GP11B-03 0900h

Geologic Noise in Near–Surface Time–Domain Electromagnetic Induction Data

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Controlled–source electromagnetic induction is a geophysical technique commonly used to aid in the identification of both anthropogenic and naturally occuring features, such as unexploded ordnance or high–permeability fluid pathways, in Earth's shallow subsurface. However, electromagnetic responses are oftentimes difficult to interpret owing to the complex, multiscale heterogeneous nature of the underlying electrical conductivity structure. We show evidence here which indicates that electromagnetic responses are indeed fractal signals, reflecting a very rough distribution of electrical conductivity in the underlying Earth. Time–domain electromagnetic data collected across a section of colluvial fill in the Rio Grande Rift valley near Albuquerque, New Mexico, show that the fractal properties of the surface electromagnetic responses depend on the complexity of the causative geological structure. Similar experiments in the frequency domain suggest that the small–scale fluctuations in the electromagnetic response due to geological noise are inherently reproducible, and are not caused by random instrumental or atmospheric effects as often assumed. New approaches to modeling electromagnetic responses are required in order to take full advantage of the rich information content of near–surface electromagnetic data.

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URL: http://beerfrdg.tamu.edu/~colt45

GP11B-04 0915h INVITED

The Use of Ground Penetrating Radar Data for the Development of Hydrogeologic Models

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Ground penetrating radar (GPR) is a geophysical technique that can provide high resolution images of the top few tens of meters of the earth. These GPR images can be used to develop models of the large-scale architecture of the subsurface and can also be used to characterize the spatial distribution of subsurface hydrogeologic properties.

At the scale of meters to tens of meters we rely on the concept of radar facies to divide the GPR image into separate regions based on the presence of distinct bounding surfaces or differences in the character of the radar response. Ideally these radar facies correspond to hydrogeologic facies, so that the large-scale architecture identified in the radar image is relevant for modeling fluid movement or contaminant transport. While the identification of radar facies has typically relied on the interpretation of a human practitioner, we have recently developed an approach using neural networks which allows us to automate the classification process.

Once the large-scale structure has been defined, estimates of geophysical properties in regions of the subsurface can be used to obtain estimates of hydrogeologic properties. The rock physics relationships that are used to extract hydrogeologic properties from geophysical measurements are usually based on laboratory measurements on relatively small homogeneous samples. If the sampled region of the subsurface is heterogeneous, these relationships become invalid and can lead to large errors in predicted property values. We address this issue by using bounding methods where we define the possible range of predicted values when general assumptions are made about the structure of sampled region. Our estimates of hydrogeologic properties can be significantly improved by incorporating more information about the structure within the sampled region.

In addition to imaging the large-scale structure, a radar data set contains information about the spatial heterogeneity of the subsurface at smaller scales. In two field studies we have found the correlation structure of the radar image itself to be an excellent representation of the spatial variability in grain size or moisture content of the subsurface. This information aids in the classification of radar facies and also assists in assigning hydrogeologic properties within the radar-based models. Forward modeling of radar data illustrates the complex nature of the relationship between the scale-dependent heterogeneity of the subsurface and the frequency-dependent radar images.

GP11B-05 0935h

Characterization of Clay Layers in the Vadose Zone Using Attenuation Tomography via Cross Borehole Ground Penetrating Radar

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Cross Borehole Ground Penetrating Radar (XBGPR) is currently being used to monitor the change in moisture content and to test the feasibility of using attenuation tomography in order to monitor the conductive solute transport in the vadose zone at a test site in Socorro, New Mexico. The test site is a fluvial deposit containing alternating layers of sand and clay. Data collection began in December 1998 using five wells along an 11-meter profile intersecting a three-meter by three-meter infiltrometer. The infiltrometer has been discharging water at a constant rate of 2.5 cm/day since February 1999 in order to ensure the constant flux source. The first arrival time and electric field amplitude are collected by the XBGPR acquisition system and are used in recovering the water content and attenuation coefficient of the subsurface, respectively. After an initial phase in isolating the specific pre-inversion processing steps necessary to produce the attenuation images, as well as determine the accuracy of this imaging method, our efforts have turned to analyzing the spatial distribution of the substance attenuation properties. The results show that two clay layers with a high attenuation coefficient can be well identified by the XBGPR in the time-lapse images. However, comparing with the concurrent moisture images produced by the velocity images, the repeated attenuation images also suggest that the infiltration of water and increase of water content do not have a considerable influence on the attenuation coefficients. Currently, sodium chloride solution has been discharge through the infiltrometer in the test site, and frequent data collecting has been conducted to recognize any change of the attenuation coefficient. Our future research will focus on using the same processing technique developed in the initial phase to identify the transport of the sodium chloride solution through the vadose zone.

GP11B-06 0950h INVITED

Vadose Zone Flow Model Parameterisation Using Cross-Borehole Radar and Resistivity Imaging

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Cross-borehole geoelectrical imaging, in particular electrical resistivity tomography and transmission radar tomography, can provide high resolution images of hydrogeological structures and, in some cases, detailed assessment of dynamic processes in the subsurface environment. Through appropriate petrophysical relationships, these tools offer data suitable for parameterizing and constraining models of groundwater flow. This is demonstrated using cross-borehole radar and resistivity measurements collected during a controlled vadose zone tracer test, performed at a field site in the UK Sherwood Sandstone. Both methods show clearly the vertical migration of the tracer over a 200 hour monitoring period. By comparing first and second spatial moments of changes in moisture content predicted from a numerical simulation of vadose zone flow with equivalent statistics from 2- and 3-D electrical resistivity tomography and cross-borehole radar profiles the effective hydraulic conductivity is estimated to be approximately 0.4 m d-1. Such a value is comparable to field estimates from borehole hydraulic tests carried out in the saturated zone at the field site and provides valuable information that may be utilized to parameterise pollutant transport models of the site.

GP11B-07 1025h INVITED

Using Flow Logging Experiments to Bridge the Scale Gap in Borehole Geophysics

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Until the recent development of high-resolution borehole flow logging equipment, geophysical well logs were indirectly related to aquifer parameters such as porosity and permeability through various interpretation equations. Heat-pulse and electro-magnetic flowmeters allow the direct measurement of aquifer permeability in situ during borehole flow experiments. An important limitation on the interpretation such flow experiments is the scale of investigation, because permeability profiles derived from flow logs apply to the immediate vicinity of the borehole. A few local samples of the permeability of heterogeneous aquifers are unlikely to apply to large-scale flow within the aquifer. The aquifer scale limitation of geophysical logging is addressed by: 1) using a borehole flow model to interpret the large scale boundary conditions driving local borehole flow; and 2) using pulsed cross-borehole flow experiments to define hydraulic connections between boreholes. Conventional geophysical logs are used to identify generalized aquifer structure, including individual bedding planes or fractures conducting flow into or out of the borehole. A flow log model is used to quantify the local-scale hydraulic conductivity of the conduits intersecting the borehole, and to estimate the hydraulic head of the large-scale aquifer or aquifers to which those conduits are connected. These estimations can be interpreted in terms of large-scale aquifer structure. In a more direct and straightforward sampling of large-scale permeability, cross-borehole flow tests consist of experiments where one borehole is stressed for a short period, and the transient flow field induced by that stress is monitored in adjacent boreholes. These experiments are used to define the flow paths between boreholes, and to identify possible hidden connections short-circuiting those flow paths. Specific examples of local flow-log data used to define large-scale aquifer properties are given for study sites in Minnesota, Massachusetts, Maine, and New York.

GP11B-08 1045h

Relationships Between Electrical, Lithological and Hydraulic Properties of Unconsolidated Sediments

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The relationship between complex conductivity measurements and hydraulic conductivity (K) of unconsolidated materials was investigated. The laboratory samples include natural sediments and artificial sand/clay mixtures. We test the Borner et al. (1996) model, based on a Kozeny-Carman equation, which incorporates electrical estimates of formation factor (F), from the real conductivity, and the specific surface-to-porosity ratio (S[por]), from the imaginary conductivity. We find that K correlates with imaginary conductivity but shows no correlation with F, which we attribute to the wide range in grain size for these materials. The Brner model appears primarily dependent on the K - imaginary conductivity relation.

The relationship between imaginary conductivity and S[por] is non-linear and appears to depend upon material type. In contrast a strong correlation between imaginary conductivity and effective grain size exists, which is relatively independent of the material type. However, we find that the strength of the correlation depends upon the frequency of the imaginary conductivity measurement and the point on the grain size distribution curve selected as the effective grain size.

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We propose a Hazen-type equation in which the effective grain size is estimated from the imaginary conductivity. This simple model provides order of magnitude K estimates for a range of unconsolidated sediments. As the imaginary conductivity is directly related to the normalized chargeability (the chargeability divided by the resistivity), our model is easily stated in terms of field induced polarization (IP) parameters. Model calibration requires grain size distribution measurements, which are relatively simple to obtain for unconsolidated materials. This laboratory study has significant implications for field IP imaging of lithologic variability in unconsolidated materials, as well as for field estimation of the spatial variability in hydraulic conductivity.

GP11B-09 1100h INVITED

Investigating Temporal and Spatial Variations in Near Surface Water Content using GPR

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Using only conventional point or well logging measurements, it is difficult to obtain information about water content with sufficient spatial resolution and coverage to be useful for near surface applications such as for input to vadose zone predictive models or for assisting with precision crop management. Prompted by successful results of a controlled ground penetrating radar (GPR) pilot study, we are investigating the applicability of GPR methods to estimate near surface water content at a study site within the Robert Mondavi vineyards in Napa County, California. Detailed information about soil variability and water content within vineyards could assist in estimation of plantable acreage, in the design of vineyard layout and in the design of an efficient irrigation/agrochemical application procedure. Our research at the winery study site involves investigation of optimal GPR acquisition and processing techniques, modeling of GPR attributes, and inversion of the attributes for water content information over space and time. A secondary goal of our project is to compare water content information obtained from the GPR data with information available from other types of measurements that are being used to assist in precision crop management. This talk will focus on point and spatial correlation estimation of water content obtained using GPR groundwave information only, and comparison of those estimates with information obtained from analysis of soils, TDR, neutron probe and remote sensing data sets. This comparison will enable us to 1) understand the potential of GPR for providing water content information in the very shallow subsurface, and to 2) investigate the interrelationships between the different types of measurements (and associated measurement scales) that are being utilized to characterize the shallow subsurface water content over space and time.

GP11B-10 1115h

Interpreting Electromagnetic Wave Velocity in Layered Soils: The Importance of Both Average and Individual Relative Layer Thickness

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With the growing use of ground-penetrating radar (GPR) in hydrogeology, we need to improve our ability to analyze electromagnetic (EM) velocity. Previous studies show that EM velocity (v) through soil layers is dependent on average relative layer thickness (λ/t) as well as dielectric constant (κ). λ/t is the ratio of the wavelength (λ) of EM wave to the layer thickness (t). When the average $\lambda/t < 1$, the average v through the soil layers is predicted by ray theory (RT). When the average $\lambda/t > 10$, the average v through the soil layers is predicted by effective medium theory (EMT). The transition zone between the two regimes falls between 1 and 10.

In this study, I numerically investigate this transition zone which can be very narrow and fall at $\lambda/t \sim 6$ or can be very wide and span between 1 and 10. As the EM wave travels through different layers, λ can fluctuate depending on the κ of each layer. EM waves that travel through high κ layers have short λs; while those that travel through low κ layers have long λs. In systems where the individual λ/t for each soil layer vary greatly (e.g. thin layers of low κ soil and thick layers of high κ soil), the EM wave oscillates between the RT and EMT regimes. As a result, as the average λ/t of such systems increases from 1 to 10, v gradually transitions from that predicted by RT to that predicted by EMT. Correspondingly, in systems where the individual λ/t for each soil layer are similar (e.g. thin layers of high κ soil and thick layers of low κ soil), the EM wave travels in either the RT or EMT regime. As a result, as the average λ/t of such systems increases, v sharply changes from that predicted by RT to that predicted by EMT at an average $\lambda/t \sim 6$.

These data show that in order to predict v in layered soils accurately, not only is the average λ/t of the system important, but so are the individual λ/ts of each layer. As we improve our ability to predict the velocity of an EM wave as it propagates numerically through a system of layers, we improve our ability to interpret measured v data gathered in the field.

GP11B-11 1130h

Combining Laboratory and Field Data to Determine Saturation and Detect Fractures In a Heated Rock Mass

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The electrical properties of porous media are sensitive to a number of factors including temperature, saturation, and nature of the pore fluid. This sensitivity makes field EM methods a powerful tool with the potential to estimate saturation and locate active fractures in a variety of geological environments. Laboratory measurements of the electrical resistivity of densely welded tuff as functions of saturation, temperature, and pressure were performed to investigate the resistivity contrast of saturated and partially saturated intact and fractured rocks. These results are used to infer saturation and test our ability to locate fractures in a 3 to 5 meter scale field test with carefully controlled conditions. Laboratory measurements on tuff from the field site were performed at confining pressures up to 10 MPa and temperatures to 145^{o}C to simulate test conditions. Intact samples showed a gradual resistivity increase when pore pressure was decreased below the phase-boundary pressure of free water, while fractured samples show a larger resistivity change at the onset of boiling. The resistivity change is greatest for samples with the most exposed surface area. Analysis of the field test provided the opportunity to evaluate fracture detection using electrical methods at a large scale where independent geophysical measurements of water content and deformation were performed. Interpretation of electrical resistance tomography (ERT) images of resistivity contrasts, guided by laboratory derived resistivity-saturation-temperature relationships, indicate that dynamic saturation changes in a heated rock mass are observable and that fractures experiencing drying or resaturation can be identified. Temperature and displacements records for the field test show abrupt localized changes coincident with the ERT determined changes in saturation. The same techniques can be used to locate fractures using electrical field methods in other regions of interest such as geothermal reservoirs, active hydrothermal systems, and environmental remediation sites.

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GP11B-12 1145h

On the Heat-Water Exchanges at the Surface Rock-Atmosphere in an Underground Cavity

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The underground cavities are the object of several studies in view of nuclear waste storage, and to study the stability of abandoned quarry. A complete comprehension of this system needs a good understanding of the interactions between the rock and the atmosphere. Two point must be clarify: the transport of heat and water vapor in the atmosphere and the boundary condition at the interface rock-atmosphere (Gensane, 2001). In this talk we deal with the boundary condition. We use the observations of 3 different experiments at Meriel and Vincennes quarry (France), and Aburatsubo cavity (central Japan). In each experiments temperature, atmospheric pressure in the atmsophere are available and self potential for the quarries and resistivity of ground floor for the cavity (we have also ground temperature profile for the cavity). The electric measurements in rock are use to have information about the water content in rock and its flow. It is shown that the atmospheric pressure induce fluid flow in the rock, the heat transport through the interface is not conductive, and that a complex relation occurs between atmospheric pressure and temperature, in the atmosphere and in the ground. We observe also strange wave trains of self potential and atmsopheric parameters (Morrat, 1995, 1999; Gensane, 2001). These observations conduct us to propose a first model for the boundary condition. The water and heat transport in the atmosphere is convective, so a thin conductive layer exist above the surface, about 2 cm (Morrat et al, 1999, Perrier et al, 2000). We propose, like observations suggest, to consider two diffusive equations for temperature and water saturation in the rock, and two others in the conductive layer. These system of 4 equations are coupled at the interface by non linear processes due to evaporation-condensation of water. We show that we can rewrite this system in 2 equation coupled at the surface. Analytical solutions are given and numerical computation are performed. This model could give a first interpretation of wave trains observed.

GP12A MC: Hall D Monday 1330h

New Results in Magnetostratigraphy

Presiding: **M Steiner,** University of Wyoming

GP12A-0201 1330h POSTER

Eocene to Miocene Magnetic, Bio- and Chemostratigraphy at ODP Site 1090 (Sub-antarctic South Atlantic)

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At ODP Site 1090, in the sub-antarctic South Atlantic, ~300m of middle Eocene to middle Miocene sediments were recovered using the advanced piston corer (APC) and the extended core barrel (XCB). The u-channel samples for the 70-230 meters composite depth (mcd) interval provide a magnetic polarity stratigraphy which is compared to shipboard pass-through magnetometer data and discrete sample data which extend the magnetostratigraphic record to 380 mcd. The magnetic stratigraphy can be interpreted by fit of the polarity zone pattern to the geomagnetic polarity timescale (GPTS) augmented by isotope data and bioevents with documented correlation to the GPTS. Two normal polarity subchrons (C5Dr.1n and C7Ar.1n), not included in the standard GPTS, are recorded at Site 1090. The base of the sampled section is correlated to C19n (middle Eocene), although the interpretation is equivocal beyond C17r. The top of the sampled section is correlated to C5Cn (base of Middle Miocene). This interpretation is consistent with strontium, oxygen and carbon isotopic values measured on foraminifera but inconsistent with the presence, in the uppermost 10m of the sampled section, of the Globorotalia sphericomiozea, a foraminifer usually associated with the Messinian and early Pliocene. For the interval spanning the Oligocene-Miocene boundary, benthic carbon and oxygen isotopic ratios from Site 1090 can be correlated to isotope records from ODP Site 929 (Ceara Rise) where the astrochronology has yielded a new age for the Oligocene-Miocene boundary (Shackleton et al., 2000). Re-scaling the Cande and Kent (1992, 1995) timescale to account for the new age (22.92 Ma) for the Oligocene-Miocene boundary, and applying this age model to Site 1090, results in a satisfactory fit of the isotope records from Sites 929 and 1090, thereby providing support for the new Oligocene-Miocene boundary age.