

tual albedo changes and to carrying out further numerical simulations with improved mathematical models until more definite conclusions can be obtained and acted upon.

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Pleistocene Extinctions

Long and Martin (1) present various radiocarbon dates of *Nothotheriops*, an extinct ground sloth. As Martin (2) claims that his Pleistocene explosive overkill hypothesis is essentially untestable except for the radiocarbon chronology, it is important that the latest dates for existence of extinct forms proceed from North to South America. The dates presented do not exhibit this pattern even though Long and Martin claim they do. In fact, the two latest dates presented come from North America. Long and Martin claim that there was a constant rate of dung deposition with no decline in deposition rate toward the top of the deposit "as might be expected if the population were coming under stress gradually," and use this relationship to support the overkill hypothesis. An annual deposition rate of "perhaps less than a week's elimination of one adult sloth" is so small as to tell us absolutely nothing about the total population fluctuations.

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Our purpose was to replicate, if we could, the radiocarbon dates on which Martin, Sabels, and Shutler based their conclusion that the Shasta ground sloth was alive at least until 10,000 years ago (1). Our new suite of samples yielded none from North America much younger than 11,000 years in age (2). Pending new discoveries or a successful replication of L-473A, Y-1163A, or C-222 we conclude that Shasta ground sloth extinction was remarkably close in time to the arrival of the first big game hunters in North America, and slightly before sloth extinction in South America.

We agree that the rate of dung deposition in Rampart Cave may not reflect population dynamics of the extinct sloths. On the other hand, seven North American caves are known to contain sloth dung. Ra-

diocarbon dates obtained since our report was published (2) show that all seven were occupied by sloths within a few hundred years of the time when we believe they suddenly disappeared. The result does not suggest a population coming under stress gradually, or one suffering a gradual reduction in its range.

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Correction in the Glacial-Postglacial Temperature Difference Computed from Amino Acid Racemization

The extent to which L-amino acids racemize to D-amino acids is a function of both time and temperature as well as other environmental conditions (1). Assuming mean paleotemperatures and comparable environmental conditions, D/L amino acid ratios have been applied to the dating of fossil bones (2, 3), shells (4), and sediments (5-7).

Conversely, when fossils are datable by other methods, the extent of amino acid racemization has been applied to estimate paleotemperatures (8, 9). In particular, Schroeder and Bada (8) have estimated the glacial-postglacial temperature difference from amino acid racemization in fossil bones which had been dated by radiocarbon methods. The purpose of this comment is to point out an error in the way the average temperature differences were computed by Schroeder and Bada. Revised calculations result in new temperature differences which lie outside the error limits originally assigned to their method, but which are somewhat closer to the differences estimated by other methods.

Schroeder and Bada use the following model for the past temperature history of the earth

$$T(t) = \begin{cases} T_p & t < 10,000 \text{ years} \\ T_p - \Delta T & t > 10,000 \text{ years} \end{cases} \quad (1)$$

where t is time in years past and T_p is the present temperature. The difference, ΔT , is the quantity being sought.

Schroeder and Bada inserted measured amino acid ratios and radiocarbon ages into the constant temperature integrated rate law for opposing first-order reactions to determine effective rate constants for two different samples, k_1 for a sample younger than 10,000 years and k_2 for a sample older than 10,000 years. The Arrhenius formula was applied to the ratio, k_2/k_1 , yielding an effective temperature difference for the two samples. This difference was equated to the time-averaged temperature difference, thus determining ΔT .

Unfortunately, because of this exponential dependence of the rate constant

Table 1. Average rate constants and temperature differences computed from D/L ratios in fossil bones.

Location	$\bar{k}_1^*$ (10^{-5} year $^{-1}$)	$t_2^\dagger$ (years)	$\bar{k}_2^\ddagger$ (10^{-5} year $^{-1}$)	ΔT (°C)	
				Eq. 6	Eq. 5
Muleta Cave, Majorca, Spain	1.72	16,850	1.25	3.9	5.6
	1.72	18,980	1.22	3.7	4.8
Lukenya Hill, Kenya	4.02	17,700	2.71	4.7	7.0

*A true rate constant for samples of aspartic acid at T_p .

† Radiocarbon age.

‡ A time average rate constant.

on temperature, the effective temperature determined for the older sample is not equal to the time-averaged temperature. Schroeder and Bada appear to recognize this [see their reference 15 in (8)], but their statement that it has no significant effect on the results is not correct. The correct relationship between $\bar{k}_2$ and the true rate constant, $k(T)$, is

$$\bar{k}_2 t_2 = 10,000 k(T_p) + (t_2 - 10,000)k(T_p - \Delta T) \quad (2)$$

Using the Arrhenius formulas, we can write

$$\bar{k}_2/\bar{k}_1 = \frac{1}{t_2} [10,000 + (t_2 - 10,000)\exp(-E_a \Delta T/RT_p^2)] \quad (3)$$

where we have used the fact that

$$(T_p - \Delta T)^{-1} = T_p^{-1}(1 + \Delta T/T_p) \quad (4)$$

to first order in $\Delta T/T_p$. Solving Eq. 3 for ΔT gives

$$\Delta T = \frac{-RT_p^2}{E_a} \ln \left(\frac{t_2(\bar{k}_2/\bar{k}_1) - 10,000}{t_2 - 10,000} \right) \quad (5)$$

which should be compared with

$$\Delta T = \frac{-RT_p^2}{E_a} \left(\frac{t_2}{t_2 - 10,000} \right) \ln(\bar{k}_2/\bar{k}_1) \quad (6)$$

which follows from the assumptions used by Schroeder and Bada.

In Table 1 we compare ΔT 's calculated with these two formulas for several locations; the data are taken directly from table 1 of (8). It is evident that one must use the improved formula, Eq. 5, if the 1°C accuracy claimed by Schroeder and Bada is to be obtained. The improved ΔT 's are in somewhat better agreement with estimates from other sources. These are 5° to 6°C (10) and 4°C (11) for the Mediterranean location and 5° to 7°C (12) and 5° to 8°C (13) for the African location.

One can show that Eq. 5 actually reduces to Eq. 6 whenever $t_2 \gg 10,000$ years or $E_a \Delta T/RT_p^2 \ll 1$; however, neither condition is met for the cases in Table 1, so the use of Eq. 6 cannot be justified.

The correction set forth here is entirely mathematical and does not itself either

challenge or support the general idea of using amino acid racemization as a chronological or paleothermometric method. This general idea has been challenged recently by Bender (14), and Bada's reply was published immediately following in the same journal (15). Whatever the validity of the method turns out to be, it will be necessary to use the corrected analysis given herein if significant numerical errors are to be avoided.

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We are pleased that the equation derived by McCullough and Smith gives closer agreement between paleotemperatures deduced from racemization data and those deduced from either isotopic or paleontological studies than did our original equation (1). However, it should be noted that their equation was derived by using a

step-function temperature model. This model is only a crude representation of the actual temperature history over the last 20,000 years. Temperature uncertainties of at least 1° to 2°C likely arise from using this model. The ultimate accuracy of racemization-deduced paleotemperatures will only be obtained when a suitable equation (probably derived from oxygen isotopic data) expressing temperature changes on the earth as a function of time is used. With this equation and with numerous racemization results from a particular site, it should be possible to carry out a stepwise numerical integration. With this type of approach, it may be possible to determine paleotemperatures with an accuracy of 1°C or less from racemization data.

McCullough and Smith state that their mathematical correction neither supports nor challenges the general idea of using amino acid racemization as a chronological or paleothermometric tool. However, we believe that the close agreement between racemization-deduced paleotemperatures and temperatures deduced from other evidence strongly supports the proposal that temperature is the major environmental factor which determines racemization rates (2). If other environmental factors, such as fluctuations in pH or leaching by groundwaters (3), had a major effect on racemization rates in bone, racemization-deduced paleotemperatures would not be expected to be consistent with paleotemperatures deduced from other evidence.

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