

NIGHT COMES TO THE CRETACEOUS

COMETS, CRATERS, CONTROVERSY, AND THE LAST
DAYS OF THE DINOSAURS

JAMES LAWRENCE POWELL

Copyright © 1998 by James Lawrence Powell

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopy, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Requests for permission to make copies of any part of the work should be mailed to: Permissions Department, Harcourt Brace & Company, 6277 Sea Harbor Drive, Orlando, Florida 32887-6777.

First published by W. H. Freeman and Company.

Library of Congress Cataloging-in-Publication Data
Powell, James Lawrence, 1936-

Night comes to the cretaceous: comets, craters, controversy, and the last days of the dinosaurs/James Lawrence Powell.—1st Harvest ed.

p. cm.

Originally published: New York: W. H. Freeman, © 1998.

Includes index.

ISBN 0-15-600703-7

1. Catastrophes (Geology) 2. Extinction (Biology) 3. Dinosaurs.

I. Title.

[QE506.P734 1999]

576.8'4—dc21 98-26503

Designed by Diana Blume

Printed in the United States of America

First Harvest edition 1999

F E D C B A

CHAPTER 4

THEORY ON TRIAL

It must be possible for an empirical scientific system to be refuted by experience.¹

Karl Popper

OF PREDICTION AND PROOF

By the early 1980s, the importance of impact in the solar system was established as a fact, as was the presence of high iridium concentrations in at least a few K-T boundary clay sites. That the Cretaceous had ended with a great mass extinction was also a fact, though the suddenness of that extinction was disputed. The Alvarezes invented a theory that tied these facts together. To explain the observational facts is merely the first obligation of a theory; often several do a good job of explaining at least some of the observations. The theories that prove to have lasting value go further: They predict new facts that have yet to be discovered. If these predicted facts are subsequently found, the theory gains strength. Curiously, however, a theory is never completely proven. The possibility always exists that some new evidence will come to light to discredit the theory, or that some clever scientist will come up with an alternative theory that explains more of the facts. Luis Alvarez never went so far as to claim that the meteorite impact theory had been proven, though he came perilously close. Typically he would assert only that the theory had met a large number of its predictions (and "postdictions," which are reasonable predictions that happened not to be thought of until later). Being human, however, he was not above, in Tennyson's phrase, "believing where we cannot prove."²

German philosopher Karl Popper has done more than anyone to advance the notion that scientific theories may be disproven, but never proven. He argued that for a theory to be called scientific, it

must be possible to disprove, or falsify, the theory.³ For a theory to qualify as part of science, it must be possible to devise tests that, if a theory is wrong, will reveal it as wrong. If no such tests can be devised, then the theory is not useful, at least for the time being. This is one reason why premature theories languish: No one can think of anything useful to do with them. Popper did allow that theories could be “corroborated”; that is, they could prove their mettle by standing up to a succession of severe tests. Corroborate is a good word—it means “to strengthen or support with other evidence; make more certain.” Corroboration falls short of proof, but shows that research is heading in the right direction.

Though philosophers and historians of science debate the utility of Popper’s formulation and are apt to go on doing so, it jibes with our common sense to say that science advances not by proving theories right but by weakening them until they are falsified. Looking back at the history of science, it is clear that this is the way it works. Yet if one were randomly to select a scientist at work and ask, “What are you doing?” one would be apt to get the answer: “I am confirming such and such a theory.” In their daily lives, most scientists try to confirm or extend theories, not to falsify them. In part this is because scientists are rewarded for breakthroughs, not for falsification. Rewards aside, however, human beings will not spend long hours and entire careers searching for falsity. Thus a contradiction exists between the way individual scientists behave and the way science as a whole evolves—as the cumulative result of the work of all scientists. A host of them, each trying to shore up their favorite theories, will in time lead to the falsification of the weakest, to the great disappointment of its proponents but to the advancement of science overall.

ALVAREZ PREDICTIONS

The Alvarez theory revolves around two key hypotheses: (1) 65 million years ago, a meteorite struck the earth, and (2) the aftereffects of the impact caused the K–T mass extinction. Since one can accept the first without accepting the second, they need to be kept separate (although the Alvarizes did not). In the rest of this chapter, I will examine the evidence for the first half of the theory. (The second half is covered in Chapters 8, 9, and 10.) Although Luis Alvarez himself identified 15 pre- and postdictions, not all are of equal importance. I will focus on six predictions that if confirmed would be especially corroborative and that can be identified largely

be false—certainly if all did—the Alvarez theory would have to be abandoned. On the other hand, if most or all are met, the theory would be strongly corroborated.

An explosion of research effort followed publication of the initial Alvarez paper as geologists around the world set to work, some seeking to confirm its predictions while others tried to refute them (in principle, intent does not matter as long as the rules are followed). Key events in the refinement of the theory were the conferences held at the Snowbird ski resort in Utah in 1981 and 1988, and in Houston in 1994.⁴ The conferences brought together the leading workers in the new field of impact studies and a variety of other specialists, proponents of the theory and opponents alike, and provided a forum for papers and for debate that went on into the wee hours. For tracing the evolution of the Alvarez theory, the reports from these conferences are indispensable.

Here are six of the most important predictions made by the Alvarez theory, followed in each case by the corresponding findings.

PREDICTION 1: Impact effects will be seen worldwide at the K–T boundary.

A global catastrophe would leave global evidence. Most if not all K–T boundary sites around the world will contain an iridium anomaly, though the concentration might be greater at sites closer to the ground zero of meteorite impact. At some locations, however, subsequent geologic processes might have removed iridium or even eroded the boundary layer entirely away, leaving a gap in the rock record. Thus although the absence of iridium from a few K–T boundary clay sites might not falsify the Alvarez theory, were iridium found nowhere other than in Italy and Denmark, the theory would be in trouble.

FINDINGS

By the time of the first Snowbird Conference in 1981, only a year after the original paper in *Science*, the number of sites with confirmed iridium anomalies had risen to 36. By the end of 1983, it had reached 50; by 1990 it had climbed to 95; today it is well over 100. Iridium concentrations in the boundary clays are the highest ever measured in terrestrial materials. Only a few K–T sections lack iridium.

One site was of critical importance, for it was the first in which the rocks studied had been deposited not in seawater but in fresh. Some had claimed that impact of a meteorite was not the only way to get iridium into a rock layer. Seawater contains trace amounts of

concentrate the iridium from a large reservoir of seawater into a particular rock layer. Iridium might be absorbed selectively on the surfaces of the clay minerals, for example. Or, perhaps the clay and iridium were once dispersed minutely throughout a thick, marine limestone bed that slowly dissolved away, leaving behind only the insoluble clay and iridium. These ideas might have applied to rocks deposited in the sea, but not to those laid down as sediments in freshwater, which contains even less iridium and where there is no opportunity to tap a vast reservoir. The discovery of a strong iridium anomaly in rocks from the Raton Basin in New Mexico and Colorado, rocks recognizable as having formed in freshwater, put the idea of seawater extraction to rest.⁵ (Luis Alvarez, with the advantage of hindsight, said that the occurrence of the iridium spike in freshwater rocks should have been one of his predictions.) At the exact level of the Raton iridium spike, several Cretaceous pollen species went extinct and ferns—which are opportunistic and move in after other species disappear—proliferated.

PREDICTION 2: Elsewhere in the geologic column, iridium and other markers of impact will be rare.

If high iridium concentrations come from meteorites, they will not be found in most other rocks. If the indicators of shock described in Chapter 3—shatter cones, shocked quartz, coesite, stishovite, and tektites—are produced only by impact, they too will be rare to nonexistent in other geological settings.

(This is an appropriate place to note that the K–T mass extinction was one of many times during which substantial numbers of species disappeared. Paleontologists have identified five, including the K–T, that were especially severe. If impact is responsible for any others of the “Big Five,” they too might show an iridium spike and impact markers. However, the presence or absence of indicators at those horizons would have no direct bearing on the Alvarez theory, which applies only to the K–T event. The possibility that impact might have caused more than one mass extinction is a related but separate theory that I will address later.)

FINDINGS

It is obviously impossible to search for iridium in every rock on the surface of the earth. Frank Kyte and John Wasson of UCLA did the next best thing by measuring iridium content in a long, continuous core of sediment pulled up from the deep seafloor in the Pacific.⁶ It captured the sedimentary record from about 35 million years ago all

the way back to the K–T boundary at 65 million years. They found iridium levels above background only at the K–T boundary. As far as we know, high iridium concentrations are exceedingly rare in terrestrial rocks.

PREDICTION 3: Iridium anomalies will be associated with proven meteorite impact craters.

The Alverezes started with an iridium spike and inferred an impact; it should be possible to move in the other direction as well. That is, it should be possible to find a crater whose origin by impact is undisputed, predict where the corresponding iridium-enriched ejecta will be located, and go find it. But since it is hard to detect terrestrial craters in the first place, and since erosion will have removed some ejecta layers, the absence of such a connection would not falsify the Alvarez theory.

FINDINGS

Two craters have been found to have associated iridium-rich ejecta layers. One is the 600-million-year-old crater at Acraman, South Australia, whose ejecta deposit contains not only iridium but other platinum group metals as well as gold.⁷ This ancient crater has been so deeply eroded that only a multiringed scar remains. Its ejecta, even though located more than 300 km away, can still be tied confidently back to the crater. The other is the 40-km diameter, 143-million-year-old Mjolnir crater, in the Barents Sea north of Scandinavia, which was detected through geophysical methods.⁸ A diligent search led by a group of Norwegian geologists found its ejecta layer, which contained both iridium and shocked quartz, in a core taken 30 km from the crater's center.

At first it may seem surprising that it is so difficult to connect iridium-rich ejecta layers to their parent craters. But remember how difficult it is to recognize terrestrial impact craters, and to find the thin ejecta layers, in the first place. Comparing it to the search for a needle in a haystack may be optimistic. In any case, the two examples prove the principle. As the science of crater detection improves, other ejecta layers will be tied back to their parent craters.

PREDICTION 4: The boundary clay layer will generally be thin and of worldwide distribution.

The immediate effects of a giant impact take place in minutes or hours; the secondary ones may last for hundreds or at most a few

thousand years. On a geologic time scale, even these are instantaneous. Thus the boundary layer will be thin everywhere except, perhaps, at sites closer to ground zero. The layer ought to be found globally, though erosion might on occasion have removed it. If a thin layer is found worldwide at the K–T boundary, it would be the first universal geologic marker—rock formations ordinarily are no more than regional.

FINDINGS

Around the world, the K–T boundary is marked by a thin clay layer, almost always with high iridium levels. (As we will see, in North America there are two boundary layers, with the thicker one on the bottom.) No other rock unit extends over even a single continent, much less over all of them and the seafloors in between. The very existence of this universal layer is evidence of a rare, perhaps unique, geologic event, and is as strongly corroborative a piece of evidence for the Alvarez theory as any.

PREDICTION 5: The K–T boundary clays will contain shock metamorphic effects.

Known markers of impact—shocked quartz grains; coesite or stishovite; glassy, tektitelike spherules—will be found in the boundary clays. The presence of these accepted indicators would provide much stronger corroboration to doubting geologists than the iridium spike, which prior to the Alvarez discovery was unrecognized as an impact marker.

FINDINGS

In 1981, geologist Bruce Bohor of the U.S. Geological Survey decided to look for shocked quartz at the K–T boundary and applied for a Survey fellowship (ironically named in honor of G. K. Gilbert). Turned down by the fellowship panel (which included a specialist in shocked quartz), Bohor reapplied, only to be rejected again. Showing admirable resolve, he went ahead on his own and shortly did locate shocked quartz at the K–T boundary in a 1 cm thick Montana claystone that also contained both a large iridium spike and a pollen extinction.⁹ Bohor's discovery was crucial in making believers out of many geologists. First of all, one of their own, rather than a know-it-all physicist, had made the discovery. Second, instead of being based on an invisible element, shocked quartz was a tried-and-true indicator that geologists had discovered

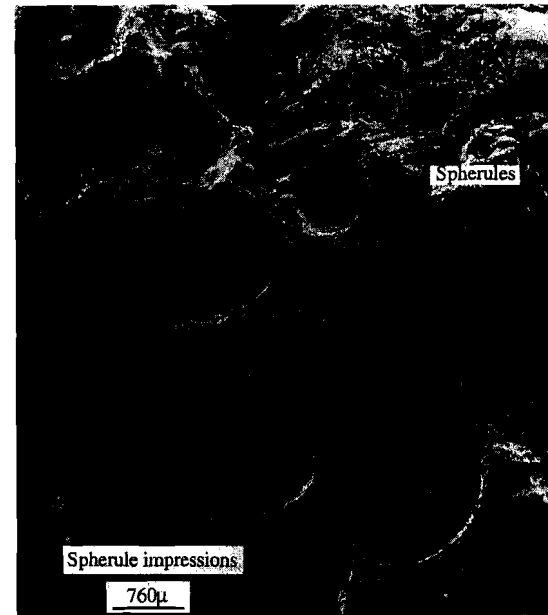


FIGURE 9 Imprints left by K–T spherules where they fell in soft clay. From a drill core that penetrated the K–T boundary underneath New Jersey. [Photo courtesy of Richard Olsson, Rutgers University.¹⁰]

themselves—it was “invented here,” and could be seen with a microscope. Bohor and others went on to find shocked quartz at many other K–T boundary sites around the world. Stishovite, which provides evidence of extreme pressures, has been found at several.

Many K–T sites have yielded millimeter-sized spherules that look for all the world like microtektites externally but that internally are composed not of glass but of various crystallized minerals. Some show beautiful flowlines on their surfaces. They have been studied extensively and have a mineralogy unlike anything geologists have seen before. The pro-impactors interpret them as droplets melted by the shock of impact and blasted into the earth's atmosphere, where they solidified and fell to earth (Figure 9), subsequently recrystallizing into the minerals that we now find.

PREDICTION 6: A huge impact crater formed 65 million years ago. If it has not disappeared, it may yet be found.

If the Alvarez theory is correct, there once existed, and we can hope there still does exist, a huge crater exactly 65 million years old. Failure to find it would not falsify the theory, however, because the crater could easily have escaped detection. The meteorite might have hit somewhere in the two-thirds of the earth's surface that is

now covered with water, leaving the crater hidden under younger sediments. It might have landed in the 20 percent of the seafloor that has subducted (carried down beneath an overriding tectonic plate) since K-T time. The crater might be buried under the polar ice caps. It might have struck on land but now be so eroded as to be undetectable, or it might be buried there beneath younger rocks. It might have triggered a volcanic eruption and now be covered with lava. Finding the crater thus would require more than good science—it would require good luck.

FINDINGS

Locating the K-T impact crater obviously would provide the most corroborative evidence of all, but prior to 1990, no crater of the right age and size had been discovered. Indeed, the only candidate much discussed was the buried structure at Manson, Iowa, but it seemed too small to create a worldwide catastrophe and, some critics said, was a cryptoexplosion structure formed by underground gas explosions, as Gilbert and Bucher had claimed for Meteor Crater. (Chapter 7 is devoted to the search for the K-T impact crater.)

The six predictions just reviewed are specific to the Alvarez theory, but there is a seventh prediction that can safely be made whenever a theory with far-reaching implications is explored.

PREDICTION 7: Unanticipated discoveries will be made.

As theories are explored, unexpected discoveries almost always turn up. Sometimes these surprising findings turn out to strengthen a theory; sometimes they provide critical evidence that helps to falsify it. With the advantage of 20-20 hindsight, one can often see that a particular discovery could have been anticipated and stated as a prediction.

FINDINGS

Prior to the Alvarez discovery, little was known about the clay layer, but now a host of techniques were applied to it. Three scientists from the University of Chicago made one of the most astonishing finds.¹¹ Searching the Danish K-T clay for a possible meteoritic noble gas component, they found large amounts of soot, which was missing in the other late Cretaceous rocks and marine sediments that they analyzed for comparison. If the clay layer had been deposited suddenly, for which there is much independent evidence,

then such a large amount of soot could only have come from global wildfires in which possibly as much as 90 percent of the total mass of living matter on the earth burned. Supporters of the impact theory naturally found the presence of the soot highly corroborative. Opponents pointed out, however, that the conclusion depends on the assumption that the clay layer was deposited rapidly; if it were not, the levels of soot would not be extraordinary.

Soot was not the only unexpected substance. Amino acids, the building blocks of proteins, and ultimately of life, are ubiquitous on the earth but also occur in a class of meteorites called the carbonaceous chondrites. Canadian scientists reported that the boundary clay contains 18 amino acids not otherwise found on the earth.¹²

Osmium is a platinum metal almost as rare in crustal rocks as iridium. Karl Turekian, a geochemist at Yale, noted that the ratio of two isotopes of osmium, Os 187 and Os 186, in meteorites is approximately 1:1, but in rocks of the earth's crust it is higher than 10:1. Although chemical and geological processes concentrate some chemical elements and deplete others, the ratios of the isotopes of heavy elements such as osmium tend to remain constant. This resistance to alteration is best illustrated by the enormous effort required in the Manhattan Project to separate fissile U 235 from U 238, which is 100 times as abundant naturally. Even the heat and shock of meteorite impact would not change the ratio of isotopes as heavy as those of osmium, and therefore they can be used as a tracer and proxy to reveal the origin of the iridium in the K-T layer. If the Os 187:Os 186 ratio in the boundary clay turned out to be close to the meteorite ratio of 1:1, then the osmium would likely be extraterrestrial, as would the iridium, an almost identical element. If the osmium isotopic ratio were much higher, then both the osmium and the iridium would likely be of crustal origin, weakening the Alvarez theory. According to David Raup, at Snowbird I, Turekian "made it abundantly clear that he expected to find ordinary crustal isotope ratios and that his study would show that the impact theory was neither necessary nor credible."¹³ A year and a half later, Turekian and a colleague reported that the osmium isotope ratios in the boundary clay were closer to meteoritic than to terrestrial levels.¹⁴ The osmium test was less definitive than had been hoped, however, because an osmium ratio of approximately 1:1 turned out to mark not only meteorites but volcanic rocks from the earth's mantle. Thus a low osmium isotope ratio could indicate a mantle source as well as an extraterrestrial one. A recent study of samples from across the last 80 million years of earth history, however, turned up a low osmium

isotopic ratio only at the K–T boundary, again strengthening the possibility that the osmium and iridium came from space.¹⁵

Spinel is a rare mineral that sometimes forms a variety of ruby. Many of the K–T clays contained a nickel-rich variety of spinel previously found only in material worn off of meteorites. Furthermore, the highest spinel abundances occurred at exactly the same place in K–T sections as the iridium spike—at some locations each gram of boundary rock contained more than 10,000 spinel spherules.

Until recently, diamonds occurred in nature only in rocks believed to have originally formed deep within the earth (where heat and pressure are high), and that subsequently were elevated to the surface. Within the last few decades they have been produced in explosion experiments and found in meteorites, where the diamonds are so tiny as to be barely detectable. The hope that diamonds would also show up at terrestrial impact sites led Canadian scientists David Carlisle and Dennis Braman to search the K–T boundary clay in Alberta, where they immediately found them.¹⁶

Now the story gets even more interesting.¹⁷ As the Soviet Union began to collapse, reports started to emerge that scientists there had not only found diamonds at several of their impact sites, but in numbers reaching into the millions. The most thoroughly tested crater was the 35-million-year-old, 100-km-wide Popigai Crater in Northern Siberia, which the Soviets probed with over 500 boreholes. Most of the diamonds there were tiny, but some were as large as peas. (Although none are of gemstone quality, they may prove useful for industrial purposes.) A British team searched the Ries Crater and soon found diamonds by the billions in the melt rock, which had been the source of the stone for the town hall and the church in Nordlingen, the medieval German town located within the crater. The citizens of that town, unbeknownst to them, had been surrounded all their lives by innumerable diamonds formed 15 million years ago by a giant impact. The Ries diamonds occur in association with silicon carbide, like diamond a rare and hard mineral. From this association and various other chemical indicators, the British scientists concluded that the diamonds and silicon carbide had not formed directly as a result of shock but rather had crystallized in midair from the white-hot impact fireball. If they are correct, then diamonds should be found at other impact craters and provide an excellent marker of impact. The search was immediately extended, and by mid-1996 diamonds had been found in each of the eight impact sites studied. No diamonds occur in rocks immediately above and below the K–T boundary—only right in it. The find-

ing of billions of diamonds at impact sites and K–T locations must rank as the most surprising and important of the unexpected discoveries triggered by the Alvarez theory.

THE FIRST HURDLE

How well, then, has the Alvarez theory done in meeting its first hurdle: being tested against the six predictions? It can be summed up as follows:

1. The K–T iridium anomaly is found worldwide.
2. With a few exceptions, the iridium enrichment is not found at other geological horizons.
3. Impact does produce distant ejecta deposits enriched in iridium.
4. Almost everywhere the K–T boundary itself can be located around the earth, the boundary clay layer is present. Except for a few sites the layer is thin.
5. Accepted indicators of impact—quartz with planar deformation features, coesite and stishovite, and spherules that resemble microtektites—are present at many K–T locations.
6. The impact crater may have been found (see Chapter 7).

In addition, the seventh prediction, of unexpected discoveries, has not only been met, the surprising findings of soot, amino acids, meteoritic osmium isotopes, spinel, and finally diamonds, some of which are difficult or impossible to explain by terrestrial causes, help to corroborate the theory.

A neutral observer examining this evidence would have to conclude that the Alverezes had a strong initial case for the impact half of their theory. But when a theory has potentially revolutionary consequences, few observers are neutral. Opponents of the theory immediately began to attack in earnest, arguing that either the tests were not valid, or, if they were, had failed. In this view, the iridium anomaly is not restricted to the K–T horizon; indeed, opponents claimed, iridium is not a true marker of impact at all. The boundary clay shows no sign of a meteoritic component; besides, shocked quartz and spherules are not diagnostic indicators of impact. The critics claimed repeatedly to have falsified the theory or to have found an alternative that fulfilled the predictions at least as well and that was

consistent with uniformitarian doctrine to boot. The Alvarez team rebutted, the critics countered, and thereby was produced one of the most bitter scientific rivalries since the great controversy between dinosaur hunters Edward Drinker Cope and Othniel Marsh, who in the late nineteenth century quarreled openly for two decades about their interpretation of the dinosaur evidence, with one even accusing the other of stealing his fossils.

CHAPTER 5

COUNTERATTACK

If you start to take Vienna—take Vienna.¹
Napoleon Bonaparte

The first to offer a detailed attack on the Alvarez theory were not paleontologists, as might have been expected since they were apparently the most offended, but a geophysicist from Dartmouth College, Charles Officer (Figure 10), and his colleague, geologist Charles Drake. Officer had had a distinguished career as a seismologist in industry; Drake was one of the most respected American geologists, having been president of the American Geophysical Union from 1984 to 1986, at the height of the controversy, and also president of the Geological Society of America. They began their rebuttal with two papers in *Science*,² which together comprised a three-part plan of attack:

1. Falsify the impact theory by showing (a) that the K-T event took place at different times around the world (and therefore could not have been the result of an instantaneous global catastrophe), and (b) that the transition from Cretaceous to Tertiary fossil species was too gradual to be consistent with an instantaneous extinction. (I will call these arguments 1a and 1b, respectively.)
2. Show that the evidence of iridium anomalies, shocked minerals, and spherules was far from diagnostic of impact and often was not even consistent with it (argument 2).
3. Substitute for impact another process that explains the evidence at least as well and that does not rely on a nonuniformitarian *deus ex machina* (argument 3).