(δ^{15}N = +15.4$^o/_{oo}$; δ^{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 (δ^{15}N = +5.3$^o/_{oo}$; δ^{18}O = +9.9$^o/_{oo}$). During certain sample collections, nitrate from the head of the slough, with an isotopic composition of +5.2$^o/_{oo}$ (δ^{15}N) and +22.0$^o/_{oo}$ (δ^{18}O), is suggestive of nitrification (δ^{15}N = +5.2$^o/_{oo}$; δ^{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 δ^{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

between age and elevation is also affected by the nature of isostatically-driven exhumation. This effect is strongly dependent on the mechanical strength of the underlying lithosphere that determines whether the isostatic response to erosion-driven exhumation is spatially correlated or not. A strong lithosphere behaves like a thick elastic beam characterized by a large flexural wavelength; a weak lithosphere is charcaterized by a small flexural wavelength. Consequently, we demonstrate that age-elevation relationships also contain information about the mechanical strength of the underlying lithopshere and we provide means of extracting it. Finally, by coupling a surface processes model to the three-dimensional heat transport model, we demonstrate how thermochronological datasets can provide important constraints on the evolution with time of major geomorphic features such as the Great Escarpment of Southeastern Australia.

H52D-05 1440h INVITED

Coupled precipitation and long-term erosion rates across the Washington Cascades

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The central Cascades mountains of Washington state form a 150-200 km wide, north-south oriented topographic high with a mean summit elevation of ∼1.5 km, and nonvolcanic peaks above 2.7 km. The largely post-late Miocene bedrock uplift that created this part of the range formed a barrier to Pacific-derived moisture, leading to a dramatic orographic rain shadow with mean annual precipitation rates >4 m/yr on the notoriously rainy west flanks and <0.2 m/yr on the sagebrush steppes to the east. To examine the timing and rate of rock exhumation across the range, as well as relationships between precipitation and erosional exhumation, we have measured over one hundred apatite (U-Th)/He ages in a transect across the range. Apatite He ages vary from 4 to 60 Ma in this part of the range, with youngest ages on the upper west flank, and the oldest ages near the summit, east flank, and far western side of the range. These ages can be inverted for model erosional exhumation rates, assuming constancy since closure of the He system, by accounting for the interdependence of cooling rate, closure temperature, and closure depth in a steady-state crustal thermal model, and correcting for mean local topography (10-km circle) on isotherm depths (method of Brandon et al., 1998). Using this model, erosion rates near the summit, east flank, and far west flank range from less than 0.05 mm/yr to about 0.10 mm/yr, while rates for the upper west flank are as high as 0.33 mm/yr. Patterns of fluivially based erosion potential indices (e.g., steepest descent slope and local channel discharge) show no correlation with the observed erosion rate variations across the range. Mean annual precipitation, however, is relatively well correlated with erosion rate across the Cascades, suggesting a strong coupling between the two processes. If the range is currently in topographic steady state, then not only erosion rates, but also rock uplift rates on the west flank are as much as an order of magnitude greater than elsewhere in the range, including at the summit. Alternatively, rock uplift rates may be constant across the range, in which case varying erosion rates reflect transient topographic development of the range.

H52D-06 1455h

Detrital Mineral Cooling-Age Signal Variability and Erosion Rates, Marsyandi Valley, Central Nepal

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Detrital mineral cooling ages from modern rivers have been used as a proxy for long-term erosion rates because they integrate bedrock cooling ages from the contributing basin. In theory, each age represents a particle's vertical travel time from the steady-state closure isotherm, such that, for a basin eroding at a constant, uniform rate that balances uplift, the shape of the predicted distribution of ages mimics the contributing area's hypsometry, and its width is defined by the erosion rate if uniform chronometer distribution and insignificant sediment transport/storage time requirements are satisfied. Based on our interpretation of new $^{40}Ar/^{39}Ar$ ages for >300 individual detrital muscovite grains from central Nepal, we suggest that results for this approach to estimating long-term erosion rates can vary significantly by grain size, sample size, site selection, and year-to-year sediment redistribution within a single tributary basin. Large samples (n>80) of fine muscovite (250-500 microns), coarse muscovite (>500 microns), and smaller samples dated by previous workers from the Marsyandi River and its tributaries were compared in order to quantify natural detrital cooling-age signal variability and to explore the degree to which model requirements are met. While the present study's trunk stream age distributions generally agree with the spread of previously dated grains, distinct populations were found in a single tributary basin for fine and coarse size fractions, samples collected in different years, and samples from nearby locations. This variability is equally consistent with significant sediment storage time due to landslide or flood, spatially or temporally variable erosion rates, unevenly distributed lithologies, and/or transient topography. In addition, no uniform steady-state vertical erosion rate can account for the entire signal in any sample from this study, highlighting the need to assess independently natural sampling variability and the likelihood of steady state at the catchment scale before this or any more complicated erosion model can be used to interpret detrital cooling ages in terms of erosion rates. It is unlikely that simple thermal/erosion models can be used to infer surface process rates from modern detrital cooling-age distributions in this setting. However, combined with structural mapping in the contributing basin, detailed bedrock thermochronology and characterization of older sedimentary deposits derived from the catchment, this type of dataset can be used to explore differential erosion, erosion-rate increase/decrease and the appropriate temporal and spatial scales for steady state.

H52D-07 1510h INVITED

Beyond Dates and Rates: The Next Step in Cosmogenic Isotope Analysis?

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The cosmogenic isotope concentrations (CICs) of detrital materials are used to estimate catchment erosion rates but have the potential to offer considerably more. This is because the detrital CIC of a grain leaving an erosional terrain reflects its particular history of erosion, transport and storage, meaning in effect that the CICs of a large number of grains provide an integrated signature of a catchment's history. This can readily be demonstrated in ideal cases, relying particularly on the co-variance of key variables (isotope production rate and perhaps erosion rate and storage time) with altitude. However, individual grains have a near-infinite range of possible histories so requiring (as yet) unfeasibly large numbers of samples. Thus, CICs cannot be used to decipher detailed catchment histories, but the approach may be used to differentiate competing hypotheses for the evolution of particular catchments. To assess the potential of this method we constructed a 1-Dimensional stochastic model of CIC acquisition incorporating more than 20 modifiable parameters; CICs are calculated for up to 1000 grains. Some of the model parameters can be fully constrained for given sites (such as geomagnetic latitude; altitude), whereas others can only be estimated with considerable uncertainty (soil creep rate; duration of fluvial storage). Using published data, estimates of the key parameters have been made for test sites, and the sensitivity of the model to different parameters established. Significant, systematic differences in CICs are obtained under different conditions (altitude, relief, erosion rate, storage), and the model is able to reproduce published CICs from different settings and from our own work in the Sierra Nevada, S Spain. These results indicate that detrital CICs do have the capability of differentiating tectonic settings / geomorphic histories. The range of CICs of sediments underlies the issue of inheritance' that causes difficulties when dating sedimentary deposits. There may be scope using the approach here for a priori estimates of inheritance that can then be accommodated in dating applications.

H52D-08 1525h

Conservation Relations for Cosmogenic Radionuclides: Application to Erosional Landscapes

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Cosmogenic radionuclides have proved to be a useful tracer allowing quantification of rates of erosion and transport of sediment and concomitant geomorphic change. In numerical models of morphodynamics, differential sediment transport is tracked using the Exner equation of conservation of sediment mass. Here a corresponding equation is developed to describe the conservation of a cosmogenic radionuclide. The combination of two equations of conservation, one for sediment mass and one for the radionuclide tracer, offers a powerful way to extend the amount of information that can be extracted from analysis of cosmogenic radionuclides. The general formulation is applied to the specific case of an eroding landscape with stochastic elevation fluctuations. In many applications to date the rate of erosion is directly tied to the concentration of cosmogenic radionuclides at the eroding surface, but the sediment sampled for radionuclides is often obtained from a river not far from the area of interest. Such river samples represent averages over an erosion rate that includes stochastic fluctuations of elevation. It is demonstrated that a failure to include these fluctuations can lead to an overestimate of the erosion rate by as much as a factor of two. A scheme is presented by which cosmogenic radionuclides can be used to estimate not only the mean erosion rate, but also the standard deviation of temporal fluctuations in bed elevation.

H52E MCC: 3022 Friday 1600h

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

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

H52E-01 1600h

Topographic Evolution of Mountains: The Influence of Episodic Rejuvenation in Southern Spain.

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Uplift and denudation of the westernmost part of the Sierra Nevada, southern Spain has been assessed using a combination of optically stimulated luminescence (OSL) dating and ^{10}Be and ^{26}Al terrestrial cosmogenic nuclide (TCN) determinations, on both in-situ bedrock and detrital quartz from recent sediments, together with apatite fission track (AFT) ages from the metamorphic core. The Tertiary record of unroofing of this mountain area is shown to be episodic over all spatial and temporal scales. The presence of Tortonian marine sediments at altitudes up to 1830 m, indicate erosion rates < 0.03 mm.a $^{-1}$ over the past 7 Ma. However, adjacent AFT determinations of 4 Ma record at least ca. 3.5 km of unroofing at similar elevations to those marine sediments. Current rejuvenation of a small (21 km^2), high relief (2 km) catchment in the western Sierra Nevada has resulted in two distinct geomorphic zones: (1) a low angle, denudationally stable (unrejuvenated) headwater region with thin regolith cover and uniform erosion rates of 0.07 ± 0.02 mm.a $^{-1}$; and (2) a steep, actively rejuvenating lower catchment dominated by landsliding with erosion rates up to 7.9 ± 0.4 mm.a $^{-1}$. Rejuvenation of this catchment began ca. 17 ka following a rapid, tectonically generated ca. 50 m change in base level. An axial channel knickzone migrated upstream at ca. 0.5 m.a $^{-1}$, successively rejuvenating tributaries and propagating up