searchers will be closely studying these genes, says Bult, for they hold the metabolic code to "a renewable, nonpolluting source of energy: natural gas."

Startling omissions

M. *jannaschii* is also surprising in what it doesn't have. For example, it apparently gets by with just a single DNA polymerase enzyme for replicating the genome. "Even in *Escherichia coli*, you need three DNA polymerases for this task," notes Roberts. "So if it's really getting away with one, this tells us that either one polymerase can do everything—or there's a whole new way to do this work that we know nothing about."

The archaeon also appears to be missing several transfer RNA (tRNA) charging enzymes, used to produce proteins in all other organisms. "These are very basic elements of life; they lie at the very heart of how an organism makes proteins," says Roberts. "So, again, either [archaea] have a very novel method for doing this, or the genes are so different that we just aren't able to recognize them." He and others were further surprised by M. *jannaschii*'s numerous inteins (18 in all), little understood elements that are inserted into proteins and then removed after the proteins are completed. "That's an astonishingly high number for something that most biologists don't even know exists," Roberts says.

That knowledge gap—and the number of unknown M. *jannaschii* genes—will shrink as other archaea genomes are sequenced. Reeve anticipates decoding the sequence of *Methanobacterium thermoautotrophicum* (the methane microbe in everyone's compost pile) before the end of the year, and more are in the works at other labs, including TIGR's. Those sequences as well as others from more primitive forms of bacteria and eukaryotes should eventually lead scientists back to the root of the tree of life. "When we have enough sequences, we'll find out the things that are universal to all life and how others diverged from this core," says Woese.

Ultimately, that search for the core may lead beyond Earth. Indeed, the recent announcement of possible fossils in a Martian meteorite had the archaea genome sequencing community all abuzz. Perhaps, suggests Venter, the original archaea arrived from space, aboard such a meteorite. Says Reeve, "Twenty years ago, no one would have thought that M. *jannaschii* could live and survive in the conditions it does—and on Earth. So it wouldn't be unexpected to find something like this elsewhere in the universe." Once on Earth, says Venter, the ancestral archaea might have "salted" the Earth's seas with the ingredients for life: "If something that was a complete autotroph, like M. *jannaschii*, splashed down from Mars, it could have created the nutrient-rich seas that many theorists regard as essential for life to have evolved."

Already, NASA is laying plans to begin searching for similar life forms on Mars (see story on p. 1040) and Jupiter's moon, Europa—and any number of labs are revving up their sequencing machines in anticipation. They may yet prove that in the beginning was the microbe.

–Virginia Morell

ECOLOGY

Exploring Biodiversity's Benefits

PROVIDENCE, RHODE ISLAND—Seeking to shed their image as ivory-tower academics, ecologists recently met here with conservation biologists* under the theme "Ecologists as Problem Solvers." Living up to that slogan, one team reported new results clarifying a problem as old as Darwin and as urgent as extinction: How does biodiversity affect an ecosystem's health?

Some scientists have favored the notion, put forward by Darwin himself, that ecosystems with many species are more productive; others have proposed the added benefit of greater stability. But the data haven't yielded clear support for either idea, as there are plenty of simple ecosystems that appear both stable and productive. In the past few years, however, a handful of studies has boosted Darwin's view. In February, for example, G. David Tilman of the University of Minnesota and colleagues reported field trials showing that species-rich ecosystems are more productive and retain more nutrients than species-poor ones (*Science*, 15 March, p. 1497). Now Tilman has new results that expand and may help explain these effects.

He told attendees at a standing-room-only session that experiments completed just this summer show that the effects of plant diversity echo throughout the food web to herbivores and pathogens, suggesting that diversity loss may destabilize ecosystems. At the same time, his group has developed new mathematical models exploring how biodiversity boosts productivity. It all adds up to an important practical message, he says: The loss of biodiversity can threaten natural ecosystems, and boosting it could improve stability and productivity in forests, grazing lands, and other managed ecosystems. The new studies "have implications for human concerns as well as the stability of ecosystems over the long term," agrees Syracuse University ecologist Sam McNaughton, who did pioneering work on ecosystem diversity in the 1970s.

D. TILMAN

Weed warriors. Students hand-weed prairie plots as part of diversity experiment.

Not all ecologists agree about these implications, but there is broad admiration for Tilman's painstaking experiments. Working with colleagues Jim Groth, Johannes Knops, Charles Mitchell, Peter Reich, Mark Ritchie, and David Wedin at the Cedar Creek Long-Term Ecology Research site in Minnesota, he planted 500 plots with varying numbers of 24 prairie species. The plots have been hand-weeded and measured by an army of students for two growing seasons thus far, in a mighty labor that Tilman calls his "25-acre heartache experiment." But the results were worth it: As reported this spring, plots with more species had more biomass, retained more soil nitrogen, and fared better during drought.

In this year's data, gathered only a few weeks ago, the team found that high-diversity plots were also more resistant to disease. For example, in low-diversity plots, aster plants were hit harder by a fungal pathogen, and prairie bunch clover plants were stricken by a different disease, bent stem syndrome. Low-diversity plots also suffered more predation by plant-eating insects (probably grasshoppers) and had higher biomasses of weedy invaders. Theory and mixed-crop agricultural experiments had suggested that diversity might affect such properties, but these controlled experiments offer important documentation, says Stanford University ecologist Peter Vitousek.

Tilman and colleagues are still exploring the mechanisms behind these effects, but they are also using their data to generate new models. With Minnesota's Clarence Lehman and Kendall Thompson, Tilman is developing models to explain the correlation between diversity and productivity. These models assume that in any group of species in a given environment, some will be more productive and therefore better competitors. If diversity is high, these species are more likely to be present, and will outcompete and even-

* Ecological Society of America and Society for Conservation Biology meetings, 11–14 August.

tually outnumber the others, thereby raising the average productivity of the plot.

The mathematical results suggest that a single species could be as productive as a multispecies group only in conditions not likely to be found in nature—when only a single resource is limiting. The modeling further suggests that as the total number of species rises, variation in productivity drops, so that a diverse ecosystem will be more predictable than a simple one.

These models suggest that what happens in the experimental plots should also be true for other ecosystems, says Tilman. He thinks the work holds a lesson for those managing forests or grasslands: Grow a mix of species rather than single-species stands in order to maximize productivity and get a more consistent yield.

But the modeling and grassland experiments haven't convinced everyone that a diverse system is always the best and quickest route to high productivity in managed ecosystems. "The jury's still out," says Vitousek, noting that the low-diversity plots at Cedar Creek haven't yet filled in and covered the ground. He and others will be watching for future results from Cedar Creek to see whether the high-diversity plots do indeed win the productivity race in the long run.

–Elizabeth Culotta

PHYSICS

Getting Familiar With the Top Quark

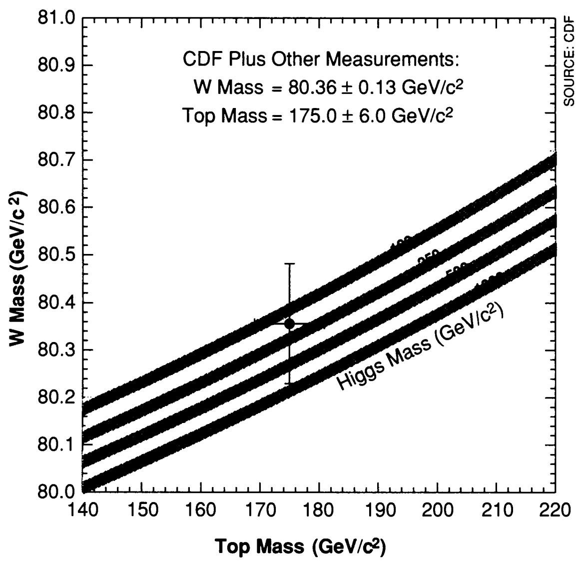
MINNEAPOLIS—Until early last year, physics textbooks were still printed with a conspicuous blank in their tables of fundamental particles. That blank finally got filled in when two collaborations at the Fermi National Accelerator Laboratory in Illinois glimpsed a massive building block of nature called the top quark. Now last year's epiphany is becoming routine. At a meeting of the American Physical Society's division of particles and fields held here last week, one group of researchers responsible for the discovery—the Collider Detector at Fermilab, or CDF—announced that they have identified roughly 100 top quarks, allowing them to nail down the mass of the now-familiar particle to within a few percent.

Physicists need that precision—greater than has been achieved for any other quark—to help them in the hunt for even bigger prey. Along with other improved particle measurements, the refined top mass provides a guidepost to the still-unseen Higgs boson, a particle that would help explain one of the major unsolved mysteries of particle physics: the array of different masses seen in other elementary particles. The top's mass implies that the Higgs could be within reach of existing accelerators. But even if it eludes them, says William Carithers, co-spokesperson for CDF, "I find it personally rather remarkable" that the top quark has yielded to close scrutiny so soon after its existence was settled. "Now it's a precision measurement."

The march toward that precision, says CDF collaborator Brian Winer of Ohio State University, came about as "we added more running time and massaged the data in a different way." The new data set covers runs of Fermilab's Tevatron collider right up until it was shut down for an upgrade early this year. The Tevatron, the world's most powerful accelerator, smashes together protons and their antimatter counterparts, antiprotons, with 1.8 trillion electron volts of energy. Over the 3 years covered by the data, the 5 trillion collisions within the house-sized CDF detector should have produced 500 or so detectable top quarks paired with their antimatter counterparts.

The top quarks themselves are too short-lived to register on any instrument, but CDF is designed to detect them indirectly, by picking up their decay products. According to the Standard Model (particle physics' current theoretical framework), virtually all top quarks decay first to a bottom quark, the next-heaviest quark, and a W particle—the carrier of the so-called weak force. Quarks can't exist alone, so the bottom quarks "cloak" themselves in other particles, producing distinctive jets of particles that trigger CDF's instruments. Altogether, the CDF researchers picked out this top quark signature in roughly 100 collisions.

To weigh the particle, the group had to take into account the top's other primary decay product, the W, which in turn decays into various leptons or quark jets. The top mass emerges when experimenters add up the energy in all of the decay products, averaged over many events. To wring extra precision from the data, the CDF group divided the events into several bins, depending on how unambiguously CDF had identified the bottom jets. This procedure, Winer says, kept "background events in 'dirty' samples from washing out good signals." Only after the data in the bins had been crunched separately were the results folded together.



Targeting the Higgs. Masses of the W particle and top quark point to mass range of the missing particle.

CDF's bottom line on the mass of the top is 176.8 billion electron volts (GeV) ± 6.5 GeV. "I thought we were going to have to wait another 5 years to know it that well," says Chris Quigg, a Fermilab theorist. Theorists have good reason to be appreciative, says Michael Barnett of Lawrence Berkeley National Laboratory: "If you believe the Standard Model, then once you know the mass of the top, you get a much better idea of what the Higgs mass should be."

That would provide clues on where to look for the particle that, theory says, is a sort of "footprint" recording how the other particles picked up mass in the first instants of the big bang. The link between the mass of the top and that of the Higgs depends on the W, for which experimenters are also getting a more precise mass: 80.37 ± 0.15 GeV, according to results announced at the meeting by Fermilab's D0 collaboration. What connects all these measurements, says Quigg, is that in an abstruse, quantum-mechanical sense, particles like the W spend part of their lives as various combinations of top quarks, Higgs bosons, and other particles, so that the values of their masses are intertwined.

But Quigg warns that the dependence of the Higgs mass on those of the other particles is "gentle," so that even with the new refinements, the range of possible masses is still fairly wide. Still, says Quigg, "it's natural for everybody to hope that the Higgs is just around the corner"—and it just might be if its mass lies in the lower part of the range suggested by the new measurements of the top and the W. In that case, the particle could be seen at CERN in Geneva, where the upgraded LEP-II collider began taking data only a few weeks ago. If the mass is larger, a glimpse of the Higgs will have to wait for a possible future upgrade of the Tevatron or for CERN's Large Hadron Collider, due to start taking data in 2006.

Meanwhile, devotees of the top. the W, and other particles will be honing their numbers still further in hopes of predicting just what the Higgs will be like when—or if—it finally fills in yet another blank in the textbooks.

–James Glanz