Letters

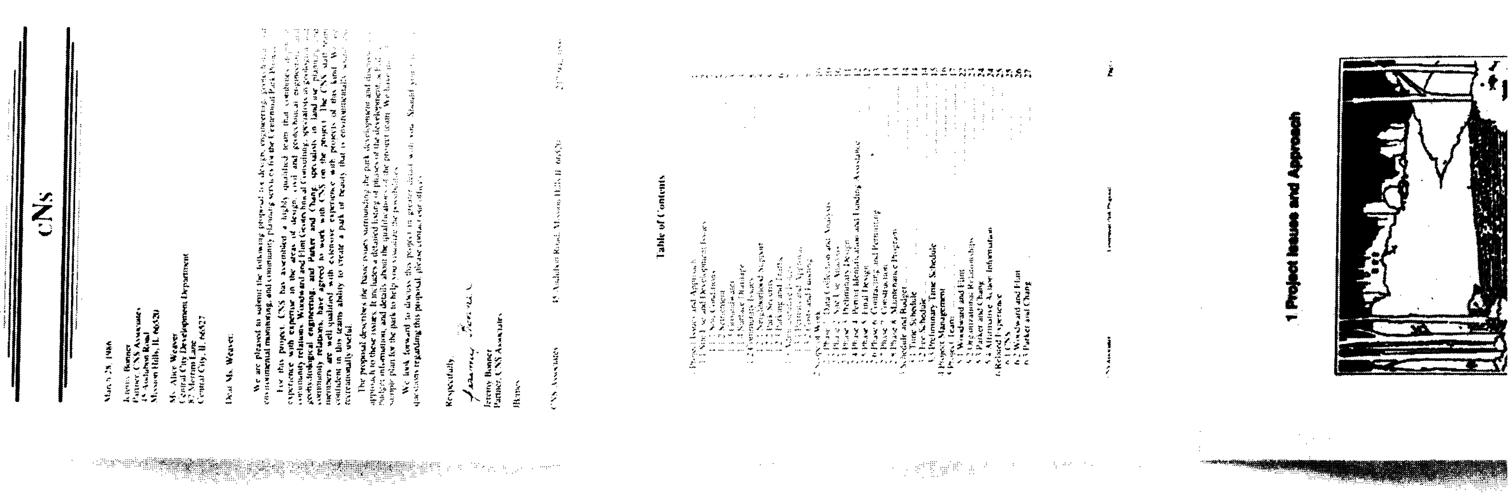
Cretaceous-Tertiary Dinosaur Extinction

Robert E. Sloan *et al.* (Reports, 2 May, p. 629) present several sets of data in support of their long held view that there was a simultaneous and gradual decline of dinosaurs and evolutionary radiation of ungulates near the Cretaceous-Tertiary boundary. Their interpretation is made without reference to taxonomic uncertainties and taphonomic biases. It appears to us that, when these matters are taken into consideration, the data of Sloan *et al.* are equally compatible with a hypothesis of abrupt extinction of dinosaurs followed by adaptive radiation of ungulates.

Sloan *et al.* conflate data on bone distribution in paleochannels and in paleosols of floodplains. Paleochannels and paleosols are such different depositional and preservational environments that we prefer to consider them separately. The apparent decline of dinosaur bone in paleosols toward the top of the Hell Creek Formation is accompanied by declining carbonate content of these paleosols, recently documented during fieldwork (by G.R.) in Bug Creek (*1*). Paleosols of the uppermost 2 meters of the Hell Creek Formation there are almost entirely noncalcareous. Bone is dissolved in acidic, noncalcareous soil environments (*2*), so this pattern of bone abundance could be preservational. Since calcareous fossils are more easily dissolved than are phosphatic ones, and small bones with their high surface-to-volume ratio are more readily destroyed than large bones (*2*), there should be a predictable sequence of last occurrences higher in the formation: land snails below mammal bones below large dinosaur bones. Such a sequence of disappearance for bones has been noted by several workers (*3*). The whole preservational sequence should be more rigorously documented.

Sloan *et al.* also report declining diversity of dinosaurs in a sequence of paleochannels, most of which are Paleocene in age (*4*). These dinosaurs are represented by isolated teeth, and reworking from older deposits is not adequately rebutted in their account. Incision of paleochannels into earlier deposits during a time of marine regression and tectonic uplift is well documented in the area of Bug Creek (*3*). Arguments against resorting on the basis of the degree of abrasion are unconvincing in light of experimental studies of bone transport in modern streams (*5*). Also unconvincing is the argument that dinosaur teeth in paleochannels are of Paleocene age and were contemporary with ungulate radiation, because these Paleocene channels lack remains of Cretaceous mammals. This would be expected if dinosaur remains were resorted from paleosols at a level within the Hell Creek Formation, where dinosaurs but not mammals were preserved because of differential dissolution. The declining abundance of dinosaurs in paleochannels could merely reflect increased cover of Cretaceous source beds by Paleocene floodplain deposits. This alternative interpretation is also open to further test, by searching for articulated dinosaur remains in Paleocene paleochannels, levee deposits, and paleosols. Until these are found, we regard as unproved the existence of Paleocene dinosaurs or the idea that dinosaurs were declining in diversity at the same time as an ungulate radiation.

Another line of evidence used by Sloan *et al.* is a compilation of dinosaur diversity showing gradual decline in numbers of dinosaur genera over the last 7 million years of the Cretaceous. Other compilations of dinosaur diversity for this time period (*6*) differ significantly from theirs, some showing declining diversity and others increasing diversity. One of us (G.D.L.) has prepared a compilation which takes into account taxonomic uncertainties between paleontologists



concerned with this issue. We find that a significant decline in dinosaur diversity is difficult to prove.

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Sloan *et al.* report gradual reduction in both diversity and population density of dinosaurs at the end of the Cretaceous. Their assertion of decreasing diversity during the last 9 million years of the Cretaceous is based on the numbers of genera in progressively younger assemblages. They found 30 genera in the combined Judith River–Oldman–St. Mary River formations; 23, 22, and 19 genera in progressively younger strata; and finally 12 genera in the upper 16 meters of the Hell Creek Formation. We disagree with the suggestion that diversity was declining because the total of 30 genera in the oldest fauna was obtained by summing total genera from a 2.5-million-year interval, while the other totals were drawn from faunas derived from about 1-million-year intervals (figure 1 of Sloan *et al.*).

A more reasonable approach would be to compare the number of dinosaurs present in the 2.5-million-year time interval at the end of the Cretaceous with the Judith River–Oldman–St. Mary River fauna. Figure 1 of Sloan *et al.* reveals 28 genera present during the last 2.5 million years of the Cretaceous. A decline from 30 to 28 genera seems very modest.

We performed a statistical test of dinosaur diversity changes on data taken from figure 1 of Sloan *et al.* We determined generic diversity at each of the time lines from 76 to 67 million years ago. We selected the two time lines with the highest diversities (23 and 27 genera at 75 and 74 million years ago, respectively) and compared them to diversities at the two most recent time lines (17 and 18 genera at 68 and 67 million years ago, respectively). We then compared the summed diversities of older and younger samples with the a priori hypothesis of no difference ($\chi^2 = 2.6$, d.f. = 1, $P > 0.10$) and found they did not differ significantly.

Sloan *et al.* also suggest that dinosaur abundance was declining through the Hell Creek Formation. On the basis of a chi-square test, they state that the highest level of the formation had a significantly lower dinosaur abundance than lower levels. However, using data from table 2 of Sloan *et al.* we compared the number of bones in each stratigraphic interval with the number that would be expected if each interval contained the average of 2.63 bones per square kilometer ($\chi^2 = 9.79$, d.f. = 5, $P > 0.05$). The test indicates that no sample (including the youngest) differed significantly from the others. In a second test, we compared the youngest interval with the combined collections of the older intervals ($\chi^2 = 2.86$, d.f. = 1, $P > 0.05$) and found no significant difference.

It appears to us that the data discussed above are consistent with constant diversity and constant abundance of dinosaurs through the last 9 million years of the Cretaceous. That the same data are open to the alternative interpretations of gradual decline and of relative constancy probably reflects the fact that the collections were made from many facies over many years and with many different purposes. Currently available information is not sufficient to establish whether or not the dinosaur extinction was gradual. Carefully designed fieldwork is needed to obtain new collections that specifically focus on patterns of dinosaur diversity at the end of the Cretaceous.

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Unequivocal evidence is required to support the assertion that dinosaurs were members of Paleocene faunas in Montana. We believe that possible reworking of dinosaur remains into younger channel deposits and their absence in nonchannel earliest Paleocene deposits are critical issues incompletely addressed by Sloan *et al.*

Bug Creek facies channel deposits (*1*) such as the Ferguson Ranch locality contain transported and reworked material (*2*). Behrensmeyer (*3*) analyzed the possibilities of mixing skeletal elements of members of temporally disjunct faunas. Channel lag deposits are concentrations of clasts, whether they are new additions or winnowed residue from reworked stream banks (*2*). The undocumented "minimal" abrasion of dinosaur teeth in Paleocene stream channel deposits (age determined palynologically) does not convincingly exclude the possibility of reworking. Limited abrasion is just as easily explained by minimal transport of exhumed teeth (and bones).

Three observations based on 16 years of fieldwork in eastern Montana require explanation. If dinosaurs lived during deposition of the Bug Creek facies channel fills, why have their articulated remains not been found in these deposits? Partial dinosaur skeletons commonly are found in undisputed Cretaceous channel fillings, for example, the type specimen of the *Tyrannosaurus rex*. Articulated remains do occur in the Bug Creek facies, but are invariably those of taxa not limited to the Cretaceous (for example, turtles and crocodiles) (*4*).

Intensive fieldwork focused on channel and overbank deposits of Paleocene age within the Z coal complex of the basal Tullock Formation has resulted in the discovery of many accumulations of nondinosaur fossil vertebrates, including articulated specimens (*4*). Purported contemporaneous dinosaur remains from the Bug Creek facies are known only from channel deposits that cut into and necessarily rework Cretaceous sediments.

The stratigraphically highest dinosaur fossils preserved in nonchannel deposits lie approximately 2 meters below the base of the Tullock Formation, and, where it has been identified palynologically, the Cretaceous-Tertiary boundary. We know of no vertebrate fossils from this interval, or within 1 meter above the Cretaceous-Tertiary boundary (excluding those in channels that cut through these strata). Thus the sample of dinosaur specimens from the uppermost 9 meters of the Hell Creek Formation (Sloan *et al.*, table 2) is actually derived from an interval with a thickness approximately 75% that of those with which it is being compared. How is this related to the alleged decrease in abundance of dinosaur remains?

The possibility that dinosaur specimens have been reworked and the apparent discrepancies between records from channel and overbank deposits demand further investigation.

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3. A. K. Behrensmeyer, *Paleobiology* **8**, 211 (1982).
4. Forty-eight localities in the Z coal complex interval, 37 yielding articulated specimens (in the University of California collections); L. J. Bryant, thesis, University of California, Berkeley, CA (1985).

Response: There are six major events recorded in the upper Hell Creek Formation of McCone County, all within chron 29r [the 0.6-million-year reversed magnetic interval, including the Cretaceous-Tertiary (K-T) boundary], and at least four of them are discrete. The oldest is the latest Maastrichtian sea level lowering (*1*) and consequent minor unconformity; closely associated with this are the introductions of ungulates and of multituberculates of Asian origin and perhaps the introduction of *Leptoceratops* from Asia and *Alamosaurus* from South America. A lowering of sea level would make intercontinental migrations across a filter bridge easier. Also associated with this is part of the reduction of pollen taxa. Retallack and Leahy's interval of deep weathering follows. The next identifiable event is the K-T boundary, marked by the iridium-rich layer in some but not all sections, principally those in contemporary oxbow lakes. This is also marked by the abrupt termination of several Cretaceous pollen taxa. Immediately following this is a short stratigraphic interval with an enrichment of fern spores, in turn followed by the great increase in conifer pollen and wood. The next event is the deposition of the continuous upper Z coal, the top of the Hell Creek Formation, followed by the major change in sedimentation type that results in the typical and definitive Tullock shales of distinctly yellowish color. This color change is due to the deposition of many closely spaced layers of siderite cemented clay, separated by layers of light gray clay. These siderite bands are mainly absent from the Hell Creek Formation. We presume this change is due to the Danian sea level rise and consequent change in base level and water table. The final event is the terminal extinction of dinosaurs in Montana. The last dinosaurs occur in a channel that does not cut down into the Hell Creek Formation. Since our report was submitted we have demonstrated that Bug Creek West (BCW), Scmenge Point and Harbicht Hill (HH) are Paleocene channels using the same criteria that we used for Ferguson Ranch (FR). We have also located two more Paleocene localities, By George and Wounded Toe, within the Hell Creek Formation, and one not yet named in the basal Tullock Formation (*2*). The K-T boundary thus falls between Bug Creek Anthills (BCA) and BCW. Only one dinosaur genus disappeared at the K-T boundary, and 11 dinosaur genera survived into the Paleocene in Montana.

The possible sources for the fossils found in the channels are (i) reworking from older and lower channels, (ii) reworking from adjacent older floodplain deposits, (iii) being swept off the surface of the floodplains, and (iv) drowning in the channels. The question is, Are all of the dinosaur teeth in the Paleocene channels of sources (i) and (ii), or are at least some of them from source (iii)? Source (iv) could of course produce semiarticulated skeletons, but we have not found any in 18 field seasons. A possible reason for the lack of articulated skeletons of dinosaurs is the lower sedimentation rate of the Hell Creek Formation and the lower Tullock formations as compared with the Lance Formation or the Judith River Formation of Alberta containing the classic Oldman fauna. Depositional units in the lower Tullock Formation are only 1 to 10 centimeters thick, too thin for the burial of skeletons other than small vertebrates. The known Tullock fossils come dominantly from coals and the channel sands. The major