BOLIDE EXTINCTION THEORY MAKES AN IMPACT

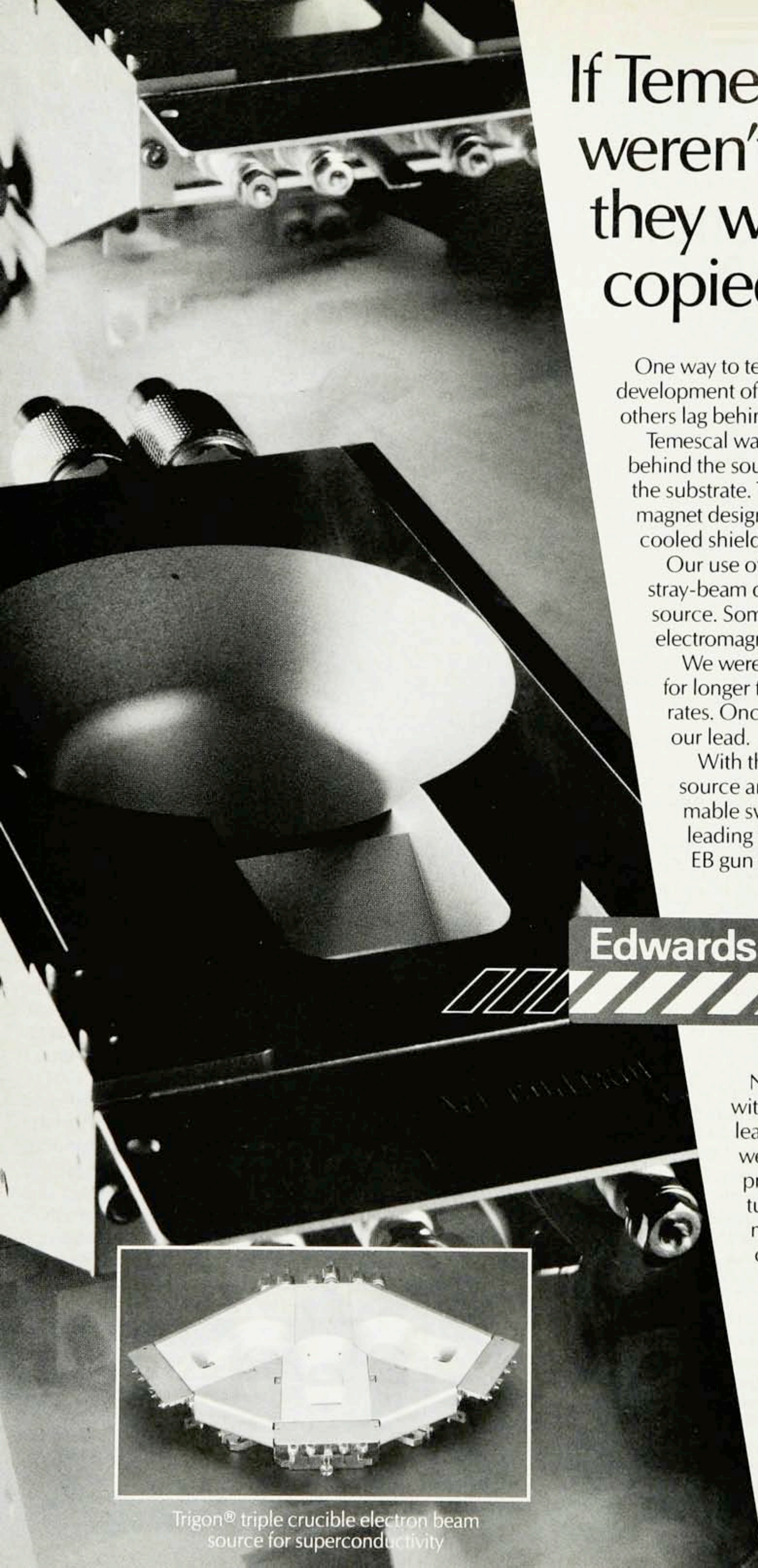
I read with much interest Luis W. Alvarez's recent article on large asteroid impacts and mass extinctions (July 1987, page 24). It presented a great deal of evidence in favor of the hypothesis that a large asteroid impacted with the Earth 65 million years ago, coincident with the wave of extinctions between the Cretaceous and Tertiary periods. However, it is not clear that current evidence supports the contention that such an impact was the *primary* cause of these extinctions. While I am not an expert in paleontology, it is my understanding that there are numerous reasons to suspect that the Cretaceous–Tertiary extinctions were triggered by terrestrial processes.

Several major geological changes were occurring at the end of the Cretaceous.[1] There was a great deal of volcanic activity, a lowering of ocean levels and a retreat of the shallow seas that covered large portions of Europe and North America. All of these processes probably altered ocean currents, blocked temperate sea breezes, changed rainfall distributions and led to general disruption of weather patterns that had previously been semitropical for most of the year. In addition to climatic changes, the loss of the continental seas opened up migratory routes that would have brought many previously separated species into competition, putting great pressure on some.[2] These changes would have been devastating not only to large land animals, but to many plants and other animals, on land, in the ocean and in the air.

Environmental changes such as these may account for the complicated pattern of extinctions seen at the Cretaceous–Tertiary boundary. In addition to the wholesale extinctions of groups such as the dinosaurs, there were cases in which some organisms survived the Cretaceous while similar ones did not.[1] For example, the flying pterosaurs became extinct while birds did not. Marine planktons were devastated, but freshwater planktons were not. North American plants and ocean-dwelling ammonites were greatly affected, but not tropical plants or squid. And most marsupial mammals disappeared, but few other mammals. It is difficult to see how a very abrupt catastrophic event such as an asteroid impact would be this selective.

There is also evidence that some groups were declining in the Late Cretaceous, before the probable impact of the asteroid. A well-documented example is the ammonites, which were becoming extinct all through the Late Cretaceous,[3] and apparently were gone before the Cretaceous–Tertiary boundary.[4] (This final extinction was not the only one felt by the ammonites, and previous depletions also occurred at times when the continental seas were regressing.) Other groups, such as the inoceramid and rudist bivalves, also seem to have vanished several million years before the beginning of the Tertiary.[4] As for the dinosaurs themselves, the number of genera in North America declined by over 50% during the last 11 million years of the Cretaceous.[1] While some paleontologists think this decline is an artifact, most do not. However, even assuming that this trend is artificial, great changes were taking place in dinosaur populations during this time.[2] The dinosaurs in an early Late Cretaceous formation, the Judith River, form a fairly heterogeneous sample. Of the large specimens, three genera of hadrosaurs and three genera of ceratopsians are fairly common. However, in the Edmonton–Hell Creek formations, from the very end of the Cretaceous, 75% of the large dinosaur fossils are of *Triceratops*, a single ceratopsian genus. Such an imbalance is probably the sign of a disturbed ecology.

The Hell Creek beds have also turned up mammalian teeth and jaw fragments that seem more similar to early Tertiary specimens than to those normally found in the Cretaceous.[1] It is not clear that these fossils are simply the result of a mixing of actual Tertiary deposits with older Cretaceous ones. This may indicate that more advanced mam-



If Temescal EB guns weren't the best, they wouldn't be copied by the rest.

One way to tell how advanced Temescal is in the development of EB gun technology is to see how far others lag behind.

Temescal was the first to use a permanent magnet behind the source to minimize radiation damage to the substrate. Those who haven't copied our rear-magnet design still rely on less effective water-cooled shields.

Our use of permanent magnets also eliminated stray-beam damage to the vacuum chamber and source. Some manufacturers continue to use electromagnets – the rest have followed our lead.

We were the first with 270° beam deflection for longer filament life and higher deposition rates. Once again our competitors followed our lead.

With the unique Trigon® triple-crucible EB source and the revolutionary new programmable sweep supply, Temescal continues leading the way to new and more efficient EB gun technology.

Edwards *First with ideas. Last to quit.*

Now, Temescal has combined forces with Edwards High Vacuum, a world leader in vacuum technology. Together, we offer the most comprehensive product ranges and support for virtually all your thin film and vacuum needs. So why wait for our imitators, call or write the industry leader today.

Temescal

Temescal Components

A Unit of Edwards High Vacuum
3279 Grand Island Boulevard • Grand Island, NY 14072 • (716) 773-7552

Trigon® triple crucible electron beam source for superconductivity mals were beginning to emerge before the Cretaceous–Tertiary boundary. A similar trend was also seen in some plant specimens.[1]

On the other hand, insects seem to have survived the Cretaceous–Tertiary extinction with little change. While more study is needed, this may be incompatible with the hypothesis that a period of darkness lasting up to several months engulfed the Earth following an asteroid impact.[5] I would be surprised if the insect data were consistent with some of the other consequences of an impact, such as widespread fires and acid rain.

While other major extinctions have occurred, there is no evidence of a major iridium excess anywhere else in the geologic record.[6] The only other known global iridium anomaly, which is only 1% the size of the Cretaceous–Tertiary iridium excess, has been found at the end of the Eocene, which is not marked by a single sudden extinction event. At least so far, it seems that large asteroid impacts are not required for mass extinctions. The Permian–Triassic extinction, for example, which is the only one larger than the Cretaceous–Tertiary event, occurred at a time when the continents were coming together to form a single large land mass. Many climatic changes like those mentioned above probably contributed to this wave of extinctions. The dinosaurs were also subject to several extinction events during the Mesozoic, such as at the ends of the Triassic and Jurassic periods. These extinctions correlate with large-scale changes in the environment due to rising and sinking seas, and with other terrestrial processes.[2] The primary difference between these events and that at the close of the Cretaceous it that new forms of dinosaurs did not evolve to take the place of old ones.

As is always the case in science, the interpretation of data can change, and many of the points that I have outlined may eventually be found compatible with an asteroid impact. I have no desire to get into a debate on the details of mass extinctions, but only want to illustrate that although there is a great deal of evidence for an asteroid impact 65 million years ago, whether this impact was the primary cause for the extinction of the dinosaurs is still an open question.

References

1. J. N. Wilford, *The Riddle of the Dinosaurs*, Vintage, New York (1985).
2. R. T. Bakker, *The Dinosaur Heresies*, Willam Morrow, New York (1986).
3. U. Lehmann, *The Ammonites*, Cambridge U. P., Cambridge, England (1976).
4. S. K. Donovan, Nature **328**, 109 (1987).
5. P. Whalley, Nature **327**, 562 (1987).
6. R. A. Kerr, Science **236**, 667 (1987).

RONALD KOLLGAARD
Brandeis University
8/87 *Waltham, Massachusetts*

The article "Mass Extinctions Caused by Large Bolide Impacts" by Luis W. Alvarez presents rather convincing evidence that the great extinction of some 65 million years ago was caused by a collision of a large mass with the Earth.

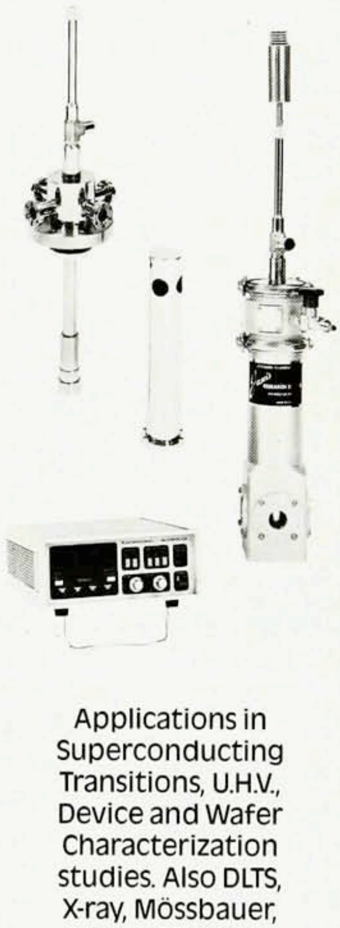
I believe Alvarez neglected significant evidence that supports his theory and that can be drawn from figures 2 and 5 of the article. In figure 2 the iridium relative abundance rises very sharply at the lower edge of the Cretaceous–Tertiary boundary (bottom of the clay layer), reaching its peak value in some 2 to 3 centimeters, and then falls back very slowly to its background value over a thickness of some 20 centimeters. This behavior suggests a sudden increase of iridium in the Earth's atmosphere—the result of an explosion or a collision—where relatively large particles, contaminated with iridium and thrown into the atmosphere, fell rather swiftly to the Earth's surface, while smaller ones hung in the air, forming a semicolloidal state. One can draw a similar conclusion from figure 5, where the pollen/spore ratio, after a sudden rise that coincides in time and depth with the iridium peak, seems to linger for a long time above its previous background level.

The asymmetry of these two peaks is significant and supports the notion that an occurrence of short duration (such as a collision) did take place, giving rise to a very rapid increase of iridium and of the pollen/spore ratio in the Earth's atmosphere, followed by a colloidal state lasting thousands of years.

S. I. SALEM
California State University,
7/87 *Long Beach*

I have just read Luis Alvarez's article "Mass Extinctions Caused by Large Bolide Impacts," and I think he makes a very good case for his thesis. He and his coworkers have done a brilliant job of unfolding the record of this awesome catastrophe from a thin layer of clay. Their discovery has an instructive value quite apart from its great scientific interest, for it reminds us how tenuous our position really is on this globe.

continued on page 118



continued from page 15

I have a question: Is there any indication *where* on the Earth's surface the Cretaceous–Tertiary impact occurred? There was, I believe, a great outpouring of lava in the region of the Deccan Plateau of India fairly close to this time, but I do not know if it is close enough actually to be a candidate site.

KENT PEACOCK
University of Toronto
7/87 *Toronto, Ontario, Canada*

The article by Luis Alvarez makes an excellent case for an asteroid impact on the Earth at the end of the Cretaceous. A question not addressed is the location of the impact.

Since quartz is abundant only in continental rock, and the largest grains of the shocked quartz that Alvarez refers to as a major verification element in the theory are to be found in the western US, B. F. Bohor[1] suggests that the impact was on land, most likely in North America. North America has several geological features suggestive of craters left by large impacts. One such feature is the circular Manicouagan Reservoir in Quebec. A particularly interesting feature (clearly visible only on topographic maps) is on the eastern edge of Greenland, where Scoresby Sund (approximately 72° N, 27° W) suggests the ringwall and central rise of a highly eroded impact crater 200 kilometers across. Other large circular features are at the north end of Baffin Island, and the nearly circular arc that forms the eastern edge of Hudson Bay.

Could one of these craters be the mark made by the impact that killed the dinosaurs?

Reference

1. B. F. Bohor *et al.*, Science **224,** 867 (1984); quoted in Sci. Am., July 1987, p. 22.

GEOFFREY A. LANDIS
Brown University
8/87 *Providence, Rhode Island*

"Mass Extinctions Caused by Large Bolide Impacts," by Luis Alvarez, addressed an issue that has intrigued me since childhood. However, Alvarez and other writers have overlooked the fact that at least one, and perhaps two or more, *extraterrestrial* craters of roughly the right size and vintage are within eyeshot of every individual on Earth, and may account for the processes noted. I refer, of course, to the craters Tycho and Copernicus (and possibly others) on the Moon.

While I can present few figures to substantiate the idea, it is obvious that a very large lunar impact could have catastrophic effects upon the terrestrial climate. Copernicus in particular, dated at roughly 70 million years, seems too glaring a candidate to overlook. Its crater is 70 or 80 miles in diameter, and its formation boosted enormous quantities of micropulverized rock, dust and possibly ice crystals into the envelope of space surrounding the Earth and Moon. This material either would have been absorbed by Earth's atmosphere immediately or would have orbited the Earth and Sun, precipitating into Earth's atmosphere over a prolonged period. Climatic effects would have been both protracted and severe, with the atmosphere absorbing and suspending meteoric debris for decades or longer. Perhaps a joint Soviet–American "Return to Luna" mission could date ejecta from the relevant craters, measure its iridium content and resolve this dilemma.

GERALD SOLOF
8/87 *San Diego, California*

It was a pleasure to read Luis W. Alvarez's article on dinosaur extinctions caused by the impact of a 10-km bolide with the Earth. Toward the end of the article he says, "There was no way a genus could have evolved so as to be protected from an occurrence that happens suddenly once every 100 million years or so." It is important for us to realize that this is not true for the human genus. We can monitor trajectories of bolides and send up nuclear bombs to fragment dangerous ones. Alvarez's article suggests to me that we should begin research on how to identify such dangerous bolides and begin planning how best to fragment them into harmless objects. Such research is essential for our survival.

The idea of well-developed, successful dinosaur life followed by destruction and then the rise of humanity is best expressed, I feel, by Beethoven's *Pastoral* Symphony. It begins with pastoral life, expressed by light, pleasant melodies, followed by the "storm," the extinction. This is followed by a slow rise of melody, signifying the gradual evolution of humans. The final melodies are richer and more complicated than the original pastoral music, showing how life after the bolide impact developed and surpassed the former life.

SANFORD ARANOFF
8/87 *Kiryat Motzkin, Israel*

ALVAREZ REPLIES: I am pleased that none of the above letters takes the position that was popular in the paleontological community a few years ago—that there is no strong evidence that a bolide impact took place 65 million years ago, and that the geophysical evidence can better be explained by a terrestrial scenario. After eight years of discussing and refuting such notions, I was prepared to continue to defend the bolide impact as the primary cause, or trigger, of the Cretaceous–Tertiary extinctions (including that of the dinosaurs). But Ronald Kollgaard takes an approach that I haven't met before: that although there is a great deal of evidence in favor of the bolide impact, there are "numerous reasons to suspect that the Cretaceous–Tertiary extinctions were triggered by terrestrial processes." I don't know what those reasons are, and Kollgaard doesn't list any that could have given rise to the exceedingly brief (less than 100 years long) deposition period for the 1-millimeter-thick iridium layer at the Caravaca site in Spain. Those who dislike the bolide scenario usually ignore Caravaca and concentrate on geologic sections where the iridium layer is several centimeters thick. But those with an appreciation for the second law of thermodynamics know that there are many processes (including the action of the seafloor equivalent of earthworms) that can smear out a thin layer, but none that can "de-smear" a thick one down to the "knife blade" layer seen at Caravaca. So we must take those Spanish layers as the "type section," and there is no way that volcanic activity (synchronous worldwide, as it would have to be), lowering of ocean levels or retreat of shallow seas could have happened as rapidly as we see at Caravaca. The geological community has had nine years to think about such matters and to reject those ideas, as the following quotation will attest. The July 1987 issue of the *Bulletin of the Geological Society of America* has a long article by Glen Izett of the US Geological Survey.[1] Izett makes no secret of the fact that he originally had great doubts about the impact theory. However, he refers to the iridium layer as the "K–T boundary impact layer" with no apology to the volcanic enthusiasts, and none of his 29 references is to anyone who doubts the impact origin of the iridium layer.

To those who haven't thought much about extinctions, and most particularly about the widely differing time scales of the kinds implied by Kollgaard's letter, the following analogy might help explain my overriding concern with the time scales and the necessity to avoid attributing an event occurring in less than 100 years to events characterized by times of

hundreds of thousands or millions of years. Everyone agrees that the end of World War II was triggered by the dropping of atomic bombs on 6 August and 9 August 1945. (The Japanese offered to surrender a few days later.) A great deal more damage had been done to Japan by high-explosive and fire bombing in the previous six months—a much longer time scale than the few days in early August. As I say in my recently published autobiography[2] [see the review in PHYSICS TODAY, December, page 83], the dropping of the atomic bombs led to the immediate extinction not only of the war against Japan, but also of all wars between major world powers—at least for more than 40 years, but more probably forever. I can't think of a more dramatic way to illustrate my attribution of importance to time scales and my rejection of most of Kollgaard's scenarios, which frequently involve long time scales, in the million-year range ("rising and sinking seas") or even 11 million years (the decline in dinosaurs).

I have given my reasons for rejecting the thoughts expressed in Kollgaard's last sentence. I believe it is no longer appropriate to say, "Whether this impact was the primary cause for the extinction of the dinosaurs is still an open question." I believe that question has been thoroughly closed off in the past several years.

S. I. Salem believes that the case for the impact is even stronger than I stated, because he finds that I "neglected significant evidence" in my figures 2 and 5. Figure 2 was drawn for the first time in 1979, and since then the errors in all the background points have been reduced by a factor of about 100, but the new data haven't been published. So I agree with Salem that the case is far stronger than I claimed—stronger even than those very figures would indicate.

The letters of Kent Peacock, Geoffrey A. Landis and Gerald Solof all deal with the question of where the K–T impact crater is located. This is a major focus of research at the present time, and I can only give tentative responses to these letters. As Peacock notes, at a time very close to the K–T boundary there was a major outpouring of basaltic lava, which now forms the Deccan Plateau of India. Basaltic volcanism is a very likely result of an impact of the size indicated for the K–T event, so this may indeed be the impact site. However, there are preliminary suggestions from magnetic polarity stratigraphy that the Deccan volcanism began before the impact. The deep-sea drilling ship JOIDES Resolution is currently taking cores in the Indian Ocean, and a better stratigraphic record of the Deccan volcanism and its relation to the K–T event may emerge from this work.

Landis points out some circular geologic features in North America as possible craters resulting from the K–T impact. Manicouagan is definitely an impact crater, but it is well dated[3] at 210 ± 4 million years, and is thus too old to be the K–T crater. The circular arc that forms the eastern edge of Hudson Bay has often been noted as a possible impact crater, but no direct geologic evidence (shatter cones, shocked minerals and so on) has been found. Even if this feature is in fact part of the ring of an impact crater, it is much too old for the K–T event, because there is unimpacted Precambrian rock exposed on the Belcher Islands, within the circular arc. The other circular features Landis notes have not previously been pointed out, to my knowledge, and will bear investigation.

Solof suggests the great rayed lunar crater of Copernicus as a candidate site for the K–T impact. He does not give a source for his 70-Myr date; Stewart Ross Taylor gives radiometric ages of 900 Myr for Copernicus and 107 Myr for Tycho.[4] In addition to the age discrepancy, it seems unlikely that a lunar impact could be responsible for the K–T extinction, as we require *all* the ejecta from a 100–150-cm crater on the Earth, and the Earth would intercept only a small fraction of the ejecta from a lunar impact event. To me, the Moon is more interesting as a recorder of impact history, and when extended geological investigation on the Moon becomes possible, we should learn from a large sample of dated craters whether there have been comet showers within the inner Solar System.

Sanford Aranoff takes me to task for saying, "There was no way a genus could have evolved so as to be protected from an occurrence that happens suddenly once every 100 million years or so." I meant, of course, no way involving natural selection in the Darwinian sense, where the ingredients were tissue and bone. I have frequently said that humans could protect themselves by detecting the incoming bolide and deflecting it so that it would miss the Earth. I have further stated that I am sure we and the Soviets would cooperate immediately in mounting rocket flights to perform the appropriate deflection of the incoming bolide, despite treaties that prohibit the explosion of nuclear devices in space. The deflection would be accomplished by detonating a nuclear device on the rocket as it passed the incoming bolide. X rays from the device would sublime a layer of the bolide at high speed, and the resulting reaction would nudge the bolide from its original trajectory. The mechanics of such an operation have been studied by many scientists, in particular Bernard M. Oliver of the NASA Ames Laboratory and Tom Gehrels of the University of Arizona. So I am pleased to find myself in agreement with Aranoff on this point.

References

1. G. A. Izett, Geol. Soc. Am. Bull. **99**, 78 (1987).
2. L. W. Alvarez, *Alvarez—The Adventures of a Physicist*, Basic, New York (1987).
3. R. A. F. Grieve, Geol. Soc. Am. Special Paper **190**, 25 (1982).
4. S. R. Taylor, *Planetary Science: A Lunar Perspective*, Lunar and Planetary Institute, Houston (1982), table 2.3, p. 31.

LUIS W. ALVAREZ
12/87 *Berkeley, California*

Geomagnetism, Sea Level and Tectonics

Your report of the recent work by Donald Morris and Richard Muller on asteroid impacts as a cause of magnetic reversals (February 1987, page 17) confirms work that Richard Stothers and I have done on the general relationships among geologic phenomena and large-body impacts.[1] Terrestial impact craters, geomagnetic reversals and major drops in sea level (along with other indicators of geologic activity) all seem to show a periodicity of about 30 million years, suggesting a common cause in comet or asteroid impacts. As an explanation for quasiperiodic comet storms, we prefer the vertical oscillation of the Solar System about the plane of the Galaxy, which brings us through the interstellar clouds of the plane region every 30 million years. Close encounters with these massive clouds would provide the necessary disturbance of the Oort Cloud comets.[2]

Morris and Muller propose that rapid drops in sea level, caused by sharp impact-induced coolings and ice formation on land, trigger the reversals of the Earth's magnetic field. They have erred, however, in their graph comparing the records of geomagnetic reversals and sudden sea level drops, in which they correlated the generally low frequency of geomagnetic reversals around 100 million years ago with an apparent concurrent minimum in the detected