fact that duality is a concept that makes sense only for linear codes. The new results dispel the mystery: The dual-like properties of nonlinear codes are inherited from their linear precursors in Z_4.

In fact, it was the self-duality of the Nordstrom-Robinson code that finally gave away its relation with the octacode. Sloane, who is one of the leading experts in coding theory, credits David Forney at Motorola Codex and Mitchell Trott at MIT with raising the possibility of a link between the Nordstrom-Robinson code and self-dual linear codes at a conference last October. "I went home and in 2 minutes thinking about it, it became clear that yes indeed, the octacode was really the same thing as the Nordstrom-Robinson code," recalls Sloane.

Calderbank and Solé added several ideas to Sloane's observation, and soon the three theorists had found linear precursors for a number of other nonlinear codes, including generalizations of the Nordstrom-Robinson code known as the Kerdock and Preparata codes. Then they discovered that they weren't alone. Working independently, Hammons and Kumar had been investigating mathematical aspects of a communication technique called code-division multiple access (CDMA), which has been touted as a basis for digital cellular radio. CDMA allows many users to broadcast simultaneously over the same communication channel, keeping their signals straight by assigning a separate code word, or sequence, to each user as an identifying tag. Because more code words means more users can have access to the system, Hammons and Kumar had been searching for ways to apply nonlinear codes. Their efforts paid off in the discovery of Z_4 linearity lurking behind the Kerdock and Preparata codes.

When the two groups discovered the overlap in their results, they decided to join forces. Together, they've gone beyond teasing out the relations between linear and nonlinear codes to devising new decoding schemes that take advantage of those links, including an explicit decoding algorithm for the Preparata code. Meanwhile, the list of no-longer-nonlinear codes is growing almost daily, says Sloane, and it may be only a matter of time before they show up in products like modems and mobile radios. "People were scared of them" because they seemed so complicated, he says. "They won't be so scared anymore."

–Barry Cipra

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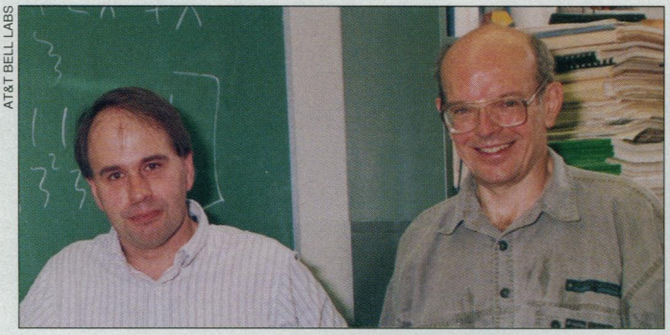
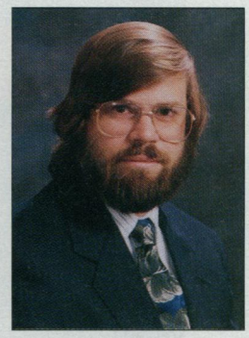
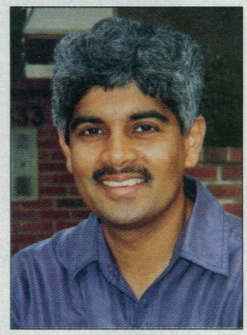




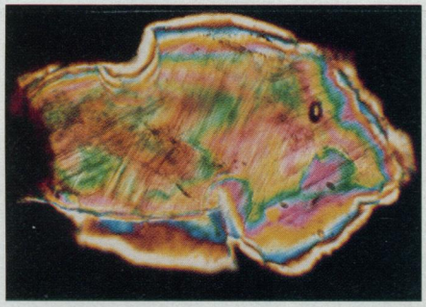


Nonlinear thinkers. From left: Bell Labs' Calderbank and Sloane, Hughes' Hammons, and USC's Kumar. A fifth member of the collaboration, Solé of the CNRS, is not shown.

EXTINCTIONS

New Crater Age Undercuts Killer Comets

One well-known Manson is definitely a killer, but another may now have been cleared of a gruesome mass murder charge. In 1989, Michael Kunk of the U.S. Geological Survey (USGS) in Reston, Virginia, and his colleagues published an age for the Manson crater in Iowa of around 65.7 million years. That put Manson tantalizingly close in age to the giant 65-million-year Chicxulub impact in the Yucatan, which may have exterminated the dinosaurs. The match, which Kunk and his colleagues tightened last spring with an additional date, led to speculation that the dinosaurs were pushed to extinction by not just one murderous impact, but two or even a whole swarm, such as a shower of comets (*Science*, 12 March, p. 1543). But the latest look at Manson puts the swarm-of-comets idea back on the shelf.



G. IZETT

Against the grain. Millimeter-sized grains of shocked quartz confirm that the Manson crater is 9 million years older than was thought.

On page 729, Glen Izett, William Cobban, and John Obradovich of the USGS in Denver, along with Kunk, present two lines of evidence that suggest Manson is nearly 9 million years older than Chicxulub. One comes from grains of the mineral sanidine, extracted from the Manson crater, that yielded a radiometric age of 73.8 ± 0.3 million years. The other comes from sedimentary rocks of roughly the same age found hundreds of kilometers away, which display signs of a powerful but distant impact.

The researchers dated the sanidine by measuring the amount of argon formed within the mineral by the steady decay of radioactive potassium. That's just what Kunk did with the earlier samples, but Izett thinks this one is more likely to have yielded an accurate age because of sanidine's straightforward origin. Sanidine only forms from rock that has melted completely, releasing all its argon and thereby resetting the radioactive clock to a zero age. The earlier samples, in contrast, had only been shocked, not melted, during the impact or were a mixture of melted and unmelted minerals.

Izett found evidence supporting the new age by going farther afield. He knew that 73.8 million years ago, the Manson site lay within the seaway that ran up the middle of North America. An impact there would have spewed debris across the seaway and churned out huge waves—effects that should be visible in sedimentary rock formed at that time. To test that idea, Izett examined exposures of sediments of roughly the right age a few hundred kilometers west of the crater.

There, within a 15- to 20-centimeter layer containing sand and centimeter-size shale fragments typical of a wave-scoured sea floor, he found mineral grains scarred by the extreme pressures of an impact. Above and below the disturbed layer, the uniformly fine-grained sedimentary layers suggested the sea was deep and tranquil. The nearest datable rocks above and below the impact layer yielded ages of 73.7 and 72.3 million years, give or take 0.4 million years, which is consistent with the new radiometric age. "The finding of the shocked mineral layer where it was predicted to be really makes the [older] age seem probable," says Kunk. It looks as if Manson the crater has now been exonerated of global mayhem.

–Richard A. Kerr