

## FINDING YOUR INNER FISH

**T**ypical summers of my adult life are spent in snow and sleet, cracking rocks on cliffs well north of the Arctic Circle. Most of the time I freeze, get blisters, and find absolutely nothing. But if I have any luck, I find ancient fish bones. That may not sound like buried treasure to most people, but to me it is more valuable than gold.

Ancient fish bones can be a path to knowledge about who we are and how we got that way. We learn about our own bodies in seemingly bizarre places, ranging from the fossils of worms and fish recovered from rocks from around the world to the DNA in virtually every animal alive on earth today. But that does not explain my confidence about why skeletal remains from the past—and the remains of fish, no less—offer clues about the fundamental structure of our bodies.

How can we visualize events that happened millions and, in many cases, billions of years ago? Unfortunately, there were no eyewitnesses; none of us was around. In fact, nothing that talks or has a mouth or even a head was around for most of this time. Even worse, the animals that existed back then have been dead and buried for so long their bodies are only rarely preserved. If you consider that over 99 percent of all species that ever lived are now extinct, that only a very small fraction are preserved as fossils, and that an even smaller fraction still are ever found, then any attempt to see our past seems doomed from the start.

### DIGGING FOSSILS—SEEING OURSELVES

I first saw one of our inner fish on a snowy July afternoon while studying 375-million-year-old rocks on Ellesmere Island, at a latitude about 80 degrees north. My colleagues and I had traveled up to this desolate part of the world to try to discover one of the key stages in the shift from fish to land-living animals. Sticking out of the rocks was the snout of a fish. And not just any fish: a fish with a flat head. Once we saw the flat head we knew we were on to something. If more of this skeleton were found inside the cliff, it would reveal the early stages in the history of our skull, our neck, even our limbs.

What did a flat head tell me about the shift from sea to land? More relevant to my personal safety and comfort, why was I in the Arctic and not in Hawaii? The answers to these questions lie in the story of how we find fossils and how we use them to decipher our own past.

Fossils are one of the major lines of evidence that we use to understand ourselves. (Genes and embryos are others, which I will discuss later.) Most people do not know that finding fossils is something we can often do with surprising precision and predictability. We work at home to maximize our chances of success in the field. Then we let luck take over.

The paradoxical relationship between planning and chance is best described by Dwight D. Eisenhower's famous remark about warfare: "In preparing for battle, I have found that planning is essential, but plans are useless." This captures field paleontology in a nutshell. We make all kinds of plans to get us to promising fossil sites. Once we're there, the entire field plan may be thrown out the window. Facts on the ground can change our best-laid plans.

Yet we can design expeditions to answer specific scientific ques-

tions. Using a few simple ideas, which I'll talk about below, we can predict where important fossils might be found. Of course, we are not successful 100 percent of the time, but we strike it rich often enough to make things interesting. I have made a career out of doing just that: finding early mammals to answer questions of mammal origins, the earliest frogs to answer questions of frog origins, and some of the earliest limbed animals to understand the origins of land-living animals.

In many ways, field paleontologists have a significantly easier time finding new sites today than we ever did before. We know more about the geology of local areas, thanks to the geological exploration undertaken by local governments and oil and gas companies. The Internet gives us rapid access to maps, survey information, and aerial photos. I can even scan your backyard for promising fossil sites right from my laptop. To top it off, imaging and radiographic devices can see through some kinds of rock and allow us to visualize the bones inside.

Despite these advances, the hunt for the important fossils is much what it was a hundred years ago. Paleontologists still need to look at rock—literally to crawl over it—and the fossils within must often be removed by hand. So many decisions need to be made when prospecting for and removing fossil bone that these processes are difficult to automate. Besides, looking at a monitor screen to find fossils would never be nearly as much fun as actually digging for them.

What makes this tricky is that fossil sites are rare. To maximize our odds of success, we look for the convergence of three things. We look for places that have rocks of the right age, rocks of the right type to preserve fossils, and rocks that are exposed at the surface. There is another factor: serendipity. That I will show by example.

Our example will show us one of the great transitions in the history of life: the invasion of land by fish. For billions of years, all

life lived only in water. Then, as of about 365 million years ago, creatures also inhabited land. Life in these two environments is radically different. Breathing in water requires very different organs than breathing in air. The same is true for excretion, feeding, and moving about. A whole new kind of body had to arise. At first glance, the divide between the two environments appears almost unbridgeable. But everything changes when we look at the evidence; what looks impossible actually happened.

In seeking rocks of the right age, we have a remarkable fact on our side. The fossils in the rocks of the world are not arranged at random. Where they sit, and what lies inside them, is most definitely ordered, and we can use this order to design our expeditions. Billions of years of change have left layer upon layer of different kinds of rock in the earth. The working assumption, which is easy to test, is that rocks on the top are younger than rocks on the bottom; this is usually true in areas that have a straightforward, layer-cake arrangement (think the Grand Canyon). But movements of the earth's crust can cause faults that shift the position of the layers, putting older rocks on top of younger ones. Fortunately, once the positions of these faults are recognized, we can often piece the original sequence of layers back together.

The fossils inside these rock layers also follow a progression, with lower layers containing species entirely different from those in the layers above. If we could quarry a single column of rock that contained the entire history of life, we would find an extraordinary range of fossils. The lowest layers would contain little visible evidence of life. Layers above them would contain impressions of a diverse set of jellyfish-like things. Layers still higher would have creatures with skeletons, appendages, and various organs, such as eyes. Above those would be layers with the first animals to have backbones. And so on. The layers with the first people would be found higher still. Of course, a single column containing the entirety of earth history does not exist. Rather, the rocks in each

location on earth represent only a small sliver of time. To get the whole picture, we need to put the pieces together by comparing the rocks themselves and the fossils inside them, much as if working a giant jigsaw puzzle.

That a column of rocks has a progression of fossil species probably comes as no surprise. Less obvious is that we can make detailed predictions about what the species in each layer might actually look like by comparing them with species of animals that are alive today; this information helps us to predict the kinds of fossils we will find in ancient rock layers. In fact, the fossil sequences in the world's rocks can be predicted by comparing ourselves with the animals at our local zoo or aquarium.

How can a walk through the zoo help us predict where we should look in the rocks to find important fossils? A zoo offers a great variety of creatures that are all distinct in many ways. But let's not focus on what makes them distinct; to pull off our prediction, we need to focus on what different creatures share. We can then use the features common to all species to identify groups of creatures with similar traits. All the living things can be organized and arranged like a set of Russian nesting dolls, with smaller groups of animals comprised in bigger groups of animals. When we do this, we discover something very fundamental about nature.

Every species in the zoo and the aquarium has a head and two eyes. Call these species "Everythings." A subset of the creatures with a head and two eyes has limbs. Call the limbed species "Everythings with limbs." A subset of these headed and limbed creatures has a huge brain, walks on two feet, and speaks. That subset is us, humans. We could, of course, use this way of categorizing things to make many more subsets, but even this threefold division has predictive power.

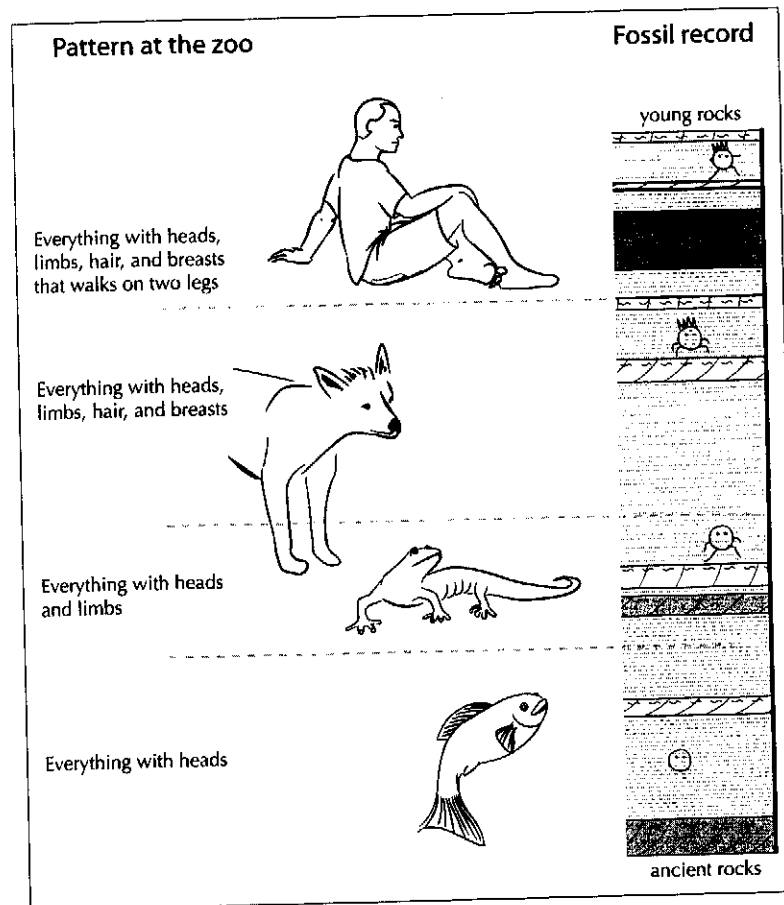
The fossils inside the rocks of the world generally follow this order, and we can put it to use in designing new expeditions. To use the example above, the first member of the group "Every-

things," a creature with a head and two eyes, is found in the fossil record well before the first "Everything with limbs." More precisely, the first fish (a card-carrying member of the "Everything") appears before the first amphibian (an "Everything with limbs"). Obviously, we refine this by looking at more kinds of animals and many more characteristics that groups of them share, as well as by assessing the actual age of the rocks themselves.

In our labs, we do exactly this type of analysis with thousands upon thousands of characteristics and species. We look at every bit of anatomy we can, and often at large chunks of DNA. There is so much data that we often need powerful computers to show us the groups within groups. This approach is the foundation of biology, because it enables us to make hypotheses about how creatures are related to one another.

Besides helping us refine the groupings of life, hundreds of years of fossil collection have produced a vast library, or catalogue, of the ages of the earth and the life on it. We can now identify general time periods when major changes occurred. Interested in the origin of mammals? Go to rocks from the period called the Early Mesozoic; geochemistry tells us that these rocks are likely about 210 million years old. Interested in the origin of primates? Go higher in the rock column, to the Cretaceous period, where rocks are about 80 million years old.

The order of fossils in the world's rocks is powerful evidence of our connections to the rest of life. If, digging in 600-million-year-old rocks, we found the earliest jellyfish lying next to the skeleton of a woodchuck, then we would have to rewrite our texts. That woodchuck would have appeared earlier in the fossil record than the first mammal, reptile, or even fish—before even the first worm. Moreover, our ancient woodchuck would tell us that much of what we think we know about the history of the earth and life on it is wrong. Despite more than 150 years of people looking for



What we discover on our walk through the zoo mirrors how fossils are laid out in the rocks of the world.

fossils—on every continent of earth and in virtually every rock layer that is accessible—this observation has never been made.

Let's now return to our problem of how to find relatives of the first fish to walk on land. In our grouping scheme, these creatures are somewhere between the "Everything's" and the "Everything's"

with limbs." Map this to what we know of the rocks, and there is strong geological evidence that the period from 380 million to 365 million years ago is the critical time. The younger rocks in that range, those about 360 million years old, include diverse kinds of fossilized animals that we would all recognize as amphibians or reptiles. My colleague Jenny Clack at Cambridge University and others have uncovered amphibians from rocks in Greenland that are about 365 million years old. With their necks, their ears, and their four legs, they do not look like fish. But in rocks that are about 385 million years old, we find whole fish that look like, well, fish. They have fins, conical heads, and scales; and they have no necks. Given this, it is probably no great surprise that we should focus on rocks about 375 million years old to find evidence of the transition between fish and land-living animals.

We have settled on a time period to research, and so have identified the layers of the geological column we wish to investigate. Now the challenge is to find rocks that were formed under conditions capable of preserving fossils. Rocks form in different kinds of environments and these initial settings leave distinct signatures on the rock layers. Volcanic rocks are mostly out. No fish that we know of can live in lava. And even if such a fish existed, its fossilized bones would not survive the superheated conditions in which basalts, rhyolites, granites, and other igneous rocks are formed. We can also ignore metamorphic rocks, such as schist and marble, for they have undergone either superheating or extreme pressure since their initial formation. Whatever fossils might have been preserved in them have long since disappeared. Ideal to preserve fossils are sedimentary rocks: limestones, sandstones, siltstones, and shales. Compared with volcanic and metamorphic rocks, these are formed by more gentle processes, including the action of rivers, lakes, and seas. Not only are animals likely to live in such environments, but the sedimentary processes make these rocks more likely places to preserve fossils. For example, in an

ocean or lake, particles constantly settle out of the water and are deposited on the bottom. Over time, as these particles accumulate, they are compressed by new, overriding layers. The gradual compression, coupled with chemical processes happening inside the rocks over long periods of time, means that any skeletons contained in the rocks stand a decent chance of fossilizing. Similar processes happen in and along streams. The general rule is that the gentler the flow of the stream or river, the better preserved the fossils.

Every rock sitting on the ground has a story to tell: the story of what the world looked like as that particular rock formed. Inside the rock is evidence of past climates and surroundings often vastly different from those of today. Sometimes, the disconnect between present and past could not be sharper. Take the extreme example of Mount Everest, near whose top, at an altitude of over five miles, lie rocks from an ancient sea floor. Go to the North Face almost within sight of the famous Hillary Step, and you can find fossilized seashells. Similarly, where we work in the Arctic, temperatures can reach minus 40 degrees Fahrenheit in the winter. Yet inside some of the region's rocks are remnants of an ancient tropical delta, almost like the Amazon: fossilized plants and fish that could have thrived only in warm, humid locales. The presence of warm-adapted species at what today are extreme altitudes and latitudes attests to how much our planet can change: mountains rise and fall, climates warm and cool, and continents move about. Once we come to grips with the vastness of time and the extraordinary ways our planet has changed, we will be in a position to put this information to use in designing new fossil-hunting expeditions.

If we are interested in understanding the origin of limbed animals, we can now restrict our search to rocks that are roughly 375 million to 380 million years old and that were formed in oceans, lakes, or streams. Rule out volcanic rocks and metamorphic rocks, and our search image for promising sites comes into better focus.

We are only partly on the way to designing a new expedition, however. It does us no good if our promising sedimentary rocks of the right age are buried deep inside the earth, or if they are covered with grass, or shopping malls, or cities. We'd be digging blindly. As you can imagine, drilling a well hole to find a fossil offers a low probability of success, rather like throwing darts at a dartboard hidden behind a closet door.

The best places to look are those where we can walk for miles over the rock to discover areas where bones are "weathering out." Fossil bones are often harder than the surrounding rock and so erode at a slightly slower rate and present a raised profile on the rock surface. Consequently, we like to walk over bare bedrock, find a smattering of bones on the surface, then dig in.

So here is the trick to designing a new fossil expedition: find rocks that are of the right age, of the right type (sedimentary), and well exposed, and we are in business. Ideal fossil-hunting sites have little soil cover and little vegetation, and have been subject to few human disturbances. Is it any surprise that a significant fraction of discoveries happen in desert areas? In the Gobi Desert. In the Sahara. In Utah. In Arctic deserts, such as Greenland.

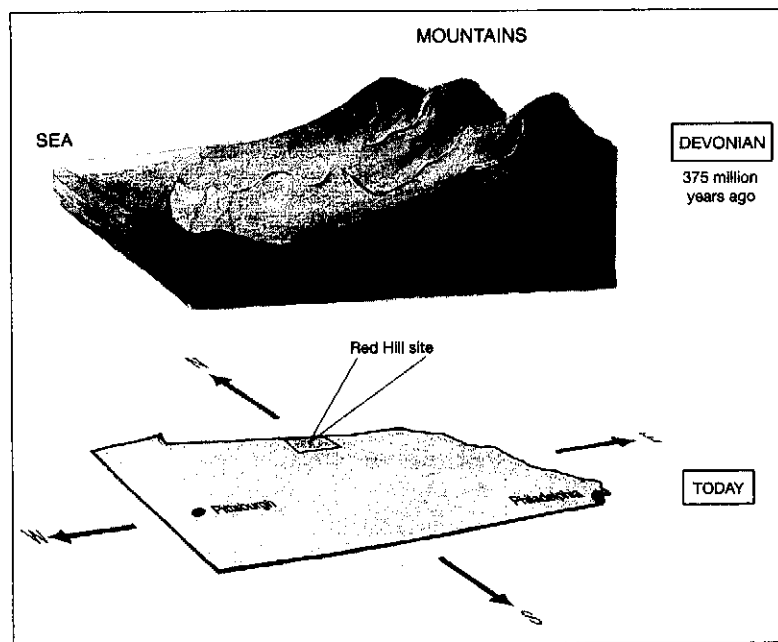
This all sounds very logical, but let's not forget serendipity. In fact, it was serendipity that put our team onto the trail of our inner fish. Our first important discoveries didn't happen in a desert, but along a roadside in central Pennsylvania where the exposures could hardly have been worse. To top it off, we were looking there only because we did not have much money.

It takes a lot of money and time to go to Greenland or the Sahara Desert. In contrast, a local project doesn't require big research grants, only money for gas and turnpike tolls. These are critical variables for a young graduate student or a newly hired college teacher. When I started my first job in Philadelphia, the lure was a group of rocks collectively known as the Catskill Formation of Pennsylvania. This formation has been extensively

studied for over 150 years. Its age was well known and spanned the Late Devonian. In addition, its rocks were perfect to preserve early limbed animals and their closest relatives. To understand this, it is best to have an image of what Pennsylvania looked like back in the Devonian. Remove the image of present-day Philadelphia, Pittsburgh, or Harrisburg from your mind and think of the Amazon River delta. There were highlands in the eastern part of the state. A series of streams running east to west drained these mountains, ending in a large sea where Pittsburgh is today.

It is hard to imagine better conditions to find fossils, except that central Pennsylvania is covered in towns, forests, and fields. As for the exposures, they are mostly where the Pennsylvania Department of Transportation (PennDOT) has decided to put big roads. When PennDOT builds a highway, it blasts. When it blasts, it exposes rock. It's not always the best exposure, but we take what we can get. With cheap science, you get what you pay for.

And then there is also serendipity of a different order: in 1993, Ted Daeschler arrived to study paleontology under my supervision. This partnership was to change both our lives. Our different temperaments are perfectly matched: I have ants in my pants and am always thinking of the next place to look; Ted is patient and knows when to sit on a site to mine it for its riches. Ted and I began a survey of the Devonian rocks of Pennsylvania in hopes of finding new evidence on the origin of limbs. We began by driving to virtually every large roadcut in the eastern part of the state. To our great surprise, shortly after we began the survey, Ted found a marvelous shoulder bone. We named its owner *Hynerpeton*, a name that translates from Greek as "little creeping animal from Hyner." Hyner, Pennsylvania, is the nearest town. *Hynerpeton* had a very robust shoulder, which indicates a creature that likely had very powerful appendages. Unfortunately, we were never able to find the whole skeleton of the animal. The exposures were too



Along the roads in Pennsylvania, we were looking at an ancient river delta, much like the Amazon today. The state of Pennsylvania (bottom) with the Devonian topography mapped above it.

limited. By? You guessed it: vegetation, houses, and shopping malls.

After the discovery of *Hynierpeton* and other fossils from these rocks, Ted and I were champing at the bit for better-exposed rock. If our entire scientific enterprise was going to be based on recovering bits and pieces, then we could address only very limited questions. So we took a “textbook” approach, looking for well-exposed rocks of the right age and the right type in desert regions, meaning that we wouldn’t have made the biggest discovery of our careers if not for an introductory geology textbook.

Originally we were looking at Alaska and the Yukon as potential venues for a new expedition, largely because of relevant discover-

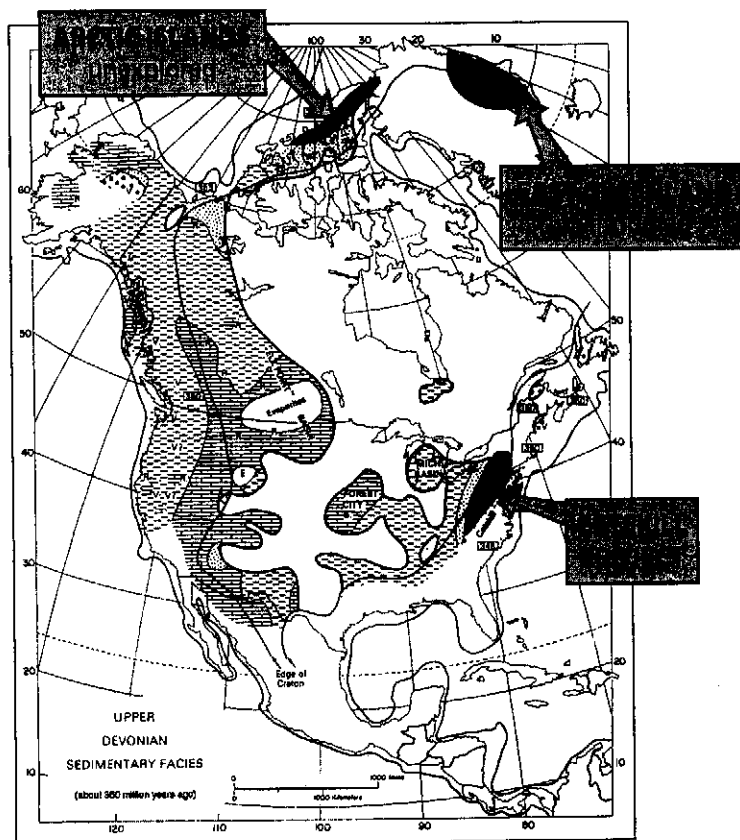
ies made by other teams. We ended up getting into a bit of an argument/debate about some geological esoterica, and in the heat of the moment, one of us pulled the lucky geology textbook from a desk. While riffling through the pages to find out which one of us was right, we found a diagram. The diagram took our breath away; it showed everything we were looking for.

The argument stopped, and planning for a new field expedition began.

On the basis of previous discoveries made in slightly younger rocks, we believed that ancient freshwater streams were the best environment in which to begin our hunt. This diagram showed three areas with Devonian freshwater rocks, each with a river delta system. First, there is the east coast of Greenland. This is home to Jenny Clack’s fossil, a very early creature with limbs and one of the earliest known tetrapods. Then there is eastern North America, where we had already worked, home to *Hynierpeton*. And there is a third area, large and running east–west across the Canadian Arctic. There are no trees, dirt, or cities in the Arctic. The chances were good that rocks of the right age and type would be extremely well exposed.

The Canadian Arctic exposures were well known, particularly to the Canadian geologists and paleobotanists who had already mapped them. In fact, Ashton Embry, the leader of the teams that did much of this work, had described the geology of the Devonian Canadian rocks as identical in many ways to the geology of Pennsylvania’s. Ted and I were ready to pack our bags the minute we read this phrase. The lessons we had learned on the highways of Pennsylvania could help us in the High Arctic of Canada.

Remarkably, the Arctic rocks are even older than the fossil beds of Greenland and Pennsylvania. So the area perfectly fit all three of our criteria: age, type, and exposure. Even better, it was unknown to vertebrate paleontologists, and therefore unprospected for fossils.



The map that started it all. This map of North America captures what we look for in a nutshell. The different kinds of shading reflect where Devonian age rocks, whether marine or freshwater, are exposed. Three areas that were once river deltas are labeled. Modified from figure 13.1, R. H. Dott and R. L. Batten, *Evolution of the Earth* (New York: McGraw-Hill, 1988). Reproduced with the permission of The McGraw-Hill Companies.

Our new challenges were totally different from those we faced in Pennsylvania. Along the highways in Pennsylvania, we risked being hit by the trucks that whizzed by as we looked for fossils. In the Arctic we risked being eaten by polar bears, running out of food, or being marooned by bad weather. No longer could we pack

sandwiches in the car and drive to the fossil beds. We now had to spend at least eight days planning for every single day spent in the field, because the rocks were accessible only by air and the nearest supply base was 250 miles away. We could fly in only enough food and supplies for our crew, plus a slender safety margin. And, most important, the plane's strict weight limits meant that we could take out only a small fraction of the fossils that we found. Couple those limitations with the short window of time during which we can actually work in the Arctic every year, and you can see that the frustrations we faced were completely new and daunting.

Enter my graduate adviser, Dr. Farish A. Jenkins, Jr., from Harvard. Farish had led expeditions to Greenland for years and had the experience necessary to pull this venture off. The team was set. Three academic generations: Ted, my former student; Farish, my graduate adviser; and I were going to march up to the Arctic to try to discover evidence of the shift from fish to land-living animal.

There is no field manual for Arctic paleontology. We received gear recommendations from friends and colleagues, and we read books—only to realize that nothing could prepare us for the experience itself. At no time is this more sharply felt than when the helicopter drops one off for the first time in some godforsaken part of the Arctic totally alone. The first thought is of polar bears. I can't tell you how many times I've scanned the landscape looking for white specks that move. This anxiety can make you see things. In our first week in the Arctic, one of the crew saw a moving white speck. It looked like a polar bear about a quarter mile away. We scrambled like Keystone Kops for our guns, flares, and whistles until we discovered that our bear was a white Arctic hare two hundred feet away. With no trees or houses by which to judge distance, you lose perspective in the Arctic.

The Arctic is a big, empty place. The rocks we were interested in are exposed over an area about 1,500 kilometers wide. The crea-

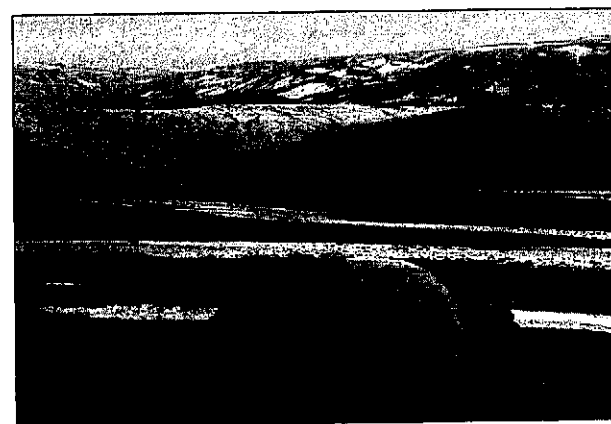


tures we were looking for were about four feet long. Somehow, we needed to home in on a small patch of rock that had preserved our fossils. Reviewers of grant proposals can be a ferocious lot; they light on this kind of difficulty all the time. A reviewer for one of Parish's early Arctic grant proposals put it best. As this referee wrote in his review of the proposal (not cordially, I might add), the odds of finding new fossils in the Arctic were "worse than finding the proverbial needle in the haystack."

It took us four expeditions to Ellesmere Island over six years to find our needle. So much for serendipity.

We found what we were looking for by trying, failing, and learning from our failures. Our first sites, in the 1999 field season, were way out in the western part of the Arctic, on Melville Island. We did not know it, but we had been dropped off on the edge of an ancient ocean. The rocks were loaded with fossils, and we found many different kinds of fish. The problem was that they all seemed to be deep-water creatures, not the kind we would expect to find in the shallow streams or lakes that gave rise to land-living animals. Using Ashton Embry's geological analysis, in 2000 we decided to move the expedition east to Ellesmere Island, because there the rocks would contain ancient streambeds. It did not take long for us to begin finding pieces of fish bones about the size of a quarter preserved as fossils.

The real breakthrough came toward the end of the field season in 2000. It was just before dinner, about a week before our scheduled pickup to return home. The crew had come back to camp, and we were involved in our early-evening activities: organizing the day's collections, preparing field notes, and beginning to assemble dinner. Jason Downs, then a college undergraduate eager to learn paleontology, hadn't returned to camp on time. This is a cause for worry, as we typically go out in teams; or if we separate, we give each other a definite schedule of when we will make contact again. With polar bears in the area and fierce storms that can roll in



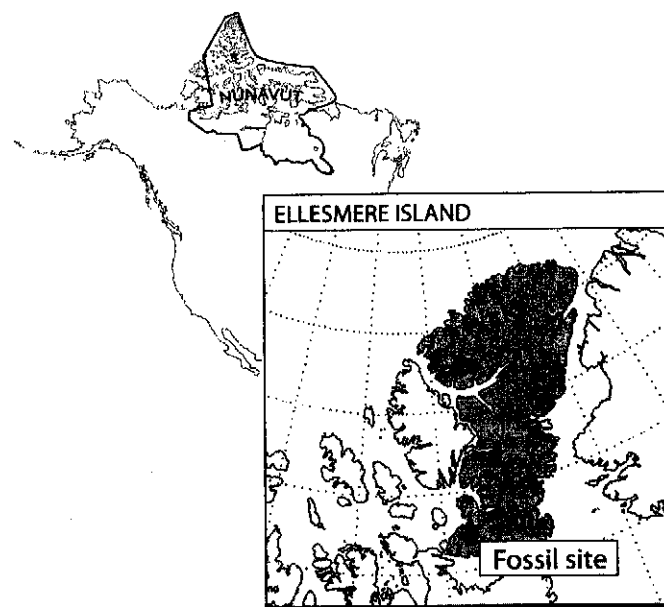
Our camp (top) looks tiny in the vastness of the landscape. My summer home (bottom) is a small tent, usually surrounded by piles of rocks to protect it from fifty-mile-per-hour winds. Photographs by the author.

unexpectedly, we do not take any chances. I remember sitting in the main tent with the crew, the worry about Jason building with each passing moment. As we began to concoct a search plan, I heard the zipper on the tent open. At first all I saw was Jason's head. He had a wild-eyed expression on his face and was out of breath. As Jason entered the tent, we knew we were not dealing

with a polar bear emergency; his shotgun was still shouldered. The cause of his delay became clear as his still shaking hand pulled out handful after handful of fossil bones that had been stuffed into every pocket: his coat, pants, inner shirt, and daypack. I imagine he would have stuffed his socks and shoes if he could have walked home that way. All of these little fossil bones were on the surface of a small site, no bigger than a parking spot for a compact car, about a mile away from camp. Dinner could wait.

With twenty-four hours of daylight in the Arctic summer, we did not have to worry about the setting sun, so we grabbed chocolate bars and set off for Jason's site. It was on the side of a hill between two beautiful river valleys and, as Jason had discovered, was covered in a carpet of fossil fish bones. We spent a few hours picking up the fragments, taking photos, and making plans. This site had all the makings of precisely what we were looking for. We returned the next day with a new goal: to find the exact layer of rock that contained the bones.

The trick was to identify the source of Jason's mess of bone fragments—our only hope of finding intact skeletons. The problem was the Arctic environment. Each winter, the temperature sinks to minus 40 degrees Fahrenheit. In the summer, when the sun never sets, the temperature rises to nearly 50 degrees. The resulting freeze-thaw cycle crumbles the surface rocks and fossils. Each winter they cool and shrink; each summer they heat and expand. As they shrink and swell with each season over thousands of years at the surface, the bones fall apart. Confronted by a jumbled mass of bone spread across the hill, we could not identify any obvious rock layer as their source. We spent several days following the fragment trails, digging test pits, practically using our geological hammers as divining rods to see where in the cliff the bones were emerging. After four days, we exposed the layer and eventually found skeleton upon skeleton of fossil fish, often lying one on



This is where we work: southern Ellesmere Island, in Nunavut Territory, Canada, 1,000 miles from the North Pole.

top of another. We spent parts of two summers exposing these fish.

Failure again: all the fish we were finding were well-known species that had been collected in sites of a similar age in Eastern Europe. To top it off, these fish weren't very closely related to land-living animals. In 2004, we decided to give it one more try. This was a do-or-die situation. The Arctic expeditions were prohibitively expensive and, short of a remarkable discovery, we would have to call it quits.

Everything changed over a period of four days in early July 2004. I was flipping rock at the bottom of the quarry, cracking ice more often than rock. I cracked the ice and saw something that I will never forget: a patch of scales unlike anything else we had yet

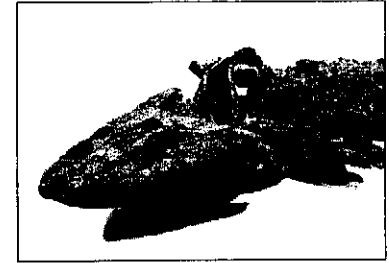
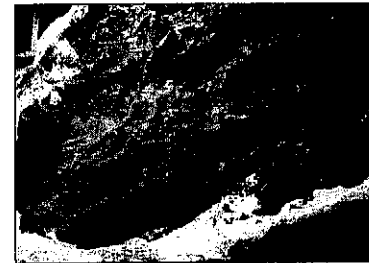
seen in the quarry. This patch led to another blob covered by ice. It looked like a set of jaws. They were, however, unlike the jaws of any fish I had ever seen. They looked as if they might have connected to a flat head.

One day later, my colleague Steve Gatesy was flipping rocks at the top of the quarry. Steve removed a fist-size rock to reveal the snout of an animal looking right out at him. Like my ice-covered fish at the bottom of the pit, it had a flat head. It was new and important. But unlike my fish, Steve's had real potential. We were looking at the front end, and with luck the rest of the skeleton might be safely sitting in the cliff. Steve spent the rest of the summer removing rock from it bit by bit so that we could bring the entire skeleton back to the lab and clean it up. Steve's masterful work with this specimen led to the recovery of one of the finest fossils discovered to date at the water-land transition.

The specimens we brought back to the lab at home were little more than boulders with fossils inside. Over the course of two months, the rock was removed piece by piece, often manually with dental tools or small picks by the preparators in the lab. Every day a new piece of the fossil creature's anatomy was revealed. Almost every time a large section was exposed, we learned something new about the origin of land-living animals.

What we saw gradually emerge from these rocks during the fall of 2004 was a beautiful intermediate between fish and land-living animals. Fish and land-living animals differ in many respects. Fish have conical heads, whereas the earliest land-living animals have almost crocodile-like heads—flat, with the eyes on top. Fish do not have necks: their shoulders are attached to their heads by a series of bony plates. Early land-living animals, like all their descendants, do have necks, meaning their heads can bend independently of their shoulders.

There are other big differences. Fish have scales all over their bodies; land-living animals do not. Also, importantly, fish have



The process of finding fossils begins with a mass in a rock that is gradually removed over time. Here I show a fossil as it travels from the field to the lab and is carefully prepared as a specimen: the skeleton of the new animal. Photograph in upper left by author; other photographs courtesy of Ted Daeschler, Academy of Natural Sciences of Philadelphia.

fins, whereas land-living animals have limbs with fingers, toes, wrists, and ankles. We can continue these comparisons and make a very long list of the ways that fish differ from land-living animals.

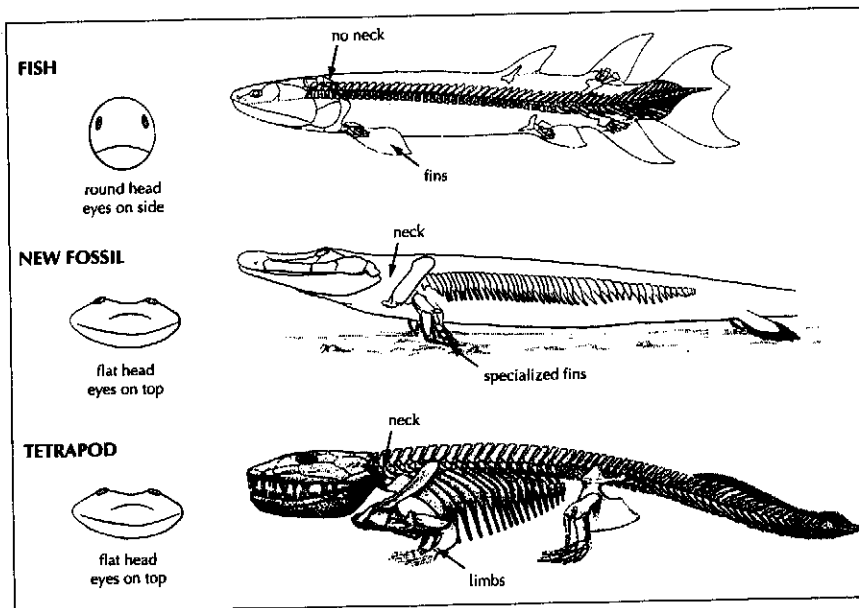
But our new creature broke down the distinction between these two different kinds of animal. Like a fish, it has scales on its back and fins with fin webbing. But, like early land-living animals, it has a flat head and a neck. And, when we look inside the fin, we see bones that correspond to the upper arm, the forearm, even parts of the wrist. The joints are there, too: this is a fish with shoulder, elbow, and wrist joints. All inside a fin with webbing.

Virtually all of the features that this creature shares with land-living creatures look very primitive. For example, the shape and

various ridges on the fish's upper "arm" bone, the humerus, look part fish and part amphibian. The same is true of the shape of the skull and the shoulder.

It took us six years to find it, but this fossil confirmed a prediction of paleontology: not only was the new fish an intermediate between two different kinds of animal, but we had found it also *in the right time period in earth's history and in the right ancient environment*. The answer came from 375-million-year-old rocks, formed in ancient streams.

As the discoverers of the creature, Ted, Farish, and I had the privilege of giving it a formal scientific name. We wanted the name to reflect the fish's provenance in the Nunavut Territory of the Arctic and the debt we owed to the Inuit people for permission to work there. We engaged the Nunavut Council of Elders, for-



This figure says it all. *Tiktaalik* is intermediate between fish and primitive land-living animal.

mally known as the Inuit Qaujimajatuqangit Katimajit, to come up with a name in the Inuktitut language. My obvious concern was that a committee named Inuit Qaujimajatuqangit Katimajit might not propose a scientific name we could pronounce. I sent them a picture of the fossil, and the elders came up with two suggestions, *Siksagiaq* and *Tiktaalik*. We went with *Tiktaalik* for its relative ease of pronunciation for the non-Inuktitut-speaking tongue and because of its meaning in Inuktitut: "large freshwater fish."

*Tiktaalik* was the lead story in a number of newspapers the day after the find was announced in April 2006, including above-the-fold headlines in such places as *The New York Times*. This attention ushered in a week unlike any other in my normally quiet life. Though for me the greatest moment of the whole media blitz was not seeing the political cartoons or reading the editorial coverage and the heated discussions on the blogs. It took place at my son's preschool.

In the midst of the press hubbub, my son's preschool teacher asked me to bring in the fossil and describe it. I dutifully brought a cast of *Tiktaalik* into Nathaniel's class, bracing myself for the chaos that would ensue. The twenty four- and five-year-olds were surprisingly well behaved as I described how we had worked in the Arctic to find the fossil and showed them the animal's sharp teeth. Then I asked what they thought it was. Hands shot up. The first child said it was a crocodile or an alligator. When queried why, he said that like a crocodile or lizard it has a flat head with eyes on top. Big teeth, too. Other children started to voice their dissent. Choosing the raised hand of one of these kids, I heard: No, no, it isn't a crocodile, it is a fish, because it has scales and fins. Yet another child shouted, "Maybe it is both." *Tiktaalik's* message is so straightforward even preschoolers can see it.

For our purposes, there is an even more profound take on *Tiktaalik*. This fish doesn't just tell us about fish; it also contains a

piece of us. The search for this connection is what led me to the Arctic in the first place.

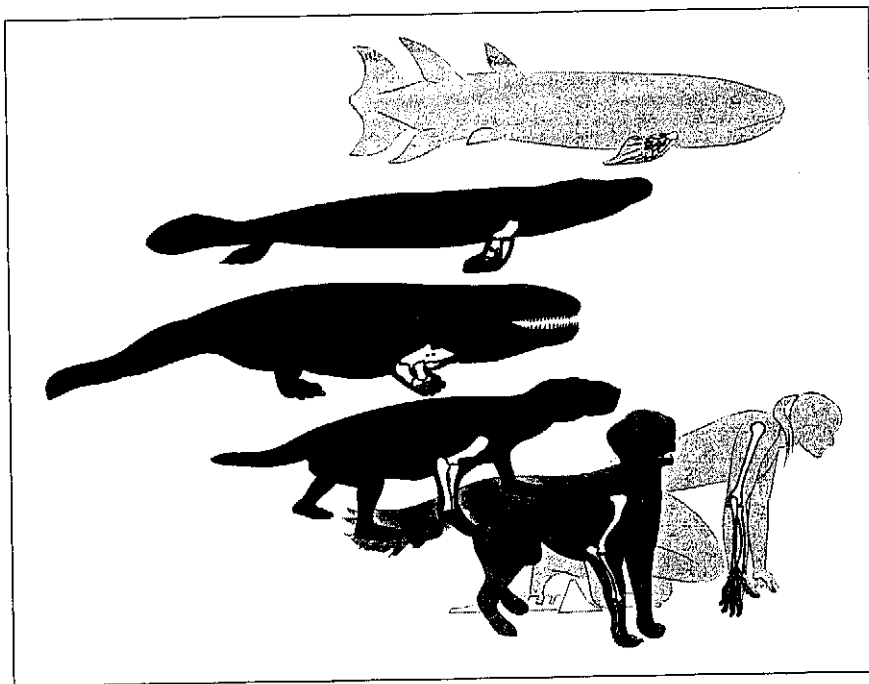
How can I be so sure that this fossil says something about my own body? Consider the neck of *Tiktaalik*. All fish prior to *Tiktaalik* have a set of bones that attach the skull to the shoulder, so that every time the animal bent its body, it also bent its head. *Tiktaalik* is different. The head is completely free of the shoulder. This whole arrangement is shared with amphibians, reptiles, birds, and mammals, including us. The entire shift can be traced to the loss of a few small bones in a fish like *Tiktaalik*.

I can do a similar analysis for the wrists, ribs, ears, and other parts of our skeleton—all these features can be traced back to a fish like this. This fossil is just as much a part of our history as the

African hominids, such as *Australopithecus afarensis*, the famous “Lucy.” Seeing Lucy, we can understand our history as highly advanced primates. Seeing *Tiktaalik* is seeing our history as fish.

So what have we learned? Our world is so highly ordered that we can use a walk through a zoo to predict the kinds of fossils that lie in the different layers of rocks around the world. Those predictions can bring about fossil discoveries that tell us about ancient events in the history of life. The record of those events remains inside us, as part of our anatomical organization.

What I haven’t mentioned is that we can also trace our history inside our genes, through DNA. This record of our past doesn’t lie in the rocks of the world; it lies in every cell inside us. We’ll use both fossils and genes to tell our story, the story of the making of our bodies.



Tracing arm bones from fish to humans.

# YOUR INNER FISH

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OF THE HUMAN BODY

NEIL SHUBIN

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