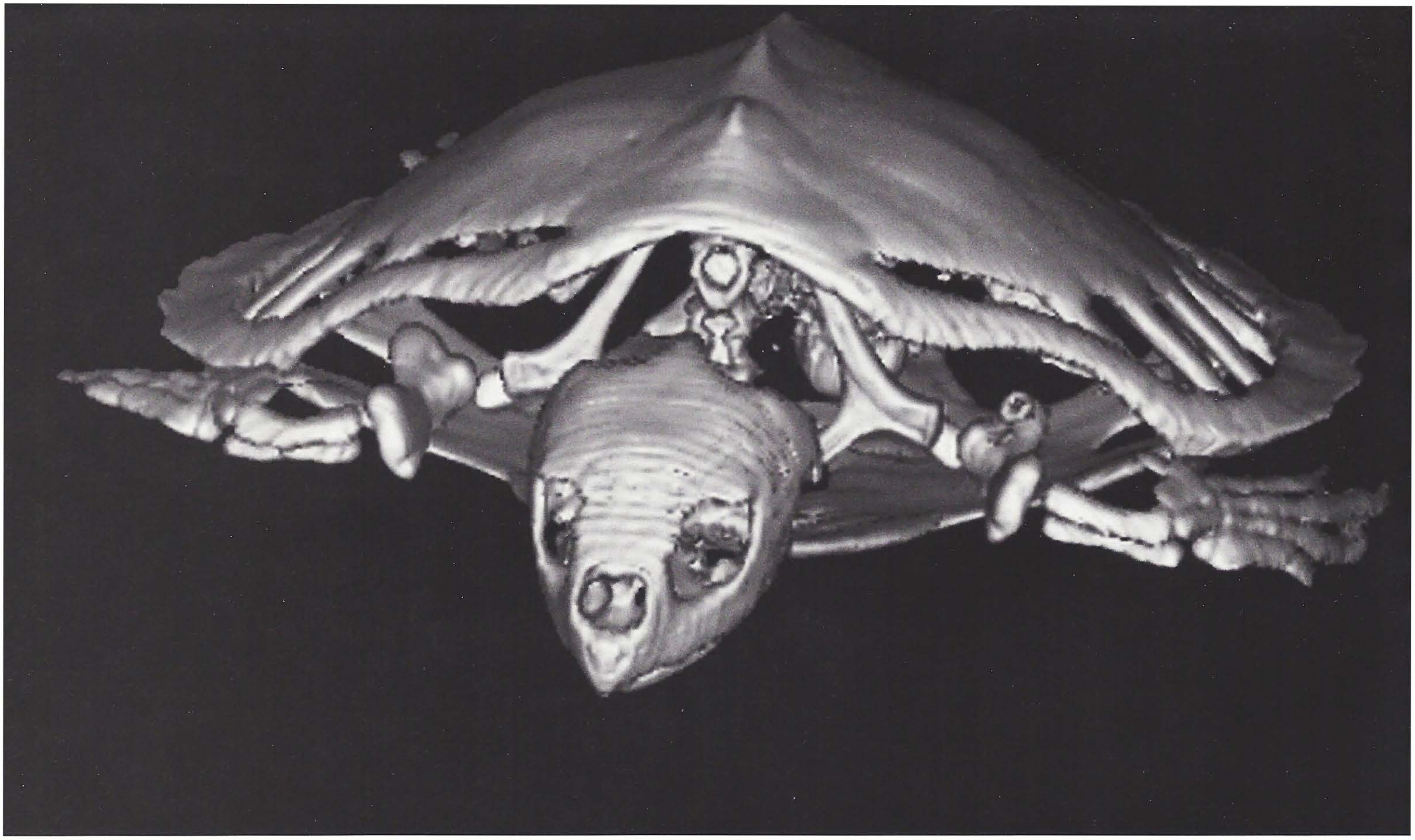


Using the Computerized Scanning and Imaging Facility (CSI) at WHOI, scientists can make three-dimensional reconstructions detailing the anatomy of sea turtles. This Kemp's ridley turtle was scanned to help diagnose a lung disease.

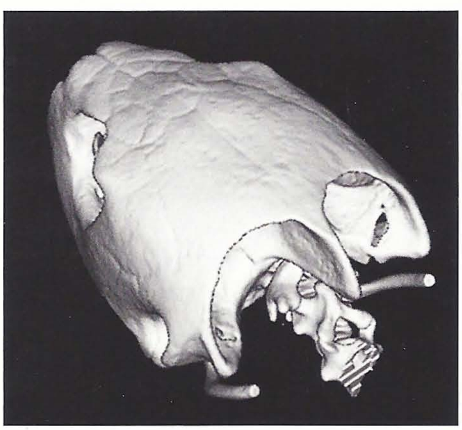
Turtle skulls prove to be shock-resistant

Could sea turtles help us design better helmets and body armor for soldiers?

Scientists and engineers from Woods Hole Oceanographic Institution (WHOI) and the U.S. Navy have discovered that sea turtles' skulls and shells protect them not only from predators but also from extraordinarily powerful underwater shock waves. The research, originally intended to help the Navy avoid harming turtles, could also point the way to designing improved body armor and helmets for soldiers on land.

To test the safety of ship designs, the U.S. Navy conducts "ship shock" trials, setting off explosions near test vessels. Navy personnel must monitor the seas to ensure that marine mammals and sea turtles are not harmed. But at what distances should various species be considered safe from the effects of pressure and sounds waves from the explosions?

"The only way to know this is to set up experiments using animal cadavers and measure the pressure [from explosions] and see what happens to the animals' tissues and bodies," said Frank Stone, director of the Marine Mammal Research and Development Program in the U.S. Navy's Environmental Readiness Division.



Darlene Ketten, WHOI Computerized Scanning and Imaging Facility

Three-dimensional reconstructions from CT scans of loggerhead sea turtles revealed that their skulls have a platelike structure and deep archways, which shield their ears, brain, and spinal cord from pressure waves.

In the experiments, WHOI biologist Darlene Ketten, a team of blast trauma researchers, and Navy engineers meticulously attached pressure sensors to fresh carcasses of dolphins and sea turtles that had died by stranding themselves on beaches. In this way, the unfortunate stranding deaths of animals serve to help protect living ones. At the Naval Surface Warfare Center and Walter Reed Army Institute of Research in Maryland, test carcasses are subjected to blast pressures equivalent to different distances from an underwater explosion.

"The object is to determine what kinds of telltale blast traumas occur in different species at various distances and to find the point of no damage for each," said Ketten, who studies blast trauma characteristics and the anatomy and function of hearing organs.

The experiments involve CT scanning the carcasses before and after the blasts, which are recorded by sensors. Then the researchers dissect the specimens to exam-

Darlene Ketten, WHOI Computerized Scanning and Imaging Facility

ine, in some cases microscopically, every major organ to detect any trauma related to the blast waves. By comparing the pressure wave readings recorded by the sensors with the CT scans and injury summaries, the researchers can determine the relationships between the pressures the animals received and the damage they sustained.

The carcasses receive pressures ranging from 0 to 300 pounds per square inch (psi). "Dolphin carcasses can suffer essentially no significant damage in the received range of 10 to 15 psi and significant damage to some organs above 25 psi," Ketten said. "At 300 psi, dolphins, well, basically, are mush." For comparison, 20 psi is about the pressure a 200-pound man's shoe heel exerts on a floor when he walks.

Quite surprisingly, however, sea turtle carcasses that received a 300-psi shock wave were astonishingly resistant. "That is an incredibly intense received pressure, like being fairly close to a major explosion," Ketten said. "Yet we found a recorded pressure of only 15 psi inside the turtle's lungs and only small regions of brain damage. Brain and lung damage appears to be prevented by the turtle's own body armor."

Turtles evolved a body plan so successful that they have remained largely unchanged since the time of the dinosaurs. Turtle shells, made of bones fused with their ribs, obviously protect vital organs against predators. But the protective ability of the turtle's skull—far greater than other animals'—was a surprise that has triggered scientists to take a closer look at the skull's architecture and engineering.

CT scans reveal that the skulls have a fairly extensive broad shelf of bone that may reflect shock waves away from the brain, Ketten said. "The turtle skull even reminds you of some of the helmets used in World War I, with a flange in back." The skulls, made of fused bone plates, might have evolved in a way that makes them flexible in the face of pressure waves and resistant to breaking, she said. "We don't yet know."

More than shape may be involved. On each side of their skulls, sea turtles have large glands that produce salty tears to keep their body fluids in balance. These "big balls of tissue on either side of the brain" may in some way act as shock absorbers, Ketten said.

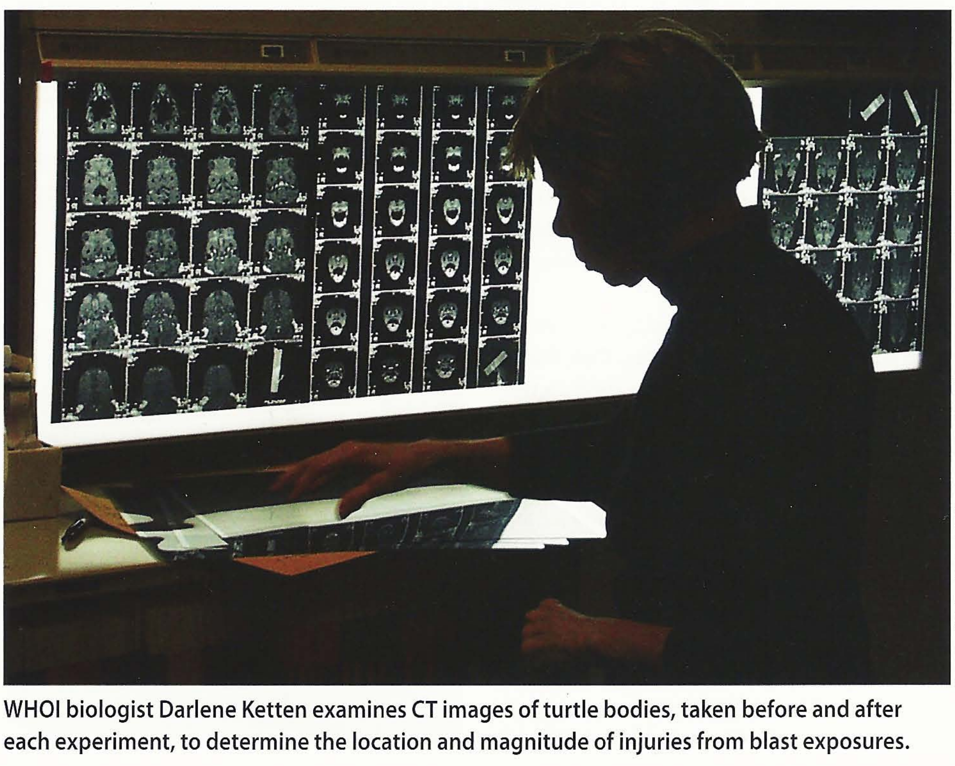
"It's speculation on my part," Stone said, "but I'd say evolution has provided great head armor for the turtle. What can be learned from evolution?"

"Turtles are a wonderful system to model for improvements to body armor for humans," Ketten said. "It's a case of looking at something theoretical and seeing the practical side of it."

—*Kate Madin*

Tom Kleindinst, WHOI

WHOI biologist Darlene Ketten and Scott Weber from the New England Aquarium prepare to examine a large female leatherback turtle, which died after stranding in the Cape Cod area, at the WHOI Computerized Scanning and Imaging Facility.



Courtesy of Darlene Ketten, WHOI

WHOI biologist Darlene Ketten examines CT images of turtle bodies, taken before and after each experiment, to determine the location and magnitude of injuries from blast exposures.