studies of the two main constituents of the lower mantle (magnesium silicate perovskite and magnesiowüstite) reveal fundamental changes in the chemical affinity of iron at 70 GPa [2], resulting in the depletion of iron in the silicate to the benefit of the oxide. Here, we will correlate the mineralogical and geophysical data, and provide a mineral-physics basis for a chemically heterogeneous and layered lower mantle. We will discuss the geophysical, geochemical, and geodynamical implications of such observations for global-Earth modelling, such as the dynamics of plumes, the chemistry at the core-mantle boundary, and heat conductivity at the basis of the lowermost mantle. [1] R. van der Hilst and S. Kárason, Science 283, 1885 (1999) [2] J. Badro et al., Science 300, 789 (2003)

T22D-08 1525h

In Situ Observation of Anisotropy Development With Pressure to 50 GPa in Olivine, Ringwoodite, Magnesiowuestite and Silicate Perovskite

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Magnesium silicates are the dominant minerals in the earth's mantle. Constraining the development of lattice preferred orientation in these materials is important for understanding anisotropy in the deep earth. Here we report results on deformation of San Carlos olivine in axial compression studied in-situ in the diamond anvil (DAC) using synchrotron radial x-ray diffraction. In order to minimize extraneous diffraction, gaskets of amorphous boron were used. Experiments were performed at room temperature, except for brief periods of in-situ laser heating to induce the phase transformations. At all conditions, high stresses and development of preferred orientation were documented. With increasing pressure (between 9 and 43GPa) olivine [001] axes align perpendicular to the compression direction. Ringwoodite (between 25 and 50GPa), develops moderate preferred orientation with a (111) compression component. After the phase transformation (at 50GPa), perovskite and magnesiowuestite display strong transformation textures. Magnesiowuestite has a [100] maximum parallel to compression, consistent with earlier observations. Patterns in perovskite, due to peak overlaps, have not yet been deconvoluted. These preliminary results indicate that significant anisotropy changes occur during phase transformations, e.g. by topotaxial growth, nucleation under stress, or martensitic mechanisms, and accompanied by deformation. All phases appear to be ductile at the high confining pressures in the DAC, even at room temperature. This is the first evidence for preferred orientation in ringwoodite and perovskite. These results will help in establishing deformation mechanisms of these minerals and are significant for interpreting seismic anisotropy in the transition zone. In the future, to be closer to earth conditions, we plan to conduct similar experiments at temperature and pressure.

T22E MCC: 3005 Tuesday 1600h

Taking the Measure of Deforming Landscapes II *(joint with G, H)*

Presiding: **M A Ellis,** Center for Earthquake Research and Information, University of Memphis**; A L Densmore,** Institute of Geology, ETH Zürich

T22E-01 1600h INVITED

Length Scale and Scaling in Both Topography Shape and Topography Dynamics

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Erosion processes both shapes topography and control topography dynamics so that it should be feasible to constrain the latter from the analysis of the former. During the last ten years, a bunch of studies have been done on analyzing topography in terms of erosion and transport laws. A kind of consensus has emerged around the power-law stream model which assumes that the erosion flux can be adequately described by its dependency on water flow and local topographic slope, and which gives that power laws with threshold are adequate functions to describe these dependencies, and that several processes (i.e. power-law functions) are necessary to cover the complete range of basin areas. But the consequences of these results in terms of dynamics have not been fully appraised yet. Thanks to a numerical surface-process model, we explore the relationship between form and dynamics, and especially the existence of characteristic time scales and their relationship to both structural and erosional parameters. Basically landscape erosion has a two-step evolution: an early phase which corresponds to the onset of drainage network, and a gentle back-to-equilibrium history. The former is very sensitive to initial topographic conditions and its dynamics is intimately related to drainage captures. We are mainly concerned with the latter which gives the long-term response of a continental system to any tectonic or climatic perturbation. Its characteristic time scale τ depends on the system size L in a power-law relationship which defines the nature of the continental-scale diffusion equation. For processes which depends linearly on slope (with or without threshold), this scaling can be written as: $\tau = \tau_H * (L/\sqrt{a_H})^{\alpha}$, where τ_H and a_H are the characteristic time scale and drainage area of hillslope, L the system size, and α the diffusion exponent which only depends on the river process. In all relevant cases, α is smaller than 1 leading to abnormally fast diffusion. In some cases (if erosion flux is highly dependent on river flux and/or if the sediment are efficiently transported in rivers), α is 0 and the system evolution is entirely controlled by hillslope dynamics. An analytical solution of α has been derived with the assumptions described above. We also show that the complete analytical solution of the topography history takes the general form: $h(t) = h_o \exp(-(t/\tau)^{\beta}) + h_{\infty}$ All parameters will be physically explained and related to system characteristics and erosion transport parameters.

T22E-02 1615h INVITED

Insights into the evolution of tectonically-active glaciated mountain ranges from digital elevation model analyses

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Glaciers have played an important role in the development of most active mountain ranges around the world during the Quaternary, but the interaction between glacial erosion (as modulated by climate change) and tectonic processes is poorly understood. The so-called glacial buzzsaw hypothesis (Brozovic et al., 1997) proposes that glaciers can incise as rapidly as the most rapid rock uplift rates, such that glaciated landscapes experiencing different rock uplift rates but the same snowline elevation will look essentially the same, with mean elevations close to the snowline. Digital elevation model-based analyses of the glaciated landscapes of the Nanga Parbat region, Pakistan, and the Southern Alps, New Zealand, lend some support to this hypothesis, but also reveal considerably more variety to the landscapes of glaciated, tectonically-active mountain ranges. Larger glaciers in the Nanga Parbat region maintain a low downvalley gradient and valley floor elevations close to the snowline, even in the face of extremely rapid rock uplift. However, smaller glaciers steepen in response to rapid uplift, similar to the response of rivers. A strong correlation between the height of hillslopes rising from the cirque floors and rock uplift rates implies that erosion processes on hillslopes cannot initially keep up with more rapid glacial incision rates. It is these staggering hillslopes that permit mountain peaks to rise above 8000m. The glacial buzzsaw hypothesis does not describe the evolution of the Southern Alps as well, because here mean elevations rise in areas of more rapid rock uplift. The buzzsaw hypothesis may work well in the Nanga Parbat region because the zone of rapid rock uplift is structurally confined to a narrow region. Alternatively, the Southern Alps may not have been rising sufficiently rapidly or sufficiently long for the glacial buzzsaw to be imposed outside the most rapidly uplifting region, around Mount Cook. The challenge now is to understand in detail why glaciers exhibit this range of behavior; why large glaciers apparently erode more efficiently than small glaciers, what are the processes that control the development of periglacial hillslopes, and why the rates of erosion on these hillslopes might be limited.

T22E-03 1630h

Topographic Steady State in the Southern Alps of New Zealand

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Steady-states between erosional and tectonic processes occurring in continental collisions are important because these represent the stable states toward which the dynamic tectonic-erosion system evolves. Topographic steady-state has been illustrated by numerical models of landscape evolution but often relies on conditions such as invariant rock uplift rate, climate, lithology, etc. Alternatively, transient surface processes such as glacial erosion may prevent the development of a topographic steady-state. Horizontal tectonic advection may also avert achievement of a topographic steady-state. This concept can be easily understood by considering the following first-order one-dimensional equation governing landscape evolution:

$$\frac{\partial h}{\partial t} = u_u - u_i - v\frac{\partial h}{\partial x} \tag{7}$$

where h is elevation, x horizontal distance, u_u rock uplift rate, u_i is incision rate (including diffusion of hillslope as well as incision of bedrock in fluvial channels) and v horizontal velocity tectonic advection. A numerical solution of this equation is proposed to investigate which major regional mechanisms may or not permit to reach a topographic steady state. This solution is then coupled with a GIS analysis of a 50m DEM of the South Island in New Zealand, where a continental collision is occurring, to extract geomorphologic features across the orogen that can be explained in terms of the solution of the equation described above.

T22E-04 1645h

Using Digital Topography to Differentiate Erosionally Exhumed and Tectonically Active Mountains Fronts

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Mountain ranges in the southern Rocky Mountains have departed on unique landscape evolutionary pathways in the late Cenozoic that are directly dependent upon the degree of post-orogenic tectonic activity they have experienced. The topography of Sierra Nacimiento, a Laramide uplift in west-central New Mexico lacking an active range-front fault, is shaped primarily by erosional exhumation that is continuous, but not steady, being driven by distal base level fall from Rio Grande incision and resultant south to north knickpoint migration. In contrast, the topography of the Taos Range, a rift flank uplift in north-central New Mexico is shaped by contrasting active stream incision and aggradation astride an active range front

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normal fault. The distinction between exhumation-dominated and tectonically-dominated mountain fronts is best quantified by analyses of a new metric we call the drainage basin volume to drainage basin area ratio (V-A ratio) as well as the gradients of first-order streams. Drainage basin volume and area are calculated by constructing topographic envelope maps from 10 m resolution digital elevation models (DEM). The envelope maps are pinned by the watershed divide and cover the maximum elevations in each drainage basin. Subtracting the original DEM from the maximum elevation envelope map produces a topographic residual map from which area and volume data can be obtained. The erosionally exhumed Sierra Nacimiento has a mean V-A ratio of 88 m while the tectonically active Taos Range has a mean V-A ratio of 140 m. Similarly, there are systematic differences in the gradients of first order streams measured both in the range block and approximately 5 km of adjacent piedmont. Streams were defined and subsequently Strahler ordered by a flow accumulation threshold of 250 water-equivalent grid cell units. First order stream channel long profiles were extracted from the DEM at 30 meter increments and gradients were calculated by a FORTRAN program. Gradients of first order streams in the exhumation-dominated Sierra Nacimiento have a mode of 6.8 degrees, significantly less than the 17.7 degrees for Taos Range first order streams. Furthermore, in the Taos Range first-order stream gradients steepen with increasing activity on the range-front fault. The distinct V-A ratio and stream gradient populations hint at an important change in the processes shaping hillslopes and low-order channels that is supported by the lack of slope-clearing landslides in the Sierra Nacimiento landscape and the presence of such landslides in the Taos Range. Slopes on Sierra Nacimiento are not steep enough to landslide and here, creep processes following a linear diffusion law dominate. In contrast, landsliding is present in the Taos Range where creep processes following a non-linear diffusion law are dominant. The signatures of distal base level fall are low V-A ratios accompanied by low modal channel gradients. Tectonically active mountain fronts have both high V-A ratios and high modal channel gradients.

T22E-05 1700h

Position of the Topographic Divide as a Measure of Tectonics, Steady-State, and Bulk Rock Strength

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The fractional position of the topographic divide relative to local base-levels defines the first-order shape of mountains over a wide range of length-scales, from spur-ridges to entire mountain ranges. We propose that the fractional position is a sensitive measure of the relative roles of tectonics, local base-levels, and bulk-strengths of rocks exposed on adjacent flanks of the range. In the absence of tectonics and in a homogenous lithology and climate, the fractional position of a steady-state divide is given by $D = F/(F+R)$ where F and R are the reliefs of adjacent flanks of the range. Departures from the predicted value indicate that one or more of the stated conditions is invalid. In cases where the topography is being generated over an active thrust, for example, the divide position expresses the relative role of tectonics. Examples from the Siwalik Hills, along the southern margin of the Himalaya, suggest that base-level is the primary control over the first-order shape of the emerging ranges. This means that attributes of the topography cannot be simply linked to the state of active faulting, but must be made with some reference to the geological history of marginal base-level changes. In cases where tectonics and differences in bedrock bulk strength can safely be disregarded, departures from the value of D speak to the response time of landscapes that are adjusting to recent changes in base-level. Such changes may be induced by climate change or to significant base-level changes (e.g., eustatic) that have subsequently migrated to the local region. In the absence of all external forcings (tectonics and climate), departures from D measure directly the difference between the bulk-strength of rocks exposed on adjacent flanks of a range. This measure is at a length-scale previously unavailable and may be of use in landscape evolution models and in landslide hazard analyses. All of this is predicated on the assumption that mean slopes measured from the topographic divide to local base-levels are ideally equal, which is a straightforward result if slopes are generated via landslides and debris flows. We propose and show supportive evidence that this is also the case where fluvial erosion is primarily responsible in the generation of range slopes.

T22E-06 1715h INVITED

What are the links between landslide distributions, topographic relief and erosion rates?

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If we wish to understand the pattern and rates of erosion in mountains, we need to understand the coupling between hillslope failure events and the evolution over time of hillslopes. There must be a link of some kind between the process that triggers the landslides and the morphology of the hillslopes sculpted by them. This link presumably determines the size, frequency and location of landslides, in combination with runoff and channel erosion processes, and together they determine the flux of sediment into the channel network. Unfortunately, it is very difficult to quantify the patterns and rates of landslide erosion, in part because individual landslides occur on scales (of area and volume) that are wildly variable, from failures a few meters across to several kilometers in size, and in part because the timing and location of landslides is complex. These problems make both data acquisition and mathematical analysis very challenging. Nevertheless, many landslide maps and inventories now exist, and with the advent of widely available digital elevation data, there is an excellent opportunity to study both in tandem. We present an analysis of several dozen landslide inventories and show that the size (planform area) distribution of landslides has more or less the same shape regardless of geographical location, bedrock lithology, or trigger mechanism. Each distribution has a heavy, power-law tail, with a similar exponent in most data sets. In some very good inventories the full shape of the distribution can be estimated with confidence, along with the modal average landslide size. We present a theoretical model that links these observations to the morphology of the landscape on which they were triggered. The model predicts a probability distribution for landslide sizes that matches very well our observations. The result is quite promising: it makes a simple link between hillslope failure and hillslope geometry, and it suggests that, in combination, high-resolution data for both may be able to tell us something about the physical parameters that drive landslide erosion and landscape evolution.

URL: http://geomorph.ldeo.columbia.edu

T22E-07 1730h

Tracking tectonism with terraces: new methods, new insights in the Gulf of Evvia, central Greece

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Coastal terraces are typically the preferred geomorphic marker to calibrate crustal deformation along tectonically active coastlines. Their elevation with respect to a horizontal reference datum - typically sea level - provides a measure of net uplift (or subsidence), whilst their dislocation or tilting can constrain the 3-D deformation field. Such tectonic interpretations, however, rest on the reliable identification, characterisation and measurement of the terraces themselves. To aid extraction of the topographic attributes of terraces from DEMs, we have developed an algorithm that rapidly and consistently delimits the spatial extent of terrace surfaces based on user-defined individual 'seed points'. The extracted topographic attributes can then be manipulated by standard structural geological 3-D visualisation techniques to inform tectonic analyses. We illustrate the methodology with a case study from the northern Gulf of Evvia, Greece. Here, on the Arkitsa headland of the gulf's western shore, a staircase set of topographic benches are carved into the uplifted tip of a major active normal fault, the Kamena Vourla fault. In the field the benches are observed to be multiple unconformable wave-cut platforms, though individual surfaces are locally faulted in places. A 10 x 10m DEM of the headland, extracted photogrammetrically from scanned air-photos, served as the testbed for the terrace delimitation algorithm. The algorithm computed a terrace map which, when combined with the digital topography, defined the altitude, slope and aspect data for each terrace fragment. The data indicate that the terrace fragments conform to two discrete populations that locate either side of a largely ignored transverse lineament, the Livanates fault. Structural reconstruction of pre-deformation terrace geometries track the differential uplift and tilting of terraces across the Livanates fault. Our tectonic interpretation proposes that this fault is an important 'release' structure to the main Kamena Vourla fault, and that this release fault has been operating at most since the penultimate interglacial period.

T22E-08 1745h

Tectonics from topography: Methods, Application, and Limitations

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Empirical observations from fluvial systems across the globe reveal a consistent power-law scaling between channel slope and contributing drainage area. Theoretical arguments for both detachment and transport limited erosion regimes suggest that rock uplift rate should exert first-order control on this scaling. Here we describe in detail a method for exploiting this relationship, in which topographic indices of longitudinal profile shape and character (stream profile concavity and steepness indices) are derived from digital topographic data. Key data handling steps include sub-sampling at uniform vertical intervals to recover contour crossings in source vector data and to more evenly distribute data in log(S)-log (A) space. In addition, we test several approaches to further smoothing data to improve the noise-signal ratio. These tests reveal that stream profile concavity and steepness indices are not sensitive to the various smoothing options considered, but that smoothing does greatly improve one's ability to recognize scaling breaks otherwise hidden in the noise. The stream profile data can then be used to delineate breaks in scaling which may be associated with tectonic boundaries. In the San Gabriel Mountains, CA, analyses of USGS 10m, USGS 30m, SRTM 30m, ASTER 30m, and SRTM 90m DEMs differ in detail, but overall yield similar results. The description of the method is followed by three case studies from varied tectonic settings. The case studies illustrate the power of stream profile analysis in delineating spatial patterns of, and in some cases, temporal changes in, rock uplift rate. Owing to an incomplete understanding of river response to rock uplift, the method remains primarily a qualitative tool for neotectonic investigations; we conclude with a discussion of research needs which must be met before we can extract quantitative information about tectonics directly from topography.

T31A MCC: 3007 Wednesday 0800h

Izu-Bonin-Mariana Arc Processes and Progress I *(joint with S, V)*

Presiding: **S Klemperer,** Stanford University**; J Gill,** University of California, Santa Cruz

T31A-01 0800h INVITED

Constructing a dynamically and geologically consistent hypothesis for the initiation of Izu-Bonin-Mariana subduction

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