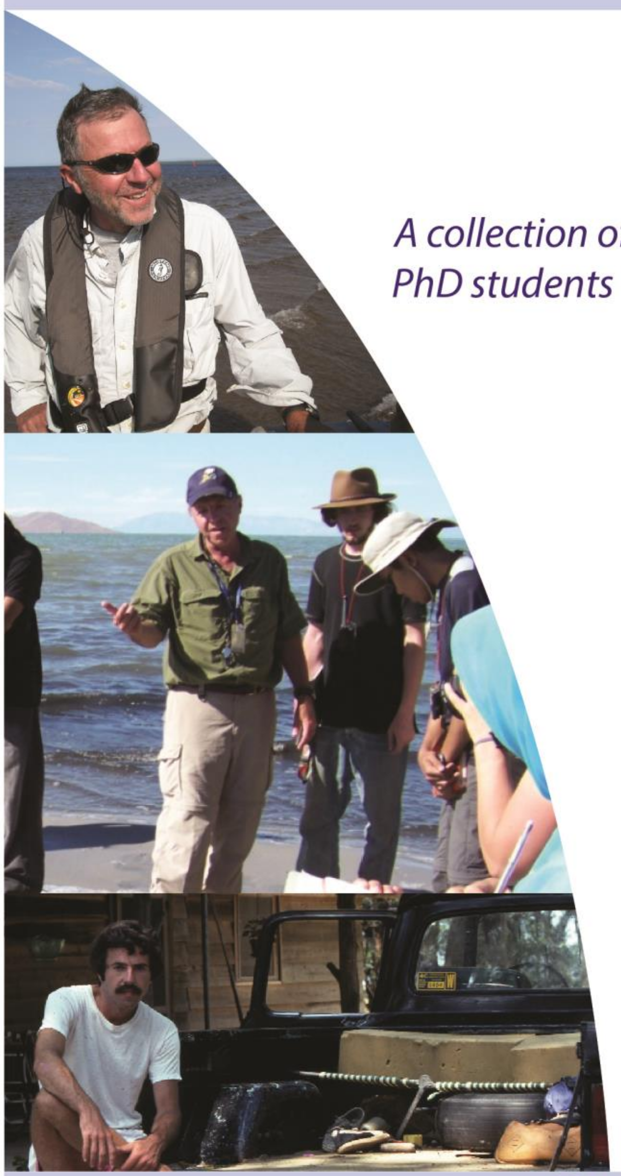
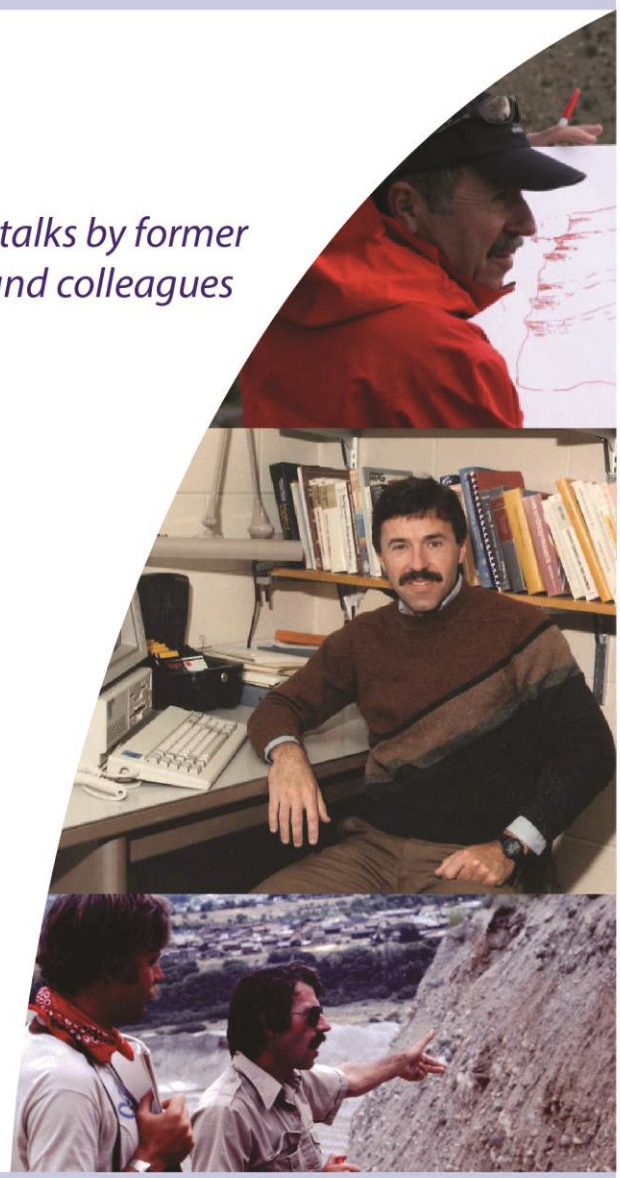
Rudy L. Slingerland: *44 Years of Research & Service at Penn State*

SlingFest: Sediment from Mountains to Seas
A Celebration of Research & Service in Honour of Rudy L. Slingerland

Pennsylvania State University
24th October 2015



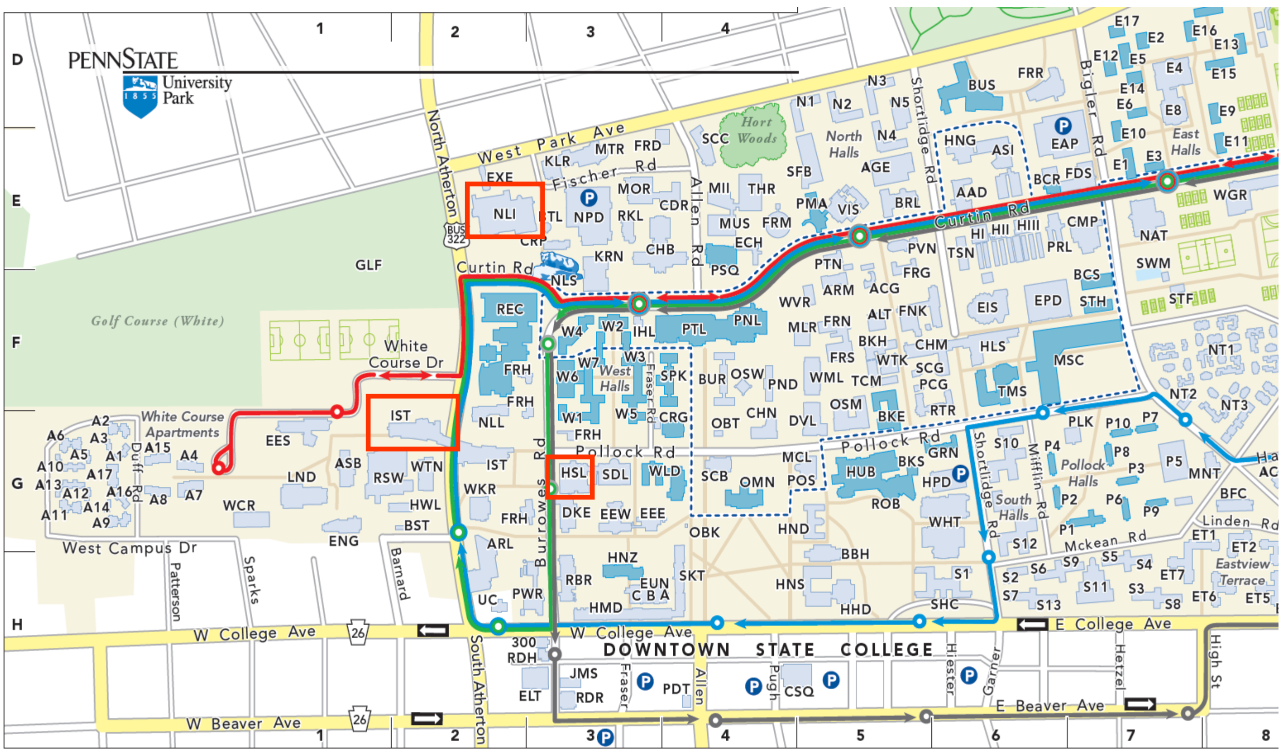
A collection of talks by former PhD students and colleagues



08:45 - 16:15
026 Hosler
Penn State Campus, State College

PENNSTATE
Department of Geosciences
Earth's deepest secrets revealed

The symposium is being held in the **Hosler Building** which is outlined by a red box in the map below **(HSL; see G3 on map)**. The Hosler Building is located on the corner of Burrows and Pollock Road. Parking is available on campus in the **Red A** parking lot next to the **Information Science and Technology Building (IST; G1-2)**. The retirement dinner is being held in the **Nittany Lion Inn Boardroom (NLI; E2)**. Parking is also available there during the day.



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Rudy L. Slingerland

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Programme of Events

08:45	**Coffee, tea**
08:55 - 9:05	**Welcome by Lee Kump**
	Session 1 (Chair: Greg Tucker)
09:05 - 09:30	Pete Adams
09:30 - 09:55	Merri Lisa Formento-Trigilio
09:55 - 10:20	Tim Keen
10:20 - 10:45	Sean Willett
10:45 - 11:15	**Tea and coffee**
	Session 2 (Chair: Tim White)
11:15 - 11:40	Jim Best
11:40 - 12:05	Doug Edmonds
12:05 - 12:30	Liz Hajek
12:30 - 12:55	Scott Rice Snow
12:55 - 13:20	Chris Paola
13:20 - 15:15	LUNCH (not provided)
	Session 3 (Chair: Ruth Robinson)
15:15 - 15:40	Niels Hovius
15:40 - 16:05	Greg Tucker
16:05 - 16:15	Concluding remarks: Ruth Robinson & Lee Kump

Rudy L. Slingerland: Thinker, Sailor, Bolder, Wry

Professor of Geosciences Rudy L. Slingerland officially retired in June of this year. Having been raised on a dairy farm in rural Bradford County, Pennsylvania, Rudy made his escape to Dickinson College from which he earned a bachelor's degree in geology, with honors. However, the conflict in Vietnam was still ongoing and Rudy joined the U.S. Navy. He served from 1969 to 1971 in the Mobile Construction Battalion (The Seabees) reaching the rank of petty officer, third class. Upon returning from military service, he enrolled at Penn State and received his master's degree in 1974 and his doctorate in 1977, both in geology. Rudy married his wife, Ellen, in 1984. He remained at Penn State as a researcher, teacher, and administrator for his entire distinguished career.

Rudy served as department head from 1997 to 2002 and as interim dean for graduate education and research in 2003. He also served on many college and department committees and taught a variety of courses, including Geosc 472 - Field Geology—the hands-on, real-world field experience affectionately known as "Field Camp."

Over his career he supervised 13 Ph.D. students, 22 M.S. students, as well as a large number of senior thesis projects. He has authored more than 70 publications in refereed journals, nearly 40 books and book chapters.

Rudy's contributions have been recognized with a number of honors including American Geophysical Union (AGU) Fellow, Geological Society of America Fellow, the G. K. Gilbert Award in Surface Processes from AGU's Earth and Planetary Surface Processes Focus Group, the National Science Foundation's MARGINS Distinguished Lecturer, and the College of Earth and Mineral Sciences' Wilson Research, Service, and Teaching Award.

As an indication of Rudy's importance to geosciences, one colleague wrote that "Rudy is a wonderfully generous and creative colleague who spans the full range from classical stratigraphy to numerical modeling of exceptional sophistication and power. This remarkable breadth has allowed him to play a critical role in bringing sedimentary geology into a new quantitative era in which prediction and hypothesis testing take the place of descriptive interpretation." Certainly, over the span of Rudy's career, the geophysical approach to stratigraphy has gone from the fringe to the mainstream, and Rudy has been at the vanguard.

Rudy's quantitative approach has been highlighted in several highly regarded books including "Simulating Clastic Sedimentary Basins," written with John Harbaugh and Kevin Furlong (1994), and more recently "Mathematical Modeling of Earth's Dynamical Systems: A Primer," co-authored with Lee Kump (2011). Rudy has used the equations of motion for unidirectional fluid flow and sediment transport to explore the origin of sediment sorting by grain size and density, placer mineral concentrations, downstream fining of grain size in rivers, channel diversions onto floodplains (avulsion), and channel bifurcations on deltas. In addition he has applied equations of shallow-marine water motion and sediment transport to explore the effects of water motion (e.g. due to tides and storms) on modern shelves and in ancient epicontinental seas including the Cretaceous Western Interior Seaway and the Devonian Catskill Sea. And beyond that, his work has combined numerical models for tectonic subsidence and uplift with those for water flow and sediment transport to simulate long-term, large-scale evolution of river systems; delta progradation; and the dynamics, stratigraphy and geomorphology of orogenic belts such as the Appalachians. Many a graduate student will recall the graduate-level course in math modeling taught by Rudy and Lee Kump as one of the most painful but, ultimately, useful courses they took at Penn State.

Rudy has been hugely important to the Department of Geosciences beyond academics and research. He has never displayed anger in public, choosing to express his "disappointment" over some issues calmly in a wry comment or two. He has informally mentored department heads and many early career faculty. In 2013, one of his former graduate students, Roland P. Sauermann and his wife, Debra C. Sauermann, created the Slingerland Early Career Professorship to honor Rudy for his work as a scientist, educator, and mentor.

Although Rudy's calm influence and knowledge of department history, tradition, and governance will be sorely missed, I suspect that we will see him somewhat frequently. If not, you might be able to catch him on his self-built sailboat on Bald Eagle Lake.

by Michael A. Arthur, Professor of Geosciences, Penn State

Quantitative Geomorphology of Tidal Inlets: "Then and Now" Insights From Two Autonomous U.S. Atlantic Coastal Inlets

Peter N. Adams[1]

1. Department of Geological Sciences, University of Florida, Gainesville, FL 32611

In an early-career publication stemming from his dissertation work, Slingerland (1983) provided a quantitative analysis of the morphologic behavior of a natural inlet subjected to a low energy wave field within a mesotidal, mixed-energy open coastal setting with low fluvial sedimentary input (Assawoman Inlet, Virginia, USA). By examining statistically-significant correlations of net volumetric change among seven pairs of morphologic elements within the inlet system, a process-based explanation was offered to account for the observed behavior and response of inlet morphology to the assailing wave field. During intervals of wave energy delivery considered to be "constructional", as evaluated from a conceptual model that accounts for wave height, period (via deep-water wavelength), and particle fall velocity, it is shown that the beach face accretes, consistently with the dominant direction of wave approach. During intervals of "destructive" wave energy delivery, observations document that the locus of deposition moves seaward from the beach face to the ramp margin shoals, further confining the ebb-tidal channel, whose seaward-flowing jet is deflected according to the dominant direction of wave approach, causing an inverse correlation between the north and south ramp margin shoals. Since the publication of the Slingerland (1983) study, the Assawoman Inlet channel has infilled and the newly constructed beach is decorated with numerous coalescing overwash fans, but the study provided quantitative evidence leading to an understanding of monthly morphologic behavior of the inlet sedimentary components in the absence of significant fluvial inputs from the adjacent terrestrial system. In a recent study, Adams et al. (in review) were able to document morphological changes of a natural inlet on the Florida Atlantic coast (Matanzas Inlet) resulting from a pulse of fluvial sedimentary input that helped reveal details of the physical mechanisms of tidal inlet accretion. The recent study used monthly RTK-GPS field measurements of beach topography adjacent to the inlet channel to document a shoreline change time series that illustrates a bi-directional, alongshore spreading pattern of accretion following an exceptionally high rainfall-discharge event in May 2009. To account for the complex patterns of current magnitudes and directions arising from the interaction of nearshore waves with ebb-tidal delta bathymetry, numerical modeling of wave set-up and nearshore currents in the vicinity of the inlet and ebb tidal delta was conducted for typical (quiescent) and extreme (storm) boundary conditions. Model results reveal depth-averaged flow velocity patterns consistent with the aforementioned field observations of coastal accretion. Results of the recent study are in agreement with an accretion mechanism, proposed by other researchers, that involves sediment delivery to the margins of the ebb tidal delta (the ramp margin shoals) during high velocity ebb flows that accompany large rainfall-discharge events, followed by onshore migration of swash bars, consistent with the Slingerland (1983) observations, during subsequent days to months, at a rate dependent upon the timing and direction of nearshore wave energy delivery to the site.

From Pediments to Impediments: How to communicate the poetry of science to a West Texas Libertarian.

Merri Lisa Trigilio[1]

1. Documentary Film maker , Deep Time Media, LLC

"I don't know if the scientific evidence is there or if that is a number they just drew out of a hat." Bruce Barrett, Farmer in West Texas responds to irrigation pumping limits supported by groundwater models developed by hydrologists at the Texas State Water Agency.

My journey from scientific research to public outreach. How do we as scientists communicate with the general public about complex science that will impact their livelihoods and get them curious about the world around them?

Twenty-five years of collaboration on the origin and characteristics of storm beds on continental shelves

Timothy R. Keen[1]

1. Retired from Naval Research Laboratory, Stennis Space Center, Mississippi, 39529

Rudy Slingerland was my thesis advisor from 1987-1991. We wanted to examine the creation of storm beds on shallow shelves like those thought to predominate within ancient shallow seas. We adopted a deterministic approach for the 3-D simulation of circulation and sediment transport, and assumed the strict uniformitarian view that a modern shallow and broad shelf with a high sedimentation rate like that of the northern Gulf of Mexico was a good analogue. This approach also permitted the study of historical tropical cyclones for model development. We published our approach in the Journal of Geophysical Research (1993) and the results for several storm beds were presented in the Journal of Sedimentary Petrology in 1993. This study allowed several generalizations to be made concerning our original hypothesis but there were still many problems to solve. One of these was the extrapolation of our method to high-latitude shelves oriented north to south. After I moved to Rutgers, we worked with Scott Glenn to complete a comparative study of storm bed formation for extratropical cyclones on the Middle Atlantic Bight and tropical cyclones in the Gulf of Mexico, which was presented at the Estuarine and Coastal Modeling conference in 1993.

Rudy invited me to help him study sedimentation in the Cretaceous Seaway during the Turonian age after I moved to the Naval Research Laboratory. I applied the updated model system to a hypothetical extratropical cyclone computed by a paleoclimate model. The results supported his hypothesis that both tidal and storm sediment transport were southward along the western margin of the seaway and that sandy storm beds would be limited in extent and of similar magnitudes to those on modern shelves. These results were discussed in an SEPM special publication (1999). I had the opportunity to collaborate with Rudy again on the NSF Margins program in the Gulf of Papua, a modern analogue for dispersal processes in clinoform development. He implemented the Navy Coastal Ocean Model at Penn State and examined tidal and wind-driven coastal currents while I examined the dispersal of terrestrial materia like dissolved metals and plant debris on seasonal and annual scales. The large-scale results were published in Geophysical Research Letters (2006) and the coastal modeling in the Journal of Geophysical Research in 2008.

The active hurricane season of 2005 allowed Rudy and me to work with other researchers to verify the predictions from the model system for Hurricanes Kate and Rita in the Gulf of Mexico. The model system results for these storms were validated using *in situ* observations and presented in Geophysical Research Letters in 2006. Our decades-long collaboration was successfully concluded in a summary study of the processes that create storm beds. Furthermore, thanks to Rudy's field work, we were able to answer the questions we originally posed when I came to Penn State and even address the fundamental problem of the preservation rate for storm beds in the stratigraphic column. We summarized our cumulative collaboration in a paper included in an IAS special publication (2012).

Where Geodynamics meets River Dynamics

Sean D. Willett[1]

1. Department of Earth Sciences, ETH Zurich, 8092 Zurich, Switzerland.

The last 25 years has seen a resurgence of interest in continental scale landscape evolution. The plate tectonic revolution quickly changed many fields, but geomorphology lingered for some decades before a few insightful scientists realized that the Earth's surface was intimately linked to the dynamics of the interior and observations of the surface provide some of the best constraints on deep Earth geodynamics. This development has motivated 2 decades of research trying to unravel the intricate connections and feedbacks between geodynamics and geomorphology. Important plate tectonic settings including collisional mountain belts and passive margins have now been investigated using a range of analytical tools. Physics-based models of landscape evolution including river dynamics have played an important role in these investigations as have empirical methods such as the use of channel stream power as a proxy for tectonic uplift rate. One of the outstanding problems of this field is the determination of whether spatial variability in quantities such as stream power is due to tectonic transients, lithologic variability or the intrinsic variations in river channel and network systems. We have recently demonstrated that the scaling between slope and area in river basins can be mapped across a landscape demonstrating which parts of a river network are out of equilibrium. This helps to determine the underlying causes of geomorphic variability. For example, we found that river basins in the eastern US were consistent with westward retreat of the Blue Ridge and other Appalachian escarpments, which together represent a geomorphic feature initiated by rifting of the Atlantic in the Jurassic. However, in spite of no recent tectonics or geodynamic uplift, we found large intra-basinal variability in channel steepness and erosion rate. This suggests that even slow geomorphic processes like escarpment retreat can destabilize the geometry of river basins, leading to river capture, divide migration and other indications of surface dynamics often interpreted in terms of recent tectonics.

All scoured out: the importance of big holes in alluvial channels

Jim Best[1]

1. Departments of Geology, Geography/GIS, Mechanical Science and Engineering and Ven Te Chow Hydrosystems Laboratory, University of Illinois, Champaign, Illinois.

Alluvial scours occur at many points in a drainage network and determine the lowest point of erosion in the absence of the effects of allocyclic forcing mechanisms. Alluvial scours can be deep, perhaps up to 6 times the mean flow depth, and may be mobile, with scours migrating across the channel belt. Such sours have sedimentological importance in the erosion surfaces and infill architecture they may leave behind, and potential geomorphic importance in the impact they may have on channel stability.

Recent work has begun to highlight the shape of such scours and how they affect local sediment transport paths, the nature of the stratigraphic surfaces produced by mobile scours and the potential role of scours in providing stable points within the lower deltaic regions of a drainage network. This talk will present a series of images of alluvial scours from a range of studies, including the Wax Lake delta, Louisiana, and the Ganges delta, Bangladesh, to speculate on the potential importance of such big holes in the functioning of river channels and deltaic distributaries. The talk will discuss the nature of smaller scale bedforms within scours and their importance for examining depth-scaling relationships for sand dunes, the stratigraphic expression of scour infills and the role of scour into underlying cohesive substrates in possibly influencing channel stability.

Developing scaling relationships for fluvial avulsions

Doug Edmonds[1], Nic Downton[1] and Liz Hajek[2]

1. Department of Geological Sciences, Indiana University, Bloomington, IN 47401
2. Department of Geosciences, Pennsylvania State University, University Park, PA 16802

Fluvial avulsion is the process by which water escapes its channel and moves into its adjacent floodplain where it creates a new path or reoccupies an old one. Avulsions are key events in the construction of the fluvial stratigraphic record and in the creation of channel planform patterns, though they are difficult to observe given their long recurrence intervals. In that sense, we seek to develop scaling relationships for the typical length and time scales of avulsion in meandering and braided systems. Towards this end we have initiated a remote sensing and image processing study to catalog river avulsions over the time period from 1984 to 2014 because we have near continuous remote sensing coverage. Using image segmentation techniques we extracted the long, linear river bodies and then classified avulsion events as those rivers that moved outside of the active channel belt within the time period. In total we found ~75 avulsions in the Amazon River basin and the Himalayan foreland basin that either initiated and/or completed over the 30 year time span. On each avulsion we measured its geographic position, the parent channel width, hop length, abandonment length, and duration. Over our thirty year time window, we find that avulsions predominantly occur within 100-200 km of the mountain front with few to no avulsions occurring farther down the transport system. The avulsion style, in almost all cases, consists of progradational or annexational events. The progradation rate of the avulsions ranges from 0.2 to 20 km yr^{-1} with an average rate of ~2 km yr^{-1}. For the avulsions that initiate and complete within the time window, the average avulsion duration is ~10 yrs. We find that avulsion size scales linearly and positively with the size of the river system as represented by parent channel width, though the scaling relationships are steeper for meandering channels than for braided ones. One measure of avulsion size is hop length, or the average channel-belt perpendicular distance from the old channel to the new channel. Hop length for meandering and braided channels ranges from 0.2-4 km from the main channel belt. Both braided (R^2= 0.62) and meandering (R^2= 0.71) river avulsion hop lengths scale with the parent channel width. Another measure of avulsion size is abandonment length, defined as the channel centerline length of the abandoned river. Abandonment length ranges from 0.5 to 150 km and scales with average parent channel width for both braided (R^2= 0.38) and meandering rivers (R^2= 0.47). Interestingly, avulsion progradation speed is strongly correlated hop length (R^2= 0.77). This suggests that large avulsions move farther away from the parent channel and proceed at a faster rate compared to smaller ones.

Connecting process-based understanding of river avulsions to the stratigraphic record

Liz Hajek[1]

1. Department of Geosciences, Pennsylvania State University, University Park, PA 16802

Rudy Slingerland's work has provided fundamental understanding of the processes and variables that control channel avulsion. This broad foundation facilitated a proliferation of studies that have improved our ability to predict where, when, and how rivers avulse. Preserved fluvial deposits provide a natural laboratory for testing models and hypotheses about river-avulsion processes. In recent years efforts to connect observations from avulsion deposits to results from numerical models and physical experiments have yielded new insight into what controls avulsion set-up, flow-path selection, and style. Here I provide an overview of recent results that leverage paleomorphodynamic information reconstructed from ancient fluvial deposits to further explore controls on avulsion processes. Integrating data from the stratigraphic record with model results has provided new perspectives on the range of conditions and balance of morphodynamic processes that influence avulsion behaviour.

The Rivers and Valleys of Pennsylvania: A 21st Century View of Neogene Topographic Rejuvenation

Scott R. Miller[1], Eric Kirby[2], Peter B. Sak[3], Paul R. Bierman[4]

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4. Department of Geology, University of Vermont, Burlington, VT 05405

The persistence of topography within ancient orogens remains one of the outstanding questions in landscape evolution. In the Appalachian Mountains, elevations exceed 800 m along much of the range yet it has been ~200 Myr since rifting and the development of eastern North America into a passive margin. Traditionally, geomorphologists have searched for evidence for whether topographic relief in the Appalachians is in a quasi-equilibrium state, decaying slowly and uniformly over many millennia, or whether relief has increased during the late Cenozoic. Here we present quantitative geomorphic data from the Susquehanna River drainage basin, as well as new results from the Potomac, James, and other basins in the Mid-Atlantic region, that provide insight into these end-member models.

First, we show that the truth lies somewhere in the middle. Using a catalog of 264 erosion rates based on cosmogenic ^{10}Be inventories of quartz sand from drainage basins underlain by a range of metamorphic, igneous, and sedimentary rock types, we show that an order-of-magnitude range in channel gradients, normalized for drainage area, can be explained by variations in rock type (and presumably erodibility). Such evidence would support the visible correlation between rock type and topographic relief common in the region. However, we also show that an equal amount of variation in stream gradients can be attributed to spatial variations in erosion rate.

Second, we present evidence for late Cenozoic topographic rejuvenation in the Susquehanna basin. Stream profiles across the Valley and Ridge, Appalachian Plateau, Blue Ridge, and Piedmont provinces have well-defined knickpoints that occur in two clusters at ~100 m and 300–600 m elevation. These knickpoints are not associated systematically with transitions from weak to resistant substrate but demarcate spatial variations in erosion rate. Erosion rates range from ~5–30 m/Myr above the high-elevation knickpoints to ~50–100 m/Myr below those knickpoints. Overall, normalized channel gradients scale linearly with catchment-averaged erosion rates. Collectively, regionally consistent spatial relationships among erosion rate, channel steepness, and knickpoint locations reveal an ongoing wave of transient channel adjustment to a change in relative base level. Reconstructions of relict channel profiles above knickpoints suggest that higher rates of incision are associated with ~100–150 m of relative base level fall that accompanied epierogenic rock uplift rather than a change to a more erosive climate or drainage reorganization. Inverting stream profiles for uplift histories, we find that rock uplift rates increased from ~20 to ~50 m/Myr during the Middle to Late Miocene, returned to ~20 m/Myr in the Late Miocene to Pliocene, and then increased to >70 m/Myr in the Plio-Pleistocene. These results are consistent with records of terrace incision on the lower Susquehanna River and deposition in the Salisbury embayment. We suggest that the channel network adjustment was likely driven by changes in mantle dynamics along the eastern seaboard of North America.

Equations in the sand: following in Rudy Slingerland's footsteps from sediment sorting to basin stratigraphy

Chris Paola[1]

1. Department of Earth Sciences, St Anthony Falls Laboratory, University of Minnesota, Minneapolis MN 55414

A misguided sedimentologist once remarked that mathematics cannot be applied to sedimentary geology, because one cannot see equations in the rock. Rudy Slingerland's career represents the emphatic negation of this statement. He has shown us how to see the math, and how to use it to see in the rock what we otherwise could not. I will focus on two examples of how Rudy Slingerland's approach and findings provided the foundation for research in my group over many years. His MIDAS grain sorting model, developed in a series of papers and applied over the range from placer deposits to basin-scale size sorting, is one of the cornerstones of current understanding of sediment sorting, which in turn is a fundamental basis for predicting downstream facies change in basins. I will discuss some of the ways we have tried to build on these ideas to develop predictive depositional models by coupling sediment sorting to mass extraction. Another major theme of Rudy Slingerland's research has been the interplay of tectonics and surface processes. His work on that has been a primary inspiration for development of the Experimental EarthScape deforming-bed experimental facility ("Jurassic Tank") at St Anthony Falls Laboratory. This facility allows quantitative study of the interplay of ongoing deformation and surface dynamics. I will review some of the main outcomes of this work, focusing on key time and length scales in the tug-of-war between tectonics and surface processes.

All of this work simply illustrates what Rudy Slingerland has been showing us all along: mathematics written in sand.

Seismological constraints on geomorphic processes

Niels Hovius[1]

1. GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam, Germany

Fifteen years ago, I stood by as Rudy tinkered with a single geophone to record bedload transport in a Taiwanese river. Ever since, the promise held by seismological approaches to monitoring of elusive activity of geomorphic processes has lured me like a Siren's song.

Any process in which solid matter moves over the Earth's surface generates seismic waves that carry information about the location, timing, magnitude and mechanism of that process. Recorded by standard seismological instruments, these signals can be used to probe the hidden details of individual process events, constrain the connections between different processes and process domains, and gain deeper insight into the dynamics of Earth's surface. This will be illustrated using examples from seismometer network deployments in Switzerland and Taiwan.

Data from three stations in the immediate vicinity of a $10^5 m^3$ rockfall in the Illgraben catchment show that catastrophic rock wall failure was preceded by cracking with exponentially increasing frequency and followed by a large number of 'afterfalls' reorganizing the rock face and scree below over a period of days. Although this episode occurred without immediate meteorological trigger, intense rainfall has caused similar rockfalls elsewhere in the catchment, which have transformed into debris flows. Our seismic data show that passage of these flows can, in turn, cause collapse of lower hillslopes and channel flanks, in an immediate, two-way link between process domains. In the Illgraben, these processes are recorded independently, but not in most other places. Moreover, only the larger events leave traces visible on remote sensed imagery. This invisible activity dominates sediment production and transport under most conditions. In the Chenyoulan catchment, seismological constraints show that the rate of small scale mass wasting is governed strongly and without delay by peak rainfall intensity, allowing definition of a relation between meteorological forcing and geomorphic response.

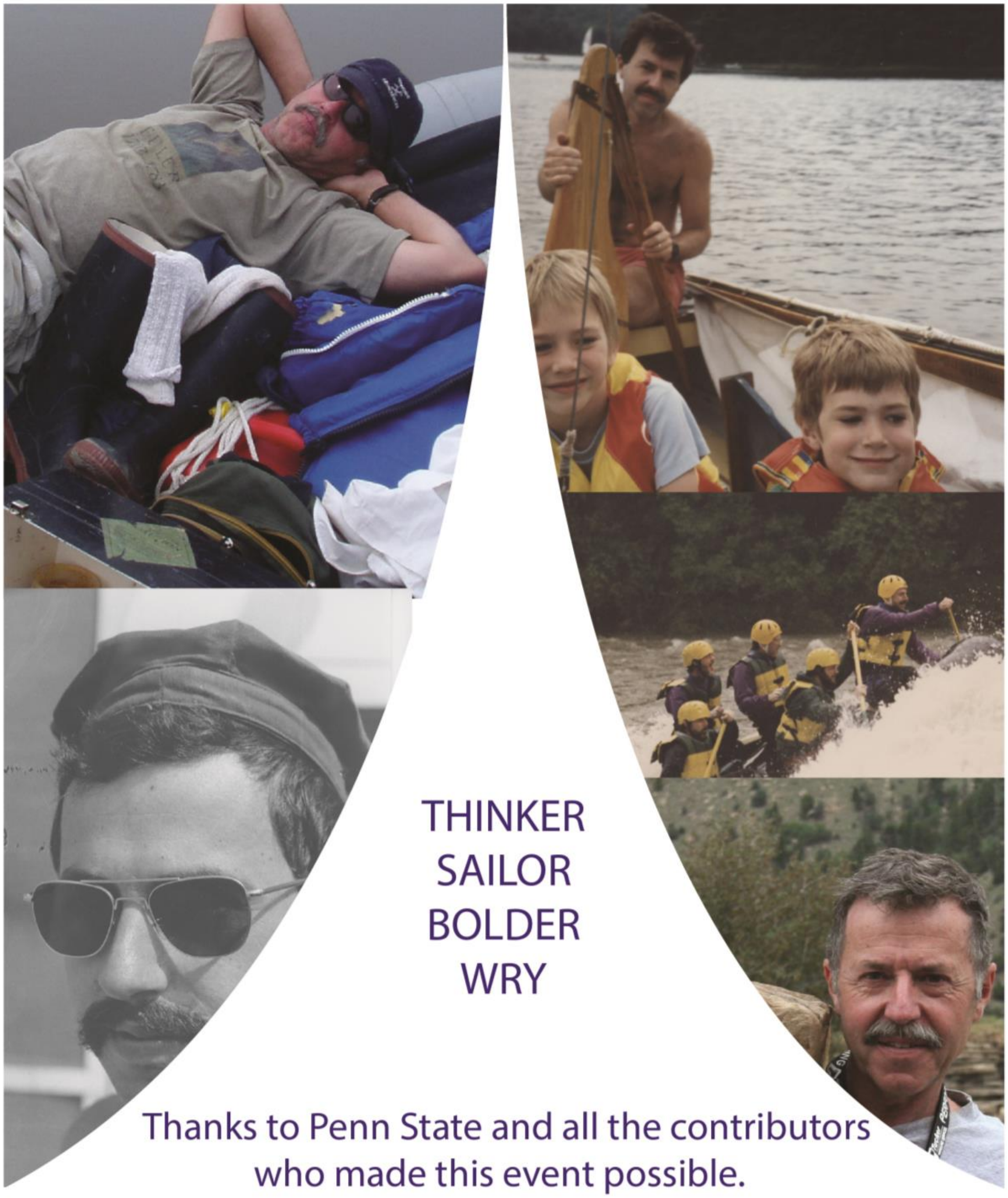
While others are exploiting the low-frequency content of teleseismic records to study the kinematics of the largest mass movements on the planet, our work is illustrating the wealth of information contained by high-frequency signals recorded by local networks and routinely filtered out by seismologists. The key challenge now is to build the theoretical framework to relate a broad range of seismic signals with the physics of key geomorphic processes.

Lowering the barrier to computational modeling of Earth's surface

Gregory E. Tucker[1]

1. Cooperative Institute for Research in Environmental Sciences (CIRES) and Department of Geological Sciences, University of Colorado, Boulder, CO 80309

Rudy Slingerland is renowned for his leadership in bringing quantitative thinking and computational modeling to the sedimentary world. In this talk, I present a new technology for earth-surface process modeling that builds on this legacy. **Landlab** is a Python-language software library that reduces the costs and barriers associated with numerical modeling. Traditionally, computer codes for modeling various Earth-surface processes have tended to be idiosyncratic, poorly documented, difficult to modify, and lacking in quality control. This situation puts modeling out of the reach of many, and promotes a tendency to re-invent the wheel of numerical software. The Landlab project aims to ease this situation by providing three core capabilities in the context of a high-level scientific programming language. First, Landlab's *gridding engine* allows a model-builder to create a two-dimensional (2D) model grid in a single line of code, and configure its boundaries with only a handful of additional lines. Grids may be regular (raster or hex) or irregular (Delauany/Voronoi). The grid topology makes it easy to implement common data structures and functions used in finite-difference and finite-volume models. Staggered-grid schemes can be developed by associating scalar data (such as water depth) with grid *nodes*, while vector data (such as flow velocity) are associated with the *links* that connect adjacent pairs of nodes. Data *fields*, which represent state variables or material properties, can be easily created and attached to elements of a grid. These capabilities make the process of building a 2D model far more efficient than it otherwise would be. Second, Landlab provides a framework for encapsulating the individual process elements of a model into *components*. A component is a self-contained piece of code that represents a particular process, such as solar radiation flux, routing of overland flow across terrain, or lithosphere flexure. Components may be coupled together to create integrated models. This capability enables researchers to save time by taking advantage of existing components, focusing their effort instead on developing the new and novel elements of a model. Third, Landlab provides built-in functions for input and output in standardized file formats. In addition, Landlab also includes a module for continuous-time stochastic cellular automaton modeling. Several examples of Landlab components are presented. Among these is a cellular model of normal-fault facet evolution, which provides a consistent, process-based explanation for the diversity of facet slope forms. Landlab is freely available under an MIT open-source license. Documentation, installation instructions, and tutorials can be found at http://landlab.readthedocs.org. The source code is available on GitHub at https://github.com/landlab/.



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Earth's deepest secrets revealed