

Estimating Geologic Age from Cosmogenic Nuclides: An Update

tal amplitude at the new synapse added after LTP be determined by the initial probability of release (p_1) at the original synapse [due to the constraint that $q_2 = (1 - p_1)$]. Because the initial probability of release can vary greatly at different synapses, the model must postulate an unprecedented and unknown mechanism which couples postsynaptic properties at the new synapse to presynaptic properties at the old synapse. Second, and more important, the model predicts significant changes in the shape of the EPSC amplitude histogram following LTP, which we do not observe experimentally (Fig. 1) (1). The predicted change in shape of the EPSC histogram is a result of the following: Before LTP, successes of transmission only result from release at the original synapse (whose quantal amplitude = a). After induction of LTP, there are now two release sites, the original site (whose quantal amplitude = a) and the new site (whose quantal amplitude = $q_2 \times a$). Successes of transmission after LTP can now fall into one of three categories: Those due to release from the new synapse alone (EPSC amplitude = $q_2 \times a$), those due to release from the original synapse alone (EPSC amplitude = a), and those due to release from both synapses simultaneously (EPSC amplitude = $a + q_2 \times a$). The contribution of the three classes of successful events to the EPSC amplitude histogram leads to the appearance of new peaks or to a broadening and shifting in the position of the two original peaks (whether or not new distinct peaks can be detected depends on the standard deviation of the various peaks).

As we do not observe changes in the shape of the EPSC amplitude histogram following LTP, we thus stand by our original conclusion. Under our experimental conditions, LTP results from an increase in probability of transmitter release with no change in quantal amplitude and no addition of new sites of synaptic transmission. However, because our data are restricted to the first 30 to 40 min after induction of LTP, it is possible that other changes may occur at later times.

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REFERENCES

1. V. Y. Bolshakov and S. A. Siegelbaum, *Science* **269**, 1730 (1995).
2. C. F. Stevens and Y. Wang, *Nature* **371**, 704 (1994).
3. ———, *Neuron* **14**, 795 (1995).

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We and others have used in situ-produced cosmogenic nuclides to estimate exposure ages of geomorphic surfaces such as moraines and alluvial fans (1). Every study published to date has calculated exposure ages using temporally averaged production rates commonly acknowledging but then disregarding variations in production rates caused by a variable geomagnetic field.

In order to improve the accuracy of exposure age estimates, we have recently developed a model which allows cosmogenic exposure ages to be calibrated for changing geomagnetic field strength (2). The model incorporates published paleomagnetic field strength records (3), field strength/rigidity relationships (4), and accepted altitude/latitude corrections (5) excluding the contribution of muons to ^{26}Al and ^{10}Be production (6). In calibrating, we assume that the current geographic latitude of a site represents its average geomagnetic latitude over the duration of cosmic-ray exposure. The model indicates that production rate response to changing field strength is a nonlinear function of altitude, latitude, and exposure duration. Geomagnetically modulated production rate changes and age inaccuracies are greatest at high altitudes and low latitudes.

Applying our model to existing data reconciles three apparently disparate production rate estimates for ^{26}Al and ^{10}Be (4, 7), generally increases calculated exposure ages, and appears to confirm recently published data suggesting that a glacial advance

in the Rocky Mountains may have occurred during Younger Dryas time (8). To demonstrate how the model changes exposure ages, we have recalculated recently published ages (1) for alluvial fan boulders (9).

Our model and relevant documentation are publicly available (10) and will be updated in the near future to include additional nuclides and paleomagnetic intensity records.

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REFERENCES

1. P. R. Bierman et al., *Science* **270**, 447 (1995).
2. E. Clapp et al., *Geol. Soc. of Am. Abstr. Programs* **27**, A-59 (1995); D. Clark et al., *Quat. Res.* **44**, 366 (1995).
3. L. Meynaider et al., *Earth Planet. Sci. Lett.* **114**, 39 (1992); M. W. McElhinny et al., *J. Geomagn. Geoelectr.* **34**, 39 (1982).
4. K. Nishizumi et al., *J. Geophys. Res.* **94**, 17907 (1989).
5. D. Lal, *Earth Planet. Sci. Lett.* **104**, 424 (1991).
6. E. T. Brown et al., *Geophys. Res. Lett.* **22**, 703 (1995).
7. P. L. Larsen et al., *Geol. Soc. Am. Abstr. Programs* **27**, A59 (1995); K. Nishizumi et al., *Geochim. Cosmochim. Acta* **55**, 2699 (1991).
8. J. Gosse et al., *Geology* **23**, 877 (1995).
9. Available from the authors at their e-mail address.
10. Compiled Macintosh code (COSMO-CALIBRATE) by anonymous ftp from beluga.uvm.edu.

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Pliocene Extinction of Antarctic Pectinid Mollusks

The report by Edward J. Petuch (1) about a two-stage Pliocene-Pleistocene mass extinction that decreased the diversity of stenothermal molluscan genera in Florida raises the question of where the climatic cooling events propagated. It is accepted that the Northern Hemisphere ice sheets began developing at the end of the Pliocene (2), but their feedback and late Neogene connection with changes in the Antarctic ice sheets (3) have not been resolved. Southern Ocean molluscan extinctions, however, provide evidence that an environmental threshold was reached at the end of the Pliocene around Antarctica. Throughout most of the Cenozoic, pectinid bivalve genera (primarily *Chlamys*) inhabited coastal environments around the continent as indicated by extensive deposits from the Eocene (4), Oligocene (5), and Pliocene (6). These Paleogene-Neogene pectinids

had large (>5 cm) thick shells, which indicate that calcium carbonate precipitation was enhanced for early Cenozoic bivalves as compared to that for subsequent cold-water pelecypods in the Southern Ocean, 70% of which are smaller than 1 cm today (7). Large thick-shelled pectinid bivalves became extinct in the Southern Ocean during the Pliocene, perhaps in conjunction with the spread and first appearance of cold-water *Chlamys* species in New Zealand (8). After the Pliocene, large wafer-thin-shelled *Adamussium colbecki* emerged into coastal environments from the deep sea around Antarctica (9), where it originated during the Oligocene (10). This endemic monospecific genus, with its circumpolar distribution (11), has been the only pectinid in Antarctic coastal areas during the Quaternary. The marked diversity decrease among Pectinidae in Antarctic coastal environ-

ments after the Pliocene, along with the marine molluscan extinctions around Florida, suggests that Pliocene-Pleistocene cooling propagated from both polar regions.

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REFERENCES AND NOTES

1. E. J. Petuch, *Science* **270**, 275 (1995).
2. N. J. Shackleton and N. D. Opdyke, *Nature* **270**, 216 (1977).
3. L. H. Burckle and E. M. Pokras, *Antarct. Sci.* **3**, 389 (1991); D. E. Sugden, D. R. Marchant, G. H. Denton, Eds., *Geograf. Ann.* **75A(4)**, 151 (1993); P. J. Barrett *et al.*, *Nature* **359**, 816 (1992); P.-N. Webb and D. M. Harwood, *Quat. Sci. Rev.* **10**, 215 (1992).
4. J. D. Stilwell and W. J. Zinsmeister, *Antarct. Res. Ser.* **55**, 1 (1992); R. H. Levy *et al.*, paper presented at VII International Symposium on Antarctic Earth Science, Scientific Committee on Antarctic Research, Siena, Italy, 11 to 15 September 1995.
5. K. Birkenmajer *et al.*, in *Geological Evolution of Antarctica*, M. R. A. Thomson, J. A. Crame, J. W. Thomson, Eds. (Cambridge Univ. Press, Cambridge, 1991), pp. 663–665.
6. A. G. Beu, *Spec. Pub. S. Aust. Dept. Mines and Energy* **5**, 1 (1985); I. G. Speden, *N.Z. J. Geol. Geophys.* **5**, 746 (1962); R. D. Turner, *ibid.* **10**, 446 (1967).
7. D. Nicol, *Science* **168**, 1248 (1970).
8. C. A. Fleming, *Trans. Roy. Soc. N.Z.* **74**, 207 (1944).
9. P. A. Berkman, T. R. Waller, S. P. Alexander, *Antarct. Sci.* **3**, 151 (1991).
10. A. G. Beu and R. K. Dell, *Bull. Misc. Ser. N.Z. Dept. Sci. Indust. Res.* **245**, 135 (1989).
11. R. K. Dell, *Bull. R. Soc. N.Z.* **27**, 1 (1990).
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