He added that it was unfortunate that buildings occupied by agencies and organizations such as the United Nations also collapsed during the earthquake. “Had they built their buildings to be earthquake-resistant, they would have stood amidst all the rubble as a symbol that we are capable of withstanding this earthquake shaking, and that it is not God’s will that everyone die. That it is not an act of God, but that it is an act of man to build these things poorly.”

Tucker noted that there have been some isolated improvements in earthquake hazard preparedness in California and elsewhere around the world. But he questioned whether these improvements are keeping pace with problems caused by rapid urbanization in developing countries. “The story is getting boring,” he said, referring to repeated earthquake tragedies. “It’s always the same thing: that people are not prepared and they spend 10 times as much money responding to and repairing the event than would be necessary if we prepared for it rather than waiting until it occurred.”

The earthquake in Haiti, Mann told *Eos*, provides the science community with an important “learning moment.” Scientists and science funders in developed countries “need to become more proactive and systematic about focusing research efforts on faults capable of M 6–8 quakes, especially in densely populated areas with poor construction practices.” He said funding also should be targeted for earthquake engineering and for earthquake education and outreach.

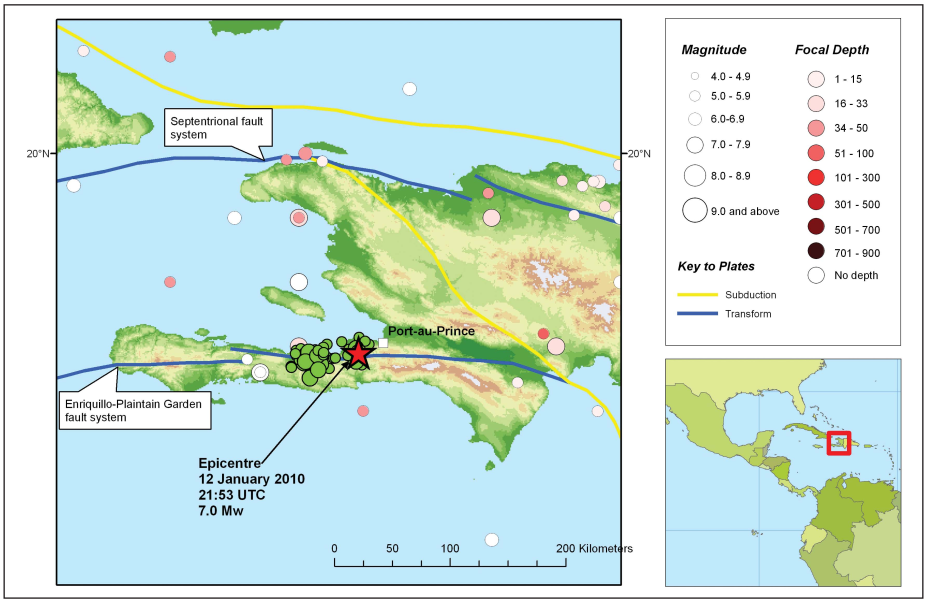

Fig. 1. Red star indicates the epicenter of the magnitude 7.0 earthquake on 12 January. Green circles indicate some of the aftershocks. Historic earthquakes are in red and pink; focal depths are in kilometers. Topography and epicenter information courtesy of U.S. Geological Survey. The figure is reproduced and modified with permission from the British Geological Survey © Natural Environment Research Council.

Mann, too, expressed concern about the potential for seismic events in other locations, including possibly along other segments of the same fault zone and along the parallel Septentrional fault zone (which, he indicated, is “exactly the same type of ‘time bomb’ plate boundary strike-slip fault as the EPGFZ ‘time bomb’ was to Port-au-Prince and its environs”).

Noting that the Haiti earthquake released about the same amount of energy (32 megatons) as the largest thermonuclear bomb ever tested and has affected millions of people, Mann added, “Countries with faults threatening dense populations need to approach earthquake ‘defense’ with the same energy, consistency, and level of scientific spending as devoted to their military defense.”

For more information, visit http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010rja6/, http://web.ics.purdue.edu/~ecalais/haiti/, and http://www.jsg.utexas.edu/news/rels/011310.html.

—Randy Showstack, Staff Writer

FORUM

Terrestrial Cosmogenic Nuclide Geochronology Data Reporting Standards Needed

PAGES 31–32

Scientists can estimate the time at which rocks at Earth’s surface became exposed (through glacial scour, faulting, sediment deposition, exhumation, etc.) in a given area using terrestrial cosmogenic nuclide (TCN) geochronology. The idea behind this technique is ingenious in its simplicity. Imagine, for example, a glacier advancing over the landscape and scouring the rocks underneath. As the glacier retreats, fresh rock surfaces become exposed to the atmosphere. Galactic cosmic rays then bombard the fresh minerals exposed at the Earth’s surface, producing rare nuclides such as beryllium-10 (^{10}Be) and aluminum-26 (^{26}Al) in the process. Thus, measuring the concentration of TCNs in rocks at the Earth’s surface allows scientists to estimate how long a surface has been exposed and/or the rate of surface denudation.

The development of TCN geochronology over the past few decades has helped revolutionize many branches of Earth science, including geomorphology, Quaternary (spanning roughly the past 3 million years) paleoclimatology, and active tectonics. TCN methods [*Gosse and Phillips,* 2001] are allowing Earth scientists to determine ages for previously undatable landforms and sediments over time scales ranging from centuries to a few million years. Numerous publications have used TCNs to determine the timing and rates of crustal displacement, define the timing of past glaciations and climate change, and measure rates of soil formation, denudation, and landscape evolution. As a consequence, TCN geochronology has become a standard dating technique for events up to several million years old, along with other well-established methods such as radiocarbon, uranium series, and optically stimulated luminescence dating.

Despite its potential usefulness, the methods and parameters used for interpreting TCN data are not yet standardized. Instead, they continue to evolve as the result of ongoing work aimed at understanding the global and temporal distribution of production rates. We feel that reporting a minimum set of sample-related parameters is required such that published data might be reinterpreted in light of new advances and to account for interlaboratory differences in calibration and analytical technique.

A Checklist for Reporting TCN Data

Without established reporting standards, information from published archives could be permanently invalidated by new knowledge of the physical parameters underlying TCN production. Only reanalysis of

Table 1. Example of a Table for Reporting Analytical Results of Terrestrial Cosmogenic Nuclide ^{10}Be Geochronology

Sample	Location (°N/°W)	Elevation (m above sea level)	Thickness[a] (cm)	Production Rate (atoms g^{-1} yr^{-1})		Shielding[d] Factor	Denudation Rate (mm yr^{-1})	Quartz[e] (g)	Be Carrier (mg)	^{10}Be/^{9}Be[f,g] (× 10^{-13})	^{10}Be Concentration[g,h,i] (10^6 atoms g^{-1} SiO_2)	Age[g,j,k] (ka)
				Spallation[b]	Muons[c]							
EOS-1	37.5947/118.0571	1750	1	17.33	0.35	1	0	20.0923	0.2668	25.16 ± 0.36	2.23 ± 0.04	129.9 ± 11.8
EOS-2	37.5946/118.0570	1752	2	17.21	0.349	1	0	20.3301	0.2671	24.60 ± 0.32	2.16 ± 0.04	126.4 ± 11.5
EOS-3	37.5947/118.0589	1730	2	16.94	0.346	1	0	20.0780	0.2657	26.36 ± 0.34	2.33 ± 0.04	139.0 ± 12.7
EOS-4	37.5948/118.0588	1753	3	17.08	0.348	1	0	20.1309	0.2628	23.18 ± 0.30	2.02 ± 0.03	119.0 ± 10.8
EOS-5	37.5943/118.0537	1760	2	17.30	0.35	1	0	20.1210	0.2641	22.09 ± 0.28	1.93 ± 0.03	112.4 ± 10.2
EOS-6	37.5950/118.0537	1729	3	16.79	0.345	1	0	20.1563	0.2641	19.21 ± 0.31	1.68 ± 0.03	100.2 ± 9.1

[a]The tops of all samples were exposed at the surface.
[b]Constant (time-invariant) local production rate based on *Lal* [1991] and *Stone* [2000]. A sea level, high-latitude value of 4.8 at ^{10}Be g^{-1} quartz was used.
[c]Constant (time-invariant) local production rate based on *Heisinger et al.* [2002a, 2002b].
[d]No geometric shielding correction for topography was necessary (horizon < 20° in all directions).
[e]A density of 2.7 g cm^{-3} was used based on the granitic composition of the surface samples.
[f]Isotope ratios were normalized to ^{10}Be standards prepared by *Nishiizumi et al.* [2007] with a value of 2.85×10^{12} and using a ^{10}Be half-life of 1.36×10^6 years.
[g]Uncertainties are reported at the 1σ confidence level.
[h]A mean blank value of 53,540 ± 10,845 ^{10}Be atoms (^{10}Be/^{9}Be = $2.994 \times 10^{-15} \pm 6.03 \times 10^{-16}$) was used to correct for background.
[i]Propagated uncertainties include error in the blank, carrier mass (1%), and counting statistics.
[j]Propagated error in the model ages include a 6% uncertainty in the production rate of ^{10}Be and a 4% uncertainty in the ^{10}Be decay constant.
[k]Beryllium-10 model ages were calculated with the Cosmic-Ray Produced Nuclide Systematics (CRONUS) Earth online calculator [*Balco et al.*, 2008] version 2.1 (http://hess.ess.washington.edu/).

sometimes irreplaceable samples would allow updated interpretation. To address these concerns, a standardized list of data should be reported whenever TCN-derived surface exposure ages and denudation rates are published [e.g., *Gosse et al.,* 1996; *Dunai and Stuart,* 2009].

We present here a list of essential data that should be reported in any manuscript dealing with new TCN ages or denudation rates. This inventory and Table 1 can be used as a checklist by both authors and manuscript reviewers to ensure that published data can be compared between laboratories and can be updated in light of future advances. Some of these parameters are known perfectly within measurement uncertainty (e.g., latitude, longitude, and altitude in tectonically stable regions) while others are model-dependent (e.g., altitude in rapidly uplifting regions, denudation rates). Nevertheless, since all of these parameters are required to allow interpretation of measured TCN concentrations, it should be made clear to the reader what values were used. Note that we do not deal with TCNs other than ^{10}Be and ^{26}Al. The essential data include the following:

- sample name;
- latitude and longitude (decimal degrees);
- elevation (measured in meters above or below sea level);
- sample density for rock or sediment (measured in grams per cubic centimeter);
- sample thickness or minimum and maximum depth of sample below surface (measured in centimeters);
- skyline shielding factor (dimensionless) including accounting for sample strike and dip;
- phase analyzed, e.g., quartz or sanidine, and its mass (measured in grams);
- chemical composition of phase analyzed including ^{9}Be (if available), ^{27}Al, and relevant target elements;
- mass of Be and/or Al carrier added (measured in milligrams);
- accelerator mass spectrometry (AMS) standards (e.g., either from the National Institute of Standards and Technology or from *Nishiizumi et al.* [2007]) and values used;
- decay constant/half-life for ^{10}Be and/or ^{26}Al;
- measured ^{10}Be/^{9}Be and/or ^{26}Al/^{27}Al ratio of samples (including errors and confidence level);
- ^{10}Be and/or ^{26}Al blank correction expressed either as ^{10}Be/^{9}Be and/or ^{26}Al/^{27}Al ratio or as number of atoms of ^{10}Be and/or ^{26}Al;
- ^{10}Be and/or ^{26}Al concentration (measured in atoms per gram of quartz or other mineral phases, including errors and confidence level);
- latitude and altitude scaling factors (dimensionless) and the scaling model used, including pressure correction;
- rate of denudation of surface samples (measured in millimeters per year);
- production rates from spallation (induced by cosmic rays hitting a target nucleus and fragmenting it) and muon capture (induced by capture of negative muons by a target nucleus), measured in atoms per gram per year and specified as being calculated for sea level and high latitude, or local values);
- surface exposure age or denudation rate (including errors and confidence level); and
- the method or calculator used to determine surface exposure age or denudation rate [e.g., *Balco et al.,* 2008].

Most publications use the term "erosion rate" when referring to the items in the list relating to the rate of denudation of surface samples. But strictly speaking, it is the rate of denudation, which includes weathering; the in situ breakdown of rock; and erosion, the breakdown of rock involving a transporting agent.

We recommend including these data in a single table with all necessary explanations listed as footnotes to facilitate easy access to such information. An example of this format is given in Table 1. For journals with strict page limits, these data can be included in tabular form as data repository items. Through adhering to these standards, authors can ensure that the records they publish will become part of a permanent archive of conditions at Earth's surface and allow for the reinterpretation of data following advances in TCN geochronology.

Acknowledgment

John Gosse is thanked for his thoughtful review, which helped greatly improve the manuscript.

References

Balco, G., J. O. Stone, N. A. Lifton, and T. J. Dunai (2008), A complete and easily accessible means of calculating surface exposure ages or erosion rates from ^{10}Be and ^{26}Al measurements, *Quat. Geochronol., 3,* 174–195.

Dunai, T., and F. Stuart (2009), Reporting of cosmogenic nuclide data for exposure age and erosion rate determinations, *Quat. Geochronol., 4,* 437–440.

Gosse, J. C., and F. M. Phillips (2001), Terrestrial in situ cosmogenic nuclides: Theory and application, *Quat. Sci. Rev., 20,* 1475–1560.

Gosse, J. C., R. C. Reedy, C. D. Harrington, and J. Poths (1996), Overview of the workshop on secular variations in production rates of cosmogenic nuclides on Earth, *Radiocarbon, 38,* 135–147.

Heisinger, B., D. Lal, A. J. T. Jull, P. Kubik, S. Ivy-Ochs, S. Neumaier, K. Knie, V. Lazarev, and E. Nolte (2002a), Production of selected cosmogenic radionuclides by muons: 1. Fast muons, *Earth Planet. Sci. Lett., 200,* 345–355.

Heisinger, B., D. Lal, A. J. T. Jull, P. Kubik, S. Ivy-Ochs, K. Knie, and E. Nolte (2002b), Production of selected cosmogenic radionuclides by muons: 2. Capture of negative muons, *Earth Planet. Sci. Lett., 200,* 357–369.

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

Nishiizumi, K., M. Imamura, M. W. Caffee, J. R. Southon, R. C. Finkel, and J. McAninch (2007), Absolute calibration of ^{10}Be AMS standards, *Nucl. Instrum. Methods Phys. Res. B, 258,* 403–413.

Stone, J. O. (2000), Air pressure and cosmogenic isotope production, *J. Geophys. Res., 105,* 23,753–23,759.

—Kurt L. Frankel, Georgia Institute of Technology, Atlanta; E-mail: kfrankel@gatech.edu; Robert C. Finkel, University of California, Berkeley; also at Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement (CEREGE), Aix en Provence, France; and Lewis A. Owen, University of Cincinnati, Cincinnati, Ohio