trons and giving them up to other atoms. But it excels at doing so only when positioned just right. The metal ordinarily hitches itself to four other chemical groups arrayed in a flat square with the copper atom at the center—a geometry that restricts copper's ability to interact with other compounds, because they can't get close enough. Galactose oxidase gets around this by forcing copper to bind to five other compounds in a pyramid-shaped arrangement—with copper at the center of the pyramid's base—that keeps it a bit unsatisfied, looking for more action.

In this case, the copper is linked to four separate amino acids and a water molecule, which takes up one of the prime reactive spots on the pyramid's base. Alcohols have a strong preference for these baseline positions as well. They kick out the water and take its spot. The copper then wrests electrons and protons—hydrogen nuclei—from the alcohol and transfers them to molecular oxygen, creating a molecule of hydrogen peroxide along with the aldehyde.

To create the same reactive geometry in their model catalyst, Stack and graduate student Yadong Wang designed a set of organic arms that would bind to the copper atom and mimic the role of galactose oxidase's key amino acids. One group, called binaphthol, takes up two of copper's binding sites and warps its bonds into a pyramidal arrangement. Another two arms contain groups known as phenols. Finally, in the activated form of the model, a water molecule inserts itself in the pyramid's base, just as in the enzyme.

The result is a compound that binds alcohols and then goes to work on them, much like the enzyme. In a series of spectroscopic experiments, Stack and Wang found that the compound duplicates the enzyme's reaction steps: After an alcohol molecule binds to the copper, the phenol arms help the copper swipe electrons and protons from the alcohol, producing the aldehyde, which drops off the catalyst. A molecule of oxygen then jumps into the free spot and snags the electrons and protons, forming hydrogen peroxide and regenerating the active catalyst in the process. X-ray structure studies of the model compound frozen in the initial step of this reaction—done by Hodgson, Jennifer DuBois, and Britt Hedman—helped support this picture.

While the new model is one of the first small molecules to truly mimic an enzyme, Stack says it's likely that many will soon follow. X-ray imaging experts are getting ever sharper pictures of the heart of other metal-containing enzymes, giving the modelers crucial guidance. Nitrogenase, which takes nitrogen in the air and converts it to a biologically useful form by tacking on hydrogens, is among the modelers' most hotly pursued prizes. Concludes Stack: "The time is right for rapid progress in this area."

–Robert F. Service

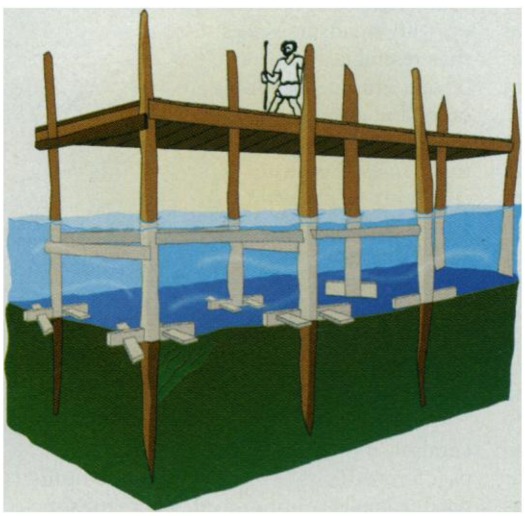
ARCHAEOLOGY

Irish Bridge Sheds Light on Dark Ages

The vaunted engineering skills that the Romans spread across Europe are supposed to have vanished during the "Dark Ages"—from the collapse of the Roman empire in the fifth century until about A.D. 1000. But a new find in the west of Ireland is challenging that assumption. A pair of underwater archaeologists has discovered the remains of a huge wooden bridge across the river Shannon. At 160 meters long, it may be the largest wooden structure from the early medieval period ever found in Europe, and its technical complexity has surprised archaeologists. Researchers now believe that the bridge, dated at A.D. 804, was the work of monks from the nearby town of Clonmacnoise, who kept Roman expertise alive over the centuries.

"The Clonmacnoise bridge fills an important gap," says archaeologist John Bradley of the National University in Maynooth. "There was no evidence of large bridges in Europe between the Roman era and about A.D. 1000." It is unlikely to be the last such discovery, adds Morgens Schou Jorgensen of the National Museum of Denmark, an expert on the large wooden bridges built by the Vikings several centuries later. "I think that other similar bridges will now be found in Ireland, as happened in Denmark after the first Viking long bridge was uncovered in 1932," says Jorgensen. If so, the finding could mean that a sophisticated land communications network may have been in place across Ireland in the 9th century.

Donal Boland and Mattie Graham, divers who specialize in underwater archaeology, had begun their survey of the river Shannon after coming across an intriguing reference to a bridge in the *Annals of Clonmacnoise*, written in 1158. They concentrated on a 500-meter stretch of the river near the remains of the monastery. In 1994, with archaeological guidance from Fionnbarr Moore of the National Monuments Service of Ireland, they found what they were looking for: an ancient oak post sticking out of the muddy riverbed. By last fall, Boland and Graham had discovered a total of 130 timbers, all neatly arranged in pairs 5 meters apart, spanning the entire 160-meter width of the Shannon. They also found nine oak dugout canoes, from which workers may have driven the pilings deep into the riverbed, and the remains of an elaborate horizontal cross-bracing system that once supported a roadway.



L. CARROLL

High technology. Reconstruction of the 9th century bridge.

The line of the posts ran directly into the ruins of a 13th century Norman castle, leading the researchers to suspect at first that the bridge was also a Norman construction. But this theory was ruled out after they sent samples of the oak timbers to Queen's University Belfast for dating by tree-ring analysis. The Belfast researchers, led by Mike Bailie, said the timbers were felled in 804, a full 365 years before Norman invaders arrived from France.

The focus of archaeologists then turned to the thriving 9th century monastic settlement at Clonmacnoise. The town of several thousand inhabitants straddled the point where an east-west route across Ireland known as the Eiscir Riada, or Esker Road, crossed the Shannon. "The bridge was built to attract commerce," says Aidan O'Sullivan, the archaeological director in charge of Clonmacnoise, "and the leadership for the project was probably provided by the monks."

The discovery of the Clonmacnoise bridge has led archaeologists such as Bradley to question whether knowledge was really lost in the aftermath of the fall of Rome, at least in distant parts of Europe that were spared the chaos of the Dark Ages. "We know the Irish preserved Roman texts, and this find suggests that they may also have preserved Roman technology and bridge-building skills," says Bradley. "Perhaps the Dark Ages were not so dark after all."

–Sean Duke

Sean Duke is a science writer in Dublin.