Improving the accuracy and precision of scaling factors for *in-situ* cosmogenic geochronometers: New measurements of cosmic-ray neutrons in India and Hawaii

DARIN DESILETS AND MAREK ZREDA

Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, 85721, USA (ddesilet@hwr.arizona.edu, marek@hwr.arizona.edu)

Production rates of *in-situ* cosmogenic nuclides are determined by the intensity of energetic cosmic-ray nucleon fluxes, which is highly dependent on elevation. An incomplete knowledge of how nucleon fluxes vary with elevation remains a major obstacle to utilizing cosmogenic nuclides as geochronometers in applications requiring small time resolution. One problem is that attenuation characteristics of nucleon fluxes depend on nucleon energy. Measurements of high-energy (>50 MeV) fluxes tend to give shorter attenuation lengths than low-energy (<1 MeV) fluxes, but these differences are not well characterized due to a lack of data at lower energies. Another problem is that the elevation dependence varies with geomagnetic cutoff rigidity (a parameter related to geomagnetic latitude), R_C, and that there has been an incomplete mapping of neutron fluxes at high R_C (low latitude). We report new measurements of neutron fluxes from altitude transects in Hawaii (R_C=12.8 GV) and Bangalore, India (R_C=17.2 GV). Our measurements in Hawaii of low-energy neutrons (median energy 1 eV) and energetic nucleons (median energy 140 MeV) confirm that nucleon scaling functions are energy dependent in the range of energies at which cosmogenic nuclides are produced. Our measurements in India extend our previously reported scaling model for spallation reactions (Desilets and Zreda, 2003, Earth and Planetary Science Letters 206, 21-42) from R_C=13.3 GV to R_C=17.2 GV, nearly the highest modern cutoff rigidity on earth. The anomalously high cutoff rigidity over India provides a geomagnetic shielding condition that is effectively the same as would be observed at the geomagnetic equator in a dipole field with an intensity 1.2 times the modern value. This makes it possible to scale low-latitude production rates to paleomagnetic fields that are stronger than the present dipole field.

Calibrating the production rate of cosmogenic ^{36}Cl from postglacial lava flows in Iceland

C.L. DENONCOURT[1], J.M. LICCIARDI[1], J.O. STONE[2] AND R.C. FINKEL[3]

[1]Department of Earth Sciences, University of New Hampshire, Durham, NH 03820, USA (cld2@unh.edu, joe.licciardi@unh.edu)
[2]Quaternary Research Center and Department of Earth and Space Sciences, University of Washington, Seattle 98195, USA (stone@geology.washington.edu)
[3]Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, Livermore, CA 94550, USA (finkel1@llnl.gov)

One large uncertainty in surface exposure dating commonly arises from incomplete knowledge of production rates of cosmogenic isotopes and their variation with latitude, altitude and time. In Iceland, the production rates of *in situ* cosmogenic isotopes are predicted to be higher than globally averaged rates due to persistent low atmospheric pressure (Stone, 2000). Licciardi and Kurz (2002) determined that ^{3}He production rates in Iceland are significantly higher than normalized values measured in the western United States (Licciardi et al., 1999), supporting Stone's prediction.

We measured cosmogenic ^{36}Cl concentrations in whole rock basalts from radiocarbon-dated lava flows in Iceland. The ^{36}Cl data were obtained from splits of rock material from the same calibration sites used by Licciardi and Kurz (2002) to calculate their ^{3}He production rates. These ^{36}Cl measurements thus allow for the first direct co-calibration between these two widely used cosmogenic isotopes.

An immediate application of our ^{36}Cl production rates is to enable accurate ^{36}Cl dating in Iceland (e.g., Principato et al., 2003). Moreover, the ^{3}He-^{36}Cl co-calibration will further elucidate the influence of atmospheric pressure on the production rate of *in situ* cosmogenic isotopes.

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Cosmogenic helium and neon extracted by crushing: A technique for discriminating between mantle and cosmogenic helium

MANUEL MOREIRA[1] AND PEDRO MADUREIRA[1,2]

[1]Institut de Physique du globe de Paris, Université paris VII, CNRS UMR 7579, 4 place Jussieu, 75005 Paris, France (moreira@ipgp.jussieu.fr)

[2]Centro de Geofisica de Évora/Departamento de Geociências da Universidade de Évora, Rua Romão Ramalho, 59, 7000-671 Évora, Portugal

The helium and neon isotopic compositions of olivines coming from a 11Ma old xenolith sampled at Mt. Hampton (West Antarctica) were analyzed by crushing and heating. The $^{4}He/^{3}He$ isotopic ratio obtained by crushing varies between 1340 and 6300 (R/Ra between 115 and 539) with ^{4}He content around 3-5 10^{-10} ccSTP/g confirming that cosmogenic helium can be extracted by crushing [Scarsi, 2000; Yocochi et al., 2004]. The neon also shows a clear cosmogenic origin ($^{20}Ne/^{22}Ne$ down to 7.7 and $^{21}Ne/^{22}Ne>0.32$) indicating that some cosmogenic neon can also be extracted by crushing out of the olivines. This result indicates that for samples that had been exposed for a long time (e.g. few Ma to Ga), a step crushing procedure may not give the mantle ratios without ambiguity and that measurement of neon can discriminate between cosmogenic and mantle origin of the ^{3}He. Melting of the powder left after the crushing experiment gives $^{4}He/^{3}He$ ratio as low as 51±5 (R/Ra=14 230) and $^{21}Ne/^{22}Ne$ as high as 0.78, close to the cosmogenic end-member. Our results show that ~0.4% of the cosmogenic helium and ~0.3% of the cosmogenic neon can be extracted out of olivines by crushing

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Grain size dependency of ^{10}Be concentrations in alluvial sediments in the Great Smoky Mountains

A. MATMON[1], P. R. BIERMAN[2], J. LARSEN[2], S. SOUTHWORTH[3], M. PAVICH[3], R. FINKEL[4] AND M. CAFFEE[4]

[1]United States Geological Survey, Menlo Park, CA 94025, USA

[2]Geology Department, University of Vermont, Burlington, VT 05405, USA

[3]United States Geological Survey, Reston, VA 20192, USA

[4]Lawrence Livermore National Laboratory, Livermore, CA 94550, USA

Analysis of multiple grain-size fractions from alluvial sediment samples in the Great Smoky Mountains (GSM), show, in five of the six samples tested, higher nuclide concentrations and by inference, slower model erosion rates, in smaller grain sizes than in larger ones. ^{10}Be concentration in the < 2 mm fractions correlate to erosion rates that range between 25±3 and 50±6mm ky^{-1}. in contrast, erosion rates 20%-40% higher are calculated for the >2 mm fractions in each sample. Field evidence for mass wasting is minimal, therefore, differences in cosmogenic nuclide concentrations between grains of different sizes cannot be explained by differences in transport mechanism. We interpret the difference in concentrations as a result of the large elevation distribution of the source and longer exposure periods on the slopes for the smaller grains compared with the narrow and relatively low source elevation of the large grains and their shorter exposure history.

Large sandstone clasts disaggregate into sand-size grains rapidly during down slope transport so only clasts from the lower parts of slopes reach the streams. A positive correlation between maximum relief in the basin and the difference in normalized ^{10}Be concentrations in the different grain size fractions suggests that our explanation is valid. We use the sampling location production rates to calculate erosion rates from ^{10}Be concentrations in the larger clasts. When site production rates are used, large grain size fractions yield erosion rates that range between 18±2 and 45±6 mm ky^{-1}, similar to those calculated from the small grain size fractions. These results support our assertion that clasts are derived from the lower parts of the slopes, that clasts are not transported long distances downslope, and that different grain sizes are generated at similar rates in the GSM.

Perspectives on dating with multiple cosmogenic nuclides

DARRYL E. GRANGER

Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, USA (dgranger@purdue.edu)

The method of dating sediment burial using the differential decay of ^{26}Al and ^{10}Be in quartz has been used since the earliest days of terrestrial cosmogenic nuclide measurements. Techniques were readily adapted from the meteoritic field, where multiple cosmogenic nuclides were routinely measured to date complex histories of exposure and shielding in space and on earth. However, because the ^{26}Al-^{10}Be pair is sensitive only on a million-year timescale, with uncertainties of 10's to 100's of thousands of years, it initially proved to be of limited use for dating earth surface processes, which tend to occur much more rapidly. More recently, a flurry of new applications has developed to date rock and sediment burial over the past 5 My, providing dates to investigate long-term river incision, marine terrace uplift, glacial histories, and biologic evolution, as well as measurements to investigate paleo-erosion rates. I will present examples of these applications from published work as well as from marine terraces and caves of central Italy.

Accurate burial dating with ^{26}Al and ^{10}Be is hampered by a large discrepancy in the half-life of ^{10}Be. Although most published ^{10}Be measurements implicitly assume a half-life of 1.5 My, an alternative measurement of 1.34 My was derived from the same parent solution; these values have never been resolved. A compilation of surface exposure data from the literature reveals that $^{26}Al/^{10}Be$ ratios near saturation are consistent with either half-life, but that they are more closely described by the shorter half-life.

Ongoing and future work with different mineral systems may employ different cosmogenic radionuclides. For example, feldspar and quartz in the same rock can be analyzed for ^{36}Cl, ^{26}Al, and ^{10}Be to reveal more complex or recent exposure and burial histories. Carbonate rocks may also prove useful for the ^{36}Cl-^{10}Be pair. Preliminary results from a Roman marble quarry show that ^{10}Be can be measured to high precision in this rock, although care must be taken to avoid secondary calcite which may contain large amounts of meteoric ^{10}Be, even many centimeters beneath the surface.

Preservation of (Early) Miocene landscapes in the Atacama Desert, northern Chile

T.J. DUNAI[1], G.A.GÓNZALEZ-LÓPEZ[2], J. JUEZ-LARRÉ[1] AND D. CARRIZO[2]

[1]Faculty of Earth and Life Sciences, Vrije Universiteit, Amsterdam, Netherlands (dunt@geo.vu.nl; juej@geo.vu.nl)
[2]Departamento de Ciencias Geológicas, Facultad de Ingeniería y Ciencias Geológicas, Universidad Católica del Norte, Antafogasta, Chile (ggonzale@ucn.cl)

Depositional surfaces of early Miocene sediments surfaces are preserved in the Coastal Cordillera, Atacama Desert, northern Chile. Measurement of cosmogenic ^{21}Ne in clasts from erosion-sensitive sediment surfaces show that these surfaces have been barely affected by erosion since 25 Ma. Predominantly hyperarid conditions since 25 Ma are required to create and preserve these oldest continuously exposed surfaces on Earth. The next oldest continuously exposed surfaces, in the Dry Valleys region, Antarctica, have about half this age. Occurrence of younger exposure ages indicate that brief pluvial episodes occurred since the Early Miocene did occur, which caused limited, localized erosion and material transport, only marginally affecting the large scale landscape.

We present new data from other, similarly old surfaces, from the coastal portion of the Atacama Desert. These data demonstrate that the exceptional landscape stability in this coastal desert is widespread, as would expected from the large scale regional factors controlling climatic conditions in this area.

The dominantly hyper-arid conditions we infer for the Coastal Cordillera since ~25 Ma ago are compatible with the hypothesis that the onset of aridity in the Atacama Desert is the cause, rather than the result of the uplift of the high Andes.

Only exceptional global climatic disturbances have occasionally permitted humidity transfer across the Andes into the driest regions of this Coastal Desert since ~25 Ma.

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Constraining landform erosion and ages from surface exposure age distributions on old Patagonian moraines

R.P. ACKERT AND S. MUKHOPADHYAY

Department of Earth and Planetary Sciences, Harvard University (rackert@fas.harvard.edu)

Applying surface exposure dating to moraines older than the last glacial maximum is challenging. For these older moraines, boulder erosion and landform degradation become important, resulting in a wide distribution of cosmogenic nuclide concentrations. Extracting meaningful exposure ages from these moraines requires accurate erosion and exhumation rates.

To better understand the evolution of exposure age distributions with time, we have started an investigation of cosmogenic ^{3}He and ^{36}Cl from a large suite of basalt boulders collected from the Telken IV (760-1016 ka; [1]) and Deseado (109-760 ka; [1]) moraines at Lago Buenos Aries (LBA), Argentina. The moraines at LBA are ideal for this study because they are the longest, best preserved glacial record outside of Antarctica. Surface exposure dating has established that the youngest moraine complex at LBA ranges in age from 16 to 26 ka (stage 2) and records millennial scale fluctuations of the ice margin during the LGM [2]. Exposure ages on the next oldest moraine complex suggest that they date to the penultimate glaciation (stage 6) but the effects of boulder erosion and exhumation are evident with many young outliers in the exposure age distribution.

We have obtained ^{3}He exposure ages of 178, 190, and 133 ka on three boulders from the Telken IV moraine, which are similar to ages obtained using ^{10}Be and ^{26}Al on nearby granitic boulders of older moraines (Telken V and VII moraines [2]). Our ^{3}He exposure ages calculated with an erosion rates of 2mm/kyr are almost twice as old, 287 and 326 ka, but still significantly less than the minimum age of the Telken IV moraine, clearly indicating the importance of boulder exhumation and erosion. Using our preliminary data, the maximum deflation rate of the moraine surface is 7 mm/kyr. We plan to obtain additional ^{36}Cl and ^{3}He data to constrain the process of boulder exhumation and erosion and thereby 1) improve the chronology of glacial history in Patagonia, 2) understand landform development and preservation in the dry Patagonian steppe, and 3) infer landform age from exposure age distributions in areas where independent chronology is not available.

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^{3}He exposure ages of boulder armored terraces in the northwestern Colorado Plateau

DAVID W. MARCHETTI[1], THURE E CERLING[1] AND JOHN C DOHRENWEND[2]

[1]Department of Geology, U. of Utah, 135S 1460E Room 719, SLC, UT 84112, USA (dwmarche@mines.utah.edu)
[2]Southwest Satellite Imaging, 223 South State, Teasdale, UT 84773-0141, USA

In the Capitol Reef and Escalante areas of the northwestern Colorado Plateau (south central Utah) there are tens to hundreds of individual basaltic-andesite armored terraces throughout the landscape. These armored terraces are former valley floors that are now 10-200 m above the local drainages. All of these armored terraces are capped with coarse basaltic-andesite boulder deposits derived from the high (>3400 m) volcanic plateaus of Boulder or Thousand Lakes Mountains. Using ^{3}He exposure age dating we determined the exposure ages of multiple boulders from several of these terraces. We interpret these deposits to be proximal debris-flows and therefore assume deposition was rapid and do not include a correction for cosmogenic inheritance due to transport. We do include a correction for non-cosmogenic (nucleogenic) ^{3}He produced in the basaltic-andesites since crystallization (~25 Ma). This component is typically less than 8% of the total ^{3}He inventory. Maximum boulder exposure ages of these land-surfaces range from 1.2 Ma to 196 ka and represent average local incision rates ranging from ~0.15 m/kyr to 0.40 m/kyr. The incision rates we calculate are some of the highest on the Colorado Plateau and add to a growing body of evidence suggesting that there was significant fluvial incision of the Plateau during the Pleistocene.

Glacial erosion and till dispersion using the source and the sink: A new cosmogenic nuclide application

JANE WILLENBRING STAIGER AND JOHN C. GOSSE

Dept. of Earth Sciences, Dalhousie University, Halifax, Nova Scotia, Canada (jane.staiger@dal.ca, john.gosse@dal.ca)

Landscape morphodynamics can be recorded by both the bedrock surface and the deposits removed from the bedrock. In this work, we analyze both the source – the bedrock – and the sink – the till – to decipher the glacial system.

Terrestrial in situ cosmogenic nuclides (TCN) extracted from glaciated bedrock surfaces can be used to assess the relative stability of each part of the landscape, thus to determine the spatial variation of glacial erosion beneath polythermal ice. We adopt a field-constrained glacial erosion rule for the Torngat Mountains of northern Labrador for use in Baffin Island, which occupies similar setting. This rule correlates modeled ice velocities with TCN-derived erosion rates from bedrock for terrain once partially covered by slow-moving, non-erosive ice (Staiger et al., 2005).

Because the spatial variation of cold-based, non-erosive ice versus wet-based, erosive ice is recorded by the bedrock TCN concentrations, each individual grain within the till has a unique history as it was previously exposed to cosmic radiation then transported by ice. Together the grains give an areal average of the basal thermal regime of the ice that entrained the sediment. In this new method, we measure ^{10}Be and ^{26}Al concentrations in 25 surface till samples from Baffin Island and Labrador and can distinguish specific sediment packages. Till samples that were predicted by geomorphological context to have been deposited by non-erosive ice contain over 100 times the TCN contentration of till thought to be deposited by highly erosive ice. We interpret these data using a finite-element, time-dependent ice sheet model that includes basal temperature and basal water calculations (Johnson and Fastook, 2003) and a forward model that calculates possible TCN concentration scenarios.

We estimate ranges of englacial traveling distances for “short-distance tills” with high TCN values and “long distance tills” with low TCN values. This work has potential applications in arctic and sub-arctic drift exploration as well as a potential for assessing the effect of glacial erosion on a glaciated landscape with fewer samples.

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Five ways to examine what isn’t there with cosmogenic isotopes

J.C. GOSSE[1], S. BAKER[1], F. PAZZAGLIA[2], M. BRANDON[3], K. KARLSTROM[4], J. PEDERSON[5] AND R. FINKEL[6]

[1]Dept. Earth Sciences, Dalhousie U., Halifax, NS, Canada (john.gosse@dal.ca)
[2]Dept. Earth & Env. Sci, Lehigh U., Bethlehem, PA, USA
[3]Dept. Geology, Yale U., New Haven, CT, USA
[4]Dept. Earth & Planet. Sci., U. New Mex., Albequerque, NM, USA
[5]Dept. Geology, Utah State U., Logan, UT, USA
[6]CAMS, Lawrence Livermore National Lab, Lawrence, CA, USA

Terrestrial in situ cosmogenic nuclides (TCN) have been used in five ways to characterise the rates of exumation or incision by streams: (1) a maximum erosion rate can be calculated by measuring one or two isotopes on a bedrock surface; (2) basin-wide average erosion rates can be calculated with one isotope measured in stream sediment; (3) escarpment retreat rate can be attained by measuring remnents of the retreating cliff; (4) stream incision rates into bedrock can be attained by dating straths; and (5) vertical incision rates can be estimated from measurements of a single isotope down a near vertical wall of a canyon. The application of each approach is demonstrated and placed in a regional context. Erosion of Archean gneiss summits in the Torngat Mountains of Labrador, Canada are as low as 1.6±0.3 m/Myr. Basin-wide average erosion rates in the Clearwater Catchment, Olympic Mtns, Washington State range from 0.4±012 mm/yr in high relief regions to 0.2±0.1 mm/yr in low relief regions over the past 10^4 yrs, in close agreement with similar timescale strath incision rates, longer timescale thermochronology, and shorter timescale stream sediment discharge. Retreat rate of the Morrison Formation escarpment in NE Arizona has been measured at 15±5 mm/yr (n=3) in one basin and 2.5±0.5 mm/yr (n=2) in an adjacent basin, consistent with estimates from soils and other measurements. Chronology of mapped fill terrace surfaces in the eastern Grand Canyon provide constraints on the age of the underlying straths that are consistent with U-series and OSL ages of the same fills, and yield an average incision rate by the Colorado River of 100-150 m/Myr. Ages on straths in the Rio Diamante, Mendoza, Argentina have provided constraints on incision through a Quaternary fold (the initiation of an antecedent stream). Rates of incision based on single nuclide measurements in canyon wall bedrock samples within 20 m above 5000 cfs stage, average 0.08±0.01 mm/yr (n=3) for the past 20 kyr to more than 3 mm/yr on higher surfaces. Higher surfaces lacked fluvial polish.

^{81}Kr-dating: From dream to practice

Z.-T. LU

Physics Division, Argonne National Laboratory, Dept. of Physics and Enrico Fermi Inst., Univ. of Chicago (lu@anl.gov)

Since radiocarbon dating was first demonstrated in 1949, the field of trace analyses of long-lived cosmogenic isotopes has seen steady growth in both analytical methods and applicable isotopes. The impact of such analyses has reached a wide range of scientific and technological areas. A new method, named *Atom Trap Trace Analysis (ATTA)*, was recently developed and used to analyze ^{81}Kr ($t_{1/2} = 2.3\times10^5$ years, isotopic abundance ~ 1×10^{-12}) and ^{85}Kr ($t_{1/2}$ = 11 years, isotopic abundance ~ 1×10^{-11}) in environmental samples. ^{81}Kr is produced by cosmic rays in the upper atmosphere. It is the ideal tracer for dating ice and groundwater in the age range of 10^4–10^6 years beyond the reach of radiocarbon dating. On the other hand, analyses of ^{85}Kr, a fission product of uranium and plutonium, can serve as a means to help verify compliance with the Nuclear Non-Proliferation Treaty as well as dating young groundwater. In ATTA, individual atoms of the desired isotope are selectively captured into a laser-based atom trap and detected by observing the fluorescence of trapped atoms. As the first real-world application of ATTA, the mean residence time of the old groundwater in the Nubian Aquifer located underneath the Sahara Desert was determined. With this demonstration and further improvements in the ATTA method, wide spread use of ^{81}Kr-dating in Earth sciences seems feasible. This work is supported by the U.S. Department of Energy, Office of Nuclear Physics, under contract W-31-109-ENG-38, and by the U.S. National Science Foundation grant EAR-0126297.

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News from the oldest ice on Earth buried in Antarctica, and a new cosmogenic tool

J. M. SCHAEFER[1], C. SCHLUECHTER[2], R. WIELER[3], S. IVY-OCHS[3], P. KUBIK[3], D. MARCHANT[4], G. KORSCHINEK[5], K. KNIE[5], G. HERZOG[6] AND F. SEREFIDDIN[6]

[1]Lamont-Doherty Earth Observatory, Palisades (schaefer@ldeo.columbia.edu)
[2]University of Berne, Berne Switzerland
[3]ETH Zuerich, Zuerich, Switzerland
[4]Boston University, Boston, USA
[5]TU Munich, Munich, Germany
[6]Rutgers University, Piscataway/New Brunswick

Methodological progress of Terrestrial Cosmogenic Nuclides (TCN) and their applications to forefront earth scientific problems have been surging over the last 10 years. We present case-studies to illustrate the potential of dating earth surface processes over a time-scale spanning from thousands to millions of years. As an example of the rapid methodological progress, we report very recent measurements of in-situ cosmogenic ^{53}Mn, a new member of the TCN family.

We give an update of our current research regarding the age, formation, and climate significance of the oldest ice on Earth in Beacon Valley, Antarctica, based on new cosmogenic noble gas data. Although there is general agreement that the buried ice bodies in the Dry Valleys represent potentially important climate archives well beyond the ice-core time-range, the formation mechanism and age of these features is still uncertain.

We used the same samples from Antarctica to perform the first successful measurements of terrestrial ^{53}Mn. The consistency between in-situ cosmogenic ^{53}Mn and cosmogenic noble gas data is striking and allows a first quantification of the production rate of terrestrial ^{53}Mn. We give a protocol to apply the new cosmogenic nuclide together with an overview of advantages, current limitations and potential improvements.

Finally, we give a short overview of the existing limitations of the TCN method and strategies to go beyond these limits. Such strategies are the core of the international multi-group CRONUS-Earth initiative, which will be introduced in detail in a companion poster.

CRONUS-EU Cosmic ray produced nuclide systematics – The European contribution

T.J. DUNAI[1] AND THE CRONUS-EU SCIENTIFIC TEAM[2]

[1]Faculty of Earth and Life Sciences, Vrije Universiteit, Amsterdam, Netherlands (CRONUS-EU@falw.vu.nl)
[2]Ten network teams throughout Europe

The main objective of the CRONUS-EU is to advance Terrestrial cosmogenic nuclide (TCN) techniques into a robust tool for Earth surface and environmental sciences. CRONUS-EU aims to achieve this goal via:

(1) High quality calibration of TCN production rates at independently dated surfaces
(2) High quality calibration of TCN production rates using artificial targets
(3) Systematic cross calibration of production rates of different TCNs
(4) Refinement of scaling factors that describe the spatial and temporal variation of the cosmic ray flux relevant for TCN production using calibration measurements and numerical modeling from physical principles
(5) Reducing the uncertainty of decay constants
(6) Establishing the use of additional mineral phases in exposure age dating
(7) Improvement and standardization of chemical routines
(8) Laboratory cross calibrations
(9) Training of young researchers and the user community

The effort necessary to achieve above goal is significant even for the strong network teams in CRONUS-EU. To strengthen our effort and to achieve international evaluation and acceptance, we are seeking close collaboration with CRONUS-Earth, the parallel-running northern American sister initiative that obtained funding through NSF. Formal links between the two initiatives are established and each consortium will address complementary aspects to achieve the common goal.

The coordination of CRONUS-EU is at the VU Amsterdam, with network teams at SUERC, Scotland; CEREGE and CRPG, France; ETH-Zürich (2 teams), Switzerland; Univ. Bratislava, Slovakia; Univ. Hannover, TU-Munich and GFZ-Potsdam, Germany; and Utrecht University, The Netherlands (see also: *www.cronus-eu.net*).

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Interpreting cosmogenic nuclide concentrations in areas with complex exposure-burial histories under ice sheets: How sensitive are results to variations in the ice cover proxy curve?

Y.K. LI[1], J. HARBOR[1], D. FABEL[2] AND A.P. STROEVEN[3]

[1]Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907-2051 (li144@purdue.edu; jharbor@purdue.edu)
[2]Research School of Earth Sciences, Australian National University, Canberra, ACT, 0200, Australia (derek.fabel@anu.edu.au)
[3]Department of Physical Geography and Quaternary Geology, Stockholm University, S-106 91 Stockholm, Sweden (arjen.stroeven@geo.su.se)

Phases of accumulation and decay of cosmogenic radionuclides in rock surfaces subject to episodes of exposure and burial by ice result in present-day nuclide concentrations that reflect the timing of initial exposure and the chronology of subsequent exposure, burial and erosion. Assuming no erosion, and using ice core or marine isotope records as proxies for the timing and duration of periods of ice cover, it is possible to constrain the timing of initial exposure and the number of phases of exposure and burial a rock surface has been subjected to using multiple cosmogenic radionuclide concentrations (typically ^{10}Be and ^{26}Al). However, in evaluating interpretations based on this approach, it is important to assess how sensitive the results are to the ice cover proxy curve. We have developed a program to evaluate variations in total exposure and burial duration as a function of different proxy curves and assumptions of cutoff values for ice free conditions. Initial results for northern Sweden and Antarctica indicate a highly variable pattern of sensitivity (step changes in results at critical ice cover / ice free cutoff values), and provide new insight into how to determine the level of reliability of calculated initial exposure dates.

Key words
cosmogenic nuclides; ice sheet; proxy climate curve; surface exposure dating

Solar modulation and scaling *in situ* cosmogenic nuclide production rates

N. A. LIFTON[1], J. W. BIEBER[2], J. M. CLEM[2], M. L. DULDIG[3], P. EVENSON[2], J. E. HUMBLE[4] AND R. PYLE[2]

[1]Geosciences Department, University of Arizona, Tucson, AZ, 85721, U.S.A. (lifton@geo.arizona.edu)
[2]Bartol Research Institute, University of Delaware, Newark, DE, 19716, U.S.A. (john@bartol.udel.edu, clem@bartol.udel.edu, penguin@bartol.udel.edu, pyle@bartol.udel.edu)
[3]Australian Antarctic Division, Kingston, Tasmania, Australia 7050 (Marc.Duldig@aad.gov.au)
[4]School of Mathematics and Physics, University of Tasmania, Private Bag 37, Hobart, Tasmania, Australia 7001 (john.humble@utas.edu.au)

Solar modulation affects *in situ* cosmogenic nuclide (CN) production rates the most at the high geomagnetic latitudes to which those production rates are traditionally referenced. This variability leads to significant scaling model uncertainties that have not been addressed rigorously to date. We have developed new CN production rate scaling models for spallogenic nucleons, slow muon capture and fast muon interactions that specifically address these uncertainties. Our spallogenic nucleon scaling model, which includes data from portions of 5 solar cycles, explicitly incorporates a measure of solar modulation, and our fast- and slow-muon scaling models (based on more limited data) account for solar modulation effects through increased uncertainties. These models improve on previously published models by better sampling the observed variability in measured cosmic ray intensities as a function of geomagnetic latitude, altitude, and solar activity.

Our results show that we can accurately account for the effects of solar modulation on measured cosmic ray intensities with our models, within the uncertainties of each of our source datasets. Published spallogenic nucleon scaling models predict scaling factors ranging from ~15% below to ~30% above those of our spallogenic model, while published muogenic scaling models predict scaling factors up to ~90% above ours. We also estimate solar modulation variations over the last 11.4 ka from a recent sunspot number reconstruction based on tree-ring ^{14}C data. These data suggest that spallogenic scaling factors in our model for sea level and high geomagnetic latitudes can vary by up to ~10%, depending on the time period over which the modulation conditions are averaged. The potential magnitude of this variation supports our contention that incorporating long-term solar modulation into CN production rate scaling is important.

Dating alluvial sediments with cosmogenic nuclides

W.M. PHILLIPS[1], L.S. BARHAM[2] AND P.W. KUBIK[3]

[1]Idaho Geological Survey, University of Idaho, Moscow, ID 83844-3014 USA (phillips@uidaho.edu)
[2]University of Liverpool, Liverpool L69 3GS UK (l.s.barham@liverpool.ac.uk)
[3]Paul Scherrer Institut, c/o ETH Hönggerberg, CH-8093 Zurich, Switzerland (kubik@phys.ethz.ch)

The dating of alluvial deposits is an important but difficult application of terrestrial cosmogenic nuclides. Initial work showed that exposure ages of surface clasts may be inaccurate because of nuclide inheritance and/or surface instability. Single nuclide depth profiles permitted inheritance to be estimated, and generated useful new ages for youthful deposits with stable surfaces. However, many alluvial deposits cannot be dated with single nuclide profiles because of surface disturbance or erosion. In the general case, three unknowns must be estimated: erosion rate of the contributing catchment; time since deposition; and erosion rate of the alluvial surface. Recently, measurements of long ^{10}Be and ^{26}Al profiles, studies of muonic production at depth, and measurement of nuclide concentrations in modern alluvium have invigorated the quest for a more robust means of dating ancient alluvium. These studies demonstrated that all three unknowns can be estimated from ^{10}Be and ^{26}Al profiles in favorable settings.

In this study, the utility of ^{10}Be and ^{26}Al depth profiles for dating alluvial deposits was investigated in an archaeological setting. The Luangwa Valley of Zambia is an extension of the African Great Rift Valley but lacks the interbedded volcanic deposits that have enabled a detailed chronostratigraphic record elsewhere in the Great Rift system. Six samples of amalgamated gravel and sand were analyzed for ^{10}Be and ^{26}Al from a 4.5 m terrace section containing Oldowan artifacts at the base. A sample consisting of surface clasts was also analyzed, as was a sample of modern alluvium. The terrace is dissected and original depositional surfaces are absent. Preliminary results suggest that gravels associated with Oldowan stone tools were deposited at about 0.9-1.0 Ma. This is younger than the dated range of Oldowan artefacts in Africa and suggests that the age is a minimum. The apparent exposure age of the surface of the section is only about 85 ka. A model terrace erosion rate of 10 m/Ma suggests that at least 9 m of section has been lost. Denudation rates from the contributing catchment vary from about 10 to 70 m/Ma, and are similar to the modern alluvium estimate of 45 m/Ma.

Integrating geomagnetic records and cosmogenic nuclide production

J.S. PIGATI[1], N.A. LIFTON[2], AND D. DESILETS[3]

[1]Desert Laboratory, 1675 W. Anklam Rd., Tucson, Arizona, 85745, USA (pigati@geo.arizona.edu)
[2]Department of Geosciences, University of Arizona, Tucson, Arizona, 85721, USA (lifton@geo.arizona.edu)
[3]Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona, 85721, USA (ddesilet@hwr.arizona.edu)

Production of cosmogenic nuclides (CNs) in geologic material is a function of the cosmic ray flux at the Earth's surface, which in turn is a function of the intensity and orientation of the Earth's geomagnetic field. Temporal variations in the intensity of the geomagnetic field and the position of the geomagnetic dipole axis (i.e. polar wander) must be considered when calculating production rates that are integrated through time. We have developed a model, based on the theoretical framework of Desilets and Zreda (2003) and a variety of geomagnetic field intensity and pole position data, that accounts for these variations in an effort to systematically determine their impact on time-integrated production of short-lived (*in situ* ^{14}C; $t_{1/2}$=5.73 ka) and long-lived (*in situ* ^{10}Be; $t_{1/2}$=1.5 Ma) CNs (Pigati and Lifton, 2004).

Our model differs significantly from previous models in that integrated production rates are normalized to the modern production rate at the *geomagnetic*, rather than *geographic*, latitude of a given site. Integrated rates that are normalized to the modern rate at a site's geomagnetic latitude explicitly account for the fact that modern production reflects the current offset between the geomagnetic and geographic poles, and that time-integrated production is affected by polar wander differently at different locations. In contrast, normalizing integrated production rates to the modern rate at a site's geographic latitude incorrectly suggests that a single correction can be applied to all sites along a given parallel.

Our modelling results show that, depending on the exposure age and location, integrated *in situ* ^{14}C production rates at sea level that account for both intensity variations and polar wander range from 27% higher to 24% lower than modern rates at the same location (modern rates are referenced to the 1945.0 Definitive Geomagnetic Reference Field). Integrated *in situ* ^{10}Be rates range from 48% higher to 26% lower than modern. Differences between integrated and modern rates for both nuclides increase significantly at higher altitudes.

References

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The CRONUS-Earth (Cosmic-Ray prOduced NUclide Systematics on Earth) Initiative

JOERG M SCHAEFER[1] , CRONUS-EARTH STEERING COMMITTEE[2]

[1]Lamont-Doherty Earth Observatory, Palisades, NY-10964
[2] Network of 9 PIs within the US

Terrestrial Cosmogenic Nuclides (TCN) have become indespendable tools in various disciplines of modern Earth Sciences. However, the understanding of the fundamental physical processes underlying TCN production remains incomplete and the intercomparibility between different investigators and methods is not satisfying.

The CRONUS-Earth initiative is an interdisciplinary, multi-group project with the primary goals (i) to provide a firm linkage between cosmic-ray physics and the systematics of TCN production, (ii) to produce generally-accepted formulations and parameters for calculation of TCN production, and (iii) to establish a rigorous basis for intercomparison between measurement of different nuclides and by different investigators.

To achieve this, CRONUS-Earth will coordinate six major components: (i) A methodological intercomparison, including sample preparation as well as analytical measurement; (ii) refinement of neutron monitor data interpretation to better understand interaction of the cosmic ray flux and the geomagnetic field; (iii) measurement of contemporary TCN production rates and scaling factors by exposing targets to cosmic rays at selected locations; (iv) measurements of production cross-sections using laboratory neutron beams; (v) calibration of TCN production rates by measuring TCN on independently dated surfaces; (vi) modeling to synthesize results. The models will include purely physical models of cosmic-ray-particle propagation through the atmosphere down to Earth, stastically-based parameter-estimation models, and user models.

CRONUS-Earth is an international, collaborative effort with a close liason to the CRONUS-EU project. The intiative starts early 2005. CRONUS-Earth consist of a collaborative network of 17 PI's, the current CRONUS-Earth steering committee includes M. Caffee, Purdue University; R. Finkel, LLNL, Livermore; T. Jull & N. Lifton, University of Arizona, Tucson; M. Kurz, WHOI, Woodshole; F. Phillips, New Mexico Tech, Socorro; J. Schaefer, Lamont-Doherty Earth Observatory, Palisades; J. Stone, University of Washington, Seattle; T. Dunai, Vrije Universiteit, Amsterdam, Netherlands (CRONUS-EU).

Inter-comparison in ^{10}Be analysis starting from pre-purified quartz

C. SCHNABEL[1], L. REINHARDT[2,3], P. BISHOP[2], A. DAVIDSON[1], L.K. FIFIELD[3], S. FREEMAN[1], C. MADEN[1] AND S. XU[1]

[1]Scottish Universities Environmental Research Centre (SUERC), East Kilbride, U.K. (c.schnabel@suerc.gla.ac.uk)
[2]Centre of Geosciences, University of Glasgow, Glasgow, U.K.
[3]Dept of Nuclear Physics, RS PhysSE, Australian National University, ACT 0200, Australia

As far as the authors are aware we present the first inter-comparison of ^{10}Be analysis in quartz at environmental levels. Due to a lack of geological standard reference materials for ^{10}Be, quality control of exposure age and erosion rate determinations based on ^{10}Be analysis from quartz is difficult. Until now inter-comparisons have neither included very low ^{10}Be concentrations nor complex sample preparation from quartz.

^{10}Be concentrations in six quartz samples from the Sierra Nevada, Spain, were analysed at ANU, Australia and at SUERC, Scotland. The samples were originally taken to determine erosion rates and these data will be published elsewhere. Pre-purified quartz prepared at ANU was divided into two aliquots and processed and analysed independently at ANU and SUERC. The table below summarizes the results for the first four samples. To compare two different chemical separation methods (addition of stable Be carrier before and after dissolution) two aliquots were prepared from sample B11 at SUERC (CF stands for carrier first and CL for carrier last addition). All results are normalised to NIST SRM 4325 using $3.00*10^{-11}$ as its Be isotope ratio. The uncertainties given are standard uncertainties that include uncertainties of the sample and the standard measurement as well as the uncertainty of the blank correction.

Sample	^{10}Be (at/g) ANU	^{10}Be(at/g)SUERC
B11(CL)	$(1.64\pm0.06)*10^6$	$(1.60\pm0.06)*10^6$
B11(CF)	-	$(1.71\pm0.08)*10^6$
Ger3	$(3.12\pm0.14)*10^6$	$(2.97\pm0.12)*10^6$
17	$(1.22\pm0.10)*10^4$	$(1.31\pm0.16)*10^4$
21C	$(2.04\pm0.14)*10^4$	$(0.70\pm0.08)*10^4$

The analyses of both laboratories agree, within their uncertainties, for all samples except 21C.

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iCRONUS meets CRONUS-Earth: Improved calculations for cosmogenic dating methods – From neutron intensity to previously ignored correction factors

MAREK ZREDA[1], DARIN DESILETS[1], YANHUA LI[1], ELIZABETH BRADLEY[2] AND KENNETH M. ANDERSON[2]

[1]Dept. of Hydrology and Water Resources, Univ. of Arizona, Tucson, AZ, 85721, USA (marek@hwr.arizona.edu)
[2]Dept. of Computer Science, Univ. of Colorado, Boulder, CO, 80309, USA (lizb@cs.colorado.edu)

We report progress on two five-year projects whose common goal is to improve cosmogenic dating methods: CRONUS-Earth will improve calibration; iCRONUS will develop a software system based on an artificial intelligence core (thus, the 'i' in the name). Calibrated production rates and correction factors modifying production rates are two critical aspects of calculating cosmogenic ages. Calibration depends on the accurate computation of neutron fluxes at the air-ground interface. The currently-used diffusion equation under-estimates neutron fluxes at the surface. Two more accurate alternatives, the physically comprehensive Monte Carlo N-Particle transport code and a simpler analytical transport model, are implemented in iCRONUS. Correction factors are of two types: global (affect all samples) and local (affect only the samples from a specific landform). Global correction factors include those that modify the secondary cosmic ray intensities; the most important are air pressure and geomagnetic cutoff rigidity of the sample site. The size of the correction depends on the location, temporal variations of the geomagnetic intensity, position of the magnetic poles, eustatic changes of sea level, temporal and spatial changes of sea-level pressure, and temporal and spatial changes of temperature and lapse rate. Every landform also requires its own, unique set of local corrections, applied on top of the global corrections. Examples include erosion of landform's surface and sampled surface, (neo)tectonic displacement, topographic shielding, cover, and variable chemistry. Our improved calibration and all correction factors form a framework implemented in the iCRONUS software. We will demonstrate a desktop version of iCRONUS at the meeting.

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