Timber treasure. Careful analysis of every remaining hull timber allowed archaeologists to reconstruct the Pepper Wreck.

duplicate cargo items. Such sales can benefit museums struggling to maintain large collections, points out Greg Stemm, chief executive officer of Odyssey Marine Exploration Inc., a deep-ocean exploration company based in Tampa, Florida, in an e-mail interview.

Most archaeologists, however, sharply disagree with the idea of selling artifacts. The history of archaeology has repeatedly shown that "where exploration and fieldwork were steered by the market value of objects, the approach and documentation are so compromised that even the most basic observations become unreliable," says maritime archaeologist Thijs Maarleveld of the University of Southern Denmark in Esbjerg.

As more and more ancient wrecks are revealed, shipwreck preservation stands "on a knife edge internationally," says archaeologist Colin Renfrew of the University of Cambridge in the United Kingdom. He also holds a seat in the House of Lords, and from there he recently blasted plans to allow Odyssey and a charitable trust known as the Maritime Heritage Foundation to excavate a historic British warship, HMS *Victory*, which foundered in the English Channel in the mid-18th century. It is very clear, he told *Science*, that governments should not allow "salvage of this kind."

The battle lines are hardening. "We speak two different languages," says Castro. "We are after knowledge and they are after money."

Aboard a Renaissance craft

Sunken ships are packed with archaeological information, says maritime archaeologist Paul Johnston of the National Museum of American History in Washington, D.C. Often the vessels went down with all the tools, supplies, and cargo needed to succeed on their voyage, and "the organic artifacts tend to be much better preserved than they are on land," he says, due to anaerobic conditions in many marine sites. Unlike terrestrial sites that were often occupied repeatedly over centuries, shipwrecks date to one moment in time, offering tight chronological control.

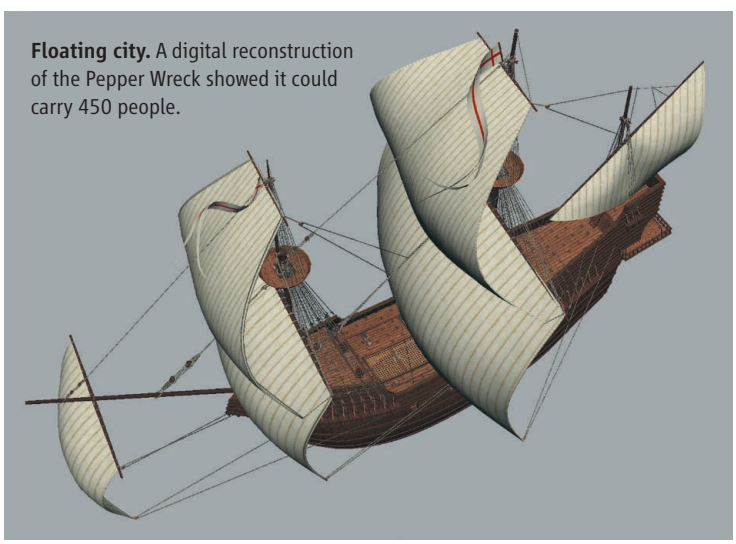
However, wresting knowledge from an underwater site is often a slow, laborious task. In the case of the Pepper Wreck found near Lisbon, Castro's team used $500,000 from the Portuguese government to dig the site and raise the hull timbers over four field seasons under the supervision of Portugal's national agency for nautical archaeology. (The equipment the team bought became part of a new national center for underwater archaeology in Lisbon.) Team members spent 2 years conserving artifacts to avoid rapid deterioration on land.

To help identify the wreck, the researchers searched historical records. In 1606, they learned, a Portuguese Indiaman christened *Our Lady of the Martyrs* sank in the area of the wreck site with a large cargo of peppercorns. Many artifacts from the Pepper Wreck fit that ship's description, including Chinese porcelain dated to 1600 and a navigational instrument called an astrolabe inscribed with the date 1605. Because the ship "was built in the royal shipyard in Lisbon, and wasn't just an anonymous ship, the level of analysis that could be carried out was immensely greater," says nautical archaeologist Brad Loewen of the University of Montreal in Canada, who was not part of the team.

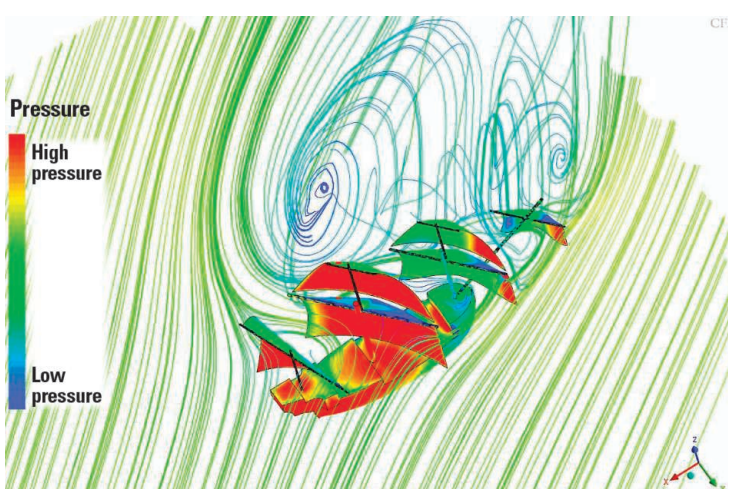
To reconstruct the ship's design, Castro painstakingly recorded the size and shape of every piece of wood, as well as the location of shipwright marks, caulking, and spikes used to join pieces together. Then he studied shipwright marks and design formulae in ancient shipbuilding treatises. By combining the formulae with their measurements, Castro and colleagues extrapolated the design, revealing a sturdy, massive ship with a 28-meter-long keel and a 31-meter-tall main mast (see image).

Could such a ship really carry 450 people and some 250 metric tonnes of cargo safely around Africa's Cape of Good Hope and through Indian Ocean monsoons? Castro and a small team combed historical records to compile a list of items needed to outfit an Indiaman for this voyage and calculated their volume and weight, from 175 tonnes of ballast to 292 tonnes of water, wine, and food. Using 3D software, the team positioned the items inside the digitally reconstructed ship to determine how much space was left for passengers and crew. Their study, published in *Historical Archaeology* in 2010, revealed that the ship indeed could have departed from Lisbon with 450 people, although conditions aboard would have been very crowded early in the voyage (when the ship was fully loaded with food and water), with just 1.3 square meters of living space per person. Such cramped quarters were "common at the time," Castro says.

What about safety? One well-known 18th century book, *The Tragic History of the Sea*, painted a bleak picture of the Indiaman's record. So the team used modern mathematical tools to see how well the reconstructed ship rode out storms. In a *Journal of Archaeological Science* paper in 2012, they



Floating city. A digital reconstruction of the Pepper Wreck showed it could carry 450 people.



Seaworthy. Computer models of a Portuguese Indiaman and the air pressure around it show that the ship met modern stability criteria; sails colored red took most of the wind.

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