nT. After more extensive processing, we will compare structures in the inverted magnetic model with features in the seismic data and explore the connection between the subsurface geology and the surface geometry of the hot springs.

NS33A-15 1330h POSTER

Economical 3D Resistivity Surveys with Non-Linear Configurations and Neural Networks

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Electrical resistivity surveys traditionally have been conducted with linear arrays, with electrodes evenly spaced. Three-dimensional surveys require the placement of parallel lines. Large-scale surveys of this type are costly to conduct in the field and to interpret. Often, it would be desirable to place electrodes in non-linear configurations, with the geometry customized to the situation in the field. For instance, a circular depression or object could be surveyed with a circular electrode configuration. Non-linear configurations pose special problems in interpretation. However, with the use of neural networks, these difficulties may be overcome, offering three-dimensional resistivity profiles at lower cost than is possible with traditional methods.

NS41A CC: 516 B Thursday 0830h

Near-Surface Geophysics: Evaluation and Management of Water Resources II *(joint with H, GC, PP, ED)*

Presiding: **R Knight,** Stanford University**; C Darnault,** Environmental Engineering and Technology, Inc.

NS41A-01 0830h

An integrated hydrogeological and hydrogeophysical characterization of potential saltwater intrusion pathways in a fractured aquifer

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Fractures and fracture zones exert strong controls on groundwater flow regimes. Fractures are often more hydraulically conductive than the surrounding host rock; however, not all fractures are open to fluid flow. The hydraulic properties of fractured media differ with fracture aperture, intensity, orientation, connectivity and infill material. The interrelationship of any or all of these factors often causes fractured systems to be hydraulically anisotropic. Moreover, the scale of fracture flow varies from the local scale of individual fractures to the regional fracture zone scale. Characterization of fractured systems is both critical and difficult because flow and transport paths are complex. In this study, 2-D electrical resistivity imaging (ERI), 3-D ERI, fracture mapping and hydrogeological results were integrated to characterize a fracture system on Saturna Island, British Columbia, Canada. Bedrock consists of sandstone-dominant and mudstone-dominant formations with interbedded zones of mudstone and sandstone at formation boundaries. The presence of bedding plane fractures, joints, and faults suggest fracturing at a variety of scales. The geophysical results are consistent with local (outcrop) geology and previous (hydrostratigraphic and hydrostructural) conceptualizations. The images show a distinction between overburden, sandstone-dominant and mudstone-dominant units and the presence of fractured zones. However, discrete fractures were not identified using ERI. Consequently, under some geologic conditions it is possible to use ERI to constrain the aquifer architecture for groundwater models at a regional and sub-regional scale. In this particular fractured setting, ERI may be useful for identifying permeable pathways for saltwater intrusion, which may be associated with fracture zones.

NS41A-02 0835h

The use of electrical resistivity methods to investigate anisotropy in a fractured groundwater system

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The hydraulic properties of fractured media differ with fracture aperture, intensity, orientation, connectivity and infill material. The interrelationship of any or all of these factors often causes fractured systems to be anisotropic. That is, the hydraulic properties of the system differ with orientation. Electrical resistivity, azimuthal and square array techniques have been used to characterize and quantify the electrical anisotropy. Often, the principal direction of electrical anisotropy is interpreted to be coincident with the principal direction of hydraulic anisotropy because of the similarity between Ohms law and Darcys law (Watson and Barker, 1999); however, a quantitative relationship between the two has not yet been developed. In this study, azimuthal and square array resistivity surveys were conducted to investigate the electrical anisotropy in a fractured aquifer on Saturna Island, British Columbia, Canada. The results of a 3-D resistivity survey produced a 3-D resistivity model of the subsurface. Offset error analysis and forward resistivity modeling were used to investigate if the anisotropic response was the result of fracturing or heterogeneities. Both offset error analyses and forward modeling indicated that the anisotropic response could be explained by relatively simple subsurface heterogeneities associated with the geology in the vicinity of a fault. If electrical anisotropy due to the fracture system orientation exists, it appears to play a secondary role in the azimuthal array response compared to geologic structure. In this geologic setting, if offset error analyses and forward modeling were not completed the electric and hydraulic anisotropy could have been incorrectly interpreted. Therefore, anisotropy results should not be interpreted without considering variations in resistivity due to subsurface heterogeneities.

Watson, K.A. and Barker, R.D. (1999). "Differentiating anisotropy and lateral effects using azimuthal resistivity offset Wenner soundings." Geophysics 64(3): 739-745.

NS41A-03 0840h

Groundwater depletion in a heavily irrigated watershed in southern India: detailed assessment using MRS and ERT (CEFIPRA Project 2700-W1)

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The stress on groundwater resources due to the pumping of large quantities of water threatens the sustainability of agricultural development. This is a main issue for hot and dry areas such as central and southern India. In this fractured crystalline context, the aquifer is shared between a capacitive part corresponding to the weathered cover and a transmissive part corresponding to fractures in the basement. At the 60 km2 Maheshwaram catchment, (Andhra Pradesh, India); since 1985, irrigated surfaces have been increased by a factor of 3, from 0.7 to 2 km2 out of a total cultivated area of 18 km2, the number of pumping wells have increased from 10 to almost 800, and the mean ground water table level have deepened by about 8m drying up the entire capacitive part of the aquifer. Computations of the groundwater balance at watershed scale between 2001 and 2002 still showed a depletion of an average of 1.2m in spite of a regular monsoon (600 mm of rainfalls).

Electrical resistivity tomography (ERT) and magnetic resonance soundings (MRS) were undertaken in a heavily irrigated area in order to characterize the water content in the subsurface. The present study compares the findings of investigations carried out in November 1999 and December 2003. Both periods belong to post monsoon season when the water level is high. The free water content estimated by MRS in 1999 was about 5% in the capacitive part of the aquifer. In 2003, no free water is detected (NMR signal level is less than the instrumental noise of 5 nV). Comparisons between ERT inverted 2D sections located at the same place shows a significant 10 to 30% mean increase of resistivity in the 5-15 m depth range. Laboratory tests of resistivity variations versus water content on small weathered material cores indicates that such variations correspond to a drastic de-saturation of the porous network. Furthermore, the resistivity variations in this capacitive part of the aquifer are inhomogeneous; the larger variations may indicate sandy bodies of the weathered materials and so drying of interesting water bearing structures. Sub-vertical anomalies through the crystalline basement, interpreted as infiltration structures, have also became more resistive indicating a high drying up and a major modification of their hydraulic behaviour.

The combined interpretation of ERT and MRS methods allows to assess in detail groundwater depletion. In the Maheshwaram case presented here, it shows that at the end of the rainy season, the capacitive part of the aquifer, i.e the weathered zone, does not present any significant recharge. As a matter of fact, the sustainability of the agricultural development in this area is threatened by clear over exploitation of the groundwater resources.

NS41A-04 0845h

A Laboratory Study of Heterogeneity and Scaling in Geologic Media

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In rocks and soils, the bulk geophysical and transport properties of the matrix and of fracture systems are determined by the juxtaposition of geometric features at many length scales. For sedimentary materials the length scales are: the pore scale (irregularities in grain surface roughness and cementation), the scale of grain packing faults (and the resulting correlated porosity structures), the scale dominated by sorting or winnowing due to depositional processes, and the scale of geomorphology at the time of deposition.

We are studying the heterogeneity and anisotropy in geometry, permeability, and geophysical response from the pore (microscopic), laboratory (mesoscopic), and backyard field (macroscopic) scales. In turn these data are being described and synthesized for development of mathematical models. Eventually, we will perform parameter studies to explore these models in the context of transport in the vadose and saturated zones.

We have developed a multi-probe physical properties scanner which allows for the mapping of geophysical properties on a slabbed sample or core. This device allows for detailed study of heterogeneity at those length scales most difficult to quantify using standard field and laboratory practices. The measurement head consists of a variety of probes designed to make local measurements of various properties, including: gas permeability, acoustic velocities (compressional and shear), complex electrical impedance (4 electrode, wide frequency coverage), and ultrasonic reflection (ultrasonic impedance and permeability). We can thus routinely generate detailed geophysical maps of a particular sample. We are testing and modifying these probes as necessary for use on soil samples.

As a baseline study we have been characterizing the heterogeneity of a bench-size Berea sandstone block. Berea Sandstone has long been regarded as a laboratory standard in rock properties studies, owing to its uniformity and "typical" physical properties. We find that both permeability and velocity exhibit complex heterogeneity at the centimeter scale. While some correlation with the outcropping of the bedding is apparent, much of the heterogeneity is not clearly associated with visual features.

For the study of soil heterogeneity at a wide range of scales, we are focusing on a local glacial deposit. This deposit is a glacial kame terrace of fluvial origin with multi-scale sedimentary structures comprised of unconsolidated sands, clays, and gravels. There are also many joints and faults in the unconsolidated sediments, allowing study of these as potential fluid flow conduits or barriers. We have obtained undisturbed soil samples from this site, allowing detailed laboratory study using similar methods to those described for the sandstone block.

NS41A-05 0850h

Widespread Occurrence of Aquifers Currently Undetectable With the MRS Technique in the Grenville Geological Province, Canada.

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In the summer of 2003, a field test was made over aquifers within or next to the Grenville geological province, Canada, to evaluate the Magnetic Resonance Sounding (MRS) technology in such environments. This contribution reports on these MRS tests in Eastern Canada and their outcome, stresses the importance of an MRS applicability assessment prior to embarking on a wide scale survey and encourages the development of MRS technology adapted to conditions similar to the Grenville province. MRS has a track record of non-invasive, groundwater selective aquifer characterization in about 20 countries. MRS is a field scale implementation of Nuclear Magnetic Resonance (NMR). An inversion of MRS data sets yields free water content and the NMR signal decay rate as a function of depth. The latter is linked to the pore-size and therefore to hydraulic conductivity. Once integrated with respect to depth or thickness, an estimate of transmissivity is supplied. Such depth-wise information allows estimating vertical boundaries for aquifer and aquitards. Using a NUMIS-PLUS MRS system from Iris Instruments, twelve MRS soundings were executed over aquifers from three areas. A TDEM sounding was also performed at each site. The areas, each with 4 sites, included sand, sand and gravel and fractured bedrock aquifers: (1) the Laurentides NW of Montral, (2) the Saguenay area, both within the Grenville province, and (3) the St-Lawrence Lowlands on the South East side of the St-Lawrence River. Some of the aquifers included discrete horizons with higher clay content. Of all these sites, one was found unsuitable due to a high level of magnetic noise, even though the site was away from industrialized sector or power line. At these sites, the depth to the water table was in the range 2 - 10 m below surface while porosity was in excess of 20% for the water bearing layers. Except for the noisy site, the expected MRS response is above the ambient noise after data stacking yet at each site no recognizable MRS response was observed. Detailed magnetic survey, samples collection, magnetic susceptibility readings on the samples and mineralogical examination were added, showing the presence of fine-grained magnetite at most sites where results are available. A shallow MRS sounding directly over a pond yielded a recognizable MRS response. The sites are hydraulically and structurally characterized through various techniques including, according to each site: boreholes & pump tests, GPR, TDEM etc. Other sites have been observed with lack of MRS response in the past; these were restricted to small areas. In this case no MRS response was observed over any of the aquifers selected within an area $\sim$ 250 x 300 km. The lack of MRS response is attributed to internal magnetic field gradient due to disseminated fine grain magnetite. This is a widespread condition in the selected areas for which results are available. Recommendations are made to: (1) go through an MRS applicability assessment prior to embarking on a wide scale MRS survey (2) allocate some of the MRS development efforts to the adaptation of the MRS technology for sites with significant internal magnetic field gradient.

NS41A-06 0855h

Acquisition and Processing of Multi-Fold GPR Data for Characterization of Shallow Groundwater Systems

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Most ground-penetrating radar (GPR) data are acquired with a constant transmitter-receiver offset and often investigators apply little or no processing in generating a subsurface image. This mode of operation can provide useful information, but does not take full advantage of the information the GPR signal can carry. In continuous multi-offset (CMO) mode, one acquires several traces with varying source-receiver separations at each point along the survey. CMO acquisition is analogous to common-midpoint acquisition in exploration seismology and gives rise to improved subsurface characterization through three key features: 1) Processes such as stacking and velocity filtering significantly attenuate coherent and random noise resulting in subsurface images that are easier to interpret, 2) CMO data enable measurement of vertical and lateral velocity variations which leads to improved understanding of material distribution and more accurate depth estimates, and 3) CMO data enable observation of reflected wave behaviour (ie variations in amplitude and spectrum) at a common reflection point for various travel paths through the subsurface - quantification of these variations can be a valuable tool in material property characterization. Although there are a few examples in the literature, investigators rarely acquire CMO GPR data. This is, in large part, due to the fact that CMO acquisition with a single channel system is labor intensive and time consuming. At present, no multi-channel GPR systems designed for CMO acquisition are commercially available. Over the past 8 years I have designed, conducted, and processed numerous 2D and 3D CMO GPR surveys using a single channel GPR system. I have developed field procedures that enable a three man crew to acquire CMO GPR data at a rate comparable to a similar scale multi-channel seismic reflection survey. Additionally, many recent advances in signal processing developed in the oil and gas industry have yet to see significant application in GPR data analysis. I have focused on applying these methods to GPR data with a particular emphasis on pre-stack analysis including reflection tomography, pre-stack migration, and amplitude vs offset analysis. Using modeling, laboratory, and field examples, I demonstrate how CMO methods can improve our understanding of the subsurface through detailed measurement of electric properties and improved subsurface images.

NS41A-07 0900h

Modeling of the relationship between relative dielectric permittivity and water content of soils

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Theoretical investigations have been carried out in order to understand the impact of the soil microstructure (water distribution, role of the microporosity related to the clay fraction) on the relationship between the soil relative permittivity and the water content. Two theoretical tools have been used: the Moment Method (MoM) and the Differential Effective Medium (DEM) theory. The MoM approach widely used in EM geophysics has been specially adapted for our purpose. Specific schemes of the DEM theory have been also introduced in order to consider soil as a three-phase medium. The results that have been compared to the so-called empirical Topps equation, show that: (a) the empirical equation can not be reproduced when randomly isotropically distributed elementary volumes of water, solid and air are considered; (b) a better agreement is obtained when the elementary volumes of water become more elongated during the increasing of the soil water content; (c) considering TDR measurement, the ohmic losses induced by salinity modify significantly the relationship between the apparent permittivity and the water content for NaCl concentration greater than 0.045 mol/l. In case of clayey soils, simulations have shown that the bound water and the geometrical effect with platy units act as competing processes: when water is added in a clayey material, the geometrical effect contributes to increase the clay relative permittivity compared to media with isotropic particles; a significant amount of bound water generates a decrease in the clay bulk permittivity. Consequently, the later results allow to identify two types of behaviour: (1) low surface area systems, typically kaolinite geomaterials, for which the geometrical effect is predominant and (2) high surface area systems, typically smectite clays, for which a balance between the geometrical effect and the bound water effect is present.

NS41A-08 0905h

Large-scale Sensing of Snow Pack Properties

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Better prognoses in avalanche and flood warning as well as in filling prediction of Nordic hydro-power reservoirs require precise determination of snow properties such as moisture, density and snow water equivalent (SWE). We developed a measurement set-up for automated determination with unshielded three-wire flat band cables. Connected to both high and low frequency impedance analysers and installed prior to winter and enclosed by snow fall, the electromagnetic properties of the cable depend mainly on the dielectrics of the snow and thus allow their determination simultaneously, non-destructively and long-term. The cables can be up to 100 m, thus the covered area can be as large as a radar pixel size and a calibration of remote sensing for SWE determination is possible. A compensation for the effect of air gaps by measuring the sensor cable with different penetration depths of the electromagnetic field is possible. With high frequency measurements and a suitable reconstruction algorithm it is also possible to do a moisture profiling along the cables to get information about spatial resolution of snow inhomogeneities e.g. percolation zones. The sensors were tested at a field site in Switzerland and at sites in Canada with different installation set-ups. Dielectric constant, snow density, and liquid water content of the snow packs were calculated from the raw signals. Also the moisture distribution along one of the horizontally laid out cables was reconstructed for different stages of the winter. The natural settling of the snow cover showed up nicely in the cable measurements. The measured increase of the snow density was in accordance with manual measurements. The determined liquid water in the melting season gave plausible results both compared to lysimeter data taken on the test field and with regard to the spatial variation of flow fingers that we normally experience in a natural snow pack. The calculation of the SWE from these measured data gave encouraging results.

NS41A-09 0910h

Effect of Temperature on Maxwell-Wagner Dielectric Behavior of Wet Soils

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Interpretation of bulk dielectric measurements for water content determination of soils and other porous media using the popular TDR (Time Domain Reflectometery) relies either on empirical relationships (Topps equation) or uses dielectric mixing models. In most applications, interfacial processes such as the Maxwell-Wagner effect and factors influencing the complex component of the dielectric constant are ignored. This study focuses on the role of Maxwell-Wagner effect on the dielectric constant of wet soils considering configuration of the various phases (solid, liquid, and air), electrical conductivity, temperature, and measurement frequency range of TDR. Results show a complex interplay between the response of bulk dielectric constant and ambient temperature. At the low frequency range (MHz) the dielectric constant goes up proportionally with increasing temperature, the magnitude of the increase is determent by the assume phase configuration and electrical conductivity. At a certain critical frequency the bulk dielectric constant of the mixture decreases with increasing temperature (due to reduction of dielectric constant of water). The critical frequency is determined by the combined effect of the Maxwell-Wagner relaxation and temperature. This effect is accentuated in unsaturated soils and virtually vanishes in saturated soils (no air phase) we ascribe the difference to phase configuration and presence of liquid-vapor interfaces. The role of these dielectric-interfacial processes on TDR measurements will be discussed.

Keywords: TDR, Dielectric constant, Maxwell-Wagner effect, Temperature

NS41A-10 0915h

Inverse Porosity-Hydraulic Conductivity Relationship in Sand-and-Gravel Aquifers Determined From Analysis of Geophysical Well Logs: Implications for Transport Processes

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It is intuitive to think of hydraulic conductivity K as varying directly and monotonically with porosity P in porous media. However, laboratory studies and field observations have documented a possible inverse relationship between these two parameters in unconsolidated deposits under certain grain-size distributions and packing arrangements. This was confirmed at two sites in sand-and-gravel aquifers on Cape Cod, Massachusetts, where sets of geophysical well logs were used to examine the interdependence of several aquifer properties. Along with K and P, the resistivity R and the natural-gamma activity G of the surrounding sediments were measured as a function of depth. Qualitative examination of field results from the first site was useful in locating a contaminant plume and inferred an inverse relation between K and P; this was substantiated by a rigorous multivariate analysis of log data collected from the second site where K and P were determined to respond in a bipolar manner among the four independent variables. Along with this result come some implications regarding our conceptual understanding of contaminant transport processes in the shallow subsurface. According to Darcys law, the interstitial fluid velocity V is proportional to the ratio K/P and, consequently, a general inverse K-P relationship implies that values of V can extend over a much wider range than conventionally assumed. This situation introduces a pronounced flow stratification within these granular deposits that can result in large values of longitudinal dispersivity; faster velocities occur in already fast zones and slower velocities in already slow zones. An inverse K-P relationship presents a new perspective on the physical processes associated with groundwater flow and transport. Although the results of this study apply strictly to the Cape Cod aquifers, they may merit a re-evaluation of modeling approaches undertaken at other locations having similar geologic environments.

NS41A-11 0920h

An Investigation of Size-scale Effects on Electrical Properties of Aquifer Materials

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Electrical property measurements of aquifer materials are important in both borehole and surface geophysical methods used to infer subsurface conditions such as porosity, clay content and water saturation. It has long been recognized that these measurements depend on the configuration of the constituents (porosity, rock grains and clay platelets) in the medium. These effects have been studied using the Differential Effective Medium Approximation (DEMA).

DEMA is based on a sequential process by which the composite medium is incrementally constructed through a series of inclusion embeddings. Electrical property estimates obtained from DEMA strongly depend on the inclusion embedding order due to a hierarchical size-scale structure imposed on the composite by the iterative process. An increasing inclusion size scale is implied by the embedding order, with structural features in the initial background matrix having a smaller size scale than any inclusions. Hence, the sequence in which constituents are added specifies size-scale relationships between the components of the heterogeneous medium.

There is a wide variation in the relative size-scales of both the pore space (microporosity - intergranular cracks, mesoporosity - main pore volume, macroporosity - vugs and fractures) and the solid grains (clay platelets, fine sand, coarse gravel) present in natural aquifer materials. Thus, an accurate interpretation of electrical properties must include size-scaling effects. Analytical solutions and numerical results are presented for the electrical properties of multi-phase heterogeneous composites using DEMA with emphasis placed on changes induced in the apparent cementation exponent (m) of Archies law. It is shown that both particle shape and pore structure variations give rise to values of $m \geq 1.5$, while only pore structure variations can reproduce measured values of $m < 1.5$.

NS41A-12 0925h

GETMAG - A New Geophysical Tool

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CSIRO is developing a new instrument for mineral exploration. The instrument, GETMAG, measures the magnetic gradient tensor and the components of the magnetic field. The sensors are high temperature superconducting quantum interference devices (SQUIDs), or HTSs. The acronym is largely historical and stands for Glass Earth Tensor Magnetic Airborne Gradiometer.

The GETMAG instument measures magnetic gradients via a novel application of high temperature superconducting tape flip-chipped onto a SQUID sensor. A gradiometer structure incorporating two opposing pick-up loops is patterned onto a tape. Due to the spatial separation of these loops, a magnetic gradient will produce a Meissner shielding current in the tape. The current is magnetically coupled to the SQUID sensor thus providing a direct measurement of the magnetic gradient. The tape is rotated to detect all gradients orthogonal to the axis of rotation. Three rotating tape systems are required to measure the full tensor. The gradients in combination with the TMI yield better resolution for magnetic surveys. Direction to individual sources and their magnetic moments (reduced according to distance) can be determined directly from the tensor.

Results from test surveys, where the GETMAG system was rotated manually, show that the gradient can be measured to an accuracy of a few nT/m. It is estimated that improving the mechanical structure, spinning the system at about 600 rpm and using an improved data extraction algorithm can reduce this noise figure by two orders of magnitude. The vector components at this stage are very inaccurate since most of the development undertaken to date has been aimed at measuring the gradients. The systems operate better as gradiometers than as magnetometers and will not challenge total field instruments such as proton precession or alkali-vapour magnetometers as scalar instruments.

The GETMAG concept has wide ranging applications in mineral exploration, environmental studies, ordnance detection, ship degaussing, submarine tracking and monitoring of marine currents.

The project was funded by CSIRO, BHP, De Beers, MIM, Newmont and WMC.

URL: http://www.tip.csiro.au/IMP/SmartMeasure/GETMAG.htm

NS41A-13 0930h

In-Well Flow Effects on Borehole Flowmeter Profiles in Long-Screened Wells

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A borehole flowmeter (BF) may be used to determine hydraulic conductivity (K) profiles in wells by measuring vertical flowrate changes at successive vertical positions under steady pumping and drawdown conditions. Usually the assumption is made that inflow to the borehole is directly proportional to K; two types of experiments with the BF operated in a centralized configuration in wells in coarse unconsolidated sediments indicate that this assumption does not hold in some cases. A series of BF profiles were run in 10-cm ID wells of PVC slotted casing in 3-m sections (with .3-m solid casing at section joints) through 15 m of saturated coarse fluvial sediments at a research wellfield (Boise Hydrogeophysical Research Site, or BHRS). Flowrates measured with the BF in upward increments in solid joint sections commonly were not constant but rather increased. This behavior was also observed in laboratory experiments of BF profiles which were conducted under a range of constant pumping rate conditions proportional to rates used during BF profiles at the BHRS. The laboratory system consisted of a nested set of three 6-m columns with 10-cm ID well screen, surrounded by uniform gravel (d ave 4 mm) to 25-cm diameter, surrounded by constant head reservoir (to 30-cm diameter). In the laboratory system, a zone of minimal flowrate increase (as was expected for the solid joint sections) was observed for an approximately equivalent length interval starting .3-.6 m below the solid joint. Also, runs yielded profiles of non-linear flowrate increase with vertical position. Previous work by Kaleris (1989) and Kaleris et al. (1995) examined and modeled the non-linear relationship between rate of inflow to a well and position for long-screened wells considering variable parameters including pumping rate, well geometry, screen characteristics, and aquifer K. Numerical modeling of conditions for most experimental runs with this model are consistent with the observed non-linear flowrate profiles. These results suggest that incremental inflow rates measured with a BF in long-screened wells may not be directly proportional to interval length. However, using the Kaleris model with average field conditions for BF profiles collected in wells at the BHRS (i.e., with lower aquifer K and lower screen K than in the lab experiments) yields a nearly linear profile except for offsets associated with solid joint sections. Offsets of flow reductions associated with solid joints indicate additional in-well flow effects related to BF tool geometry and, to some degree, to pumping rate; future work will include adding these effects to the Kaleris model.

NS41A-14 0935h

Searching for facies indicators in ground penetrating radar data

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Developing an accurate conceptual model of subsurface spatial heterogeneity is a critical step in producing reliable predictions of hydrogeologic processes. One approach to this problem is to divide the subsurface into distinct geologic units or facies. Obtaining a realistic facies model in complex geologic environments, however, can be impossible using well-based data alone. Therefore, alternative data that have the potential to sample large volumes of the subsurface, such as ground penetrating radar (GPR) reflection images, can be valuable tools to aid in facies characterization.

GPR images provide a record of the interactions between an electromagnetic wave and subsurface heterogeneity. Due to the complexity of the processes encoded in this image, it cannot be considered a direct image of the subsurface. As a result, building a facies model from GPR data typically requires expert interpretation. Manual interpretations have the disadvantages of being highly labor intensive, subjective, and qualitative. Unsupervised classification techniques, such as clustering algorithms and neural networks, have the potential to overcome these disadvantages. It is currently unclear, however, whether these automated approaches can be used to obtain facies classifications that are consistent with expert interpretations or geologic reality. In particular, it is uncertain whether there are key elements, or attributes, of a radar image that can be used as primary indicators for different facies.

To address these questions, we compare the facies classifications obtained by expert interpretation to those obtained using K-means clustering for GPR data obtained from the Whitemans Creek watershed in southern Ontario, Canada. The automated classification was performed once using instantaneous attributes, such as envelope, phase, and frequency, and again using structural attributes, which are related to the geometric arrangement of reflectors in the subsurface. In this example, the structural attributes were obtained by projecting the radar data onto natural basis functions derived through principle components analysis. We have found that for the case of Whitemans Creek, the structural attributes provide facies classifications that are more consistent with those obtained by expert interpretation than those obtained using instantaneous attributes. This study demonstrates that unsupervised classification techniques have the potential to aid in the interpretation of GPR data, particularly when different facies are composed of reflectors with distinct patterns.

NS41A-15 0940h

Case History: Merging the Tools of DC Resistivity and Fracture Trace Analysis for Locating High Yield Domestic Water Wells in Karst Terrain, Shenandoah Valley, Virginia, USA

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The karstic eastern margin of Virginias Shenandoah Valley hosts large volumes of high quality ground water in discrete zones or pockets. Industrial and culinary exploitation poses a challenging exploration problem. Recent work by the authors using geophysical and aerial photogrammetric techniques resulted in the successful location of three high- yield water wells. This indirect methodology increases the probability of locating valuable wells by locating geologic features that may harbor water-bearing zones.

The eastern Shenandoah Valley is geologically complex. The underlying bedrock is dominantly limestones, dolomites, and shales of Cambrian age that have been extensively folded, fractured, and faulted. Geomorphologic features such as solution cavities, caves, disappearing streams, and sinkholes are common. Extensive alluvial fan and river terrace deposits, comprised dominantly of quartzite gravel and sand, cover much of the land surface, and fill surface depressions. The combination of sand and gravel filtering and large storage capacity in the voids makes this region ideal for producing a large quantity of high quality groundwater.

Two sites were investigated for karst aquifers near the town of Stuarts Draft. Interbedded limestones and dolomites underlie Barth Farm, situated on the north bank of the South River. The owners attempted to installed a water well to service an active vineyard. The drilling located a previously unknown, water-filled cavern ∼5 m below the surface; subsequent high pumping rates in finishing the well resulted in a surface collapse and the creation of a sinkhole. A second effort, offset by ∼30 meters, resulted in a catastrophic collapse, and seriously endangered the lives of the drillers. A subsequent dipole-dipole DC resistivity survey delineated a conductive zone coincident with the two sinkholes. Fracture trace analysis of pre-drilling aerial photographs indicates the presence of lineaments that pass through this drilling site, suggesting underground voids. This knowledge could serve as a future guide for both well placement and for site evaluation of the potential for sinkhole occurrence.

The second site is located 5 km due south of the Barth Farm. A potential residential and farm operations site was being evaluated for construction based on the availability of adequate water yield. Previous attempts of drilling on a contiguous property resulted in a fruitless 800 ft dry hole. The site is mapped as folded sedimentary rock (limestone, dolomite, shale), but outcrops are masked by ∼25 m thick alluvial deposits of quartzite gravel and sand. The presence of numerous sinkholes and ponds suggests karst terrain.

Fracture trace analysis was initially conducted to identify zones that may contain water-bearing conduits. A dipole-dipole DC resistivity survey followed in areas specifically delineated by the fracture trace analysis. The results lead to two strong wells, one producing 60-100 gpm at 286 ft deep, and the second well 40 gpm at 395 ft.

Based on the previous drilling difficulty in this terrain, the complementary tools of high-resolution resistivity and fracture trace analysis are effective in locating high-yield water wells in karst environments. In the first case, the shallow aquifer was detected directly by the resistivity and indirectly by photo interpretation; in the second, both methods provided indirect evidence. The combined use of near-surface indications of underlying karst reservoirs is recommended for future exploration work.

NS41A-16 0945h

The Effect of the Resolution of a Radar Measurement on the Determined Correlation Structure of Subsurface Properties

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An essential part of the evaluation of groundwater resources is the development of models of the subsurface that contain accurate information about the spatial variability in hydrogeologic properties. While useful information can be obtained from wells, there is rarely the density of wells required to adequately characterize the lateral variability in properties at a site. Ground penetrating radar (GPR) is a near-surface geophysical technique that can be used to acquire high resolution images of the top few tens of meters of the earth. The reflections in a GPR image correspond to subsurface locations across which there are changes in the dielectric constant of the geologic materials. Given that changes in the dielectric constant are closely related to changes in subsurface properties, a GPR reflection image contains information about the spatial distribution of subsurface properties. We are investigating the requirements that must be met in order for the correlation structure of the radar reflections to yield an accurate estimate of the horizontal correlation length of subsurface properties.

Studies have shown that the horizontal correlation length determined from geostatistical analysis of a GPR image can be highly dependent on the frequency used in acquiring the GPR data. Given that the frequency determines the support volume, or resolution, of the GPR data, these results have led us to investigate the effect of resolution on the determined horizontal correlation length. We consider the case where the geological system being sampled with GPR is anisotropic, with a horizontal correlation length much greater than the vertical correlation length. The support volume of a GPR measurement is also anisotropic with the vertical dimension of the support volume (i.e. the vertical resolution) much less than the horizontal dimension of the support volume (i.e. the horizontal resolution).

We first show, using digital photographs of both natural and man-made objects, how changes in the horizontal and vertical resolution, change both the horizontal and vertical correlation lengths in ways that depend on the initial structure and the form of data averaging. We conduct the analogous exercise with GPR reflection images. We start with a model of subsurface water content and generate a set of corresponding GPR images for which we vary the resolution by varying the frequency of the simulated GPR wavelet. Geostatistical analysis of the GPR images shows that the determined horizontal correlation length decreases as the resolution of the image improves. In the anisotropic systems we consider, a loss of vertical resolution can have a significant impact on the horizontal correlation length by increasing the apparent connectivity of horizontal structure.

NS41A-17 0950h

Surface and borehole radar data analysis for shallow aquifer characterization

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It is known that GPR data can supplement hydrogeological data for estimating the spatial distribution of porosity in an aquifer. However, to estimate porosity, the ground velocity has to be known or estimated precisely. Although the surface radar survey gives information on the stratigraphy, the estimation of the velocity is difficult and often lack accuracy. Borehole radar surveys in suitably located piezometers is helpful to obtain reliable estimates of the velocity field.

Surface and borehole radar surveys were performed on a site displaying two aquifers. The shallow unconfined aquifer is separated from a semi-confined aquifer by a thin clay lens. The site is instrumented with piezometers where water levels are frequently monitored. Several radar profiles were obtained. The borehole survey consisted of several VRP and a complete tomographic scan between two holes.

A porosity model was built combining drilling logs, surface GPR and borehole radar data. A tomographic algorithm based on slowness covariance modeling was first used to compute the velocity field between the holes. The reconstructed velocity field is composed of cells of constant velocity. This velocity model was used to perform 2D migration of the surface radar profiles. Then, the drilling logs and the migrated image were used to build a stratigraphical section of the subsurface between the holes. The velocity cells along the interpreted interfaces and along the boreholes are then fixed within a constrained tomographic process to produce a final velocity model. The values of the velocity constrains are selected based on the stratigraphical and log information.

The final velocity model allowed to compute the porosity using Topp formulations. The computed porosity was compared with the one measured on sand samples. The estimates obtained by tomography are close to the values obtained on the sand samples.

Within the interpretative model, we show that it is possible to estimate the spatial porosity distribution between holes using combined surface and borehole radar surveys.

NS41A-18 0955h

Near Surface Geophysical Support of Water System Understanding in the Ogallala Aquifer

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Our globally integrated society is facing numerous challenges in managing water resources. For example, regionally, short-term consumption of groundwater in the Ogallala Aquifer provides for a dynamic socio-economic system through irrigated agriculture. In the long term, transition to sustainable usage that matches natural recharge rates will impact economies, demographics, plant communities and the landscape. Near surface geophysical data are widely available as GIS coverages for aquifer and hydrological properties. These geophysical data are being used within models to characterize present and future water availability based upon a variety of current and forecasted water-use scenarios. Case studies will be discussed that evaluate the hydrologic impact of proposed scenarios. The usefulness of this information to understanding the integrated system containing economics, land-use and ecosystems will be discussed.

NS41A-19 1000h

Capacitive Resistivity Logging to Characterize Hydrostratigraphy: Field Tests at the Boise Hydrogeophysical Research Site

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A new borehole probe was recently developed for measuring the resistivity of geological formations. The probe uses capacitive electrodes, instead of galvanic electrodes or inductive coils, to measure resistivity. Unlike the galvanic resistivity method, the capacitive method works in plastic-cased or air-filled holes, and unlike the inductive method, the capacitive method works well in highly resistive conditions (> 1000 ohm-m). With these advantages, the capacitive resistivity method should prove useful for many near-surface hydrogeological and environmental applications. In order to further the development and testing of this method, we conducted a series of logging experiments at the Boise Hydrogeophysical Research Site (BHRS) located in Boise, ID. The BHRS is a research wellfield located in a shallow, unconfined, coarse alluvial aquifer. Capacitive resistivity data were collected in 14 wells at this site and the resulting logs were used to identify the stratigraphy at each well. The resistivity stratigraphy was also compared to the porosity stratigraphy derived from neutron logging. The zonations determined from resistivity and porosity compare favourably. This is because conduction through the sediments is primarily ionic; the deposits are comprised predominantly of cobble and sand, with very little clay. The capacitive resistivity logs are a little more expressive and variable than the neutron porosity logs. This may be because the capacitive resistivity logs are more sensitive to subtle changes in sediment properties, or because the two logs are sensing different things. The capacitive resistivity data are also compared to induction log (EM39) data and the correlation between these two datasets is poor. Where resistivities are high, the induction log shows very little sensitivity to changes in material properties. At the BHRS, the capacitive resistivity method provides more accurate and reliable data than the induction method. Results from the field tests suggest that capacitive resistivity logs can be used to refine the working hydrostratigraphic model for the site. In addition, correlation of capacitive resistivity values between wells leads to a better understanding of the three-dimensional architecture of the aquifer.

NS41A-20 1005h

Development of a Geocryologic Model of Permafrost From 2D Inversion of IP Profiling

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Non-invasive investigation of permafrost along a planned route of pipeline, road or airstrip in cold regions involves the use of effective methods for detecting, characterizing, mapping and monitoring permafrost conditions on various spatial and temporal scales. Among the available near-surface geophysical methods, the electrical resistivity imaging is probably the most suitable method since the resistivity contrast between unfrozen and frozen ground can be one or two orders of magnitude.

Induced polarization (IP) profiling was carried out to study the spatial distribution of ground ice in two permafrost mounds near Umiujaq in Nunavik, Canada. A dipole-dipole array was used to perform the IP profiling. Pseudo-sections of electrical resistivity and chargeability giving a misrepresented cross-section of the sub-surface were first draw. The inversion of IP profiling was also performed using DCIP2D developed by UBC-GIF for estimating the spatial distribution of electrical properties in the ground to create realistic models of sub-surface resistivity and chargeability cross-section. The inverse models show clearly the presence of ice-rich core in the permafrost mounds. The ice-rich cores are underlined by high resistivity values while the unfrozen zones show low resistivity values. The localisation of the permafrost table is highlighted by a strong contrast of resistivity while the permafrost base is marked by a transitional change in resistivity. In the hollow between the permafrost mounds, the models show low resistivity values characteristic of unfrozen zone. A synthetic resistivity sounding built from the most acceptable inverse model correlates well with electrical resistivity logging carried out in the permafrost mound during cone penetration tests. The inversion of IP profiling is fundamental for defining realistic models of sub-surface resistivity and chargeability.

Electrical resistivity imaging is a appropriate near-surface geophysical method for permafrost investigation such as detecting the absence/presence of permafrost, assessing the cryostratigraphy, mapping the lateral changes in permafrost conditions, estimating the ice/unfrozen water content, determining the permafrost base for shallow permafrost occurrences and monitoring seasonal variations in permafrost conditions from electrical resistivity imaging carried out at regular interval. Electrical resistivity imaging can be used for the delineation of ice-rich zone in frozen ground along major transect such as the route of pipeline, road and airstrip in cold regions.

NS41B CC: 220 C-E Thursday 0830h

Near-Surface Geophysics Posters: Evaluation and Management of Water Resources *(joint with H, GC, PP, ED)*

Presiding: **R Knight,** Stanford University

NS41B-01 0830h POSTER

Poster Component of Near-Surface Geophysics: Evaluation and Management of Water Resources II.

Near-Surface Geophysics (noe-mail@xxx.xxx)

Near-Surface Geophysics, Posters From the Oral Session NS41A

A list of the abstracts and authors that will be presenting posters in this session can be found in session NS41A. The authors are each giving a 5-minute overview of their poster in the session Near-Surface Geophysics: Evaluation and Management of Water Resources II. The presentations start at 0830h in Room 516B on Thursday.

NS43A CC: 516 B Thursday 1330h

Near-Surface Geophysics: Evaluation of Transportation, Building and Energy Infrastructure, and Related Resources I

Presiding: **L Pellerin,** Green Engineering, Inc.**; M Chouteau,** Ecole Polytechnique

NS43A-01 1330h

How Much Gravel? Use of Ground Penetrating Radar for Aggregate Resource Evaluation

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Ground penetrating radar (GPR) was tested in two gravel quarries in eastern Newfoundland, Canada, to determine its usefulness for aggregate resource evaluation.

In Mercer's Pit, near Tors Cove, GPR profiles show irregular, discontinuous reflections that extend to depths of more than 30 m. Boulders are common at depth (identified on the profiles by numerous individual diffractions). The area is interpreted as a much thicker gravel deposit than had been estimated by previous methods, however, the presence of boulders could indicate a lower quality resource. Analysis of a peat bog near the pit shows a prominent contact on the GPR profiles. It is interpreted as the hummocky surface of the gravel deposit (continuous, high amplitude reflections), which underlies a much weaker reflective zone of peat.

At Snow's Pit, near Bay Roberts, a series of overlapping diffractions at depth are interpreted as representing the bedrock surface, which varies from 5 to 15 m below the surface. Aggregate deposits overlie the bedrock (irregular, discontinuous reflections) and contain very few boulders. This deposit also was found to be larger than previously thought, and is low in boulder content throughout.

GPR was found to be an effective tool for delineating the extent and volume of aggregate resources in these examples. It provides a detailed view of the subsurface and large amounts of information are gathered quickly and easily. GPR can be used to revise volume calculations of quarries already in operation and to estimate the volume of potential new deposits. It is also useful for planning pit development and analysing prospective areas that quarry operators do not yet own or have rights to, with virtually no environmental impact on the land surveyed.

NS43A-02 1335h

Electrical Resistivity Imaging for Investigating Slope Stability, Fort St. John, British Columbia

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The Peace River District of northeastern British Columbia is characterized by steep river valleys that have been incised up to 300 m deep in poorly consolidated Cretaceous and Quaternary sediments. Since the area is a major producer of oil and gas, numerous pipelines and roads transect these valleys. Slope stability has been a major problem at several locations and will continue to pose a problem for future development in the area. Understanding the mechanisms of slope stability will allow better assessment of the risks to infrastructure. The Geological Survey of Canada is conducting studies to determine the role that groundwater infiltration and flow have in controlling slope movements. Near-surface geophysical surveys provide a quick non-invasive method of investigating ground conditions. Since moisture content of the underlying strata plays an important role in slope stability, electrical methods are particularly suitable. For this study, two-dimensional electrical resistivity imaging was conducted along three pipeline route slopes in the Fort St. John area during July 2002. An automated electrical resistivity imaging system was used to acquire continuous Wenner array images up to 1300 m in length. The system used 48 electrodes spaced 5 m apart, to obtain a high-resolution image of the subsurface with an exploration depth of approximately 40 m. Two-dimensional inversion software was used to obtain topography-corrected electrical resistivity models for each slope. Borehole information was incorporated in the interpretation of the results. Electrical resistivity imaging proved to be a fast and effective method for investigating the extremely steep slopes encountered in the Fort St. John area. The results indicate that the method is very useful in identifying seepage zones and extending hydrostratigraphy from borehole observations. These studies will assist modeling of groundwater flow by confirming areas of predicted groundwater discharge and by delineating areas where moisture content changes are taking place.

NS43A-03 1340h

Assessment of Continuous Resistivity Profiling for the Characterization of Paved Roads

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We have assessed the continuous resistivity profiling method using towed arrays as a diagnostic NDT method for the evaluation of pavements. Whether the pavement consists of a sequence of asphalt, concrete slab and subgrade layer (rigid pavement) or a layer of asphalt overlying a subgrade and grade base layers (flexible pavement) defects within those different layers can cause pavement deterioration that must be identified. We first examine the response of the method to the various problems using numerical modeling. It is shown that with an optimally designed system the method allows the determination of the thickness and the location of cracks in the asphalt cover. It is also sensitive to the presence of cracks, internal defects and chloride ions (de-icing salt) within the concrete slab below. For reinforced concrete it is possible to estimate the concrete resistivity related directly to its composition (quality) and the thickness of the top coating over the level of rebars. A low resistivity of concrete will usually be diagnostic of advanced stage of rebar corrosion and delamination could occur. However it is shown that the rebars cause current channeling and the depth of investigation is limited then to the depth of the first row of rebars. Finally heterogeneities within the foundation reflecting subsidence, bad drainage, frost-defrost cycles or cavities can be mapped. The optimal design is based on a system with 10 to 20 receiver dipoles and one transmitter dipole (first or last of the array) with a dipole length typically of 10 cm that can be used in equatorial or in-line mode. Static resistivity measurements have been carried out at the laboratory scale over concrete slabs built to verify results obtained from the numerical modeling. Observed data fit very well the modeled data and validate the overall conclusions. Tests have been performed in December 2003 in some selected streets (6 visited, 3 re-visited) of Montreal using a CORIM system (Iris Instruments, France), a capacitively-coupled resistivity towed equatorial array that continuously record data collected with six receiver dipoles and one transmitter dipole. Typical acquisition sampling and velocity were 0,20-0,50 m and 1 to 2 km/h respectively. Although the system is not optimally designed for the applications described above it provides useful diagnostic information about the state of deterioration of pavement. Data have been imaged using 2D resistivity inversion. In general it shows a high resistivity for the shallow depth related to the asphalt layer and a decreasing resistivity with depth related to the concrete slab first and the granular foundation below. Lateral variations appear to be correlated with degradation of the concrete slab.

NS43A-04 1345h

Near Surface Characterization Of Concrete Structures Using Rayleigh Waves

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