List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:

Amanda Keen-Zeebert, Amanda.Keen-Zebert@dri.edu, Desert Research Institute
Ellen Wohl, Ellen.Wohl@ColoState.edu, Colorado State University
Matt Covington, mcoving@uark.edu, University of Arkansas
Brian Yanites, byanites@indiana.edu, Indiana University
Josh Roering, jroering@uoregon.edu, University of Oregon

REVIEWERS NOT TO INCLUDE:

Oliver Chadwick--previous interactions over aspects of research related to climate and landscape evolution in Hawaii make me doubt his ability to be unbiased towards Dr. Gasparini and myself.

Martha-Cary Eppes--Expressed to Dr. Gasparini that perhaps we should not be working on some topics broadly related to climate, lithology and erodibility that Eppes is working on, which also makes me doubt her ability to be unbiased towards this proposal.

List of Suggested Reviewers or Reviewers Not To Include (optional)

SUGGESTED REVIEWERS:
Not Listed

REVIEWERS NOT TO INCLUDE:
Not Listed

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

Please complete this template (e.g., Excel, Google Sheets, LibreOffice), save as .xlsx or .xls, and upload directly as a Fastlane Collaborators and Other Affiliations single copy doc. Do not upload .pdf.

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- **All of the individual's Ph.D. thesis advisees.**

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2 Editorial Board does not include Editorial Advisory Board, International Advisory Board, Scientific Editorial Board, or any other subcategory of Editorial Board. It is limited to those individuals who perform editing duties or manage the editing process (i.e., editor in chief).

List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department (optional)
Fixed column widths keep this sheet one page wide; if you cut and paste text, set font size at 10pt or smaller, and
To insert *n* blank rows, select *n* row numbers to move down, right click, and choose Insert from the menu.
You may fill-down (crtl-D) to mark a sequence of collaborators, or copy affiliations. Excel has arrows that enable sorting.
For "Last Active Date" and "Last Active" columns dates are optional, but will help NSF staff easily determine which information remains relevant for reviewer selection.
"Last Active Date" and "Last Active" columns may be left blank for ongoing or current affiliations.

Table 1: List the individual's last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 r	Last Active Date
	Johnson, Joel P. L.	The University of Texas at Austin	01/05/2019 (present)
		Arizona State University (courtesy appointı	01/05/2019 (present)

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

R: Additional names for whom some relationship would otherwise preclude their service as a reviewer.

to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:				

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual's Ph.D. advisors; and
T: All of the individual's Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)
G:	Whipple, Kelin X	Arizona State University	School of Earth and Space Exploration (SESE)

T:	Olinde, Lindsay J	City of Austin	Lindsay.Olinde@austintexas.gov
T:	Brendan Murphy	Utah State University	bpmurphy@aggiemail.usu.edu
T:	Kealie Pretzlav	Balance Hydrologics	kealie@pretzlav.com

Table 4: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following:

A: Co-authors on any book, article, report, abstract or paper with collaboration in the last 48 months (publication date may be later); and

C: Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

to disambiguate common names

4	Name:	Organizational Affiliation	Optional (email, Department)	Last Active
A:	Gasparini, Nicole	Tulane University		
A:	Hancock, Greg	College of William and Mary		
A:	Kim, Wonsuck	UT Austin		
A:	Small, Eric	University of Colorado Boulder		
A:	Sklar, Leonard	Concordia University		
A:	Lamb, Michael	Caltech		
A:	Tsai, Victor	Caltech		
A:	Gimbert, Florent	IGE Grenoble		
A:	Mohrig, David	UT Austin		
A:	Rickenmann, Dieter	Swiss Federal Inst. For Forest, Snow and Landscape Research WSL		
A:	Turowski, Jens	University of Potsdam		
A:	Yager, Elowyn	University of Idaho		
A:	Hodge, Rebecca	University of Durham, UK		
A:	Fuller, Brian	Caltech		
A:	Delbecq, Katy	formerly UT Austin		
A:	Masteller, Claire	University of Potsdam; Washington University		
A:	Finnegan, Noah	University of California-Santa Cruz		
A:	Rempe, Daniella	University of Texas at Austin		
A:	Matheney, Ashley	University of Texas at Austin		
A:	Storz-Peretz, Yael	Ben Gurion University of the Negev		
A:	Laronne, Jonathan	Ben Gurion University of the Negev		

Table 5: List editorial board, editor-in chief and co-editors with whom the individual interacts. An editor-in-chief must list the entire editorial board.

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

E: Other co-Editors of journal or collections with whom the individual has directly interacted in the last 24 months.

to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:	Hubbard, Bryn	Aberystwyth University	Journal of Geophysical Research-Earth Surface	
B:	Buffington, John	U.S. Forest Service	Journal of Geophysical Research-Earth Surface	
B:	Coco, Giovanni	University of Auckland	Journal of Geophysical Research-Earth Surface	

The following information regarding collaborators and other affiliations (COA) must be separately provided for each individual identified as senior project personnel. The COA information must be provided through use of this COA template.

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List names as Last Name, First Name, Middle Initial. Additionally, provide email, organization, and department
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Table 1: List the individual’s last name, first name, middle initial, and organizational affiliation in the last 12 months.

1	Your Name:	Your Organizational Affiliation(s), last 12 ı	Last Active Date
	Gasparini, Nicole M	Tulane University	current

Table 2: List names as last name, first name, middle initial, for whom a personal, family, or business relationship would otherwise preclude their service as a reviewer.

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to disambiguate common names

2	Name:	Type of Relationship	Optional (email, Department)	Last Active
R:	Brendan Yuill	Family		

Table 3: List names as last name, first name, middle initial, and provide organizational affiliations, if known, for the following.

G: The individual’s Ph.D. advisors; and

T: All of the individual’s Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)

G:	Bras, Rafael	Georgia Institute of Technology	
T:	Adams, Jordan	University of Colorado, Boulder	
T:	Han, Jianwei	Computer Consultant	
P:	Brandon, Mark	Yale University	
P:	Whipple, Kelin	Arizona State University	

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4	Name:	Organizational Affiliation	Optional (email, Department) *to disambiguate common names*	Last Active
A:	Bandaragoda, Christina	University of Washington		
A:	Brocard, Gilles	University of Sydney		
A:	Capolongo, Domenico	University of Bari		
A:	Crosby, Ben	Idaho State University		
A:	Dawers, Nancye	Tulane University		
A:	DiBiase, Roman	Penn State University		
A:	Forte, Adam	Louisiana State University		
A:	Giachetta, Emanuele	ETH Zurich		
A:	Goldstein, Evan	University of North Carolina, Chapel Hill		
A:	Hancock, Greg	William and Mary University		
A:	Hijma, Marc	Deltares		
A:	Hobley, Dan	Cardiff University		
A:	Hutton, Eric	University of Colorado, Boulder		
A:	Istanbulluoglu, Erkan	University of Washington		
A:	Johnson, Joel	University of Texas		
A:	Li, Qi	Georgia Tech University		
A:	Mauz, Barbara	University of Liverpool		
A:	Murphy, Brendan	Utah State		
A:	Murray, A. Brad	Duke University		
A:	Nudurupati, Sai	University of Washington		
A:	Ouimet, Will	University of Connecticut		
A:	Pazzaglia, Frank	Lehigh University		
A:	Rittenour, Tammy	Utah State		
A:	Refice, Alberto	Italian National Research Council		
A:	Shen, Zhixiong	Coastal Carolina University		
A:	Sklar, Leonard	San Francisco State University		
A:	Small, Eric	University of Colorado, Boulder		
A:	Straub, Kyle	Tulane University		
A:	Strauch, Rhonda	University of Washington		
A:	Törnqvist, Torbjörn	Tulane University		
A:	Tucker, Gregory	University of Colorado, Boulder		

A:	van der Wegen, Mick	Deltares		
A:	Willenbring, Jane	University of San Diego		

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	Barnhark, Katherine	University of Colorado at Boulder	

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to disambiguate common names

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R:				

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T: All of the individual’s Ph.D. thesis advisees.

to disambiguate common names

3	Advisor/Advisee Name:	Organizational Affiliation	Optional (email, Department)

G:	Anderson, Robert S	University of Colorado at Boulder	Geological Sciences
T:			

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C: Collaborators on projects, such as funded grants, graduate research or others in the last 48 months.

4	Name:	Organizational Affiliation	Optional (email, Department) *to disambiguate common names*	Last Active
A:	Anderson, Suzanne	University of Colorado	Suzanne.Anderson@colorado.edu	**12/1/14**
A:	Foster, Melissa	US Bureau of Reclamation		**12/1/14**
A:	Kelly, Patrick	US Environmental Protection Agency		**12/1/14**
A:	Langson, Abigail	Kansas State University	alangston@ksu.edu	**12/1/14**
A:	Mahon, Robert	University of Arkansas	rmahon1@uwyo.edu	**5/1/15**
A:	McElroy, Brandon	University of Wyoming	bmcelroy@uwyo.edu	**5/1/15**
A:	Shaw, John	University of Arkansas	john.burnham.shaw@gmail.com	**5/1/15**
A:	Liang, Man	University of Texas at Austin		**12/1/15**
A:	Paola, Christopher	University of Minnesota	cpaola@umn.edu	**12/1/15**
A:	Voller, Vaughn	University of Minnesota	volle001@umn.edu	**12/1/15**
A:	Kay, Jennifer	University of Colorado	jennifer.e.kay@colorado.edu	**3/1/16**
A:	Miller, Christopher	Unaffliated	christopher.ryan.miller@gmail.com	**3/1/16**
A:	Overeem, Irina	University of Colorado	irina.overeem@colorado.edu	**3/1/16**
A:	Akin, Heather	University of Missouri	akinh@missouri.edu	**8/1/16**
A:	Hall Jamieson, Kathleen	University of Pennsylvania	kathleen.jamieson@asc.upenn.edu	**8/1/16**
A:	Hilgard, Joseph	Illinois State University	jbhilga@ilstu.edu	**8/1/16**
A:	Kahan, Daniel	Yale University	dan.kahan@yale.edu	**8/1/16**
A:	Landrum, Asheley	Texas Tech University		**8/1/16**
A:	Li, Nan	Texas Tech University		**8/1/16**
A:	Lull, Robert	California State University Fresno	lull@mail.fresnostate.edu	**8/1/16**
A:	Scheufele, Dietram	University of Wisconson, Madison	scheufele@gmail.com	**8/1/16**
A:	Winneg, Kenneth	University of Pennsylvania	ken.winneg@appc.upenn.edu	**8/1/16**
A:	Savi, Sara	University of Potsdam	Sara.Savi@geo.uni-potsdam.de	**12/1/16**
A:	Schildgen, Taylor	GFZ Potsdam	taylor.schildgen@gfz-potsdam.de	**12/1/16**
A:	Strecher, Manfred	GFZ Potsdam	strecker@geo.uni-potsdam.de	**12/1/16**
A:	Tofelde, Stephanie	GFZ Potsdam	stefanie.tofelde@gfz-potsdam.de	**12/1/16**
A:	Wickert, Andrew	University of Minnesota	awickert@umn.edu	**12/1/16**
A:	Aberman, Jakob	Asiaq Greenland Survey		**10/1/17**
A:	Benedixen, Mette	University of Colorado		**10/1/17**
A:	Bjork, Anders	Centre for GeoGenetics, Natural History Museum of Denmark, University of Co		**10/1/17**
A:	Box, Jason	Geological Survey of Denmark and Greenland		**10/1/17**
A:	Eberling, Bo	University of Copenhagen		**10/1/17**
A:	Iverson, Lars	University of Copenhagen		**10/1/17**
A:	Khan, Shfaquat	Technial University of Denmark		**10/1/17**
A:	Kroon, Art	University of Copenhagen		**10/1/17**
A:	Langley, Kirsty	Asiaq Greenland Survey		**10/1/17**
A:	Westergaard-Nielson, Ande	University of Copenhagen		**10/1/17**

A:	Adams, Jordan	University of Colorado	Jordan.Adams@colorado.edu	**12/1/17**
A:	Castronova, Anthony	Consortium of Universities for the Advancement of Hydrological Science		**12/1/17**
A:	Phuong, J	University of Washington	jphuong@uw.edu	**12/1/17**
A:	Strauch, Rhonda	University of Washington	rstrauch@uw.edu	**12/1/17**
A:	Tarbotton, David G	Utah State University	dtarb@usu.edu	**12/1/17**
A:	Wang, Shao-Wen	University of Illinois at Urbana Champaign	shaowen@illinois.edu	**12/1/17**
A:	Yin, Dandong	University of Illinois at Urbana Champaign	dyin4@illinois.edu	**12/1/17**
A:	Doty, Sandra	Unaffliated	sgdoty@gmail.com	**1/7/18**
A:	Bandaragoda, Christina	University of Washington	cband@uw.edu	
A:	Coe, Jeffery	US Geological Survey	jcoe@usgs.gov	
A:	Gasparini, Nicole	Tulane University	eric.hutton@colorado.edu	
A:	Ghent, Jessica	Front Range Community College	jessghent@gmail.com	
A:	Glade, Rachel	University of Colorado	rachel.glade@colorado.edu	
A:	Hill, Mary	University of Kansas	mchill@ku.edu	
C:	Hill, Mary	University of Kansas	mchill@ku.edu	
A:	Hobley, Daniel	Cardiff University	HobleyD@cardiff.ac.uk	
A:	Hutton, Eric	University of Colorado	eric.hutton@colorado.edu	
A:	Istanbulluoglu, Erkan	University of Washington	erkani@u.washington.edu	
A:	Kean, Jason	US Geological Survey	jwkean@usgs.gov	
C:	Kleiber, William	University of Colorado	william.kleiber@colorado.edu	
A:	Nudurupati, Sai Siddhartha	University of Washington	saisiddu@gmail.com	
A:	Rengers, Francis	US Geological Survey	frengers@usgs.gov	
A:	Rossi, Matthew	University of Colorado	Matthew.Rossi@colorado.edu	
A:	Shobe, Charles	University of Colorado	chsh5846@colorado.edu	
A:	Smith, Joel	US Geological Survey	jbsmith@usgs.gov	
A:	Staley, Dennis	US Geological Survey	dstaley@usgs.gov	
A:	Tucker, Gregory	University of Colorado	gtucker@colorado.edu	
C:	Tucker, Gregory	University of Colorado	gtucker@colorado.edu	

must list the entire editorial board.

B: Editorial Board: List name(s) of editor-in-chief and journal in the past 24 months; and

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to disambiguate common names

5	Name:	Organizational Affiliation	Journal/Collection	Last Active
B:				
E:				

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE **NSF 15-560**	☐ Special Exception to Deadline Date Policy	**FOR NSF USE ONLY** **NSF PROPOSAL NUMBER** **1918351**
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01/15/2019	3	06030000 EAR	7458	170230239	02/05/2019 5:27pm S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN) **746000203**	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE **University of Texas at Austin** AWARDEE ORGANIZATION CODE (IF KNOWN) **0036582000**	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE **University of Texas at Austin** **3925 W Braker Lane, Ste 3.340** **Austin, TX. 787595316**
NAME OF PRIMARY PLACE OF PERF **University of Texas at Austin**	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE **University of Texas at Austin** **2275 Speedway Stop C9000** **Austin ,TX ,787121722 ,US.**

IS AWARDEE ORGANIZATION (Check All That Apply) ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

TITLE OF PROPOSED PROJECT **Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
$ 319,683	36 months	09/01/19	

THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW

☐ BEGINNING INVESTIGATOR
☐ DISCLOSURE OF LOBBYING ACTIVITIES
☐ PROPRIETARY & PRIVILEGED INFORMATION
☐ HISTORIC PLACES
☐ VERTEBRATE ANIMALS IACUC App. Date ________
PHS Animal Welfare Assurance Number ________
☒ TYPE OF PROPOSAL **Research**

☐ HUMAN SUBJECTS Human Subjects Assurance Number ________
Exemption Subsection ________ or IRB App. Date ________
☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED
☒ COLLABORATIVE STATUS
A collaborative proposal from multiple organizations (PAPPG II.D.3.b)

PI/PD DEPARTMENT **Geological Sciences**	PI/PD POSTAL ADDRESS **P.O Box 7726** **Austin, TX 787137726** **United States**
PI/PD FAX NUMBER **512-471-9425**	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME **Joel Johnson**	DPhil	2007	512-471-6424	joelj@jsg.utexas.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

CERTIFICATION PAGE

Certification for Authorized Organizational Representative (or Equivalent) or Individual Applicant

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(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.
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Certification Dual Use Research of Concern

By electronically signing the certification pages, the Authorized Organizational Representative is certifying that the organization will be or is in compliance with all aspects of the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME Dale Cherry	Electronic Signature	Jan 15 2019 3:08PM

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER
512-471-5138	cherry@austin.utexas.edu	512-471-6564

COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./DUE DATE NSF 15-560	☐ Special Exception to Deadline Date Policy	FOR NSF USE ONLY NSF PROPOSAL NUMBER **1918459**
FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.) EAR - GEOMORPHOLOGY & LAND USE DYNAM		

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
01/15/2019	3	06030000 EAR	7458	053785812	02/05/2019 5:27pm S

EMPLOYER IDENTIFICATION NUMBER (EIN) OR TAXPAYER IDENTIFICATION NUMBER (TIN) 720423889	SHOW PREVIOUS AWARD NO. IF THIS IS ☐ A RENEWAL ☐ AN ACCOMPLISHMENT-BASED RENEWAL	IS THIS PROPOSAL BEING SUBMITTED TO ANOTHER FEDERAL AGENCY? YES ☐ NO ☒ IF YES, LIST ACRONYM(S)

NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE Tulane University	ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE Tulane University 6823 St Charles Avenue New Orleans, LA. 701185698
AWARDEE ORGANIZATION CODE (IF KNOWN) 0020297000	
NAME OF PRIMARY PLACE OF PERF Tulane University	ADDRESS OF PRIMARY PLACE OF PERF, INCLUDING 9 DIGIT ZIP CODE Tulane University 6823 St. Charles Avenue New Orleans ,LA ,701185698 ,US.

IS AWARDEE ORGANIZATION (Check All That Apply) ☐ SMALL BUSINESS ☐ FOR-PROFIT ORGANIZATION ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS ☐ IF THIS IS A PRELIMINARY PROPOSAL THEN CHECK HERE

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REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
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☐ INTERNATIONAL ACTIVITIES: COUNTRY/COUNTRIES INVOLVED ________
☒ COLLABORATIVE STATUS
A collaborative proposal from multiple organizations (PAPPG II.D.3.b)

PI/PD DEPARTMENT Earth and Environmental Sciences	PI/PD POSTAL ADDRESS 6823 ST CHARLES AVENUE NEW ORLEANS, LA 701185698 United States
PI/PD FAX NUMBER 504-865-5199	

NAMES (TYPED)	High Degree	Yr of Degree	Telephone Number	Email Address
PI/PD NAME Nicole Gasparini	PhD	2003	504-862-3197	ngaspari@tulane.edu
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				
CO-PI/PD				

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Norey B Laug**	**Electronic Signature**	**Jan 15 2019 4:37PM**

TELEPHONE NUMBER	EMAIL ADDRESS	FAX NUMBER
504-865-5272	**norey@tulane.edu**	**504-862-8674**

Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM.

Joel Johnson, The University of Texas at Austin (UT); Nicole Gasparini, Tulane University (TU).

Overview

Qualitatively, it is apparent that contrasts in bedrock properties are expressed in the topography of many eroding landscapes. However, the ability to quantitatively "read" topographic signatures of lithology is currently limited by our understanding of feedbacks among rock properties, erodibility, sediment production, and surface processes. The Guadalupe Mountains (GM) of Texas and New Mexico are an excellent field area for isolating lithologic controls on topography. Bedrock lithologies with contrasting rock properties vary spatially and systematically, with subhorizontally-bedded limestones, dolomites, sandstones, shales, and evaporites. The area is not tectonically active. Spatial variations in climate are minor for a natural mountain range, and semi-arid conditions allow for extensive bedrock exposure along channels and surrounding hillslopes.

Building on previous and preliminary work, we hypothesize that bedrock properties mainly influence fluvial channel steepness and morphology in two ways: *directly, by setting local bedrock erodibility*, and *indirectly, by controlling coarse sediment production* in upstream watersheds. Hypotheses will be tested using four primary research methods: (a) *Cosmogenic radionuclide analysis* will quantify bedrock erosion rates along channels, using ^{36}Cl and ^{10}Be, in collaboration with Prof. Arjun Heimsath at Arizona State University and Prof. Lisa Tranel at Illinois State University. (b) *GIS analysis* of extensive (~600 km^2) airborne Lidar data, high resolution structure-from-motion topography, and DEMs will quantify channel steepness and other topographic metrics across scales. (c) *Field surveys* will quantify bedrock properties--in particular distributions of intact rock strength (measured with Schmidt hammers) and discontinuity spacing (fractures and stratigraphic bed thicknesses)--and determine which measurable bedrock properties best predict erodibility at different spatial scales. (d) *Landscape evolution modeling* will quantify how rock properties are both expressed in topography and influence signals of external forcing (tectonics, climate) during lithology-dependent topographic evolution through time, in collaboration with Dr. Katy Barnhardt.

Intellectual Merit

Our ability to interpret climatic and tectonic forcing from topography is limited by our understanding of how lithology modulates landscape responses to environmental and base level perturbations. Quantitative models are required to isolate and predict how rock properties influence landscape evolution. Methods for inferring relative rock property differences from topography—and understanding sources of uncertainty--would be useful for many other endeavors in Earth and planetary science, including bedrock mapping in remote or inaccessible areas, hazard mapping (e.g. landslide, debris flow, post-wildfire erosion susceptibility), and interpretations of planetary surface geology from remotely sensed topography.

Broader Impacts

Improved hazard mapping would have direct societal benefits. We will develop college-level course content based on the GM field area--and record video lectures in the field--for use in a dual-enrollment Earth and environmental science course called "Earth Wind and Fire", taught annually through UT Austin's Onramps program to ≈1700 high school students across Texas. In addition, we will also bring a group of Onramps high school teachers to the GM field area to improve their Earth science knowledge. Through the Onramps course and teacher training, this project will enhance Earth science education for high school students from underrepresented groups, improving "pipelines" to geosciences in college. Finally, to communicate with the general public, we will develop educational content to be displayed at Carlsbad Caverns and Guadalupe Mountains National Parks.

TABLE OF CONTENTS

For font size and page formatting specifications, see PAPPG section II.B.2.

Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

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Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM.

Joel Johnson, The University of Texas at Austin (UT); Nicole Gasparini, Tulane University (TU).

Introduction

In eroding landscapes, topography results from the interplay of climate, tectonics and surface processes acting on bedrock. Since the recognition that feedbacks among these factors influence orogenic, crustal and atmospheric evolution, research has greatly improved our ability to "read" signatures of tectonics and climate from topography [e.g. Wobus et al., 2006; Hilley and Arrowsmith, 2008; Whittaker et al., 2008; Tranel et al., 2015; Yanites, 2018]. For example, uplift patterns and base level history can be interpreted from channel reach slopes and knickpoint positions [e.g. Berlin and Anderson, 2007; Roberts and White, 2010; DiBiase et al., 2015; Shelef et al., 2018]. Contrasting bedrock properties are also clearly expressed in the topography of eroding landscapes [e.g., Jansen et al., 2010; Scharf et al., 2013; Bursztyn et al., 2015; Forte et al., 2016; Yanites et al., 2017]. For example, "cliff former" and "slope former" units are common in flat-lying stratigraphy. Another classic example is waterfall evolution, such as at Niagara Falls, where the erosion and undermining of less resistant rock below harder rock causes knickpoint retreat upstream [e.g. Gilbert, 1907].

Because it remains unclear how to separate lithologic effects from tectonic and climatic forcing, many studies choose field sites with a single lithology [e.g., Dixon et al., 2009; Chadwick et al., 2013; Menking et al., 2013, Murphy et al., 2016], or by assuming that rock erodibility is spatially uniform while acknowledging possible complications from contrasting lithologies [e.g., Wobus et al., 2006; Whittaker et al., 2007; Harvey et al., 2015]. For example, Willett et al. [2014] assumed uniform bedrock erodibility in calculating a particular topographic metric, χ, to identify unstable (migrating) drainage divides [Perron & Royden, 2012; Forte and Whipple, 2018]. The χ metric builds on the shear stress/stream power model which assumes that erosion rates can be approximated by a power law function of reach slope and drainage area [e.g. Howard, 1994; Stock and Montgomery, 1999]. The model is widely applied in tectonic geomorphology to infer relative erosion rates, although is equally sensitive to erodibility differences [e.g., Whipple and Tucker, 1999, Wobus et al. 2006]:

$$S = \left(\frac{E}{K}\right)^{\frac{1}{n}} A^{-\frac{m}{n}} \qquad (1)$$

where K is fluvial bedrock erodibility, S is channel slope, E is erosion rate, A is drainage area, and m and n are exponents that can be calibrated to local topography [e.g. Whipple and Tucker, 1999].

Focusing on the rock properties aspect of erodibility, K is thought to be lower in relatively harder rocks. Erodibility characterizes incisional efficiency, i.e. the bedrock erosion that occurs for a given amount of hydrologic forcing (often shear stress or stream power [e.g., Whipple et al., 2000; Garcia-Castellanos and O'Connor, 2018]). Erodibility is a model dependent parameter; eq. 1 represents one such parameterization [e.g. Lague, 2014]. A key challenge our proposal directly addresses is how to relate erodibility to measurable bedrock properties.

If one assumes that E is balanced by rock uplift rate (i.e., steady state), relative uplift patterns can be inferred from topography. This is typically done using

$$S = k_{sn} A^{-\theta_{ref}} \qquad (2),$$

where normalized channel steepness k_{sn} and reference concavity θ_{ref} are determined from the relationship between S and A, which are in turn calculated from topography [Wobus et al., 2006]. For spatially constant or known K and n, combining eq. 1 and 2 allows patterns of E to be inferred from k_{sn}. Equivalently, for known E, patterns of erodibility (K) could be inferred from k_{sn}.

For hillslopes, engineering-based classification schemes for assessing slope stability, such as "Selby Rock Mass Strength" (RMS) (a semi-quantitative metric that includes fracture spacing and orientation in addition to intact rock strength measurements), correlate with rock surface slope in some but not all landscapes [e.g., Brook and Tippett, 2002; Matasci et al., 2015; Moore et al., 2009; Selby, 1980]. Differing fracture patterns can result from a wide variety of factors including tectonic stresses, topographic stresses, cooling stresses, climatic and geomorphic processes, in turn influencing spatial weathering, erosion and erodibility patterns [Molnar et al., 2007; Clarke and Burbank, 2011; St. Clair et al., 2015; Voigtlander et al., 2017; Eppes and Keanini, 2017; Eppes et al., 2018]. Differences in bedrock weatherability also influence hillslope form and erosion rates in regolith-mantled landscapes [Hurst et al., 2013; Johnstone and Hilley, 2015], including in the Guadalupe Mountains [Clubb et al., 2016].

For rivers, experiments show that bedrock incision from impact wear is inversely correlated with rock tensile strength squared [Sklar and Dietrich, 2001]. For mapped bedrock units across the Colorado Plateau, Bursztyn et al. [2015] found that reach slope increased with rock strength. Valley width increased with increasing fracture spacing (wider blocks), although the authors note that relationships between strength and fracturing complicate interpretations. In contrast, Spotila et al. [2015] found that channel widths decreased with increasing spacing of bedrock fractures and related discontinuities such as bedding and foliation.

Rock properties also influence sediment production [e.g., Sklar et al., 2017; Keen-Zebert et al., 2017; Eppes and Keanini, 2017; Roda-Boluda et al., 2018]. Sediment size distribution and supply in turn influence channel steepness and morphology [e.g., Duval et al., 2004; Johnson et al., 2009; Finnegan et al., 2017]. Keen-Zebert et al. [2017] found systematic variations in valley width, terrace formation, and gravel production from bedrock units of different strength. Thaler and Covington [2016] found that channels incising into the same bedrock units could have different steepness (k_{sn}), depending on the presence or absence of an upstream caprock unit with widely spaced fractures that supplied boulders. At their site, the intact strength of the caprock unit was actually weaker than the downstream bedrock, suggesting that joint spacing can be more important than intact bedrock strength for controlling reach slope. DiBiase et al. [2018] found that more widely spaced fractures led to bigger boulders and steeper fluvial channels downstream. However, Sklar et al. [2006] suggested that rapid downstream fining of coarser grains led to relative insensitivity of both GSD and transport rate variations to the GSD of the supply. While rock properties strongly influence erosion processes, these cited studies and many others show that rock strength and discontinuity spacing both influence erodibility in complicated and poorly predictable ways [e g., Whipple et al., 2000; Scott and Wohl, 2018].

Landscape evolution models (LEMs) generally assume erodibility values, or calibrate spatially-averaged erodibilities based on topography, without linking to measurable rock properties. Recently, LEM studies have explored the impact of erodibility contrasts on fluvial channels [Forte et al., 2016; Perne et al, 2017; Yanites et al.,

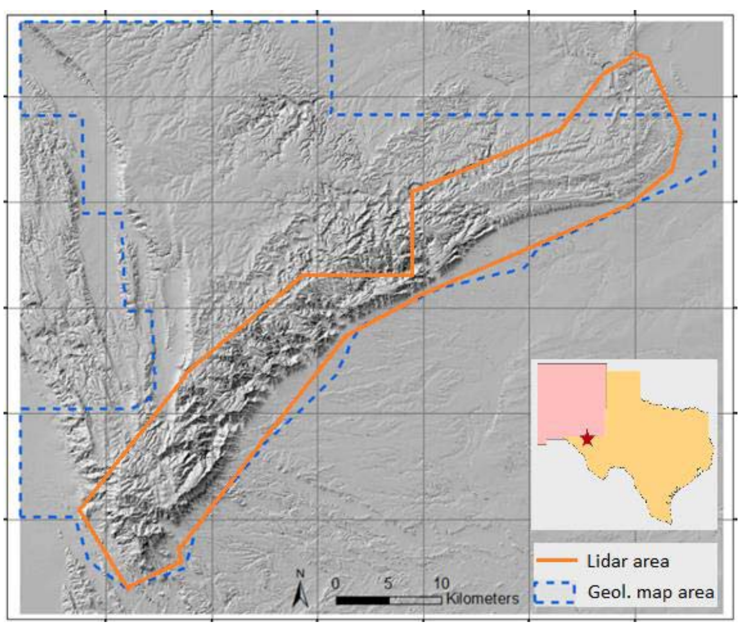

Fig. 1: Guadalupe Mountains shaded relief map, with available coverage of airborne Lidar and digital geological maps in the mountains.

2017]. These studies modeled incision consistent with eq. (1). The presence of horizontal or dipping planar rock layers with different erodibilities leads to eroding landscapes in which topographic steady state (constant elevations through time across a landscape) cannot technically be reached, although quasi-equilibrium forms can develop relative to the orientation of the layers [Perne et al., 2017]. Perne et al. [2017] also found that the influence of erodibility contrasts on landscape form was strongest with horizontal layers, and that channels can be steeper or less steep in harder rocks compared to softer, depending on incision model scaling exponents. Forte et al. [2016] demonstrate that harder rocks may erode faster or slower than weaker rocks, depending on the ordering of rock units (hard over/under soft rocks). These studies highlight that relations between morphology and erodibility can be non-unique.

As these field and modeling studies illustrate, our geomorphic 'familiarity' with rock property contrasts expressed in topography masks a surprising lack of quantitative, mechanistic, and predictive understanding of how measurable rock properties control landscape form and evolution. For example, how much of an erodibility contrast is required between units to develop cliffs vs slopes? How do measurements of bedrock properties relate to fluvial erodibility parameters? If functional relationships among topography, erodibility, and rock properties were better understood, it should be possible to put imperfect but quantitative bounds on relative erodibility and rock property contrasts from topographic data alone. Currently this cannot be done across a landscape to any degree of certainty. We tackle this problem through an integrated field, cosmogenic radionuclide (CRN), and numerical modeling study of bedrock channels in the Guadalupe Mountains (GM) of New Mexico and Texas, USA.

Field Area

The GM (Fig.1) include both Carlsbad Caverns and Guadalupe Mountains National Parks, as well as Forest Service and BLM land. Field area elevations vary from ~1000 m to 2667 m. Mean annual precipitation (MAP) increases with elevation over a relatively narrow semiarid range from ~35 to ~55 cm/year [National Park Service, 2010], with negligible spatial variability due to orographic rain shadow effects. While the tectonic history of the GM remains incompletely constrained, significant uplift and internal tectonic deformation are thought to have last been active in Miocene to early Pliocene time [Polyak et al., 1998; Hill, 1998, 2000; Decker et al., 2018]. Modern day rates of regional extension near the Rio Grande rift are very low (≈0.12 mm/yr over 100 km; Berglund et al., 2012). The mountains represent a Permian reef and shelf complex. Relief decreases from south to north, consistent with a stratigraphic transition from more resistant carbonate barrier reef mounds to more horizontally-bedded shelf deposits with higher proportions of siliciclastic rocks [e.g. Kerans et al., 2017]. Kosa and Hunt [2006] showed that cave formation and other karst features are often associated with syndepositional and later faults, which we will both identify when present and avoid when possible in our field work. While carbonates and evaporates may erode through chemical dissolution, Covington et al. [2015] argue that carbonate dissolution along bedrock streams is probably minimal in dry climates like this one.

Fig. 2: Visualization of field site lithologic variability based on published geological unit descriptions (Marino and Johnson, 2017)

The GM are an excellent field site to isolate rock property controls on topography for many reasons. (a) Bedrock lithology varies within the landscape, as illustrated by a "word cloud" from published unit descriptions of 22 geological units comprising the field area [NPS Geologic Resources Inventory Program, 2006; 2007] (Fig. 2). Bedrock consists not only of carbonates, but also sandstone, shale and evaporites, with variable bed thicknesses. (b) The stratigraphy in many places is ≈horizontally bedded without extensive faulting and folding, allowing adjacent bedrock properties to be spatially predictable [e.g., Kosa and Hunt, 2006]. (c) The landscape has not recently undergone significant internal tectonic deformation, simplifying the range of likely controls on the present-day topography. (d) Compared to most mountain ranges, spatial variations in climate are minimal. (e) The dry climate results in ephemeral flow and relatively sparse vegetation, allowing rocks to be exposed on both hillslopes and in channels, making field measurements of rock properties feasible. In addition, another benefit of this particular field site is that we have been granted access to ~600 km^2 of airborne Lidar data (Fig. 1) that belong to Dr. C. Kerans at UT and are not publicly available [e.g, Playton and Kerans, 2018]. Nonetheless, for this project we have permission to publish raw data from the specific channel reaches and hillslope swaths that we use, ensuring that our analyses will be open and

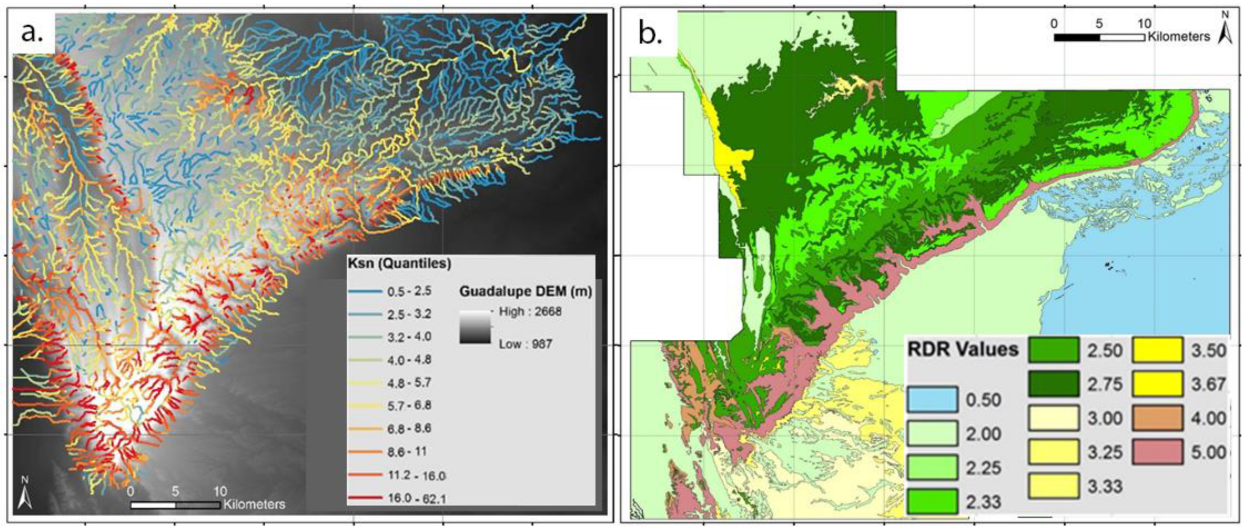

Fig. 3a. Channel steepness (Ksn). b. Relative Durability Rating (RDR) for 22 mapped geologic units; some units have matching RDR values and do not show up as distinct polygons at this scale (Marino and Johnson, 2017).

reproducible.

Preliminary Analyses

We next present preliminary results at the regional scale, and then at the reach and outcrop scale. Our regional GIS analysis of topography and bedrock lithology is based in part on a recent Masters degree project advised by JPJ [Marino, 2017; Marino and Johnson, 2017]. Fig. 3a shows channel steepness (k_{sn}) calculated for 1050 streams in the field area. Overall, steepness is highest on the southern escarpment and systematically decreases to the northeast. A key goal of Marino and Johnson [2017] was to determine how well k_{sn} and other topographic metrics could be predicted by regionally mapped bedrock units. Marino and Johnson [2017] also analyzed concavity (θ), but we do not include those results due to space limitations.

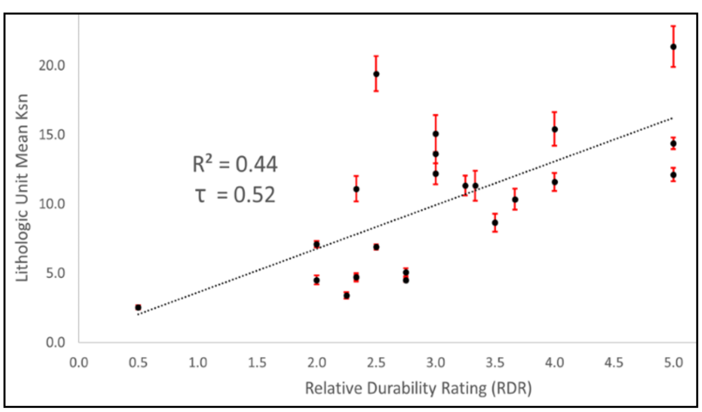

Fig. 4: Ksn and RDR are correlated; error bars represent +/- 1 std error (Marino and Johnson, 2017).

To relate rock unit descriptions to a metric relevant to landscape erosion, they developed a simple, unitless and semi-quantitative classification scheme called "Relative Durability Rating" (*RDR*) based on mapped unit descriptions (Fig. 3b). Higher *RDR* should correspond to less erodible (more durable) bedrock. To calculate *RDR*, lithologies are assigned numbers indicating the relative ranking of inferred durabilities, with evaporate=1, shale=2, sandstone=3, and carbonate (limestone or dolomite)=4. Units that are characterized as “massive” or “thickbedded” are assigned +1, while unit descriptions that emphasize thin bedding or rock type heterogeneity are given -1. These numbers are summed and divided by the number of rock types. For example, the Queen formation (*Pq*) is made up of sandstone (3), with some dolomite beds (4) and anhydrite and salt (1), with lithologic heterogeneity from interbedding (-1). For this unit, *RDR*=(3+4+1-1)/3=2.33. Our numeric classification approach for constraining erodibility differences is conceptually similar to Syvitski and Milliman [2007] and Garcia-Castellanos and O'Connor [2018].

After spatially averaging steepness (k_{sn}) over the area corresponding to each of the 22 geological units in the GM study area, Marino and Johnson [2017] found that k_{sn} is moderately but significantly correlated with *RDR* (Fig. 4; R^2=0.44 with p=6e-4; Kendall’s τ=0.52 with p=7e-4). Thus, while *RDR* is imperfect at best, it can explain roughly half of the variability in channel steepness across the GM. Marino and Johnson [2017] also found structure in the scatter: channels eroded into rock units below a more resistant rock are steeper than expected (relative to the Fig. 4 regression line), while channels above resistant units are less steep than expected (Fig. 5). The k_{sn} residual (y axis) is calculated as k_{sn} for a given unit minus the Fig. 4 regression. Positive values indicate steeper channels than expected for a given *RDR*, and negative values indicate lower slopes than expected. The x axis (*RDR Difference*) indicates whether a given rock unit is expected to be weaker than (lower *RDR*) or as strong as (same *RDR*) the strongest unit ($RDR_{strongest}$) in the stratigraphic column in the area where a given unit outcrops, and whether above or below (Fig. 5). If a given unit has the same *RDR* as the strongest unit in the stratigraphic section, then *RDR Difference* = 0. If a given unit is weaker and stratigraphically *above* the strongest unit in the section, then *RDR Difference* is *negative* (calculated as RDR_{above}-$RDR_{strongest}$). If a given unit is weaker and stratigraphically *below* the strongest unit in the section, then *RDR Difference* is *positive* (calculated as $RDR_{strongest}$-RDR_{below}). Thus, negative *RDR Difference* indicates weak over strong, and positive *RDR Difference* indicates weak under strong. The correlation between k_{sn} residual and *RDR Difference* is significant (R^2=0.41 with p=9E-4; Kendall’s =0.59 with p=8.5E-5).

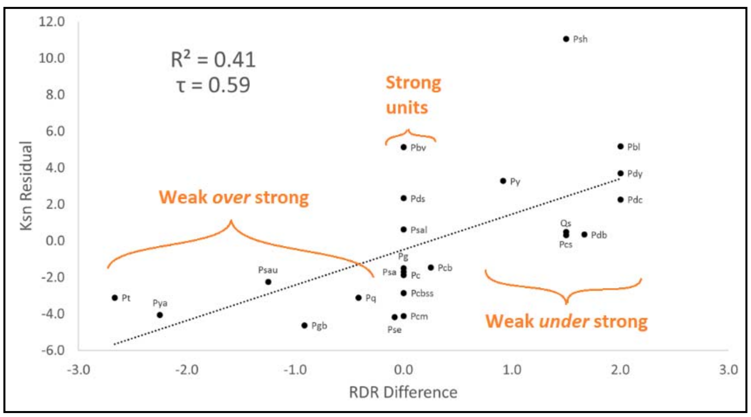

Fig. 5: Ksn residuals indicate that the spatial ordering of bedrock units influences local steepness (Marino and Johnson, 2017).

Overall, we interpret that (a) local bedrock properties influence *local* erodibility (Fig. 4), and also that (b) more resistant rock units both upstream and downstream exert *nonlocal* lithologic control on channel reach evolution, through sediment production and base level controls (Fig. 5). We are encouraged that *RDR* works as well as it does, because it suggests that mapped geological units—available at varying resolutions for practically all of Earth’s land surface—can be useful for understanding lithologic controls on topography. At the same time, limitations of the *RDR* metric are clear. Importantly, geological units are typically chosen based on depositional facies or other genetic characteristics of rock bodies, are often spatially and internally heterogeneous, and need not have spatially consistent rock properties or erodibility. Values are semi-quantitative (at best), and are not (yet) directly linked to physical, measureable rock properties. Our proposal is designed to address these limitations.

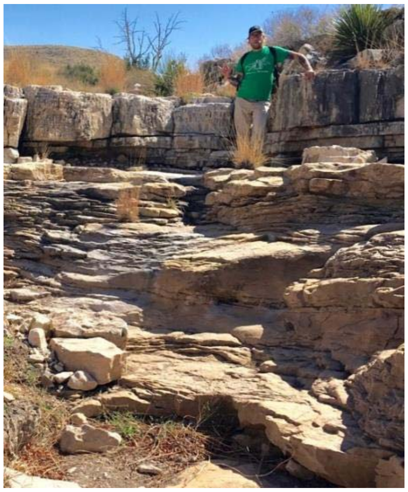

Fig. 6: Field photograph showing varaibility in discontinuity spacing along a channel step.

At the smaller spatial scale of channel reaches, preliminary field observations indicate differences in strength and fracture spacing between sandstone and limestone rocks (Fig. 6). We measured in situ compressive rock strength using a Schmidt hammer in exposed bedrock in ~30 m channel lengths. In all reaches, 30 strength measurements were made at regular intervals along a measuring tape laid along the thalweg of the channel. The spacing between fractures intersecting the tape was also measured. We combined data from sandstone reaches and limestone reaches along a single channel. Surprisingly, we found that Schmidt Hammer rebound values were statistically higher in the sandstone rocks (mean, median, and maximum values) and that fracture spacing was greater in the sandstone beds (fractures are farther apart). While we expect that this result will not be universal across the field area, it demonstrates that differences in strength and fracturing can be quantified. In future surveys we will measure fracture and discontinuity spacing in 3 dimensions to better quantify the variability that is present.

Finally, recent work by Prof. Lisa Tranel at Illinois State University and a Masters student has measured bedrock exposure ages/erosion rates using ^{36}Cl and ^{10}Be CRN analysis, for 16 sandstone and carbonate samples on the western margin of the GM [Happel and Tranel, in review], to constrain the climatic, tectonic and geomorphic history of this escarpment. Three of the samples came from a bedrock channel, and suggest fluvial erosion rates of 71±9, 70±13 and 54±7 m/myr. While relating erodibility to rock properties was not the main focus of her CRN dating, Dr. Tranel will be a collaborator for this project. Working together will provide all of us with a more complete picture of the mechanisms and erosional history of this landscape (see letter of collaboration).

Hypotheses

Our interrelated hypotheses are designed to (a) quantify how bedrock properties influence processes and are expressed in the topography of the GM, across a range of spatial scales from small first-order basins up to orogen-scale patterns of channel network topography, and (b) evaluate how bedrock properties quantitatively influence landscape evolution through time, including how rock properties, climate and tectonics could be imperfectly inferred from topography. Hypotheses 2-5 are designed to evaluate specific mechanisms and implications of hypothesis 1.

Overarching Hypothesis OH1: Channel steepness is influenced by bedrock properties through two primary mechanisms:

- *OH1.1*: **Directly**, by controlling local channel bed erodibility.
- *OH1.2*: **Indirectly**, through coarse sediment produced from bedrock erosion in the upstream watershed.

Hypothesis H2: Bedrock erodibility is influenced by bedrock strength, but more strongly by bedrock discontinuity spacing (e.g. bed thicknesses and/or fracture spacing). Therefore, channel steepness/morphology will correlate more strongly with discontinuity spacings than with Schmidt hammer-based rock strengths.

- *H2.1*: Because larger blocks are harder to pluck, local channel steepness will correlate more strongly with relatively thick beds (e.g., the 84th percentile of the local bed thickness distribution) than with thinner beds (e.g. the median of the bed thickness distribution).

Hypothesis H3: The distribution of coarse grain sizes, which derive from erosion of bedrock, is controlled by the distribution of discontinuity spacings. Therefore, changes in coarse GSDs along channels will vary with changes in discontinuity spacing distributions in the upstream catchments.

Hypothesis H4: The spatial organization of relative rock strength contrasts can lead to bedrock with the same properties expressing a different steepness depending on the properties of upstream and downstream bedrock, through the following mechanisms:

H4.1: More resistant units primarily influence **upstream** weaker units through **local base level control**, potentially decoupling upstream and downstream reaches.

H4.2: More resistant units primarily influence **downstream** weaker units through the **grain size distribution (GSD) of coarse sediment** derived from these resistant units.

H4.3: The downstream distance over which channel steepness is controlled more strongly by coarse sediment supply than by bedrock erodibility corresponds to length scales of downstream fining.

Hypothesis H5: The present-day topography of the Guadalupe Mountains has evolved to clearly but non-uniquely express bedrock properties (through the mechanisms of local erodibility and coarse sediment production), even though landscape erosion is not in long-term steady state with uplift.

H5.1: Only when eroding bedrock landscapes are farthest from equilibrium are rock properties not dominantly reflected in topography.

Research Methods and Tasks

We propose to evaluate these hypotheses using four primary *methods*: (a) cosmogenic radionuclide (CRN)-based bedrock erosion rates using ^{10}Be and ^{36}Cl, (b) GIS and spatial analysis of DEMs, airborne and ground-based Lidar and photogrammetry, (c) field quantification of bedrock properties (e.g. strength, bed thicknesses, fracture spacings) and sediment GSDs, and (d) landscape evolution models (LEM).

To evaluate the hypotheses in a tractable manner, our research plan focuses on two parts of the channel network. First, data collection will be done in relatively small first-order watersheds up to ~1 km^2 to understand rock property feedbacks with channel topography over spatial scales from meters to 100s of m. This scale is large enough to exhibit lithologic variability, but small enough to minimize complexities such as significant sediment storage from cut and fill cycles of valley alluviation. Second, to explore how spatial patterns of rock properties control channel topography at larger spatial scales up to 10s of km, data will be collected in reaches from upstream to downstream of more resistant units. We next describe these methods and associated tasks, and then explain how hypotheses will be tested.

(a) Erosion rates and erodibilities using CRNs: What are rates of present-day downcutting along channels, and how do they vary both spatially and with rock type? Erosion rates are needed for calculating erodibilities, and as boundary conditions for LEMs. We propose to use discrete bedrock samples from channel beds. Because erosion and sediment production may vary both spatially and with rock type, uniform erosion and mixing assumptions of standard basin-averaged methods would not be met. Following established bedrock surface sampling and processing protocols, we will use ^{10}Be for sandstones and ^{36}Cl for carbonate in collaboration with Prof. Arjun Heimsath at Arizona State University (ASU), who is currently setting up ^{36}Cl processing capabilities in-house (see attached letter of collaboration). Both Dr. Heimsath's and Dr. Tranel's expertise in using CRNs to quantify geomorphic rates and processes justifies our collaboration. Dr. Heimsath and Dr. Tranel will collaborate on all aspects of this project, including field work and data interpretation.

Erodibilities will be calculated from measured erosion rates based on eq. 1 (solving for K as a function of topography-based slope and area for straightforward comparison to other studies) [e.g. Stock and Montgomery, 1999; Murphy et al., 2016], and also for the particular LEM equations that we will use [Shobe et al., 2016].

GIS analysis and preliminary field observations will be used to choose watersheds and reaches for sampling. First, sampling focused on relating erodibility to rock properties (*H2*) will be done in ~5 <1 km^2 first-order drainages. These small basins will be chosen where there is no evidence of alluvial terraces or cut and fill cycles (to reduce the likelihood of ages being systematically affected by prior alluvial shielding). Each of these small basins will have ~5 separate CRN samples collected that target different rock layers. This number of samples (25 focused on small basins) represents a balance between resolving topographic and lithologic influences on erosion rates and budgetary constraints.

Second, additional sampling will measure erosion rates upstream, within and downstream of more resistant units. This work will evaluate base level and coarse sediment controls on erosion patterns (*H3.1, H3.2*), determine the extent to which channel morphology has adjusted to give spatially consistent erosion rates (*H4*), and further evaluate local rock property controls on erodibility (*H2*). We will do this for 3 different channels, with 3 CRN samples collected within the most resistant stratigraphic section, 3 samples upstream, and 3 downstream, for a total of 27 samples focused on how larger-scale lithologic contrasts influence spatial erosion patterns and processes. Overall, the combined number of samples (52) is needed in order to constrain variability and uncertainty in lithologic controls at different spatial scales.

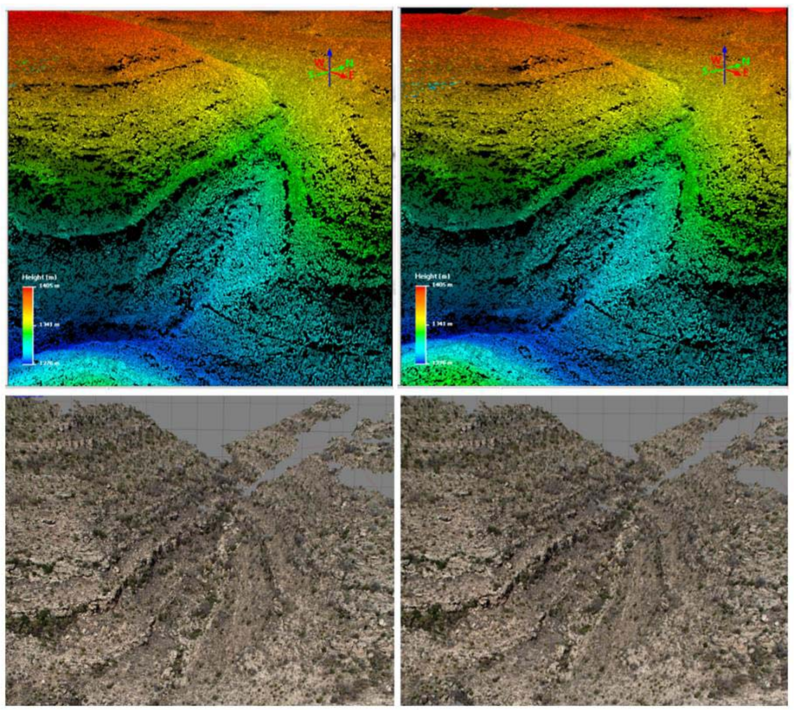

Fig. 7: Comparison of bare-earth Lidar point cloud (above) and structure-from-motion topography (below), for a valley at 32.17 N lat, -104.511 lon. View in stereo by relaxing one's eyes. Field of view is ~150 m.

(b) GIS and geospatial analysis to quantify channel topography: Further GIS analysis is needed to build on the preliminary results (Fig. 3-5), to choose field survey reaches and watersheds, to more precisely relate topography to rock properties and erodibility, and to make predictions of stratigraphic layer thickness and rock property distributions that can be tested in the field. At the first-order watershed scale, we will use a combination of airborne lidar where available (Fig. 1), Structure From Motion (SFM) at smaller spatial scales (10s to ~100 m) from field photos using Agisoft Photoscan software, and ground-based Lidar surveys where SFM does not work well (e.g. in overly vegetated reaches of interest). Fig. 7 compares a bare-earth lidar point cloud (above) and SFM topography (below) for a small first-order watershed. We will calculate topographic metrics including local channel steepness, surface roughness, and variability in these values over different window sizes along channel topographic swaths. Concavity (θ) will also be evaluated over somewhat larger spatial scales. These metrics will be compared to erodibilities and rock properties (described below). For example, does average discontinuity spacing correlate with length scales of surface roughness along channel reaches?

To keep the proposed research tractable, the overall project is focused on channels, not hillslopes. Nonetheless, Fig. 7 shows that there is a clear stratigraphic signature in the topography of hillslopes, which we will explore in relation to channels. We will attempt to use airborne Lidar to predict bed thickness distributions prior to collecting these data in the field. JPJ has previously developed algorithms to identify stair-step contour artifacts from USGS DEMs [Wobus et al., 2006]; these will be modified to identify stair-stepped topography at relevant spatial scales of stratigraphy.

(c) Field quantification of bedrock properties and GSDs: Field work will quantify bedrock properties--primarily distributions of rock strength, fracture spacing, and bed thickness--along channels and some adjacent hillslopes. Guided by the GIS analysis, we will survey specific channel reaches in multiple watersheds that span a range of rock types and channel steepnesses while avoiding mapped faults. First, we will measure rock properties at high spatial resolutions (several m intervals) along entire channels (hundreds of m up to ≈1 km) in the ≈5 first-order watersheds. Second, for the larger-scale study of how rock property variability controls topography (*H4*), we will survey multiple reaches ≈100 m in length upstream, through, and downstream of more resistant units. These survey reach positions will be chosen prior to detailed field observations, in order to avoid selection bias (consistent with methods of Thaler and Covington [2016]). Overall, between these different field survey tasks, we envision extensive surveying along over ~20 km of channel distance. This amount is warranted for robust statistical comparisons, and is ambitious but feasible based on previous channel surveying [Johnson, 2007].

Schmidt hammers will be used to quantify distributions of intact (i.e. locally unfractured) rock strength. Previous work [Bursztyn et al., 2015; Murphy et al., 2016] shows that these field data correlate strongly with lab-measured tensile strengths, which in turn predict experimentally-measured rock resistance to abrasion [Sklar and Dietrich, 2001]. Although we think chemical weathering-related reductions in bedrock strength are minor in this landscape, Murphy et al. [2016, 2018] demonstrated that Schmidt hammer strengths can quantify physical strength reductions due to chemical weathering, and account for weathering influences on erodibility. We will measure stratigraphic sections of bed thicknesses and rock types, and corresponding Schmidt hammer strengths. Fracture spacing will similarly be measured, both along the channel bed and as part of measuring stratigraphic sections. Our data will also quantify how well bed thickness can predict fracture spacing, as expected from previous rock mechanics work [e.g. Gross et al., 1995]. We will also measure the other variables required to calculate Selby Rock Mass Strength (e.g. fracture orientation, width, continuity, groundwater seepage), to compare this established metric of rock properties to erodibility [Selby, 1980]. Survey protocols will be carefully described, in order to improve and validate protocols needed for quantifying fracture characteristics in the field [Scott and Wohl, 2018].

Bedding contacts and fractures define discontinuity spacings that in turn control erodible block sizes and coarse sediment production [e.g., Spotila et al., 2015; Keen-Zeebert et al., 2017; Sklar et al., 2017]. Gravel GSDs will be measured using random-walk point counts measured in discrete reaches. Nested sampling reaches will be chosen to evaluate how strongly or weakly bedrock discontinuity spacings in the upstream watershed influence channel GSDs. In every reach we will also measure maximum boulder sizes (e.g., intermediate diameters of the 50 largest clasts in each reach), as well as estimated fractions of alluvial cover [e.g., Johnson et al., 2009; Thaler and Covington, 2016].

(d) Landscape evolution modeling provides an opportunity to quantify how the topographic expression of rock properties varies as landscapes evolve through time and away from steady state. Model development will build on and contribute to Landlab, an open-source Python library for modeling Earth surface processes developed by a team that includes NMG [e.g., Hobley et al., 2017]. The LEM we use will be as simple as possible while accounting for key process interactions between topography, bedrock erodibility and coarse sediment supply. To make models tractable and for simplicity, our LEM will not include topographic fracturing feedbacks with localized weathering [e.g. St Clair et al., 2015].

<u>Rock Properties</u>: Landlab can track material layers, both subsurface rock layers with different imposed erodibilities and sediment thicknesses deposited on the bedrock surface (Fig. 8) using the LithoLayers and Lithology components. These components were created by Dr. Katy Barnhart, who will collaborate with the team on model improvement and research (see letter of collaboration).

<u>Fluvial Bedrock Erosion & Sediment Entrainment/Deposition</u>: The Landlab SPACE 1.0 component will be used to model river channel evolution [Shobe et al., 2018]. For brevity, we do not include the SPACE (Stream Power with Alluvium Conservation and Entrainment) equations here. This model captures the erosion, entrainment, and deposition dynamics of mixed bedrock-alluvial channels. Where

locally exposed, bedrock erosion follows eq. (1). Alluvial cover inhibits incision (the "cover effect") [e.g., Sklar and Dietrich, 2004; Johnson and Whipple, 2009]. The thickness of sediment and the bedrock elevation are tracked. Bedrock erosion (on both hillslopes and channels) produces two size classes of sediment: a fine size that is suspended during floods, and a coarse size that can be entrained and deposited. We will modify the model to enable rock-property dependent variations in the size of produced sediment, as well as downstream fining of sediment [e.g. Sklar et al., 2006]. We will model a distribution of storms (a capability already in Landlab), because discharge variability is important for mobilizing coarse sediment with spatial variations in size [e.g. Lague, 2014; DiBiase and Whipple, 2011].

Hillslope processes: We will model hillslopes using a non-linear diffusion model [e.g. Roering, 2008], with diffusivity, critical slope, and sediment production potentially varying among rock layers. This approach greatly simplifies actual hillslope processes, and more sophisticated models exist for hillslope sediment production and block movement [e.g. Johnstone and Hilley, 2015; Glade et al., 2017]. Because our main focus is on channel evolution, using a relatively simple and established hillslope model is appropriate for calculating the flux of coarse sediment to channels through time.

How should one scale up from lithologic heterogeneity at bed scales to bedrock erodibility expressed in channel reaches and watersheds? To tackle this question, we will model first-order watersheds with similar sizes as those studied in the field, about 1 km^2. It will be feasible to run these models using a grid spacing of ~ 5 m, with discrete bedrock bed thicknesses of several meters with contrasting erodibilities (since channel slopes are relatively low, there will be multiple channel grid cells for each lithologic layer). For these small drainages we will model both hillslopes and channels. We will start with a flat topography (with small surface roughness) and uplift it to develop a watershed. Some runs will continue with uplift and erosion, while some will stop uplift and allow the watershed to erode down to lower slopes over time. The watershed-scale model will not be able to resolve bed thickness distributions at the submeter-scales quantified in the field, but the field data will nonetheless provide model constraints on distributions of bed thicknesses, erodibilities, and coarse sediment sizes. Using the model, we can explore whether erodibility variations over short distances are expressed in topography. Coarse sediment from upstream may mask the local rock erodibility.

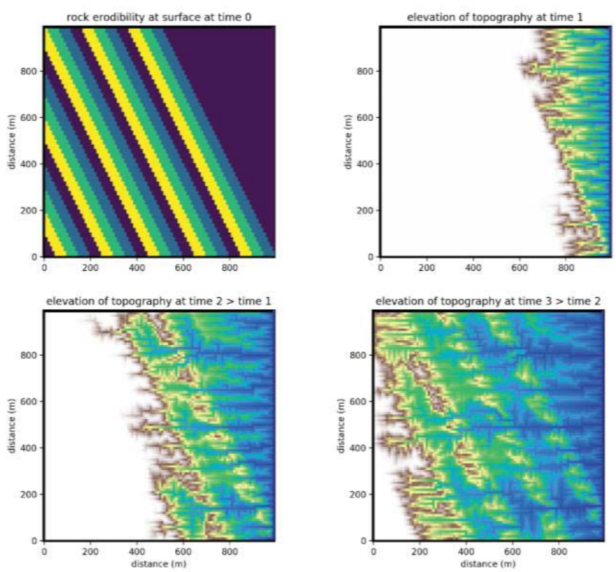

Fig. 8. Example of layering and topographic evolution in Landlab. Top left shows map of rock erodibility exposed on a flat surface at the initiation of a model run. Rocks dip to the east, north-east. Upper right, to lower left, to lower right panels show the time progression of surface elevation as the landscape evolves, draining to an open boundary on the east side. Note that maximum and minimum elevation vary among the topographic maps.

One systematic set of experiments will explore how to best average erodibilities, by starting with fine-scale erodibility variations in different beds, and comparing to model runs with smaller numbers of progressively thicker beds. End-member cases of single erodibilities will also be modeled. A second set of experiments will explore how the relationship between local channel steepness and local erodibility change through time as a watershed evolves towards a quasi-steady-state form. Finally, for model comparison we will also run experiments using models simpler than the full SPACE components, such as detachment-limited models comparable to Forte et al. [2016] and Perne et al. [2017]. The flexibility to turn model components on and off in Landlab will let us explore the importance of different feedbacks and model parameters.

Numerical experiments will also be run at the larger spatial scale of more and less resistant units (e.g. *H4*), building on our preliminary RDR analyses. Models will explore how spatially variable bedrock erodibility, local baselevel control by resistant units, and coarse sediment production influence channel steepness upstream and downstream of resistant units. We will start by uplifting a flat topography to develop erosion into an escarpment. We will model different uplift scenarios, including steady uplift and short periods of very rapid uplift. Our modeling domain will be ~ 20 km by 10 km, encompassing roughly four large watersheds draining the mountain front in our field area. Experiments will systematically explore how contrasts in erodibility influence incision rates, sediment cover, and channel steepness. The parameter range that we explore will be broader than what we observe in the GM, to gain a generalizable understanding of how rock properties impact landscape evolution. We will evaluate how well local channel steepness can predict local erodibility through time as these landscapes evolve.

Hypothesis testing and research tasks

Hypothesis H2: What field-measurable bedrock properties best predict patterns of erodibility, and/or can be inferred from topography? A challenge is scale: bedrock properties vary spatially over much shorter distances than reach-averaged channel steepness or erodibility. Our analysis will address this by calculating metrics derived from rock property distributions (e.g bed thickness, fracture spacing, and Schmidt hammer strength distributions) over relevant channel reach lengths. We propose several specific ways to calculate rock property metrics. (a) *H2.1* argues that a specific metric--the 84th percentile bed thickness-will best predict steepness. Importantly, both rock mechanics theory and empirical observations indicate that fracture spacing in layered bedrock is commonly correlated with layer thickness [e.g. Gross et al., 1995]. The bed thickness distribution should therefore predict discontinuity spacing and block size distributions in layered rocks (an assumption to be tested with our field data). (b) Assuming that erodibility scales as 1/(tensile strength)^2 as expected for impact wear alone [Sklar and Dietrich, 2001], erodibility may correlate inversely with the mean of Schmidt hammer strengths in a reach, or with some percentile of the distribution of bed strengths (e.g. 84th percentile Schmidt hammer strength). (c) Erodibility could also best correlate with a weighted combination of Schmidt-hammer based strength, discontinuity spacing, and the apparent dip (orientation) of contacts or joints relative to the stream bed, or similarly with Selby's rock mass strength (*RMS*) [Selby, 1980].

We will evaluate *H2* and *H2.1* through the strength of statistical correlations between variables. For example, *H2* would be supported if the correlation between discontinuity spacing-based erodibility metrics and local reach steepness was much stronger than the correlation between steepness and Schmidt hammer strength. A methodological challenge is that searching for correlations among many variables might lead to spurious correlations and interpretations (sometimes described as "p-hacking", e.g. Nuzzo [2014]). To avoid related pitfalls, prior to data analysis we will detail in writing, pre-registered through "Open Science Framework" or a similarly appropriate venue, what variable combinations we will test for correlations and why [e.g., Nuzzo, 2014; Head et al., 2015].

Hypothesis H3: To evaluate how upstream bedrock discontinuity spacing distributions influence channel GSDs, we will compare statistics of field-measured distributions for both variables, both among different watersheds, and also within nested watersheds along channels. Statistical tests will be applied to see if discontinuity spacing distributions and GSDs are significantly different. In addition, we look for correlations between the means, medians, and other percentiles (e.g. D_{84}) of discontinuity spacings and GSDs among different watersheds and nested watersheds. For example, a significant correlation between GSD medians and the median fracture spacings or bed thicknesses among the different first-order watersheds would support *H3*, and also give a measure of the sensitivity of GSDs to upstream discontinuities. We will also test whether incorporating Sternberg's "law" for exponential decreases in grain size with transport distance, applied to discontinuity spacings at progressive distances upstream, improve GSD predictions [e.g. Sklar et al., 2006].

Hypothesis H4: This hypothesis is designed to evaluate the mechanisms underlying our preliminary observation that weaker units upstream of resistant units have lower steepnesses than expected (*H4.1*), while channel reaches downstream of more resistant units are steeper than expected (*H4.2*). Nonuniqueness between rock properties and channel steepness (*H4*) will be evaluated by comparing the strength of correlations between reach steepness and rock property metrics (as described above for *H2*).

If CRN-based erosion rates are systematically lower on resistant units and upstream weaker units but higher in downstream reaches, then the local baselevel control hypothesis (*H4.1*) would be supported. However, upstream reaches may simply reflect topographic adjustment to local bedrock properties/erodibility, while downstream reaches are more strongly influenced by coarse sediment production from more resistant units. This would not require differences in erosion rate or local base level control. Finally, landscape evolution modeling will importantly allow us to evaluate the temporal evolution of erosion rates and steepness upstream and downstream of more resistant layers, and to generalize the degree to which local base level influences steepness.

Hypotheses *H4.2* and *H4.3*--coarse sediment from resistant units causes steeper downsteam reaches, over length scales corresponding to downstream fining--will be evaluated from field surveys and GIS analysis downstream of resistant units. In addition, LEMs will vary sediment production from resistant units (size, proportion of coarse to fine sediment, length scale of downstream fining), to determine how steepness changes through time in response to coarse sediment loads downstream of resistant units.

Hypothesis H5: CRN erosion rates, field surveys of rock properties, and landscape evolution modeling will all be important for determining the extent to which non-steady-state landscape erosion influences the topographic expression of bedrock properties. This hypothesis is fundamental for understanding the limits of quantitatively inferring bedrock properties from topography, in relation to boundary condition signals of tectonic or climatic history. CRN erosion rate patterns will show the degree to which erosion rates are systematically variable or spatially consistent. Comparisons of local channel steepness, bedrock properties, and coarse sediment GSDs will indicate the degree to which rock properties are currently expressed in landscape form (e.g., *H2*, *H3*). Landscape evolution modeling will test *H5.1* and determine how strongly contrasting rock properties are expressed in topography when landscapes are far from quasi-equilibrium form. We will run a range of models with varying external forcing (such as pulses of relative base level fall). Patterns of channel steepness will be calculated for numerical landscapes further from and closer to quasi-equilibrium conditions, to determine the extent to which topography reflects bedrock erodibility rather than external forcing. Similarly, we will compare away-from-equilibrium landscapes to quasi-equilibrium topography, to see how signals of lithology mask and obscure the history of tectonic and/or climatic forcing.

Overarching Hypothesis O*H1*: Finally, the specific mechanisms and controls evaluated through *H2-5* will together let us determine how rock properties control the evolution of topography, directly through local erodibility and indirectly through coarse sediment production. We acknowledge that it may be difficult to separate local erodibility (*OH1.1*) vs sediment production controls (*OH1.2*), as these controls should themselves be correlated: both are predicted to depend on similar bedrock properties, such as discontinuity spacings. Nonetheless, the evaluation of *H2*, *3*, *4.2* and *4.3* will separate these factors to the extent possible in our data.

Research personnel and logistics

The proposal will support a PhD student at both Tulane (TU) and UT Austin (UT). At least one undergraduate at each institution will do an Honors Thesis or research project. **The budget includes**

funding for salary, field work, and conference attendance for both undergraduate and graduate students at TU and UT. The two PhD projects will be catered to the interests and strengths of each student, but both students will gain broad expertise in field work, CRN and GIS analysis, and landscape evolution modeling. All researchers involved--JPJ, NMG, Dr. Katy Barnhart, Dr. Lisa Tranel, Dr. Arjun Heimsath, and students will participate in overlapping field work. Both PhD students will learn to do CRN sample processing at ASU through Heimsath. JPJ and NMG will make sure that field data collection is done following consistent methods by students working closely together. To ensure close collaboration and communication, participants will hold group videoconference meetings every 1-2 weeks. JPJ and NMG have successfully collaborated on a previous project (see Results from Prior NSF Support).

We envision having the TU student focus on the first-order basins, both in terms of field data collection and analysis (including *H2*), and modeling. Overall the TU PhD project will be more modeling focused. The student will work with Dr. Katy Barnhart and NMG to modify and develop Landlab components needed for the overall modeling effort. **Barnhart is an early career scientist, and the TU budget includes funding to support her time on this project.** In addition to modeling first-order basin evolution with hillslope-channel coupling, this student will take the lead on modeling how the expression of rock properties varies during landscape evolution away from steady-state (*H5*). The UT PhD student will do a somewhat more field work-heavy project, primarily focused on quantifying the mechanisms and feedbacks by which contrasting lithologies interact and how more resistant units influence topography both upstream and downstream along channels (*H4*). They will also take the lead on understanding how sediment GSDs are influenced by bedding and fractures (*H3*). This student will do less landscape evolution model development, but will apply Landlab to address *H4*.

We have already obtained a National Park Service permit to do field work and some CRN sampling in Carlsbad Caverns National Park (Permit# CAVE-2018-SCI-0005). We have spoken in person with representatives from both CCNP and Guadalupe Mountains NP; both parties indicated that our research plans sounded reasonable. Collaborator Tranel also previously received permission for CRN sampling in Guadalupe Mountains NP. Finally, much of the field area is Forest Service and other public land where National Park sampling restrictions do not apply. Reconnaissance field work indicates that our logistics are feasible, including road and hiking access to areas both inside and outside of the National Parks.

Intellectual Merit

In conclusion, our proposed research will improve quantitative interpretations of rock properties from high resolution topography, spanning spatial scales from individual sedimentary beds to 10s of km along channels. Equally important, we will also evaluate non-uniqueness and uncertainty in interpreting bedrock properties, process and history from topography. The availability and spatial resolution of digital topographic data has arguably outpaced our ability to rigorously understand it. While much research has inferred signatures of tectonics from topography [e.g. Wobus et al., 2006; Hilley and Arrowsmith, 2008; Harvey et al., 2015], less work has focused on "reading" underlying controls of contrasting rock properties from topography [e.g. Bursztyn et al., 2015; Forte et al., 2017; DiBiase et al., 2018]. This is in spite of the fact that rock property controls will always be present when trying to infer subtle signals of the history of tectonic and climatic boundary conditions from landscapes. Our research plan is designed to not only isolate separate controls of rock properties on erodibility and sediment production, but also to integrate these factors to understand how spatial contrasts in rock properties become expressed across an entire natural landscape.

Improving our ability to interpret rock properties from topography across spatial scales has many potential benefits and applications. Because topography is measurable remotely, the geology of inaccessible or otherwise unreachable locations could be mapped with improved accuracy from topographic constraints. Better interpretations of rock properties from topography would be useful for planetary sciences. For more accessible field areas, improved abilities to interpret erodibility and rock properties from topography would help with hypothesis building and planning for future field work. Constraining spatial variations in rock properties at high spatial resolutions could improve hazard predictions over large areas, such as landslide susceptibility which depends strongly on local near-surface conditions. Finally, our proposed work is designed to improve process feedbacks in landscape evolution models, allowing lithologic controls to be modeled with more accuracy and confidence. We will make all Landlab codes available through CSDMS and GitHub (see CSDMS support letter).

Broader Impacts

In addition to educating graduate and undergraduate students in conducting scientific research at UT and TU, we propose to (a) communicate science to public visitors at the two national parks, (b) incorporate geoscience education based on the Guadalupe/Carlsbad field sites into an undergraduate course curriculum that is taught to thousands of high school students across Texas through UT's Onramps program, and (c) create a field experience for small groups of Texas high school teachers participating in Onramps to improve their geoscience knowledge, teaching, and enthusiasm.

JPJ and NMG will make efforts to recruit graduate students and undergraduate research assistants from groups underrepresented in geosciences to work on this project. Both have successful track records in this regard: to date Johnson has advised 5 women to completion of graduate degrees (out of 7 students) and advised one female postdoc, while NMG has advised one female post-doc, 2 female graduate students to completion (out of 5 students) and currently has a female Hispanic MS student. NMG has advised 6 female undergraduate students on theses or projects (out of 10 students). Of these 6 female undergraduates, 5 have gone on to graduate school, and the other has not yet graduated.

Representatives of both Guadalupe Mountains and Carlsbad Caverns NPs expressed interest in having us develop outreach poster presentations to exhibit in park visitor centers, describing our projects to the broader public (see support letter from Carlsbad NP). QR links will be provided on these posters to a website we develop describing this research project and highlighting related educational videos.

At UT, JPJ teaches Geo302E "Earth Wind and Fire" (EWF), a geoscience literacy course that enrolls ~250 undergraduate non-geoscience majors each year on campus. JPJ is also the "Faculty Lead" for an equivalent version of this course that has been taught for the last 3 years to 1,219 Texas high school students through UT's Onramps program (OnrampsEWF). Enrollment in this class is rapidly growing-- ≈1700 high school students are expected to complete OnrampsEWF in the 2018-2019 school year alone, taught by ~65 local high school teachers. A complete inquiry-based learning curriculum developed under Johnson's guidance is provided to teachers. Assignments are uploaded and graded at UT, and exams are taken online. Students who pass can receive UT college credit at no direct cost to them.

UT developed the Onramps program to expand opportunities for college education to students across Texas, with a strong emphasis on making college (and UT) more affordable and accessible to students from underrepresented groups. Geosciences are one of the least diverse of all STEM fields, in part because students are introduced to it later than other sciences [e.g. Haacker, 2015; Bernard and Cooperdock, 2018]. Because geosciences are not usually part of high school curricula, Onramps-EWF provides a specific and unique opportunity to engage high school students from diverse backgrounds in geosciences. Onramps collects diversity data through student surveys. To date, 56% of Onramps-EWF enrollees have self-reported as Hispanic, consistent with Texas high school demographics. Onramps-EWF effectively introduces Earth sciences to students from underrepresented groups.

Broader outreach from this project will be included in OnrampsEWF in two ways. First, we will incorporate the field geology of the Guadalupe Mountains into inquiry-based learning assignments, to make Earth science feel more relatable, relevant and closer to home for the Texas-based students. The field area has world-class caves, Permian reefs and fossils, and stratigraphy relevant for hydrocarbon exploration and production. Short 5-10 minute video lectures are already integrated into the Onramps-EWF curriculum. JPJ, NMG and students will together film additional video segments in the GM/CC field area. These will also be posted on the research/education project website for the broader public.

The high school teachers who apply and are chosen to teach OnrampsEWF are taught by Johnson and other Onramps staff during an intensive 2-week summer program, with additional in-person professional development sessions each year. These high school teachers tend to be highly engaged in the content, but rarely have prior geoscience backgrounds. To address this challenge, in years 2 and 3 we will bring ~10 high school teachers on a voluntary, intensive, and fun long-weekend mini-course on the geology and geomorphology of the area, covering content integrated into the EWF-Onramps curriculum. **Funding is included in the UT budget to cover expenses for the high school teachers during this field trip.** Getting teachers into the field with geologists doing research in that region provides a broader exposure to many concepts covered in OnrampsEWF. All of this knowledge and enthusiasm taken back to the classroom should increase student engagement and let them see "real world" examples and applications of the geoscience they are studying. We would poll the teachers after the trip (and again after the school year) to find out if and how the field experience improves their understanding, teaching, and student interest. Finally, we would ask these instructors to help teach related content in future teacher professional development sessions. This field geology experience for teachers would have a multiplicative effect—improving training for 10 teachers in years 2 and 3 would impact much larger numbers of students over the duration of the project.

Results from prior NSF support

Collaborative Research: Modeling and monitoring of landscape evolution along a climate gradient: Kohala Peninsula, Hawaii. $393,198, PI Gasparini (EAR-1025055), Co-PI Johnson (EAR-1024982), 8/01/2010-7/31/2015 (including no-cost extensions for Johnson).

Intellectual Merit: The fundamental goal of this project was to understand specific mechanisms and processes by which climate controls bedrock channel incision, and also to quantify the strength of climate forcing on landscape evolution. We found that that climate-erosion coupling mechanistically occurs in part through weathering-dependent bedrock weakening [Murphy et al., 2016; Han et al., 2014]. Climatic controls on erosion rate and bedrock erodibility influences topography over orders of magnitude of spatial scale, from channel bed roughness (~meter) to longitudinal river profiles (10s of km at this field site) [Murphy et al., 2018]. We quantified the strength of the weathering-rock-strength-precipitation relation at the Kohala field site [Murphy et al., 2016]. Finally, landscape evolution modeling to generalize the results to understanding how climate gradients imprint onto watershed form [Han et al., 2015].

Peer-reviewed **publications** made possible by this grant have all been first-authored by students, and are published in Nature [Murphy et al., 2016], Geology [Murphy et al., 2018], JGR-Earth Surface [Han et al., 2014], ESPL [Han et al., 2015], and GSA Bulletin [Menking et al., 2013]. Data are available in supplementary material from these papers and in two PhD Theses [Murphy, 2016; Han, 2014]. Code additions made to the CHILD model are available via GitHub.

Broader Impacts: The project supported the core PhD research of two students (Brendan Murphy, UT PhD 2016, and Jianwei Han, TU PhD 2014), and supported undergraduate research that became a first author paper [Menking et al., 2013]. Field examples based on this project have been incorporated into the curriculum of at least four different UT and TU classes. Working with Hawaii landowner Sweetwater LLC (formerly New Moon Foundation), we developed outreach material for the broader public, as both brochures and a permanently installed informational display that was part of an "ecotourism" zipline operated on their property. Gasparini presented results from this research as part of her 2016 Gilbert Club Talk given to ~ 300 members of the geomorphology community, and she continues to give invited departmental seminars on the project.

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"*" Denotes student advisee of JPJ or NMG.

"†" Denotes publication supported by NMG & JPJ's prior NSF project

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Biographical Sketch

Prof. Joel P. L. Johnson
Department of Geological Sciences
The University of Texas at Austin, Austin, TX, USA
joelj@jsg.utexas.edu

Professional Preparation

Massachusetts Institute of Technology, Cambridge, MA, USA 1993-1997
B.S. in Earth Science, June 1997
Massachusetts Institute of Technology, Cambridge, MA, USA 2001-2007
Ph.D. in Earth Science, September 2007
U.S. Geological Survey, Menlo Park, CA 2007 - 2009
Mendenhall Postdoctoral Fellow

Appointments

Department of Geological Sciences, The University of Texas at Austin
Associate Professor 9/2017 – Present
Assistant Professor 2009 –2017

New England Research, Inc., White River Junction, VT 1997-2001
Staff Scientist at a small company focused on rock mechanics (www.ner.com).

Products

"*" Denotes student advisee of JPJ

Most closely related publications

*Murphy BP, **JPL Johnson**, NM Gasparini, GS Hancock, EE Small (2018), Weathering and abrasion of bedrock streambed topography, *Geology*, 46(5); 459-462, doi:10.1130/G40186.1

*Murphy BP, **JPL Johnson**, NM Gasparini, LS Sklar (2016), A mechanism for the climatic control of bedrock river incision, *Nature* , 532, 223-227, doi:10.1038/nature17449

Johnson JPL (2016), Gravel threshold of motion: A state function of sediment transport disequilibrium?, *Earth Surface Dynamics*. 4, 685-703, doi:10.5194/esurf-4-685-2016

Johnson JPL (2014), A surface roughness model for predicting alluvial cover and bed load transport rate in bedrock channels, *J. Geophys. Res. Earth Surf.,* 119, 2147-2173, doi: 10.1002/2013JF003000

Han J, NM Gasparini, **JPL Johnson**, *BP Murphy (2014), Modeling the influence of rainfall gradients on discharge, bedrock erodibility, and river profile evolution, with application to the Big Island, Hawai'i, *J. Geophys. Res. Earth Surf.,* 119, 1418-1440, doi: 10.1002/2013JF002961

Other significant publications

Johnson JPL (2017), Clustering statistics, roughness feedbacks and randomness in experimental step-pool morphodynamics, *Geophys. Res. Lett.,* 44, doi:10.1002/2016GL072246

Johnson, JPL, K Delbecq, W Kim (2017), Predicting paleohydraulics from storm surge and tsunami deposits: Using experiments to improve inverse model accuracy, *J. Geophys. Res. Earth Surf.*, 122, doi:10.1002/2015JF003816

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*Olinde LJ, **JPL Johnson** (2015), Using RFID and accelerometer-embedded tracers to measure probabilities of bed load transport, step lengths, and rest times in a mountain stream, *Water Resources Research*, 51, 7572-7589, doi: 10.1002/2014WR016120

Johnson, JPL, *AC Aronovitz, W Kim (2015), Coarser and rougher: Effects of fine gravel pulses on experimental step-pool channel morphodynamics, *Geophys. Res. Lett.*, 42, 8432–8440, doi:10.1002/2015GL066097

Synergistic Activities

Faculty lead for Onramps Geo 302E: Earth Wind and Fire, a dual-enrollment UT Austin college course in Earth and environmental science class taught to thousands of high school students across Texas, 6/2016-present. My role involves curriculum development and working directly with high school teachers to improve their Earth science knowledge and professional development.

Associate Editor, Journal of Geophysical Research-Earth Surface, 2/2016-present.

Presented hands-on Earth science demonstrations and lectures to various elementary school classes (first, 2nd, 5th grades) in 2011, 2013, 2014, 2016, 2017.

Co-proposed and co-chaired sessions at fall AGU meetings in 2010, 2012, 2013, 2014, 2016.

Co-organized and co-led (with Arjun Heimsath, ASU) Friends of the Pleistocene field conference to the Henry Mountains, Utah. October 15-17, 2010. Approximately 100 people attended, including my UT geomorphology class.

NICOLE M. GASPARINI

Associate Professor
Tulane University
Department of Earth and Environmental Sciences
101 Blessey Hall
New Orleans, LA 70118
504-862-3197
ngaspari@tulane.edu

a) PROFESSIONAL PREPARATION

- **University at Buffalo, State University of New York**, Buffalo, NY, USA
  Mathematics, BS, 1995
  Physical Geography, BA, 1995
- **Massachusetts Institute of Technology**, Cambridge, MA, USA
  Civil and Environmental Engineering, SM, 1998
  Civil and Environmental Engineering, PhD, 2003
- **Yale University, Department of Geology and Geophysics**, New Haven, CT, USA
  Bateman Postdoctoral Fellow, October 2003 – August 2005
- **Arizona State University, School of Earth and Space Exploration**, Tempe, AZ, USA
  Postdoctoral Researcher, September 2006 – December 2007

b) APPOINTMENTS

- **Tulane University, Department of Earth and Environmental Science**, New Orleans, LA, USA
  Associate Professor, January 2015 - Present
  Assistant Professor, January 2008 – January 2015
- **Office of Congressman Edward Markey (MA)**, Washington DC, USA
  GSA/USGS AAAS Congressional Fellow, September 2005 – August 2006

c) PRODUCTS

i. Five most relevant (* indicates student author)

The CHILD Model: http://csdms.colorado.edu/wiki/Model:CHILD.

The Landlab Model: http://landlab.github.io/#/.

Gasparini, N. M., Whipple, K. X. and Bras, R. L., 2007, Predictions of steady state and transient landscape morphology using sediment-flux-dependent river incision models, *J. Geophys. Res.*, 112, F03S09, doi:10.1029/2006JF000567.

*Murphy, B. P, Johnson, J. P. L., **Gasparini**, N. M., Hancock, G. S., Small, E. E., 2018, Weathering and the abrasion of bedrock stream topography, *Geology*, doi: https://doi.org/10.1130/G40186.1.

Hobley, D.E.J., *Adams, J.M., *Siddhartha Nudurupati, S. Hutton, E.W.H., **Gasparini,** N.M., Istanbulluoglu, E., Tucker, G.E., 2017, Creative computing with Landlab: an open-source toolkit for building, coupling, and exploring two-dimensional numerical models of Earth-surface dynamics, *ESurf*, doi:10.5194/esurf-5-21-2017.

ii. Five other publications

*Murphy, B. P, Johnson, J. P. L., **Gasparini**, N. M., and Sklar, L. S., 2016, A mechanism for the climatic control of bedrock river incision, *Nature*, doi: 10.1038/nature17449.

*Han, J., **Gasparini**, N.M., Johnson, J.P.L., & *Murphy, B.P., 2014, Modeling the influence of rainfall gradients on discharge, bedrock erodibility, and river profile evolution, with application to the Big Island, Hawai'i. *Journal of Geophysical Research: Earth Surface*, doi: 10.1002/2013JF00296.

Gasparini, N.M., and Whipple, K.X., 2014, Diagnosing climatic and tectonic controls on topography: Eastern flank of the northern Bolivian Andes. *Lithosphere*, doi: 10.1130/L322.1.

Willenbring, J.K., **Gasparini**, N.M., Crosby, B.T., and Brocard, 2013, What does a mean mean? The temporal evolution of detrital cosmogenic denudation rates in a transient landscape, *Geology*.
Gasparini, N.M. and Brandon, M. T., 2011, A generalized power-law approximation for fluvial incision of bedrock channels, *JGR*, Vol 116, doi:10.1029/2009JF001655.

d) FIVE SYNERGISTIC ACTIVITIES

- **Advisor – Currently advising**: two MS students (one female, URM), one post-doc. **Past advising**: one post-doc (female), two PhD students (one female), three MS students (one female), three undergraduate honors scholars (thesis required) (two female), two undergraduate capstone projects (one female), five undergraduate research projects (3 female). Of the ten undergraduates (over ten years) whom I have worked with closely, eight have gone on to graduate school, and one is still an undergraduate. For context, I involve ~20% of departmental undergraduate majors in my research.
- **Co-chair of the Community Surface Dynamics Modeling System (CSDMS, [http://csdms.colorado.edu/wiki/Main_Page)](http://csdms.colorado.edu/wiki/Main_Page) Terrestrial Working Group (TWG)** – May 2016 – Present. The TWG has over 700 members. We regularly outreach to the community to advertise meetings and science and hear our communities needs and concerns with the aim of building tools to help them or highlighting where they can get help. We recently began a research "spotlight" award, the first of which was given to a female graduate student.
- **Meeting Organization: Primary organizer of the 2017 Gilbert Club Meeting at Tulane University**. Gilbert Club is a one-day, self-funded, geomorphology meeting with international attendees that follows the annual AGU meeting. There were 320 attendees. Two of the three primary speakers were women. Gasparini received no salary support for this effort. **Organizing committee member of the NSF-supported 2018 Workshop on Coupling of Tectonic and Surface Processes**. Gasparini helped plan and advertise the meeting, personally emailing early career scientists and women encouraging them to apply (94 attendees total; 38% female, 80% early career), ensured women were included as key-note speakers (3/9 female), panel members (2/5 female), and break-out group session leaders (9/20 female). Gasparini organized all the breakout groups to make sure they included a mix of early career and senior scientists and kept the percentage of women in the break-out groups roughly uniform. Gasparini received no salary support for this effort.
- **Co-led short-courses** on the Landlab modeling framework at CSDMS annual meetings (2014, 2015, 2016, 2017), at NCED summer schools (2015, 2018), at the University of Houston (2016), at Scripps Oceanographic Institute (2018), and at Lehigh University (2018).
- **Girls in STEM at Tulane (GiST):** Have led and participated in five GiST workshops in the past 4 years. Workshops are held during an all-day Saturday science and engineering event at Tulane. Our workshop uses GoogleEarth and rock exploration to introduce fifth to seventh grade girls to different aspects of earth science. Self-reported data shows that 46% of the girls identify as African American and 9% as Hispanic/Latino American.

Katherine R Barnhart
Postdoctoral Fellow
University of Colorado at Boulder
Department of Geological Sciences
2200 Colorado Avenue; Boulder, CO 80309
work phone n/a ; e-mail **katy.barnhart@gmail.com**, kbarnhar@colorado.edu

(a) Professional Preparation

Princeton University	Princeton, NJ	Civil and Environmental Engineering	B. S. E., 2008
University of Colorado	Boulder, CO	Geological Sciences	M. S., 2010
University of Colorado	Boulder, CO	Geological Sciences	Ph.D., 2015

(b) Appointments

(i) Postdoctoral Fellow, Department of Geological Sciences, University of Colorado at Boulder, October 2016-present
(ii) William Henrich Distinguished Postdoctoral Fellow, Annenberg Public Policy Center, University of Pennsylvania, September 2015-August 2016

(c) Products

5 Selected Products Relevant to the Present Proposal

E. Hutton, D. Hobley, G. Tucker, S. Nudurupati , J. Adams, N. Gasparini, J. Knuth; R. Strauch; C. Shobe; **K. R Barnhart,** F. Rengers. (2016). landlab/landlab: Rapunzel [model]. Zenodo. http://doi.org/10.5281/zenodo.154179

K. R. Barnhart, C. R. Miller, I. Overeem, and J. E. Kay. “Mapping the future expansion of Arctic open water”. In: Nature Climate Change (Nov. 2015). DOI: 10.1038/nclimate2848. URL: http://www.nature.com/doifinder/10.1038/nclimate2848.

R. C. Mahon, J. B. Shaw, **K. R. Barnhart**, D. E. Hobley, and B. McElroy. “Quantifying the stratigraphic completeness of delta shoreline trajectories”. In: Journal of Geophysical Research-Earth Surface 120.5 (2015), pp. 799–817. DOI: 10.1002/2014JF003298. URL: http://onlinelibrary.wiley.com/doi/10.1002/2014JF003298/.

K. R. Barnhart, R. S. Anderson, I. Overeem, C. Wobus, G. D. Clow, and F. E. Urban. “Modeling erosion of ice-rich permafrost bluffs along the Alaskan Beaufort Sea coast”. In: Journal of Geophysical Research-Earth Surface 119.5 (May 2014), pp. 1155–1179. DOI: 10.1002/2013JF002845. URL: http://doi.wiley.com/10.1002/2013JF002845.

K. R. Barnhart, I. Overeem, and R. S. Anderson. “The effect of changing sea ice on the physical vulnerability of Arctic coasts”. In: The Cryosphere 8 (2014), pp. 1777–1799. DOI: 10.5194/tc-8-1777-2014. URL: www.the-cryosphere.net/8/1777/2014/.

5 Selected Additional Products

K. R. Barnhart, K. H. Mahan, T. J. Blackburn, S. A. Bowring, and F. O. Dudas. “Deep crustal xenoliths from central Montana, USA: Implications for the timing and mechanisms of high-velocity lower crust formation”. In: Geosphere (Nov. 2012). DOI: 10.1130/GES00765.1. URL: http://geosphere.gsapubs.org/cgi/doi/10.1130/GES00765.1.

K. R. Barnhart, P. J. Walsh, L. S. Hollister, C. G. Daniel, and C. Andronicos. “Decompression during Late Proterozoic Al2SiO5 Triple-Point Metamorphism at Cerro Colorado, New Mexico”. In: The Journal of Geology (2012). DOI: 10.1086/665793. URL: http://www.jstor.org/stable/10.1086/665793.

T. J. Blackburn, S. A. Bowring, J. T. Perron, K. H. Mahan, F. O. Dudas, and **K. R. Barnhart**. “An Exhumation History of Continents over Billion-Year Time Scales”. In: Science 335.6064 (Jan. 2012), pp. 73–76. DOI: 10.1126/science.1213496. URL: http://www.sciencemag.org/content/335/6064/73.full.

(d) Synergistic Activities

Student Member, Geological Society of America Membership Committee, 2014-2017
Member, Geological Society of America Student Advisory Council, 2014-2017
Reviewer, Geomorphology, 2015; Natural Hazards, 2016, Earth Surface Processes and Landforms, 2018; JGR-Earth Surface, 2018
Convened Sessions at AGU in 2012, 2015; Sessions at EGU in 2015, 2016

SUMMARY PROPOSAL BUDGET

YEAR 1

FOR NSF USE ONLY	
PROPOSAL NO.	DURATION (months) Proposed / Granted
AWARD NO.	

ORGANIZATION
University of Texas at Austin

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Joel Johnson

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Joel Johnson - Associate Professor**	0.00	0.00	0.25	**2,919**	
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	**2,919**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**1**) GRADUATE STUDENTS				**28,873**	
4. (**1**) UNDERGRADUATE STUDENTS				**2,954**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**34,746**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**10,027**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**44,773**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				**6,300**	
2. INTERNATIONAL				**0**	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ **0**					
2. TRAVEL **0**					
3. SUBSISTENCE **0**					
4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**3,795**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**0**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**1,200**	
5. SUBAWARDS				**0**	
6. OTHER				**18,286**	
TOTAL OTHER DIRECT COSTS				**23,281**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**74,354**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **56.50% of modified total direct costs (Rate: 56.5000, Base: 62143)**					
TOTAL INDIRECT COSTS (F&A)				**35,111**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**109,465**	
K. SMALL BUSINESS FEE				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**109,465**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Joel Johnson

ORG. REP. NAME*
Dale Cherry

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

1 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 2

		FOR NSF USE ONLY			
ORGANIZATION University of Texas at Austin		PROPOSAL NO.	DURATION (months)		
			Proposed	Granted	
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR Joel Johnson		AWARD NO.			

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Joel Johnson - Associate Professor	0.00	0.00	0.25	3,007	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	3,007	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				29,739	
4. (1) UNDERGRADUATE STUDENTS				3,043	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				35,789	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				10,492	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				46,281	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				16,240	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $ 0					
2. TRAVEL 0					
3. SUBSISTENCE 0					
4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				890	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				1,200	
5. SUBAWARDS				0	
6. OTHER				32,017	
TOTAL OTHER DIRECT COSTS				34,107	
H. TOTAL DIRECT COSTS (A THROUGH G)				96,628	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) 56.50% of modified total direct costs (Rate: 56.5000, Base: 84050)					
TOTAL INDIRECT COSTS (F&A)				47,488	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				144,116	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				144,116	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME Joel Johnson	FOR NSF USE ONLY		
	INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* Dale Cherry	Date Checked	Date Of Rate Sheet	Initials - ORG

2 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **University of Texas at Austin**	**FOR NSF USE ONLY** PROPOSAL NO.	DURATION (months) Proposed / Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Joel Johnson**	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Joel Johnson - Associate Professor**	0.00	0.00	0.25	**3,097**	
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	**0**	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	**3,097**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	**0**	
2. (**0**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	**0**	
3. (**1**) GRADUATE STUDENTS				**7,658**	
4. (**1**) UNDERGRADUATE STUDENTS				**3,134**	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				**0**	
6. (**0**) OTHER				**0**	
TOTAL SALARIES AND WAGES (A + B)				**13,889**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				**3,624**	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				**17,513**	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				**0**	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				**13,440**	
2. INTERNATIONAL				**0**	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ **0** 2. TRAVEL **0** 3. SUBSISTENCE **0** 4. OTHER **0**					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				**0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				**500**	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				**2,000**	
3. CONSULTANT SERVICES				**0**	
4. COMPUTER SERVICES				**1,200**	
5. SUBAWARDS				**0**	
6. OTHER				**8,438**	
TOTAL OTHER DIRECT COSTS				**12,138**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**43,091**	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **56.50% of modified total direct costs (Rate: 56.5000, Base: 40727)**					
TOTAL INDIRECT COSTS (F&A)				**23,011**	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				**66,102**	
K. SMALL BUSINESS FEE				**0**	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				**66,102**	

M. COST SHARING PROPOSED LEVEL $ **0** AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Joel Johnson**	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Dale Cherry**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

1918351

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **University of Texas at Austin**			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Joel Johnson**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Joel Johnson - Associate Professor**	0.00	0.00	0.75	9,023	
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.75	9,023	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (3) GRADUATE STUDENTS				66,270	
4. (3) UNDERGRADUATE STUDENTS				9,131	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				84,424	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				24,143	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				108,567	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				35,980	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				5,185	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				3,600	
5. SUBAWARDS				0	
6. OTHER				58,741	
TOTAL OTHER DIRECT COSTS				69,526	
H. TOTAL DIRECT COSTS (A THROUGH G)				214,073	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				105,610	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				319,683	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				319,683	

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Joel Johnson**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Dale Cherry**	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget justification for PI Johnson, UT Austin

A. Senior Personnel

For PI Johnson, summer salary is requested, for only 1 week each year in order to keep total project costs down.

B. Other Personnel

Four full semesters and three summers of funding are requested to be able to competitively recruit and admit a PhD student to UT Austin to work on this project. Funds are also requested to support undergrad research for this project, which will form the basis of an honors thesis, and also ensure the availability of a field assistant for the PhD student.

C. Fringe Benefits

Fringe benefits are budgeted at 31% in Year 1, 31.50% in Year 2 and 32% in Year 3 for the professor and GRA and 5.82% is budgeted for the URA for all three years.

E. Travel

For field work, we have budgeted for a minimum of 1 month each year for the PhD student and field assistant, with at least 1 week in the field each year for PI Johnson. Funds are also included for other collaborators to join us for 1 week (Dr. Arjun Heimsath and Dr. Lisa Tranel are included on this budget; Dr. Katy Barnhart is included in Gasparini's budget). Transportation for the graduate student and field assistant will use a UT Austin department vehicle (high clearance suburbans, 4wd available), available for use at $0.77/mile. The vehicle can be used for as long as needed, allowing field seasons to be extended at minimal additional cost as needed. Plane flights to/from El Paso TX are budgeted at $300 for Johnson and other collaborators. Food is budgeted at 30/day per person (below the allowable UT per diem rate). Lodging will primarily be staying in researcher housing that is available for reservation at both Carlsbad Caverns and Guadalupe Mountains National Park for $15/person/night. Through our existing research permit, Johnson and Gasparini have already stayed with students in the Guadalupe Mountains researcher housing (the historic Wallace E. Pratt "Ship of the Desert" house). While the modest cost and availability of electricity to charge devices and enable efficient work in the evening makes researcher housing worthwhile, field work will also be done when convenient or necessary by camping (available at no cost on BLM and forest service land located in New Mexico, with locations convenient to most areas of the park).

Funds are also requested for the UT graduate student to travel to ASU to learn and do cosmogenic radionuclide (CRN) sample processing in years 1, 2 and 3, with a majority of samples processed in year 2 (see below).

We have also budgeted for Broader Outreach trips to the field area for Onramps Earth Wind and Fire (EWF) high school teachers. This professional development (PD) training will be done in each of years 2 and 3 over a long weekend. (In year 1, our outreach focus will be on developing educational material for the broader public, enhancing educational curriculum for the Onramps course including planning and recording succinct video lectures while in the field, and planning for these larger outreach trips) We have budgeted an average of $300 for each teacher to travel to/from El Paso from their locations in Texas, as well as for another Onramps employee who coordinates the course. The PD trip will be planned for when Johnson and Gasparini (and graduate students) are in the field already with a large UT field vehicle. We will only have to rent one additional minivan to transport the group from and back to El Paso. For this trip we will camp with the teachers. In past years, Johnson and Onramps Earth Wind and Fire have already run optional weekend camping trips for Onramps EWF teachers, and we know from experience that camping is acceptable for most people (we will not exclude any teachers from participating based on camping, and will accommodate within our existing budget any teachers with disabilities for whom camping is not appropriate). On the final night we will stay in a motel in El Paso to provide showers before returning (shared rooms, 100/room/night). Food is also budgeted at 30/person/day for this group.

Funds are requested for conference travel (1800/trip) for the UT graduate student in years 2 and 3, and for the PI in year 2, to present results of this project.

G. Other direct costs

1. Materials and Supplies

$1300 is requested for a laptop to use in the field for data collection and analysis for this project. Trimble Pathfinder Office software is also required to do submeter-accuracy post-processing of GPS data using JPJ's handheld Trimble GeoXT. The cost is $1995 for an initial year of license, and $390 for two additional years. Cyclone software from Leica is needed for data processing of airborne and ground-based Lidar, combined with structure-from-motion point clouds. Academic licenses are $500/yr.

A total of $31,590 is requested for Cosmogenic Radionuclide analysis. This includes funds for materials to do sample preparation, costs of AMS analysis through the Prime Lab at Purdue, and funds for x-ray flourescence analysis of bulk and trace elements needed for 36Cl dating. While we plan to do sample processing at ASU for both 10Be (which Dr. Heimsath is already set up to do) and 36Cl (which he is setting up to do), as a backup plan our budget has sufficient funds to cover Prime Lab sample processing costs for 36Cl (at the cost of $270/sample, based on their publicly available AMS price list). We have budgeted for 10 samples to be processed and run in year 1 (to allow exploratory results that guide more intensive sampling and processing in year 2), 32 samples in year 2, and 10 samples in year 3 (allowing flexibility in sampling and acknowledging that our research plan may evolve).

2. Publications Costs/Documentation/Distribution

$2000 is requested in year 3 to offset page fees for peer-reviewed publications from this project.

3. Consultant Services

None requested through UT Austin.

4. Computer Services

The UT Austin Department of Geological Sciences has a $2000/ year charge for faculty for computer services. $1200/year is requested to cover a portion of this annual fee, which will include field laptop services and computer support for the UT graduate student working full time on this project, and data storage and reliable backup capabilities made possible by the departmental IT system.

5. Subcontracts

None requested through UT Austin.

6. Other

Tuition for four full semesters and three summer semesters is requested for the PhD student involved.

H. Indirect Costs

The University has a new negotiated Facilities and Administrative (F&A) Cost Rate Agreement with the U.S. Dept. of Health and Human Services at a 56.5% rate for all proposals with a start date of September 1, 2016. The Agreement is dated September 1, 2014. Indirect costs are applied to modified total direct costs, consisting of all salaries and wages, fringe benefits, materials, supplies, services, travel, and subgrants and subcontracts up to the first $25,000 of each subgrant or subcontract (regardless of the period covered by the subgrant or subcontract). Modified direct costs exclude equipment, capital expenditures, tuition remission, scholarships and fellowships, rental costs of off-site facilities, as well as the portion of each subgrant and subcontract in excess of $25,000.

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **Tulane University**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted		
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Nicole Gasparini**	AWARD NO.				

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Nicole Gasparini - Professor**	0.00	0.00	0.25	2,445	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	2,445	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (0) GRADUATE STUDENTS				0	
4. (1) UNDERGRADUATE STUDENTS				4,800	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				7,245	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				312	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				7,557	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				6,000	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				1,849	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				12,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				13,849	
H. TOTAL DIRECT COSTS (A THROUGH G)				27,406	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **All Items above (Rate: 51.5000, Base: 27406)**					
TOTAL INDIRECT COSTS (F&A)				14,114	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				41,520	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				41,520	
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $				

PI/PD NAME **Nicole Gasparini**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Norey Laug**	Date Checked	Date Of Rate Sheet	Initials - ORG

1 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 2

FOR NSF USE ONLY		
PROPOSAL NO.	DURATION (months)	
	Proposed	Granted
AWARD NO.		

ORGANIZATION
Tulane University

PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR
Nicole Gasparini

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Nicole Gasparini - Professor	0.00	0.00	0.25	2,518	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	2,518	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				25,746	
4. (1) UNDERGRADUATE STUDENTS				4,800	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				33,064	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,720	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				35,784	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				13,750	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				0	
3. CONSULTANT SERVICES				12,000	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				12,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				61,534	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) All Items above (Rate: 51.5000, Base: 61534)					
TOTAL INDIRECT COSTS (F&A)				31,690	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				93,224	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				93,224	

M. COST SHARING PROPOSED LEVEL $ 0 AGREED LEVEL IF DIFFERENT $

PI/PD NAME
Nicole Gasparini

ORG. REP. NAME*
Norey Laug

FOR NSF USE ONLY		
INDIRECT COST RATE VERIFICATION		
Date Checked	Date Of Rate Sheet	Initials - ORG

 ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **Tulane University**			FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Nicole Gasparini**			AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Nicole Gasparini - Professor**	0.00	0.00	0.25	2,594	
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.25	2,594	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0	
3. (1) GRADUATE STUDENTS				26,518	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				29,112	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				2,567	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				31,679	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)					
TOTAL EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				7,150	
2. INTERNATIONAL				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				0	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				0	
TOTAL OTHER DIRECT COSTS				2,000	
H. TOTAL DIRECT COSTS (A THROUGH G)				40,829	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **All Items above (Rate: 51.5000, Base: 40829)**					
TOTAL INDIRECT COSTS (F&A)				21,027	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				61,856	
K. SMALL BUSINESS FEE				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				61,856	

M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME **Nicole Gasparini**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Norey Laug**	Date Checked	Date Of Rate Sheet	Initials - ORG

 *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

1918459

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **Tulane University**				FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Nicole Gasparini**				AWARD NO.		
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)	
1. Nicole Gasparini - Professor	0.00	0.00	0.75	7,557		
2.						
3.						
4.						
5.						
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0		
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	0.00	0.75	7,557		
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)						
1. (0) POST DOCTORAL SCHOLARS	0.00	0.00	0.00	0		
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	0		
3. (2) GRADUATE STUDENTS				52,264		
4. (2) UNDERGRADUATE STUDENTS				9,600		
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0		
6. (0) OTHER				0		
TOTAL SALARIES AND WAGES (A + B)				69,421		
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				5,599		
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				75,020		
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.)						
TOTAL EQUIPMENT				0		
E. TRAVEL 1. DOMESTIC (INCL. U.S. POSSESSIONS)				26,900		
2. INTERNATIONAL				0		
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0						
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0		
G. OTHER DIRECT COSTS						
1. MATERIALS AND SUPPLIES				1,849		
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				2,000		
3. CONSULTANT SERVICES				24,000		
4. COMPUTER SERVICES				0		
5. SUBAWARDS				0		
6. OTHER				0		
TOTAL OTHER DIRECT COSTS				27,849		
H. TOTAL DIRECT COSTS (A THROUGH G)				129,769		
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)						
TOTAL INDIRECT COSTS (F&A)				66,831		
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				196,600		
K. SMALL BUSINESS FEE				0		
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				196,600		
M. COST SHARING PROPOSED LEVEL $ 0	AGREED LEVEL IF DIFFERENT $					
PI/PD NAME **Nicole Gasparini**				FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Norey Laug**				Date Checked	Date Of Rate Sheet	Initials - ORG

C *ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

GASPARINI BUDGET JUSTIFICATION

A. SENIOR PERSONNEL

Principal Investigator
Faculty salaries are based on a 9-month academic appointment. A quarter month of summer salary is requested in all three years. A 3% salary increase has been projected for each year.

Graduate Student
Salary is requested to fund a graduate student in years 2 and 3. A 3% salary increase has been projected for each year.

Undergraduate Students
Salary for an undergraduate summer researcher for 10 weeks at 40 hours per week is requested for years 1 and 2.

C. FRINGE BENEFITS

The fringe benefit costs have been calculated based on Tulane's federally negotiated rates. The rates are dependent upon the employee's classification (faculty, staff, etc.) The fringe benefit costs for faculty summer salary are 5.1%. Fringe benefits for the graduate student are 3.9% plus $1401/yr for health insurance. Fringe benefits for the undergraduate student are 3.9%.

D. EQUIPMENT

No equipment is requested.

E. TRAVEL

Domestic
Year 1: $6,000 is requested to cover gas, flights, lodging, and food in the field. Gasparini and Barnhart will be in the field for 14 days and the graduate student and an undergraduate for four weeks. The undergraduate and graduate student will drive to and from the field from New Orleans using a departmental vehicle. Gasparini will drive with them and fly back. Barnhart will fly to and from the field.

Year 2:
$5,150 is requested to cover gas, lodging, flight, and food in the field. Gasparini will be in the field for 14 days and the graduate student and an undergraduate to the field for four weeks. The undergraduate and graduate student will drive to and from the field from New Orleans using a departmental vehicle. Gasparini will drive with them and fly back.
$5400 is requested to support travel to an annual meeting (e.g. AGU or GSA) for Gasparini, the graduate student, and the undergraduate from year 1. We assume a one year lag in the undergraduate attending a conference because of abstract deadlines.
$3,200 is requested to support the graduate student to spend 4 weeks at ASU performing geochemical analyses in Dr. Arjun Heimsath's lab.

Year 3: $1,750 is requested to cover all costs for the graduate student to be in the field for 30 days. The Tulane graduate student will meet the UT graduate student, and funds are not requested for anyone else from the Tulane team to go in the field in year 3.

$5,400 is requested to support travel to an annual meeting (e.g. AGU or GSA) for Gasparini, the graduate student, and the undergraduate from year 2. We assume a one year lag in the undergraduate attending a conference because of abstract deadlines.

F. PARTICIPANT SUPPORT COSTS

N/A

G. OTHER DIRECT COSTS

1. Publication Costs/Documentation/Distribution

Year 3: $2,000 is requested to support a publication.

2. Consultant Services

Year 1: $12,000 is requested to support Dr. Katy Barnhart as a consultant on the project. This will support approximately 2 months of salary. Barnhart will work with the team to adapt the Lithology component of Landlab to work with the proposed modeling experiments.
Year 2: $12,000 is requested to support Dr. Katy Barnhart as a consultant on the project. This will support approximately 2 months of salary. Barnhart will work with the team to adapt the Lithology component of Landlab to work with the proposed modeling experiments.

3. Minor Equipment
$1,300 for a field laptop is requested

4. Supplies
$549 is requested for an educational license of Agisoft Photoscan.

H. TOTAL DIRECT COSTS

These are the sum of the above budget categories.

I. TOTAL INDIRECT COSTS

$66,831 is requested for Indirect Costs. Tulane University's Federally Negotiated Indirect Cost Rate is 51.5% MTDC, which does not include equipment.

Current and Pending Support

(See PAPPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Joel Johnson

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM (THIS PROPOSAL)

Source of Support: National Science Foundation

Total Award Amount: $ 319,682 Total Award Period Covered: 09/01/19 - 08/31/22

Location of Project: University of Texas at Austin

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.25

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: GP-IMPACT: More than Just Science: Increasing Geoscience Diversity through Undergraduate Mentoring in Dual-Enrollment High School Introductory Earth Science Courses

Source of Support: National Science Foundation

Total Award Amount: $ 351,165 Total Award Period Covered: 07/01/19 - 06/30/22

Location of Project: University of Texas at Austin

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.50

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See PAPPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Nicole Gasparini

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: The legacy of transience: Understanding dynamic landscape adjustment following mountain uplift in two CZO field areas

Source of Support: NSF

Total Award Amount: $ 132,828 Total Award Period Covered: 06/01/14 - 05/31/19

Location of Project: Tulane

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.64

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: SI2-SSI: Landlab: A Flexible, Open-Source Modeling Framework for Earth-Surface Dynamics

Source of Support: NSF

Total Award Amount: $ 532,320 Total Award Period Covered: 08/01/15 - 07/31/20

Location of Project: Tulane

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 1.00

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: From rock to regolith to rivers: weathering, grain size, and controls on soil production and fluvial incision

Source of Support: NSF

Total Award Amount: $ 230,620 Total Award Period Covered: 01/01/19 - 12/31/20

Location of Project: Tulane

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.25

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM (This proposal)

Source of Support: NSF

Total Award Amount: $ 195,584 Total Award Period Covered: 09/01/19 - 08/31/22

Location of Project: Tulane

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Sumr: 0.25

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Collaborative Research: TESPRESSO - Tectonic Encoding, Shredding, and PRopagation of Environmental Signals as Surface Observables

Source of Support: NSF

Total Award Amount: $ 249,903 Total Award Period Covered: 05/01/19 - 04/30/22

Location of Project: Tulane

Person-Months Per Year Committed to the Project. Cal:0.00 Acad: 0.00 Summ: 0.20

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See PAPPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Nicole Gasparini

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: CZ RCN: Building capacity to deepen the critical zone: expanding boundaries and exploring gradients through data-model synergy

Source of Support: NSF
Total Award Amount: $ 499,698 Total Award Period Covered: 05/01/19 - 04/30/24
Location of Project: Colorado School of Mines
Person-Months Per Year Committed to the Project. Cal: 0.00 Acad: 0.00 Sumr: 0.17

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Current and Pending Support

(See PAPPG Section II.C.2.h for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Katherine Barnhart

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title: Dynamics from drones: using high-resolution repeat topography and grain size to differentiate between physically-based models of debris creation and debris flow

Source of Support: NSF

Total Award Amount: $ 174,000 Total Award Period Covered: 01/01/18 - 12/31/19

Location of Project: University of Colorado

Person-Months Per Year Committed to the Project. Cal:12.00 Acad: 0.00 Sumr: 0.00

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

Facilities, Equipment and Other Resources

Except for a field laptop and the software explicitly mentioned in the budget, PI Johnson's research group has the field equipment necessary to complete this project. Gasparini's group has some redundant equipment if needed as backup, and UT's Department of Geoscience also has shared equipment (for example, a Trimble robotic total station) that can be used if needed. Johnson has a functioning Trimble GeoXT handheld GPS (submeter accuracy with postprocessing), which will be used for determining positions of field reaches and survey data in relation to DEMs and airborne Lidar. If more accuracy is needed, Johnson also has a Leica RTK GPS system (cm accuracy) which could be used. Johnson also has a Leica ScanStation C10 terrestrial Lidar scanner, which will be used for field surveys in reaches with signficant vegetation. However, most high-resolution measurements of topography will be done using structure-from-motion from field photos using Agisoft Photoscan. While preliminary Photoscan processing can be done in the field on the field laptop, Johnson has a workstation at UT with 64 Gb of RAM and dual GPUs designed for efficient Photoscan processing, in addition to GIS and Lidar analysis. UT Austin provides complete access to Matlab and ArcGIS software. As described in the proposal, we also have access to airborne Lidar data for the region through Dr. Charles Kerans.

Johnson also has a Schmidt Hammer for field measurements of rock strength, as well as a calibration anvil to ensure the accuracy of measurements. We also have digital cameras (with built-in GPS georeferencing capabilities) for field use, and other survey equipment such as tape measures. Department of Geosciences field vehicles with high clearance and 4wd capability are available to Johnson at per-mile cost (see budget justification).

At Arizona State University, collaborator Dr. Arjun Heimsath has a lab for CRN sample processing (see budget justification). If there were for some reason problems with this, ^{10}Be samples could also be processed at similar cost at Tulane University in the lab of Dr. Brent Goehring, and ^{36}Cl samples could be processed through Prime lab.

Facilities, Equipment, and Other Resources – Tulane University

Gasparini has a computer laboratory, which is equipped with 4 windows workstations, 4 Mac workstations, and a color laser printer. The mac workstations are the best working environment for Landlab. The windows machines are available for GIS work. Gasparini also has two workstations in her office.

Gasparini has miscellaneous field equipment that will likely be useful for the field campaigns. Equipment that may be useful includes GPS, iPads, laser range finder, and Schmidt hammers.

Data Management Plan

The project will produce field, GIS and landscape evolution (LE) modeling data. Field survey data will include GPS coordinate positions, Schmidt hammer field strength measurements, fracture spacing and orientations, and field notes. They will also include extensive archives of field photographs, and processed photographs to measure structure-from-motion topography for certain reaches. GIS analysis will be done primarily in ArcGIS and Matlab. Relevant data files include raw data, our custom data processing codes, and processed data. LE modeling data include input and setup files, versions of LandLab code used, and saved model outputs.

At UT Austin, prior to being shared and published, data will be stored on Johnson's computers. These computers are backed up automatically as part of UT Austin Department of Geological Sciences, which has several full-time Information Technology employees, and runs backup systems for all department computers (through Crashplan software, and also through dedicated networked backup servers). Department IT also provides internal data archives with essentially no limit to size; internal storage of multiple terrabytes of raw and processed data from this project can be stored without a problem.

We commit to making all data from this project available to people who would like to use it. Nonetheless, the reality is that a larger overall quantity of data will be produced (especially landscape evolution model runs) as part of this project than can be feasibly posted to the web for immediate access. We will prioritize making data publicly available that we feel are most useful, both to others and also the data that are most useful to us. All data made publicly available will be given DOIs to make them accessible, and will have a creative commons license that we assign (e.g CC BY 2.0). We will also provide machine-readable metadata, following best practices recommended in the community (e.g. Hsu et al., 2015). Data will be made publicly available through a stable data repository, such as SEAD or the Texas Data Repository (TDR, a data repository for the University of Texas system). In addition, all peer-reviewed publications from this project will have associated data archives specific to those works.

Rock samples collected for cosmogenic radionuclide analysis will be destroyed as part of the analysis. Any rock samples not used completely that are collected through the research permits of the national parks will be returned to the parks and archived by them, following their strict regulations and requirements. Other remaining rock sample material collected outside of the parks will be stored at the UT Austin Department of Geosciences.

As mentioned in the proposal, we have permission from Dr. Kerans to share airborne Lidar data from the specific areas that we use for data analysis in this project, along channel reaches of interest and hillslope swaths.

As part of broader outreach, curricular materials will be produced, including short instructional videos and assignments based on Guadalupe Mountains geology. In addition to sharing instructional videos on YouTube, broader outreach will include a website aimed at the general public that explain how to "read" topography in terms of rock properties and the history of climate and tectonics, and that also explain basic geological information of interest about the Guadalupe Mountains. This website will be hosted through UT Austin. Select curricular materials of particular interest to the broader community will also be shared through SERC (Science Education Resource Center) at Carleton College, subject to their interest in posting them.

The source codes of all Landlab numerical models developed for this project, along with the contributions to the main Landlab code library (new components, utilities, and plotting tools) will be regularly made available through the main Landlab GitHub pages (https://github.com/landlab). Further standard Landlab practices for component documentation, in-line testing (to make sure new additions do not break old code), and tutorials explaining code will be followed. In detail:

- All code that is not a model will be added to the main Landlab repository (https://github.com/landlab/landlab). We will strive to make these additions available as soon as they are tested, but no later than when manuscripts describing and using the code are submitted.
- Model driver codes that are specific to this project or to specific manuscripts will reside in new repositories on the main Landlab page (for example, see https://github.com/landlab/pub_tucker_etal_gmd). These new repositories will be posted when manuscripts are submitted. These repositories will include model python code files (every Landlab model is a unique python file that calls code in the existing Landlab library) and also information on the unique version of Landlab on which the model(s) were run. These repositories would also include any initial condition and input files required to run the model.
- Any tutorials developed that explain how to use new parts of the Landlab library will be stored in the tutorial repository (https://github.com/landlab/tutorials).
- Any tutorials developed for classroom purposes will be stored in the teaching tools repository (https://github.com/landlab/landlab_teaching_tools). Classroom tutorials are designed to illustrate concepts, in contrast to the tutorials described in the previous bullet, which are designed to illustrate how to use parts of Landlab. Classroom tutorials are written in a way that even if a user does not know anything about coding, he can still explore and experiment with a model. All teaching tutorials will also be made available through Hydroshare (https://www.hydroshare.org/) enabling students to access and run tutorials without needing to install Landlab locally.
- Changes, updates, and additions that are made to the main code base through this project will be fully documented on the Landlab documentation pages (https://github.com/landlab/landlab/wiki/User-Guide).

Hsu L, RL Martin, B McElroy, K Litwin-Miller, W Kim (2015), Data management, sharing, and reuse in experimental geomorphology: Challenges, strategies and scientific opportunities. *Geomorphology* 244, 180-189, doi:10.1016/j.geomorph.2015.03.039 .

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http://csdms.colorado.edu/

CSDMS
COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

September 6th, 2018

To: NSF – EAR Geomorphology and Landuse Dynamics Program
By signing below (or transmitting electronically), I acknowledge that CSDMS is listed as a collaborator on (or that we will cooperate in helping support the activities of) the proposal entitled "Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM." with Joel Johnson and Nicole Gasparini as Principal Investigators.

I agree to undertake the tasks associated with CSDMS as described in the project description of this proposal, and/or commit to provide or make available the resources designated in the proposal.

Sincerely,

Greg Tucker, CSDMS Executive Director
Fellow, Cooperative Institute for Research in Environmental Sciences
Professor, Department of Geological Sciences
University of Colorado, Boulder

University of Colorado
Boulder

INSTAAR
University of Colorado Boulder

CIRES

United States Department of the Interior
NATIONAL PARK SERVICE
CARLSBAD CAVERNS NATIONAL PARK
3225 National Parks Highway
Carlsbad, New Mexico 88220-5354

September 10, 2018

Re: NSF – EAR Geomorphology and Landuse Dynamics Program

To Whom it May Concern:

This letter is to state support for the outreach project in Carlsbad Caverns National Park that is included in the proposal "Collaborative Research: Reading lithology from topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM." with Joel Johnson and Nicole Gasparini as Principal Investigators. If this proposal is funded, I will work with Johnson and Gasparini to enable scientific communication with the public at the park.

Sincerely,

Rodney D. Horrocks

Rodney Horrocks
Chief of Resource Stewardship and Science
Carlsbad Caverns National Park

University of Colorado at Boulder

Department of Geological Sciences
Boulder, Colorado 80309-0399
303-492-8141
Fax: 303-492-2606

To: NSF – EAR Geomorphology and Landuse Dynamics Program

I acknowledge that I am listed as a collaborator on the proposal entitled "Collaborative Research: Learning to read topography: How rock properties influence landscape form and evolution in the Guadalupe Mountains, TX and NM." with Nicole Gasparini and Joel Johnson as Principal Investigators. I agree to undertake the tasks associated with Landlab as described in the project description of this proposal.

July 20, 2018

Katherine Barnhart
University of Colorado at Boulder
July 20, 2018