which will in this way search for optimal machine-language translations of computer programs beyond the usual optimization procedures of conventional compilers.

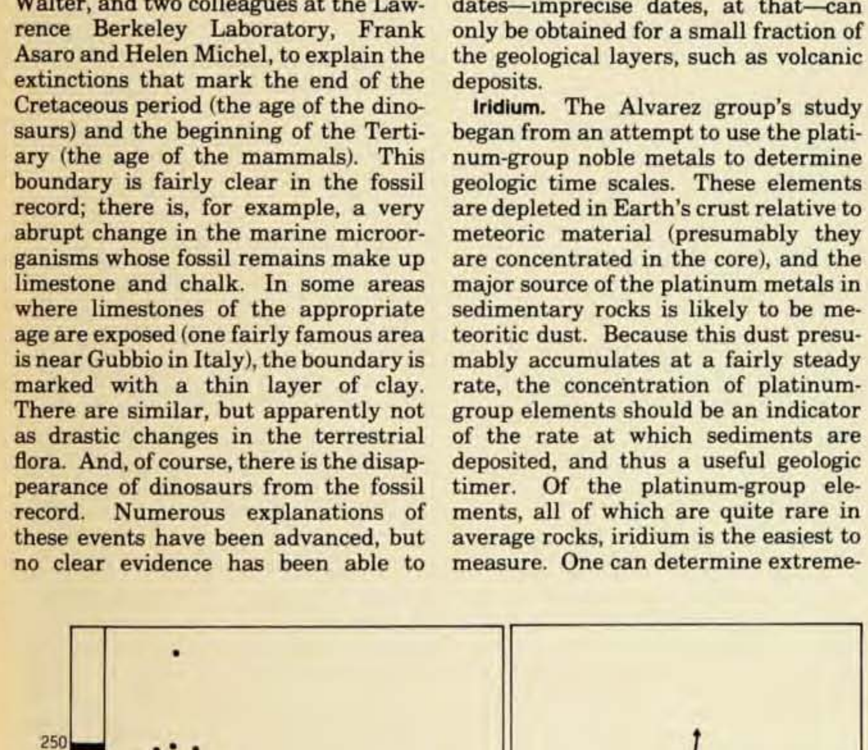
The IBM group describes optimization by simulated annealing as "an example of an evolutionary process modeled accurately by purely stochastic means." One might regard it as a plausible model of natural selection, they suggest. "As such," they tell us, "it provides an intriguing instance of artificial intelligence, in which the computer has arrived almost uninstructed at a solution which might have been thought to require the intervention of human intelligence." —BMS

Dinosaur extinction due to asteroid?

Recent developments appear to confirm what at first seemed an outrageous idea: A meteorite or asteroid a few kilometers in diameter hit Earth about 65 million years ago and caused a major wave of biological extinctions.

The hypothesis was suggested[1] two years ago by Luis Alvarez, his son Walter, and two colleagues at the Lawrence Berkeley Laboratory, Frank Asaro and Helen Michel, to explain the extinctions that mark the end of the Cretaceous period (the age of the dinosaurs) and the beginning of the Tertiary (the age of the mammals). This boundary is fairly clear in the fossil record; there is, for example, a very abrupt change in the marine microorganisms whose fossil remains make up limestone and chalk. In some areas where limestones of the appropriate age are exposed (one fairly famous area is near Gubbio in Italy), the boundary is marked with a thin layer of clay. There are similar, but apparently not as drastic changes in the terrestrial flora. And, of course, there is the disappearance of dinosaurs from the fossil record. Numerous explanations of these events have been advanced, but no clear evidence has been able to distinguish among them. It is not even clear whether the extinctions were simultaneous or separate, catastrophic or gradual. Layers of sediment allow one only to give relative times of events within a single sequence; correlations among different kinds of deposits are generally difficult, and absolute dates—imprecise dates, at that—can only be obtained for a small fraction of the geological layers, such as volcanic deposits.

Iridium. The Alvarez group's study began from an attempt to use the platinum-group noble metals to determine geologic time scales. These elements are depleted in Earth's crust relative to meteoric material (presumably they are concentrated in the core), and the major source of the platinum metals in sedimentary rocks is likely to be meteoritic dust. Because this dust presumably accumulates at a fairly steady rate, the concentration of platinum-group elements should be an indicator of the rate at which sediments are deposited, and thus a useful geologic timer. Of the platinum-group elements, all of which are quite rare in average rocks, iridium is the easiest to measure. One can determine extremely low concentrations by neutron-activation analysis: Iridium has a large neutron-capture cross section and gives off some easily detected characteristic gamma rays.



Iridium abundance and pollen count as a function of depth near the Cretaceous–Tertiary boundary. The black bars in the column at left indicate coal layers in a core from the Raton basin; the graph at right shows the ratio of angiosperm pollens to fern spores. (From reference 3.)

When the Alvarez group measured iridium concentrations in the clay layer that marks the Cretaceous–Tertiary boundary, they found anomalously high values: The bottom few millimeters of clay have iridium concentrations some thirty times the background value in the limestones above and below the clay. Other clay layers in the Gubbio formation show only the ubiquitous concentration of roughly 0.3 parts per billion.

Of the readily determined elements, only iridium shows such an anomaly. Other elements show more or less uniform concentrations through the clay layer that marks the boundary.

To check whether the iridium anomaly is a local phenomenon, the Alvarez group measured elemental concentrations from a clay layer that marks the Cretaceous–Tertiary boundary in a Danish limestone. Again they found iridium to be enhanced—this time by factors larger than 100. The clay layer here also differs from the surrounding limestone in other elements. Interestingly, the deviations are roughly what one would expect of extraterrestrial material. Terrestrial iridium-bearing ores show a rather different elemental composition.

Subsequent investigations confirmed the enhancement of platinum-group metals in Cretaceous-Tertiary boundary sediments.[2] Thus far, the iridium anomaly has been found in at least 15 marine sediments from sites in Italy, Denmark, Spain, the South Atlantic, New Zealand, the North Pacific and Texas. In each case the anomaly is associated with the Cretaceous–Tertiary boundary.

That some bizarre mechanism at work in the oceans served to concentrate noble metals to near-meteorite concentrations appears to be ruled out by the recent discovery that nonmarine sediments also show the anomaly. Charles J. Orth, James S. Gilmore and Jere D. Knight (all at Los Alamos) and Charles L. Pillmore, Robert H. Tschudy and James E. Fassett (US Geological Survey) last December reported[3] a thousand-fold iridium enrichment in sediments deposited in fresh water. The sediments, from the Raton basin in Northeastern New Mexico, consist of layers of shale, mudstone, siltstone, coal and sandstone, apparently deposited from a swamp. The iridium anomaly here is very sharp; it is associated with a layer of coal about 10 cm thick. It coincides with an abrupt drop in the ratio of pollen grains to fern spores and the extinction of several kinds of pollen: The flora essentially shifts from

Cretaceous species to Tertiary species. The boundary-layer coal also exhibits the same behavior with respect to other elements that the marine sediments show.

The Los Alamos–USGS group has now analyzed samples from other sections of the Raton basin. They find the same sharp iridium layer associated with pollen extinctions in the corresponding places. Samples from other geological layers show no enhancement. Such iridium-enhanced layers are apparently at least as rare on land as in the oceans. (They are, however, not unique to the boundary layer; other sedimentary layers with anomalous iridium concentrations, and associated with meteoritic debris, have been found. One example[4] is a sedimentary layer 2.3 million years old from the North Atlantic; no major extinctions are associated with this layer.)

Asteroids. Apparently a thin layer of sediment enriched in platinum-group elements covered the entire Earth about 65 million years ago. It now is clear, Alvarez told us, that there is a single event responsible for the layer, and the most plausible explanation is the impact of a small asteroid or large meteorite. Many earlier investigators had suggested a nearby supernova explosion as an explanation for the Cretaceous extinction. If debris from such an explosion is included in the iridium layers, one would expect to find plutonium, which is also produced by supernovas. Neither the Alvarez group nor Orth and his collaborators, however, found plutonium in the samples they have investigated.

Asteroids and meteorites of all sizes cross Earth's orbit all the time, and one expects large objects to hit the Earth occasionally. To deposit meteoritic material (mixed with terrestrial matter) all over the Earth in a layer about a centimeter thick, the impacting object would have to be on the order of ten kilometers in diameter. Such objects are estimated to hit Earth on the average of every 100 million years or so, and it is therefore no surprise to have evidence of an impact 65 million years ago.

Thomas Ahrens and John D. O'Keefe of Caltech have been calculating the physical effects such an impact would have. The kinetic energy of the meteorite or asteroid is turned mostly to heat at the impact; about twice the mass of the meteorite vaporizes, twenty times its mass of material melts, and much larger amounts of rock are pulverized and displaced. Much of this material is ejected with considerable force from the impact site, and a total mass of some 10–100 times the original mass of the meteorite (including most of the extraterrestrial material) can be carried up as far as the stratosphere. There it disperses in a matter of months and then slowly precipitates to the surface.

In the case of an impact on the ocean the effects would be similar, but a large cloud of steam would be projected into the stratosphere as well. Because the stratosphere is normally very dry, a great increase in water vapor at those altitudes may well have an effect on the energy balance of Earth, Ahrens told us, enhancing the terrestrial "greenhouse" for several decades. Shock waves in the atmosphere can produce nitrous oxide, which in turn may lead to a depletion of the ozone layer and an increased level of uv radiation at the surface.

Both land and sea impacts would have other effects as well. An impact on land should leave a crater on the order of a hundred km across; the impact itself should produce an earthquake of magnitude 11 or 12. (The Alaska earthquake of 1964 had a magnitude of 8.4.) Neither the crater nor evidence of the earthquake, such as mudflows or turbidity-current deposits in the ocean, have been found in the geologic record of the Cretaceous–Tertiary boundary. An impact on the ocean should produce a 5-km tidal wave; no clear evidence for this has been found either. Based on the available evidence, however, a land impact is the more probable of the two, Ahrens said.

Extinctions. The notion that has captured the popular imagination, of course, is the effect of the impact on the biosphere: Did it cause the extinction of the dinosaurs? The evidence is not yet clear.

Marine fossils show a sharp discontinuity at the Cretaceous–Tertiary boundary; a large number of species become extinct at the same time. David M. Raup (Field Museum of Natural History) and J. John Sepkoski Jr (University of Chicago) have recently performed[5] a comprehensive statistical analysis of marine animal families, examining 3300 families, 2400 of which are now extinct. In a plot of extinction rates as a function of time there are four mass extinctions with rates significantly larger than the mean ($P<0.01$). The most recent of these is at the end of the Cretaceous: Some 11% of marine families disappeared essentially simultaneously. Walter Alvarez, who has studied the marine sequences, told us that the plankton extinction corresponds precisely with the iridium layer—to within 1 mm, for example, in the case of the Spanish sedimentary section.

Terrestrial flora are not yet as well documented as the marine species, and the evidence is therefore less clear. There is, apparently, a change in flora that is associated with the iridium layer. However, it is not clear that that change is all there is to the Cretaceous–Tertiary boundary. Leo Hickey, a paleobotanist at the Smithsonian Institution, told us that the fossil record indicates a gradual change at the end of the Cretaceous rather than a catastrophic one. Pollen species disappear one by one at various levels of sediment below the top of the Cretaceous layers, up to several meters from the top,[6] Hickey said, while other species are continuous through the boundary. On the other hand, Alvarez pointed out, in the Raton basin the disappearance of Cretaceous pollen species is simultaneous and abrupt, as the Los Alamos–USGS data show.

The case of animals is even more difficult. Their fossilized remains give us only a very sketchy and incomplete record of their evolution. In only a very few places are animal fossils found in a region where one can also observe both the plant and geological stratigraphy. One of these regions is a fairly large area in Western North America, which, at the end of the Cretaceous,

Boundary layer between Cretaceous and Tertiary sediments in a formation near Gubbio in Italy. The clay layer with the iridium anomaly is marked by the 500-Lire coin. (Photo courtesy of LBL.)

was the western and northern boundary of a receding shallow sea that covered much of the US. In general, the latest dinosaur bones lie several meters below the strata that show the change in flora. The northernmost deposits have the largest separations: up to 8 m in Alberta compared to a meter or two in Colorado and Wyoming. Assuming average sedimentation rates, Hickey concludes[6] that these represent times on the order of 10 to 100 thousand years. Mammals became dominant some time during that interval between the last dinosaurs and the change in flora.

The Alvarez group has analyzed rocks from one of the Montana sites and found the iridium anomaly there. The last dinosaur fossils found in this area come from layers about $3\frac{1}{2}$ meters below the iridium layer; between the last dinosaur and the iridium layer one finds fossil mammals and pollens from Tertiary species. The shift from Cretaceous to Tertiary pollens is about a meter below the Ir anomaly. This sequence suggests, Clemens said, that Tertiary mammals and plants became established some time after dinosaurs became extinct at this site; the asteroid hit Earth at a still later time.

The statistical significance of the $3\frac{1}{2}$-m distance between the last dinosaur bones and the iridium layer is disputable, Alvarez told us. He pointed out that dinosaur bones that are clearly associated with geologic strata (and not just accidentally moved there by weathering or some other process) are quite sparse, and a vertical gap of more than $3\frac{1}{2}$ m between fossils is not unexpected on purely statistical grounds. Given the continuous existence of dinosaurs for 150 million years up to that point, as well as the relative infrequency of preserved skeletons, the 30 000-year gap is insignificant, Alvarez told us.

Effects. A large cloud of dust or steam thrown into the stratosphere should have sizeable effects, cooling and darkening Earth by reflecting and absorbing incident sunlight. Depending on how great these physical effects are and on how long they last, one can expect either mild or catastrophic effects on the biosphere. The impact of a 10-km asteroid would release an energy of 10^{14} tons of TNT equivalent.

In the Alvarez group's original scenario, Earth was appreciably darkened for several years. The resulting drastic decrease in photosynthesis led to a collapse of marine and terrestrial food chains, thus leading to a massive wave of extinctions—including the dinosaurs. Small animals and plants able to survive long periods of deprivation would have survived, to become the founders of Tertiary species.

Later calculations, based on more complete data, have shortened the darkening by a factor of ten. This would have produced problems for the worldwide dispersal of the meteoritic material via the stratosphere, Alvarez told us, but computer modeling by Eric Jones at Los Alamos shows that the impact itself can send material around the world in ballistic orbits. Several months of darkening and worldwide meteoritic fallout would still have had disastrous consequences on the biosphere.

Both Hickey and William Clemens, a paleontologist at Berkeley, believe that the fossil record cannot support such a catastrophic event. It is much more likely, Hickey told us, that a gradual change in the general global climate together with a gradual withdrawal of the shallow sea covering North America produced a gradual (on the order of 10^5 years) change in flora and fauna. Near the end of this period an additional sudden change in marine and some terrestrial flora is associated with the iridium layer.

This sequence of events, although plausible, has not yet been confirmed in enough different regions, and has enough difficulties with the data in hand, that it cannot be considered as more than a potentially useful working hypothesis, Clemens told us. In other parts of the world, outside the Eastern Rocky Mountains, the late Cretaceous is not nearly as well preserved, not nearly as rich in fossils, and therefore much more difficult to interpret.

The Alvarez group is now meeting weekly with Clemens and other paleontologists to focus on the research problems and to develop programs for field investigation this summer. Ideally, Clemens said, one would like to have data from the Cretaceous–Tertiary boundary along a line running from Texas to Alberta, looking for fossils, pollens and the iridium layer at many different latitudes. Money, of course, is a problem, and it will probably be quite some time before enough data are in hand to clarify all the questions raised by the iridium anomaly. —TVF

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Theory institute thrives in its third year

Gazing out his office window recently, J. Robert Schrieffer saw a whale blowing. That's just one of the attractions at the NSF Institute for Theoretical Physics, now in its third year of operation at the University of California in Santa Barbara. The climate and scenery are delightful, and the office space looks more like an executive suite than a collection of rooms for physicists to work in. But most important, the institute is attracting good physicists who are producing noteworthy research.

When NSF announced its concept of a theory institute in 1976, after considerable maneuvering in the academic community, 15 proposals were submitted. One of the five finalists was Santa Barbara. A feature of its proposal, which probably enhanced its attractiveness, was the offer of three permanent faculty positions plus a perma-

A discussion at the Institute for Theoretical Physics in Santa Barbara involves (from left) Walter Kohn, director, J. Robert Schrieffer (Santa Barbara) and Pierre Hohenberg (Bell Labs).