iridium peak occurred near the end of a 2-million-year comet storm, and that evidence of such a storm will be found in the period immediately before 67 million years ago, for which Kyte and Wasson have no data. If the mass extinction during this period was truly extended in time, then more than one impact must have occurred near the Cretaceous-Tertiary boundary.

To determine whether comet storms have actually taken place will require study of rock that had a higher sedimentation rate than the sample used by Kyte and Wasson. With such rock the background level of iridium will be lower and iridium spikes from individual impacts can be resolved. Kyte and Wasson were unable to detect clearly even the well-known iridium peak near the Eocene-Oligocene boundary (*11*). They saw two broad bumps in the region and stated that either of them "could represent this event." They do not mention the obvious possibility that they could be seeing two impacts, evidence of a comet storm.

It is incorrect to conclude that the data of Kyte and Wasson give "strong evidence" against the occurrence of comet storms. In fact, their data are consistent with the factor of 2 change in the level of iridium that comet storms are expected to give.

RICHARD A. MULLER
Lawrence Berkeley Laboratory,
University of California,
Berkeley, CA 94720

REFERENCES AND NOTES

1. L. W. Alvarez, W. Alvarez, F. Asaro, H. V. Michel, *Science* **208**, 1095 (1980).
2. D. P. Whitmire and A. A. Jackson, *Nature (London)* **308**, 713 (1984).
3. M. Davis, P. Hut, R. A. Muller, *ibid.*, p. 715.
4. M. R. Rampino and R. B. Stothers, *ibid.*, p. 709.
5. J. G. Hills, *Astron. J.* **86**, 1730 (1981).
6. W. Alvarez and R. A. Muller, *Nature (London)* **308**, 718 (1986).
7. J. S. Trefil and D. M. Raup, *Earth Planet. Sci. Lett.*, in press.
8. D. M. Raup and J. J. Sepkoski, *Proc. Natl. Acad. Sci. U.S.A.* **81**, 801 (1984).
9. G. Keller, S. D'Hondt, T. Vallier, *Science* **221**, 150 (1983).
10. R. A. Muller, in *The Search for Extraterrestrial Life, Recent Developments*, M. D. Papagiannis, Ed. (IAU Symposium 112, International Astronomical Union, Kluwer, Academic, Hingham, MA, 1985), pp. 233–243; *Lawrence Berkeley Laboratory Report LBL-18271* (1984); P. Hut and P. R. Weissman, in preparation.
11. F. Asaro, L. W. Alvarez, W. Alvarez, H. V. Michel, *Geol. Soc. Am. Spec. Pap.* **190**, 517 (1982); R. Ganapathy, *Science* **220**, 1158 (1983).
12. Supported in part by Department of Energy contract DE-AC03-76SF 00098 and by the Research Corporation. This work was done while the author was a fellow of the John D. and Catherine T. MacArthur Foundation.

Kyte and Wasson point out that the size and stratigraphic span of the iridium maximum at the Cretaceous-Cenozoic boundary in the central North Pacific seem too small to fit the cometary swarm model of Davis *et al.* (*1*). Their conclusions, however, that this "is strong evidence against the occurrence of comet showers" and that it casts doubt on the existence of periodic catastrophic extinctions are not justified by their observations.

Although details of the model of Davis *et al.* (*1*) for periodic cometary impacts are not supported by the observations of Kyte and Wasson, this does not negate periodic comet showers, if such a shower can involve appreciably fewer terrestrial impacts than the approximately 25 suggested by Davis *et al.* (*1*). Kyte and Wasson indicate that the dynamics of alternative models must be similar to those of Davis *et al.* (*1*) "in order to ensure that there are enough large impacts to yield periodic extinctions." This conclusion is questionable. Perhaps 25 impacts are 24 more than necessary to account for a major extinction event.

Evidence against the existence of periodic comet showers of the intensity and duration proposed by Davis *et al.* (*1*) is not evidence against periodicity in catastrophic mass extinctions, whether caused by extraterrestrial body impact or not. Several studies have indicated that the more catastrophic biological extinctions are periodic (*2*), although periodicity has not been firmly established. If major extinctions are periodic, the periodicity may or may not be causally related to episodic impact by comets or asteroids. If the cause is cometary impact, the duration and number of impacts per extinction event may or may not be as great as suggested by Davis *et al.* (*1*). Of the above considerations, it is only this last point that is critically examined by the observations of Kyte and Wasson.

CRAIG BOND HATFIELD
Department of Geology,
University of Toledo,
Toledo, OH 43606

REFERENCES

1. M. Davis, P. Hut, R. A. Muller, *Nature (London)* **308**, 715 (1984).
2. D. M. Raup and J. J. Sepkoski, Jr., *Proc. Natl. Acad. Sci. U.S.A.* **81**, 801 (1984); A. G. Fischer and M. A. Arthur, in *Deep-Water Carbonate Environments*, H. E. Cook and P. Enos, Eds. (Society of Economic Paleontologists, Tulsa, OK, 1977), pp. 19–50; M. R. Rampino and R. B. Stothers, *Nature (London)* **308**, 709 (1984); C. B. Hatfield and M. J. Camp, *Geol. Soc. Am. Bull.* **81**, 911 (1970).

Response: In his comment on our work, Muller states that our data on iridium in sediments are insensitive to comet storms of the sort predicted by him and others. He then proceeds to reduce his hypothesized comet storm to a comet drizzle that we indeed could not have detected. However, the intensity of this drizzle was much too low to have produced periodic extinctions. It sounds like the first line of a joke: "How many impacts does it take to make an extinction?" Hatfield's explicit (and Muller's implicit) answer that it only takes one is correct, but misses the key point, namely, that it seems to require a very large impact. The mass of the body that impacted at the end of the Cretaceous appears to have been $\gtrsim 10^{18}$ grams (*1*); thus it seems that the complete answer to the question is that only one comet or asteroid with a mass of 10^{18} grams was needed to produce the degeneration at the K-T. But a swarm of Oort-cloud comets with masses up to 10^{18} grams will have a size distribution that can probably be approximated by $n = kr^{-2}$, where k is a constant and n is the number of objects having radii $\geq r$ (*2*). According to this size relationship, an expectation value of 1 $\geq 10^{18}$-gram object implies 3.6 objects having masses between 10^{17} and 10^{18} grams, 21 objects having masses between 10^{16} and 10^{17} grams, and 74 objects having masses between 10^{15} and 10^{16} grams. Thus the intrusion of a comet swarm into the inner solar system will necessarily produce a large number of smaller impacts as well as the enhanced accretion of cometary dust that we showed (*3*) to be absent.

A serious deficiency of the paper by Davis *et al.* (*4*) proposing that periodic extinctions resulted from periodic comet swarms was that they did not define a lower radius limit on the comet population, which leaves order-of-magnitude uncertainties in the terrestrial mass influx during such a hypothetical comet swarm. Their estimate of 25 terrestrial impacts during the passage of a comet swarm through the inner solar system offered no information about the number of 10^{18}-gram bodies expected to strike the earth during the 1 to 3 million years of the duration of this episode.

In our article, we assumed that the 25 impacts of Davis *et al.* (*4*) corresponded to a population with radii of ≥ 0.5 kilometer and masses of $\geq 10^{15}$ grams (*5*). Under these circumstances the expectation value of a comet with $\geq 10^{18}$-gram mass (≥ 5 km radius) is ~ 0.3, considerably lower than the expectation value of ~ 2 required in order to have a 90% probability of at least one such event per swarm passage. Thus the cometary dust influx with which we tested the comet shower hypothesis in our article was already conservatively low. Reduction of the size of the comet swarm by a factor of ≥ 10 reduces the probability of a Cretaceous-Tertiary (K-T)–sized event to ≤ 0.03 per swarm passage.

The reduced comet swarm of the size now proposed by Muller cannot be distinguished from random noise. Davis *et al.* (*4*) assumed that each shower comet, on average, makes four trips through the inner solar system and has two chances to hit the earth during each perihelion passage; they set the probability that an individual comet will impact the earth to 1.6×10^{-9}, the earth's cross-sectional area divided by the solar-system area inside 1 astronomical unit. The expected number of impacts per passage of Muller's swarmlet of 4×10^7 comets is

$$4 \times 10^7 \times 1.6 \times 10^{-9} \times 4 \times 2 = 0.5$$

This is a factor of 5 lower than the estimate given by Muller because he incorrectly added a 16/3 multiplier to allow for additional returns, a factor already included (the factor of 4) in the Davis *et al.* estimate (*6*). Muller states that the smallest comets in his swarm produce craters with a diameter of 10 km. At a mean cometary impact velocity of 52 km per second, craters of this size correspond to comets with radii of only 0.15 km and, at a density of 2 grams per cubic centimeter, to masses of 2×10^{13} grams. Even if one increased the size of the swarm by a factor of 5 in order to yield 2.5 impacts per passage, during most swarm passages the mass of the largest impacting comet will be $<10^{14}$ grams, four orders of magnitude smaller than that needed to produce a mass extinction event.

What would be the geological record of the passage of this swarmlet through the inner solar system? Not resolvable is the answer. Muller's swarmlet yields three craters with diameters $\geq$10 km every 30 million years. According to Wetherill and Shoemaker (*7*), impacts capable of creating craters with diameters of $\geq$10 km occur each 10^5 years, that is, 300 are produced in 30 million years, a flux 100 times larger.

How large must a comet swarm be to cause a mass extinction? Certainly the number of large impacts would need to be comparable to the random background or the signal cannot be resolved from the noise. The earth-crossing asteroids appear capable of accounting for all known terrestrial craters (*7*). Weissman (*5*) estimated that modern long-period comets account for about 5% of the crater record. We suggest that, given the noisy and incomplete nature of the cratering and mass extinction records, the number of impacts due to swarm passages would need to be about half of all impacts, and thus the impact rate would be enhanced by a factor of $\gtrsim$10 (over the mean impact rate of *all* objects) during swarm passages. The conclusions of our article stand: the Ir data are inconsistent with periodic increases of comet accretion large enough to produce most observed mass-extinction events.

Hatfield objects to our statement that our results cast "serious doubt on the existence of periodicities in castastrophe-induced extinctions." Let us first agree that our data offer no evidence regarding the periodicity of mass extinctions. The question we attempted to address was whether periodic accretion of extraterrestrial objects could have imposed a periodicity on these extinctions. Although we did not raise the issue of a terrestrial mechanism to produce periodic (in the strict sense) extinctions, we do indeed doubt that there is evidence to support such a model.

We justify this assertion on the basis of three arguments: (i) Our data place severe limits on comet swarms as currently hypothesized. Large periodic swarms of comets (the only extraterrestrial agent that could plausibly impose a periodicity and also explain the K-T event) are virtually ruled out. (ii) By demonstrating that the K-T iridium profile is very different from that in the succeeding 30 million years, our data strengthen the case for a major impact event at the end of the Cretaceous. Although a direct causal relationship between the impact event and the mass extinction remains circumstantial, the close temporal relationship between the Ir anomaly, the extinction of marine plankton, and the evolution of nonmarine flora strongly support such a hypothesis. (iii) Given that an extraterrestrial agent of periodicity is lacking, but the temporally best-resolved mass extinction has a probable extraterrestrial cause, we question whether a terrestrial periodicity can be justified. How strong is the evidence for periodic extinctions if the K-T event was caused by a random extraterrestrial event and must be removed from the data set? These arguments do cast "serious doubts" on the generation of mass extinctions by periodic earth-indigenous catastrophes.

FRANK T. KYTE
JOHN T. WASSON
Institute of Geophysics and Planetary Physics,
University of California,
Los Angeles, CA 90024

REFERENCES AND NOTES

1. L. W. Alvarez *et al.*, *Science* **208**, 1095 (1980); R. Ganapathy, *ibid.* **209**, 921 (1980); F. T. Kyte, J. Smit, J. T. Wasson, *Earth Planet. Sci. Lett.* 73, 183 (1985).
2. E. Everhart, *Astron. J.* 72, 1002 (1967); P. R. Weissman, *Astron. Astrophys.* **118**, 90 (1983); in *Protostars and Planets II*, D.C. Black and M. S. Matthews, Eds. (Univ. of Arizona Press, Tucson, AZ, 1985), pp. 895–919.
3. F. T. Kyte and J. T. Wasson, *Science* **232**, 1225 (1986).
4. M. Davis, P. Hut, R. A. Muller, *Nature (London)* **308**, 715 (1984).
5. P. R. Weissman, *Geol. Soc. Am. Spec. Pap. 190*, 15 (1982). By choosing 0.5 km as a minimum radius we were able to use Weissman's estimate of 16 long period comets per astronomical unit per year as the modern background flux.
6. Actually Weissman (5) estimates that on the average, long-period comets make five passes through the inner solar system. This is why he estimates that although the modern flux of long-period comets is 16 per astronomical unit per year, only three are dynamically new.
7. G. W. Wetherill and E. M. Shoemaker, *Geol. Soc. Am. Spec. Pap. 190*, 1 (1982).
8. Supported by National Science Foundation grant OCE-84-10177.

Fact Versus Supposition

Arthur H. Neufeld's recent letter "Reproducing results" (3 Oct., p. 11) raises the question, "Does anybody care?" (if much of what is published goes unchallenged and may be untrue). In comparing modern science with that of "[s]everal decades ago," Neufeld also asks, "who has the time, interest, money, or need to reproduce another scientist's results?" One should also consider whether it is a prudent use of time and money to conduct research on the basis of supposition rather than fact.

Supposition should become fact by withstanding challenge, not by reiteration. It should not be sufficient to merely "reproduce another scientist's results by exactly duplicating the experiments." There is a need to design experiments that enable hypotheses to be challenged while viable theories (that is, verifiable explanations for particular phenomena) are being established. It appears to be customary under the modern peer review system to categorically reject papers for publication that do not support the accepted dogma, irrespective of whether the dogma is fact or supposition. Bucking this trend is time-consuming and reduces productivity, putting a damper on scientific progress without altering the proportions of information and misinformation in the literature.

Those of us who care and thought we were alone may gain encouragement from the fact that psychologists have had these problems under study since the early 1970's. Surprisingly their findings have only recently been brought to the attention of the general scientific community (*1*). The prospects for reeducating those already indulging in "self-deception" are probably remote, but we can have hopes for the education of future scientists.

DELTA E. UPHOFF
Division of Cancer Biology
and Diagnosis,
National Cancer Institute,
Bethesda, MD 20892

REFERENCES

1. M. J. Mahoney, "Self-deception in science," paper presented at the AAAS Annual Meeting, Philadelphia, PA, 28 May 1986; D. Dickson, *Science* **232**, 1333 (1986).

Erratum: In the article about AIDS in Belle Glade, Florida, by Colin Norman (News & Comment, 24 Oct., p. 415), a footnote to a table showing the distribution of AIDS cases among risk groups stated that the total number of homosexual and bisexual men included 4322 who were also intravenous drug users. The correct figure should have been 1997.

Erratum: In the cover caption for the issue of 5 September (p. 1013), the giant larva appears at the left (not the right, as indicated) and the smaller larva appears at the right.