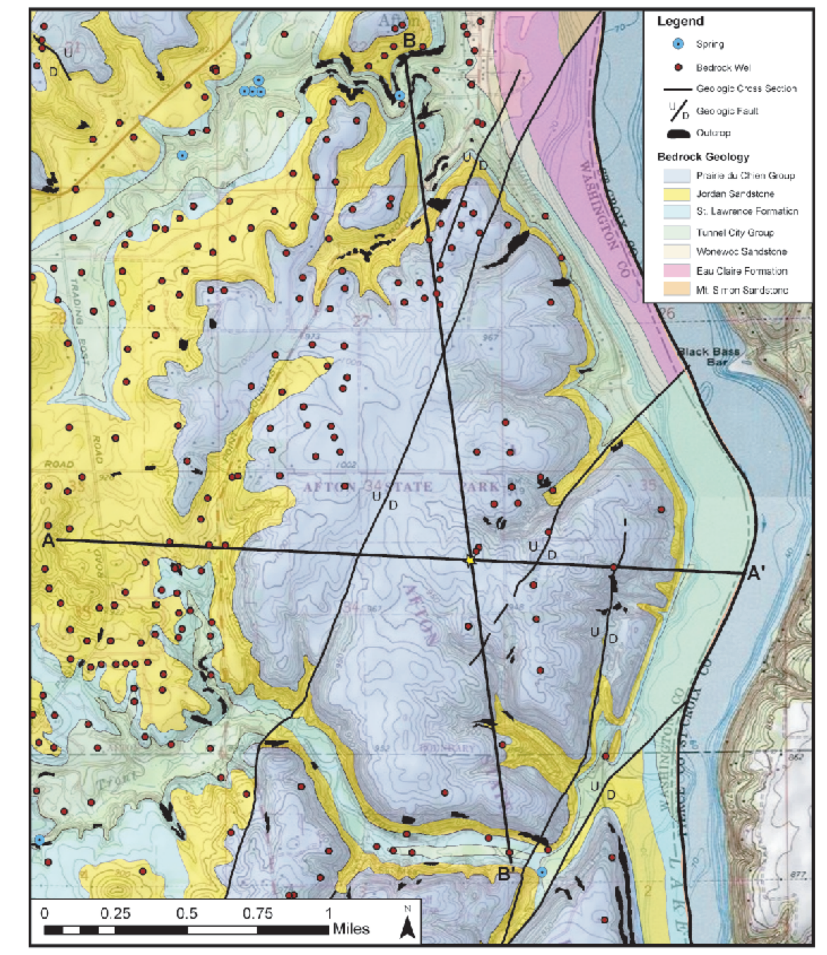
Moderate intergranular permeability

Lowest intergranular permeability

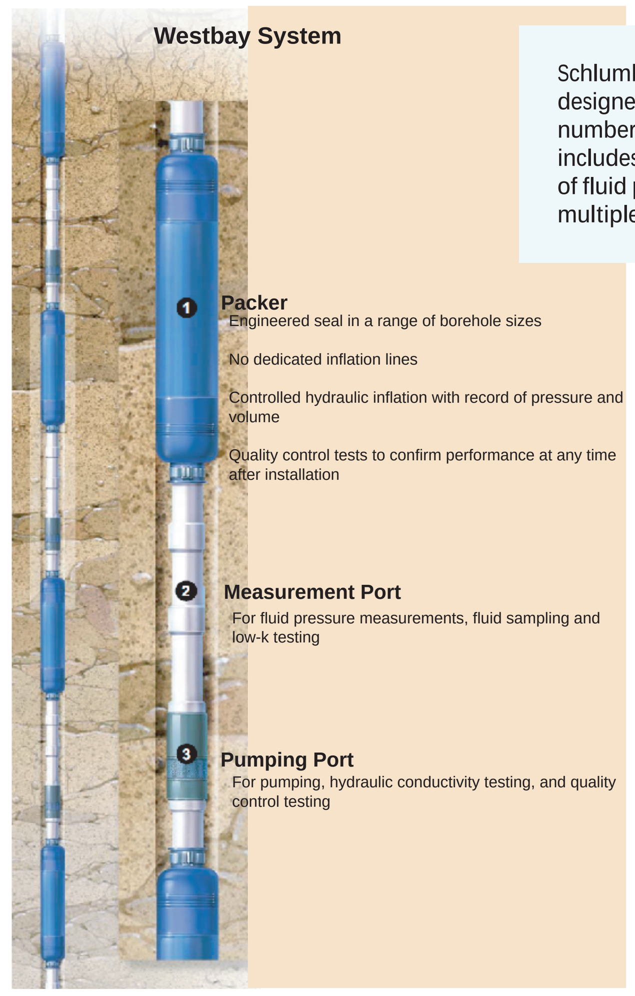
Bedding plane fractures. Question marks indicate fractures not confirmed as high K, yet.

Intervals separating largest jumps in hydraulic head (thickness not to scale)

Solid bars represent February 2013 water samples
Dashed lines represent March 2013 water samples



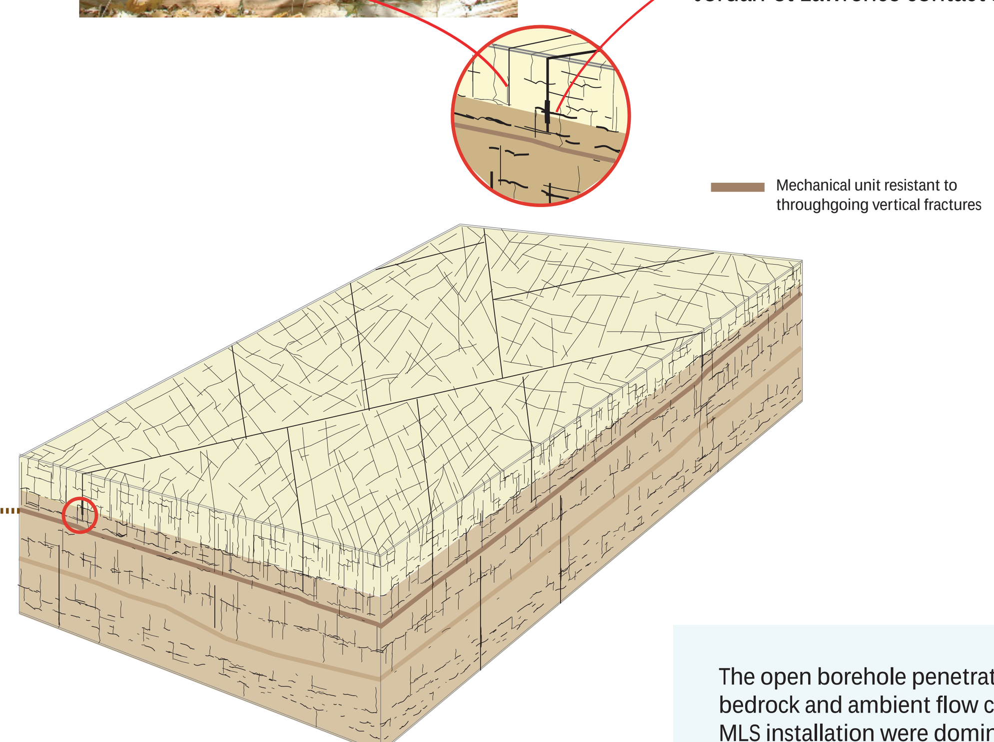
The instrumented well is located in Afton State Park, Washington County. The site was chosen in part on basis of water well and MN DNR Observation well information that indicated a large head differential across the St Lawrence Formation might be present in this area. The site is characterized geologically by a relatively thin cover of unconsolidated glaciogenic sediment (usually less than 50 feet, except in bedrock valleys) on top of an incised topography of Cambrian and Lower Ordovician bedrock. In this part of Washington County groundwater generally moves from west to east, discharging to the nearby St Croix River. Bedrock faults are common.



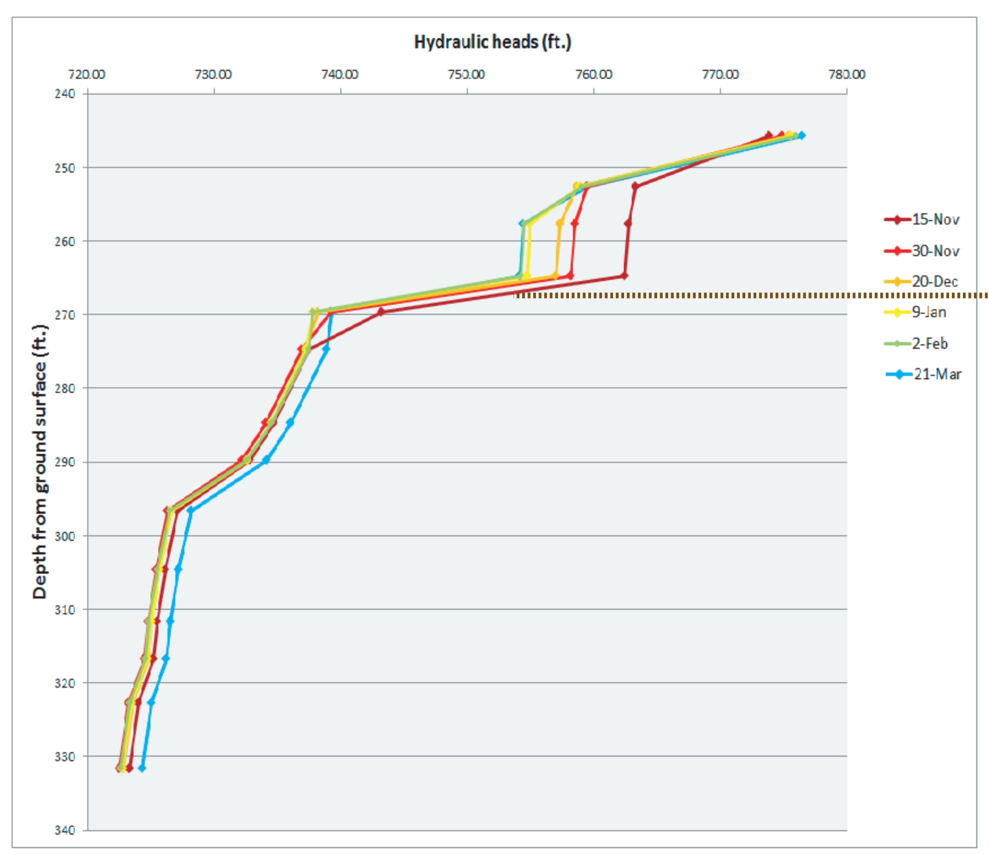
Schlumberger Water Services/ Westbay System is designed for collecting subsurface data at large numbers of discrete positions within a single well. This includes testing of hydraulic conductivity, monitoring of fluid pressure and collection of fluid samples from multiple zones.

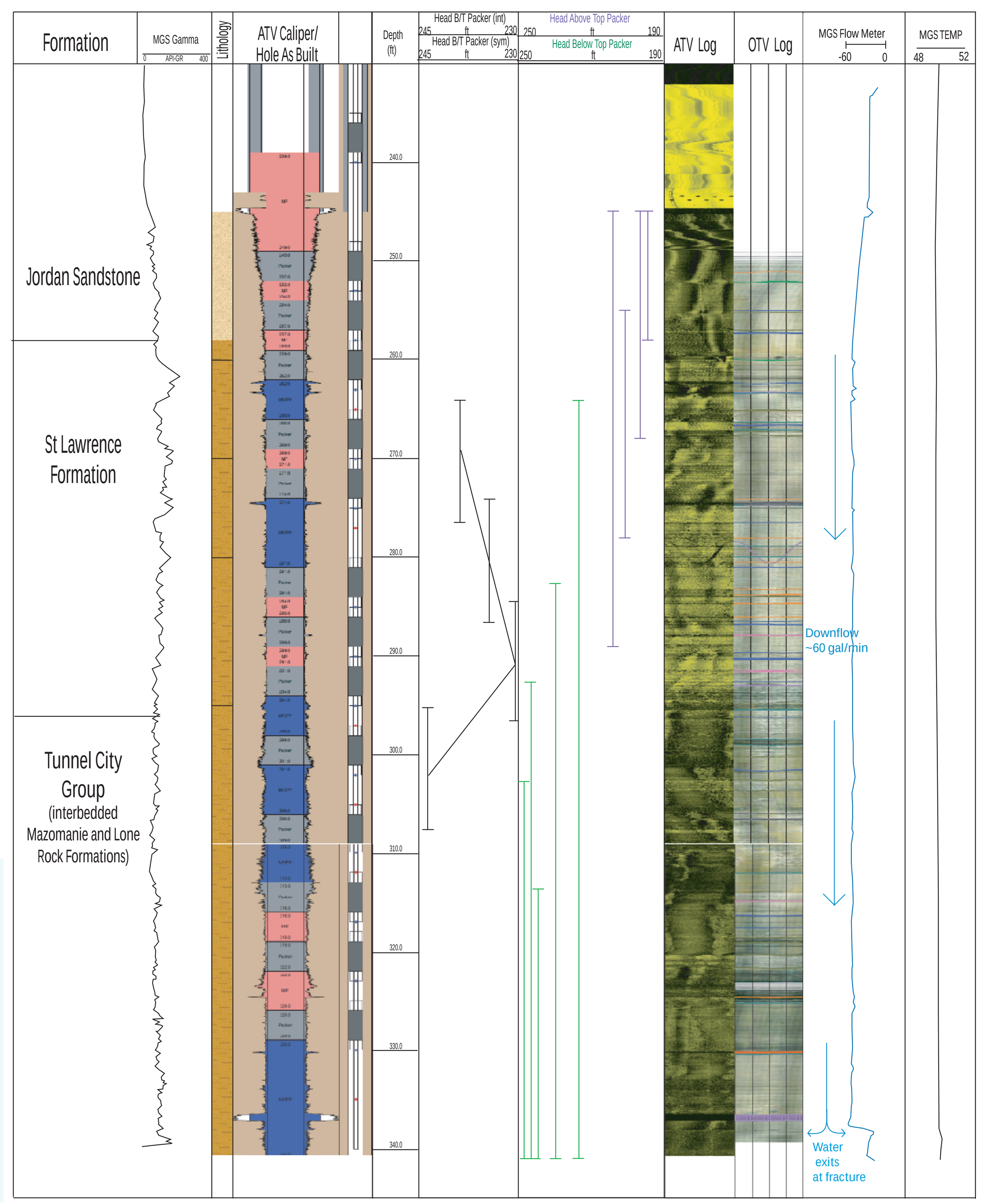
Analysis of water chemistry from our Minnesota MLS is ongoing, but initial results show variability between units defined by head deflections. For example, distinct changes in chloride, sulfate, nitrate and manganese concentrations, as well as electrical conductivity, approximate the position of the largest head deflection, in the upper St Lawrence Formation. Additionally, there is some evidence that water from discrete fractures may differ in some chemical parameters from water sampled largely from matrix. For example, the water chemistry from port 1, which is open to a highly conductive bedding fracture in the Tunnel City Group, is different in several parameters from the water sampled in Tunnel City ports that are not open to recognized high hydraulic conductivity fractures.

Jordan-St Lawrence contact spring



Hydraulic head measurements collected since installation of the MLS in November, 2012 reveal that a head difference of ~50 ft between the top and bottom of the open hole is mostly expressed as distinct, large deflections across four thin (<10 ft) intervals in the lower Jordan Sandstone and St Lawrence Formations. Meyer et al. (2008) documented similarly abrupt shifts in the Paleozoic bedrock of Wisconsin, and suggested they may reflect poor vertical connectivity of fracture sets in adjacent geomechanical and (by definition) hydrogeologic units.





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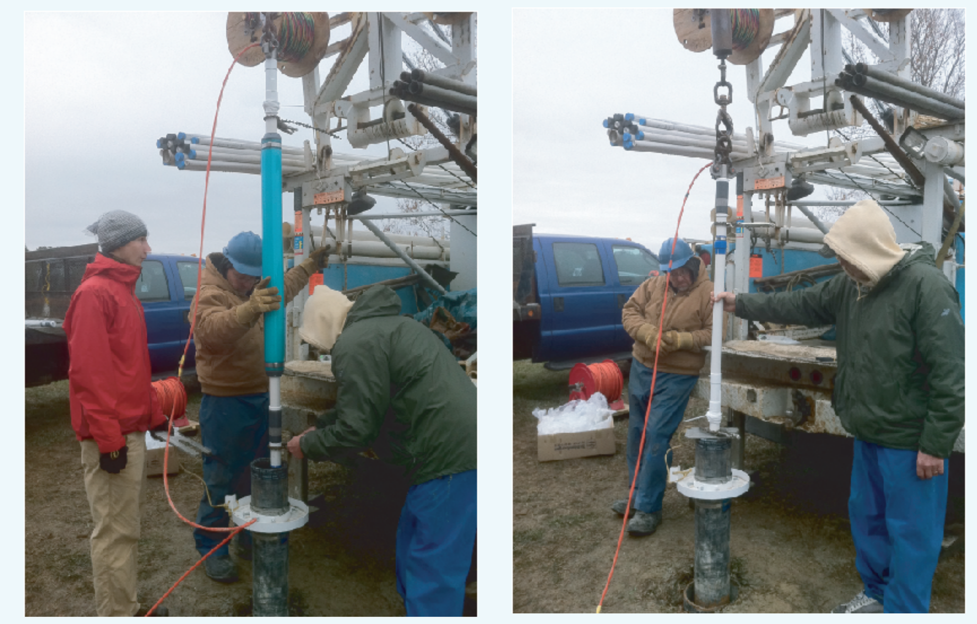
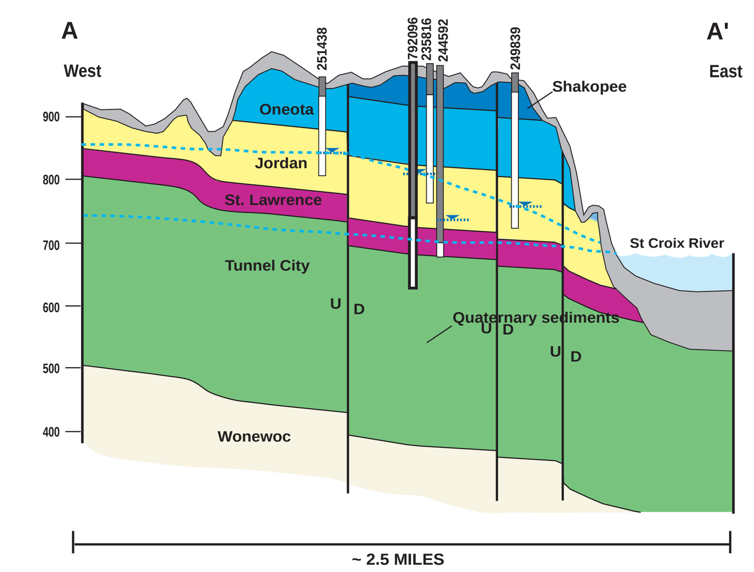
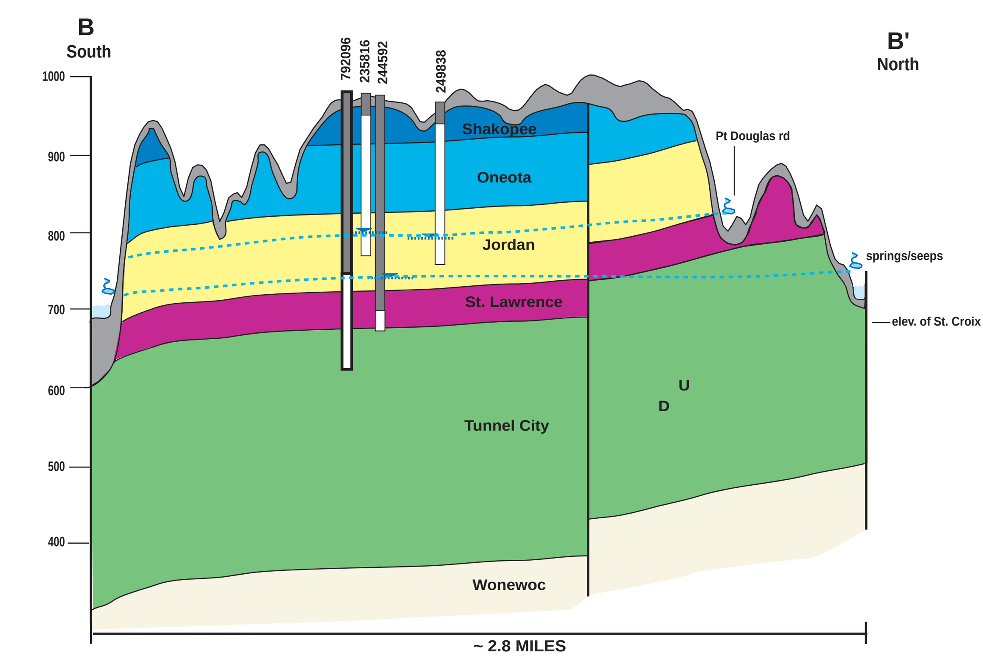


Photographs taken during installation of MLS, showing one of the packers and one of the monitoring ports.

Photographs taken after installation, showing typical set up for taking pressure profile measurements during fall and winter conditions in Minnesota.





References

Meyer, J.R., Parker, B. L., Cherry, J.A., 2008, Detailed hydraulic head profiles as essential data for defining hydrogeologic units in layered fractured sedimentary rock, Environmental Geology 56:27–44.

Acknowledgements

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