UPCOMING EAPS MEETINGS

EAPS STAFF MEETINGS
Thursday, Nov. 20, 2014
9:00-10:00 a.m.
HAMP 2201

EAPS RECEPTIONS AT CONFERENCES

AGU (SAN FRANCISCO)
Wednesday, Dec. 17, 2014
7:00 - 9:00 p.m.
Thirsty Bear-Billar Room

AMS (PHOENIX)
Tuesday, Jan. 6, 2015
6:30 - 8:30 p.m.
Sheraton Phoenix Downtown Hotel

FALL FACULTY MEETING SCHEDULE
Tuesday, Nov. 18, 2014
3:00-4:30 p.m.
HAMP 3201

SPRING FACULTY MEETING SCHEDULE
Tuesday, Jan. 27th, Feb. 10th (Dean’s Visit to Dept.), Mar. 24th, and Apr. 14th, 2015
3:00-4:30 p.m.
HAMP 3201

PUBLICATIONS


EAPS COLLOQUIA

“Profiling Developing Tropical Storm Environments Using GPS Airborne Radio Occultation”
Brian Murphy
PhD Candidate
Tuesday, Nov. 11, 2014 at 4:00 p.m.
HAMP 2201

“Opportunities and Challenges of Shale Gas Development”
Mark D. Zoback
Thursday, Nov. 13, 2014 at 4:00 p.m.
Matthews Hall/Room 210
Please see attached map.

(Please see attached fall 2014 EAPS Colloquia)

EAPS NEWS

ELEMENTS MAGAZINE

The most recent issue of Elements magazine is devoted to cosmogenic nuclides; an area in which EAPS and Purdue have become a world leader. Two out of six articles in this feature are authored by our own Nat Lifton and Darryl Granger. It is an honor for our department and our faculty to be featured so prominently in such a high profile journal read by earth scientists who want to know about what people in other fields are doing. We are very proud of efforts made by both Nat and Darryl as well as PRIME lab and Marc Caffee to make it possible.
Please see attached.
EAPS OMBUDSMAN

What is an Ombudsman? The ombudsmen are an informal, neutral, confidential resource for people in the department, especially students, to raise questions or concerns about any aspect of their academic experience. The EAPS ombudsman is Barbara Gibson (HAMP 2169B; barbara@purdue.edu) - please feel free to contact her if needed.

UNDERGRADUATE AND GRADUATE STUDENT INFORMATION

OPENHATCH

On Sunday, Nov. 16th, OpenHatch and Purdue’s Computer Science Women’s Network are hosting a day-long (12:30 - 6:30) open source software immersion event. We invite Earth, Atmospheric, and Planetary Science students to join us! You can sign up here: http://purdue.openhatch.org/

You don’t need to be a programmer to contribute to open source, or to attend and enjoy our event. Most open source projects are also in need of designers, translators, documenters, bug-finders and testers. The event is open to all students.

Open source software -- software that is shared freely and available to build upon -- has become part of our daily lives. Popular projects like WordPress, Firefox, Adium, and Ubuntu have millions of users. In the atmospheric sciences, agencies like the EPA and the National Weather Service lead development of open source projects like GEMPAK, a weather forecasting, display and analysis software package, and CMAQ, a program for air quality modeling, not to mention the dozens of other projects in academia and industry. You can learn more about these projects, and start helping out with them, at our event.

Open source participation is one way to gain real-world skills and make connections that will last you through your career. Volunteer staff will include professionals and academics that use open source daily.

TALENTED WRITERS

The Writing Lab is looking for talented undergraduate writers of all majors who demonstrate a strong interest in business, technical, or professional writing to join us as Business & Professional Writing Consultants. Prospective consultants will enroll in a Spring 2015 training course which will prepare them to work with students on a variety of workplace documents and course assignments, including resumes, cover letters, memos, and reports.

- Undergraduates of all majors are invited to apply for spring 2015;
- Prerequisite courses include one of ENGL 203, 306, 309, 420, 421, or 422;
- Applications must include a recommendation from a former English instructor as well as a current résumé and cover letter.

PETROLEUM AND GEOSYSTEMS ENGINEERING INTERNSHIPS

Summer research internships are available for undergraduate students within the UT Austin Petroleum and Geosystems Engineering Department. UT PGE is currently accepting applications for interns, where they will work for 10 weeks in the summer of 2015 for a salary of $4000 plus on-campus housing, a meal plan and travel to Austin. The interns will be mentored by a UT PGE faculty member and work on a project that is of interest to them. This is a great opportunity for an undergraduate to get research experience, learn about the energy industry and a taste of the grad school experience. SURI will consider application students from all engineering and science majors with at least a 3.25 GPA. This program only accepts students who are U.S. Citizens or permanent residents. The deadline to apply is January 12, 2015. Apply to PGE.

TAIWAN SPRING BREAK TRIP

Krannert is opening spaces for the Taiwan Spring Break program, Asian Emerging Markets and Economies, to all Purdue majors at this time. During the program, students get to heavily interact with students from National Chengchi University, while learning about Asian economy and culture from the top professors and business executives in Taipei. Students receive 1 credit for the program and almost all costs are included in the program price. Information: Program applications will be open until Saturday, November 15th and we would love to have students from multiple disciplines at Purdue participate in the program.
INTERNSHIP OPPORTUNITIES IN THE NATIONAL PARK SERVICE PARTNERS

National parks and NPS programs develop and oversee structured projects in one or more of the following interdisciplinary areas: climate change science and monitoring; resource conservation and adaptation; policy development; sustainable park operations; facilities adaptation; and communication/interpretation/education. During the internship, students apply critical thinking and problem solving skills to climate change challenges and communicate with diverse stakeholders. Interns who successfully complete the YLCC, an approved Direct Hire Authority Internship program, will be eligible to be hired non-competitively into subsequent federal jobs once they complete their degree program. These jobs would be in the Department of Interior (DOI), NPS, or one of the other bureaus within the DOI. An intern must qualify for the job in order to be hired non-competitively.

Quick Facts and Deadlines:
- The YLCC is managed cooperatively with the University of Washington
- Internship opportunities and application forms are posted on parksclimateinterns.org
- Internships are 11-12 weeks (40 hours/week) during the summer
- Interns are paid $14/hour plus benefits
- Applications are accepted from early December 2014 until late January 2015

This is a great opportunity for students who might be interested in a climate change internship. Upon completion, students will be eligible to be hired non-competitively into subsequent federal positions once they have completed...
for their degree programs. Application deadline is January 30, 2015.

For More Information contact Tim Watkins, Climate Change Response Program, NPS, TimWatkins@nps.gov

~ ~ ~ ~ ~

INDIANA STATE DEPARTMENT OF HEALTH
October 29, 2014

The first cases of Ebola Virus Disease (EVD) diagnosed in the United States have heightened awareness of our global community and this serious disease. It also raised the level of concern for the safety of travelers both to the affected countries, and those returning to Indiana from an affected country, and the safety of the academic community.

The Ebola virus is not spread through the air, by water or food, or by casual contact. People with Ebola can only spread the Ebola virus when they have symptoms. There is no known risk of transmission if someone does not have symptoms. Ebola is only spread through direct contact with blood or body fluids (including but not limited to urine, saliva, feces, vomit and semen, or a needlestick) of a person who is sick with Ebola or the body of a person who has died from Ebola.

Currently in the U.S., individuals at risk for developing EVD are those who have arrived in the U.S. from Guinea, Liberia, or Sierra Leone within the past 21 days (the maximum incubation period for Ebola virus). Previous travel to these countries outside the 21-day incubation period is not a risk factor for Ebola.

Individuals who have had direct contact with identified Ebola cases in the U.S. may also be at risk for the EVD if that contact occurred at the time the case was symptomatic. Ebola symptoms include fever, headache, nausea, vomiting, diarrhea, muscle or body aches, and fatigue. The Indiana State Department of Health (ISDH) website has more information about EVD at www.statehealth.in.gov.

The Centers for Disease Control and Prevention (CDC) has prepared a document specifically addressing the unique concerns of colleges, universities, and students around the EVD occurring in the West African countries of Guinea, Liberia, and Sierra Leone. You can find that information at: http://wwwnc.cdc.gov/travel/page/advice-for-colleges-universities-and-students-about-ebola-in-west-africa.

To read more, please see attached.

APPLICATIONS SOUGHT FOR NEXT IMPACT COHORT
November 3, 2014

The IMPACT program is now taking applications for the spring 2015 cohort, and applications are due by 5 p.m., Nov. 28th. The application link and information about the program are available at www.purdue.edu/impact.

IMPACT (Instruction Matters: Purdue Academic Course Transformation) is a campus-wide initiative begun in 2011 by the Provost's Office for the redesign of classes. Its aim is to engage students more fully in their learning, thereby improving competency, retention and completion in classes that serve students across the entire campus. It is related to Purdue Moves and the University's efforts to be the national forerunner in transformative higher education.

For more information on the program, contact Chantal Levesque-Bristol, director of the Center for Instructional Excellence, at cbristol@purdue.ed

BIRTHDAYS

Nov. 10th Tim Filley
Nov. 11th Frank Bakhit
Nov. 12th Gerald Krockover
Nov. 12th Ken Ridgway
IMPORTANT NOTICE ABOUT THIS NEWSLETTER
This newsletter is used as the primary information source for current and upcoming events, announcements, awards, grant opportunities, and other happenings in our department and around campus. Active links to additional information will be provided as needed. Individual email announcements will no longer be sent unless the content is time-sensitive. We will continue to include our publications, presentations and other recent news items as well. Those using paper copies of the newsletter should go to our newsletter archive on the EAPS website at www.purdue.edu/eas/ and Click on News to access active links as needed. Material for inclusion in the newsletter should be submitted to Fallon Seldomridge (fseldomridge@purdue.edu) by 5:00pm on Thursday of each week for inclusion in the Monday issue.

If it is in the newsletter, we assume you know about it and no other reminders are needed. For answers to common technology questions and the latest updates from the EAPS Technology Support staff, please visit http://www.purdue.edu/eas/info_tech/index.php.
Also, as an additional resource for information about departmental events, seminars, etc., see our departmental calendar at

What people think about during your conference talk
An extensive set of airborne radio occultation (ARO) data has been collected by GISMOS, the GNSS Instrument System for Multi-static and Occultation Sensing, while deployed during the PRE-Depression Investigation of Cloud systems in the Tropics (PREDICT) experiment in 2010 to study developing tropical storms in the southern Atlantic and Caribbean region. This is the first time RO observations have been used to investigate the spatial and vertical variability of moisture with sufficient density (~ 7 profiles within 450 km of the storm center ) to characterize the mesoscale storm environment. GISMOS applies the radio occultation technique to remotely sense the atmosphere by measuring the phase delay and amplitude of received GPS radio signals due to the density and water vapor content of the atmosphere. High resolution vertical profiles of atmospheric refractivity below the aircraft altitude are obtained from the ARO data. Both geodetic GPS receivers using conventional phase-lock loop tracking and a high rate 10 MHz GPS recording system were used to collect GPS signal data over twenty-six missions. The ARO profiles retrieved from the geodetic receivers consistently agree within ~2 % of refractivity profiles calculated from the European Center for Medium-range Weather Forecasting (ECMWF) model interim re-analyses as well as from nearby dropsondes and radiosondes. The number of profiles and the minimum altitude sampled by the profiles obtained from the geodetic receivers were limited by the conventional phase-lock loop tracking which does not perform optimally in the lower tropical atmosphere where moisture levels result in sharp changes in refractivity causing rapid changes in GPS signal phase. A much larger set of profiles extending farther below aircraft height is obtained from the 10 MHz recorded GPS signal data using an open loop tracking algorithm, which is implemented in a software receiver. We will demonstrate the consistency of the combined dropsonde and RO dataset with increasing moisture in the mid-to-upper tropopause over the hurricane genesis time period for Karl.
Abstract: The proven ability to produce large quantities of natural gas from organic-rich shale formations is changing the energy picture in many parts of the world. In this talk I will discuss steps that can be taken to assure such resources are developed in an optimally efficient and environmentally responsible manner. Responsible development of shale gas resources has the potential to substantially reduce greenhouse gas emissions in the near term and significantly reduce air pollution and benefit public health. I will discuss several on-going research projects investigating the wide variety of factors affecting the successful gas production from these extremely low permeability formations and procedures for managing the risks of earthquakes triggered by injection of hydraulic fracturing waste water.

Dr. Mark D. Zoback is the Benjamin M. Page Professor of Geophysics at Stanford University. Dr. Zoback conducts research on in situ stress, fault mechanics, and reservoir geomechanics with an emphasis on shale gas, tight gas and tight oil production. Dr. Zoback was one of the principal investigators of the SAFOD project in which a scientific research well was successfully drilled through the San Andreas Fault. He is the author of a textbook entitled Reservoir Geomechanics published in 2007 by Cambridge University Press, the author/co-author of 300 technical papers and holder of five patents. Dr. Zoback has received numerous awards and honors, including the 2006 Emil Wiechert Medal of the German Geophysical Society and the 2008 Walter H. Bucher Medal of the American Geophysical Union. In 2011, he was elected to the U.S. National Academy of Engineering and in 2012 elected to Honorary Membership in the Society of Exploration Geophysicists. He recently served on the National Academy of Engineering committee investigating the Deepwater Horizon accident and the Secretary of Energy’s committee on shale gas development and environmental protection.
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Speaker/Advisor</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 4</td>
<td>When Engineering Geology Meets Geotechnical Engineering</td>
<td>Gary Luce, Knight Piesold &amp; Co., AEG President</td>
<td>Host: West</td>
</tr>
<tr>
<td>Sept. 9</td>
<td>The Impact of Climate Change and Agricultural Activities on Water Cycling in Northern Eurasia</td>
<td>Yaling Liu, PhD Candidate</td>
<td>Advisor: Zhuang</td>
</tr>
<tr>
<td></td>
<td><strong>Tuesday, 4:00PM, Room 2201/HAMP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept. 11</td>
<td>The DOE Accelerated Climate Modeling for Energy Project</td>
<td>Dr. Robert Jacob, Argonne National Laboratory</td>
<td>Host: Harshvardhan</td>
</tr>
<tr>
<td>Sept. 18</td>
<td>The Origins of Volatile-rich Solids and Organics in the Outer Solar Nebula</td>
<td>Prof. Fred Ciesla, University of Chicago</td>
<td>Host: Minton</td>
</tr>
<tr>
<td>Sept. 25</td>
<td>Long-term Morphological Changes in Mature Supercell Thunderstorms Following Merger with Nascent Supercells</td>
<td>Prof. Ryan Hastings, Purdue University</td>
<td></td>
</tr>
<tr>
<td>Sept. 30</td>
<td>Making Weather and Climate Data More Usable for Agriculture Across the U.S. Corn Belt</td>
<td>Olivia Kellner, PhD Candidate</td>
<td>Advisor: Niyogi</td>
</tr>
<tr>
<td></td>
<td><strong>Tuesday, 4:00PM, Room 2201/HAMP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct. 2</td>
<td>New Perspectives on Tidewater Glacier Mass Change</td>
<td>Dr. Tim Bartholomaus, University of Texas-Austin</td>
<td>Host: Elliott</td>
</tr>
<tr>
<td>Oct. 9</td>
<td>Sulfur Cycling on Mars from a Perspective of Sulfur-Rich Terrestrial Analogs</td>
<td>Prof. Anna Szynkiewicz, University of Tennessee</td>
<td>Host: Horgan</td>
</tr>
<tr>
<td>Oct. 16</td>
<td>Climate Impacts and Extremes in Large Earth System Model Ensembles</td>
<td>Prof. Ryan Sriver, University of Illinois-Champaign/Urbana</td>
<td>Host: Wu</td>
</tr>
<tr>
<td>Oct. 21</td>
<td>Towards a Paradigm Shift in the Modeling of Soil Carbon Decomposition for Earth System Models</td>
<td>Yujie He, PhD Candidate</td>
<td>Advisor: Zhuang</td>
</tr>
<tr>
<td></td>
<td><strong>Tuesday, 4:00PM, Room 2201/HAMP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct. 23</td>
<td>Anthropogenic Signals in InSAR</td>
<td>Prof. Rowena Lohman, Cornell University</td>
<td>Host: Elliott/Flesch</td>
</tr>
<tr>
<td>Oct. 28</td>
<td>Giant Impacts on the Asteroid Vesta</td>
<td>Tim Bowling, PhD Candidate</td>
<td>Advisor: Melosh</td>
</tr>
<tr>
<td></td>
<td><strong>Tuesday, 4:00PM, Room 2201/HAMP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct. 30</td>
<td>Abiotic and Biogeochemical Controls on Reactive Nitrogen Cycling on Boundary Layer Surfaces</td>
<td>Prof. Jonathan Raff, Indiana University</td>
<td>Host: Shepson</td>
</tr>
</tbody>
</table>

(continued on next page)
<table>
<thead>
<tr>
<th>Date</th>
<th>Topic</th>
<th>Presenter/Advisor</th>
<th>Location/Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 6</td>
<td>Andean Foreland Basins: A Thermochronologic Perspective on Sediment Provenance, Deformation, and Basin Thermal Histories</td>
<td>Prof. Julie Fosdick, Indiana University</td>
<td>Host: Ridgway</td>
</tr>
<tr>
<td>Nov. 11</td>
<td>Profiling Developing Tropical Storm Environments Using GPS Airborne Radio Occultation</td>
<td>Brian Murphy, PhD Candidate</td>
<td>Advisor: Sun/Haase</td>
</tr>
<tr>
<td></td>
<td><strong>Tuesday, 4:00PM, Room 2201/HAMP</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov. 13</td>
<td>Shale Gas Development and the Environment</td>
<td>Prof. Mark Zoback, Stanford University</td>
<td>Host: Nowack</td>
</tr>
<tr>
<td></td>
<td><strong>Thursday, 4:00pm, Room 210/MTHW (joint with the Physics Dept.)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov. 20</td>
<td>The Role of Monsoon Circulation on Tropopause Variability</td>
<td>Prof. Yutian Wu, Purdue University</td>
<td></td>
</tr>
<tr>
<td>Dec. 4</td>
<td>CSI Patagonia: Tracking Glacial and Climate Dynamics over the Last Glacial Cycle</td>
<td>Alessa Geiger, University of Glasgow</td>
<td>Host: Harbor</td>
</tr>
</tbody>
</table>
The Nuts and Bolts of Cosmogenic Nuclide Production

Tibor J. Dunai and Nathaniel A. Lifton

Over the last 60 years, our understanding of how cosmic rays produce cosmogenic nuclides has grown from basic physical considerations. We introduce the different types of cosmic ray particles and how their flux varies with altitude, latitude, and time. Accurately describing these variations remains a challenge for some regions when calculating production rates. We describe current and emerging computational methods for calculating production rates that address this challenge. Continuing developments in our understanding of modern and prehistoric cosmic ray fluxes and energy spectra in Earth’s atmosphere and at its surface are bound to contribute in the future to more robust applications.

KEYWORDS: cosmogenic nuclide production, reaction, scaling factor, cosmic ray

INTRODUCTION

Cosmic rays are high-energy charged particles that impinge on the Earth from all directions from space. The majority of cosmic ray particles are atomic nuclei, but they also include electrons, positrons, and other subatomic particles. Typical energy levels range from a few mega–electron volts (MeV) up to ~10^{20} eV, with a maximum energy of a few hundred MeV per nucleon (Eidelman et al. 2004). For the purposes of in situ and atmospheric cosmogenic nuclides, the term cosmic rays usually refers to galactic cosmic rays, which originate from sources outside the Solar System. Supernova explosions, which occur approximately once every 50 years in our galaxy, produce most galactic cosmic rays, with energies of up to 10^{15} eV (Eidelman et al. 2004; Diehl et al. 2006). The galactic cosmic ray flux is generally assumed to be isotropic and to have been approximately constant over the last 10 million years (Leya et al. 2000). Good entry-level reviews on cosmic ray physics can be found, for example, in Rossi (1964) and in reviews on geologic applications of cosmogenic nuclides (Gosse and Phillips 2001; Dunai 2010). In the following section, we draw from these sources, and their references, to introduce the nature of cosmic ray particles and the mechanisms of cosmogenic nuclide production.

COSMIC RAY PARTICLES

At the top of the Earth’s atmosphere, galactic cosmic rays are dominated by protons (87%) and α-particles (12%), with a small contribution of heavier nuclei (~1%). Upon entering the Earth’s atmosphere, these primary cosmic rays interact with the atoms in the air to produce secondary cosmic rays. Some of these secondary particles (neutrons and muons) are responsible for most of the atmospheric and in situ cosmogenic nuclides on Earth.

Nucleons

The high energies of the primary (and many secondary) cosmic rays are well in excess of the binding energies of atomic nuclei (typically 7–9 MeV per nucleon). Consequently, the dominant nuclear reaction is that of spallation, the process by which nucleons are sputtered off target nuclei. Spallation-produced nucleons largely continue in the direction of the impacting particle and can retain enough energy to keep on inducing spallation in other target nuclides, producing a nuclear cascade in the Earth’s atmosphere (Fig. 1).

Because neutrons do not lose energy through ionization as do protons, the composition of cosmic rays undergoes changes from proton-dominated to neutron-dominated over the course of the nuclear cascade. At sea level, neutrons constitute 98% of the nucleonic cosmic ray flux. However, energy losses incurred with each interaction result in the mean energy of the secondary neutron flux being significantly lower than that of the primary flux (Fig. 1).

Muons

In addition to producing secondary atmospheric neutrons, collisions of high-energy primary cosmic rays with atomic nuclei high in the atmosphere produce elemental particles known as pions, which decay within a few meters of travel to either positively or negatively charged muons. Muons can be considered the heavier brother of the electron (206.7 times heavier).

Muons interact only weakly with matter—therefore, they have a much greater penetration depth than neutrons, and hence are the most abundant cosmic ray particles at sea level. However, due to stronger interaction with matter, the
nucleonic component dominates atmospheric and terrestrial cosmogenic nuclide production. Muons, in turn, are responsible for the majority of subsurface production.

**COSMGENIC NUCLIDES**

Cosmogenic nuclides are the products of interactions of primary and secondary cosmic ray particles with atomic nuclei. At the Earth’s surface, more than 98% of the cosmogenic nuclide production arises from secondary cosmic ray particles, such as neutrons and muons. Depending on the energy of these particles, a range of nuclear reactions can produce cosmogenic nuclides (Fig. 1).

**Spallation**

In spallation reactions, high-energy nucleons (largely neutrons at ground level) collide with atomic nuclei (“target nuclei”) and knock off protons and neutrons, leaving behind a lighter residual nucleus. The mass difference between a target nucleus and the lighter product is usually a few atomic mass units. Thus, target elements with nuclide masses nearest to the resulting cosmogenic nuclide usually contribute most to its production.

**Neutron Capture**

The majority of neutrons in the nuclear cascade eventually slow down to energies corresponding to the temperature of their surroundings. These “thermal” neutrons (energies of ca 0.025 eV) can subsequently be captured by nuclei. Some thermal neutron–capture reactions have very high probabilities of occurrence and can produce appreciable amounts of cosmogenic nuclides (e.g. $^3$He, $^{36}$Cl).

**Muon Reactions**

There are two main types of muon reactions leading to cosmogenic nuclide production: negative muon capture and high-energy (fast) muon interactions. Negative muons that have been decelerated by ionization to thermal energies (termed “stopped muons”) can be captured by an atom’s electron cloud, and they quickly cascade to the lowest electron shell. There they decay, or are captured by the nucleus where they neutralize one proton. The probabilities for negative muon–capture reactions are much lower than those involving neutrons.

Fast muons give rise to Bremsstrahlung (“braking radiation”), which produces gamma ray photons. This phenomenon occurs when charged particles slow down due to interactions with other charged particles. Such muon-derived gamma rays can be of sufficiently high energy to produce secondary neutrons from nuclei, the so-called photoneutrons, which may produce cosmogenic nuclides. They generally have a very low abundance and become important only at depths greater than 20 m below the Earth’s surface, where fast muons remain as the sole reaction-inducing “survivors” of the cosmogenic cascade.

**Production Rates and Scaling Factors**

The production rates of cosmogenic nuclides are a function of the energy spectrum of the impacting cosmic ray particles and the corresponding reaction probabilities for target nuclei (Reedy 2013). The energy spectrum itself is a function of altitude and position in the geomagnetic field. As discussed in von Blanckenburg and Willenbring (2014 this issue), nuclide production occurs both in atmospheric gases (“atmospheric”) and in the minerals of the upper several meters of the Earth’s surface (“in situ”). In the atmosphere, nuclide production rates are typically estimated from theoretical and/or numerical models (e.g. Masarik and Beer 1999), while nuclide delivery is computed from atmospheric circulation models (Heikkinen et al. 2013). In contrast, terrestrial production rates of in situ cosmogenic nuclides are typically experimentally established at sites that have independently determined ages (e.g. moraines, lava flows) and well-constrained exposure histories (i.e. no significant prior exposure, erosion, burial, or other disturbance that can impact the cosmogenic nuclide inventory in the rock since initial exposure) (Gosse and Phillips 2001; Dunai 2010).

Identifying suitable calibration sites for terrestrial production rates requires careful characterization, and the number and geographic distribution of these sites remain limited. Scaling factors are required to translate the local production rates obtained at calibration sites to values valid elsewhere on the globe, where practitioners may use cosmogenic nuclides to obtain exposure ages and rates of geological processes. Again, this is because the cosmic ray energy spectrum varies spatially. Scaling factors must also account for temporal variations in geomagnetic and atmospheric shielding at a given location that can affect the cosmic ray flux and its energy spectrum (Fig. 2).

**Geomagnetic and Atmospheric Shielding**

Primary cosmic rays are charged particles and are thus affected by Earth’s magnetic field. At a given location, particles with kinetic energy below a certain threshold cannot penetrate the Earth’s magnetic field and approach the Earth’s surface. This threshold is referred to as the “cutoff rigidity,” or $R_c$, and is defined as the momentum of a particle per unit charge (in gigavolts, GV).
Secondary neutrons produced in the atmospheric nuclear cascade attain a maximum flux at an altitude of about 16 km (Lal and Peters 1967). Below that level, their abundance decreases approximately exponentially with atmospheric depth, which is described by the attenuation length (Fig. 2n). As a rule of thumb, the nucleonic cosmic ray flux decreases by half for every 1000 m decrease in altitude (Dunai 2010).

Systematic changes in the secondary cosmic ray spectrum as a function of atmospheric depth and $R_c$ lead to corresponding variations in attenuation lengths (Lifton et al. 2014). Current scaling models account for this variation by directly varying attenuation lengths (Dunai 2001; Desilets and Zreda 2003) or by parameterizing altitudinal and latitudinal variation in other ways (Lal 1991; Lifton et al. 2014).

It is worth noting that while meteoric cosmogenic nuclides, such as $^{10}$Be, are also produced in the atmosphere largely by spallation reactions, applications of such meteoric $^{10}$Be are instead concerned with fluxes of the nuclide from the total inventory in the atmospheric column above a given site (Willenbring and von Blanckenburg 2010). It is significant that >99% of the atmospheric inventory is produced above 3 km altitude—thus, no altitude scaling is required for most of Earth’s surface. Rather, the $^{10}$Be production signal is dominated by the high cosmic ray fluxes in low $R_c$ regions (Willenbring and von Blanckenburg 2010). Once produced, meteoric $^{10}$Be quickly adsorbs to aerosol particles that are transported by atmospheric circulation and delivered to the Earth’s surface by either dry or wet deposition. Combination of $^{10}$Be production and atmospheric general circulation models indicates that $^{10}$Be fluxes are dominated by wet deposition—therefore, mid-latitudes that experience high precipitation also experience the highest fluxes (Willenbring and von Blanckenburg 2010; Heikkilä et al. 2013).

Modern $R_c$ values are approximately zero near the poles, where essentially all energies present in the primary flux can penetrate the magnetic field. This value increases to approximately 17 GV near the equator (ca 50 % of the polar flux at sea level) (Figs. 2a). At $R_c < 1–2$ GV (≥ ca 60° geomagnetic latitude), the lowest-energy particles do not have enough energy to generate an atmospheric cascade, and so toward the poles the increases in the number of particles that enter the atmosphere do not yield corresponding increases in the flux responsible for cosmogenic nuclide production.

The cosmic ray spectrum at high latitudes is not sensitive to temporal changes in the geomagnetic field. Hence, terrestrial production rates are usually normalized to hypothetical values at sea level and high latitudes. However, the effects of secular geomagnetic field variations on nuclide production become more pronounced with increasing $R_c$ (at lower latitudes) and need to be considered when calculating nuclide production in the past (Dunai 2001; Desilets and Zreda 2003; Lifton et al. 2008; Fig. 3).

Modern $R_c$ values are approximately zero near the poles, where essentially all energies present in the primary flux can penetrate the magnetic field. This value increases to approximately 17 GV near the equator (ca 50 % of the polar flux at sea level) (Figs. 2a). At $R_c < 1–2$ GV (≥ ca 60° geomagnetic latitude), the lowest-energy particles do not have enough energy to generate an atmospheric cascade, and so toward the poles the increases in the number of particles that enter the atmosphere do not yield corresponding increases in the flux responsible for cosmogenic nuclide production.

The cosmic ray spectrum at high latitudes is not sensitive to temporal changes in the geomagnetic field. Hence, terrestrial production rates are usually normalized to hypothetical values at sea level and high latitudes. However, the effects of secular geomagnetic field variations on nuclide production become more pronounced with increasing $R_c$ (at lower latitudes) and need to be considered when calculating nuclide production in the past (Dunai 2001; Desilets and Zreda 2003; Lifton et al. 2008; Fig. 3).

Modern $R_c$ values are approximately zero near the poles, where essentially all energies present in the primary flux can penetrate the magnetic field. This value increases to approximately 17 GV near the equator (ca 50 % of the polar flux at sea level) (Figs. 2a). At $R_c < 1–2$ GV (≥ ca 60° geomagnetic latitude), the lowest-energy particles do not have enough energy to generate an atmospheric cascade, and so toward the poles the increases in the number of particles that enter the atmosphere do not yield corresponding increases in the flux responsible for cosmogenic nuclide production.

The cosmic ray spectrum at high latitudes is not sensitive to temporal changes in the geomagnetic field. Hence, terrestrial production rates are usually normalized to hypothetical values at sea level and high latitudes. However, the effects of secular geomagnetic field variations on nuclide production become more pronounced with increasing $R_c$ (at lower latitudes) and need to be considered when calculating nuclide production in the past (Dunai 2001; Desilets and Zreda 2003; Lifton et al. 2008; Fig. 3).
Scaling Factors for In Situ Cosmogenic Nuclide Production

Computationally complex calculations are required to consider the effects of spatial and temporal variations in the geomagnetic field and atmospheric pressure on scaling of in situ nuclide production. To allow nonexperts to perform these analyses, user-friendly calculators are now available (e.g., Balco et al. 2008). The scaling factors that are currently used perform well for generally describing the relative flux of cosmic rays as a function of altitude, latitude (Stone 2000; Dunai 2001; Desilets and Zreda 2003; Balco et al. 2008; Lifton et al. 2008), variations in geomagnetic field strength (Dunai 2001; Desilets and Zreda 2003; Lifton et al. 2008), and changes in solar activity (Lifton et al. 2008). At latitudes greater than 30° and elevations below 3 km, their results are generally very similar (Balco et al. 2008). However, large differences between models (up to 30%) emerge for estimates at lower latitudes and higher elevations. These variations arise from the different neutron flux proxies used (neutron monitors, photographic emulsions) and their responses to changes in the neutron energy spectrum (Lifton et al. 2014).

Recent advances have made it feasible to consider the temporal changes in the energy spectrum quantitatively and estimate their influence on nuclide production (Argento et al. 2013; Lifton et al. 2014). Previously, this omission was due to the lack of detailed environmental neutron energy spectra and the lack of accurate neutron reaction probability functions; both have become recently available (Sato et al. 2008 and references therein; Reedy 2013). These new studies (Argento et al. 2013; Lifton et al. 2014) indicate that nuclide-specific scaling factors may be warranted for some nuclides, such as 3He. They also indicate that the larger contribution of protons at high elevations, which are undercounted by neutron monitors (Clem and Dorman 2000), needs to be considered for nuclide production.

CONCLUSIONS

This brief review presents the fundamental principles of cosmogenic nuclide production in the atmosphere and in terrestrial settings. The foundations for this science were initially laid over 50 years ago, but recent advances in our abilities to model temporal variations in nuclide production are certain to propel the field forward. In the coming years, these developments will help to ensure that the rapid progress in accurately measuring cosmogenic nuclides (Christl et al. 2014 this issue) will be matched by our understanding of the rates at which these nuclides are produced.

ACKNOWLEDGMENTS

The authors thank Pieter Vermeesch, Greg Balco, and an anonymous reviewer for their constructive and helpful comments on the manuscript.

REFERENCES


Cosmogenic Nuclides and Erosion at the Watershed Scale

Darryl E. Granger1 and Mirjam Schaller2

INTRODUCTION

At the grandest scale, Earth’s topography represents an accumulation of potential energy from mantle convection and tectonics, balanced by decay from chemical weathering and physical erosion. Over timescales of $10^5-10^6$ years, hillslope erosion, soil formation, and sediment accumulation define the distribution and fertility of soil upon which our societies depend. There is a critical need to understand how soil erosion from land use is depleting this natural resource and how modern rates compare with those from the past. Climate change also affects erosional processes in complicated ways, which can be difficult to discern without accurate measurements of erosion rates over various timescales.

Curiously, the problem is that the rate of erosion is a tricky thing to measure. It is a measure of something that isn’t there anymore, and of how quickly it went away. What is needed is a sensitive way to measure how much material was once at a given place and the rate at which that material was lost to dissolution, erosion, and sediment transport. There have been a number of traditional approaches to the problem. For example, over long timescales (millions of years), one can use thermochronology to infer the rate of rock cooling due to exhumation by erosion from the surface. In other words, the cosmogenic nuclide concentration contained in a mineral grain today reflects the natural history of the grain’s approach toward the Earth’s surface. This involves understanding the rate of rock cooling due to exhumation by erosion from the surface.

DETERMINING EROSION RATES

Theory and Methods

Cosmogenic nuclides such as $^{10}$Be (half-life, $t_{1/2} = 1.39$ My) and $^{26}$Al ($t_{1/2} = 0.702$ My) are produced in minerals such as quartz by reactions with secondary cosmic ray neutrons, protons, and muons (for details see Dunai and Lifton 2014 this issue). These nuclides can be used to infer erosion rates because their production rates within a mineral grain depend on their proximity to the Earth’s surface. Production rates decrease exponentially with depth in rock or soil (with a mean cosmic ray penetration length of ~60 cm in rock of density 2.6 g cm$^{-3}$). For an eroding surface, this means that the cosmogenic nuclide concentration integrates the history of a grain’s approach toward the surface. In other words, the cosmogenic nuclide concentration contained in a mineral grain today reflects how quickly the overlying mass went away.

Mathematically, it can be shown that the cosmogenic nuclide concentration in an eroding rock is inversely proportional to erosion rate (Lal 1991). Erosion, as used
Erosion rate here, refers to the combination of physical erosion and chemical weathering that removes mass near the surface. Early in the development of cosmogenic nuclide applications, it was recognized that bedrock outcrops can be used to determine the denudation history of that particular rock. However, in the mid-1990s researchers realized that cosmogenic nuclides in detrital sediment grains can also be used to determine erosion rates [for reviews see Bierman and Nichols (2004) and Granger and Riebe (2013)].

Two key realizations led to interpreting cosmogenic nuclides in sediment. The first was that for a well-mixed soil eroding at a steady state (and in the absence of a high degree of chemical weathering within the soil), the average concentration of cosmogenic nuclides in the soil is the same at all soil depths. This concentration is equal to the concentration contained in the surface of a rock outcrop eroding at the same rate. In other words, for a given erosion rate, a sample of well-mixed soil has exactly the same concentration as exposed bedrock. The effects of chemical weathering are somewhat more complex, as they vary with depth, and an entire research field has emerged dedicated to interpreting weathering rates with cosmogenic nuclides (e.g. Dixon and Riebe 2014 this issue).

The second key to interpreting cosmogenic nuclides in sediment is that for well-mixed stream sediment, the average concentration in the sediment yields the average erosion rate in the watershed (Fig. 1). This relies on the assumptions that sediment is supplied at a rate that is proportional to the erosion rate, that the mineral being analyzed (i.e. quartz) is evenly distributed throughout the entire catchment, and that the cosmogenic nuclide in question was absent before the rock approached the surface.

It is worth examining these assumptions in detail. We begin with the idea that detrital sediment from well-mixed soil on a hillslope has a cosmogenic nuclide concentration that is inversely proportional to the hillslope erosion rate. For a watershed that is eroding homogeneously (i.e. everywhere at the same rate), then the concentration in stream sediment is equal to that of the soils on the hillslopes and the stream sediment yields the erosion rate. In most cases we can ignore sediment storage and transport time in the stream system, which occurs much faster than the timescale of erosion rates, that is, the time to erode the landscape by 60 cm. For a watershed that is eroding heterogeneously, a surprisingly simple solution emerges if we consider the flux-averaged cosmogenic nuclide concentration. That is, areas of the landscape that are eroding quickly provide a large fraction of the quartz but have a low cosmogenic nuclide concentration; conversely, areas eroding slowly provide less quartz but have a high cosmogenic nuclide concentration. In this case, the average cosmogenic nuclide concentration in the sediment reflects the spatially averaged erosion rate from the entire watershed. Remarkably, the equation to determine the erosion rate from an entire watershed is functionally identical to the equation used to determine the erosion rate from a single eroding outcrop. For example, the cosmogenic nuclides contained in a single sample of sand can yield the spatially averaged erosion rate of a watershed ranging in size from the catchment of a small upland creek to the entire Amazon River basin (Fig. 2; Wittmann et al. 2011).

While the assumption of well-mixed and representative stream sediment may hold approximately true, landslides or other such episodic events may deliver an overwhelming load of sediment that temporarily biases the average. If the preponderance of a sample comes from just one landslide, then the inferred erosion rate will reflect primarily only that area. Moreover, if the landslide incorporates fresh bedrock or saprolite, then the cosmogenic nuclide concentration will be lowered and the inferred erosion rate will be faster than the long-term average. On the other hand, if landsliding dominates sediment delivery in the watershed, then it is important to sample that material or the inferred erosion rate will be too slow. The best solution is to sample a sufficiently large catchment with enough landslides so that any single event does not significantly influence the average cosmogenic nuclide concentration (e.g. Yanites et al. 2009).

**Timescale of Erosion**

The timescale over which in situ-produced cosmogenic nuclides measure erosion rates is one of the major strengths of the method, but this also limits the sorts of problems
to which cosmogenic nuclides can be applied. Because cosmogenic nuclides integrate the history of production rates and because production rates fall off exponentially with depth, for a steady erosion rate the concentration is equivalent to the mineral residence time within the top 160 g cm\(^{-2}\) (60 cm in rock of density 2.6 g cm\(^{-3}\), or ~1 m in soil of density 1.6 g cm\(^{-3}\)). In other words, the timescale of bedrock erosion is equal to the time it takes to lower the landscape by ~60 cm, roughly equivalent to the timescale of soil formation in many landscapes. This timescale implies that cosmogenic nuclides effectively dampen rapid changes in erosion rate. If erosion rates change suddenly—for example, due to recent land use or climate change—then the cosmogenic nuclide concentration in the soil will change only slowly, with a response time determined by both the soil mixing depth and the time taken to erode ~60 cm of rock (Fig. 3). The damped response time means that the cosmogenic nuclide concentration measured in soils today represents the long-term average erosion rate, which is usually independent of recent changes in land use and soil degradation.

**Examples of Catchment-Wide Erosion Rates**

Over the past 20 years, erosion rates have been estimated by measuring the cosmogenic nuclides contained in thousands of river-sediment samples from virtually every climatic and tectonic environment in the world (e.g. Portenga and Bierman 2011; Covault et al. 2013 and references therein). Generally, these erosion rates are based on the measurement of \(^{10}\)Be produced in situ in quartz. Several persistent themes have emerged from the data.

One surprising conclusion from these cosmogenic nuclide–based erosion rates is that climate is less important for regulating erosion rates than previously assumed. While erosion rates certainly vary strongly under conditions of climatic extremes where erosional processes are fundamentally different (for example, erosion is slow in hyperarid deserts with little biological activity and fast in glacial and periglacial environments), climate generally plays a secondary role in determining erosion rates over most of the planet. Climate strongly affects the degree of soil weathering (Dixon and Riebe 2014), but the total erosion rate is more commonly determined by factors such as river and hillslope gradients that are adjusted to balance local uplift. Thus, erosion rates on low-relief continental shields are generally slow regardless of climate (~1–10 m/My), while they are much faster (~10\(^3\)–10\(^4\) m/My) on rapidly uplifting mountain ranges.

The conclusion that landscape erosion rates are ultimately set by tectonics driving river incision and hillslope erosion rather than by climate has a number of implications. Perhaps the most important is that cosmogenic nuclide–based erosion rates can be used as a proxy for local river incision and uplift rates (e.g. Wobus et al. 2005). This is a powerful notion for landscapes at dynamic equilibrium because it suggests that a handful of sand can provide the local incision and uplift rates (Kirby and Whipple 2012).

The numerous cosmogenic nuclide measurements now available allow comparison of erosion rates over different timescales. Catchment-averaged erosion rates from cosmogenic nuclides can be compared to short-term suspended- and dissolved-sediment loads in rivers (e.g. Wittmann et al. 2011; Covault et al. 2013). Interestingly, Covault et al. (2013) found that the vast majority of cosmogenic nuclide–based erosion rates are faster than those inferred from monitored sediment yield. This tendency was first noticed by Kirchner et al. (2001), who invoked the importance of large but infrequent events in sediment delivery. While the abundances of cosmogenic nuclides average such variability, stream-gauging methods are likely to miss the largest and most important events that may happen only once in a decade or a century. In addition, sediment storage in floodplains tends to buffer rapid changes in sediment supply due to land use (Wittmann et al. 2011). Only in the most highly modified landscapes or in landscapes with very low sediment storage capacity do modern erosion rates consistently exceed cosmogenic nuclide–based erosion rates (e.g. Hewawasam et al. 2003).

**PALEO–EROSION RATES**

If modern-day river sediment contains information about the erosion rate of its source area, then sedimentary deposits should be able to tell us about paleo–erosion rates and how erosion rates have varied through time in response to changes in climate or tectonics. Estimates of paleo–erosion rates provide powerful insights into the behavior of ancient landscapes. It must be recognized, however, that the cosmogenic nuclides that are generally useful for determining erosion rates, such as \(^{10}\)Be and \(^{26}\)Al in quartz, are radioactive. Also, cosmogenic nuclide production does not fully stop even after several meters of burial. Thus, accurate paleo–erosion rate determinations require correcting for loss due to radioactive decay as well as continued production by deeply penetrating muons. The slower the paleo–erosion rate and the more deeply buried the sediment, the further back in time one can infer paleo–erosion rates—generally up to 5–10 million years.

Of course, accurate paleo–erosion rate determinations require knowing the depositional age of the sediment. But what if the age is not known independently? The beauty of cosmogenic nuclides is that it is possible to date the sediment directly using “burial dating.” Measuring at least two nuclides in the same mineral grains (such as \(^{10}\)Be, \(^{26}\)Al, and/or \(^{21}\)Ne in quartz; Balco and Shuster 2009) allows one to solve for the burial age and the paleo–erosion rate simultaneously.
Examples of Paleo–erosion Rates

A good example of how paleo–erosion rates can be estimated over glacial/interglacial timescales comes from the pioneering work of Schaller et al. (2002). In their study of sediments in terraces of European rivers, they found that erosion rates were roughly twice as fast during the Last Glacial Maximum (LGM) as they are today. Estimates show that the ~80 m/My determined for the LGM became much slower, to ~30–40 m/My, through the Holocene to the present. The faster rates may be due to frost-cracking and/or periglacial processes that accelerated erosion and soil transport during the LGM (e.g. Delunel et al. 2010).

Paleo–erosion rates can also be determined from buried sediment over much longer timescales of millions of years to decipher how landscapes have responded to climate change and tectonic uplift (Schaller et al. 2004). Paleo–erosion rates (and burial dates) allow one to explore how erosion rates and valley-incision rates have varied at the same site over millions of years, and thus to quantify how landscapes have responded to long-term climate change and uplift. For example, a compilation of paleo–erosion rate determinations that span million-year timescales (Fig. 4) records the varied responses of landscapes to the expansion of Northern Hemisphere glaciation near 2.5 My ago. Together these types of studies provide an opportunity to examine the influence of long-term climate change on hillslope erosion rates.

Measurements of cosmogenic nuclides also show that erosion rates have increased in many glaciated or partially glaciated watersheds, even during interglacials. This is true in the northern Swiss Alps (Haeuselmann et al. 2007), the Sierra Nevada of California, USA (Stock et al. 2004), and the Tian Shan in China (Charreau et al. 2011) (Fig. 4). Erosion rates have increased in some unglaciated watersheds as well, particularly in areas subject to a periglacial climate. Schaller et al. (2004) found increased erosion in the Meuse River, the Netherlands, likely due to both climate change and uplift of the Ardennes Mountains. A dramatic increase in erosion rate is documented in an unglaciated valley in the Sangre de Cristo Range, Colorado, USA (Refsnider 2010). Anthony and Granger (2007) studied sediment in caves along the Cumberland Plateau in the unglaciated southeastern United States and showed that paleo–erosion rates systematically increase in the Pleistocene hundreds of kilometers south of the Laurentide ice sheet margin. Interestingly, data from Mammoth Cave in central Kentucky (Granger et al. 2001) do not show any change in paleo–erosion rates across this same climatic transition, even though the site is closer to the ice margin.

DEVELOPING TRENDS: METEORIC 10Be

While the discussion thus far has focused on 10Be produced in situ within mineral grains, there is another, much larger, inventory of meteoric 10Be in soil. 10Be is produced in the atmosphere and delivered to the surface by wet and dry deposition (e.g. Dunai and Lifton 2014). As a fallout radio-nuclide, meteoric 10Be is incorporated into a variety of archives, including snow and ice; lacustrine, estuarine, and marine sediment; manganese nodules on the sea floor; and soil. Measurements of meteoric 10Be have been used to address a wide range of geologic problems, from snow and ice accumulation to sediment recycling in subduction zones. We focus here on the specific use of meteoric 10Be for determining erosion rates. For recent reviews, see Willenbring and von Blankenburg (2010), Graly et al. (2010), and Granger et al. (2013).

Meteoric 10Be is a particle-reactive species that adsorbs strongly to mineral grains, particularly clays, for soil pH greater than about 6. Unlike in situ–produced 10Be, the meteoric variety migrates within the soil profile, to a depth determined largely by soil pH, soil texture, and grain size. More recently, the 10Be/9Be ratio of beryllium adsorbed to sediment has been used to simultaneously determine the erosion rate and the degree of chemical weathering of bedrock within a watershed. The 10Be is derived from meteoric fallout while the 9Be comes from the chemical weathering of bedrock (von Blankenburg et al. 2012). Advantages of the meteoric technique are that only ~1 gram of fine-grained material is required and that the 10Be/9Be ratio is nearly independent of lithology.

![Figure 4](image-url)

**Figure 4** Paleo–erosion rates from ancient sediment as a function of time for seven northern-latitude sites that span at least 1 million years. All but one show increasing erosion rates and/or erosional variability, whether for slowly eroding landscapes such as the Cumberland Plateau, USA, or the Meuse River in the Netherlands where maximum erosion rates are 60 m/My or for high mountains such as the Swiss Alps or the Tian Shan, China, eroding more than 10 times faster. All ages and erosion rates are plotted as originally reported by the authors (cited in the text) and have not been adjusted to a uniform 10Be production rate and half-life, which would result in minor changes.
During the early years of cosmogenic nuclide applications, meteoric $^{10}\text{Be}$ was widely used for exploring surface processes because of its relatively high atmospheric concentrations. This approach, however, was largely eclipsed by measurements of the in situ-produced variety in the early 1990s as methods were developed for determining $^{10}\text{Be}$ contained in quartz. Recent years have seen a resurgence in the meteoric variety’s popularity, but one must recognize that beryllium mobility in the environment can be complex and is still poorly understood. Meteoric $^{10}\text{Be}$ holds great promise for exploring erosion rates and sediment transport, as well as changing environmental conditions.

**SUMMARY**

Cosmogenic nuclides are now the “gold standard” for determining erosion rates of rocks and watersheds. The method is rooted in the physics of energetic-particle attenuation, which allows geologists to query a rock about the material that used to be on top of it and the rate at which the material was lost. A handful of sand from a riverbed can tell us about the average erosion rate upstream. Sedimentary archives offer a unique record of how erosion rates have changed through time. Cosmogenic nuclides are finally allowing geologists to answer age-old questions about how the landscapes and soils around us reflect their combined legacy of climate, tectonics, and land use.

**ACKNOWLEDGMENTS**

We would like to acknowledge the helpful comments by the guest editors as well as reviews by P. Belmont, B. Bookhagen, and V. Godard.

**REFERENCES**


Granger DE, Fabel D, Palmer AN (2001) Pliocene–Pleistocene incision of the Green River, Kentucky, determined from radiocative decay of cosmogenic $^{26}\text{Al}$ and $^{10}\text{Be}$ in Mammoth Cave sediments. GSA Bulletin 113: 825-836


Kirchner JW and 6 coauthors (2001) Mountain erosion over 10 yr, 10 k.y., and 10 m.y. time scales. Geology 29: 591-594


Portenga EW, Bierman PR (2011) Understanding Earth’s eroding surface with $^{10}\text{Be}$. GSA Today 21(8): 4-10


Geochemistry would not be where it is today if it were not for Savillex Corporation.

- Dr. Mike Cheatham, Syracuse University

Savillex Corporation has been proudly serving the geochemistry community for over 35 years. Our fluoropolymer labware products are used throughout the world for sample digestion, separations, storage and many other applications. We understand the unique needs of geochemists and now our new line up of ICP-OES and ICP-MS sample introduction products combine the highest performance and the lowest metal background with the ruggedness and reproducibility required for routine analysis.

All of our ICP sample introduction products are designed, molded and tested in house, using only the highest purity grade PFA resins.

Nebulizers – C-Flow

- C-Flow microconcentric PFA nebulizer range with the narrowest uptake rate specification
- New C-Flow 35 with uptake rate of 35uL/min +/-7uL/min
- C-Flow range for desolvators – standard fitment on the CETAC Aridus II
- C-Flow 700d with removable uptake line for high solids applications – up to 25% TDS
- All C-Flows can be backflushed without tools

Inert Kits

- PFA kits with Scott type chamber
- True double pass design gives lower RSDs
- O-ring free end cap
- Platinum or sapphire injectors
- Available for Agilent 7500/7700/8800 and Thermo Element 2/Neptune

For technical notes, videos and to find your local Savillex distributor, visit www.savillex.com.

Savillex Corporation
Phone: 952.935.4100 | Fax: 952.936.2292
Email: info@Savillex.com | www.savillex.com
The implications of climate change are challenging and far-reaching, particularly for land managers tasked with protecting the resources of national parks and other protected areas. To meet this challenge, managers need to encourage and make use of the creative and innovative thinking of the next generation of youth scientists and leaders.

The George Melendez Wright Initiative for Young Leaders in Climate Change (YLCC) builds a pathway for exemplary students in higher education to apply cutting-edge climate change knowledge to park management. Through a summer-long internship, undergraduate and graduate students will gain valuable work experience, explore career options, and develop leadership skills under the mentorship and guidance of the National Park Service. Parks and programs will increase their capacity to understand and respond to climate change and its impacts.

National parks and NPS programs develop and oversee structured projects in one or more of the following interdisciplinary areas: climate change science and monitoring; resource conservation and adaptation; policy development; sustainable park operations; facilities adaptation; and communication/interpretation/education. During the internship, students apply critical thinking and problem solving skills to climate change challenges and communicate with diverse stakeholders. Interns who successfully complete the YLCC, an approved Direct Hire Authority Internship program, will be eligible to be hired non-competitively into subsequent federal jobs once they complete their degree program. These jobs would be in the Department of Interior (DOI), NPS, or one of the other bureaus within the DOI. An intern must qualify for the job in order to be hired non-competitively.

Quick Facts and Deadlines:

- The YLCC is managed cooperatively with the University of Washington
- Internship opportunities and application forms are posted on parksclimateinterns.org
- Internships are 11-12 weeks (40 hours/week) during the summer
- Interns are paid $14/hour plus benefits
- Applications are accepted from early December 2014 until late January 2015

Who was George Melendez Wright?

George Melendez Wright was deeply influential in bringing science to the management of America’s national parks. Working as a naturalist in Yosemite National Park in the 1920s, Wright argued that good science was needed for effective conservation. In 1930, he was appointed Chief of the Wildlife Division for the NPS where he encouraged the agency to embrace science-based approaches to conserving species, habitats, and other natural conditions in the parks. Although he died while he was still a young man, Wright’s legacy lives on in the NPS’s commitment to use the best available science for preserving the resources of our National Parks.

For More Information: Tim Watkins, Climate Change Response Program, NPS, Tim.Watkins@nps.gov
October 29, 2014

To College and University Administrators:

The first cases of Ebola Virus Disease (EVD) diagnosed in the United States have heightened awareness of our global community and this serious disease. It also raised the level of concern for the safety of travelers both to the affected countries, and those returning to Indiana from an affected country, and the safety of the academic community.

The Ebola virus is not spread through the air, by water or food, or by casual contact. People with Ebola can only spread the Ebola virus when they have symptoms. There is no known risk of transmission if someone does not have symptoms. Ebola is only spread through direct contact with blood or body fluids (including but not limited to urine, saliva, feces, vomit and semen, or a needlestick) of a person who is sick with Ebola or the body of a person who has died from Ebola.

Currently in the U.S., individuals at risk for developing EVD are those who have arrived in the U.S. from Guinea, Liberia, or Sierra Leone within the past 21 days (the maximum incubation period for Ebola virus). Previous travel to these countries outside the 21-day incubation period is not a risk factor for Ebola.

Individuals who have had direct contact with identified Ebola cases in the U.S. may also be at risk for the EVD if that contact occurred at the time the case was symptomatic. Ebola symptoms include fever, headache, nausea, vomiting, diarrhea, muscle or body aches, and fatigue. The Indiana State Department of Health (ISDH) website has more information about EVD at www.statehealth.in.gov.

The Centers for Disease Control and Prevention (CDC) has prepared a document specifically addressing the unique concerns of colleges, universities, and students around the EVD occurring in the West African countries of Guinea, Liberia, and Sierra Leone. You can find that information at: http://wwwn.cdc.gov/travel/page/advice-for-colleges-universities-and-students-about-ebola-in-west-africa.

The CDC has issued a Level 3 Warning travel advisory, urging all U.S. residents to avoid non-essential travel to Liberia, Guinea, and Sierra Leone because of unprecedented outbreaks of Ebola in these countries. In addition, the CDC is screening all passengers departing from airports in Liberia, Guinea, or Sierra Leone for contacts with persons diagnosed with Ebola and symptoms of Ebola. Exit screening involves travelers responding to a traveler health questionnaire, being visually assessed for potential illness, and having their body temperature measured before they board the flight. Passengers with a positive screen are not permitted to board flights.

To augment the screening process, the CDC Division of Global Migration and Quarantine began screening passengers from Liberia, Guinea, and Sierra Leone arriving at five U.S. ports of entry on October 11, 2014. Beginning this weekend, all passengers traveling from these countries will be routed through the five airports where screening has been established. Passengers will complete a health assessment form, provide destination and contact information, and have their temperature checked. Anyone with risk factors for Ebola will be further evaluated on site at the airport by a CDC medical officer. Arriving passengers with symptoms will be
transported to a designated hospital for medical evaluation in the mTival city. Those with risk factors will be restricted from traveling on commercial conveyances (air, bus, train, taxi/limousine) until the 21-day incubation period has passed.

Travelers at low risk will be allowed to proceed to their destinations, with notification provided to the state health department. The ISDH has already begun receiving notification about any traveler with Indiana as a destination and has an established system, with local public health officials, for monitoring these travelers for fever and other symptoms, so they can be immediately hospitalized should they develop symptoms of Ebola. All passengers arriving from the Liberia, Guinea, and Sierra Leone, regardless of their exposure level, will be monitored by ISDH and local health departments twice daily for 21 days. This includes, checking temperature and symptoms.

To read more about enhanced screening of travelers from Liberian, Guinea, and Sierra Leone at airports in the U.S., please visit the CDC website at: [http://www.cdc.gov/media/releases/2014/p1008-ebola-screening.html](http://www.cdc.gov/media/releases/2014/p1008-ebola-screening.html). CDC has strongly recommended that people avoid non-essential travel to Guinea, Liberia, or Sierra Leone at this time. CDC advises that education-related travel to these countries be postponed until further notice. If you have students, faculty, or staff from Liberia, Guinea, or Sierra Leone on campus who are planning to return to one of these countries over winter break, they should expect to be monitored for symptoms of Ebola twice daily by the local health department for 21 days upon their return. They should also understand that, depending on their risk for developing Ebola, there may be movement restrictions placed on them during that 21 day monitoring period.

The Ebola situation in West Africa and the U.S. is changing rapidly. Please advise your students, faculty or staff intending to travel to Liberia, Guinea, or Sierra Leone to monitor the travel situation carefully as it is subject to change.

For the most up-to-date information, please visit the CDC website at [www.CDC.gov/ebola](http://www.CDC.gov/ebola), or the ISDH website at [www.statehealth.in.gov](http://www.statehealth.in.gov).

If you have additional questions, please feel free to call the ISDH Ebola Call Center at 1-877-826-0011. The call center is open 24 hours a day, seven days a week.

Sincerely,

JEROME M. ADAMS, MD, MPH
STATE HEALTH COMMISSIONER