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Time

Capsules

Paleontologist Bruce MacFadden uses chemical clues to tease out facts about 4-million-year-old giant sharks

Bruce MacFadden

remembers vividly the moment when he morphed from a prehistoric horse expert into a prehistoric shark novice.

He was leading a group of children through the Florida Museum of Natural History's Powell Hall in 2001 when a 4-year-old boy pointed to a 60-foot-long mural of an extinct shark called *Megalodon* and asked "How did *Megalodon* get so large?"

MacFadden had previously used chemical analyses to tease out ever-more specific information about prehistoric land animals and their ancient environments, publishing papers in top-tier journals like *Science* and *Nature*. But the boy's question left him stumped.

"The question kept tugging at me," MacFadden says. "What environmental or evolutionary forces drove *Megalodon* to such a large body size? What made it go extinct?"

So MacFadden started digging for information about fossil sharks, especially those in the "large-toothed" family.

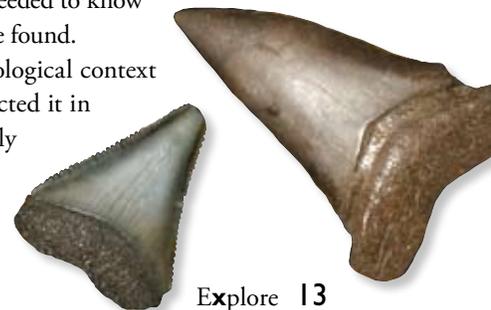
Now, as a rule, sharks don't fossilize well. Their cartilaginous skeletons decompose before chemical changes can cause them to harden into fossils. Luckily, one of the world's top shark fossil collectors lives in Gainesville.

Gordon Hubbell, who retired to Gainesville after a career in veterinary medicine, is a world authority on fossil sharks.

Among the many shark fossils in his collection were a partial shark jaw, along with about 225 teeth and 45 vertebral centra that Hubbell unearthed in South America in 1988. MacFadden, the museum's vertebrate paleontology curator, realized it was one of the oldest and most complete fossil great white sharks known to science.

To conduct the kind of geochemical research MacFadden had in mind, however, he needed to know more about where the fossils were found.

"We needed to know the geological context of where Gordon Hubbell collected it in order to date it and know exactly how old it is," MacFadden says.





Bruce MacFadden and colleagues from the Museo de Historia Natural in Lima, Peru, gather shark fossils and other material during a collecting trip to the Sacaco Basin in southern Peru.



Today, fossil finds are routinely marked using global positioning satellite, or GPS, coordinates. But a map, some field notes and a few photographs of the site's horizon line were all that MacFadden and his colleagues — Florida Museum Director Doug Jones and graduate student Dana Ehret — had to go on.

Armed with these few clues, the three researchers set out in mid-August to find a 5-foot-square by 2-foot-deep hole in a barren stretch of Peru's Sacaco Basin, about 100 kilometers south of Nazca in the rain shadow of the Andes Mountains. Three to five million years ago, the Sacaco Basin was a shallow sea teeming with whales, giant penguins, clams, fish and sharks. Today, it is the northern extension of the Atacama Desert, one of the driest places on Earth.

"To be honest, I had my doubts that we were going to find the site," MacFadden says.

Guided by Hubbell's field notes, MacFadden, Jones, Ehret and colleagues Tom DeVries from Seattle's Vashon Island High School and Rodolfo Salas Gismondi and Marcelo Stucci from the natural history museum in Lima got close to where they thought the spot was, then walked up and down sloping rises holding up the horizon-line photo, visually scanning for a match. In the distance, a slight rise with a distinct, flattened top precisely matched one in the photo. It led them straight to the site.

Although wind had filled in the hole with slightly different-colored sand, "We found bits of plaster in the sand where they dug up the shark, and some remaining shark teeth that they didn't get," MacFadden recounted as he flipped through pictures of the trip.

But finding the location of the shark fossil was just the beginning of the dating process. MacFadden and Jones collected samples of volcanic ash and marine invertebrate shells from the geological layer where the shark fossil was found and will use these for dating using various geochemical techniques.

"In the end, we were very successful in Peru," MacFadden says. "But we still have a lot of questions to answer about large shark evolution."

While he has been known for three decades as a horse evolution expert — publishing numerous papers in top journals and authoring the seminal book *Fossil Horses: Systematics, Paleobiology, and Evolution of the Family Equidae* — MacFadden



has more recently been interested in the use of geochemical clues preserved in fossil vertebrates to interpret ancient ecology and evolution.

“I really like looking at the chemistry of fossil teeth and bones to determine aspects of ancient ecology, past climates, environments and extinction events,” MacFadden explains.

For example, we are able to tell if extinct horse species were primarily leaf-eating browsers or grass-eating grazers based on differences in the carbon signatures preserved in the fossil horse teeth.

MacFadden says that after visiting the fossil shark site in Peru, and understanding the geological context, he is convinced Hubbell’s fossil is about four million years old. Although it might not be the oldest great white shark known to science, it is the most complete, and because great whites are thought to be at least 5 million years old, this specimen is a good candidate for revealing something about their early evolution.

LargeToothed

Megalodon, which means “large toothed,” is an extinct giant shark species belonging to the Lamnidae family, that also includes great whites and makos. Great whites are either cousins or direct descendants of Megalodon, depending upon who you ask. Based on their recent field experiences in Peru, MacFadden and Ehret say they’re cousins, with Megalodon more closely related to mako sharks.

“Ultimately I would like to know, in terms of shark evolution, what were the evolutionary mechanisms that resulted in Megalodon getting so big?” MacFadden explains. “Its ancestors were much smaller than Meg. So the question becomes, how do you evolve the capacity to grow very large body sizes?”

MacFadden also wants to know what Megalodon ate over its lifetime, whether it migrated and if it competed with other sharks for prey.

By analyzing the chemistry of fossilized Megalodon centra, MacFadden and Ehret hypothesize they can determine dietary shifts and perhaps even where the shark lived over its lifetime. And by comparing the unique carbon signatures present in both great whites and Megalodon, they may be able to determine if the two species competed for food.

“We think that when Megalodon got very large, it was feeding on baleen whales,” MacFadden says. “We’ve found some large whale rib bones that seem to have very large gashes, probably from shark teeth.”

But to test this idea, they need to find and sample Megalodon centra, which they currently don’t have. For now, Ehret is investigating this line of thought by analyzing incremental

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growth rings in the centra of the ancient great white shark Hubbell found in Peru.

The higher an animal is on the food chain, the more heavy isotopes it accumulates in its body, which is ultimately preserved in its fossilized skeleton. Ehret drilled out microscopic amounts of powder from the centra and analyzed it for carbon isotopes, which would tell him and MacFadden which level of the food web the animal fed on at different life stages.

“Isotopes are fascinating,” Ehret says. “By using isotopes like carbon we can look at dietary shifts in animals during their individual lifetimes. So the thought is that maybe we can tease out dietary shifts in some of these groups of fossil sharks.”

Despite his new interest in sharks, MacFadden hasn't given up on land animals. In a study published in the journal *Nature* in February, he was part of a team that used an analysis of carbon and oxygen isotopes extracted from fossilized teeth of plant-eating herbivores to show how a drastic and abrupt 15-degree temperature cooling had occurred in central North America. The study spanned the 400,000-year transition from the Eocene to the Oligocene epochs, about 33.5 million years ago, and was among the first attempts to refine details of this cooling period on land.

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“Fossil mammals are archives of ancient information,” MacFadden says. “Their teeth are like little time capsules that allow us to analyze chemicals captured millions of years ago within the animals' skeletons.”

For another study, also published in February in the journal *Geology*, he used rare earth elements that occur naturally in groundwater and which create unique chemical signatures, to date fossilized bones of *Titanis walleri* — also known as the “terror bird.”

“We used rare earth elements because they can be specific to certain time periods and different groundwater conditions,” MacFadden says. “This was the first time that the uptake of rare earth elements during the early stage of fossilization has been used to determine the age of fossils in North America.”

Rainforest Revelations

Following his interest in unlocking the chemical clues archived in fossil teeth and bones, MacFadden is also spearheading a 10-year fossil collection project along the banks of the Panama Canal to learn about ancient herbivores and their environment.

“I want to know what kinds of animals lived in what is now the rainforest, what they were eating, and how the development of the early rainforest affected herbivorous mammals,” MacFadden says.

In collaboration with the Smithsonian Tropical Research Institute, he's piggy-backing his project on the Panamanian government's current widening of the canal to accommodate larger ships.

“It's a once-in-a-century opportunity to understand what ancient life in the neotropics was like,” MacFadden says. “The Panamanian government is removing the overburden for us as they excavate along the Canal, which is a huge benefit.”

Preliminary findings show that many of the species turning up are about 15 million years old and have origins in North America. Bear dogs, deer, rhinos, horses and peccaries have all been identified at the site.

At that time, most geologists believe a seaway separated North America from South America. There was likely a volcanic archipelago forming but the two continents didn't fully fuse until about 4 million years ago, he says.

Through a grant from UF's Research Opportunity Fund, MacFadden has been developing research and education related to the widening of the Panama

Canal at the site and he hopes to start offering courses there through a field school.

“I'm interested in also training the next generation of paleontologists who will work in the neotropics,” MacFadden says.

Communicating Science

MacFadden harbors a strong bent for public outreach, a trait that was strengthened by the seven years he spent overseeing the Florida Museum's exhibit hall and public programs at Powell Hall.

Darcie MacMahon, the museum's director of exhibits, says this experience gave MacFadden the opportunity to have “a



conversation with the other half of the museum, the exhibits and public program side.”

MacFadden believes scientists should communicate their work to the public, not just to other scientists.

For more than a decade he directed the wildly popular “Pony Express” fossil dig at UF’s Thomas Farm site. He also helped start a neighborhood nature group where he gives talks about “fossils in your backyard” and leads museum tours.

“It’s about bringing fossils alive to people,” MacFadden says. “I love seeing kids enjoy natural history, seeing the wonder on their faces.”

Jones says MacFadden derives an immense amount of satisfaction from seeing his research through from the initial investigation, to publication and then to outreach.

“To be able to cross over and explain what you do to the lay public, and why it is important — as he does — is rare,” Jones says.

MacFadden’s current shark research and outreach, and work along the Panama Canal is funded by the Earth Sciences, Informal Science Education and International divisions of the National Science Foundation. ❌

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Related Web site:

<http://www.flmnh.ufl.edu/vertpaleo/>



Bruce MacFadden says chemical analysis of fossil teeth and bones like this oreodont jaw provide evidence of a dramatic climate change about 33.5 million years ago.



Graduate student Dana Ehret drills out microscopic amounts of powder from fossilized shark centra, or vertebra. The material is analyzed for carbon isotopes that indicate what the animal ate.

