ES01: Forms and Processes of bedrock erosion in fluvial and glacial landscapes

Conveners: Eva Kwoll[1], Jeremy Venditti[2], and Flavien Beaud[3]

Co-chairs: Eva Kwoll[1], Jeremy Venditti[2], and Flavien Beaud[3]

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Session Description

The erosion of bedrock in mountain terrain is one of the key processes determining the evolution of landscapes over time. In these settings, hillslope, glacial and fluvial processes act to carve out steep mountain valleys with distinct land forms. Bedrock erosion occurs through a variety of processes from plucking of entire rock blocks, abrasion by sediment load, chemical solution and rock fall. The relative magnitude of each process depends on the geological setting and the underlying mechanism, namely the flow of water or ice or the stability of a rock wall. In this interdisciplinary session, we aim to bring together fluvial and glacial geomorphologists / glaciologists / hydrologists working on bedrock erosion in mountain landscapes. We invite novel contributions across the variety of spatial and temporal scales inherent to these complex systems. Studies will include state of the art field projects, laboratory experiments and numerical models. We particularly invite contributions aimed to disentangle the relative importance of individual bedrock erosion processes and resulting sediment yield.

Primary Affiliation: CGU / Earth Surface Processes

NOTE: THIS DOCUMENT CONTAINS INFORMATION FOR ALL SESSION SUB-SECTIONS. PRESENTER ABSTRACTS ARE FOUND AT THE END OF THE DOCUMENT.

SCHEDULE MAY BE SUBJECT TO CHANGE.

ORAL SESSION ES01a

Chairs: E. Kwoll, J. Venditti, and F. Beaud **Room: GEOG 229**

Tuesday, May 30th

TIME	AUTHORS	TITLE
16:00	David J. Harbor, Clare Wilkinson, Elliott Helgans, and Joel P. Kuehner	Initiation of plucking in rapidly varied flow: results of flume experiments
16:30	Colin Rennie, Michael Church, Jeremy G. Venditti	Influence of bedrock on river geometry and hydrodynamics: Fraser River
16:45	Eva Kwoll, Jeremy G. Venditti, Colin Rennie, Dan Haught, and Michael Church	The effect of flow stage on velocity inversions and morphology in actively incising bedrock canyons
17:00	Saber Ansari*, Colin Rennie, Eva Kwoll, Jeremy G. Venditti	Shore-based monitoring of turbulent flow structure in a bedrock canyon river
17:15	Jeremy G. Venditti, Eva Kwoll, Colin Rennie, Michael Church	What is the formative flow in bedrock canyons?

POSTER SESSION ES01

Chairs: E. Kwoll, J. Venditti, and F. Beaud **Room: ESB Atrium**

Monday, May 29th

Poster No.	AUTHORS	TITLE
P01-ES01	Clare Wilkinson*, David Harbor, and Simon D. Levy	Sensing fluid pressure during plucking events in a natural bedrock channel

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SUBMITTED ABSTRACTS

ES01-01 Initiation of plucking in rapidly varied flow: results of flume experiments

David J. Harbor[1], Clare Wilkinson[1], Elliott Helgans[1], and Joel P. Kuehner[2]

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Abstract
River channel erosion by plucking is poorly understood even though it is a dominant mechanism for bedrock river profile evolution in many settings. In an experimental flume with fractured slabs of plaster as model bedrock, block lift and plucking is enhanced in nonuniform flow, particularly rapidly varied flow that includes hydraulic jumps and free-surface undulations, and possibly lateral channel velocity gradients in the presence of steps or jumps. We hypothesize that the mechanism enhancing block lift is a pressure gradient developed in the sub-bed fracture network. Change of water surface elevation at hydraulic jumps and surface waves, generates potential flow through cracks toward low-head regions. However, this gradient changes with the position and shape of the water surface, which creates long wavelength signals that travel upstream across sub-block pressure sensors. Near the critical threshold for block uplift, or neutral buoyancy, turbulent flow structures could provide the localized pressure disturbances that trigger block uplift prior to block protrusion. Blocks are lifted from an initially smooth bedrock layer, whereupon protrusion and stagnation pressure likely help complete the plucking process once blocks are elevated into the flow. The experimental results are consistent with the ability of bedrock rivers to generate scour holes in fractured bedrock below the steps and constrictions that generate nonuniform flow. Lack of continued transport of blocks out of nonuniform flow reaches may act as negative feedback to limit transport capacity where the accumulation of blocks below the zone of plucking changes the flow to decrease further plucking.

Presentation type: Oral Presentation

ES01-02 Influence of bedrock on river geometry and hydrodynamics: Fraser River

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Abstract
A 524 km reach of Fraser River was surveyed, between the towns of Quesnel and Chilliwack, where the channel alternates between gravel-bedded reaches that are incised into semi-consolidated glacial deposits and bedrock-bound reaches, including the Fraser Canyons. Based on a continuous centre-line acoustic Doppler current profiler (aDcp) survey and detailed field observations of bedrock confinement on each bank, supplemented with analysis of air photos and satellite imagery, we examine the influence of bedrock on channel width, depth, depth-averaged velocity, water surface slope, and bed shear stress. Accounting for change in discharge along the survey reach, downstream hydraulic geometry relations show expected scaling exponents of 0.5 for width, 0.4 for depth, and 0.1 for velocity, provided the alluvial and rock-influenced sections are analyzed separately. The downstream hydraulic geometry relations also demonstrate that rock-bound sections are narrower, deeper, and slower than alluvial sections. The survey reach was subdivided into 10 morphological sub-reaches, which ranged from alluvial gravel-bed reaches with relatively moderate slope to steep non-alluvial rock-walled canyons. From the alluvial to the semi-alluvial to the canyon sub-reaches, river widths decreased, while water depths, flow velocities, water surface slopes, and bed shear stresses increased. Measured data were grouped within each sub-reach based on presence of bedrock confinement on both banks, either bank, or neither bank. Within each sub-reach, locations with bedrock encroachment on both banks were narrower and deeper with higher bed shear stresses, but had lower depth-averaged velocity and water surface slope, particularly in the canyon reaches. A conceptual model is presented to explain this apparent discrepancy, representing a canyon reach as an alternating series of relatively low gradient deep rock-walled pools and steep semi-alluvial sections.

Presentation type: Oral Presentation

ES01-03 The effect of flow stage on velocity inversions and morphology in actively incising bedrock canyons

Eva Kwoll[1], Jeremy G. Venditti[1], Colin Rennie[2], Dan Haught[1], and Michael Church[3]

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Abstract
Active incision in bedrock rivers sets the pace of landscape evolution. The rate at which fluvial incision occurs depends primarily on the shear stress exerted by the flow on the bed and the sedimentological and geological characteristics of the river reach. Little is known about the flow field in steep-walled bedrock canyons, where flow experiences significant friction of the walls. Recently, a complex flow structure has been identified in particularly narrow canyons: high-velocity, near-surface flow plunges towards the bed upon entering the canyons, causing an inversion in the velocity profile. The plunge is accompanied by a lateral circulation pattern, which results in upwelling along the canyon walls. What controls the occurrence of this plunging flow structure is presently not known. Here, we present results from a recent field campaign into the Fraser Canyon in BC. A set of flow and topography measurements through several bedrock canyons under low flow conditions (discharge <2000 m^3/s) is compared to the new data set collected during this year's spring freshet (discharge >5000 m^3/s). We present 3D velocity maps collected with acoustic Doppler profilers as well as high-resolution topographic maps of the canyon floor and walls derived from a multibeam echosounder survey. Our results show that under high flow condition, plunging flow occurs in almost all the bedrock canyons surveyed, even in canyons were plunges are not detected under low flows. The higher discharge causes an increase in water depth of ~8 m, resulting in a drop in the width-to-depth ratio for each canyon. Plunging occurs repeatedly within one canyon and is at all times preceded by a narrowing of canyon width and a simultaneous deepening of the canyon floor. The morphological data provide evidence of plucking and undercutting of the canyon walls by lateral flow divergence associated with the plunging flow structure. The channel alluviates under low flow condition, likely inhibiting further erosion of the alluviated reaches. Our findings suggest that canyon morphology is maintained by the plunging flow structure.

Presentation type: Oral Presentation

ES01-04 Shore-based monitoring of turbulent flow structure in a bedrock canyon river

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Abstract
River bedrock erosion influences terrain evolution. A variety of different processes cause bedrock erosion in rivers, including plucking of bedrock blocks and abrasion by saltating bedload and suspended load induced by highly turbulent flows. Various investigations have been conducted to discover the relations between river flow characteristics, sediment transport, and bedrock erosion. For a better understanding of these relations, a comprehensive study has been conducted on Fraser River, in British Columbia. This presentation focuses on shore-based imagery of the river coupled with concurrent Acoustic Doppler Current Profiler (ADCP) velocity measurements, which when combined led to the development of a cost effective and easy to use tool for turbulent flow structure monitoring. Upwelling surface boils were observable in the shore-based video imagery. Automated image analysis tools were developed to quantify the structure, sizes, and advection rates of these boils. Finally, the ADCP measured 3D flow patterns were compared with the boil observations to estimate secondary circulation patterns and 3D flow structures. Results of this study may further be used to study flow structures in similar rivers.

Presentation type: Oral Presentation

ES01-05 What is the formative flow in bedrock canyons?

Jeremy G. Venditti[1], Eva Kwoll[1], Colin Rennie[2], Michael Church[3]

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Abstract
In alluvial channels, it is widely accepted that river channel configuration is set by a formative flow that represents a balance between the magnitude and frequency of flood flows. The formative flow is one that is just capable of filling a river channel to the top of its banks. Flows much above this formative flow are thought to cause substantial sediment transport and rearrange the channel morphology to accommodate the larger flow. This idea has recently been extended to semi-alluvial channels where it has been shown that even with bedrock exposed, the flows rarely exceed that required to entrain the local sediment cover. What constitutes a formative flow in a bedrock canyon is not clear. By definition, canyons have rock walls and are typically incised vertically, removing the possibility of the walls being overtopped, as can occur in an alluvial channel at high flows. Canyons are laterally constrained, have deep scour pools and often have width to maximum depth ratios approaching 1, an order of magnitude lower than alluvial channels. The bed may have intermittent or seasonal sediment cover, but during flood flows the sediment bed is entrained leaving a bare bedrock channel. It has been suggested that canyons cut into weak, well-jointed rock may adjust their morphology to the threshold for block plucking because the rock bed is labile during exceptionally large magnitude flows. However, this hypothesis does not apply to canyons cut into massive crystalline rock where abrasion is the dominant erosion process. Here, we argue that bedrock canyon morphology is adjusted to a characteristic flow structure developed in bedrock canyons. We show that the deeply scoured canyon floor is adjusted to a velocity inversion that is present at low flows, but gets stronger at high flows. The effect is to increase boundary shear stresses along the scour pool that forms in constricted bedrock canyons, thereby increasing abrasion rates and the potential for block plucking from massive crystalline rock beds.

Presentation type: Oral Presentation

P01-ES01 Sensing fluid pressure during plucking events in a natural bedrock channel

Clare Wilkinson[1*], David Harbor[1], and Simon D. Levy[2]

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Abstract
Plucking, the wholesale removal of bedrock blocks from channel beds, is thought to be a dominant mechanism of river incision over geologic time, yet it remains a greatly understudied phenomenon. Observations and data from our flume studies indicate that hydraulic structures such as jumps and standing waves characteristic of nonuniform flow create conditions capable of plucking blocks. Plucking is most likely to occur in the presence of these free surface undulations produced by resistant bedrock steps or flow constrictions. We hypothesize that these free surface undulations also create sub-block pressure differences that are transmitted through the crack networks of fractured beds, which may contribute to the plucking process. To investigate the relationship between fluid pressures and block movement, we employ a suite of data-logging electronics to capture fluid pressure variations and associated movement of a “pluckable” study block in a natural channel. Electronics include an IMU6050 to detect acceleration and rotation along the block’s three axes, two MS5803 pressure sensors to detect fluid pressure both above and below the study block, and a Teensy 3.6 data logger to log data at a rate of 40 samples/sec. The study site closely resembles the experimental setup from our flume studies; the study block sits in a relatively sediment-free zone downstream of a resistant bedrock step that produces a hydraulic jump and ensuing standing waves. Early studies suggest that the device records both block movement and fluid pressure as expected. A “controlled” experiment involving purposeful introduction of flow obstructions to change local pressure and turbulence reveals that water exchange between the crack network and the river does occur. Film footage of puffs of sediment escaping from under the block as well as changes in pressure recorded by the sensors support the presence of dynamic sub-block pressure transmission around blocks susceptible to plucking.

Presentation type: Poster Presentation