carried Marx and Mao's stamp of approval. Their safe haven, he says, lay in an approach to calculus known as nonstandard analysis, which epitomizes the mathematical qualities that appealed to Marx and Mao. The method, developed in the early 1960s by Abraham Robinson at the University of California, Los Angeles, uses sophisticated principles of mathematical logic to create a model of the real number system that includes infinitely large and infinitely small numbers along with such familiar values as 1, 2, $\sqrt{5}$, and π.

The model's infinitely small numbers provide a rigorous basis for the original concept of vanishingly small increments that Newton called "fluxions" and Leibniz labeled "infinitesimals"—they put flesh on what Bishop Berkeley, an early critic of calculus, derided as "the ghost of a departed quantity." As such, Robinson's theory gives a precise meaning to some of the intuitions that mathematicians and physicists bring to the study of functions, and it has led to solutions to a handful of problems that had eluded standard approaches. But it hasn't caught on widely, at least in the United States.

For Chinese mathematicians, though, Robinson's extension of the standard real numbers could be viewed as the dialectical synthesis of zero and nonzero—a use of the theory that Dauben learned about from Chinese mathematicians while he was writing a biography of Robinson. Nonstandard analysis provided "a means of reinterpreting the infinitesimal calculus within a materialist framework, to justify and promote their own mathematical study," Dauben says. "This saved many of them from being shipped out to the countryside."

Marx's mention of infinitesimals "made nonstandard analysis seem more acceptable than other fields to the authorities at the time," agrees Renling Jin, a nonstandard analyst at the University of Wisconsin, who grew up in China during the Cultural Revolution. Although he was too young then to witness what was going on in the Chinese universities, he says it is "very likely" that many mathematicians held on to their jobs by being politically correct à la Mao.

Interest in Robinson's theory led to an all-China symposium on nonstandard analysis in 1976. And although the revolutionary fervor of those days is long past, enthusiasm for nonstandard analysis remains high, as indicated by meetings in 1984, 1987, 1989, and 1996. Most of the research presented there has appeared only in Chinese, Dauben notes. But he thinks it's only a matter of time before its influence will be felt in the West. As Mao put it (albeit in a different context), "We must encourage our comrades to think, to study the method of analysis, and to cultivate the habit of analysis." Even bad times, it seems, can give birth to good—if nonstandard—mathematics.

–Barry Cipra

EXTINCTIONS

Cores Document Ancient Catastrophe

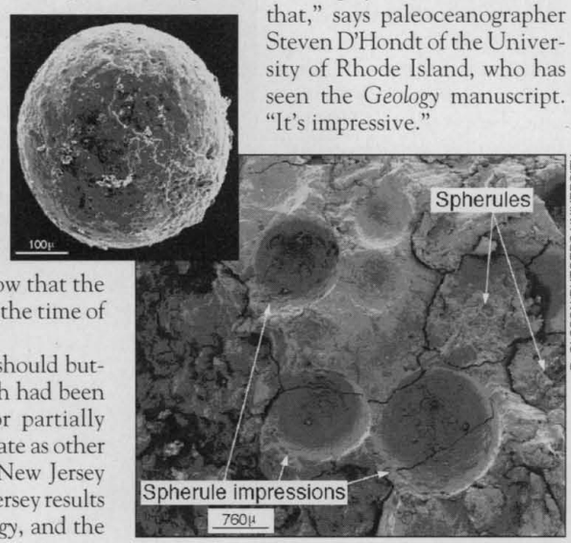
Last week, cores of ancient sea-floor sediment made a splash in the media, when a first look at deep-sea samples unloaded from the drill ship *JOIDES Resolution* revealed a layer of debris ejected from the great meteorite impact 65 million years ago. The cores, from off the U.S. southeast coast, were heralded by some as proof of the impact's potency. But researchers hardly needed proof beyond the 180-kilometer crater itself, identified nearly 5 years ago (*Science*, 14 August 1992, p. 878); for them, the real controversy is not whether the impact happened but whether it caused all or only a few of the extinctions that took place at the end of the Cretaceous period, 65 million years ago. And while public attention spotlighted the *Resolution* cores, another group of paleoceanographers has already retrieved—and analyzed—a similar core that they say convicts the impact of slaughtering most of the extinction's marine victims.

In a core drilled from a former seabed that now lies high and dry in southern New Jersey, Richard Olsson of Rutgers University and his colleagues in the New Jersey Coastal Plain Drilling Project found that many species of microfossils—remains of one-celled organisms such as foraminifera, nannoplankton, and dinoflagellates—flourished right up to the debris layer, then vanished. "It would be very hard to argue now that the impact did not occur precisely at" the time of the extinctions, says Olsson.

The chronology, Olsson says, should buttress earlier records, some of which had been disturbed, chemically altered, or partially eroded. Still, there's sure to be debate as other scientists get a look at both the New Jersey and the deep-sea cores. The New Jersey results were only just submitted to *Geology*, and the *Resolution* crew "just got off the boat," notes paleoceanographer Gerta Keller of Princeton University. "Any scientist will have to be skeptical" until the data become public.

Already, the cores establish the U.S. East Coast as a rewarding place to study the effects of the impact, which struck several thousand kilometers to the southwest on the Yucatán Coast. Closer to the crater, around the Gulf of Mexico and the Caribbean, the sea-floor record is a jumble of victims, survivors, and putative impact debris, perhaps because it was scrambled by giant tsunamis rushing out from the shallow-water impact (*Science*, 11 March 1994, p. 1372). "The effects [of the impact] were so large—boulders were moved around in some places—that there has been some uncertainty as to when the extinctions were in relation to the geologic effects," notes Kenneth Miller of Rutgers, chief scientist of the New Jersey drilling team. The new cores, which are further from the impact and so undisturbed, should help remedy the dearth of convincing records.

Miller and his colleagues retrieved their core last November when they used a modest truck-mounted rig to drill in Bass River State Park just north of Atlantic City, New Jersey. Like the deep-sea cores, this core has each layer of sediment in the expected order, as indicated by each interval's distinctive microfossils. Between the last denizens of the Cretaceous and the few survivors of the subsequent Tertiary period are 6 centimeters of sand-size spherules of now-solidified melt: debris that splashed out of the crater while white-hot from the impact. The geologic instant of the catastrophe is so well preserved, says Olsson, that each spherule at the base of the impact layer can be seen to have left its own depression in the soft Cretaceous mud it settled on. "You can't get much finer physical resolution than that," says paleoceanographer Steven D'Hondt of the University of Rhode Island, who has seen the *Geology* manuscript. "It's impressive."



Mark of extinction. Spherules of solidified impact melt *(top)* were nestled in mud from the end of the dinosaur age.

Olsson and his colleagues find that the denizens of the latest Cretaceous disappear precisely at the debris layer, while in the Tertiary new species appear thousands of years after the impact layer. The record "establishes a unique tie between ballistic ejecta from the Chicxulub crater and the extinction of marine organisms," says Miller, who concludes that the impact caused all the extinctions. That work will have to be confirmed by others, but between the New Jersey core and the three returned by *Resolution*, there should be plenty of slices of impact debris to go around.

–Richard A. Kerr