KEYNOTE LECTURE: Electrical monitoring of nano- and micro-scale particle injections for in-situ groundwater remediation

Adrián Flores Orozco[1], Matthias Bücker[1]

(1) TU-Wien, Department of Geodesy and Geoinformation, Geophysics Institute, Vienna, Austria

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The application of nano and micro-scale particles has emerged as a promising in-situ technology for the remediation of contaminated groundwater, particularly for areas difficult to access by other remediation techniques. The performance of nanoparticle injections is usually assessed through the geochemical analysis of soil and groundwater samples. However, this conventional approach only provides information on volumes close to the sampling points and is not suited for real-time monitoring. To overcome such limitations, we present the application of Induced Polarization (IP) imaging, which provides information on the low-frequency conductive and capacitive electrical properties of the subsurface, commonly expressed in terms of the complex resistivity. Changes in the complex resistivity during the injection permit a quasi-real-time monitoring and allow tracking the propagation of the injected particles. Our interpretation of the measured complex-conductivity response is based on borehole geochemical data and a novel electrochemical model, which permits to take into account the geometry of the pore space and the electrochemical properties of groundwater and particle surfaces. Here, we present IP monitoring results for data collected during two different experiments: (i) the injection of nano-Goethite particles (NGP) used for the stimulation of the biodegradation of a BTEX plume (i.e., benzene, toluene, ethylbenzene, and xylene); and (ii) the injection of microscale zero-valent iron (mZVI) to enhance the chemical transformation of a chlorinated aliphatic hydrocarbon (CAH) plume. Our IP imaging results reveal large variations (> 50%) in the proximity of the injection points; yet also important changes were observed at different locations close to the surface indicating the creation of preferential flow paths (i.e., fractures) during the injection and the delivery of particles into volumes not targeted during the design of the experiment. Temporal changes in the electrical images are consistent with variations in particle concentrations detected in groundwater and soil samples, as well as geochemical parameters such as pH and oxidation-reduction potential. Our results demonstrate the applicability of IP imaging for the real-time monitoring of nano- and micro-scale particle injections and the detection of stimulated geochemical changes in the subsurface.