ESS 560 – Cosmogenic Nuclides in Geomorphology

Instructor: John Stone
JHN 345
1-6332 / 1-6383 (Lab) stone@ess.washington.edu

3 CR Meets :	Monday	2:30-3:20	JHN 366
	Wednesday	2:30-4:20	JHN 366

Overview: In this course you will learn to predict the build-up of cosmic-ray-produced nuclides at and beneath the Earth's surface. With the basic understanding we derive in the first few weeks you will be able to calculate the age of static rock surfaces from cosmogenic nuclide data. Taking it a little further, you will be able to apply similar theory to surfaces that are changing in time, and calculate rates for the geomorphic processes responsible, such as erosion or burial.

The underlying theme of the course is that every "geomorphic model" {x, y, z(t)} makes a prediction about cosmogenic isotope concentrations {x, y, N(z,t)}. Thus we should be able to test geomorphic models by making cosmogenic isotope measurements. Having learned to predict nuclide concentrations at and beneath geomorphic surfaces, you will be able to decide which geomorphic parameters can be estimated from cosmogenic nuclide data, how many samples you will need to make useful estimates, and how and where to sample to get the most information from the fewest measurements.

The first few weeks of the course will consist of lectures covering the physics, chemistry, and mathematics of cosmogenic nuclide production and accumulation. During the second half of the quarter you will select an interesting geomorphic process, describe it mathematically, and integrate your model with a description of cosmogenic nuclide accumulation. Your model will show how the rate and timing of the geomorphic process affects cosmogenic nuclide concentrations and profiles.

Expectations and assessment The lecture series will cover the topics listed on the accompanying syllabus. Weekly homework problem sets will account for 50% of your final assessment. An exam at the end of Week 7 will cover all of the lecture material, and will account for 25% of your grade.

The remaining 25% will be based on your research project carried out in week 8-10. You will construct a mathematical model of a geomorphic process, and explore what can be learned about the process from cosmogenic nuclide data. Your research should be documented in a brief report, accompanied by the EXCEL, MATLAB, or MATHEMATICA code that you used to reach your conclusions.

Textbook: No book on cosmogenic nuclides has yet been published. The accompanying page lists some review papers and relevant books that you can read to accompany the lecture series, as well as research papers on which to base your modeling investigations.

Review Papers and Related Reading

Cosmic Radiation

Wolfendale A.W. (1963) Cosmic Rays. G. Newnes, London.

Hayakawa S. (1969) *Cosmic Ray Physics*. John Wiley and Sons.

Grieder, P.K.F. (2001) Cosmic Rays at Earth: Researcher's Reference Manual and Data Book. Elsevier, Amsterdam, 1093 pp.

Nuclear Physics and Chemistry

Friedlander G., Kennedy J.W. and Miller J.M. (1981) *Nuclear and Radiochemistry* Wiley, NY.

Lederer C.M. and Shirley V.S. (1978) *Table of Isotopes*. Wiley.

Cosmogenic Nuclides – General reviews

Cerling, T. E. and Craig, H. 1994, Geomorphology and *in situ* cosmogenic isotopes: Annual Reviews of Earth and Planetary Science, v. 22, p. 273-317.

Morris, J.D., 1991. Applications of cosmogenic ^{10}Be to problems in the earth sciences. Ann. Rev. Earth Planet. Sci., 19: 313-350.

Gosse, J.C. and Phillips, F.M., 2001. Terrestrial in situ cosmogenic nuclides: theory and application. Quaternary Science Reviews, 20(14): 1475-1560.

Cosmogenic Nuclides – Production, dispersal and accumulation

Lal D. and Peters B. (1967) Cosmic ray produced radioactivity on the earth. In *Handbuch der Physik* (ed. S. Flugg), Vol. XLVI/2, pp. 551-612. Springer.

Lal D. (1988) In situ produced cosmogenic isotopes in terrestrial rocks. *Annu. Rev. Earth Planet. Sci.* **16,** 355-388.

Lal D. (1991) Cosmic ray labeling of erosion surfaces: *in situ* nuclide production rates and erosion models. *Earth Planet. Sci. Lett.* **104,** 424-439.

Use of cosmogenic nuclides to constrain geomorphic processes

Stone, J., Lambeck, K., Fifield, L.K., Evans, J.M. and Cresswell, R.G., 1996. A lateglacial age for the Main Rock Platform, western Scotland. *Geology*, 24, 707-710.

Heimsath, A.M., Dietrich, W.E., Nishiizumi, K. and Finkel, R.C., 1999. Cosmogenic nuclides, topography, and the spatial variation of soil depth. *Geomorphology*, 27, 151-172.

Nichols, K.K., Bierman, P.R., Hooke, R.L., Clapp, E.M. and Caffee, M., 2002. Quantifying sediment transport on desert piedmonts using Be-10 and Al-26. *Geomorph.*, 45, 105-125.

Granger, D.E. and Smith, A.L., 2000. Dating buried sediments using radioactive decay and muogenic production of Al-26 and Be-10. *Nucl. Instr. Meth. B* 822-826.

Monaghan, M.C., McKean, J., Dietrich, W. and Klein, J., 1992. ^{10}Be chronometry of bedrock-to-soil conversion rates. *Earth Planet. Sci. Lett.*, 111, 483-492.

Syllabus and Lecture Topics

Lectures (first half):

Introduction. Exposure dating *vs* applications to evolving surfaces.

Cosmic radiation. Primary *vs* secondary cosmic rays. Energy considerations. Nucleon, muon and electron-gamma components.

Nuclear reactions / mass-energy conservation relations. High and low energy interactions.

Cosmogenic nuclides. "Meteoric" nuclides *vs* nuclides produced *in situ*. Dependence of production on chemical composition. Survey of nuclides produced in air ("meteoric" nuclides) and below ground ("*in-situ*" nuclides).

Production rates. Production thresholds *vs* radioactive decay energies. Background levels in terrestrial materials. The importance of scarcity! Basics of detection methods.

Isotope accumulation - simple cases of exposed and eroding surfaces, for stable and radioactive isotopes. Quantitative consideration of the effects of half-life, production rate, erosion and/or burial rates. Introduction to geomorphic problems involving simple shielding histories.

Effects of atmospheric and geomagnetic shielding. Correction formulae. Paleomagnetic variation; effect of magnetic intensity and dipole orientation changes on nuclide production rates. Nuclide accumulation with allowance for changing production rate. Paleo-altimetry and paleomagnetically-corrected exposure ages.

Effects of target composition, sample thickness, and exposure geometry. Simple thickness and 'horizon' corrections. Depth-dependence of nuclide production for $2\Pi-$, dipping surface, and arbitrary exposure geometries.

Production rate calibration. Cross-sections and nuclear models *vs* empirical calibration. Critical evaluation of production rate data.

Complete calculation of production rates and exposure ages.

Depth dependence of reactions. Spallation reactions, thermal and epithermal neutron capture, muon capture, fast muon reactions. Production profiles for different nuclides. Constraints from paired measurements of spallogenic and neutron-capture nuclides.

General equation for isotope accumulation. Integration of shielding histories. Forward models for prescribed erosion and burial histories. Incorporation of time-dependent production rates. Constraints on complex exposure/burial histories from measurements of multiple nuclides. Brief comments about inverse approaches.

Cosmogenic isotope measurements - Accelerator Mass Spectrometry (AMS). Theory and practice. Sample preparation considerations. Precision and sensitivity considerations.

Geomorphic models (second half):

ESS 460: Read one or more research papers describing the use of cosmogenic nuclide measurements to solve a specific geomorphological problem. Set up a mathematical model describing cosmogenic nuclide accumulation in the geomorphic environment described in the paper. Use the model to predict cosmogenic nuclide concentrations, ratios or profiles, discover the parameters that control the model, and evaluate the claims made in the paper.

ESS 560: Develop an original model of cosmogenic nuclide accumulation in a chosen geomorphic setting. Your aim is to start with a geomorphic process model and predict how nuclide concentrations/profiles depend on the parameters governing the model. Use your results to determine whether cosmogenic isotope measurements (with realistic uncertainties) can: (i) Verify, disprove or improve the geomorphic model. (ii) Provide useful, quantitative constraints on the process. Your model results will also serve as a guide for sampling: Where should samples be collected, and how many samples need be collected – to establish useful constraints?

Examples of geomorphic processes and environments:

- Sediment accumulation on a surface (easy, slightly harder for non-constant burial rate).
- Non-steady erosion (e.g. alternating erosion and chemical weathering). What constraints can be established using multiple nuclides with different half-lives and production profiles?
- Soil creep and hillslope evolution as a function of the soil production rate and creep rate (both spatially variable).
- Development of horizons in soil (will allow us to combine "in-situ produced" isotope information with "meteoric" isotopes).
- Evolution of cliff faces and talus slopes beneath. Interesting questions about statistical distribution of measurements.
- Episodic emergence of the footwall face of a bedrock fault scarp. (The forward problem, predicting nuclide concentrations resulting from a specified sequence of earthquakes is not too bad. The general problem, in which neither timing nor throw of the earthquake events is known, is much harder).
- Evolution of a fault scarp in alluvium (hard, all material in the scarp has a prior exposure history).
- Sediment production and dispersal through a drainage network (hypothetical problem is simple; real-world case is difficult but potentially rewarding ...). How to incorporate the effect of landslides?
- Sea-level change. Cutting and emergence of a shore platform, including the effect of tides.
- Your choice ....