H42A-1067 1330h POSTER

Contrasts in shallow cloud cover and rainfall intensity over deforested regions in the Amazon basin

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This paper addresses the impact of human induced land-use change on local and regional atmospheric circulation. To this end, the particular case of Amazonian deforestation is investigated. The first issue investigated is the enhancement of shallow cumulus clouds over deforested regions that has been observed qualitatively and in numerical model simulations. A set of shallow cumulus cloud recognition algorithms are presented, and are applied to Geostationary Operational Environmental Satellite (GOES) visible and infrared image pairs collected over the Amazon basin. Relative statistics about the occurrence of shallow clouds over forested and deforested regions are compiled, and their significance is assessed using a Monte-Carlo approach in which landcover patterns are randomized. The sensitivity of the results to the cloud recognition algorithm and landcover randomization scale are investigated. The conditional shallow cloud statistics are also stratified with respect to the synoptic circulation pattern and antecedent soil moisture conditions in order to investigate the conditions under which shallow cumulus contrasts arise. A similar analysis is performed on data from the Tropical Rainfall Measuring Mission (TRMM) precipitation radar to investigate the effect of the landcover heterogeneities on shallow warm rain cells.

H42A-1068 1330h POSTER

Diagnosing the influence of radiative forcing on local recycling of precipitation using a three-dimensional recycling model

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Knowledge on precipitation recycling is an important access to understand the the impact of radiative forcing on the regional water cycle and water availability. In this paper, a recycling model was developed as a precipitation recycling diagnosis tool. The recycling diagnosis tool will be introduced. Results from tests performed with artificial data will be presented to evaluate this three-dimensional diagnosis tool. We will apply the recycling diagnosis tool to data from climate model simulations performed with CCSM with recent CO_2 and increased CO_2 to examine the impact of radiation changes on local recycling of precipitation. The analysis will focus on the temporal and spatial changes.

H42B MCC: Level 2 Thursday 1330h

The Influence of Scale on Characterization of Fractured-Rock Aquifers I Posters *(joint with T, NG)*

Presiding: **W C Burton,** U.S. Geological Survey**; A M Shapiro,** U.S. Geological Survey

H42B-1069 1330h POSTER

Ground Water Flow Modeling in a Layered Sedimentary Fractured Media Aquifer System using MODFLOW with the PMF Package

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Ground water movement in fractured media is markedly different from that in porous media. This difference can be summarized as a continuous change of flow properties in porous media as opposed to a discrete change of flow properties in fractured media. Therefore, the direct use of MODFLOW, which was originally developed to simulate porous media systems, to model fractured media systems is quite limited. Indeed, a special characteristic of ground water movement in fractured media, namely preferred fluid pathways, is difficult to simulate in a finite difference model such as MODFLOW. In order to define this preferred fluid pathway, the model domain should have several different categories of cells such that one would represent densely fractured areas while the others represent sparsely fractured areas in the model domain. We developed the PMF package (a Preprocessor to MODFLOW for Fractured media) using percolation theory in order to allow the model domain of MODFLOW to show preferred fluid pathways composed of fracture connections. The layered sedimentary fractured media located in Piscataway, NJ, was simulated by MODFLOW with the PMF package in this study. Its hydrogeological structure consists of a water bearing unit having a dense fracture distribution and a confining unit having a sparse fracture distribution. Ground water flows mostly through the connected fractures in the water bearing units, which can be considered to be the preferred fluid pathway. The PMF package allowed the model domain to show these two different units by the distribution of two different types of cells and produced a simulation having better fits to observation data and a better agreement with the geological characteristics of system than simulations performed by MODFLOW alone. We can conclude that the application of the PMF package to a layered sedimentary fractured aquifer to simulate ground water flow yielded superior results, as its application also provided better results in a crystalline fractured aquifer in a previous study.

H42B-1070 1330h POSTER

Constraining Fold-shape Models With Simultaneous Non-linear Regression to Characterize Fold Related Fractures

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Bedding-plane partings and axial-plane spaced cleavage are examples of fractures in sedimentary rocks that can be related to field scale fold structures. These fracture systems can be modelled regionally if the fold structure can be approximated mathematically through the use of fold shape models. The theory of a new technique to estimate parameters of fold shape models using geologic horizon elevation and bedding plane data is presented. Observations of the elevation of a geologic horizon are used to regress the parameters of a model of the horizon in a fold, while observations of bedding planes are used to regress the same parameters in the gradient of an isotimic surface function that reduces to the horizon model when the isotimic constant is zero. The gradient thus corresponds to the normal to the tangent (bedding) plane to the horizon, i.e. the pole to bedding. Therefore the normalized components of the gradient correspond to the direction cosines of the pole to bedding, and comprise three models in the same parameters as the horizon model. A simultaneous regression can be constructed using both the horizon elevation and bedding plane observations. The sensitivities of both the horizon model and gradient models depend upon the values of the parameters, and thus the regression is non-linear. The theory is developed and an example using a sum-of-sines function is presented for upright, symmetric folds in the Mahantango Creek watershed of Pennsylvania.

H42B-1071 1330h POSTER

Estimating Equivalent Continuum Scales in Fractured Aquifer Watersheds Using Discrete Feature Network Simulation

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Fractured aquifers serve as primary water resources throughout the western United States. In light of diminishing water supply, management practices must be improved to promote resource sustainability. Groundwater flow models are often the preferred management tool, but can be computationally expensive and difficult to implement in large-scale fractured environments. Discrete feature network (DFN) simulation is a robust approach for modeling fluid movement in fractured architecture, but numerically expensive for large-scale models. By using an equivalent continuum model (ECM) numerical expense may be substantially reduced. An intrinsic assumption of the ECM approach is that the geologic media is represented accurately as a continuum, requiring that grid scale discretization correspond to representative elementary scale (RES) at each location within a fractured aquifer. Heterogeneity and compartmentalization likely cause regions with large differences in fracture permeability and connectivity, resulting in spatially variable RES. Thus, while regional flow may be honored using essentially any grid pattern, failure to properly represent spatially variable RES could lead to erroneous predictions of local flow and transport, especially in highly heterogeneous zones. The purpose of our study is to determine whether head predictions from DFN flow simulations can delineate spatially variable RES in fractured aquifers. Provided there is a correlation of simulated hydraulic head to continuum scale, we hypothesize that RES can be identified using spatially disperse water level observations within a fractured aquifer watershed. Preliminary results suggest there is potential for using hydraulic head data to determine the RES. Ongoing research is necessary to confirm these preliminary results and our hypothesis.

H42B-1072 1330h POSTER

Interpretation of Hydraulic Tests and Implications Toward the Representative Volume Element for Bedrock Systems

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A bedrock site was studied over the past four years. The primary objective of site research was in situ bioremediation. During the course of the site research, seven wells in competent bedrock were constructed to augment the pre-existing site investigation wells. The new wells had multiple hydraulics tests performed in various lengths of discrete intervals of the open well bore. These tests included over 200 slug and 10 pumping tests. One pumping test was a site-wide test that involved wells in overburden, weathered bedrock, and competent bedrock. This wealth of information provided a database to make statistical inferences about bedrock hydraulic parameters. In addition, the analysis of the slug test data takes on new meaning when the data is analyzed by a heterogeneous conceptual model rather than the more common homogeneous models. Lastly, due to the varying size of formation investigated by the different hydraulic tests, it is possible to identify the representative volume element (RVE) - the size of formation over which small changes from average hydraulic characteristics occur. Pumping tests included standard constant rate pumping as well as non-constant pumping. Slug tests used gas pressurization and vacuum for traditional changes in instantaneous head (less than one meter), as well as large displacements on the order of 15 meters. For all data sets, data was analyzed with homogeneous analytical models (Hantush, Cooper, etc.) and a simple radial, two-zone heterogeneous finite-difference numerical model. This model used two zones, radially centered on the stressed well, with different hydraulic properties (usually with transmissivity one or two orders of magnitude higher in the outlying zone compared to the zone containing the stressed well). For the pumping tests and the large displacement slug tests, in addition to the analysis of the data from the stressed well, data from monitoring wells was also analyzed to develop hydraulic parameters. Hydraulic parameters, resulting from the analysis of the following hydraulic tests, were similar: the site-wide pumping test, the interval pumping tests, and the slug test far field (outer zone). Since each of these tests, evidenced by monitoring wells, investigated different sized portions of the bedrock and because the resulting hydraulic parameters were similar, this begins to define the bedrock RVE. More importantly, this RVE was identifiable from slug tests in single wells, for single intervals without the use of nearby monitoring wells. At this site, the RVE was on the order of 10 meters. This RVE from hydraulic tests is compatible with what can be estimated from fracture density observed in cores, outcrops, and geophysical logs. The interrelation between hydraulic testing of well bore intervals and testing the entire open well bore may in fact overlap in the description of the RVE. If one considers that an open borehole is a vertical zone in which to study hydraulic parameters, and that this zone is on the order of the RVE, then open well bore hydraulic tests may yield RVE-scale information. Arithmetic and geometric sums of well bore interval transmissivity compared favorably to the open borehole transmissivity, which supports this conclusion. The probability distributions representing the slug test hydraulic conductivity from homogeneous and heterogeneous methods will be presented and discussed. The heterogeneous, far field hydraulic conductivity probability distribution

differed from the homogeneous distribution in median, mode, mean, and standard deviation.

H42B-1073 1330h POSTER

An Analysis of Core Log Quality and Hydraulic Test Interval Length on Estimation of Fracture Aperture Statistics

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The density of fracturing (i.e. fracture spacings) and the distribution of flow among fractures (i.e. fracture apertures) both play a crucial role in controlling the ability of a bedrock aquifer to attenuate the movement of solute away from a contaminant source. One way to determine these parameters is through hydraulic testing of discrete intervals along boreholes. When the density of fracturing is high compared to the density of test intervals, however, the statistical properties of the fractures are masked by the averaging effect of the testing method. Fracture data collected from the core log can alleviate this problem, but caution must be used in its interpretation. In this study, the relationship between sampling interval length and estimates of the mean and variance of individual fracture spacings and apertures is explored. It is shown that larger test intervals are more useful for estimating the mean of aperture, while smaller test intervals are more useful for estimating its variance. Transmissivities measured at 2 m and 0.5 m spacing across the thickness of a bedrock aquifer in Smithville, Ontario, as well as data from three separate loggings of the core are used to illustrate the relative importance of accurate core logging vs. greater density of hydraulic testing in predicting solute arrival times at a point down-gradient of a contaminant source in a fractured bedrock aquifer.

H42B-1074 1330h POSTER

Multiscale Investigation of Fracture Permeability Within a Single Borehole

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Permeability controls mass and energy transfer through rocks and soils. Studies conducted in different hydrogeological environments suggest that permeability varies with measurement scale. In many cases this scale effect is evident from the comparison of permeability data obtained from: 1) core to borehole tests and 2) single borehole tests to larger scale pumping tests conducted between multiple boreholes. A pronounced permeability scale effect has been previously observed from the analyses of data from single- and cross-hole pneumatic injection tests in unsaturated fractured tuff at the Apache Leap Research Site (ALRS) in central Arizona, USA (Illman and Neuman, 2001; 2003; Vesselinov et al. 2001a-b). Here, I ask the question whether such an effect is seen at the ALRS when one examines permeability data collected at multiple measurement scales (0.5, 1.0, 2.0, 3.0, and 20 m) within a single borehole. Results from the multiscale single-hole pneumatic injection tests show that permeability decreases with scale for the 0.5 through 3.0-m scale tests. However, permeability increases with scale when the data are compared against the 20-m scale data, but the increase is considerably lower than what has been previously surmised at the site. I hypothesize that the suppression in the magnitude of scale effect is due to the decreased connectivity of the fracture continuum when tests are conducted within a single borehole at this site.

H42B-1075 1330h POSTER

Mono- and Multi-Fractal Scalings of Air Permeability Data from Unsaturated Fractured Tuff

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Air permeabilities in unsaturated fractured tuff at the Apache Leap Research Site (ALRS) near Superior, Arizona, exhibit a pronounced scale effect. The effect appears to be consistent with a view of the permeability field as a truncated random mono-fractal [Hyun et al., 2002]. We investigate the extent to which single-hole air permeability data, obtained at the site on a nominal support scale of about 1 m, are compatible with various scaling models including fBm (fractional Brownian motion), fGn (fractional Gaussian noise), fLm (fractional Levy motion), bfLm (bounded fractional Levy motion) and UM (Universal Multifractals). We find that log permeability data have a Levy -like distribution at small lags but become Gaussian as the lag increases, corresponding to bfLm. Though this implies multiple scaling it is not consistent with the UM model, which considers a unique distribution. If one nevertheless interprets the log permeability data on the basis of UM one obtains a very small codimension, suggesting that multiple scaling is of minor consequence. Doing the same for permeabilities (as opposed to their logarithm) yields a larger codimension but is otherwise not consistent with UM. Variogram and (rescaled) range analyses of the log-permeability data yield comparable estimates of the Hurst coefficient. Rescaled range analysis shows that the data are not compatible with fGn. The data appear to be represented most closely by a truncated fBm model of log permeabilities.

H42B-1076 1330h POSTER

Investigation of effects of fractured porous media on pneumatic tests: An experimental study on mesoscale

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The understanding of the response of an investigated system to particular hydraulic measurements is an essential prerequisite especially for the characterization of highly heterogeneous or anisotropic systems, such as fractured porous aquifers. This understanding is fundamental for the identification of the governing flow and transport processes as well as for the calculation and prediction of flow and transport in such systems. However, most investigation techniques have limitations with respect to the spatial resolution needed to characterize such systems. In this presentation a study of high-resolution pneumatic tests is introduced that are conducted on a fully unsaturated fractured sandstone block (about 1 m^3 volume) based on the aquifer analogue approach. The principle of an aquifer-analogue is to obtain hydrogeological information on a generally inaccessible confined aquifer system based on direct information from outcrops. For the introduced pneumatic tests a constant pressure was injected over a vertical borehole in the center of the sandstone block and the transient pressure buildup was recorded at the sealed block surface. The analysis of the temporal and spatial evolution of the pressure buildup during the pneumatic tests shows that the direction and contribution of the pressure buildup is highly dependent on the spatial distribution and the characteristics of the fracture network as well as the position of the observation points with respect to highly conductive structures. In addition, the introduced test methods are suitable tools for the characterization of the heterogeneous nature of fractured porous media and for the interpretation of the effects of such highly heterogeneous systems on pneumatic tests.

H42B-1077 1330h POSTER

Measurement of Fracture Geometry for Accurate Computation of Hydraulic Conductivity

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Fluid flow in rock mass is controlled by geometry of fractures which is mainly characterized by roughness, aperture and orientation. Fracture roughness and aperture was observed by a new confocal laser scanning microscope (CLSM; Olympus OLS1100). The wavelength of laser is 488nm, and the laser scanning is managed by a light polarization method using two galvano-meter scanner mirrors. The system improves resolution in the light axis (namely z) direction because of the confocal optics. The sampling is managed in a spacing 2.5 μm along x and y directions. The highest measurement resolution of z direction is 0.05 μm, which is the more accurate than other methods. For the roughness measurements, core specimens of coarse and fine grained granites were provided. Measurements were performed along three scan lines on each fracture surface. The measured data were represented as 2-D and 3-D digital images showing detailed features of roughness. Spectral analyses by the fast Fourier transform (FFT) were performed to characterize on the roughness data quantitatively and to identify influential frequency of roughness. The FFT results showed that components of low frequencies were dominant in the fracture roughness. This study also verifies that spectral analysis is a good approach to understand complicate characteristics of fracture roughness. For the aperture measurements, digital images of the aperture were acquired under applying five stages of uniaxial normal stresses. This method can characterize the response of aperture directly using the same specimen. Results of measurements show that reduction values of aperture are different at each part due to rough geometry of fracture walls. Laboratory permeability tests were also conducted to evaluate changes of hydraulic conductivities related to aperture variation due to different stress levels. The results showed non-uniform reduction of hydraulic conductivity under increase of the normal stress and different values of mechanical aperture from hydraulic aperture due to rough geometry of fracture walls. The hydraulic conductivity did not follow the cubic law. It verifies that a parallel plate model is not suitable to express the hydraulic conductivity including local fracture geometry. The measurement results are used to compute hydraulic conductivity along a rock fracture based on the homogenization theory.

H42B-1078 1330h POSTER

Frequency-Dependent Fracture Specific Stiffness

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Monitoring the hydraulic properties of fractures remotely through their seismic signatures is an important goal for field hydrology. Empirical studies have shown that the hydraulic properties of a fracture are implicitly related to the fracture specific stiffness through the amount and distribution of contact area and apertures that arise from two rough surfaces in contact. Complicating this simple picture are seismic measurements that indicate frequency-dependent stiffness, i.e., a scale-dependent fracture stiffness where the scale is set by the wavelength. Thus relating the hydraulic properties of fractures to seismic measurements becomes a scale dependent problem. We have performed laboratory experiments to examine the phenomenon of frequency dependent fracture specific stiffness to aid in the assessment of the hydraulic properties of a fracture using seismic techniques. To this end, we have developed a photolithographic technique with which we can construct synthetic fractures of known fracture geometry with feature sizes controlled over several orders of magnitude. The synthetic fracture (and the control non-fractured samples) are made from acrylic cylinders that measure 15.0 cm in diameter by 7.7 cm in height. The diameter of the samples enables us to sample the acoustic properties of the fracture using acoustic lens over regions that range in scale from 10 mm to 60 mm. A confinement cell controls the normal stress on the fracture. Seismic measurements were made with broadband compressional-mode piezoelectric transducers enabling one-order of magnitude in frequency. We found that when the wavelength is smaller than the asperity size, a linear dependence of fracture specific stiffness on frequency occurs. In this geometric ray regime the asymptotic value of the transmission function provides a direct measure of the contact area of the fracture. On the other hand, when the asperity spacing is less than an eighth of a wavelength, the fracture behaves as a displacement discontinuity and exhibits a frequency-independent fracture specific stiffness. For intermediate asperity spacings, mixed behavior (that may include resonant scattering) was observed. By understanding how to interpret fracture specific stiffness as a function of frequency, we seek to develop a better interpretation of the hydraulic properties of fractures based on seismic measurements. Acknowledgments: The Authors acknowledge support of this research by the Geosciences Research Program, Office of Basic Energy Sciences, US Department of Energy. LJPN wishes to acknowledge Purdue University Faculty Scholar

H42B-1079 1330h POSTER

Magnetic Resonance Imaging of Dense and Light Non-Aqueous Phase Liquid in a Rock Fracture: Scaling Implications

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The migration of non-aqueous phase liquid (NAPL) through fractures is influenced by hydraulic gradient, fracture aperture, surface wettability, and buoyancy. These factors occur at different scales and have varying levels of importance depending upon the constituent fluids (e.g. dense versus light NAPL). Our investigations were conducted in the laboratory at the centimeter scale. Magnetic resonance imaging (MRI) was used to observe the flow of dense (FC-75) and light (dodecane) NAPLs through water-saturated dolomite fractures. MRI was capable of characterizing the fracture geometry and the fluid flow, but was limited by outlet flow conditions in the sample and acquisition times. This method permits observation of two-phase flow under natural wettability and matrix porosity, providing significant advantages over plastic or glass replicas. Animated color images allow dynamic fluid behavior to be observed. We observed dynamic two-phase behavior that was influenced by (1) buoyancy of the NAPL relative to the aqueous phase, (2) fracture aperture distribution, and (3) alteration of wettability by long-term presence of NAPL phase. These results raise issues with respect to both spatial and temporal scale of NAPL transport. Minor changes in fracture aperture and elevation appeared to strongly affect overall NAPL movement, implying that local spatial variations may lead to larger-scale variations in transport behavior. Pre-saturation of the fracture with NAPL also affected transport, implying that the rate at which a NAPL front migrates may influence the capillary resistance to fluid advance.

URL: http://www.geology.buffalo.edu/Research/hydro/MRI.htm

H42B-1080 1330h POSTER

Characterization of Fractured Zones With Multidirectional Electrical Methods

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In granitic bedrocks the network of joints and localized fractured zones are the only features with water storage and water conduction capabilities. Fractured zones can range from a few meters to tens of meters wide (in the case of important fault zones) or even hundreds of meters wide when major faults are concerned. These fractured zones imprint an anisotropic character to granitic massifs. Electrical apparent resistivity measurements show rock anisotropy dependence and have been used namely in the determination of fracture orientation. The field technique consists in performing apparent resistivity measurements along a number of azimuths around a common point and plotting the results in a polar diagram. Some recent approaches make use of the Wenner array (Busby, 2000; Watson and Barker, 2002). In late to post-tectonic Hercynian granites of central Portugal, fractures are the only broad anisotropic rock features. Field surveys were conducted in these areas using both the Schlumberger and the square arrays. Measurements performed with these arrays show a strong dependence on the orientation of subvertical structures. In theoretical macroanisotropic situations Schlumberger multidirectional measurements are in accordance with the anisotropy paradox, which means that apparent resistivity is higher along the strike direction of the structure and lower at right angles. Square array multidirectional measurements yield the opposite effect. Field surveys have shown that Schlumberger and square array results are dependent not only on the strike of the structure, but also on the width of the structure and on the position of the array centre. This has been confirmed by analytical and numerical modelling. Fractured zones may have a single character or they may correspond to limited, localized macroanisotropic situations with alternating domains of stronger/weaker fracturation intensity. Schlumberger multidirectional results may be misleading in differentiating the two situations, but square array results are clearly discriminating. When Schlumberger arrays are centred inside a single fractured zone, the longitudinal apparent resistivity is higher than the transverse apparent resistivity (for array spacings larger than the zone width). The results can be much the same in the case of localized macroanisotropic situations. On the other hand, and as long as array spacings do not exceed much the width of the fractured zone, multidirectional square array apparent resistivities for localized macroanisotropic fractured zones are consistent with the theoretical situation. This is not the case with single type structures. Moving the centre of the arrays may lead to completely different results. Thus, along with strike determination, it is possible to evaluate the width and the macroanisotropic versus single character of a fractured zone. Busby, J.P., 2000. The effectiveness of azimuthal apparent-resistivity measurements as a method for determining fracture strike orientations. Geophys. Prosp., 48, 677-695. Watson, K.A. and Barker, R.D.,2002. Use of the azimuthal offset Wenner technique to characterise a single dipping interface. Europ. J. Environm. Engin. Geophys., 7, 103-120

H42B-1081 1330h POSTER

Optimizing a Hydrogeologic Investigation of a Fractured Bedrock Aquifer With a Seismic Reflection Survey

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This project involves extensive investigation and focused remediation of chlorinated solvents in fractured bedrock and overlying alluvium in Northern California. Primary contaminants include 1,1,1-TCA, 1,1-DCE, and 1,1- DCA. The source area includes recoverable DNAPL, with a maximum accumulated thickness of 29 feet in a well, and dissolved concentrations in excess of 500 mg/L. The dissolved plume extends away from the source through an extensive fracture network to a depth of 450 feet. A bedrock high corresponds to the source area, with the absence of overlying sediments providing a migration pathway into the bedrock for DNAPL. The depth to bedrock and location/depth of fracture zones are highly variable across the site, with both factors significantly influencing drilling costs. The investigation involved drilling wells to depths up to 700 feet, borehole geophysics, a seismic reflection survey, and aquifer testing. The seismic reflection survey was performed to identify zones of increased fracturing, and to map the topography of the upper bedrock interface. To address the objectives of the survey, both p-wave and shear wave methods were tested in an effort to identify fracture orientation and density. A split-spread configuration with station spacing of five feet and 144 recording channels was used to collect the data for both methods. A microvibrator was used as the energy source, varying its orientation to generate p- and shear waves. Preliminary review of the test sections revealed abundant faulting, which would complicate p-/shear rotational analysis and is the likely cause of areas of increased fracturing. Based on the data quality and survey objectives, the remainder of the survey, totaling linear 6,570 feet, was collected with a p-wave source and receivers, using a 50 to 300 Hertz linear sweep. Unique aspects of the survey include a target depth of up to 1,000 feet and operational constraints associated with working in the aircraft movement area of a major maintenance facility. To address the challenges of abundant noise due to vehicular activity, both aircraft and ground equipment, and the need to quickly clear an area for aircraft movement, surficial adhesive was used to couple the geophones to the concrete surface. The seismic reflection survey identified en-echelon, southeast dipping normal faults and antithetic, southwest dipping reverse faults that are generally consistent with the orientation of features in the nearby San Andreas fault zone. The results have been used to create a hydrogeologic model of the site that includes three major fault blocks and predicted areas of increased fracturing, ground water flow, and contaminant transport. The seismic interpretation was developed by integrating extensive borehole data from the site related to lithology and fracture orientation, and is consistent with ground water flow and contaminant occurrence. The results demonstrate the effectiveness of seismic reflection surveys to support investigation and remediation in structurally complex areas.

H42B-1082 1330h POSTER

Statewide Characterization of Bedrock Fractures in Connecticut for Hydrogeologic Purposes

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The State of Connecticut relies on wells bored into fractured bedrock for most of its domestic drinking-water supplies, and there is concern about how best to characterize the source areas for these wells and protect them from contamination. Roughly three-quarters of the State is underlain by metamorphosed sedimentary and igneous rocks in the form of schists and gneisses; the remainder is underlain by clastic sedimentary rocks and basalt flows of the early Mesozoic Hartford and Pomperaug basins. Unconsolidated surficial deposits of variable thickness from the Pleistocene continental glaciation overlie most of the bedrock. Aquifer tests indicate that the surficial deposits constitute the most productive reservoir for ground water but that joint sets in bedrock constitute the most important pathways for ground-water flow to bedrock wells. Single near-vertical joint sets in bedrock may produce elliptical zones of contribution to wells having long axes that are parallel to the fracture trend. Bedrock geologic maps at 1:24,000 scale have been published for nearly all of the State, so lithologic units and formations have well-known distributions and foliation patterns, although fracture data are limited. If the fracturing habit of each formation is internally consistent with respect to foliation, however, then a limited number of observations of each formation should allow us to infer the approximate nature and orientations of the dominant bedrock fracture sets throughout the State from published geologic maps. We are currently analyzing representative outcrops of each of the major bedrock formations in the State to determine the relationship between the degree and nature of foliation and the orientation and intensity of associated fracture sets. Our preliminary observations indicate that the most fundamental difference is between layered and nonlayered rocks. Layered rocks, including schists, gneisses, and the early Mesozoic clastic sedimentary rocks, commonly have a dominant layer-parallel joint set, or parting, aligned along pre-existing rock fabric including foliation, compositional layering, or bedding. The degree of development of this parting can vary depending on such variables as lithology and the presence or absence of tectonic folds. In many of these rocks, a second set of near-vertical joints is developed orthogonal to the strike of foliation and parallel to dip direction. In both the layered and the nonlayered rock types, a third set of unroofing joints is developed subparallel to the land surface and decreases in intensity with depth; in areas with gently dipping foliation or layering, these unroofing joints develop along foliation parting. The early Mesozoic basalts, which are classified as nonlayered, have well-developed cooling joints. A hydrogeologic map of the State of Connecticut depicting these bedrock fracture characteristics and their dominant trends will be useful to State and local managers concerned with the protection of ground-water supplies.

H42B-1083 1330h POSTER

Characterizing Ground-Water Flow Paths in High-Altitude Fractured Rock Settings Impacted by Mining Activities

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The Rocky Mountains of the western USA have tens of thousands of abandoned, inactive and active precious-metal(gold,silver,copper)mine sites. Most of these sites occur in fractured rock hydrogeologic settings. Mining activities often resulted in mobilization and transport of associated heavy metals (zinc,cadmium,lead) which pose a significant threat to aquatic communities in mountain streams.Transport of heavy metals from mine related sources (waste

rock piles,tailings impoudments,underground workings, mine pits)can occur along numerous hydrological pathways including complex fracture controlled groundwater pathways. Since 1991, the United States Environmental Protection Agency, the Colorado Division of Minerals and Geology and the University of Colorado (INSTAAR)have been conducting applied hydrologic research at the Mary Murphy underground mine. The mine is in the Chalk Creek mining district which is located on the southwestern flanks of the Mount Princeton Batholith, a Tertiary age intrusive comprised primarily of quartz monzonite.The Mount Princeton batholith comprises a large portion of the southern part of the Collegiate Range west of Buena Vista in Chaffee County, CO. Chalk Creek and its 14 tributaries drain about 24,900 hectares of the eastern slopes of the Range including the mining district. Within the mining district, ground-water flow is controlled by the distribution, orientation and permeability of discontinuities within the bedrock. Important discontinuities include faults, joints and weathered zones. Local and intermediate flow systems are perturbed by extensive underground excavations associated with mining (adits, shafts, stopes, drifts, , etc.). During the past 12 years numerous hydrological investigations have been completed. The investigations have been focused on developing tools for characterizing ground-water flow and contaminant transport in the vicinity of hard-rock mines in fractured-rock settings. In addition, the results from these investigations have been used to develop a sound conceptual model of ground-water flow and transport of heavy metals from the mine workings to Chalk Creek. Ground-water tracing techniques (using organic, fluorescent dyes) have been successfully used to delineate ground-water flow paths. Surface-water tracing techniques have been used to acquire very accurate stream flow measuements and to identify ground-water inflow zones to streams. Stable (O18/D)and radioactive (tritium,sulphur 35) isotope anlysis of waters flowing into and out of underground workings have proved useful for conducting end member mixing analysis to determine which inflows and outflows are most significant with respect to metals loading. Hydrogeologic mapping, inverse geochemical modeling (using MINTEQAK code)and helium 3 analysis of ground water have also proven to useful tools. These tools, used in combination have provided multiple lines of evidence regarding the nature, timing and magnitude of ground-water inflow into underground mine workings and the distribution and types of hydrologic pathways that transport metals from the underground workings to Chalk Creek. This paper presents the results of some of the more important hydrologic investigations completed at the site and a conceptual model of ground-water flow in fractured rock settings that have been impacted by underground mining activites.

H42C MCC: Level 2 Thursday 1330h

Form, Process, and Climate in Landscape Evolution III Posters

Presiding: **K M Cuffey,** University of California, Berkeley**; M Strecker,** University of Potsdam

H42C-1084 1330h POSTER

Fluvial Responses to Holocene sea Level Variations Along the Macdonald River, New South Wales, Australia

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The Macdonald River drains the rugged eastern flanks of Australia's Great Dividing Range. It has a catchment area of 2000km^2, restricted alluvial lowlands confined by bedrock interfluves and flows into the Hawkesbury River, a larger estuarine valley. The Macdonald valley is presently tidal for 14km from the Hawkesbury. At about 8000 year before present (BP), rising sea level invaded the Macdonald Valley for at least 35km upstream of the Hawkesbury River. Rapid aggradation occurred between 8000 and 6000 years BP and a sand bed river was established in the Macdonald Valley, its mouth prograding rapidly towards the Hawkesbury. Little is known about the character of the sand bed river during the +2 meter sea level highstand occurring between 5000 and 4000 BP. However, from 3000 to 1500 BP when sea level was consistently at +1 to +1.5m, major floodplain and levee-like structures, now virtually inactive, were established. The bed is inferred to have been elevated above its present day level and consequently intersected mean sea level (MSL) downstream of its present location. This is consistent with reported sea levels at +1 to +2m above present levels for the New South Wales coast at this time. From 1500 years BP, local sea level fell rapidly to its present level. Aggradation of the levee crests ceased and sedimentation along the valley became restricted to aggradation of an inset floodplain, within the pre-1500 BP deposits. The channel contracted and the sandy river bed incised. An equivalent and synchronous change in sedimentation style is observed along the Tuross River 400km south of the Macdonald, lending support to sea level variations being the factor driving this change. By 1850 AD, the bed dipped below MSL about 10km upstream of its inferred position prior to 1500 years BP. A series of large floods between 1949 and 1955 eroded significant volumes of sandy sediment from the Holocene deposits. The channel bed widened from between 25 and 50m width to ∼100m along some 35km of river, mostly upstream of the tidal limit, and meanders were cut off. The bed aggraded by 3m and the point of intersection of the river bed with MSL shifted 7.6km down valley. The channel has contracted since these floods and is building a new floodplain below the post-1500 BP inset floodplain. The late Holocene fluvial history of the Macdonald River is one of rapid adjustment to falling base level. The formation of the major fluvial landforms of the valley coinciding with late Holocene sea level at +1 to +2m, followed by subsequent abandonment of this surface with associated bed incision and channel straightening, may be a common phenomenon along river systems of eastern Australia. If so it may explain the propensity for instability of rivers along the New South Wales coast.

H42C-1085 1330h POSTER

Heterogeneous Soil Morphology on the Taoyuan Terrace, Northwestern Taiwan

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In this study soil geomorphology is selected to work on the reciprocal relationship between the landscape evolution and soil genesis. Among geological studies on the Taoyuan area, it has remained a concern to apply lateritisation as an index on terrace correlation. To answer this question, the basic knowledge of laterite formation must be clearly understood. On the other hand, pedologists have long been interested in the genesis of laterite, especially those thick ones on the higher terraces. To give insights pedosequences must be built up to distinguish the influence of specific factor. Without assistance of geological data, this goal is hardly achieved. In spite of the obvious demand of interdisciplinary integration, it is short of dialogue between geology and pedology in Taiwan until the last decade when the first soil chronosequence was established in this area. However, the tacit assumption that soils on one geomorphic surface were homogeneous has never been carefully examined. A later study on soil toposequence in the coastal area of Taoyuan terraces soon discovered that soils on one surface were heterogeneous both morphologically and chemically. This finding was explained as the influence of the seasonal undulation of groundwater table. To understand whether the upland soils on geomorphic surfaces are also heterogeneously developed, the soil morphology on the Taoyuan Terrace is selected as target being carefully studied. The relationships among the soil morphology, the undulation of groundwater table (GWT), and the processes of soil formation are established by field investigation and previously reported datasets. Based on recompilation of the published soil maps, the soil series in study area can be divided into eight groups. To compare the soil morphology and assess the reliability of the soil maps, fifteen hand cores are drilled in the field. The datasets of engineering boreholes are also collected to assist the explanation on the spatial variation of soil morphology. We discovered that the soil morphology systematically changes from the terrace edge to the interior, showing a toposequence of red soil, orange soil, yellow soil, mottled soil, and gley soil. Based on the profile reconstructed by the engineering borehole data, the GWT is inconsistent with the subsurface lithology but controlled by the terrace geomorphology. Since soils on the terrace edge are usually developed in well-drained condition for lateritisation, we consequently suggest that they are the best prospective soils for terrace correlation.

H42C-1086 1330h POSTER

Cosmogenic ^{36}Cl dating of the all time limit of glaciation, Del Bonita upland Alberta/Montana border and insights into changing extents and ice-flow patterns in successive continental ice sheets

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The Del Bonita upland is a nearly horizontal, unglaciated interfluve along the Alberta, Canada/Montana, USA border (centered on 49°N and 113°W). It separates the basins of the Milk and St. Mary rivers. It is capped by the distinctive maroon Flaxville gravel of late Tertiary age. It is bordered to the west, north and east by a belt of moraine and glaciofluvial channels. The moraine represents the local limit of glaciation. It contains clasts derived from the Canadian Shield, Interior Plains and Rocky Mountains. Whether it is Late Wisconsinan in age or older has been disputed, with proponents on both sides of the international border arguing at various times for Wisconsinan and pre-Wisconsinan ages. Ages of emplacement were determined for eight large glacial erratics (2-30 m^3) using the cosmogenic ^{36}Cl exposure dating method. These included carbonate and quartzite erratics from the Rocky Mountains and plutonic and metamorphic erratics from the Canadian Shield. Erratics were situated between 112° 02' W to 112° 51' W and 49° 1'N to 49° 6'N. Zero erosion ages are, in increasing age (in years): 11,500±420,14,040±510, 15,500±630,19,600±780, 20,800±780, 21,050±670, 22,100±800, 30,300±1160. All, save the last age, indicate emplacement during the Late Wisconsinan Stage. The ca. 30 ka age was determined on one of the quartzite 'Foothills erratics'. It indicates some pre-exposure to cosmic radiation. That is consistent with the rockfall-on-mountain-glacier origin of the Foothills erratics. The mixture of Rocky Mountain and Canadian Shield erratics in this area is consistent with southeast flow of coalescent Laurentide Ice Sheet and Rocky Mountain piedmont glaciers along the eastern margin of the Rocky Mountain Foothills during the climax of the Late Wisconsinan Stage. The clearly Late Wisconsinan age of the erratics further supports the view that the Laurentide Ice Sheet of the LGM was the most extensive of all Pleistocene ice sheets in southwestern Alberta. Furthermore, when combined with the regional distribution of tills predating the Late Wisconsinan in southeastern Alberta, southwestern Saskatchewan and northern Montana, the southeastern flow pattern in the southwestern margin of the Laurentide Ice Sheet during LGM is shown to be unique: previous ice sheets had north to south or northeast to southwest flow patterns in the same region.

H42C-1087 1330h POSTER

Landscape Evolution and Carbon Accumulation: Uniformitarianism Revisited

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What is the role of hillslope transport in long-term carbon accumulation in soils? How do parent material, climate, and landform interact to produce the landscapes we observe today and to what extent can we use present day conditions to infer the dominant processes of the past? We use the CREEP [Rosenbloom, N.A. et al., 2001] process-response model to ask these questions, exploring the time-evolution of landscape form, soil distribution, and carbon accumulation in an undisturbed prairie site in western Iowa [Harden, J.W. et al., 2002]. The CREEP model simulates differential transport of soil particles, blanket deposition of atmospheric 10Be with eolian dust, and passive advection of soil carbon and 10Be, enabling the preferential enrichment and