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Field and Laboratory GPR Monitoring of Biological Activity in Saturated Porous Media

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Recent studies of the geophysical signatures of biological processes in earth environments have resulted in the emergent field of "biogeophysics". The ability to monitor remotely and to quantify active biological processes in the subsurface can have transformative implications to a wide range of investigations, including the bioremediation of contaminated sites. Previous studies have demonstrated that ground-penetrating radar (GPR) can be used to detect the products of microbial activity in the subsurface, such as changes in bulk electrical conductivity, mineral dissolution and precipitation, and the formation of biogenic gas. We present a field study and a laboratory experiment that offer insights to the response of GPR signals to microbial activity.

In the field, time-lapse borehole radar tomography was used to monitor biodegradation of a hydrocarbon plume over a period of two years. A dense grid of fourteen borehole pairs monitoring the bioactive region showed radar wave velocity changes of +/-4% and signal attenuation changes of +/-25%. These GPR observations correlated spatially and temporally to independent measurements of groundwater velocity and geochemical variations that occurred in response to microbial activity. The greatest relative changes in radar wave velocity of propagation and attenuation were observed in the region of enhanced bacterial stimulation where biomass growth was the greatest. Radar wave velocity and attenuation decreased during periods of enhanced biostimulation. Three competing mechanisms are postulated to cause the changes observed in the radar data: 1) biogenic gas production, 2) mineral dissolution, and 3) biomass growth. However, due to the inherent complexity and uncertainties associated with field experimentation, the relative effect of each mechanism on the GPR signal could not be confirmed.

To overcome the limitations of field observations in assessing the response of GPR signals to biomass formation, a 90-day laboratory-scale experiment was conducted under controlled conditions. GPR signals were transmitted through a water-saturated quartz-sand reactor during the course of enhanced biostimulation. Radar wave velocity initially decreased as a result of bacterial activity and subsequently increased rapidly as biogenic gas formed in the pore space. Radar signal attenuation increased during the course of the experiment as a result of pore fluid electrical conductivity increase. The relative GPR velocity changes observed in the reactor experiment were small in magnitude but consistent and comparable to the changes observed in the field investigation. The radar wave velocity decrease observed in the experimental reactor provides direct evidence of GPR signal response to bacterial growth in water saturated porous media.

We conclude that field and laboratory GPR observations of enhanced biological activity in saturated porous media offer evidence that GPR can be used to monitor biostimulation in earth environments.