Valley of the Whales

An Egyptian desert, once an ocean, holds the secret to one of evolution's most remarkable transformations.

By Tom Mueller

National Geographic
August 2010

THIRTY-SEVEN MILLION YEARS AGO, in the waters of the prehistoric Tethys Ocean, a sinuous, 50-foot-long beast with gaping jaws and jagged teeth died and sank to the seafloor.

Over thousands of millennia a mantle of sediment built up over its bones. The sea receded, and as the former seabed became a desert, the wind began to plane away the sandstone and shale above the bones. Slowly the world changed. Shifts in the Earth's crust pushed India into Asia, heaving up the Himalaya. In Africa, the first human ancestors stood up on their hind legs to walk. The pharaohs built their pyramids. Rome rose, Rome fell. And all the while the wind continued its patient excavation. Then one day Philip Gingerich showed up to finish the job.

At sunset one evening last November, Gingerich, a vertebrate paleontologist at the University of Michigan, lay full length beside the spinal column of the creature, called *Basilosaurus,* at a place in the Egyptian desert known as Wadi Hitan. The sand around him was strewn with fossil shark teeth, sea urchin spines, and the bones of giant catfish. "I spend so much time surrounded by these underwater creatures that pretty soon I'm living in their world," he said, prodding a log-size vertebra with his brush. "When I look at this desert, I see the ocean." Gingerich was searching for a key bit of the creature's anatomy, and he was in a hurry. The light was failing, and he needed to return to camp before his colleagues started to worry. Wadi Hitan is a beautiful

but unforgiving place. Along with the bones of prehistoric sea monsters, Gingerich has found the remains of unlucky humans.

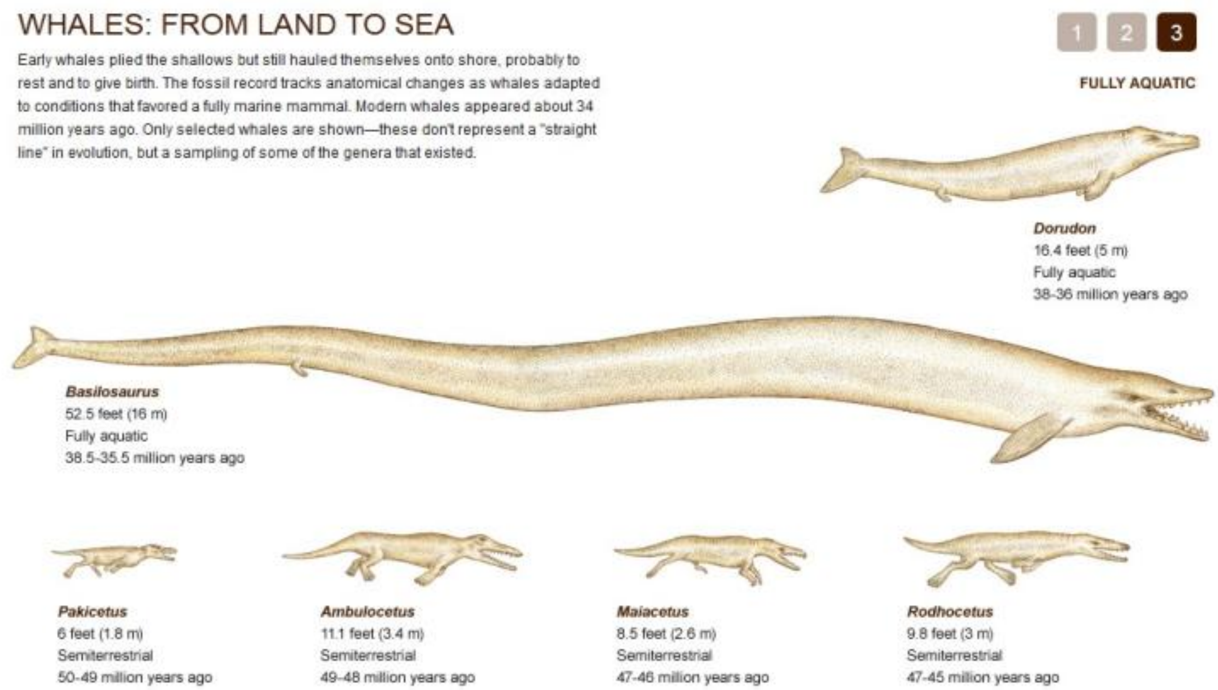
He moved down the spine toward the tail, probing around each vertebra with the handle of his brush. Then he stopped and set down the tool. "Here's the mother lode," he said. Clearing the sand delicately with his fingers, he laid bare a slender baton of bone, barely eight inches long. "It isn't every day that you see a whale's leg," he said, lifting the bone reverently in both hands.

Basilosaurus was indeed a whale, but one with two delicate hind legs, each the size of a three-year-old girl's leg, protruding from its flanks. These winsome little limbs—perfectly formed yet useless, at least for walking—are a crucial clue to understanding how modern whales, supremely adapted swimming machines, descended from land mammals that once walked on all fours. Gingerich has devoted much of his career to explaining this metamorphosis, arguably the most profound in the animal kingdom. In the process he has shown that whales, once celebrated by some as the best evidence against evolution, may be evolution's most elegant proof.

"Complete specimens like that *Basilosaurus* are Rosetta stones," Gingerich told me as we drove back to his field camp. "They tell us vastly more about how the animal lived than fragmentary remains."

Wadi Hitan—literally "valley of whales"—has proved phenomenally rich in such Rosetta stones. Over the past 27 years Gingerich and his colleagues have located the remains of more than a thousand whales here, and countless more are left to be discovered. When we pulled into camp, we met several of Gingerich's team members just back from their own fieldwork. We were soon discussing their results over a dinner of roast goat meat, *foul mudamas* (fava bean puree), and flatbread. Mohammed Sameh, chief ranger of the Wadi Hitan protected area, had been prospecting for whales farther to the east and reported several new bone piles—fresh clues to one of natural history's great puzzles. Jordanian postdoc Iyad Zalmout and grad student Ryan Bebej had been excavating a whale rostrum poking out of a cliff face. "We think the rest of the body is inside," said Zalmout.

The common ancestor of whales and of all other land animals was a flatheaded, salamander-shaped tetrapod that hauled itself out of the sea onto some



muddy bank about 360 million years ago. Its descendants gradually improved the function of their primitive lungs, morphed their lobe fins into legs, and jury-rigged their jaw joints to hear in the air instead of water. Mammals turned out to be among the most successful of these land lovers; by 60 million years ago they dominated the Earth. Whales were among a tiny handful of mammals to make an evolutionary U-turn, retrofitting their terrestrial body plan to sense, eat, move, and mate underwater.

How whales accomplished such an enormous transformation has baffled even the greatest scientific intellects. Recognizing the conundrum as one of the great challenges to his theory of evolution by natural selection, Charles Darwin took a stab at accounting for whales in the first edition of *Origin of Species.* He noted that black bears had been seen swimming with their mouths open for hours at a time on the surface of a lake, feeding on floating insects. "I can see no difficulty in a race of bears being rendered, by natural selection, more and more aquatic in their structure and habits, with larger and larger mouths," Darwin concluded, "till a creature was produced as monstrous as a whale." His critics poked such loud and gleeful fun at this image, however, that he eventually omitted it from later editions of his book.

Nearly a century later George Gaylord Simpson, the preeminent paleontologist of the 20th century, was still at a loss to explain where whales fit in his otherwise orderly evolutionary tree of mammals. "The cetaceans are on the whole the most peculiar and aberrant of mammals," he remarked peevishly. "There is no proper place for them in a *scala naturae.* They may be imagined as extending into a different dimension from any of the surrounding orders or cohorts."

If science could not account for the transformation of whales, antievolutionists argued, perhaps it never happened. They contended that land animals that began to adapt to aquatic life would soon be neither fowl nor fish, incapable of surviving in either medium. And if whales really had made this huge transition, where were the fossils to prove it? "The anatomical differences between whales and terrestrial mammals are so great that innumerable in-between stages must have paddled and swam the ancient seas before a whale as we know it appeared," wrote the authors of *Of Pandas and People,* a popular anti-evolution textbook first published in 1989. "So far these transitional forms have not been found."

Philip Gingerich had unintentionally taken up this challenge in the mid-1970s. After earning his Ph.D. at Yale, he began excavating in Wyoming's Clarks Fork Basin, documenting the meteoric rise of mammals at the beginning of the Eocene, after the extinction of the dinosaurs ten million years earlier. In 1975, hoping to trace migrations of mammals from Asia to North America, he started fieldwork in middle Eocene formations in the Punjab and North-West Frontier (now called Khyber Pakhtunkhwa Province) Provinces of Pakistan. He was disappointed to discover that the 50-million-year-old sediments he had targeted were not dry land but marine beds on the eastern edge of the Tethys Ocean. When his team uncovered some pelvic bones in 1977, they jokingly attributed them to "walking whales"—a preposterous notion. At that time the best known fossil whales were thought to be similar to modern whales, with sophisticated mechanisms for underwater hearing, powerful tails with broad flukes, and no external hind limbs.

Then in 1979, a member of Gingerich's team in Pakistan found a skull about the size of a wolf's but with prominent—and very unwolflike—sails of bone at the top and sides of the skull to secure robust jaw and neck muscles. Stranger still, the braincase was little bigger than a walnut. Later the same month Gingerich came across some archaic whale specimens in museums in Lucknow and Kolkata (Calcutta), India. "That's when the tiny braincase started to make sense, because early whales have big skulls and relatively small brains," Gingerich remembers. "I began to think that this small-brained thing might be a very early whale."

When Gingerich freed the skull from its matrix of hard red stone back in his lab in Michigan, he found a grape-size nugget of dense bone at its base called the auditory bulla, with an S-shaped bony crest on it known as the sigmoid process—two anatomical features that are characteristic of whales and help them hear underwater. Yet the skull lacked several other adaptations that living whales use to hear directionally beneath the waves. He concluded that the animal had probably been semiaquatic, spending significant time in shallow water but returning to land to rest and reproduce.

Discovering this most primitive known whale, which Gingerich named *Pakicetus,* made him see whales in a new light. "I started thinking more and more about the huge environmental transition that whales had made," he remembers. "This was a creature starting out as a terrestrial animal and literally turning into an extraterrestrial. Since then, I've been consumed by the search for the many transitional forms in this huge leap from land back into the sea. I want to find them all."

In the 1980s Gingerich turned his attention to Wadi Hitan. Along with his wife, paleontologist B. Holly Smith, and their Michigan colleague William Sanders, he began looking for whales in formations some ten million years younger than the beds where he'd found *Pakicetus*. The trio excavated partial skeletons of fully aquatic whales like *Basilosaurus* and the smaller, 16-foot *Dorudon.* These had large, dense auditory bullae and other adaptations for underwater hearing; long, streamlined bodies with elongated spinal columns; and muscular tails to drive them through the water with powerful vertical strokes. The area was teeming with their skeletons. "After a short time in Wadi Hitan you think you're seeing whales everywhere," Smith says. "And after a little more time you realize you really are. We soon understood that we'd never be able to collect all the whales, so we started mapping them and excavating only the most promising specimens."

It wasn't until 1989, however, that the team found the link they were seeking to the whales' terrestrial ancestors, almost by accident. Near the end of the expedition Gingerich was working on a *Basilosaurus* skeleton when he uncovered the first known whale knee, on a leg positioned much farther down the animal's spinal column than he had expected. Now that the researchers knew where to look for legs, they revisited a number of previously mapped whales and rapidly uncovered a femur, a tibia and fibula, and a lump of bone that formed a whale's foot and ankle. On the last day of the expedition Smith found a complete set of slender, inch-long toes. Seeing those tiny bones brought her to tears. "Knowing that such massive, fully aquatic animals still had functional legs, feet, and toes, realizing what this meant for the evolution of whales—it was overwhelming," she remembers.

Though unable to support a *Basilosaurus's* weight on land, these legs weren't completely vestigial. They had attachments for powerful muscles, as well as functional ankle joints and complex locking mechanisms in the knee. Gingerich speculates that they served as stimulators or guides during copulation. "It must have been hard to control what was going on down there on that long, snakelike body, so far from the brain," he says.

Whatever *Basilosaurus* actually did with its little legs, finding them confirmed that the ancestors of whales had once walked, trotted, and galloped on land. But the identity of these ancestors remained unclear. Certain skeletal features of archaic whales, particularly their large, triangular cheek teeth, strongly resembled those of mesonychids, a group of hoofed Eocene carnivores. (The massive, hyena-like *Andrewsarchus,* probably the largest carnivorous mammal that has ever lived on land, may have been a mesonychid.) In the 1950s immunologists had discovered characteristics in whale blood that suggested a descent from artiodactyls, the mammalian order that includes pigs, deer, camels, and other even-toed ungulates. By the 1990s molecular biologists studying the cetacean genetic code concluded that the whale's closest living relative was one specific ungulate, the hippopotamus.

Gingerich and many other paleontologists trusted the hard evidence of the bones more than the molecular comparisons of living animals. They believed whales had descended from mesonychids. But to test this theory, Gingerich needed to find one bone in particular. The astragalus, or anklebone, is the most distinctive element of the artiodactyl skeleton, because it has an unusual double-pulley shape, with clearly defined grooves at the top and bottom of the bone like the grooves on a pulley wheel that holds a rope. The shape gives artiodactyls greater spring and flexibility than the single-pulley form found in other quadrupeds. (Living whales were of no help, of course, because they have no anklebones at all.)

Back in Pakistan in 2000, Gingerich finally saw his first whale ankle. His graduate student Iyad Zalmout found a grooved piece of bone among the remains of a new 47-million-year-old whale, later named *Artiocetus*. Minutes later Pakistani geologist Munir ul-Haq found a similar bone at the same site. At first Gingerich thought the two bones were the single-pulley astragali from the animal's left and right legs—proof that he'd been right about the origin of whales. But when he held them side by side, he was troubled to see that they were slightly asymmetrical. As he pondered this, manipulating the two bones as a puzzler maneuvers two troublesome puzzle pieces, they suddenly snapped together to form a perfect double-pulley astragalus. The lab scientists had been right after all.

Walking back to camp that evening, Gingerich and his team passed a group of village children playing dice with the astragali of a goat. (People in various cultures have used the anklebones of domestic artiodactyls in games and fortune-telling for millennia.) Zalmout borrowed one and gave it to Gingerich, then watched in amusement as his professor spent the rest of the evening alternately staring at the whale ankle in one hand and the goat ankle in the other, noting the unmistakable similarities. "That was a major find, but it upset my applecart," Gingerich says with a wry smile. "Still, now we knew for sure where whales came from and that the hippopotamus theory wasn't complete science fiction."

Since then Gingerich and a handful of other paleontologists have filled in the story of early whales, tooth by tooth, toe by toe. Gingerich believes the first cetaceans probably resembled anthracotheres, svelte hippo-like browsers that inhabited swampy lowlands in Eocene times. (An alternative theory, advanced by paleontologist Hans Thewissen, is that whales descended from an animal similar to *Indohyus,* a prehistoric deerlike artiodactyl the size of a raccoon that was partly aquatic.) Whatever their shape and size, the earliest whales appeared about 55 million years ago, like all other modern mammalian orders, during the spike in global temperatures at the beginning of the Eocene. They lived along the eastern shores of the Tethys, where the waters exerted a strong evolutionary pull: warm, salty, rich in marine life, and free of aquatic dinosaurs, which had gone extinct ten million years earlier. Chasing new kinds of food sources deeper into the water, these early waders gradually developed longer snouts and sharper teeth better suited for snapping up fish. By about 50 million years ago, they'd reached the stage exemplified by *Pakicetus:* proficient four-legged swimmers that still moved about on land.

By adapting to water, early whales gained access to an environment closed to most other mammals, rich in food and shelter, and short on competitors and predators—perfect conditions for an evolutionary explosion. What followed was a starburst of idiosyncratic experiments in being a whale, most of which ended in extinction long before modern times. There was the hulking, 1,600-pound *Ambulocetus,* an ambush hunter with squat legs and huge snapping jaws, like a hairy saltwater croc; *Dalanistes,* with a long neck and head like a heron; and *Makaracetus,* with a short, curved, muscular proboscis that it may have used for eating mollusks.

Around 45 million years ago, as the advantages of a water environment drew whales farther out to sea, their necks compressed and stiffened to push more efficiently through the water, behind faces lengthening and sharpening like a ship's prow. Hind legs thickened into pistons; toes stretched and grew webbing, so they resembled enormous ducks' feet tipped with tiny hooves inherited from their ungulate ancestors. Swimming methods improved: Some whales developed thick, powerful tails, bulleting ahead with vigorous up-and-down undulations of their lower bodies. Selection pressure for this efficient style of locomotion favored longer and more flexible spinal columns. Nostrils slid back up the snout toward the crown of the head, becoming blowholes. Over time, as the animals dived deeper, their eyes began to migrate from the top toward

Head restorer William Sanders of the University of Michigan Museum of Paleontology and his team spent a year making casts of a Basilosaurus's fossil bones, shown here with ribs in the foreground, vertebrae behind. The white casts will be painted to match the rust-hued originals.

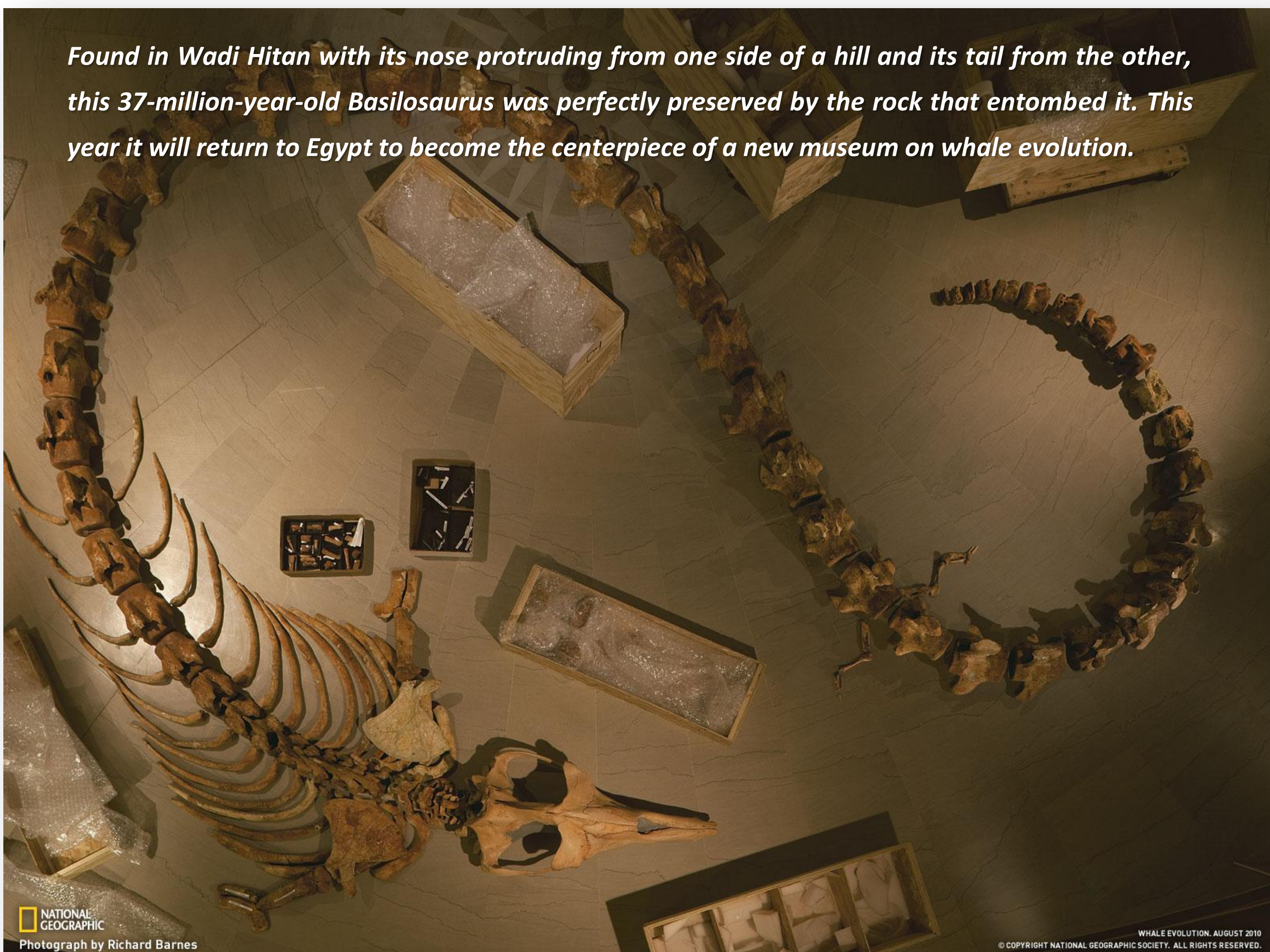
the sides of the head, the better to see laterally in the water. And whale ears grew ever more sensitive to underwater sound, aided by pads of fat that ran in channels the length of their jaws, gathering vibrations like underwater antennae and funneling them to the middle ear.

Though finely tuned to water, these 45-million-year-old whales still had to hitch themselves ashore on webbed fingers and toes, in search of fresh water to drink, a mate, or a safe place to bear their young. But within a few million years whales had passed the point of no return: *Basilosaurus, Dorudon,* and their relatives never set foot on land, swimming confidently on the high seas and even crossing the Atlantic to reach the shores of what is now Peru and the southern United States. Their bodies adjusted to their exclusively aquatic lifestyle, forelimbs shortening and stiffening to serve as flippers for planing, tails broadening at the tip in horizontal flukes to create a hydrofoil. The pelvis decoupled from the spine, allowing the tail a broader range of vertical motion. Yet like talismans from a long-forgotten life ashore, their hind legs remained, complete with tiny knees, feet, ankles, and toes, useless now for walking but good perhaps for sex.

The final transition from basilosaurids to modern whales began 34 million years ago, during the sudden phase of cooling climate that ended the Eocene epoch. A drop in water temperatures near the Poles, shifts in ocean currents, and an upwelling of nutrient-rich seawater along the western shores of Africa and Europe drew whales into entirely new environmental niches and drove the remaining adaptations—big brains, echolocation, insulating blubber, and in some species, baleen in place of teeth for straining krill—present in cetaceans today.

Thanks in large part to Philip Gingerich, the fossil record of whales now offers one of the most stunning demonstrations of Darwinian evolution rather than a refutation of it. Ironically, Gingerich himself grew up in a strictly principled Christian environment, in a family of Amish Mennonites in eastern Iowa. (His grandfather was a farmer and lay preacher.) Yet at the time, he felt no clash between faith and science. "My grandfather had an open mind about the age of the Earth," he says, "and never mentioned evolution. Remember, these were people of great humility, who only expressed an opinion on something when they knew a lot about it."

Gingerich is still baffled by the conflict that many people feel between religion and science. On my last night in Wadi Hitan, we walked a little distance from camp under a dome of brilliant stars. "I guess I've never been particularly devout," he said. "But I consider my work to be very spiritual. Just imagining those whales swimming around here, how they lived and died, how the world has changed—all this puts you in touch with something much bigger than yourself, your community, or your everyday existence." He spread his arms, taking in the dark horizon and the desert with its sandstone wind sculptures and its countless silent whales. "There's room here for all the religion you could possibly want."



Found in Wadi Hitan with its nose protruding from one side of a hill and its tail from the other, this 37-million-year-old Basilosaurus was perfectly preserved by the rock that entombed it. This year it will return to Egypt to become the centerpiece of a new museum on whale evolution.

Photograph by Richard Barnes