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

and little or no fractionation in areas of low concentration, as expected for algae using nitrate as a primary nutrient. The d15N of the nitrate was generally between +10 and +15 per mil, which could indicate either denitrification or a nitrate source of animal waste and/or sewage. A multi-isotope approach suggested that the high d15N values were only rarely caused by denitrification, implicating animal waste/sewage as a significant source of nitrate.

H52C-02 1405h

Fate and Transport of Nitrate in an Alpine Catchment Based on Dual-Isotopic and End-Member Mixing Analysis

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Attempts to understand nitrate loss from small watersheds have been the focus of much research. In general, these results have shown that understanding how sources and flowpaths of nitrate-rich waters change with time necessitates a combination of isotopic, chemical, and hydrometric data. New and evolving tools to understand the fate and transport of nitrate include dual-isotopic analysis of both the nitrogen and oxygen atoms in the nitrate molecule, and end-member mixing analysis (EMMA). However, to-date no one has combined these two approaches. Here we present results from both dual-isotope analysis and EMMA to understand the fate and transport of nitrate in the high-elevation Green Lakes watershed of the Colorado Front Range. Thirty-five samples were collected and analyzed for the dual isotopes of nitrate, and showed that values of $\delta^{18}O$ in atmospheric deposition had considerable overlap with values in stream waters. There was a strong counterclockwise pattern of hysteresis when $\delta^{18}O$ is plotted versus stream discharge, consistent with a mixture of atmospheric and microbial nitrate sources on the rising limb of the hydrograph, then mostly a microbial source on the recession limb of the hydrograph. A chemograph of nitrate sources developed using EMMA shows atmospheric deposition the predominant source at the initiation of snowmelt runoff, with soil water and talus becoming the dominant source at peak runoff, and talus-water and baseflow both important on the recession limb of the hydrograph. We were able to qualitatively evaluate the EMMA results by developing a 2-component nitrate source model using the dual-isotope values. The dual-isotope mixing model agreed well with the atmospheric and subsurface sources of nitrate identified using EMMA.

H52C-03 1420h

Nitrogen isotopes as indicators of streamflow generation processes in a headwater forested catchment: Focusing on atmospheric NO_3^- contribution using $\delta^{18}O$ signature

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To quantify the contributions of atmospheric nitrogen deposition and mechanisms of nitrate discharge to stream, nitrogen chemistry and isotopes ($\delta^{15}N$ and $\delta^{18}O$ of NO_3^-) of streamwater were studied as part of an ongoing study of nutrient dynamics at the Sleepers River Research Watershed in Vermont, USA. We employed novel analytical procedures for high throughput of NO_3^- isotopic measurements. The denitrifier method for measurement of $\delta^{15}N$ and $\delta^{18}O$ of NO_3^- requires a smaller volume of water samples than previously applied methods, thus it enables fine resolution analysis of isotopes for stream, well, and soil water samples. Samples were collected throughout the spring 2003 snowmelt. Snowmelt runoff was initiated in the middle of March and peaked at the end of the month. Then, the runoff rate decreased gradually through April and May, and responded to several storm events. The highest concentration of NO_3^- in the stream was observed at the beginning of snowmelt (the end of March), and thereafter it declined continuously. The temporal course of NO_3^- discharge process during snowmelt period was divided into four phases based on changes in the relationship between runoff rate and NO_3^- concentration. During the earliest phase (very low runoff rate and highest NO_3^- concentration) isotope signatures, especially $\delta^{18}O$ of NO_3^-, indicated higher contribution of the atmospherically derived NO_3^-, meaning that the direct discharge from snow pack was the dominant source of NO_3^- to the stream. This also suggested that streamwater consisted only of a small volume of groundwater discharge and melt water of the in-stream snow pack and/or stream-covering snow pack. The $\delta^{15}N$ and $\delta^{18}O$ isotope compositions of NO_3^- during the middle phase of snowmelt indicated that the contribution of the NO_3^- generated by nitrifiers in soil increased gradually accompanied with increase of groundwater level. These detailed descriptions in the changes of NO_3^- discharge during snowmelt events were enabled by the dual-isotope analysis of NO_3^-. The fine resolution isotope analysis of NO_3^- in our experiment can provide advantages for elucidating the discharge mechanisms of nitrogen in forested watersheds with high atmospheric nitrogen depositions.

H52C-04 1435h

What can $\Delta^{15}N$ and $\Delta^{18}O$ isotopes tell us about sources, transport, and fate of nitrate in the Mississippi River Basin?

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Water and nutrients, primarily nitrate (NO_3) in Mississippi River discharge, affect the size and severity of the Gulf of Mexico hypoxic (depleted dissolved oxygen) zone. Approximately 120 water samples were collected from 16 sites on small streams and 6 sites on large rivers within the Mississippi River Basin in 1997-98 to see if NO_3 sources and transformations can be identified using the stable isotopic ratios $\Delta^{15}N$ and $\Delta^{18}O$. Results from Lagrangian sampling at the large river sites indicate that nitrate mass decreases slightly, while $\Delta^{15}N$ and $\Delta^{18}O$ isotope ratios are unchanged in the 1500 river kilometers between the Upper Mississippi-Ohio River confluence and the Gulf of Mexico. Results also show that $\Delta^{15}N$ and $\Delta^{18}O$ values from small streams draining lands dominated by row crops or livestock tended to be distinct from those dominated by urban or undeveloped land. Mean $\Delta^{15}N$ values at the 16 sites on small streams were most strongly correlated (Pearson's r) with manure production rate (0.64), percent residential land use (-0.45), and urea use rate (0.43). The best multiple linear regression (MLR) model for mean $\Delta^{15}N$ values (r2=0.69) used manure production rate and ammonium nitrate use rate as explanatory variables. Mean $\Delta^{18}O$ values were most strongly correlated with percent wetlands (0.72), mean NO_3 concentration (-0.71), and percent residential land use (0.58). The best MLR model for mean $\Delta^{18}O$ values (r^2=0.85) used percent residential land use, percent wetlands, and ammonium nitrate use rate as explanatory variables. Mean NO_3 concentrations were most strongly correlated with percent row-crops land use (0.84), nitrogen-fertilizer use rate (0.74), and hog-manure production rate (0.66). The best MLR model for mean NO_3 concentration (r^2=0.85) used percent row-crops land use and percent grain-crops land use as explanatory variables. MLR equations developed from the 16 smaller streams were used to predict mean $\Delta^{15}N$ and $\Delta^{18}O$ values and NO_3 concentrations at the 6 large river sites. The predicted mean $\Delta^{15}N$ and $\Delta^{18}O$ values tended to be less (lighter) than the measured values, and the predicted mean NO_3 concentrations were greater than the measured values. These results indicate that a significant portion of the nitrate that leaves relatively small Mississippi Basin watersheds is denitrified or assimilated during transport to the Mississippi River and its major tributaries.

H52C-05 1450h

Investigating Natural Attenuation and Sources of Nitrate in Groundwater Using Stable Isotopes and Other Techniques

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We conducted an interdisciplinary study to characterize the distribution and fate of nitrate in groundwater at Lawrence Livermore National Laboratory (LLNL) Site 300, a high-explosives test facility in the semi-arid Altamont Hills of California. Site 300 groundwater contains nitrate concentrations ranging from <0.5 to >200 mg NO_3^-/L. Several lines of evidence strongly suggest that denitrification is naturally attenuating nitrate in the confined, oxygen-depleted region of the bedrock aquifer under study ($Tnbs_2$): (a) both nitrate and dissolved oxygen (DO) concentrations in groundwater decrease dramatically as groundwater flows from unconfined to confined aquifer conditions, (b) stable isotope signatures (i.e., $\delta^{15}N$ and $\delta^{18}O$) of groundwater nitrate indicate a trend of isotopic enrichment that is characteristic of denitrification, and (c) dissolved nitrogen gas, the product of denitrification, was highly elevated in nitrate-depleted groundwater in the confined region of the $Tnbs_2$ aquifer, as determined by membrane-inlet mass spectrometry. Long-term nitrate concentrations were relatively high and constant in recharge-area monitoring wells and relatively low and constant in the downgradient confined region, suggesting a balance between rates of nitrate loading and removal by denitrification. Chemolithoautotrophic denitrification with pyrite as the electron donor is plausible in the $Tnbs_2$ aquifer, based on the low dissolved organic carbon concentrations that could not support heterotrophic denitrification, the common occurrence of disseminated pyrite in the aquifer, and the trend of increasing sulfate as groundwater flows from aerobic, unconfined to anoxic, confined aquifer conditions. Nitrate sources were investigated by experimentally determining the $\delta^{15}N$ and $\delta^{18}O$ signatures of nitrate from three potential anthropogenic sources of nitrate at Site 300: barium nitrate (mock explosive), nitric acid, and photolysis of the explosive RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine). The isotopic signatures of these potential nitrate sources were markedly different than those of nitrate in $Tnbs_2$ groundwater samples, suggesting that other sources must contribute significantly to the nitrate loading at Site 300.

H52C-06 1505h

New Stable Isotopic Techniques of Nitrate Applied to Investigation of Estuarine Nitrate Sources in Elkhorn Slough, CA

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Elkhorn Slough is a tidally flushed estuary with exceptionally high amounts of N loading within the watershed. The main sources of N are thought to be in the form of nitrate from surface water runoff, agricultural fields, dairy farms, and urban runoff. More poorly quantified sources of nitrate may also include significant groundwater discharge as well as tidal inputs from Monterey Bay. Traditional studies, involving natural abundance stable isotopes within the N cycle, have been limited to $\delta^{15}N$ and thus to a 'one-dimensional' perspective on N cycling. The use of a multiple isotope ($\delta^{15}N$ and $\delta^{18}O$) model allows disentanglement of superimposed transformation processes. Furthermore, a dual isotope approach permits a more discrete characterization of these sources, with the goal of estimating their roles in the N budget of Elkhorn Slough. The isotopic values of nitrate from transects, conducted in the main channel of the slough during both flood and ebb tides, suggest mixing of a marine end member ($\delta^{15}N = +11.6^o/_{oo}$; $\delta^{18}O = +10^o/_{oo}$) with several other nitrate sources having discernable isotopic compositions. The Moss Landing Harbor, near the mouth of Elkhorn Slough, has very high nitrate concentrations (>200uM) and is likely a significant source of nitrate to the slough

($\delta^{15}N = +15.4^{o}/_{oo}$; $\delta^{18}O = +9.9^{o}/_{oo}$). With each rising tide, there is a distinct tidal bore from Monterey Bay also delivering nitrate (approx. 30uM) of a unique nitrate isotopic composition ($\delta^{15}N = +5.3^{o}/_{oo}$; $\delta^{18}O = +9.9^{o}/_{oo}$). During certain sample collections, nitrate from the head of the slough, with an isotopic composition of $+5.2^{o}/_{oo}$ ($\delta^{15}N$) and $+22.0^{o}/_{oo}$ ($\delta^{18}O$), is suggestive of nitrification ($\delta^{15}N = +5.2^{o}/_{oo}$; $\delta^{18}O = +22.3^{o}/_{oo}$). Each of these estuarine members reflects both the composition of the original source of nitrate within the sub-watershed as well as the degree of transformation of these sources. The $\delta^{18}O$ value for marine nitrate in this system is markedly higher than has been reported in open ocean systems - implying a coupling of the coastal and estuarine system. These initial data suggest cycling of nitrate within the main channel may be non-conservative.

H52C-07 1520h

Reactive Transport of Nitrate in Northern California Groundwater basins: An Integrated Characterization and Modeling Approach

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More than 1/3 of active public drinking water supply wells in California produce water with nitrate-N levels indicative of anthropogenic inputs (> 4 mg/L). Understanding how the distribution of nitrate in California groundwater basins will evolve is vital to water supply and infrastructure planning. To address this need, we are studying the basin-scale reactive transport of nitrate in the Livermore and Llagas basins of Northern California. Both basins have increasingly urban populations heavily reliant on groundwater. A distinct nitrate "plume" exists in the Livermore Basin (Alameda County) whereas pervasive nitrate contamination exists in shallow groundwaters of the Llagas Basin (Santa Clara County). The sources and timing of nitrate contamination in these basins are not definitively known; septic systems, irrigated agriculture and livestock operations exist or have existed in both areas. The role of denitrification in controlling nitrate distribution is also unknown; dissolved oxygen levels are sufficiently low in portions of each basin as to indicate the potential for denitrification. We have collected water from 60 wells, and are determining both groundwater age (by the $^{3}H/^{3}He$ method) and the extent of denitrification (by the excess N_2 method). Excess nitrogen is being determined by both membrane-inlet and noble gas mass spectrometry, using Ar and Ne content to account for atmospheric N_2. We are also analyzing for stable istotopes of nitrate and water, nitrate co-contaminants, and general water quality parameters. Preliminary analysis of archival water district data from both basins suggests positive correlations of nitrate with Ca^{+2}, Mg^{+2} and bicarbonate and negative correlation with pH. In the Llagas Basin, a negative correlation also exists between nitrate and temperature. Flow path-oriented reactive transport modeling is being explored as a tool to aid in the identification of both the sources of nitrate and evidence for denitrification in both basins. Geostatistical realizations of Llagas Basin lithology provide a framework for addressing complexity in nitrate flow paths and spatial variation of denitrifying conditions. Particle transport simulations help calibrate the flow field to groundwater age data. Changes in groundwater geochemistry along the flow paths are used to constrain inverse geochemical models that employ redox reactions, carbonate mineral equilibria, and ion exchange mechanisms to attribute nitrate source types, and, in conjunction with excess N_2 data, quantify nitrate losses via denitrification.

H52D MCC: 3022 Friday 1340h

Quantifying Rates of Geomorphic Processes II *(joint with T, V)*

Presiding: **A M Heimsath,** Dartmouth College**; T Ehlers,** University of Michigan**; L Reinhardt,** University of Glasgow

H52D-01 1340h

Chemical Weathering in Steady State Orogens

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We present an analytical model for steady-state chemical weathering with an emphasis on the effect of uplift on the total rate of weathering is a depth profile. This one-dimensional model accounts for chemical weathering of the various constituent minerals and the total release of cations from the weathering profile as material moves from the bottom of a weathering zone to the surface at constant velocity. This model is parameterized in terms of "effective surface age", which is defined as the amount of time it takes for rock to move from the lower boundary of the weathering profile to the surface. The parameters that determine the effective surface age, the weathering depth and uplift velocity, are variables that are measurable and are generally uniform over large areas of the earth's surface. Thus, the effective surface age is a useful parameter to compare chemical weathering rates in different tectonic regimes. Comparison of model results with data sets from granitic catchments throughout the world show that in general our model reproduces the observed trends in chemical weathering. The following results come from this analysis: 1) Chemical weathering rates are closely linked with tectonism. The chemical weathering rate declines sharply with increasing effective surface age, dropping by more than an order of magnitude between active collisional orogens to temperate cratons; 2) Chemical weathering rates vary in a predictable and systematic fashion within a steady-state orogen. Coupling the one-dimensional model with calculated vertical velocities for a steady-state orogen shows that high weathering rates occur in areas of high uplift, the Inboard region, and lower weathering rates occur in the areas of low uplift of the Outboard region.

H52D-02 1355h

Geochemistry of the Red River and Chang Jiang - Constraints on the Weathering Flux Associated with the Indo-Tibetan collision

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Red River and the headwaters of the Chang Jiang in western China and Vietnam are in the tectonically active part of the Himalayan-Tibetan orogeny. Riverine fluxes associated with weathering along these rivers contribute to the total weathering yield associated with the main collision. The riverine flux carried by Himalayan rivers is considered to be a significant fraction of continental weathering budgets globally. Interpreting the geochemistry of rivers in terms of lithology, weathering rates, tectonics and global climate implications pose a challenge and we therefore use a suite of geochemical tools, including but not limited to, major ion and trace element concentrations and analyses of various isotope systems namely Sr, Os, Li, U among others. Over 150 samples were obtained from pristine locations along these rivers during the summer and winter seasons spanning a period of 3 years. Major element chemistry along with some trace element analyses (Sr, Rb, Ba, Cs, U and Th) is comparable to that of the large rivers draining the Himalayan mountain belt. For example, Sr concentrations range from 0.2 to 7.0 uM for Red River and 0.07 to 13 uM for the Chang Jiang. Sr isotope analyses provide additional constraints on the source of the weathering flux (silicate v/s carbonate), which in turn provides constraints on interpretations of the global marine Sr isotope record, atmospheric CO_2 drawdown and changing global climate.

H52D-03 1410h

Effects of climate and mineral supply rates on long-term chemical weathering rates in granitic landscapes

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We used cosmogenic nuclide and geochemical mass balance methods to measure long-term rates of chemical weathering and physical erosion of granitic terrain. Our 43 study sites encompass widely varying climates and denudation rates; mean annual temperatures vary from 2 to 32°C, average annual precipitation spans a 20-fold range (from 22 to 420 cm/yr), and denudation rates vary by 32-fold across our sites. Long-term chemical weathering rates for these 43 sites range from 0 to 173 t km^{-2} yr^{-1}, in several cases exceeding the highest granitic weathering rates on record from previous work. Chemical weathering rates are highest at sites with rapid denudation rates, consistent with strong coupling between rates of chemical weathering and mineral supply from physical erosion of rock. To account for effects of mineral supply in analyzing how climate affects chemical weathering, we introduce the "Weathering Intensity Factor" (WIF), the ratio of chemical weathering rate to physical erosion rate. WIF's increase systematically with average annual precipitation and mean annual temperature, both for the soil as a whole, and for individual component elements including Si, Na, and Ca. Between 59 and 79 percent of the variance in WIF's can be explained by a simple Arrhenius-like relationship based on mean annual temperature and average annual precipitation. Moreover, when we couple this Arrhenius relationship with our measurements of long-term erosion rates, we obtain a simple prediction equation that explains between 79 and 93 percent of the variance in long-term chemical weathering rates. The temperature-dependence of WIF is roughly half what one would expect from laboratory measurements of activation energies for feldspar weathering. Our results imply that the strength of climate change feedbacks between temperature and silicate weathering rates may be weaker than previously thought, at least in actively eroding, unglaciated terrain similar to our study sites. Our results further indicate that chemical weathering rates may often be limited by the rates that fresh minerals are supplied to soils by erosion, implying that tectonic uplift may be an important regulator of long-term chemical weathering rates in mountainous, granitic landscapes.

H52D-04 1425h INVITED

Constraining Landscape Evolution from Age-Elevation Relationships: a Quantitative Approach

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Using a complex three-dimensional model of heat transport that incorporates the effects of heat conduction, advection and production, under a finite-amplitude, rapidly changing surface topography, we have recently demonstrated how the rate of landscape evolution can be constrained in a variety of tectonic settings by careful analysis of the relationship between rock cooling ages and elevation. This is because the perturbation to the temperature structure caused by surface topography is a strong function of the wavelength of the topography. To demonstrate this point, we show how the effects of the recent glaciations on the morphology of the Southern Alps in the South Island of New Zealand can be extracted from low-temperature thermochronological datasets and separated from the effects on the ages caused by the rapid exhumation along the Alpine Fault. Turning our attention to post-orogenic settings, we demonstrate that the relationship