By improving our ability to predict the likelihood of meander cut-off, resource managers will be better able to balance habitat restoration with future demands for flood control and water supply

H52A-1182 1330h POSTER

When did the Nile Begin?: Remote Sensing Analysis of Paleo-drainages Near Kom Ombo, Upper Egypt

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The geomorphology of Southern Egypt is dominated by numerous dry riverbeds termed wadis, many of which formed before the modern transcontinental Nile began flowing north. Many of these are relict channels that formed part of an older (Late Miocene) drainage system that flowed westward from the Red Sea Hills and only drained the area of modern Egypt. This older drainage was disrupted and reworked by the modern north-flowing Nile in the mid- to late Pleistocene but is well-preserved in the hyper-arid Sahara and can be studied using remote sensing images. Various optical and radar data along with digital elevation models (DEM) extracted from Shuttle Radar Topography Mission (SRTM) data were used in combination to map and establish the chronological order of different drainage systems and to study the drainage reorganization in southern Egypt. Remote sensing analysis revealed stream capture events in the region around the city of Kom Ombo, on the northern flank of the Nubian Swell. The images show that the older, west-flowing Wadi Abu Suberia has been captured by the north-flowing wadis of Ellawi and Kharit. These streams may owe their aggressive headwater erosion to development of the east-west trending Kom Ombo graben. Analysis of SRTM DEMs shows that the drainages in southern Egypt are dominantly oriented east-west and flow into the Nile. SIR-C radar images reveal that Wadi Kubbaniya, located immediately west and across the Nile from Wadi Abu Suberia and now draining east, was once the downstream section and Wadi Abu Suberia the upstream section of the same river. This W-to NW- flowing drainage has been referred to as the Kubbaniya Nile. The Kubbaniya Nile can be traced on the SIR-C images as far north as the southernmost extent of the Gallaba Gravel Plain where it is lost under Quaternary gravel and sand deposits. Analysis of the present-day drainage using SRTM DEMs suggests that a subtle channel runs north through the Gallaba Plain and joins the Nile channel further upstream. This study indicates important neotectonic movements of the E-W trending Nubian Swell centered on the Egypt-Sudan border during Plio-Pleistocene times caused a massive reorganization of drainages in southern Egypt and allowed the Nile to flow north across the swell. These observations are also important for identifying and exploiting groundwater resources in the region. Ancient paleochannels of the Kubbaniya Nile and other components of the pre-Nile drainage system are promising locations to explore for groundwater. Establishing a chronology for when the east-west trending drainages were disrupted can be used to constrain when the modern, transcontinental Nile began to flow across the Nubian Swell.

H52B MCC: 3024 Friday 1340h

The Influence of Scale on Characterization of Fractured-Rock Aquifers II

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

H52B-01 1340h INVITED

Strategies for Dealing with Scaling Issues in Data Acquisition, Characterization and Numerical Modeling of Fractured Aquifers.

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Fractures and their flow and transport properties scale significantly, in different ways and at different rates. Thus, the importance of a factor at one scale may differ significantly at another scale. This implies that characterization, data acquisition, and modeling of fractured aquifers should be carried out at the scale of the process of interest; unfortunately, this is rarely possible. Often data for fractured aquifers are acquired at several scales over different orders of magnitude, and none of them are at the scale of the process of interest. These scaling issues often make it challenging to develop a workflow of data acquisition, characterization and modeling to achieve useful flow and transport predictions. This talk will illustrate, through presentation of field case histories, factors that have proven to be important in a variety of scales, rock types and geologic settings, and strategies for developing project workflows that focus on these factors. First, the factors that govern the connectivity of the fracture network, and control the spatial variations in this connectivity, at the scale of the process heterogeneity, are often the most important factors to accurately characterize, while other factors play a far less important role. To identify what these factors may be, it is useful to distinguish between three scales: the process scale, the heterogeneity scale, and the data scale(s). The process scale, the scale at which a change in pressure, flow or transport is expected to take place in the aquifer is important for the ultimate project results and a function of time as well; the heterogeneity scale, the scale below which spatial heterogeneity in material properties do not impact the predicted results is critical for mathematical or numerical characterization and not a function of time; and the data scales, which are the scales over which the data reflect fractured aquifer characteristics and are essential for upscaling fracture or aquifer properties to the heterogeneity scale, and may or may not be a function of time. Secondly, it is highly beneficial to collect analogous or complementary data on fracture geometry and network flow response at multiple scales. Third, it is often best to have a lot of "soft" data rather than a little "hard" data. Fourth, given the high uncertainty of any fractured aquifer characterization at virtually any scale of interest, it is exceedingly useful to have a means of validating the aquifer characterization. Methods for validating a model of a fractured aquifer to assess whether it is adequate for the purpose intended will also be discussed.

URL: http://fracman.golder.com

H52B-02 1355h

Fanay-Augères Revisited: Stochastic Continuum Modeling of Flow and Transport in a Crystalline Rock Mass

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A stochastic discrete-fracture model was used by Cacas et al.(1990a-b) to interpret flow measurements and transport experiments in a fractured crystalline rock mass at Fanay-Augères. They considered continuum models to be incapable of properly interpreting small-scale measurements or tracer tests in fractured systems, which in their view require three-dimensional modeling of numerous discrete channels; in their opinion, continuum modeling applies only to average flow on a relatively large scale. Cacas et al. considered their discrete fracture model to have been validated by its demonstrated ability to reproduce selected experimental results. In this paper flow and transport at Fanay-Augères are modeled by viewing the fractured rock as a stochastic continuum in a manner originally proposed by Neuman (1987). The stochastic continuum approach obviates the need for detailed information about fracture geometry or assumptions about how individual fractures control flow and transport. All it requires is the delineation of a few dominant features, which can be embedded into the stochastic continuum model as heterogeneous porous slabs. Though a fault zone has been identified at the Fanay-Augères experimental site, it has been modeled neither by Cacas et al. nor in this paper. In fact, in this paper a larger selection of experimental results than those considered by Cacas et al. are reproduced merely by modeling the rock as a statistically homogeneous continuum in two dimensions. These results demonstrate that a continuum approach may be well suited for the analysis of flow and transport in fractured rock. This does not constitute a validation of the continuum approach, just as the results of Cacas et al. fall short of validating the discrete fracture approach. Instead, the two sets of results illustrate jointly the well-established principle that an open system, especially one as complex as fractured hydrogeologic environments tend to be, cannot be described uniquely on the basis of sparse data and need not be described in great detail to capture its salient behavior by a model.

H52B-03 1410h

Stochastic models of fracture networks based on the broad-range fracture length distribution and the long-range fracture correlations.

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The fact that fractures exist at all scales, and that fracture distributions do not exhibit any obvious length scales except the fracture domain size, poses the question of the relevant model for describing fluid flow in such highly heterogeneous system. Is it possible to use equivalent porous media theory; is it sufficient to consider the major fractures? We tackle these questions by setting up a decision framework for the a priori choice of the modelling framework. Our approach relies on a synthetic fracture-network model based on the geological characteristics of fractures. The first study concerns the connectivity of the fracture network, because connectivity is a prerequisite to any hydraulic property. We then handle the classical hydraulic properties like the equivalent permeability, the flow structure and the well test responses. Non-intuitive results show up. Connectivity is scale-dependent as long as the variance of the fracture length distribution is undefined. It is generally possible to define a homogenization scale mainly function of the fracture density, the fracture length and aperture distributions. This homogenization scale can however be very large splitting the scale range in two parts where fracture networks have different hydraulic behaviours and variabilities. Below the homogenization scale, we have looked for the relevant well-test interpretation framework.

H52B-04 1425h

Field Evidence for Abundant Fracture Connectivity in Sedimentary Rocks

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The behavior of contaminants in fractured rock is strongly dependent on the degree of fracture connection in the fracture network. Although many fracture connectivity studies have been done by cross-hole testing, little is known about fracture connectivity at the scale of contaminant plumes. Field evidence for abundant fracture connectivity obtained from chemical analysis of rock core samples is presented from sites contaminated with chlorinated solvents, such as trichloroethene (TCE), in sedimentary rocks. These analyses determine the contaminant mass in the low-permeability rock matrix. This mass occurs in the matrix due to diffusion-driven mass transfer from the fractures, where all or nearly all the advective transport occurs. The contaminant mass in the rock matrix blocks between fractures represents an imprint of the contaminant migration pattern formed over many years of plume evolution. Vertical core holes were drilled through zones of chlorinated solvent contamination in the depth range of 10 to 300 m bgs at several sites. The chemical analyses were done at close spacing along each core to provide detailed information about concentration versus depth. Also, hydraulic head and other types of borehole information were determined in some of the core holes. The concentration profiles show that the plumes have contaminant mass originating from contaminant transport in numerous fractures rather than just a few fractures with apparent, large, local aperture indicated by borehole hydraulic and geophysical tests. The abundant contaminant migration pathways perceived from the rock core analyses are consistent with simulations of plume behavior using a 2-D model (Fractran) with statistically generated fracture networks of othrogonal fractures with variable apertures and lengths and strong connectivity. Without the constraints on the simulations imposed by the rock core chemical data, the perceptions of the nature of contaminant plumes would be much different.

H52B-05 1440h

Representing Regional-Scale Fracturing in Groundwater Studies: Field Data to Conceptual Model

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Determining the sustainability of regional aquifers requires understanding of the controlling geologic architecture, hydrologic conditions, and water use information. In fractured aquifers consideration must be given to the nature of the fracture network at all scales, which creates a hierarchy of secondary permeability. Site-scale investigations typically provide detailed data that, while important at a local scale, may not fully represent the heterogeneity imparted by large-scale structural elements such as fracture zones, faults, and folds. Groundwater resources on the southern Gulf Islands in southwestern British Columbia are derived from fractured sedimentary bedrock aquifers. The islands consist of a thick sequence of alternating sandstone- and mudstone-dominant formations, which have been folded and extensively fractured during several tectonic events. A fracture-mapping program was undertaken to identify and quantify fracture distribution around faults and folds and to qualitatively analyze lithology-related fracture variation. Results indicate that tectonically-related fracturing is heterogeneously distributed and that fractures concentrations are highest around individual fault and joint zones. Fracturing is pervasive in the mudstone-dominant formations and fine-grained interbeds within sandstone-dominant formations, and therefore, the mudstone-dominant formations may act as the primary aquifers on the islands. In contrast, the sandstone-dominant formations have low primary porosity, and unless fractured, are considered relatively impermeable. Pumping test data show hydraulic responses to be strongly influenced by linear flow, particularly in wells situated adjacent to or close by fracture zones and faults, which themselves could be identified by surface geophysical surveys, geologic investigations, and on air photos. At the site scale, borehole flow meter experiments, examined in conjunction both with borehole video logs and the standard suite of borehole geophysical logs, indicate that fluid flow (both fresh and saline) is primarily through fine-grained interbeds or through discrete narrow vertical fractures in the sandstones. Major ion chemistry indicates that cation exchange, whereby calcium exchanges for sodium, is dominant throughout the islands, providing further evidence that the groundwater flows predominantly through fine-grained units. A conceptual model is presented which attempts to integrate the observed scale-related fracturing, and which may be applicable for representing regional-scale fracturing for groundwater studies.

H52B-06 1455h

Characterisation of Scale Effects in a Karst Aquifer at Local and Catchment Scale

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Hydraulic parameters of karstified limestone aquifers are usually only available for individual boreholes not necessarily representative for the prediction of groundwater discharge and the assessment of water resources at catchment scale. There is a generally high density of wells in valleys, i.e. in an environment, where an increased degree in karstification is observed due to flow convergence. As a result of these circumstances, the values obtained cannot be directly used as input parameters for a regional model. The selection of the appropriate hydraulic parameters requires a careful analysis of the scale, the values are applicable at and the allocation of the parameters to the respective part of the system, characterised by an extreme contrast in hydraulic conductivity and storage. Karst aquifers consist of highly conductive, low storage transit (conduits) and a low conductivity, high storage flow (fissured) system. Slug tests, injection, packer and pumping tests were used to obtain parameter estimates of the low and intermediate range of the hydraulic conductivity spectrum, which reflect the response of the aquifer at local scale. Regional parameters could be evaluated using several approaches. Applying Darcy and with the information on discharge and head gradient, spatial variation of average transmissivities can be calculated, representing the slow regional system. Taking the concept of Rorabaugh (1964) for flow from bank storage, regional parameters were computed, using the recession coefficients for the fast and slow flow system. The necessary storage coefficients for the fast system could be derived from tracer tests and for the slow system from the quotient between the discharged volume of water and the drained rock volume. It could be observed that hydraulic conductivities generally increase with the scale of investigation which results from the added contribution to volume averaged hydraulic conductivity of highly conductive features at the respective scale.

H52B-07 1510h

Characterization of the Different Solute Transport Behaviours in a Fissured and Fractured Chalk by Multi-Tracer Tests and Modelling

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Thirty-five injections of tracers, distributed between 11 sites, were performed under groundwater convergent flow conditions to pumping wells or towards a collecting gallery in a regional Cretaceous chalk aquifer near Liege (Belgium). It was known that the double porosity effect could have a strong influence on the transport behaviour in such a micro-fissured, fissured, fractured and even locally slightly karstified aquifer. The high chalk hydraulic conductivity values are due to fissure flow systems using preferential dissolution along discontinuities and zones of weakness, such as bedding phases and tectonic fractures. In the chalk matrix, however, the hydraulic conductivity value is much lower although the total porosity can be very high. A morphostructural study associated to geophysical prospection results provided information on the main fracturation axis where mostly advective transport was expected. Results of multi-tracer tests, interpretation and modelling in each of these particular sites have allowed to characterize three solute transport behaviours in the chalk aquifer, illustrated by three kinds of typical breakthrough curves. (1) Transport with a dominant advective component: narrow and symmetrical observed breakthrough curves showing maximum velocity of tracer included between 10 and 110 mh-1 (for distances between 5 and 130 m and for fluorescent dyes as well as ionic tracers). The concentration tailing is also rapid as nearly no retardation (adsorption/desorption) and nearly no diffusion into the porous chalk matrix are observed. Groundwater flow occurs mainly in the preferential fissured (or slightly karstified) channels which were most often previously detected by morphostructural analysis and shallow geoelectrical prospection. (2) Transport with advective and dispersive components: more spread-out breakthrough curves are observed with maximum velocity of the tracer from 1 to 10 mh-1. Retardation effects can affect the breakthrough curves creating a non-symmetrical trend. This type of transport behaviour occurs in micro-fissured/ fractured zones of the chalk matrix. (3) Transport with a dominant dispersive component, advection remains but can be considered slow in comparison with (1) and (2): the breakthrough curve is flat and the maximum recorded velocities are lower than 1 mh-1. Retardation and immobile water effects induced a low decrease of the concentration after the peak. This transport behaviour can be considered as typical for the chalk matrix.

H52B-08 1525h INVITED

Influence of Fracture Trends on Ground Water Flow Directions in Metamorphic Bedrock Aquifers, Eastern Massachusetts

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Geologic mapping and aquifer tests at three high-yield municipal water systems in glaciated fractured metamorphic bedrock in eastern Massachusetts indicate distinct structural controls on ground water flow directions in the bedrock at each site. The West Newbury well sites (yield = 251 gpm) are located in biotite-grade phyllite. Possible pathways for ground water flow include sub-horizontal sheeting fractures along a layer-parallel foliation, steeply dipping cleavage with quartz-calcite veins and associated vugs, and steep fractures. Borehole geophysical logs indicate sub-horizontal water bearing zones within 100 feet of the land surface and steeply dipping water bearing zones to a depth of 200 feet. Drawdown during aquifer tests shows an elliptical northeast trend that correlates with the strike of the steep cleavage and a principal fracture trend. Numerical modeling suggests, however, that the northeast trend is best simulated by a laterally extensive sub-horizontal transmissive zone rather than aquifer anisotropy along steeply dipping fractures. During the tests, ground water in the bedrock shows a connection to ground water in the overburden and to surface water, presumably along steep fractures. The Maynard well site (780 gpm) is located in sillimanite-grade schist. Secondary porosity in the rock is the result of intense fracturing between the east-northeast trending Spencer Brook and Assabet River faults. Fractures near the well site have sulfide mineralization and show complex orientation trends. Borehole geophysical logs show wide variations in water-bearing fracture trends. Drawdown during aquifer tests shows an elongate east-west trend that potentially correlates with a sulfide-mineralized principal fracture trend. Numerical modeling with an east-west transmissive zone adequately simulates aquifer properties. During the tests, ground water in the bedrock shows a direct connection to ground water in the overburden, presumably along steep fractures. The Paxton well site (148 gpm) is located in sillimanite-grade schist and granofels. Here, rocks contain a pervasive, gently dipping foliation that exhibits excellent sheeting but limited vertical fracturing. Drawdown during aquifer tests occurs parallel to the trend of a deep water-bearing zone along the foliation. Two contrasting numerical models, a 2 layer model and a gently dipping 5 layer model, adequately simulated aquifer properties, with the latter providing better approximation of heads in observation wells. During the tests, ground water in shallow bedrock wells shows direct connection to water in the overburden and to surface water, but deep bedrock wells show limited connection. These findings illustrate the importance of pre-existing fabrics in foliated metamorphic bedrock to flow dynamics in fractured rock aquifers. Where foliation dips gently, fracturing is enhanced during isostatic unloading. Where foliation dips steeply, subsequent fracturing may create vertical pathways and potential along-strike directional drawdown. The highest yield well sites exhibit vertical pathways between deep ground water and shallow ground water in the overburden, locally along steeply dipping fractures parallel to foliation or in high-angle fault zones. In all cases, these findings support geologically acceptable watershed-scale ground water flow models in glaciated metamorphic bedrock aquifers.

URL: http://geology.er.usgs.gov/eespteam/brass/ma.html

H52C MCC: 3020 Friday 1340h

Nitrogen Sources and Cycling in Aquatic Systems III *(joint with B, OS)*

Presiding: **C Kendall,** U.S. Geological Survey**; R B Alexander,** U.S. Geological Survey

H52C-01 1345h INVITED

Isotopic Study of the Sources and Cycling of Nitrate and Algae Associated with Low Dissolved Oxygen Concentrations in the San Joaquin River, California

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Fish migration through the deep-water channel in the San Joaquin River near the city of Stockton is inhibited by periodic low oxygen concentrations during the summer and fall. The cause of this condition appears to be decomposition of algae with attendant oxygen consumption. Development of a successful remediation plan requires knowledge of the source areas of algal production, and of the nutrient sources upon which they thrive. To identify the sources of nutrients and algae, samples of seston and water were collected monthly at several river sites during the summers of 2000 and 2001, and along a transect of the entire river-delta-bay system in 2002. These samples were analyzed for major chemical constituents, nitrate d15N, d18O, seston d15N, d13C, and water d18O. Chlorophyll-a and C:N ratios indicate that the seston consisted largely of plankton. The d15N of the plankton usually tracked the d15N of the associated nitrate with about a 5 per mil fractionation in areas of high nitrate concentrations