2012

A Study of Bedrock Strength Controls on the Erosion of the Colorado Plateau

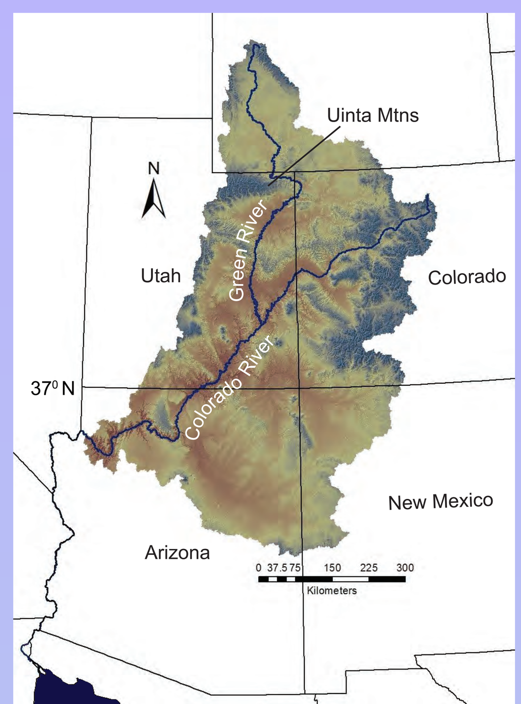
Natalie Bursztyn
Utah State University

Joel Pederson
Utah State University

A Study of Bedrock Strength Controls on the Erosion of the Colorado Plateau

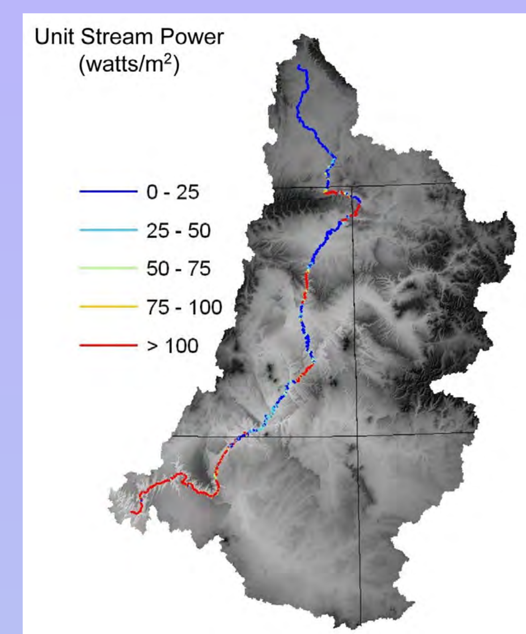
Natalie Bursztyn: nbursztyn@mac.com, Joel Pederson: joel.pederson@usu.edu

UtahStateUniversity



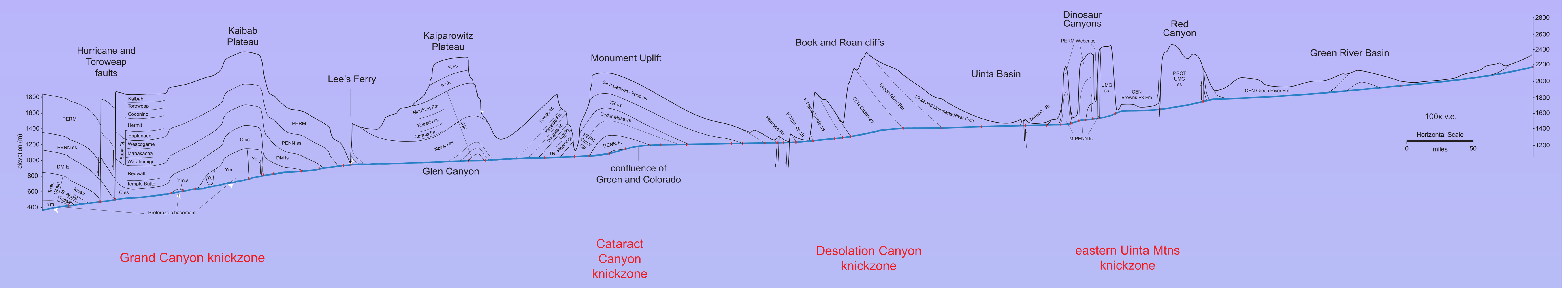
Introduction

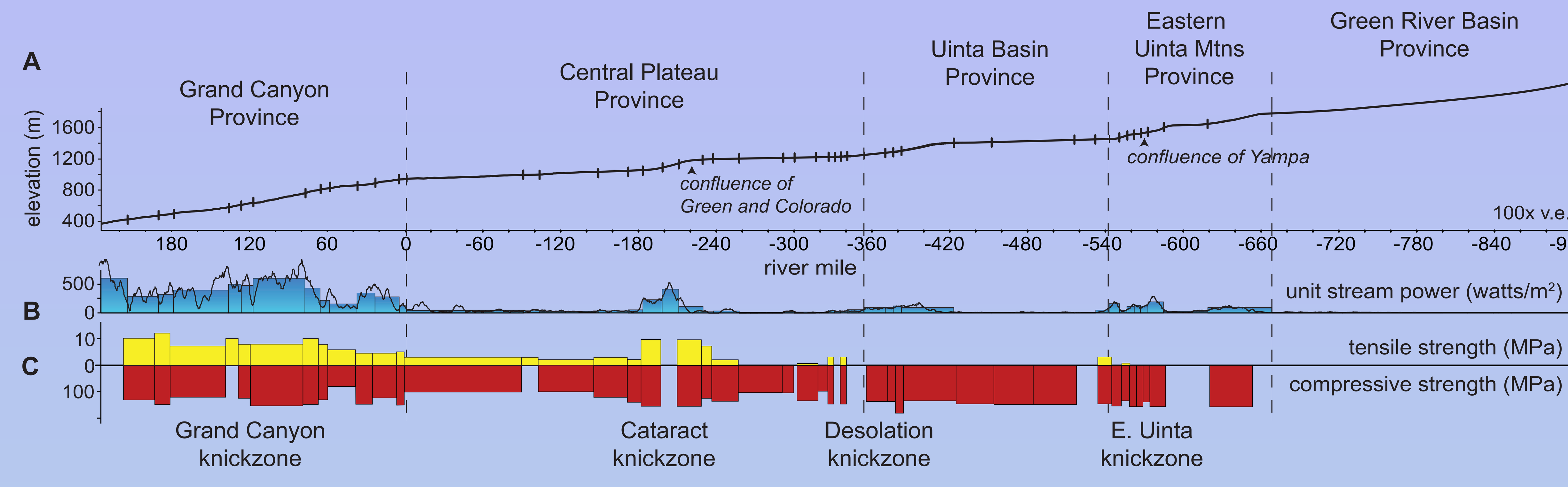
There has been renewed debate over the mechanisms of uplift and erosion in the Colorado Plateau, and in order to understand the patterns of topography and process in this landscape a third factor of bedrock properties must be considered. Our goal is to compile a dataset of bedrock strength and explore it in the context of topographic metrics. To do so, a methodology problem must be addressed. Traditional rock-strength measures such as Schmidt hammer rebound, Selby rock-mass strength (RMS), or tensile strength ignore weak rock types. We hope to develop an indirect, topography-based method that reliably estimates the strength of mud-rocks that are too incompetent to test directly.



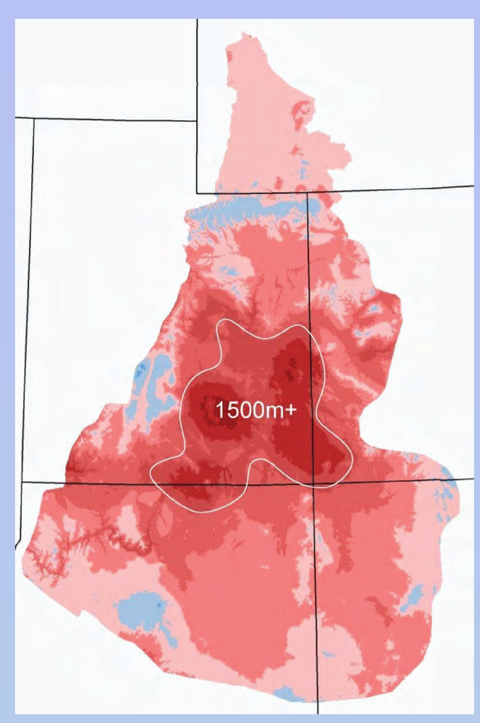
Goals

We will complete measurements of the characteristics of rock formations along the Colorado and Green rivers to allow erosional resistance to be quantified. The drainage in the Colorado Plateau can be broken up into 48 reaches underlain by a variety of bedrock compositions including quartzite, sandstone, shale, limestone, evaporites, and crystalline basement. Compressive strength data from most of the outcropping rock formations have been collected from all reaches, however tensile strength data for these rocks are incomplete, and there are no data from any incompetent rocks. Our existing data indicate there are strong relations between rock strength and channel/valley width and gradient and stream power. Documentation will be done to complete modified Selby rock mass strength evaluations, noting thickness and proportion of beds that are too weak to be tested. From these new data, we aim to back-calculate strength of "weak" beds using functional relations between measured channel widths and known rock strengths, similar to previous numerical modeling in the region.





The above show unit stream power with measures of compressive and tensile rock strength along profile of Green and Colorado rivers. We propose that the effective tensile strength of rocks too weak to sample may be back-calculated from a complete dataset of channel metrics and rock strengths. We have all the relevant stream metrics to solve for K (erodibility) in the unit stream power equation for all reaches, similar to the method of Pelletier (2010). We propose to regress through a dataset of reach-averaged values of K and the measured tensile strength of intact rocks to estimate the effective tensile strength for mud-rocks.

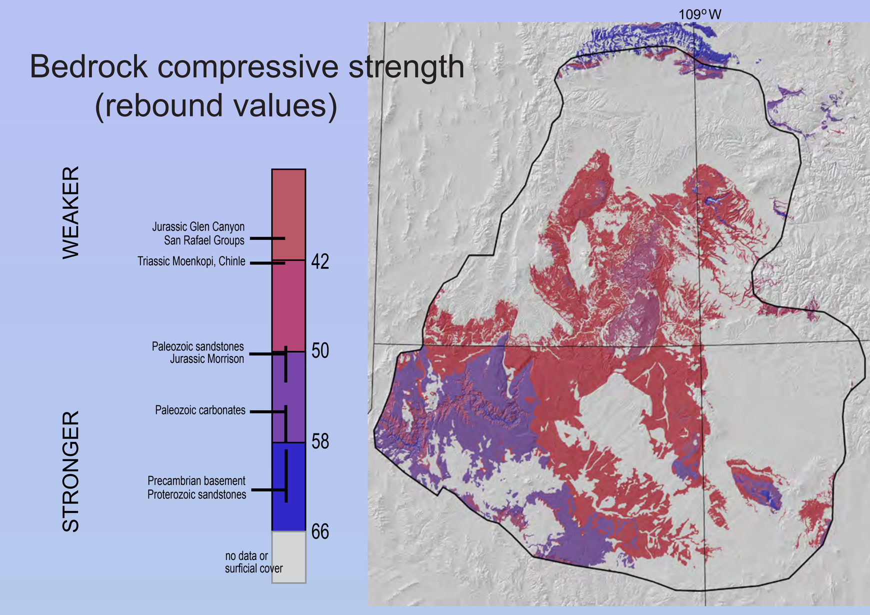


Methods

Compressive strength is quantified using a Schmidt (rebound) hammer in the field. Schmidt hammer measurements can be directly converted to a compressive strength value through an empirical relation ($C = 2.12 * R^{1.06}$). However, the modal value ascertained by at least 50 repeated Schmidt hammer measurements in situ is also an important component of the semi-quantitative modified Selby RMS classification. Other factors compiled into this classification include groundwater, weathering, fracture/joint spacing, orientation and width. We propose that some of these factors (such as groundwater and fracture/joint orientation) are less important contributors to bedrock river erosion. Other, not-included, factors such as the volume of weak rock (i.e. shale) that makes up the rock formation should probably be included in the RMS classification. See table of modified Selby RMS measures below.

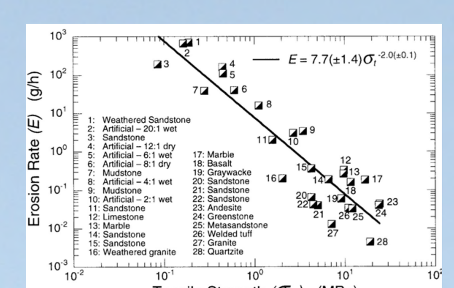
Tensile strength is determined by the Brazilian splitting test in the lab. This method requires 1-inch thick and 2-inch diameter rock disks, cored from intact formations, to which a uniaxial stress is applied until a primary fracture forms parallel to the loading vectors.

Neither of these methods currently include a means to quantify the strength of mud-rocks.



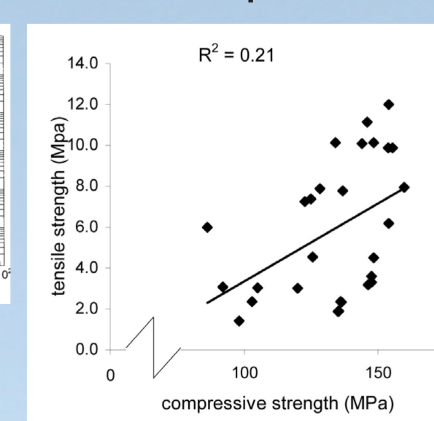
Initial Results

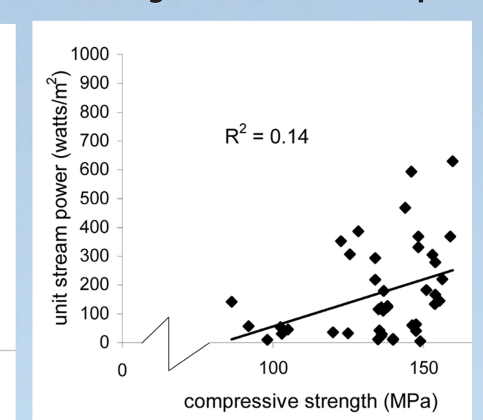
Compressive and tensile strength of rocks in the Colorado Plateau are rather poorly correlated with each other. Since rocks are weaker and break in tension, the tensile strength of a rock is a better value to use for the determination of that formation's erodibility. Experimental results from Sklar & Dietrich (2001) suggest that tensile strength is good measure of bedrock erosion rate. Our initial results support this hypothesis with a significantly better correlation of unit stream power with tensile strength than either compressive strength or modified Selby rock mass strength.

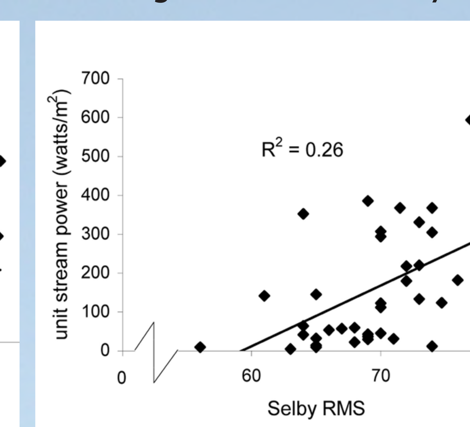


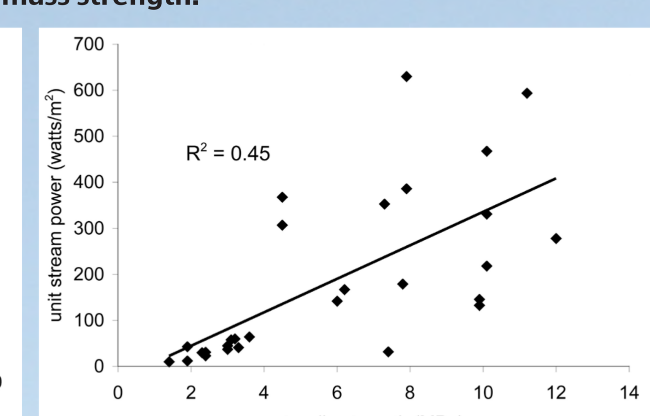
Sklar & Dietrich (2001) figure 2: Variation in measured erosion rate with rock tensile strength.

Geology; December 2001; v. 29; no. 12; p. 1087-1090









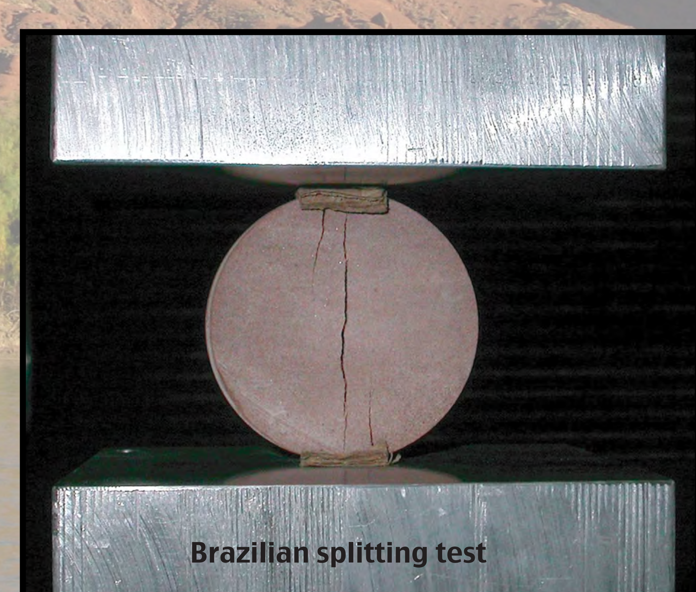
	Compressive strength	Tensile strength	Selby RMS
Tensile strength	0.50		
Selby RMS	0.46	0.42	
Unit stream power	0.53	0.75	0.53
Gradient	0.59	0.81	0.49
Valley Width	-0.21	-0.72	-0.38

Note: Results from Spearman rank correlation (R_s) of reach-average values of hydraulic-driving forces to bedrock-resisting forces, within reaches that have been studied.

Planned Work

- Field work will primarily entail collecting samples from formations for which we currently lack tensile strength data.
- Application of the additional proposed factor "proportion of mud-rock" to the modified Selby rock mass strength measure will be used to refine that semi-quantitative dataset.
- Formations of rock too weak to sample will be documented along with their corresponding channel metrics in order to generate a functional relation that we can use to estimate relative rock strength.

Schmidt hammer

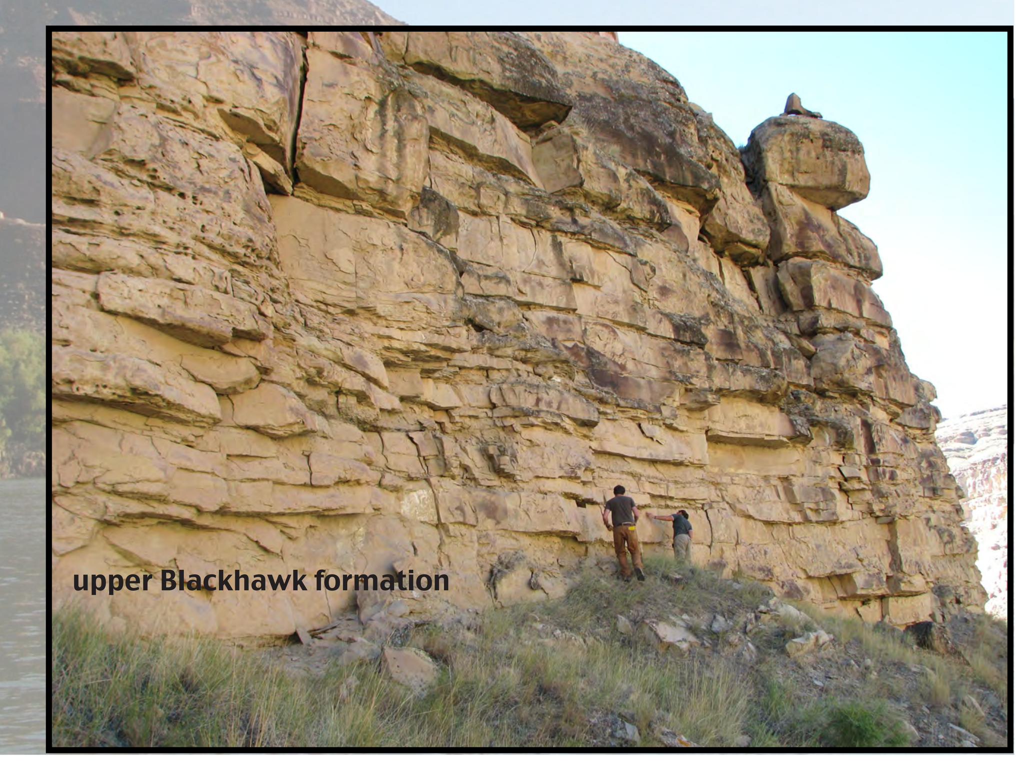


Brazilian splitting test

Modified Selby Rock Mass Strength Measures

Weathering:	Unweathered	Slightly	Moderate	Highly	Completely
Spacing:	>3 m	3-1 m	1-0.3 m	300-50 mm	<50 mm
Orientations:	Very favorable	Favorable	Fair	Unfavorable	Very unfavorable
Widths:	<0.1 mm	0.1-1 mm	1-5 mm	5-20 mm	20 mm
Continuity:	None	Few	Continuous, no infill	Continuous, thin infill	Continuous, thick infill
Groundwater:	None	Trace	Slight	Moderate	Great
Schmidt RMS:	100-60	60-50	50-40	40-35	35-10
Vol. mud-rock:	0-5%	5-15%	15-30%	30-50%	>50%

Cutler formation



upper Blackhawk formation