quantifying styles of porosity using borehole nmr logging in sedimentary bedrock of ontario, canada

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The Geological Survey of Canada and the Morwick G360 Groundwater Research Institute are collaborating in a range of research activities at their respective bedrock borehole calibration facilities in Ottawa (the Bells Corners Borehole Calibration Facility) and Guelph (the Fractured Rock Observatory). A topic of focus is the application of slim-hole nuclear magnetic resonance (NMR) logging to characterize the amount and type of porosity in fractured sedimentary bedrock, a key parameter in predicting both groundwater flow and the migration of contaminants. Quantifying in situ porosity can be challenging and expensive, particularly where extensive laboratory analysis is required in heterogeneous sedimentary rock. Borehole NMR logging technology provides a continuous downhole measurement of volumetric water content (porosity in saturated materials) and an estimate of the pore size distribution in the formation surrounding the borehole. Slim-hole NMR tools, with the ability to differentiate mobile water content from interstitial and capillary bound water, also allows for a second order estimate of bulk hydraulic conductivity from NMR parameters (KNMR) and has generated considerable interest among the hydrogeological community in recent years.

In 2018 and 2019, NMR logging was carried out in fractured Silurian dolomitic (Guelph) and Cambrian sandstone (Ottawa) boreholes where aquifer and aquitard units provide a range of clay contents, and primary and secondary porosity types (e.g. fractures, reefal structures, vugs, karstic features). The first phase of the study involved assessing indicators of instrument performance, including the tool’s vertical response curve, repeatability of porosity measurements, resolution at various fracture apertures, and how motion during logging affects tool response and acquisition time. Overall, NMR was found to provide a robust measurement of matrix porosity and pore size distribution throughout the borehole, and NMR porosity estimates were found to agree with core measurements to within ±0.04 porosity in both the dolostone and sandstone. It was observed, however, that the correlation deteriorated in finely bedded lithologies, and where fracturing is present. Much of the discrepancy is attributed to differences in scale between small core samples and the larger volume measured by NMR probes.

To investigate the importance of scale when comparing core and field measurements, the current phase of the study is integrating medical-scale computerized tomography (CT) scans of several metres of core in dry and saturated conditions. These scans are characterizing sub-millimetre to cm-scale porosity, providing insight into the pore shape, connectivity, and vertical variability of the heterogeneous pore network within a range of depositional conditions, including carbonate (e.g. reef mounds, deeper and shallow water conditions, and dissolution) and siliciclastic rock. These additional CT datasets, along with observations from other complementary geophysical logs, will provide an opportunity to map heterogeneity in the distribution and connectivity of the macro/mesopore network within a stratigraphic context, and to better identify the relationship between core-scale porosity and NMR porosity.