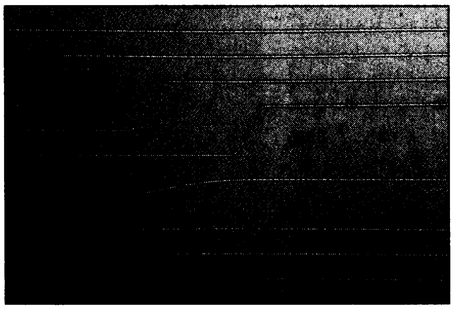
readily emit or absorb light when electrons excited into a higher energy band recombine with positively charged "holes" in the resting energy band. That's why these semiconductors can be made into light-emitting diodes, semiconductor lasers, and light detectors. But light can't be channeled from one device to another on the same chip without some confining mechanism, and that's where the waveguides come in.

One way to create waveguides is to place masks over the crystal and expose it to a plasma, etching deep canyons into the unmasked regions. The canyon walls, like the edges of polished sheets of glass, act as mirrors when photons strike them at glancing angles, trapping light within the "plateaus" on either side. But Larry Coldren, head of the Optoelectronics Technology Center at the University of California, Santa Barbara, notes that "it's difficult to get the sidewalls very smooth." As a result, says Krames, "scattering losses [of the light] can start to kill you." What's more, the etching process can disturb the entire QWH, making it difficult to etch high-quality waveguides on the same chip with light-emitting or detecting devices.

Krames and his colleagues, however, knew of another way to alter the optical properties of aluminum-gallium-arsenide: converting it to a hard, durable oxide material discovered by Holonyak and John Dallesasse in 1990. This oxide has a much



KRAMES ET AL.

Map of the future? Oxide waveguides thread a gallium arsenide–based chip.

lower refractive index than the original semiconductor, and the researchers reasoned that light would be confined to the unaltered semiconductor between oxide regions. To create the oxide waveguides, the group first masked the crystals, then heated them in a humid atmosphere. In the areas left bare by the mask, oxygen from the water vapor reacted with the aluminum, producing a "deep oxide" layer that grew into the crystal.

One challenge awaited the researchers at the center of the QWH, where the lack of aluminum held up the reaction. To get around this problem, the researchers had to smear out the QWH's layers, jumbling aluminum atoms into the center of the well, by diffusing silicon through the structure. Once that hurdle was overcome, the researchers succeeded in producing deep regions of low refractive index, in a process far gentler than etching.

The waveguides bounded by the oxide regions also turned out to leak far less light than etched structures "that you can actually make [an optoelectronic] device out of," says DeTemple, in part because of the lower scattering losses. When the researchers tested the waveguides' ability to carry light around bends, he says, they measured losses an order of magnitude lower than seen in earlier waveguides in QWHs. "The curves are as short as you're going to see" in an optoelectronic circuit, says DeTemple. "It looks wonderful."

Still, even DeTemple cautions that promising advances in this field have had a way of fizzling out. Next, the researchers plan to see whether the waveguides work as well when incorporated into integrated circuits. The group will also have to move beyond the shorter wavelengths studied so far to the infrared light used in telecommunications.

But Krames, DeTemple, and the rest of their group have a powerful spur to their efforts: other researchers' fervent hopes that they will succeed. "For me, this business of turning a corner is absolutely essential," says Harry Jordan, a researcher in optical computing at the University of Colorado, Boulder. "If somebody can figure out how to do that," he says, "I can design the chip."

–**James Glanz**

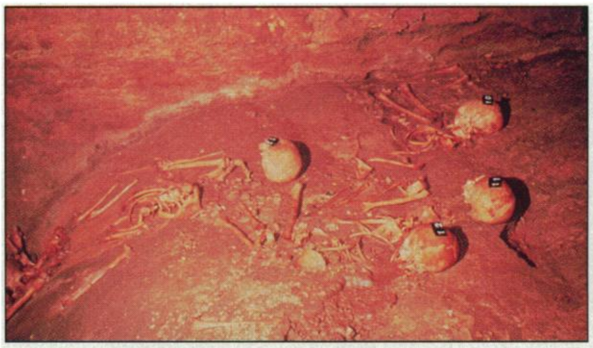
ARCHAEOLOGY

Masters and Slaves in an Iron Age Cave?

PARIS—Death is often described as the great equalizer—but the same can't be said of burial. The rich spend eternity in cushy mausoleums, while the poor elbow each other for space in common graves. And that social distinction isn't new. Nearly 2800 years ago in southern France, 22 people apparently received radically unequal treatment in death, which could help archaeologists understand the origins of social stratification and urban development in this region.

Early this year, explorers and scientists discovered two groups of almost perfectly preserved human skeletons in a cave near the village of Boussac, in the department of Lot. Nineteen of them had gone unadorned to their burials. But three others, apparently interred at the same time in a nearby chamber, were outfitted with jewelry, tools, and weapons.

Such "sharp status differences ... could be really interesting," says University of Minnesota archaeologist Peter Wells, possibly indicating that the 19 unadorned bodies were servants or slaves of the other three more "aristocratic" individuals. Almost nothing is known about the structure of the societies that existed during this period—the early Iron Age—in the Western Mediterranean area. And that makes the cave extremely important, says Michel Vidal, the French archaeology service's conservator for the Midi-Pyrenées region and leader of the research team. So important that, although it was discovered in February, the French government kept the cave's existence secret until late April, when the site could be properly secured.



PHOTOS BY FRENCH MINISTRY OF CULTURE

Aristocratic afterlife? Some skeletons from an Iron Age cave in France had an unadorned burial *(above)*, while others were outfitted for eternity with jewelry and tools *(right)*.

Vidal says that the details of the implements found with the smaller group of skeletons—an iron lance and knife, iron bracelets, and a bronze torque (neck ring)—are typical of the 7th or early 8th century B.C. This would correspond to the early Iron Age societies in temperate Europe known collectively as the Halstatt culture (named for an archaeological site in central Austria), which flourished from the 8th century to the 5th century B.C. The Halstatt connection makes the Boussac discovery "very particular," says Vidal, because cave burials are extremely rare during the Halstatt period. Wells agrees that "cave burials are very unusual. ... In this period there are hundreds of known cemeteries, but they are all out there in the landscape."

Moreover, most Iron Age graves consisted of burial mounds sheltering only one individual. But not at Boussac—the two groups appear to have been chosen for a single subterranean burial. So not only were there apparent status differences between the two groups, but also between all the buried people and the rest of society. The big question, says Wells, "is why did these individuals get this unusual burial? Is there a social status difference or ritual religious difference between [different] groups in society?" Richard Osgood of the Institute of Archaeology at Oxford University draws an analogy to burials of "the Zulu chiefs of the 19th century. ... Once the chiefs died, their entire entourage was killed and buried with them." Although it's sheer speculation, he says, a similar relationship could be behind the Boussac interments.

If scientists could determine the family relationships between the individuals in the cave, they might be able to bolster some of these theories or rule them out. To get a handle on genetic relations, Vidal's group of regional archaeologists is teaming up with anthropologists at the University of Bordeaux to extract DNA from the skeletons. They also plan to examine arm, shoulder, and other bones for marks made where muscles were attached. The severity of such marks can reveal whether or not the people were habitually engaged in hard labor. Activity differences might, for instance, provide support for the servant hypothesis. And artifacts on the cave floor near the burials might yield clues about lifestyle.

Archaeologists have been hunting for evidence of social complexity in this region for some time, says Wells. Although the first urban centers, complete with divisions of labor and status among the population, emerged in the Near East during the Bronze Age, about 3500 B.C., the rise of towns in temperate Europe is thought to be an independent development, which begins to show up in the archaeological record at about 600 B.C. "These finds [at Boussac] from a century or two before," Wells says, "might tell us something about the process of social and economic change leading to the formation of these more complex communities."

The first step will be radiocarbon dating of the two groups of skeletons, as well as other organic material—such as bits of wood—that may eventually be found, to confirm that they were buried simultaneously. Vidal expects these tests, the DNA work, and the other studies to be completed later this year. If they do support the notion of social distance between the adorned and unadorned bodies, it would be a discovery to ornament any archaeologist's career.

–**Michael Balter**

MATHEMATICS

Princeton Mathematician Looks Back on Fermat Proof

It's official: Fermat's Last Theorem has been proved. Less than 2 years after the first announcement of a proof, and within 7 months of the release of a revised manuscript correcting a mistake in the original, Princeton University mathematician Andrew Wiles's solution of the famous 350-year-old problem has passed scholarly muster and is slated to appear in the May issue of *Annals of Mathematics*. The impending publication was celebrated at a special presentation at Princeton last week, where Wiles gave a personal account of his 7-year pursuit of a childhood dream.

It was a tortuous journey toward a goal that sounds deceptively simple: Proving that the equation $x^n + y^n = z^n$ has no solutions in positive integers x, y, and z if the exponent n is greater than 2. The French mathematician Pierre de Fermat made this claim in the late 1630s in the margin of a mathematics text, tantalizing future generations of mathematicians by noting (in Latin) that he had "a remarkable proof which the margin is too small to contain." Recalled Wiles, "I spent some of my childhood trying to solve it on the assumption that Fermat had had a solution and ... I didn't know too much less than he would have known."

In fact, the proof took far more than Fermat could have known, but the final version still fits his comment to a tee. It is both remarkable and larger than a margin could contain, occupying an entire issue of the *Annals*, which is doubling its normal print run for what is sure to be a collector's item. The proof consists of two papers. The first is substantially the theory offered by Wiles in 1993. The second, written with Richard Taylor of Cambridge University (a former Wiles student), corrects—or rather circumvents—the notorious "gap" experts identified near the end of Wiles's original argument.

Even with the gap, Wiles's original exposition had qualified as an important and powerful contribution to number theory, but this time there's little doubt he has completed the proof. Because of their historic significance, the two papers have been through an unusually thorough review. One reviewer reportedly went so far as to double-check some of the work by other people on which Wiles's proof depends.

The significance of the feat isn't just historical, though. When the young Wiles was beguiled by Fermat's Last Theorem, it was widely seen as a mathematical curiosity. Wiles himself eventually put it aside to pursue more mainstream mathematics. But in 1986, Ken Ribet at the University of California, Berkeley, proved that Fermat's Last Theorem actually was part of mainstream mathematics. "What Ribet [did] was to link Fermat's Last Theorem with a problem in mathematics that would never go away," Wiles explained.

NEW JERSEY NEWSPHOTOS

QED. Andrew Wiles reviews his 7-year struggle.

The newer problem, known as the Taniyama-Shimura conjecture, is an assertion about objects in number theory known as elliptic curves—the solutions to particular classes of equations. Since it was formulated in the 1960s, number theorists had struggled to make any progress in proving the conjecture. When Ribet linked it to Fermat's Last Theorem—still unproven after 350 years—many mathematicians saw confirmation of their fears that the conjecture was profoundly difficult. But not Wiles, who saw a "wonderful excuse" to return to his boyhood dream. He set out to prove the Taniyama-Shimura conjecture for the class of elliptic curves linked to Fermat's Last Theorem.

"He [Ribet] had finally given me the excuse to put my professional expertise to work against my childhood passion," Wiles recalled. "Immediately when I heard about it in the summer of '86, I knew I would never let it go."

Even so, Wiles said, "I started without any idea how to proceed." He likens the experience to "entering a darkened mansion. You enter a room, and you stumble months, even years, bumping into the furniture. Slowly you learn where all the pieces of furniture are, and you're looking for the light switch. You turn it on, and the whole room is illuminated. Then you go on to the next room and repeat the process."

The project would have been discourag-