Salk colleague Paolo Sassone-Corsi have evidence indicating that cells' contain factors that repress transcription of the gene in addition to factors, such as the SRE-binding protein, that increase transcription.

Previous work in Verma's laboratory showed that conversion of the normal cellular *fos* gene to a transforming gene requires the loss of a noncoding sequence located after the termination site. This apparently increases the stability of the messenger RNA transcribed from the gene, thereby permitting more prolonged production of the *fos* protein.

Cell biologists currently know very little about how signals are transmitted from the cell membrane to the genes in the nucleus. Dissecting *fos* gene regulation may help in this regard by enabling researchers to track backward from the nucleus.

Identifying the *fos* regulatory sites and the proteins that bind there is one step toward accomplishing this goal. Indications are, for example, that the SRE-binding protein is already in place when appropriate stimuli are received, and that the protein undergoes some modification that brings about an increase in gene transcription, which is the first step in protein synthesis.

According to the current educated guess, the modification is the addition (or removal) of phosphate groups. The next step in tracing signal transmission back to the cell membrane would therefore be identifying the enzyme that adds the phosphates or accomplishes whatever alteration of the SRE-binding proteins does bring about increased *fos* transcription.

Clearly, a great deal still remains to be learned about *fos*. Control of the gene is turning out to be very complicated. Nevertheless, researchers now have toeholds that may enable them to learn both how *fos* is regulated and what the cellular consequences of its activity are. The central role of the gene in cells' responses to stimuli guarantee it the attention of the research community. ■ JEAN L. MARX

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Searching Land and Sea for the Dinosaur Killer

The impact that triggered a mass extinction and possibly the death of the dinosaurs left clues to its location

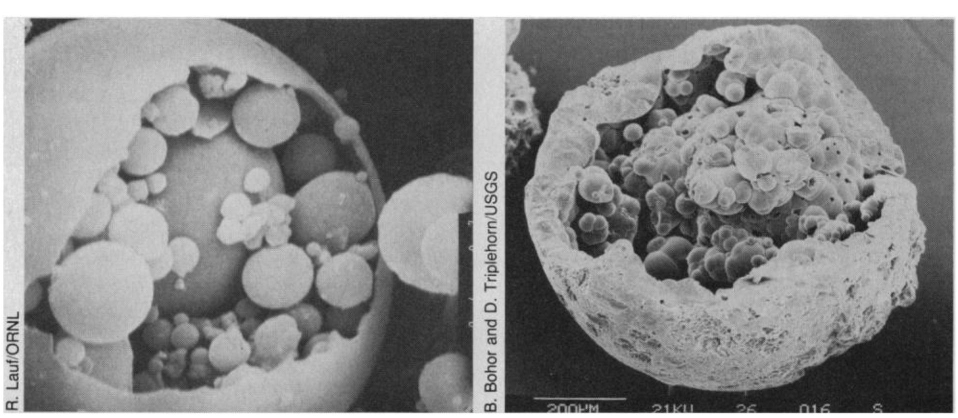
SOMETHING 100 kilometers or more in diameter would not seem that difficult to find, but the scar left by the asteroid or comet that hit Earth 65 million years ago and triggered a mass extinction is proving elusive. The impact did leave subtle clues as to its location that are being extracted from the dust and debris scattered around the globe. So far, opinion tends to favor an impact that threw up both continental and oceanic debris, suggesting that the impactor hit ocean crust loaded with sediments washed from a nearby continent. The continent may have been North America. Alternatively, an impact might have nearly dug through a continent into ocean-like rock, or two or more simultaneous impacts could have created the mixed debris.

An early potential clue to the whereabouts of the crater involved the layer of iridium that first led researchers to conclude that there had been an impact. Rare on the surface of Earth, the iridium carried by the impactor formed a distinctive layer at the boundary between the Cretaceous and Tertiary periods (called the K-T boundary). But a map of the amount of iridium in the boundary layer, rearranged to account for 65 million years of continental drift, showed no pattern that might point to the crater.

If chemistry could not pin down the crater, geochemists reasoned, perhaps isotopes could at least narrow the search. Donald DePaolo and Frank Kyte of the University of California at Los Angeles and their colleagues determined the strontium and neodymium isotopic compositions of the K-T boundary layer at Caravaca, Spain. They concluded that debris from at least 3 kilometers down in the ocean crust dominated the boundary material.

Narrowing the search to the ocean would certainly help, but there was a potential downside. Since 65 million years ago, ocean crust equal to 20% of the surface area of Earth has sunk into the mantle at deep-sea trenches. That subduction has wiped out the crust of the eastern, northern, and western Pacific and much of the Indian Ocean that existed then. If the impact hit any of these parts of the ocean, the crater is gone forever.

In 1984 the discovery in the boundary layer of quartz grains damaged by the shock of an impact seemed to point to a continental, not an oceanic, impact. Bruce Bohor and his colleagues at the U.S. Geological Survey (USGS) in Denver first found K-T shocked quartz in Montana and have now found it in the North Pacific, Europe, and New Zealand (*Science*, 8 May 1987, p. 666). Quartz is abundant in continental rock but scarce in ocean crust. In addition, the largest grains



The old and the new ash? *The fly ash on the left came from a modern coal-burning power plant. The object on the right is 65 million years old and was found in association with the debris of the large impact that caused a mass extinction. The spherules may have formed as hot mantle rock exposed by the impact exploded into fine dust. The diameters of the enclosing spherules are about 35 micrometers (left) and 800 micrometers (right).*

from western North America are several times larger than the largest from anywhere else in the world. This led Bohor and Glen Izett of the USGS in Denver to suggest that the impact was on a continent and that the continent was probably western North America. A likely although undersized candidate was Manson crater, a 32-kilometer feature in Iowa buried by sediments since its formation 61 ± 9 million years ago.

New chemical analyses offer support for a resolution of the continent-ocean conflict created by the mineralogical and isotopic analyses. More so than for other groups of elements, the relative abundances of the dozen or so rare earth elements produce patterns that reflect the origin of the rock being analyzed. Alan Hildebrand and William Boynton of the University of Arizona determined the rare earth composition of the nonimpactor portion of the boundary at a site in Colorado and one in Alberta. They found rare earth abundances that bear much the same relation to one another as those found in continental sediments, but the absolute abundances are about one-tenth of those found in continental rock. "This extraordinary rare earth element pattern is not exhibited by any common terrestrial rock," they note.

Hildebrand and Boynton suggest that the best match to the observed rare earth pattern is a mixture of the material that would be excavated by a near-miss of a continent—thick continental sediments from which the observed shocked minerals could form, ocean crust, and uppermost ocean mantle from at least as deep as 40 kilometers. There is no sign in the analyses of the clays that dominate ocean sediments far from the continents. Hildebrand and Boynton tentatively assume that the impact was in the eastern Pacific. If that is true, the search would be over. That part of the ocean crust has since sunk beneath North America.

Although the rare earth results reinforce a trend of opinion toward a near-continent impact, there may be alternative means of generating the two types of material found at the boundary. One means is through multiple impacts, at least one being on a continent and one in the ocean.

The most ambitious multiple impact hypothesis comes from Virgil Sharpton and Kevin Burke of the Lunar and Planetary Laboratory in Houston. They were struck by the existence of five craters whose best determined ages allow them to be 65 million years old. (The ages range from 57 to 65 million years with errors of 9 million years.) More striking perhaps is the inclusion in the five of two sets of twin craters: Kara and Ust-Kara in the Soviet Arctic and Gusev and Kamensk near the northern shore of the Black Sea. It is generally agreed that the craters of each pair formed simultaneously only a few tens of kilometers apart.

When Sharpton and Burke plotted the locations of the two pairs with that of the fifth crater, which is Manson in Iowa, they all fell within 12 degrees of a great circle arc across the Arctic. On the assumption that a single group of objects splattered across the globe to form all five craters, these researchers suggest that the required ocean crater or craters might be found on the floor of the Arctic Ocean.

If the impact was in the eastern Pacific, the search would be over. That part of the ocean crust has since sunk beneath North America.

Five simultaneous, widely dispersed impacts would certainly be consistent with the increasingly popular idea that the K-T event was exceptional if not unique in the past half billion years, but their dispersion also creates what Burke terms "substantial problems with the dynamics" of multiple cratering. Dynamicists have always found it difficult to explain the separation of twin craters without resorting to hypothesized but still unconfirmed asteroids with satellites. To explain a string of craters around one quarter of the globe, Burke and Sharpton suggest the breakup of a large comet nucleus as it rounds the sun, a commonly observed event.

Another alternative to a single near-continent site, according to Bohor, is a single continental impact that almost bores through the continental crust. He cites the computer simulation of a large ocean impact by David Roddy of the USGS in Flagstaff and his colleagues. In this simulation, the crater temporarily reaches a depth of 40 kilometers, instantly depressuring crustal and mantle rock that is as hot as 500°C. That "would expose about 15,000 square kilometers of the inner-crater floor," according to the modelers, which "could be expected to degas violently, adding ash to the atmosphere that may exceed all other cratering contributions."

Bohor and Don Triplehorn of the USGS in Denver believe that they recognize that ash at K-T sites in the western interior of North America. At these once marshy lowland sites, the boundary includes an upper layer only 2 to 3 millimeters thick containing shocked minerals and iridium and a lower layer 20 to 30 millimeters thick containing no shocked minerals, little iridium, but numerous hollow spherules. These resemble fly ash spherules produced by the burning of coal in power plants.

Bohor and Triplehorn suggest that the upper layer is continental impact ejecta that fell from great altitudes after a volcanic-like cloud containing the spherules emerged from the crater and spread through the lower atmosphere. Because that cloud would have sampled the lower crust and upper mantle, they reason, the bulk of the boundary material would have not an average continental crustal composition but one resembling a mixture of continental sediment, oceanic crust, and mantle. Hildebrand counters that the rare earth and isotopic data as well as the relative scarcity of shocked quartz limit the continental contribution to about 15%. That seems unlikely in the case of a continental impact, he says.

The possible clues to the whereabouts of the K-T crater are hardly all in yet. Chemical, isotopic, and mineralogical analyses of the two-layer sites are still in progress. Maps of the mass of shocked quartz around the globe have yet to be drawn. And no one has even reported searching for two-layer sites outside North America.

Researchers in pursuit of the K-T impact site might find encouragement in the search for another crater, the 35-million-year-old crater from which debris was scattered across the southeastern edge of North America. Billy Glass of the University of Delaware reports that he has found a unique example of that impact's debris layer off New Jersey. It is one of only two sites where microtektites—globules of glass associated elsewhere with known craters—are found with tektite fragments. It is the only site with shocked minerals as well as tektites, and the tektites make up the bulk of the debris grains, making them orders of magnitude more abundant than elsewhere. All this points to a nearby crater, Glass says, perhaps the one recently identified southeast of Nova Scotia. With an ocean crater and its debris blanket in hand, researchers might know better how to look for clues that have not been swallowed by subduction. ■

RICHARD A. KERR

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