temperature variations. Present climates that have a 2° to 4°C CMM (the estimate accepted by Brouwers *et al.*) occur south of 55° N, at lower latitudes than the paleolatitude of 70° to 85°N inferred for the Late Cretaceous North Slope. At lower latitudes, diurnal temperature variations occur throughout the year, and a 2° to 4°C CMM invariably produces freezing. If, however, total darkness prevails, diurnal temperature variations and freezing would be absent with a CMM of 2° to 4°C.

If Alaskan dinosaurs overwintered [see also (*3*) for alternatives] and tolerated a CMM of 2° to 4°C, perhaps by reducing activity as suggested by Brouwers *et al.* and others (*2, 3*), this does not necessarily imply that dinosaurs could have tolerated temperatures at the K-T boundary, which in the Western Interior are inferred to have reached a mean of near 0°C for 1 to 2 months (*4*). Although diurnal temperature variations would be greatly reduced by a dust cloud, even small variations should produce subfreezing temperatures. Further, whereas overwintering Alaskan dinosaurs presumably had an extended period of metabolic adjustment to gradually decreasing temperature, the temperature excursion at the K-T boundary would have started within hours after the presumed impact (*5*), and the first few days would have created a metabolic crisis.

JACK A. WOLFE
Box 25046, MS-919,
U.S. Geological Survey,
Denver, CO 80225

REFERENCES

1. J. A. Wolfe and G. R. Upchurch, Jr., *Palaeogeogr. Palaeoclim. Palaeoecol.*, in press.
2. J. T. Parrish, J. M. Parrish, J. H. Hutchison, R. A. Spicer, *Geol. Soc. Am. Prog. Abs.* **19**, 326 (1987).
3. J. M. Parrish, J. T. Parrish, J. H. Hutchison, R. A. Spicer, *Palaois* **2**, 377 (1987).
4. J. A. Wolfe and G. R. Upchurch, Jr., *Proc. Nat. Acad. Sci. U.S.A.* **84**, 5096 (1987); *Nature (London)* **324**, 148 (1986).
5. O. B. Toon *et al.*, *Geol. Soc. Am. Spec. Pap.* **190**, 187 (1982).

Response: Galbreath suggests that the occurrence of dinosaurs on the North Slope does not test the hypothesis relating their extinction to the terminal Cretaceous event. He correctly states that the potential ability to survive a Cretaceous winter in the Arctic would only be of value if the hypothesized catastrophic darkening of the earth by a dust cloud occurred at the beginning of the Arctic winter. Otherwise, an extended cold season would put the animals in a position of needing to survive an extended lean period. Thus, Galbreath believes that North Slope dinosaurs constrain the season in which the catastrophe occurred. We too considered this important factor, but realized that dinosaurs also lived in the Southern Hemisphere (*1*). A catastrophe that extended the Northern Hemisphere winter would fall at the beginning of the Southern Hemisphere winter, thereby leaving those dinosaurs minimally affected. That dinosaurs gradually became extinct through the Late Cretaceous (*2*) may decouple the extinction mechanism(s) from the terminal Cretaceous event.

Galbreath notes that most Cretaceous dinosaurs inhabited environments in lower latitudes. Indeed, the most interesting aspect of the Alaskan dinosaur population is that they constituted a marginal population living in an environment characterized by extreme seasonality. We would not expect similar responses to ecologic perturbations from low- versus high-latitude populations. The Alaskan dinosaur population should have been able to survive the dark and cold conditions of the terminal Cretaceous.

We agree with Wolfe that paleotemperature estimates for the North Slope based on plant megafossils have a degree of uncertainty, but for different reasons. Our cold mean month (CMM) estimate of 2° to 4°C was intended as an approximate upper limit in contrast with the lower limit of −11°C. We disagree with his assertion that if the CMM was above freezing, temperatures below 0°C would not occur during a 3- to 4-month night. Wolfe's extrapolation of CMMs from lower latitudes is inappropriate precisely because of diurnal temperature variations.

If we assume present obliquity (*3*) and approximate coincidence of the Maestrichtian rotational and paleomagnetic poles (*4*), the Cretaceous North Slope experienced from 2 to 4 months of winter darkness (excluding twilight), depending on paleolatitude (*5, 6*). Diurnally induced freezing conditions at modern lower latitudes with a CMM of 2° to 4°C are due to lack of insolation for nights of less than 18 hours in duration. With nights that are 3 or 4 months long, the lack of insolation results in a gradual temperature decline throughout the winter (*6*). Modern-day winter diurnal temperature variations at high latitudes, however, are even greater than during the summer (*6*) because of storm-induced atmospheric turbulence due to the enhanced pole-to-equator thermal gradient created by darkness at the pole (*7*). The Cretaceous CMM of 2° to 4°C, therefore, implies that occasional freezing conditions are probable. The winter cold may have been punctuated by pulses of warmth transported to the North Slope by high-latitude storm penetration (*7*). Temperatures during the coldest month were unlikely, therefore, to have been as constant as Wolfe implies. Linear or near linear extrapolation of CMM temperatures from latitudes experiencing winter darkness of less than 24 hours in duration to environments subject to 3 to 4 months of darkness is inappropriate.

In the Cenomanian, where a North Slope mean annual temperature (MAT) of approximately 10°C has been inferred, minimal organic degradation (*8*) in conjunction with other evidence, suggests winter temperatures of less than 4°C (*3*). Starting with the ~5°C lower MAT estimate (*9*) for the Maestrichtian, winter temperatures toward the end of the Cretaceous are likely to have declined below freezing for at least parts of the coldest month; the CMM for that period would therefore have been lower than that suggested by Wolfe.

Wolfe suggests that the Alaskan dinosaurs needed a period of metabolic adjustment with the onset of winter cold conditions and that the inferred dramatic drop of temperature at the Cretaceous-Tertiary boundary would have been catastrophic because it would not have allowed for this adjustment. However, comparing dinosaurian physiology and behavior with those of modern reptiles is inappropriate. Current interpretations of hadrosaurian dinosaurs indicate that comparisons with modern birds and mammals are more appropriate (*10*).

ELISABETH M. BROUWERS
U.S. Geological Survey,
Denver, CO 80225
ROBERT A. SPICER
Goldsmiths' College,
Creek Road,
London SE8 3BU, United Kingdom
WILLIAM A. CLEMENS
Museum of Paleontology,
University of California,
Berkeley, CA 94720

REFERENCES

1. R. Molnar, in *The Fossil Vertebrate Record of Australasia*, P. V. Rich and E. M. Thompson, Eds. (Monash University Offset Printing Unit, Clayton, Victoria, Australia, 1982), pp. 169–226.
2. W. A. Clemens, in *Dynamics of Extinction*, D. K. Elliot, Ed. (Wiley, New York, 1986), pp. 63–85.
3. R. A. Spicer and J. T. Parrish, *Geology* **14**, 703 (1986).
4. A. Lottes, *Geol. Soc. Am. Prog. Abstr.* **19**, 749 (1987).
5. *Air Almanac* (Government Printing Office, Washington, DC, 1983).
6. E. Vowinckel and S. Orvig, in *Climates of the North Polar Regions*, S. Orbig, Ed. (Elsevier, Amsterdam, 1970), pp. 129–252.
7. J. R. Eagleman, *Meteorology* (Wadsworth, Belmont, CA, 1985).
8. R. A. Spicer, *Geol. J.* **A96**, 265 (1987).
9. J. M. Parrish *et al.*, *Palaios* **2**, 377 (1987).
10. R. T. Bakker, in *Dinosaurs Past and Present*, S. J. Czeikas and E. C. Olson, Eds. (Natural History Museum, Los Angeles County, and Univ. of Washington Press, Seattle, WA, 1987), vol. 1, pp. 38–69.

Erratum: David J. Ingle's name was inadvertently omitted at the end of the response (18 Dec., p. 1732) to Richard A. Young's Technical Comment "Color vision and the Retinex theory" (18 Dec., p. 1731).