

corded in ice cores is not steady; instead it comes in a series of pulses—just what you would expect, he says, if gas trapped under the hydrate layer were suddenly being released by submarine landslides.

Moreover, James Booth of the USGS in Woods Hole, collaborating with Dillon, noticed that scars left on the ridge by submarine landslides were common all along the eastern United States at water depths of between 500 and 700 meters—just where the ice-age drop in sea level might have decomposed the hydrates gluing the topmost sediment layers together. According to Robert Kayen of the USGS in Menlo Park, “a pervasive belt of landslides” has also been spotted along the continental slope in the Arctic Ocean. The slip surface—the bottom of the sliding sediment mass—tends to match the base of the hydrate layer, Kayen says, although he’s skeptical that hydrate-triggered landslides would release sufficient methane to the atmosphere to trigger climate changes.

Indeed, there’s much that needs to be resolved about the world’s hydrate deposits—a situation that may have led at least one researcher to go off the deep end. A few years back, a petroleum geologist proposed that pulses of gas released from hydrate layers might explain the loss of ships and planes in the Bermuda Triangle. An ocean roiling with gas bubbles, he said, might swallow up a ship so quickly it would have no time to send a distress signal—and the cloud of methane rising from the sea surface might choke the engines of planes.

While few researchers are buying that idea, most would agree that given all the mysteries about hydrates, there’s a need for what Steve Lewis of the USGS in Menlo Park calls “a little bit of ground truthing.” That won’t be long in coming, Lewis hopes. He will be one of two chief scientists on leg 141 of the Ocean Drilling Project, the successor to the DSDP. On the 2-month leg, scheduled to run from mid-November of this year through mid-January of 1992 off the coast of southern Chile, researchers will for the first time drill all the way through a hydrate layer, studying its makeup and probing the amount and pressure of the gas trapped below the BSR. What they find is likely to affect thinking about hydrates as a force in climate change, an underpinning of the seafloor, and a future energy resource.

Until recently, Lewis remarks, “the official policy of the ODP was to forbid drilling to the depths of the BSR,” into what some workers saw as a potentially dangerous pool of free gas. Now the ODP researchers are laying cautious plans to do just that. They and their landlocked colleagues can’t wait to see what’s there. ■ **TIM APPENZELLER**

How Many Genes Had to Change to Produce Corn?

Recent molecular data suggest that mutations in as few as five key genes may have done the evolutionary trick

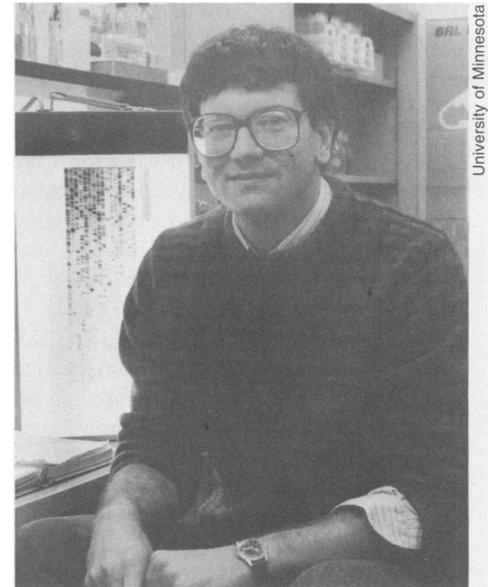
CORN IS CREDITED AS THE GRAIN THAT CIVILIZED the New World, its history entangled with that of humans since it first appeared in the archeological record roughly 7000 years ago. Today, farmers harvest more than \$40 billion worth of corn each year. But as familiar as this American icon is, biologists still can’t agree on how it evolved—even though they need look no further than modern Mexican roadsides to study corn’s presumed ancestor, a wild and weedy plant called teosinte. Now, molecular data* from evolutionary biologist John Doebley of the University of Minnesota and his colleagues may help resolve the controversy and perhaps even shed some light on a broader debate about the rate of evolution generally.

The corn controversy reflects a split that has had evolutionary biologists at loggerheads for a decade or more. The problem? Corn—or maize, as botanists and Britons prefer to call it—looks as different from its putative parent teosinte as any changeling ever left on a doorstep. “I can’t think of another major crop that has such a gap between the cultivated form and the putative wild ancestor,” says Major Goodman, a crop geneticist at North Carolina State University in Raleigh. “It’s a grand canyon that separates the two, and that’s what caused so much controversy over the years.”

One glance at the ears of the two plants illustrates what Goodman is talking about. Teosinte sports a meager ear, with only two interwoven rows of well-armored kernels, each tightly enclosed in a nut-hard fruit case. The ear itself shatters when ripe, scattering kernels far and wide. In contrast, the corn ear brims with hundreds of kernels arranged in at least eight rows. The kernels are protected only by easily stripped husks, and the cob conveniently hangs together until long after the ear is mature.

How did this dramatic change come about? Evolutionary traditionalists say slowly, the result of the accumulation of small changes in many genes. But if that were the case, why would paleontologists not have fossils galore of interim stages? From its first appearance in the archeologi-

*Some of the data has been published in *Proc. Natl. Acad. Sci. USA* 87, 9888 (December 1990).



Maize mapper. John Doebley traces the mutations in corn evolution.

cal record, corn looks like corn, with no intermediates. So members of the opposing school hold that corn evolution was rapid, propelled by a change in one or a few key genes. To support this view, they can point to the fact that although teosinte and corn look different, they are so closely related genetically that they can be crossed easily, producing fertile offspring. Indeed, botanists consider all the races of corn and some types of teosinte to belong to a single species, *Zea mays*.

The notion of rapid evolution is hotly debated on many fronts. In the case of corn it has an outspoken advocate in botanist Hugh Iltis at the University of Wisconsin, Madison. Back in 1983, Iltis argued in *Science* (23 November, p. 886) that corn made its great leap when the teosinte tassel (the male flower) was suddenly feminized, converting it into the female flower, which bears the ear. That “catastrophic” transformation is consistent with the architecture of the plants, Iltis maintains, and isn’t as traumatic as it sounds. Switching sex isn’t too tough for a corn flower: Parasites like corn smut can do the trick today.

Proponents of rapid evolution such as Stephen Jay Gould of Harvard University picked up on corn as a rare example of a

“hopeful monster”—a drastically mutated life form that turns out to be successful. But many corn biologists were less than captivated by the idea of catastrophic evolution. At the time, traditionalist Goodman pointed out that Iltis’ proposal was long on innovative thought but short on data.

Enter Doebley, who can be considered a sort of hybrid himself. Doebley was a graduate student in Iltis’ lab and then a postdoc with Iltis’ longtime rival Goodman. Now he says: “I think both sides of the controversy overstated themselves. Gould makes it sound all too simple, with big genes with lots of effects always causing drastic structural change. Quantitative geneticists say only very rarely, if ever, do you have large genes. I think that when the truth is known, as in so many cases, it will lie somewhere in the middle.”

Doebley came to this conclusion in a series of experiments in which he and his colleagues crossed teosinte and corn plants. They did this as a way of getting a handle on the genes needed to specify the traits that distinguish corn from teosinte. In an analysis of 200 plants produced by the hybrid offspring of the initial crosses, they looked for associations between traits such as the number of rows on an ear, the hardness of the fruitcase surrounding the kernels and the tendency of the ears to shatter, and the genetic markers known as restriction length polymorphisms (RFLPs). This is the same basic technique that researchers use to hunt down human disease genes.

Doebley and his colleagues found that each of the nine traits was linked to markers in at least four different chromosomal locations, a result indicating that each trait is controlled by at least four separate genes. This finding would appear to give comfort to the researchers who favor the idea that corn evolved slowly in a stepwise fashion. But the Doebley group’s analysis of the quantitative contributions of each genomic region points in the other direction.

Most of the genes have only small effects, he says. But a small number, perhaps as few as five, have a striking effect on corn morphology, together accounting for between 50% and 80% of the difference between teosinte and corn. “If you took those five [genomic] regions from

maize and put them into teosinte, the thing you’d have in front of you would be called maize,” Doebley says. For example, a single region on chromosome 4 was associated with the change of part of teosinte’s hard fruitcase (called a glume) into the soft pliable covering that catches between the teeth of sweet corn lovers.

The Doebley group’s results confirm an older idea, proposed by the late Nobel laureate George Beadle, that only a handful of genes is responsible for the difference between corn and teosinte. The results also favor a scenario in which corn evolved rapidly. “The work shows that fewer genes are accounting for much of the transition and so it was probably a short process,” says molecular geneticist Timothy Helentjaris of the University of Chicago. “I think it will turn out that big steps are more common than we thought before.”

The new genetic work also deals Iltis’ catastrophic theory a partial vindication—and a partial defeat. Doebley and his colleagues confirmed the existence of a gene that controls the sex of teosinte flowers by

altering plant architecture, in just the way Iltis proposed. According to Doebley, however, other important traits are controlled by additional, independent genes. So catastrophic evolution, caused by a single genetic change, appears to be ruled out—a finding that members of the stepwise school of evolution welcome.

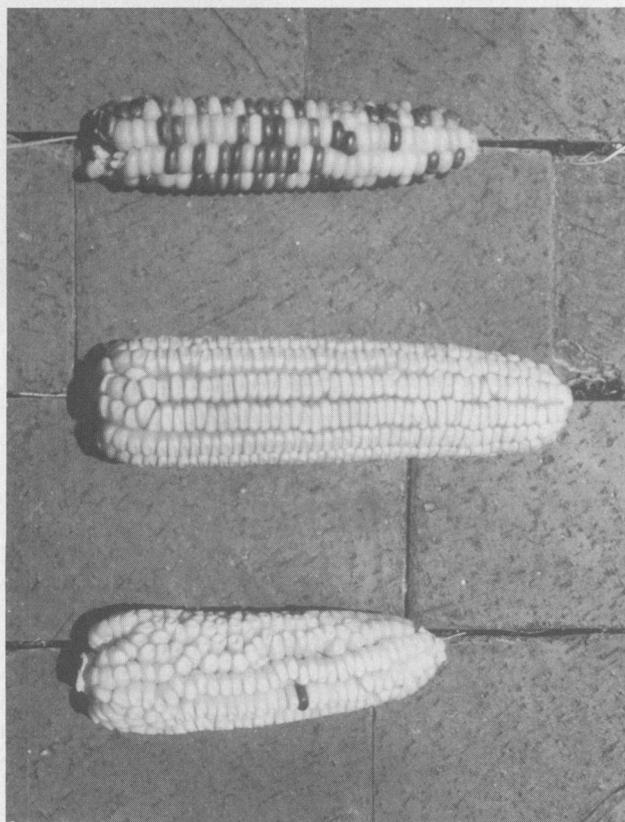
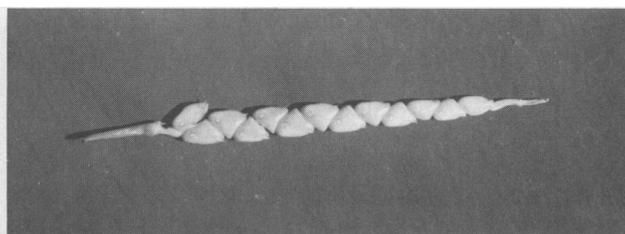
Noting that mutations in five major genes, as well as in another 15 to 20 minor gene regions, have been implicated in corn evolution, Goodman says: “It looks like evolution occurred step by step. I don’t know how else you could do it. The probability of them [the mutations] occurring simultaneously is tiny.”

While Doebley agrees that evolution probably was stepwise, he maintains that it still could have occurred swiftly, in less than a thousand years. He points to the mutation leading to the soft glume as being particularly critical to that process. Since teosinte’s hard glume makes it very difficult to eat, softening of the glume may well have triggered intensive domestication of plants bearing that mutation, thereby attracting a human helping hand to the development of modern corn.

But even if corn evolution was rapid, that doesn’t mean all evolution was, warns geneticist and stepwise advocate Russell Lande of the University of Oregon in Eugene. Domesticated corn may be a bad test case for probing the genetic basis of morphological evolution, he argues. With human help, organisms can tolerate major mutations that might otherwise be lethal. For example, the mutation that led to soft glumes would be highly deleterious to wild teosinte because it would leave the kernels vulnerable to predation. Moreover, the ears would no longer shatter when ripe, thereby preventing seed dispersal—a result that is not a problem for a cultivated crop plant.

Meanwhile, Doebley is not dismayed by the storm his findings seem to have kicked up. He and his colleagues are now trying to clone the genes they have identified as key to corn evolution. The first target is the glume gene. If Doebley and his Wisconsin colleague Jerry Kermicle clone it, they will try to transfer it into teosinte. And if that succeeds, they may be able to retrace an evolutionary step taken thousands of years ago in the valleys of southern Mexico. ■ ELIZABETH CULOTTA

John Doebley



Evolutionary leap. *Corn ears look nothing like the ear of their putative ancestor teosinte (top).*