Near-Surface Geophysics (SEG and EEGS)

NS13A CC: 516 B Monday 1330h

Near-Surface Geophysics: Contaminants I *(joint with H)*

Presiding: **E A Atekwana,** University of Missouri at Rolla**; S S Hubbard,** Lawrence Berkeley National Laboratory

NS13A-01 1330h

Monitoring Microbe-Induced Sulfide Precipitation Under Dynamic Flow Conditions Using Multiple Geophysical Techniques

Kenneth H Williams[1,2] (khwilliams@lbl.gov)

Susan Hubbard[2] (sshubbard@lbl.gov)

Dimitri Ntarlagiannis[3] (dimntar@pegasus.rutgers.edu)

Jill Banfield[1] (jill@eps.berkeley.edu)

[1]UC Berkeley, ESPM, Berkeley, CA 94720, United States

[2]LBNL, 1 Cyclotron Rd., Berkeley, CA 94720, United States

[3]Rutgers Univ., 195 Univ. Ave., Newark, NJ 07102, United States

A laboratory study was undertaken to investigate the feasibility of using minimally invasive geophysical techniques to monitor microbe-induced sulfide precipitation in saturated sand-packed columns under dynamic flow conditions. Specifically, the effect of zinc and iron sulfide precipitation on geophysical signatures was evaluated during stimulated sulfate-reduction by *Desulfovibrio vulgaris*. Four inoculated columns and one non-inoculated control were operated under a continuous upward flow velocity of 50cm/day with the following measurements made: multi-port fluid sampling, cross-column acoustic wave propagation, induced polarization, time domain reflectometry and saturated hydraulic conductivity. Over a period of seven weeks, the onset and progression of sulfate reduction within the columns was confirmed through decreasing substrate and aqueous metals concentrations, increased biomass, and visible regions of sulfide accumulation. Decreases in initial lactate and sulfate concentrations (2.8mM and 4.0mM, respectively) followed predicted stoichiometric relationships and soluble Zn(II) and Fe(II) concentrations (0.31mM and 0.36mM, respectively) were reduced to levels below detection through sequestration as insoluble sulfide phases. The areas where sulfide precipitation and accumulation occurred resulted in significant changes in two of the three geophysical measurements. High frequency (400-600kHz) acoustic wave amplitudes were reduced by nearly an order of magnitude over the course of the experiment with no significant accompanying change in wave velocity. Neither the wave amplitudes nor the velocities changed significantly in the downgradient portions of the column where microbial activity and sulfide precipitation were depressed due to depleted substrate and metals concentrations. The frequency content of the transmitted waves remained unchanged throughout the course of the experiment. Over the frequency range of the induced polarization measurements (0.1-1000Hz), significant changes in both the phase shift and calculated imaginary conductivity were observed with only minimal changes in the real conductivity. No significant polarization effects were observed in the downgradient regions lacking visible precipitates. There were no significant changes in either the electromagnetic wave travel times or amplitudes recorded by the time domain reflectometry system. Saturated hydraulic conductivity measurements showed a final decrease of nearly two orders of magnitude from those recorded initially. All of the above results were compared to a substrate- and metals-amended but non-inoculated control column. Geophysical measurements in the control column showed no change in acoustic wave amplitudes, induced polarization, or hydraulic conductivity over the same time-period. Final destructive analysis of the columns was performed in order to assess the sediment-affixed cell densities throughout the column using phospholipid fatty acid analysis. Both scanning and transmission electron microscopy were performed to evaluate the nature of the microbe-sulfide associations and to elucidate the spatial arrangement of the sulfides within the sedimentary pore space. Evaluation of the multiple data sets suggests that microbe-induced sulfide precipitation is both directly detectable using geophysical techniques and capable of altering saturated flow conditions. The geophysical monitoring approach may prove useful at the field-scale for the time-course monitoring of contaminant metals remediation during engineered bioremediation.

NS13A-02 1345h

IP Response of Bacterially - Induced Sulfide Mineral Precipitation

Dimitrios Ntarlagiannis[1] (973 596 5757; dimntar@pegasus.rutgers.edu)

Kenneth Hurst Williams[2,3] (khwilliams@lbl.gov)

Lee D Slater[1] (lslater@andromeda.rutgers.edu)

Susan S Hubbard[2] (sshubbard@lbl.gov)

[1]Rutgers University, Department of Earth and Environmental Sciences, 195 University Avenue, Newark, NJ 07102, United States

[2]Lawrence Berkeley National Laboratory, Earth Sciences Division, 1 Cyclotron Road, Berkeley, CA 94720, United States

[3]University of California at Berkeley, Dept. Environmental Science, Policy and Management, Hilgard Hall, Berkeley, CA 94720

Effective bioremediation strategies require an understanding of the coupled biogeochemical processes that are associated with them. Initial steps have been made to investigate the potential of high resolution geophysical methods for monitoring such processes in a non-invasive manner. Although geophysical methods cannot detect these processes directly, they may be able to detect changes in chemical and physical parameters associated with them. We performed lab-scale experiments using multiple and identical flow-through measurement columns to investigate the effect of biologically induced sulfide precipitation (Zn and Fe) on electrical, seismic, and radar responses. In this presentation, we focus on the analysis of low-frequency electrical responses to the biostimulation experiments. One of the columns was used for monitoring fluid chemistry and microbiology, and two of the other columns (a biotic and an abiotic column) were used to acquire complex conductivity measurements between 0.1 and 1000 Hz. Seven non polarizing Ag-AgCl electrodes, located along the length of the column, were used to measure IP changes; these ports were positioned at the same location as the fluid sampling ports located on the biogeochemical measurement column. Samples from the influent and effluent were collected in all columns. Each column was filled with quartzite sand (20 30 mesh), and the experiments were performed in an anaerobic chamber. Bacteria were injected and fluid enriched in lactate and sulphate, iron and zinc introduced. The biostimulation resulted in Fe and Zn sulfide precipitation, which formed as a precipitation front. The precipitation front initiated at the location of the bacterial injection (in the middle of the columns), and gradually migrated toward the location of nutrient injection (at the base of the column). Measurements from different electrode pairs, located along the length of the column, were used to assess the electrical response of the migrating precipitation front. At the active front of precipitation and intense microbial activity, distinct changes in the measured phase shift (up to seven mRads) and calculated imaginary conductivity (more than 2 orders of magnitude increase) were observed, and minimal changes (maximum of 10% relative increase) in the real conductivity (conduction magnitude) were observed. Concurrent with observed changes in imaginary conductivity, the metal concentration in solution, the sulfate concentration, and the lactate concentration were reduced, while the microbial population increased. When the precipitation rate at a particular location decreased, the imaginary conductivity also declined. Following completion of the microbiologically induced precipitation, the imaginary conductivity and phase returned to the initial background level. These measurements indicate also that the IP effect followed the active microbial front throughout the column. Our results indicate that the temporally variable IP effect was not exclusively the result of the precipitated sulphides but resulted instead from the dynamic, biologically induced redox active precipitation front associated with elevated microbial activity.

NS13A-03 1400h

On the Pitfalls and Limitations of Applying Petrophysical Models to Geophysical Tomograms: Examples in Cross-Borehole Radar and Electrical-Resistivity Tomography

Frederick D Day-Lewis[1] (860 487 7402 x21; daylewis@usgs.gov)

Kamini Singha[2] (650 725 8070; ksingha@pangea.stanford.edu)

Andrew M Binley[3] (a.binley@lancaster.ac.uk)

[1]US Geological Survey, Office of Ground Water, Branch of Geophysics, 11 Sherman Place, Unit 5015, Storrs, CT 06269, United States

[2]Dept. of Geological and Environmental Sciences, Stanford University, Geocorner, Building 320, Stanford, CA 94305, United States

[3]Environmental Sciences Dept., Lancaster University, Bailrigg, Lancaster LA1 4YQ, United Kingdom

Geophysical field data have traditionally provided qualitative information on aquifer structure for hydrogeologic characterization; however, there is increasing interest in the application of petrophysical models to convert geophysical tomograms of electrical resistivity or radar velocity, for example, to hydrologic parameters, such as permeability, porosity, water content, and (or) salinity. Unfortunately, application of theoretical or empirical petrophysical models may be inappropriate in many situations, given the limited and variable resolution of tomographic estimates. The resolution of tomograms is a function of (1) the measurement physics, for example, electrical conduction or electromagnetic wave propagation; (2) the parameterization and regularization used for inversion; (3) measurement error; and (4) the length scale of heterogeneity. We present a framework to predict how core-scale relations between geophysical properties and hydrologic parameters break down in the inversion, which produces smoothly-varying pixel-scale estimates. Our approach upscales the core-scale relationship to the pixel-scale based on the model resolution matrix from the inversion, random field averaging, and spatial statistics of the geophysical property. In synthetic examples, we use the approach to evaluate the utility of tomograms for quantitative hydrologic estimation, in light of their resolution-dependent limitations. Comparison of examples for cross-borehole electrical resistivity tomography and radar tomography demonstrates the role of the measurement physics on the spatially-variable pixel-scale relationships between geophysical estimates and hydrologic parameters of interest. The goals of this work are to (1) raise awareness of the limitations of geophysical data, (2) provide a framework to improve survey design and assess tomograms for hydrologic estimation, and (3) promote additional research to improve the links between geophysical and hydrogeologic characterization.

NS13A-04 1415h

Inversion of Hydrological Tracer Test Data Using Tomographic Constraints

Niklas Linde[1,2] (1-510-495-2507; nlinde@lbl.gov)

Stefan Finsterle[1] (1-510-486-5205; safinsterle@lbl.gov)

Susan Hubbard[1] (1-510-486-5266; sshubbard@lbl.gov)

[1]Lawrence Berkeley National Laboratory, 1 Cyclotron rd. ms 90-1116, Berkeley, CA 94720, United States

[2]Uppsala University, Department of Earth Sciences/Geophysics Villav. 16, Uppsala 75236, Sweden

Most approaches that utilize geophysical data to determine the permeability structure of the subsurface presuppose a known and stationary petrophysical relationship or assume that such a relationship can be accurately established from laboratory data, borehole data, and sometimes from geophysical attributes at collocated tomographic pixels. In this study, we invert hydrological tracer test data using the shape and relative magnitude variations within the geophysical attribute anomalies derived from tomographic data to regionalize the inverse problem. The approach does not require that the petrophysical relationship be known a-priori, but that it is linear and stationary within each geophysical anomaly. We use the estimated errors associated with the acquisition geometry to define a space-varying measure that describes how large deviations from the background model must be to constitute an anomaly. To avoid interpreting anomalies that do not carry hydrogeological information (such as inversion artifacts), our initial permeability model is constant. Synthetic studies are used to investigate (1) under what conditions the problem is well-posed, (2) how a weak petrophysical relationship affects the results, (3) how much correlation between the geophysical attribute and the permeability is lost through the geophysical inversion process, (4) the effects of errors in the geophysical data acquisition on the inversion results, and (5) how a poor description of the acquisition geometry affects the results. Data from the DOE Hanford, WA and Oyster, VA sites are used to assess the validity and robustness of the approach. In addition to obtaining hydrological estimates through our inversion procedure, the results can be used (1) to estimate a-posteriori the petrophysical relationship; (2) to assess if the relationship is stationary between anomalies; and (3) to compare the results with earlier estimates that did not include the tracer data. The inversion statistics will also be useful for assessing what type of geophysical data (i.e., radar velocity, radar attenuation, seismic velocity, or seismic attenuation) contributes most to the solution.
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NS13A-05 1430h

Differential Surface Wave Analysis: a Technique to Mmonitor Changes in Fluid Flow in Shallow Aquifers.

Leland Timothy Long[1] (404 904 2860; tim.long@eas.gatech.edu)

Tatiana Toteva[1] (404 385 4407; ttoteva@eas.gatech.edu)

[1]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, ga 30318 0340, United States

The objective of differential surface-wave analysis is to identify temporal perturbations in the shear-wave velocity, and hence monitor in time the degree of water saturation and/or water pressure in shallow soils. We are testing a new analysis technique to directly measure perturbations in velocity by a direct comparison of seismic traces obtained before and after a change in the water saturation. Perturbations in phase velocity are measured by computing the Fourier transform of the difference of normalized traces. The perturbed structure can then be computed relative to a reference structure that need only approximate the actual structure. In effect, the perturbations of surface-wave group or phase velocity are inverted directly to velocity perturbations instead of inverting the dispersion curve for shear-wave structure. The test site is the Panola Mountain Research Watershed, a small controlled watershed where a thin (1-5m) soil overburden lies above granite. The water level varies significantly between times of rain and drought. Typically rain events are followed by a decayed runoff, indicating significant variations in water saturation in the soils.

NS13A-06 1445h

Magnetic Mapping and Classification of Contaminant Impact Levels in Lake Sediments

Joe I. Boyce[1] (905-525-9140 x24188; boycej@mcmaster.ca)

William A. Morris[1] (905-525-9140 x24195; morriswa@mcmaster.ca)

Matthew R. Pozza[2] (905-709-3135; matt@marinemagnetics.com)

[1]McMaster University, 1280 Main St. West, Hamilton, ON L8S 4K1, Canada

[2]Marine Magnetics Corp., 52 West Beaver Creek Rd., Richmond Hill, ON L4B 1L9, Canada

Magnetic property measurements of Hamilton Harbour cores show that concentrations of hydrocarbons (PAH) and some heavy metals (Pb, Zn, Fe) in an upper contaminated sediment layer are strongly correlated with magnetic susceptibility. The magnetic contrast between contaminated and clean pre-colonial sediments is sufficient to generate a total field anomaly (ca. 2-20 nT) that can be measured with a magnetometer towed above the lake bottom. Systematic magnetic surveying (> 500 line km) of the harbour using an Overhauser marine magnetometer clearly identifies a number of localized magnetic anomalies that coincide with known accumulations of contaminated sediments on the harbour bottom.

Apparent susceptibility maps calculated from the total field data provide a further attribute for classifying contaminant impact levels, as susceptibility is directly linked to pollutant levels. Magnetic detection of near-surface anomalies requires a closely-spaced survey grid and careful post-cruise processing to remove diurnal, regional and water-depth related variations in the magnetic field intensity. These results demonstrate the potential of lake-based magnetic surveying as a rapid reconnaissance method for mapping large areas of bottom contamination prior to detailed coring work.

NS14A CC: 516 B Monday 1530h

Near-Surface Geophysics: Climate Change and Earths Surficial Processes *(joint with H, GC, PP)*

Presiding: **S McGeary,** University of Delaware**; J J Daniels,** Ohio State University

NS14A-01 1530h

Internal Structure and Development of an Active Parabolic Sand Dune Determined with Ground-Penetrating Radar

Chris H Hugenholtz[1] (403-283-2626; chhugenh@ucalgary.ca)

Brian J Moorman[1] (403-220-4835; moorman@ucalgary.ca)

Stephen A Wolfe[2] (613-992-7670; swolfe@nrcan.gc.ca)

[1]Department of Geography, University of Calgary, 2500 University Drive N.W., Calgary, AB T2N 1N4, Canada

[2]Geological Survey of Canada, Terrain Sciences Division, 601 Booth St., Ottawa, ON K1A 0E8, Canada

Ground-penetrating radar data were used to investigate the internal structure and development of an active parabolic sand dune in the Bigstick Sand Hills of southwestern Saskatchewan, Canada. This study is part of a broader investigation into the morphodynamics of parabolic sand dunes on the Canadian prairies. The study dune is up to 9 m high and has been migrating eastwards during the last 70 years at an average rate of about 2 ma-1. The radar survey was conducted in a grid configuration using a Sensors and Software Inc. Noggin Plus (250 MHz). Radar profiles oriented downwind reveal a variety of high- and low-angled dipping reflectors which are interpreted as cross-stratification and bounding surfaces. Well defined sets of grainflow cross-stratification along profiles near the central downwind axis were used to resolve former slipface positions and compared with historical aerial photographs. Radar profiles orthogonal to the prevailing wind direction were characterized by convex-up and concave-up cross-stratification along the dune head which are interpreted to be the result of scour and fill processes and migration of superimposed bedforms. Radar profiles over the trailing arms revealed an arrangement of stratification similar to the profiles oriented along the main downwind axis. Observations of exposed surface stratigraphy following extensive wind erosion lend support to the interpretations made from the GPR data. Taken together, the results provide a basis for a tentative model of the stratigraphic development of parabolic dunes.

NS14A-02 1545h

Temporal Variations in Glacier retreat and Bed Characteristics Derived From Ground-penetrating Radar Data

Brian J. Moorman[1] (1-403-220-4835; moorman@ucalgary.ca); Tristram D.L. Irvine-Fynn[1] (tdlirvin@ucalgary.ca); Amy Lyttle[2] (adaca@hamlca.on.ca); Frederick A. Michel[3] (fredmichel@sympatico.ca); Jeffery L. Williams[1] (jlwillia@ucalgary.ca); Frederick S.A. Walter[1] (fswalter@ucalgary.ca)

[1]Department of Geography, University of Calgary, 2500 University Dr., Calgary, AB T2N1N4, Canada

[2]Hamilton Conservation Authority, P.O. Box 7099 838 Mineral Springs Rd., Ancaster, ON L9G3L3, Canada

[3]Earth Science Department, Carleton University, 1125 Colonel By Drive, Ottawa, ON K1S 5B6, Canada

Temporal Variation in Glacier Retreat and Bed Characteristics Derived From GPR Data Stagnation Glacier on Bylot Island in the eastern Canadian Arctic (72°N 78°W) has been rapidly retreating over the last 50 years. Over 40 km of ground-penetrating radar (GPR) surveys were conducted in the ablation area of the glacier in 1993, 1994, 1999, and 2002 to examine its hydrological, structural and bed characteristics. This polythermal glacier has exhibited a dramatically varying hydrological regime over the period of this study that is thought to result from the changing subsurface thermal structure. The GPR surveys have recorded changes in the bed characteristics that are interpreted to be a function of changes to the thermal structure of the glacier. The radar signature of the glacier and its bed have been observed to change over the study period on a seasonal and inter-annual basis. The results presented demonstrate how GPR can be utilized to monitor that changing internal physical, thermal and hydrological structure of a polythermal glacier.

NS14A-03 1600h

Resolving Large Pre-glacial Valleys Buried by Glacial Sediment Using Electric Resistivity Imaging (ERI)

Moise C.-Pontbriand[1] ((403) 210-5493; MCoulomb@UCalgary.ca)

Derald G Smith[1] ((403) 220-6191; DGSmith@Ucalgary.ca)

[1]University of Calgary, Department of Geography Earth Sciences 356 2500 University Drive N.W., Calgary, AB T2N 1N4, Canada

Two-dimensional electric resistivity imaging (ERI) is the most exciting and promising geological tool in geomorphology and stratigraphy since development of ground-penetrating radar. Recent innovations in 2-D ERI provides a non-intrusive mean of efficiently resolving complex shallow subsurface structures under a number of different geological scenarios. In this paper, we test the capacity of ERI to image two large pre-late Wisconsinan-aged valley-fills in central Alberta and north-central Montana. Valley-fills record the history of pre-glacial and glacial sedimentary deposits. These fills are of considerable economical value as groundwater aquifers, aggregate resources (sand and gravel), placers (gold, diamond) and sometime gas reservoirs in Alberta. Although the approximate locations of preglacial valley-fills have been mapped, the scarcity of borehole (well log) information and sediment exposures make accurate reconstruction of their stratigraphy and cross-section profiles difficult. When coupled with borehole information, ERI successfully imaged three large pre-glacial valley-fills representing three contrasting geological settings. The Sand Coulee segment of the ancestral Missouri River, which has never been glaciated, is filled by electrically conductive pro-glacial lacustrine deposits over resistive sandstone bedrock. By comparison, the Big Sandy segment of the ancestral Missouri River valley has a complex valley-fill composed of till units interbedded with glaciofluvial gravel and varved clays over conductive shale. The fill is capped by floodplain, paludal and low alluvial fan deposits. The pre-glacial Onoway Valley (the ancestral North Saskatchewan River valley) is filled with thick, resistive fluvial gravel over conductive shale and capped with conductive till. The cross-sectional profile of each surveyed pre-glacial valley exhibits discrete benches (terraces) connected by steep drops, features that are hard to map using only boreholes. Best quality ERI results were obtained along the Sand Coulee and Onoway transects where the contrast between the bedrock and valley-fill was large and the surficial sediment was homogeneous. The effects of decreasing reliability with depth, 3-D anomalies, principles of equivalence and suppression, and surface inhomogeneity on the image quality are discussed.

NS14A-04 1615h

Thick Permafrost: MacKenzie Delta, North West Territories, Canada

Douglas R Schmitt[1] (780-492-3985; doug@phys.ualberta.ca)

Marek Welz[1] (780-492-1054; mwelz@phys.ualberta.ca)

C. Dean Rokosh[1] (780-492-4126; drokosh@phys.ualberta.ca)

[1]Inst. for Geophysical Research, Dept. of Physics, U. of Alberta, Edmonton, AB T6G 2J1, Canada

A 2D seismic reflection profile and a corresponding pseudo-3D single fold volume were obtained at the ICDP Mallik gas-hydrate research well in the MacKenzie River Delta of the N.W.T., Canada in February 2002. While the main target of this work was to obtain seismic images of the gas-hydrate zones, the permafrost itself displayed numerous features. These data were simultaneously acquired over 240 14-Hz geophone singles using the Univ. of Alberta seismic vibrator sweeping from 12 to 180-Hz. Common midpoints were spaced at 2-m. The stratigraphy imaged, to about 1400-m depth, consists primarily of flat-lying Tertiary to Quarternary fluvial, deltaic, and glacial sediments. Both the stacked 2D profile and the minimally processed volume display short (50 to 100 m) discontinuous zones of high reflectivity and support earlier surveys conducted in the vicinity (Miller et al., USGS Open-File Report 2003-36). The source of these short variations in reflectivity remain unknown in part due to the lack of quality logs or core through the permafrost zone that extends to depths of about 640-m. However, the permafrost is not completely frozen and has a complex structure that includes i) zones saturated with unfrozen brines in which salts have been concentrated during the freezing process, and ii) zones of free gas saturation the source of which may be dissociation of gas hydrates or even methanogenic bacteria. The differences in the

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