When Whales Had Feet

PALEONTOLOGISTS TRACE ONE GIANT LAND MAMMAL'S RETURN TO THE SEA

BY KATHLEEN MCAULIFFE

When the wind parts the dunes the spines of leviathans rise

Piled with food crates and a 125-gallon water drum, our truck sets off on the road—the only road—heading southwest from Cairo into the desolate expanse of the Libyan desert. Several hours later, with the great Pyramid of Cheops a long-faded memory on the horizon behind us, we turn off into the open sand dunes. A pile of oil cans is the only road marker pointing the way to our final destination, Zeuglodon Valley, 45 miles due south in a geological formation famous among fossil-hunters and known as the Fayum depression.

"Welcome to paleontologist's paradise," shouts Philip Gingerich above the roar of the engine. His wife, Holly Smith, smiles as she braces herself against the bronco-bucking ride over the dunes. The couple, both vertebrate paleontologists at the University of Michigan in Ann Arbor, haven't had a shower or a decent meal in six weeks, but the deprivation doesn't show on their faces. This fall day is their first season back in the valley since the spectacular finale of a fossil-collecting trip here two years earlier. In November 1989, on the last day of a five-week expedition, Gingerich's team made a widely heralded discovery: It uncovered an extinct whale with feet.

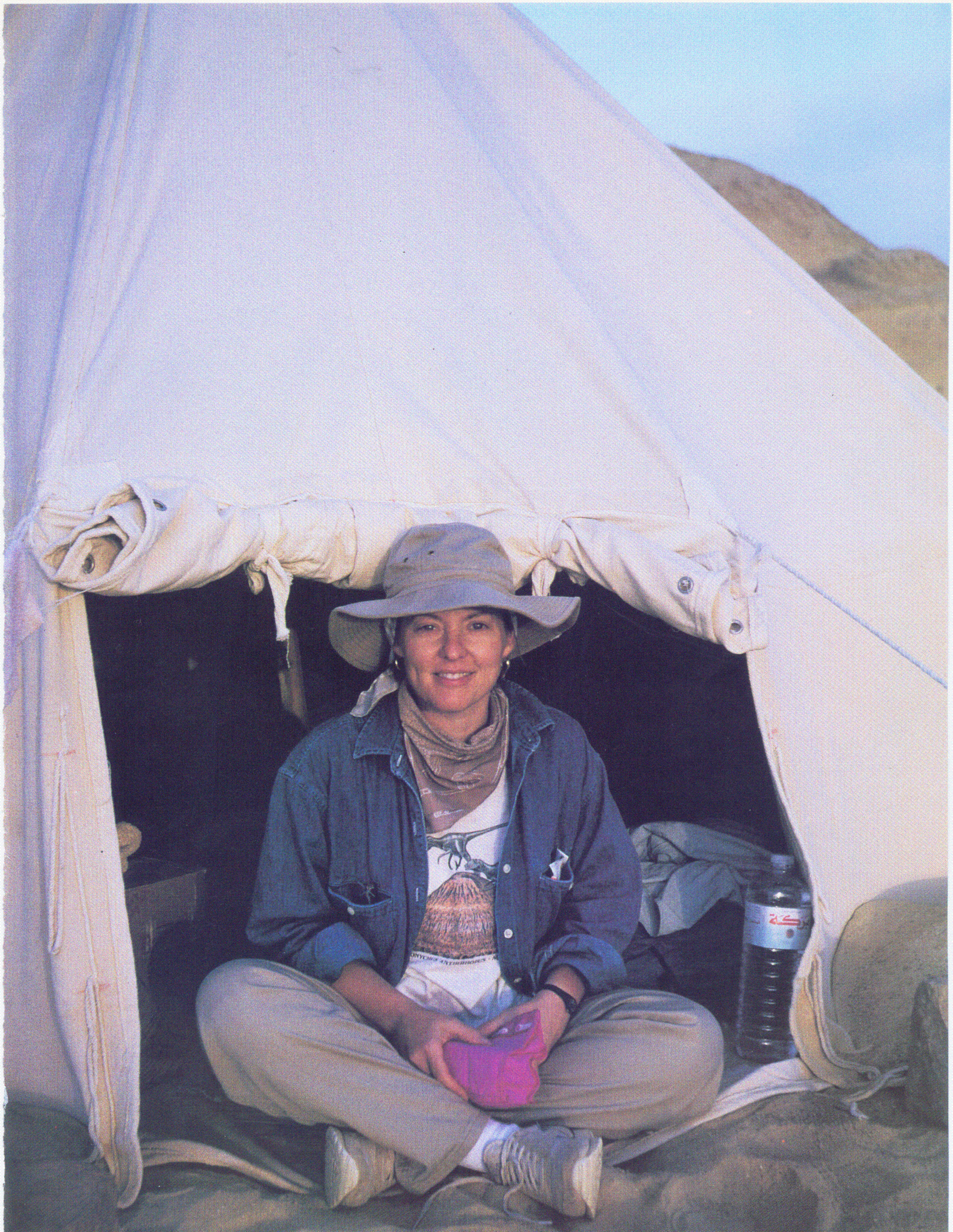
Zeuglodon Valley is the site of an ancient seabed that was once submerged by the Tethys Sea, of which the Mediterranean is but a puddle-sized remnant. It is a graveyard for marine animals, a place littered with more bones than all the mummified remains of the Pharaohs buried in the Hills of Thebes. If whales with feet seem out of place even here, it is because they are an evolutionary missing link, an awkward transitional form like *Archaeopteryx*, with its reptilian tail and first traces of birdlike feathers, or the amphibious lungfish, whose simple air sac documents how life in the sea first came ashore. Whales with feet are testimony to an evolutionary about-face: Three hundred million years after the colonization of the land, the ancestors of modern whales—a primitive group of four-legged mammals—waded back into the water.

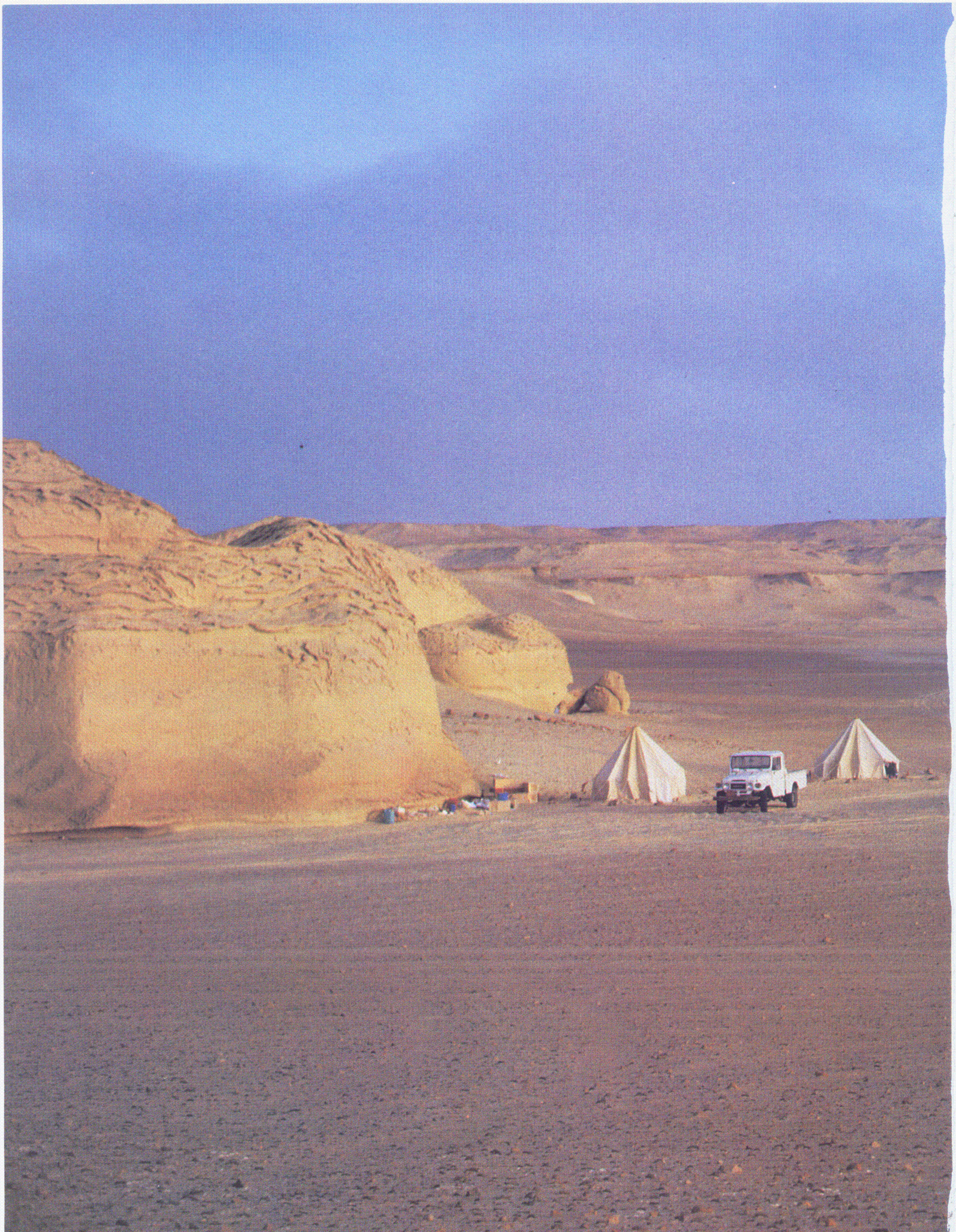
No other terrestrial mammal has undergone such a dramatic metamorphosis. Breathing, locomotion, thermal regulation, diet—virtually every aspect of the animal's design had to be remodeled to accommodate to an aquatic existence. By shedding light on the details of this transformation, Gingerich and Smith hope to gain insights into central evolutionary processes.

Our descent into the Fayum takes us backward in time and down through the ages. "Right now," says Gingerich, putting his foot on the accelerator, "we're going to come up over a ledge and onto lagoonal sediments laid down in the late Eocene, or about 40 million years ago." As the truck plunges over the ridge, the flat gravelly terrain erupts into black shale mesas that were once sandbars level with the African continent. Still older and more exotic scenery awaits us ahead: One-hundred-sixty-foot sandstone cliffs with candy-striped ridges, and, scattered along the arroyo below, scarps that metamorphose into frozen waves, gigantic wedding cakes, spired castles, and tree-sized mushrooms that could have been carved by Henry Moore. According to Gingerich, these massive blocks of weathered sandstone date back to mid-Eocene, about 45 million years ago, and are all that remains of a barrier beach that separated the lagoon from the inner shelf of the Tethys Sea.

The barrier beach is the gateway to Zeuglodon Valley. It takes two revving-starts and the grinding of gears to traverse the crumbling dunes onto the old seafloor. This is the area densest in marine fossils.

Previous page: Paleontologist Philip Gingerich excavates the skeleton of a small whale in Zeuglodon Valley, Egypt. Right: Paleontologist Holly Smith takes a break from excavations at the Zeuglodon Valley camp.





They crumble out of the rocks and crunch under foot. No one who has come here has ever missed them. When the wind parts the dunes, the pillar-thick spines of leviathans rise out of the desert floor. Still clinging to the upper terraces of rocks are perfectly preserved beds of oysters and clams. The sand itself shimmers with nummulites—a calciferous sea creature the size and color of a baby's thumbnail. "The nummulites give the valley its character of light," says Gingerich. "It is as if the desert were paved with silver coins."

Gingerich is a tall, broad-shouldered figure with a trim, black mustache and round-rimmed glasses that give his face a quizzical, slightly bemused look reminiscent of James Joyce. He is a lover of the outdoors, a reserved man who is an observer by temperament. "I can't believe we're the first people to come here and really study how whales evolved," he says with ingenuous delight. "Only a few other groups have come here this century, but they were mostly collecting trophies—skulls and teeth for museum displays."

The front limb was doglike, but the skull belonged to a whale

Given what Gingerich's crew has unearthed, his predecessors missed the best trophy of all. But it is unfair to fault them. Gingerich almost missed the prize himself. As the veteran fossil hunter recalls, he was scouting for new whale remains when he spotted a bone jutting up out of the ground with the unmistakable shape a of femur—or thigh bone. "It was only eight inches long," says Gingerich, "but the leg was next to a 50-foot-long skeleton so I was quite sure it was part of the same specimen."

The next day the entire crew fanned out to see if members had overlooked the slender leg in earlier excavations of other skeletons. Sure enough, they found an ankle joint and two lower leg bones. "It was amazing," says Gingerich. "Once we knew where to look, bits of legs started turning up everywhere." But the best was yet to come. On the last day of the trip, as the crew broke camp, Smith unearthed the ultimate treasure—tiny toe bones.

The dainty feet belonged to a behemoth by the name of *Basilosaurus isis*, a long eel-shaped creature with a disproportionately small head and large splicing teeth. Exhumed from its sandy grave, its four-foot-long skull is still a chilling sight to behold. "This was no plankton-feeding whale," says Gingerich, pointing to three-inch-long premolars with serrated edges. "It was quite possibly one of the most terrifying carnivores that ever lived."

Owing to a case of mistaken identity in 1832, this menacing whale was initially assumed to be a reptile, and hence was dubbed *Basilosaurus*, or "king of the lizards." The error was soon corrected, but the misnomer persisted along with many other misperceptions about the creature. To the American slaves who dug up a near-identical species in an Alabama field a few years later, it was a fallen angel. To other Americans living in the 19th century, *Basilosaurus* bore a striking resemblance to reported sea monsters. To complete the likeness, the

Previous page, left: University of Michigan digs in Zeuglodon Valley, Egypt. Previous page, right: Holly Smith finds the foot bones near the tail of a skeleton of a 50-foot *Basilosaurus isis* in Zeuglodon Valley. Right, above: The fossilized skeleton of *Basilosaurus isis* on display at the Smithsonian's National Museum of Natural History had to be updated after Gingerich and Smith made their 1989 discovery. Right, below: The six-inch-long three-toed foot of *Basilosaurus isis*.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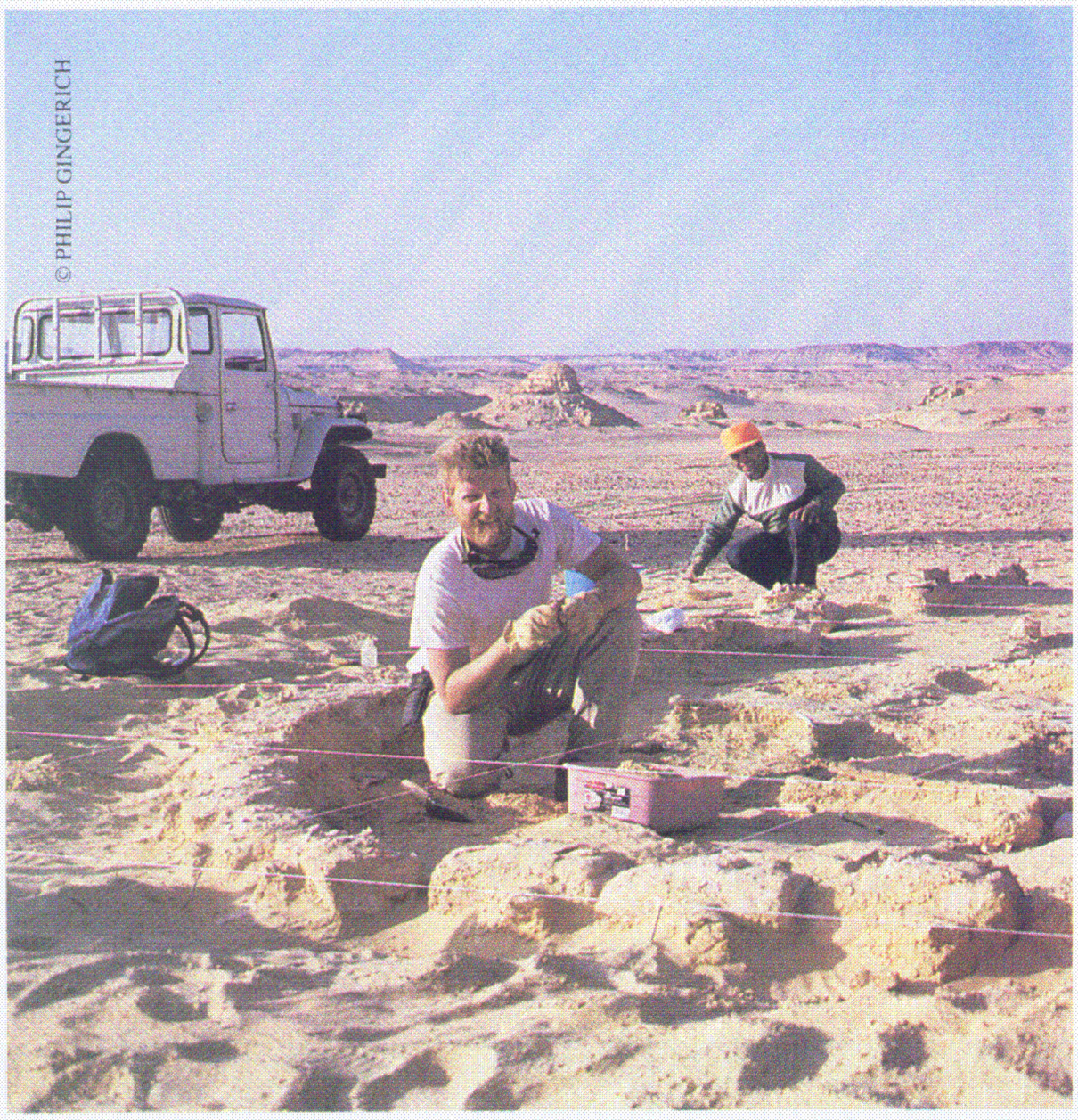

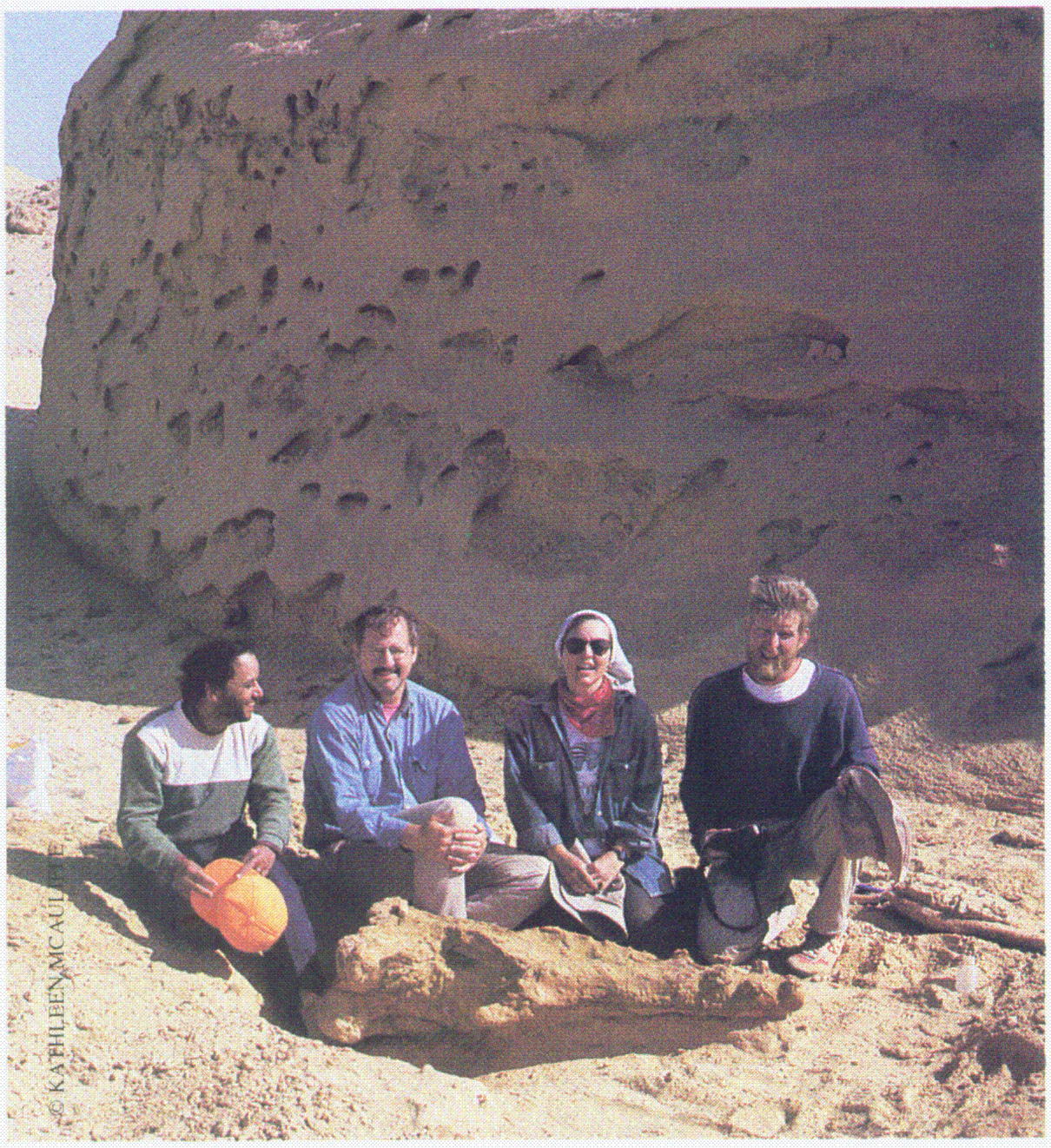

skeleton was frequently mounted in a serpentine posture—sometimes with extra vertebrae tacked onto its spine—and displayed in Victorian exhibits that liberally mixed science and showmanship.

Against this colorful backdrop of confusion and intrigue, it tickles Gingerich that the truth about the fossil has proven even stranger than the fiction. The novelty of feet on a whale is testimony to a fascinating—and long-obscured—chapter in natural history. Since at least as far back as the Greeks, humans have known that whales were not simply big fish. They are warm-blooded, have vestigial hairs in the form of whiskers, give birth to live young, and even have a minute remnant of the thigh bone embedded in their ventral wall. In short, they display a collection of traits unique to mammals. This provided the most solid clue to their origins, for all mammals evolved on land in the early Mesozoic era during the age of dinosaurs.

Beyond that, little more was known about the roots of the cetacean clan. What type of mammal was its terrestrial ancestor? And when did it begin its seaward migration?

A number of scientists argued that whales emerged from a large-bodied group of mammals called mesonychids, which lived 60 to 37 million years ago. The mesonychids, which ranged from the size of a house cat to a grizzly bear, arrived on the scene at just the right time to be the progenitors of whales. And while many mesonychids grazed on vegetation, others preferred meat—including fish. Similarities between the teeth of mesonychids and early whales had even sparked taxonomic disputes. On a field trip to Pakistan in 1975, Gingerich pulled the tooth of a mesonychid out of an ancient nummulite bed. "I was surprised to find part of a land-dwelling mammal in a seabed," he says. "Then I thought, this looks more like a whale tooth." He recommended the fossil be reclassified as a primitive whale.

Subsequent expeditions to Pakistan provided more evidence of a direct link between mesonychids and whales. In another marine bed of roughly the

Left, top: White strings mark a grid of one-meter squares where William Sanders and El-Said Hashem Sherif work on a *Basilosaurus isis* skeleton. Left, bottom: El-Said Hashem Sherif, Philip Gingerich, Holly Smith, and William Sanders gather around the excavated skull of a Cairo Geological Museum specimen of the footed whale.

same age, Gingerich found a fossil with an incongruous mixture of characteristics from each group. "The skeleton had a front limb that was quite doglike," he reports. "Yet its skull seemed to belong to a whale." Not only were its teeth typical of a primitive cetacean, but its well-preserved ear bones were large and dense—an adaptation seen in later whales for underwater hearing. A still older skull showed only the beginning of this ear modification—but it had the elongated snout of a whale. Although nothing of the animal remains below the neck, Gingerich assumes it was also a doglike amphibian. He dubbed this 50-million-year-old fossil *Pakicetus* and concluded that it was close to the granddaddy of all whales.

Not everyone was convinced. To be sure, most paleontologists could see merit in his reasoning, but holes—and occasional chasms—in the fossil record left too much room for doubt. Explains Andre Wyss, a paleontologist at the University of California in Santa Barbara: "The highly transformed appearance of modern whales—especially the absence of legs—makes it extremely difficult to reconstruct their link to land mammals."

Put another way, Gingerich's theory needed to be placed on surer footing. Enter *Basilosaurus*. The unveiling of its now famous feet does not take all the guesswork out of whale evolution, but the anatomy of the appendage offers some tantalizing hints. *Basilosaurus*, which made its debut ten million years after *Pakicetus*, is far enough along the path toward becoming a whale that its affiliation in this group is indisputable. Yet, just as Gingerich and others had predicted, its foot bears the imprint of a mesonychid.

Basilosaurus has no first toe and has virtually lost the second toe (it's the size of a pearl), but the third, fourth, and fifth toes are well developed. Most telling, these toes are symmetrically arranged around the third and fourth digits, which are by far the largest. In Gingerich's view, this pattern suggests that whales emerged from the even-toed (or so-called "cloven hoof") lineage of the mesonychid stock. If so, the closest living relatives of cetaceans would be cows, camels, and other cloven-hoof mammals who are believed to be offshoots of the less-adventurous side of the clan that stayed on terra firma.

On the surface of things, a connection between a grass-chomping holstein and a majestic blue whale would seem outrageous. But another set of clues garnered far afield of paleontology also supports such a relationship. Comparative studies of fetal blood sugar, blood composition, chromosomes, insulin, uterine morphology, and tooth-enamel microstructures all point to the same conclusion.

What could have prompted one branch of the mesonychid family to return to the sea from which life first evolved? As Gingerich underscores, this "backward" trend in evolution is scarcely unique in the history of whales. During the age when dinosaurs reigned supreme, reptiles such as the paddle-legged plesiosaur and lizardlike mosasaur became very well adapted to the marine environment. Millions of years later, crocodiles, iguanas, and other reptiles followed their example. Among the marine mammals, sea cows emerged at the same time as whales and have also severed all ties to the land. Although no other mammals have become fully aquatic, seals, sea lions, and walruses have taken up part-time residence in the ocean. So, too, have an exotic menagerie of extinct mammals. Newly unearthed fossils from the Pacific Northwest attest to the existence of a 20-million-year old "beach bear" that munched on mollusks. And in Peru, scientists found evidence of an amphibious giant sloth that lived in coastal pools as recently as

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five million years ago.

Of the land mammals now alive, otters and polar bears would appear to be next on the diving board. At least one bird also has become a formidable swimmer. The penguin, whose ancestors transcended gravity to soar into the skies, has forfeited flight, adapting wings into flippers.

These species that currently straddle environments are particularly revealing to evolutionary biologists. They suggest that one major allure of the sea is more abundant resources. Consider the polar bear. Observes Lawrence Barnes, curator of the Natural History Museum of Los Angeles County: "No solely terrestrial animal in the Arctic grows anywhere close to the size of a polar bear. The ocean offers it far more opportunity for food than snow-covered rocks."

While enjoying plentiful food, it helps if no other heavy-weight competitor has claimed the same meal first. Shortly after the evolution of flowering plants, for example, primitive sea cows entered the ocean to harvest the rich bloom of seagrasses. Owing to priority, they remain the only large herbivore of coastal waters to this day. Should they suddenly vanish, however, experts predict another animal—perhaps a hippopotamus—would soon fill the niche. As Daryl Domning, a paleontologist at Howard University in Washington, D.C., points out: "Hippos eat grass and spend lots of time submerged in water so they're already well poised to exploit such an opportunity."

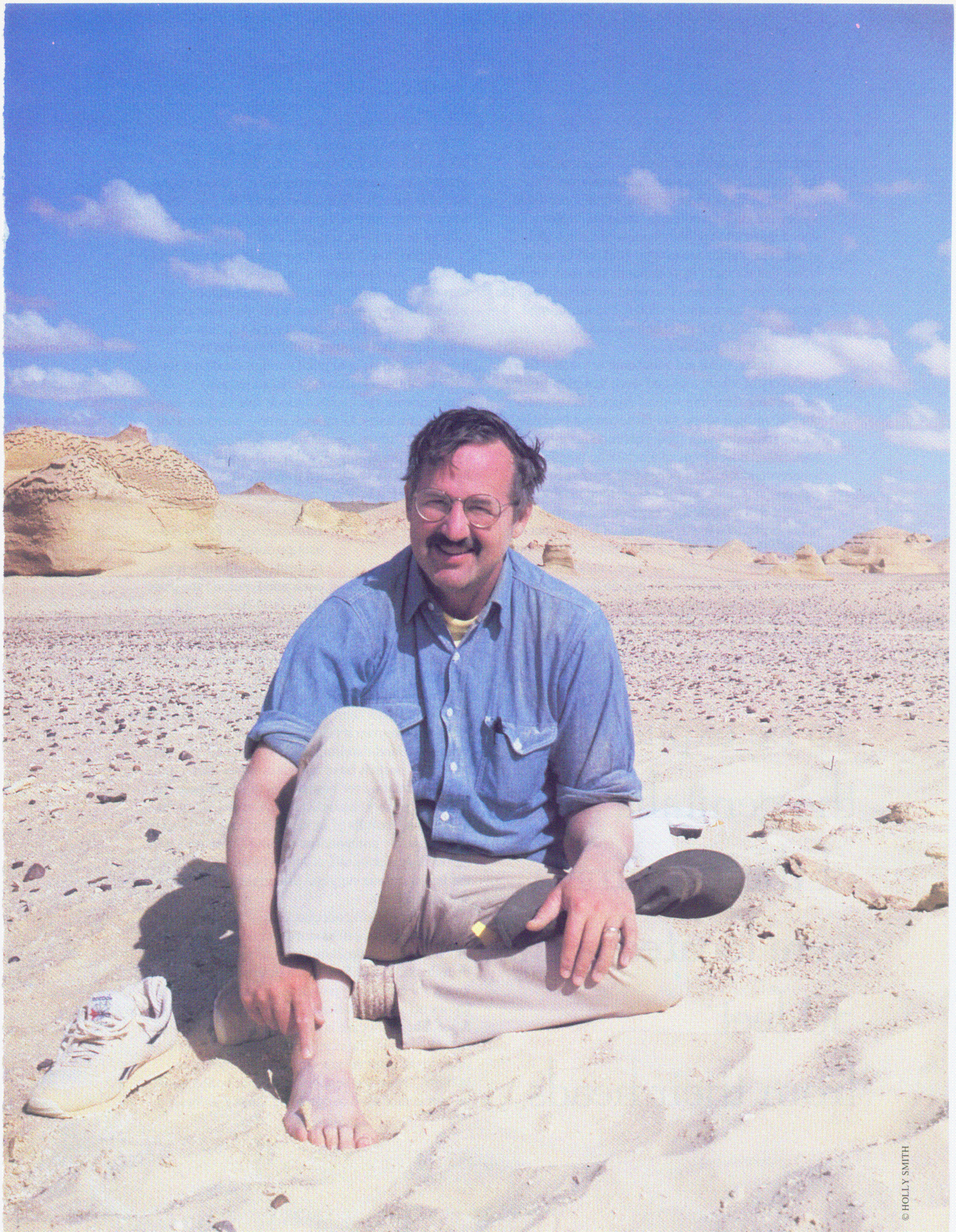
The phenomenal success of whales, Gingerich believes, can likewise be attributed to an absence of competition during the years that gave them a powerful head start at sea. Fifteen-million years before their advent, the great marine reptiles had conveniently exited with the dinosaurs, opening a vacancy for a big predator. What's more, the Eocene-epoch seas were calm, warm as a bath, and teeming with fishes.

From this piecemeal picture of how things were, evolutionary biologists have distilled their own version of the "big splash"—that historic moment that foreshadowed the rise of cetaceans. Gingerich's favorite account features a shaggy, wolf-sized mesonychid with a striking resemblance to *Pakicetus*. Its brain is not much larger than a walnut, but what it lacks in intelligence it makes up for in sharp-toothed avarice. Spread beneath its rocky perch is a delectable seafood banquet. Something darts beneath the waves. In a moment of unpremeditated portent, the protagonist makes a stab at a new life-style.

"The animal probably started out like a grizzly bear, which goes into the water seasonally," says Gingerich. "Then it became otterlike. Eventually it ventured further from the coast like a seal. And one day it doesn't turn around." What happens next is the subject that now preoccupies Gingerich. When does an arm become a flipper, or a tail become a fluke? How long did whales retain their legs? "I'm interested in the pace of evolution—whether it happens gradually or in sudden spurts," he explains.

Whales were not initially the focus of his research. As curator of the University of Michigan's Museum of Paleontology, Gingerich established a name for himself by amassing one of the world's best collections of early land mammals. But as his research progressed, he began to wonder about the parallel development of early aquatic mammals. In 1983, he was introduced to Zeuglodon Valley by Elwyn Simons, director of Duke University's Primate Center, who had come to the eastern edge of the Fayum to excavate terrestrial specimens. Since then, Gingerich and a handful of American colleagues have returned every alternate year to excavate marine fossils in collaboration with paleontologists from the Egyptian Geological

Paleontologist Philip Gingerich's bare foot holds the tiny toe bone of a 50-foot-long footed whale.



Survey and Mining Authority. This joint enterprise operates as a satellite of Simons' larger encampment, which provides weekly rations from Cairo.

As an outpost of an outpost, life at Zeuglodon Valley is a daily exercise in hardship. Water is so scarce that a sponge bath is viewed as an indulgence. The staples are canned beef and bread so brittle that it cracks in your hand. The days are long and the work arduous. The wind quickly undoes the excavator's labor, and, to add to the insult, sand blasts eyeballs. Goggles are essential. So, too, are a strong back and patience.

Of course, there are handsome rewards—like the discovery of whale toes and teeth that glitter in the sun because their thin film of enamel is still intact after 40 million years. But these are not everyday finds. To do this year after year requires a hunger to understand how pieces of a scientific puzzle fit together and a love of bones that borders on a perversion. Smith, a physical anthropologist by training and a whale specialist through involvement in her husband's work, jokingly calls it a "morbid streak." Her first love was not paleontology—but Egyptology. Since she was eight years old, she wanted "to dig up treasures and be an archaeologist." In hindsight, she realizes it was the mummies that enthralled her. "My attitude was, 'Show me the bodies!'" she says, widening her cobalt-blue eyes in mockery of that impressionable girl.

To be explicit, the genitalia of these animals were located some 30 feet from their heads

For Gingerich, on the other hand, paleontology holds the lure of forbidden fruit. The child of Mennonites, Gingerich never learned about evolution at home. "It was a taboo topic," he says. "So when I went out to a dig in Wyoming during my college years, I was instantly captivated."

Gingerich and Smith have not let any time go to waste in "paleontologist's paradise." During five seasons in the valley, their team has mapped 340 whales. If they could dissolve the skeletons out of the surrounding cliffs, they'd expect to find at least three times that number. Only about one in 50 fossils, however, is in good enough condition for the crew to bother excavating it. In addition to *Basilosaurus,* the fossils include five smaller species of extinct whales. Gingerich is now certain that at least one of these species had legs. In good time, he expects to prove that all of them did. His hunch is based on badly weathered fragments of pelvic girdles and leg bones.

Owing to sheer size, *Basilosaurus* is by far the best-preserved of the bunch. In death, its ventral tendons contracted, pulling the giant into a fetal position that belies its menacing posture in life. Today, the bent spines of these animals trace huge question marks in the sand.

Through their grave-robbing, Gingerich's team has assembled a nearly complete mosaic of the titan. They have proven it is a superb intermediate between a land-dwelling mesonychid and a modern whale. Its nostrils have moved midway back on the snout, intimating the beginnings of a blowhole. Its front limbs have expanded into flippers, but, unlike the rigid hydrofoils of modern whales, they bend at the elbow. By comparison, its hind limbs are vastly reduced. As for its tail, a point of flexion in one of the last vertebrae suggests *Basilosaurus* had already sprouted a fluke.

As every fossil collector knows, it's notoriously difficult to deduce behavior from bones. But this much is certain: *Basilosaurus* was better at eating than thinking. Bill Sanders, a paleontologist with a knack for exhuming powder-soft bones intact, shows off a pristine skull—the result of a week's labor. The brain case is no bigger than a rolled-up fist. In contrast, the cavities that held the muscle to operate the claptrap jaws take up six times that volume. "No trace here yet of the big brains found in later cetaceans like dolphins," says Sanders.

Nor does *Basilosaurus* appear to have been much of a diver. "Look at its cricket-bat-shaped ribs," says Sanders. "You'd never see that on today's whales. I think those heavy ribs were to ballast the animal so that its head wouldn't pop out of the water when its lungs filled with air."

Basilosaurus was great for its time—the "Cadillac of whales," as Sanders puts it. But it was almost certainly an evolutionary dead end. Its long, string-bean proportions, cricket-bat ribs, and other idiosyncrasies suggest that it wandered too far from the mainstream to be a direct ancestor of modern whales. Gingerich believes one of its smaller cousins at Zeuglodon Valley was much more likely to have provided the stem stock. His favorite candidate is a 15-footer called *Prozeuglodon atrox*. "It had generalized features and the compact build of a modern whale so the potential was certainly there," he argues.

Those are the broad strokes of whale evolution. But many details remain to be filled in. Just when whales lost their hind limbs is still not known. Some scientists now theorize that the appendage may have been retained by the first modern toothed and baleen whales, which made their debut about 35 million years ago. The very existence of whale legs poses an even deeper riddle. While the missing link speaks volumes about the transition from the land to the sea, it also mystifies as much as clarifies. Indeed, Gingerich and Smith never expected to find a whale with feet. Not that they doubted the animal's terrestrial origins for a moment. Rather, they assumed that such vestiges of their former life on land would have been shed long before their ancestors became fully aquatic.

When Barnes of Los Angeles's Natural History Museum started to put hind limbs on display models of primitive whales in the late 1970s, Gingerich and Smith were among a large group of his peers who laughed at his flight of fancy. In the majority opinion, a stumplike remnant on a whale was plausible. But legs complete with fully formed toes stretched the limits of credibility. Such a thing would imply the appendage had a function. And as Barnes recalls: "Everyone knew it would be ridiculous for whales to have feet."

So much for preconceptions. Now that Gingerich and Smith have been tripped up by their own discovery, the pressure is on to find a purpose for the evolutionary surprise. So far, their best hunch is that primitive whales used their feet to grasp their partners while mating. The researchers argue that "copulatory guides" would have been especially important for a long, snaky whale like *Basilosaurus*. To be explicit, the genitalia of these animals were located some 30 feet from their heads, making sex in an undulating sea a tricky proposition.

Not everyone buys their argument. "Those ancient whales had flexible front flippers so they could probably hold hands," says Barnes, "but I doubt they could hold feet." His favorite theory: They used their lower appendage to "tippy toe" through the shallows.

With further excavation of the smaller whales that Gingerich now presumes to have feet, perhaps the mystery will finally be resolved. But excavation is painstaking work, and the field season is once again coming to a close with less accomplished than hoped.

It takes four groaning people to heave Sanders' prize *Basilosaurus* skull onto a mattress in the back of the truck. It's too big for a box—so its plaster cast and a strip of foam will be its only protection against the jarring ride over the dunes. Fortunately, the skull's final destination is Cairo—not the United States. Then an air crate would be essential, and Gingerich would have to deliver the coup de grace—cracking the skull with one hard whack between the eyes to make it fit into a crate. According to legend, in a previous year, he split a skull into two clean pieces. Sanders still cringes at the memory. "Happy endings," he notes, "are never guaranteed."

Thanks to *Basilosaurus* in the back, the suspension springs of the truck are less inclined to eject us from our seats on the roaring ascent up the steep, sandy embankment. Ahead of us, far out of sight, is a pyramid that now seems as new as a skyscraper. We're moving up out of the valley and forward in time. But Gingerich seems lost in the past. The truck stalls in the dunes as his eyes wander from the tire tracks to a swelling in the desert floor. Another question mark catches his attention.

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