

WHALES: Walking Into the Past

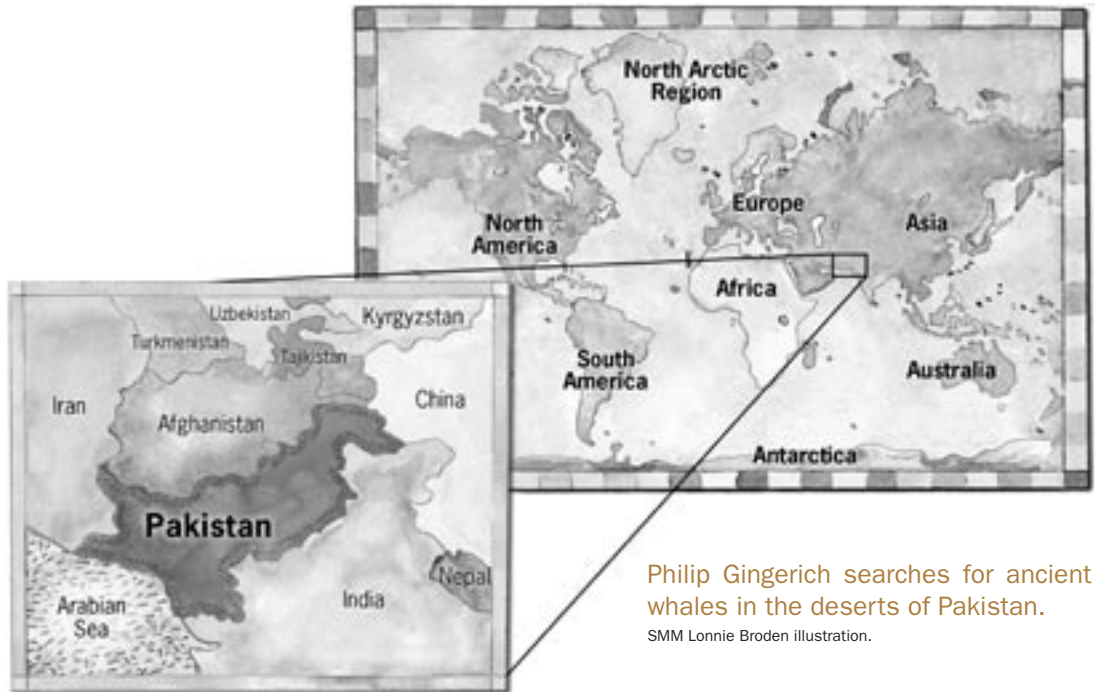
Whales with knees and toes? Incredible as it seems, whales once walked on legs and lived on land. Millions of years of biological change have erased the whale's legs from its body. But a faint trace remains. Hidden inside the streamlined body of many modern whales are tiny hip and leg bones. The story of how the whale—marvel of the oceans—evolved from a four-legged mammal is an amazing one. So far, it provides one of the best examples of how organisms change over time. And like whales, the story is still evolving.

Just about everything to do with whales was once a big puzzle, even what kind of animal it was. Fish or mammal? Scientists had trouble deciding. From the small dolphin to the enormous grey whale, these animals look and live like fish. They can't survive out of water—but on the other hand, they can drown in water. Every 15 minutes or so they have to swim to the water's surface to breathe. Like all mammals, whales are warm-blooded, give birth to babies rather than lay eggs, and nurse their young with milk. They even have a belly button.



Philip Gingerich, paleontologist at the University of Michigan, digs for fossil whales.

Photo courtesy University of Michigan Museum of Paleontology.



So, if whales are mammals, how did they come to live like fish? Could their ancestors have been land mammals that gradually took to the oceans? When scientists first asked these questions, there was little fossil evidence to provide answers. Until, that is, paleontologist Philip Gingerich discovered a bone in the desert of Pakistan.

Many of the great scientific discoveries happen by accident, if the scientist is open to surprises. Philip Gingerich wasn't looking for whales when he arrived in Pakistan in 1977 with a team of international scientists. Dr. Gingerich was an expert on extinct land mammals. So he was disappointed to find that the first place he had targeted to look for fossils was an ancient seashore. The rocks were filled with fossilized snails and other shellfish—not the best place to find the bones of a land mammal.

Like kids in a giant sandbox, Gingerich and his team went to work anyway. After a week of scouring the exposed rocks, they found a few pieces of bone that looked promising: They could make out part of a pelvis and a backbone. Gingerich recalls joking with his team about finding a “walking whale” with hips and legs, but back then it was just a joke. The team assumed that the fossils were bits and pieces of an ancient elephant ancestor, a land mammal that had drifted out to sea after death.

But on a December day in 1979, the team found a specimen that was not so easy to explain. Embedded in rock as hard as cement, it was a curious fossil skull. Gingerich took the skull home to his lab. When the fossil was cleaned up, Gingerich could see that it was no bigger than a wolf's skull and had many wolf-like features. The teeth were a mix of canines and molars, and the nostrils were set close to the snout. But attached to the skull was a set of tiny thickened ear bones. The only animals on Earth, living or extinct, that have ear bones thickened this way are the whales.

Gingerich named the creature *Pakicetus* (pack-eh-SEA-tus), Whale of Pakistan. It lived about 48.5 million years ago. Based on the land mammal-like features of the skull, Gingerich hypothesized that this whale probably went into the water to

feed but came out on land to rest and to give birth. After the unexpected discovery of *Pakicetus*, Gingerich began to hunt for whales in earnest. Whale fossils are large, and they are relatively easy to find in the desert. Sometimes the wind lends a hand by scouring away the sands and shales, leaving entire skeletons exposed. One valley in Egypt was especially rich in whales. On a series of visits starting in 1983, Gingerich and his team found virtually a whale a day. The final tally came to 379 whales. He found some with hipbones, but Gingerich also hoped to find legs and feet.

In 1989 Gingerich was mapping the spine of a well-preserved 50-foot-long skeleton of *Basilosaurus* (bah-sill-oh-SOAR-us), a fossil whale that lived about 10 million years after *Pakicetus*. Two-thirds of the way down the spine he found a small round bone standing vertically. This seemed out of place, and the top was weathered away. When the rest was excavated, the bone proved to be an upper leg bone with the knee joint preserved. No one had ever seen the knee of a whale before.

Counting down the spine, this bone was near the 48th vertebra. The whole team went to work brushing sand away from this part of all the *Basilosaurus* that had been mapped so far. Soon they found, astonishingly, not only more hips and upper legs, but also lower leg bones, anklebones, and finally, one by one, the bones of three tiny toes. These were the first hind limbs and feet ever found with a fossil whale skeleton.

Basilosaurus was a huge ocean-going whale, with retracted nostrils forming a blowhole halfway up its four-foot-long skull. Its body was equipped with legs, but they were too small to support the animal's weight on land.

Gingerich predicted that scientists would unearth many more missing links between land and sea whales. He wasn't disappointed. Some of the most important finds were yet to come. In the 1990s J. G. M. Thewissen and Gingerich discovered two whales that were almost as old as *Pakicetus*. Both had legs larger than *Basilosaurus*, even though the skeletons were only 10 to 12 feet long. One was named *Ambulocetus natans* (am-bue-low-SEA-tus-NAY-tans) and the other *Rodhocetus kasranii* (row-deh-SEA-tus-kaz-RAN-nee-eye). Like *Pakicetus*, both of these whales found their food in water and were good swimmers, but both still hitched their way ashore to rest and to give birth.

Some crucial parts of the *Rodhocetus* skeleton were still missing. The hands, feet, and tail were poorly known. But Gingerich persevered, and eventually his team found



Rodhocetus, “the barely walking whale.”

John Klausmeyer illustration.

a complementary *Rodhocetus* skeleton with hands and feet intact. He named this one *Rodhocetus balochistanensis* (bah-low-CHIS-stan-en-sis), after the province in Pakistan where it was found. This discovery brought new surprises. The middle three fingers of each hand retained a tiny hoof. And the anklebones proved to be the kind that belonged only to hoofed mammals known as artiodactyls (arty-oh-DAK-tils). Artiodactyls include cows, goats, pigs, and hippos. *Rodhocetus* combined features of an aquatic whale with features of a hoofed mammal all in the same skeleton.

Scientists doing DNA studies had already claimed that the whale's closest living relatives were artiodactyls like the hippopotamus, and here was confirmation. The fossil record and DNA evidence were now saying the same thing. *Rodhocetus* was like an arrow pointing backward to a hoofed ancestor and forward to an ocean-dwelling dolphin.

In this activity you'll have a chance to meet *Rodhocetus*, the barely walking whale, excavate and sort some "fossils" of your own, and learn how to read bones like a paleontologist to understand the whale's remarkable transition from land to sea.

PART ONE

Sweet excavation

Discovering fossils is not like in the movies where whole skeletons of ancient critters magically reveal themselves in all their magnificence at the flick of a whiskbroom. The process is more like reassembling bits of roadkill that were buried millions of years ago and cemented into rock. Finding fossil bones is just the first step. The bones then have to be carefully dug up, and then packed and shipped back to the lab. There they are cleaned, studied, and assembled. It is slow work. Try your own hand at excavating some fossil “bones” and making sense of your finds.

An exciting new discovery of “fossil pretzel bones” has arrived in your lab. Your job is to excavate, sort, and assemble the bones. Then see if you can assemble the parts well enough to identify what kind of pretzel creature these bones belong to.

Work with a partner

Each team will need:

- Pretzel Species sheet
- stiff paper or cardboard
- liquid glue

Either of two options:

- 1** Fossil Evidence Envelope
 - pretzel broken into 3–4 pieces
 - envelope
- 2** Cookie Fossil Rocks
 - cookie dough baked with 3–4 pretzel pieces inside
 - big nail or metal nail file

PREP NOTE: This activity can be done in either of the following two ways, depending on the amount of preparation time available:

Fossil Evidence Envelope:

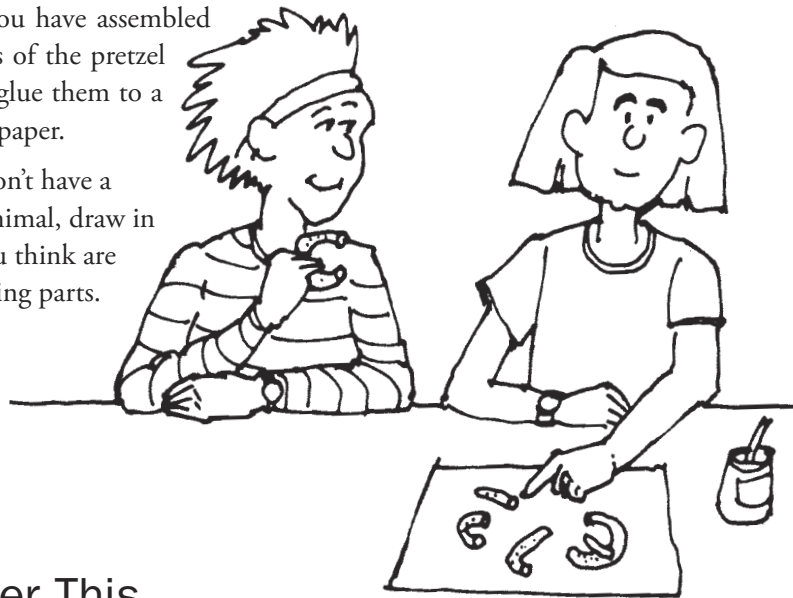
To prepare, break a pretzel into about 3–4 parts and place the parts into an envelope. For more challenge, add extra pretzel parts, remove some, or try working with several shapes of pretzels and mix the parts.

Cookie Fossil Rocks:

To make each cookie fossil rock, mix pretzel pieces with enough cookie dough to contain them. Bake according to cookie directions. Hard, dry cookies will be difficult to excavate.

1 Making Sense of Fossils

- a** Look at the Pretzel Species sheet of some known species of the pretzel family to get familiar with their body forms. Open your “fossil evidence envelope” or excavate your “cookie fossil rocks” with a tool like a metal nail file. Lay out the pretzel parts.
- b** You may or may not have parts for a whole animal, but what you do have represents ONE species. Some of the parts may have been eaten by scavengers or gotten lost. Assemble the parts in a way that makes sense, using the shapes on the Pretzel Species sheet to help you sort and assemble.
- c** When you have assembled the parts of the pretzel animal, glue them to a sheet of paper.
- d** If you don't have a whole animal, draw in what you think are the missing parts.

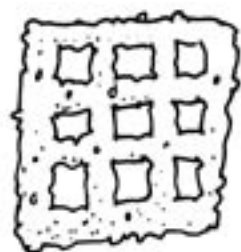


2 Consider This

Does your pretzel look like one of the known species or is it a new variety? Describe how your fossil finds compare to the ones on the Pretzel Species sheet.

When scientists discover a new kind of animal, they have the honor of naming the new species. If you think your pretzel bones belong to a new and different pretzel species, make up a name, and write it here.

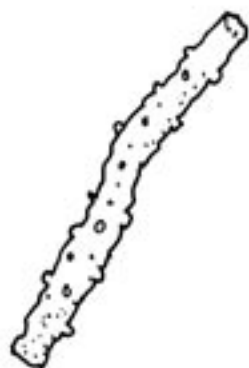
Pretzel Species: These are some members of the Pretzel Family



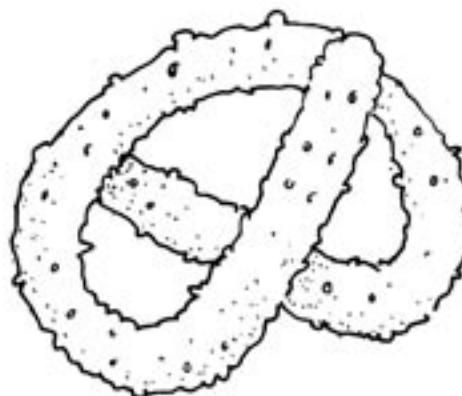
Pretzel cubicus



Pretzel normalist



Pretzel stickia



Pretzel giganticus

Linda Allison illustration.

PART TWO

Read some bones

When Philip Gingerich found the mystery bones in Pakistan, he knew they were not the bones of a modern animal. Gingerich knew he was digging in a layer of rocks that was about 47 million years old, which gave him a good estimate of about how old the bones were. He also knew from studying the rocks that the bones had been deposited near a shallow sea. He took the bones back to his lab and after many months of painstaking work, his team cleaned and assembled the skeleton of the animal he named *Rodhocetus*.

Even if a bone was buried for millions of years, a paleontologist can study a fossil bone and learn many things about the animal it came from. By comparing the shapes of fossil bones to modern bones, a lot can be learned about how the fossil animal might have lived and worked.

Work with a partner

Each team will need:

- One Mystery Fossil Bones card (cut separate cards for Fore Limbs, Hind Limbs, Skull & Teeth, OR Spine, Neck, & Ribs)
- One matching Some Known Bones sheet (Fore Limbs, Hind Limbs, Skull & Teeth, OR Spine, Neck, & Ribs)
- One Sum It Up sheet (Fore Limbs & Hind Limbs OR Skull & Spine)
- Scissors

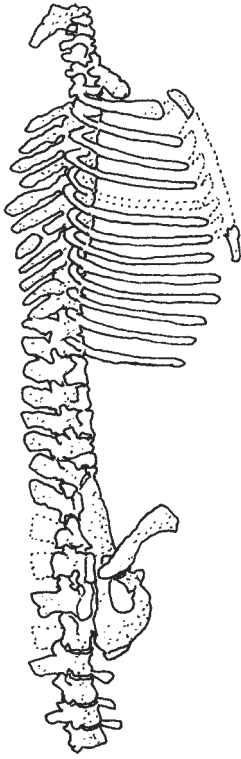
1 Bone Reading

Study some pictures of mystery fossil bones excavated by Dr. Gingerich in Pakistan. See how much information you can “read” from these mystery fossil bones by comparing them to the bones of some modern animals alive today.

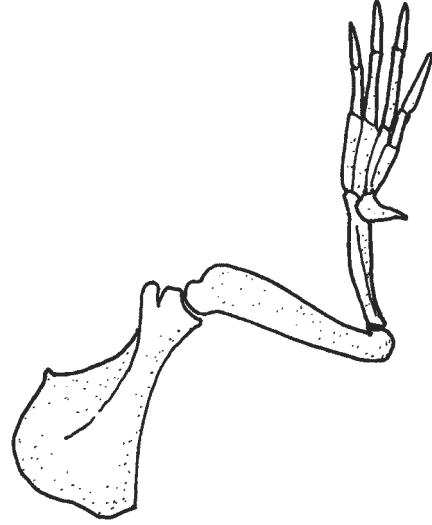
Every team should get a Mystery Fossil Bone card and the matching Some Known Bones sheet. Complete the questions in the challenge section of the Some Known Bones sheet.



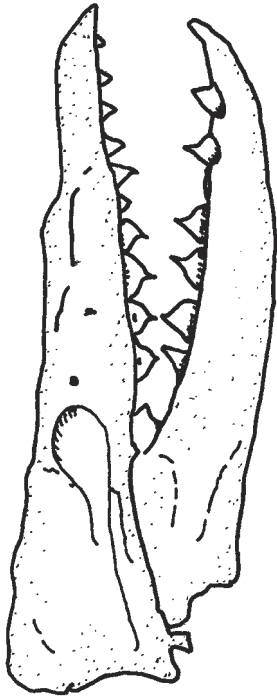
MYSTERY FOSSIL BONES: SPINE, NECK, & RIBS



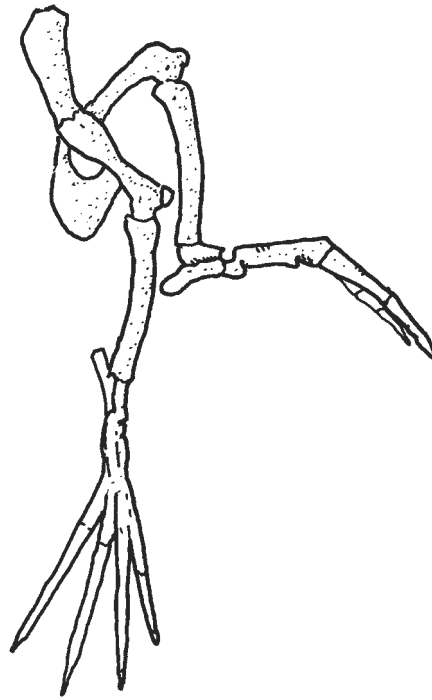
MYSTERY FOSSIL BONES: FORE LIMBS



MYSTERY FOSSIL BONES: SKULL & TEETH



MYSTERY FOSSIL BONES: HIND LIMBS



SKULL & TEETH: Some Known Bones

CHALLENGE:

FIND THE MODERN SKULL AND TEETH MOST LIKE THE MYSTERY FOSSIL BONES.

1. Get the card "Mystery Fossil Bones: Skull and Teeth."
2. Compare the mystery skull and teeth to the bones of modern animals shown on this page.
3. Which skull and teeth do you think are most like the Mystery Fossil Bones?

4. List the clues that helped you decide:

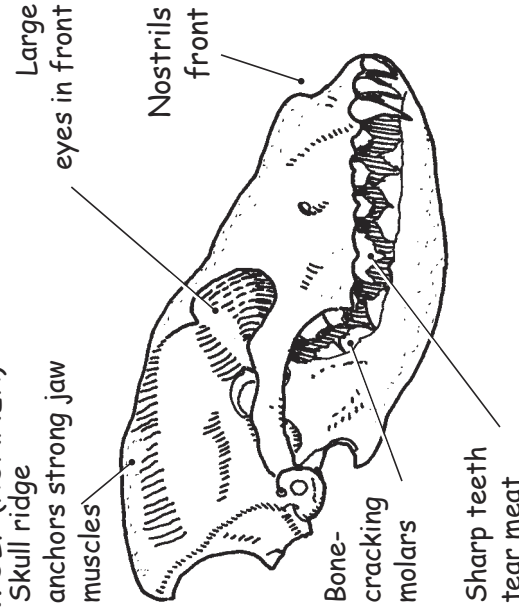
5. Based on the bone clues, what type of critter did the Mystery Fossil Bones belong to?

An animal's skull acts like a hard hat to protect its brain. Sharp teeth are suited for tearing into flesh; flat teeth are better for grinding plant foods. Animals with large eye sockets pointing ahead have good forward vision while eyes to the sides are better for seeing all around.

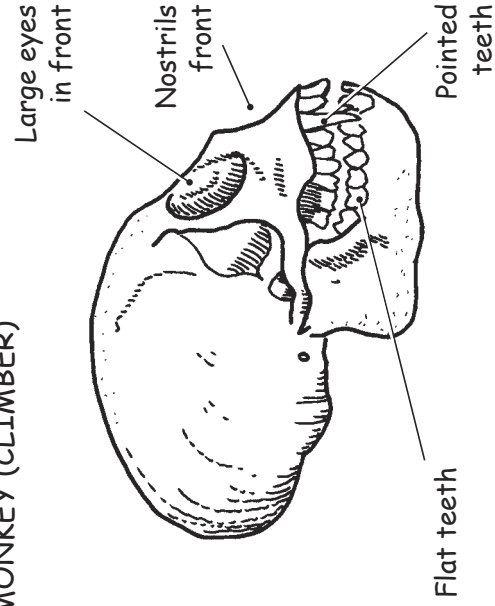
- Wolves use their forward-pointing eyes and nose for hunting. Sharp teeth stab and hold prey.
- Monkeys use their keen eyes and nose for finding food. They use their diverse teeth to eat a mixed diet.
- Dolphins breathe at the water's surface from nostrils on top of their head.

Note how the shapes of the bones give clues to an animal's lifestyle.

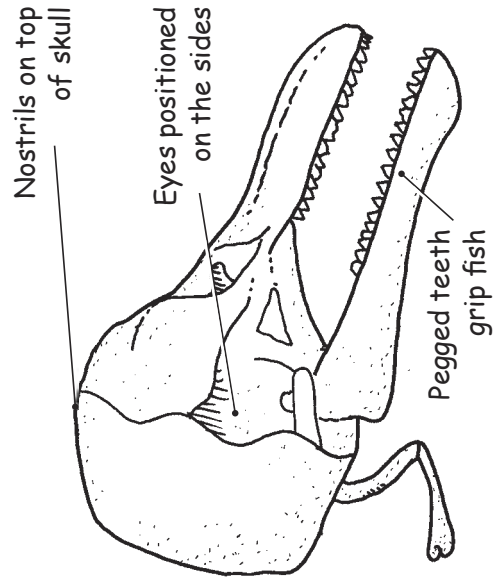
WOLF (RUNNER)



MONKEY (CLIMBER)



DOLPHIN (SWIMMER)



FORE LIMBS: Some Known Bones

CHALLENGE:

FIND THE MODERN FORE LIMBS MOST LIKE THE MYSTERY FOSSIL BONES.

1. Get the card "Mystery Fossil Bones: Fore Limbs."
2. Compare the mystery fore limbs to the bones of modern animals shown on this page.
3. Which fore limbs do you think are most like the Mystery Fossil Bones?

4. List the clues that helped you decide:

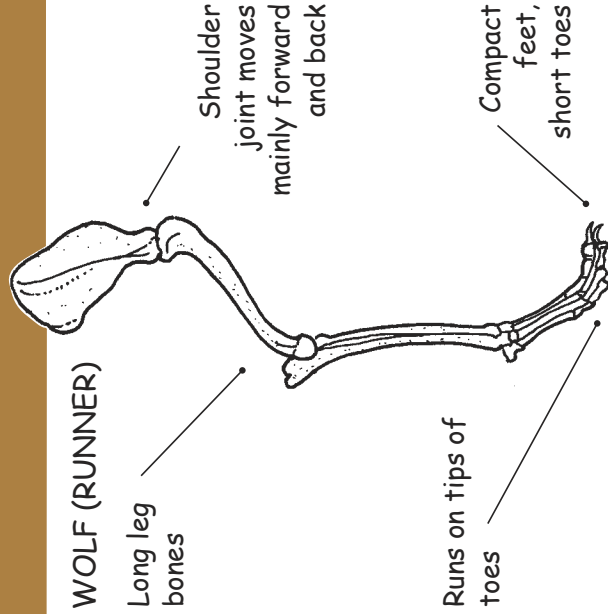
5. Based on the bone clues, what type of critter did the Mystery Fossil Bones belong to?

Animals often use their fore limbs or front legs for specialized jobs like digging, paddling, and grabbing. Their back legs are mainly used for locomotion. Notice how different animals use their fore limbs in different ways:

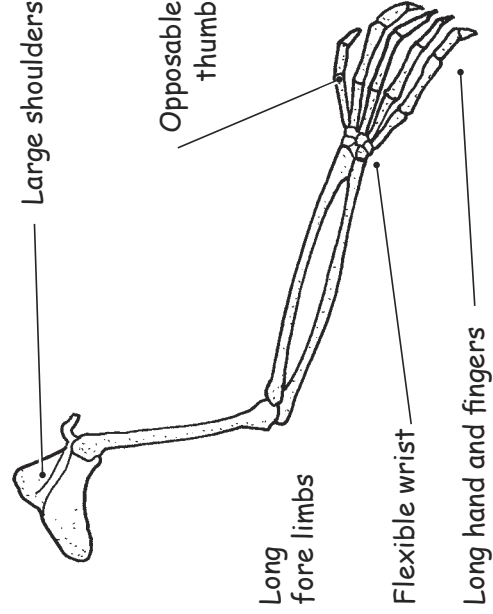
- Wolves run on their long legs and compact feet.
- Strong shoulders support their body weight.
- Monkeys swing through trees with their long arms and grasping hands.
- Dolphins swim using their flippers as paddles.

Note how the shapes of the bones give clues to an animal's lifestyle.

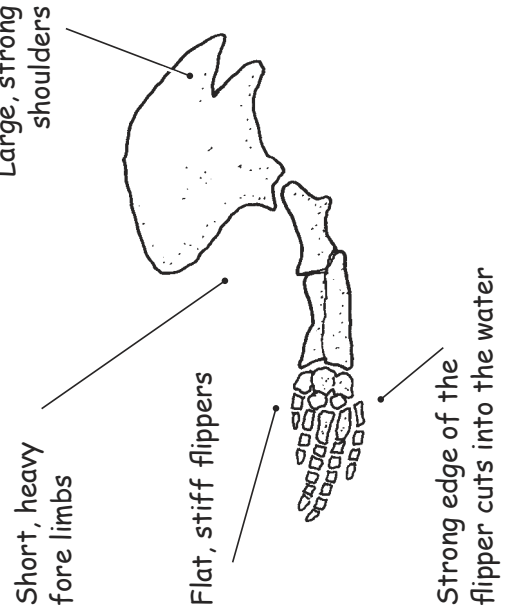
WOLF (RUNNER)



MONKEY (CLIMBER)



DOLPHIN (SWIMMER)



Linda Allison illustration.

HIND LIMBS: Some Known Bones

CHALLENGE:

FIND THE MODERN HIND LIMBS MOST LIKE THE MYSTERY FOSSIL BONES.

1. Get the card "Mystery Fossil Bones: Hind Limbs."
2. Compare the mystery hind limbs to the bones of modern animals shown on this page.
3. Which hind limbs do you think are most like the Mystery Fossil Bones?

4. List the clues that helped you decide:

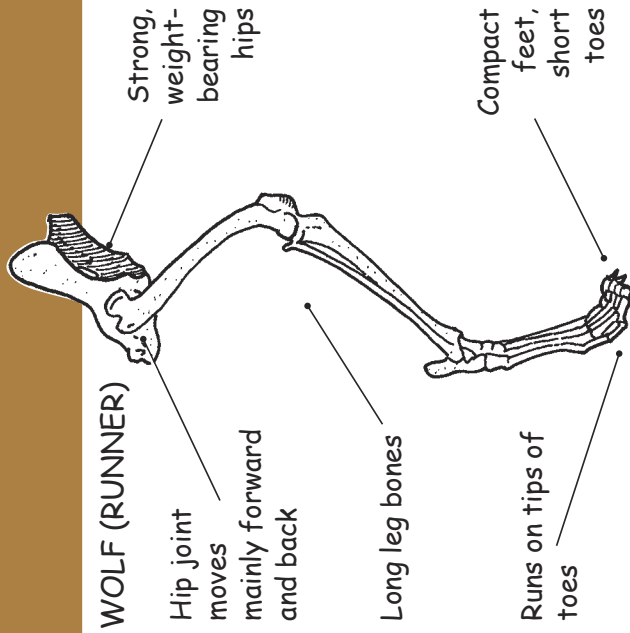
5. Based on the bone clues, what type of critter did the Mystery Fossil Bones belong to?

Animals use their hind limbs or legs mostly for locomotion. Their front legs are often used for more specialized jobs like digging, paddling, or grabbing. Notice how different animals use their hind limbs:

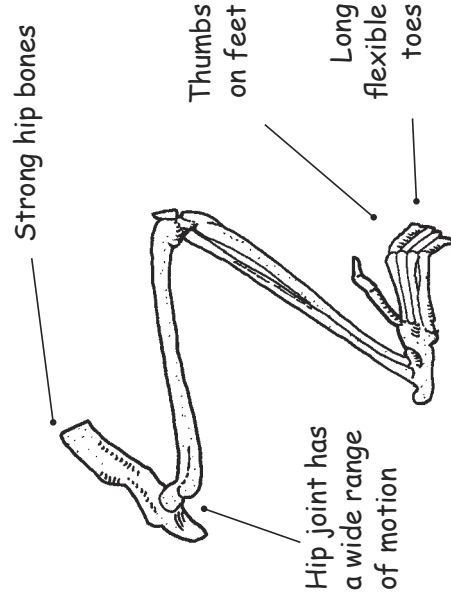
- Wolves run on their long legs and compact feet. Strong hips support their body weight.
- Monkeys swing through tree branches with their long legs and grasping feet.
- Dolphins swim through water with their streamlined bodies. They lack legs.

Note how the shapes of the bones give clues to an animal's lifestyle.

WOLF (RUNNER)

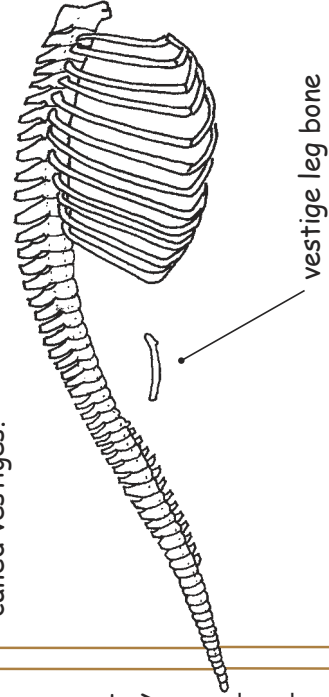


MONKEY (CLIMBER)



DOLPHIN (SWIMMER)

Dolphins have no hind legs on the outside, but their skeletons have tiny, useless leg bones called vestiges.



SPINE, NECK, & RIBS: Some Known Bones

CHALLENGE:

FIND THE MODERN SPINE, NECK & RIBS MOST LIKE THE MYSTERY FOSSIL BONES.

1. Get the card "Mystery Fossil Bones: Spine, Neck, & Ribs."
2. Compare the mystery spine, neck, & ribs to the bones of modern animals shown on this page.
3. Which spine, neck, & ribs do you think are most like the Mystery Fossil Bones?

4. List the clues that helped you decide:

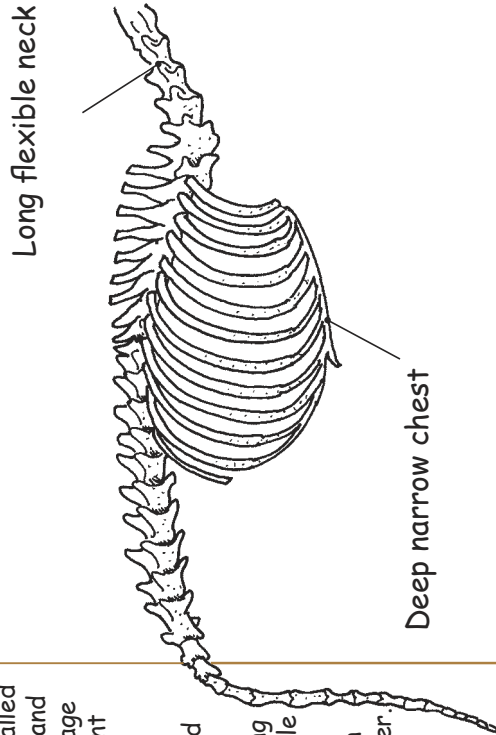
5. Based on the bone clues, what type of critter did the Mystery Fossil Bones belong to?
- _____
- _____
- _____

An animal's spine acts as a rod from which the other bones are hung. It is made of sections called vertebrae that form a strong, flexible support and provide anchors for the muscles. Ribs form a cage to protect heart and lungs. Notice how different animals use the spine in different ways:

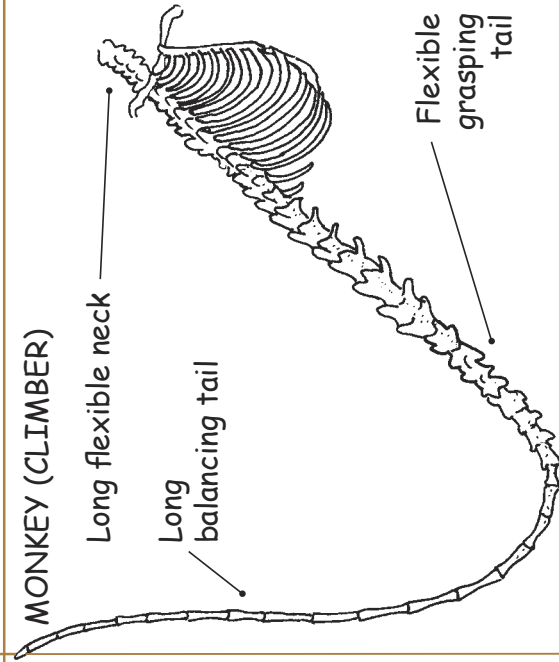
- Wolves use their long necks to move the head for better sight, smell, and hearing.
- Monkeys travel through trees using their long tails for grabbing and balancing. Their flexible necks aid their keen vision.
- Dolphins swim using their powerful tails in an up and down motion to push through the water.

Note how the shapes of the bones give clues to an animal's lifestyle.

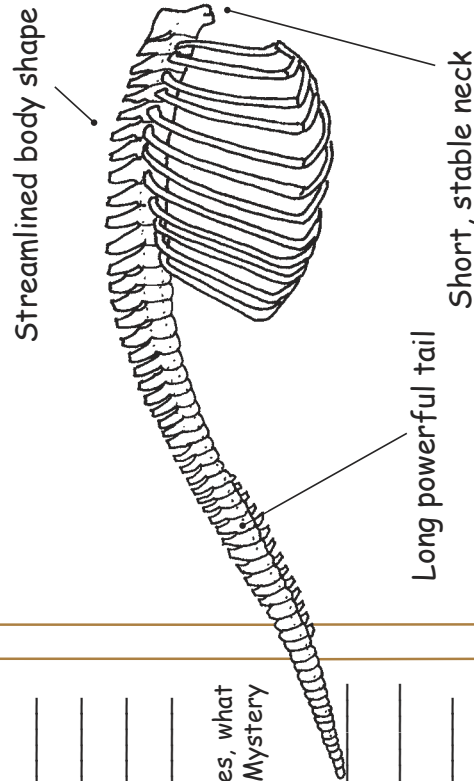
WOLF (RUNNER)



MONKEY (CLIMBER)



DOLPHIN (SWIMMER)



2 Share Your Findings

Scientists seldom find complete skeletons. To learn more, they often must share information from other skeletons and from other dig sites.

- a** Partner with another group so Fore and Hind Limbs teams work together and Skull and Spine teams work together.
- b** Discuss your findings with partner group, and summarize them on one of the Sum It Up charts. See if you can come to an agreement about how your mystery animal moved, what it ate, and its habitat.

Sum It Up: Fore limbs and hind limbs

TEAM	ANALYSIS: Note your ideas about type of animal and its lifestyle
Fore Limbs	
Hind Limbs	
Both Teams	Which of the three modern animals might have a body part similar to this?
Summarize: How mystery animal moved, what it ate, and its habitat	

Sum It Up: Skull and spine

TEAM	ANALYSIS: Note your ideas about type of animal and its lifestyle
Skull & Teeth	
Spine, Neck, & Ribs	
Both Teams	Which of the three modern animals might have a body part similar to this?
Summarize: How mystery animal moved, what it ate, and its habitat	

3 Consider This

Philip Gingerich named the mystery bones *Rodhocetus*, the barely walking whale. This whale was found in an ancient shallow water habitat. After analyzing the bones, Dr. Gingerich believes that this animal lived both in and out of the water, and it was a meat eater that breathed air. How does your team's conclusion agree or disagree with Gingerich's analysis?

PART THREE

Creature features

When a new fossil skeleton is discovered, one of the first questions a scientist asks is what animal or family of animals it is similar to. Even a partial skeleton allows a paleontologist to identify features that match with other animals. By identifying similar features, scientists can sort which animals are closer relatives and where an animal fits into the overall scheme of living things. In the case of extinct animals, scientists can attempt to sort out if they are the ancestors of living animals, and how they evolved over time.

Take the next few minutes to consider the assembled *Rodhocetus* skeleton. Compare it to the skeleton of a modern dolphin (a type of small whale) and a modern shark. These two aquatic animals are similar in size but belong to different families. Check out the creature's features. Then decide if *Rodhocetus* is more closely related to a shark than to a dolphin.

Work with a partner

Each team will need:

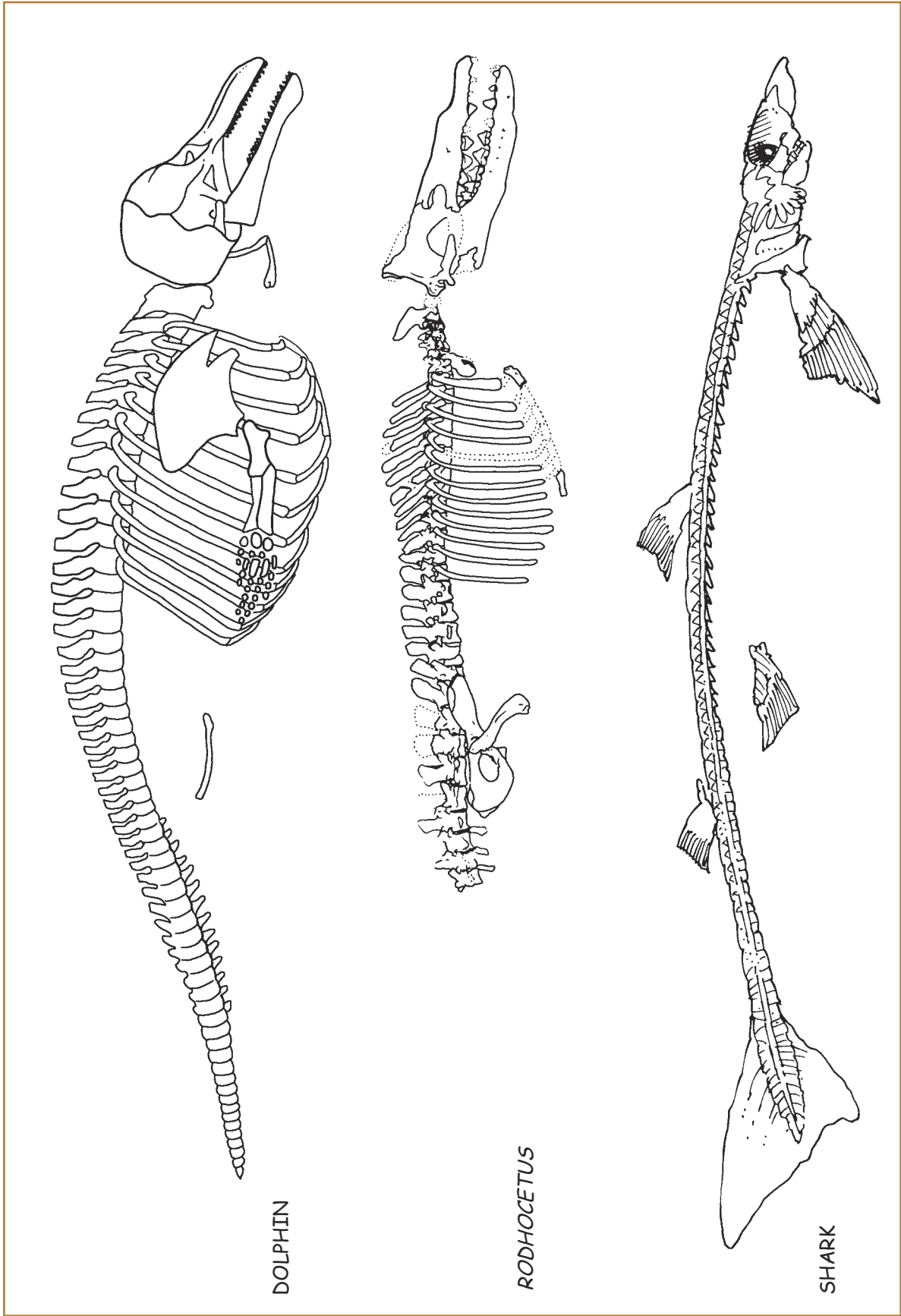
- Creature Features: Comparing Anatomy sheet

1 Comparing Skeletons

Compare the three skeletons on the Creature Features sheet.

Would you say the modern whale or the modern shark is a closer relative of *Rodhocetus*? List the clues you noticed that helped you decide.

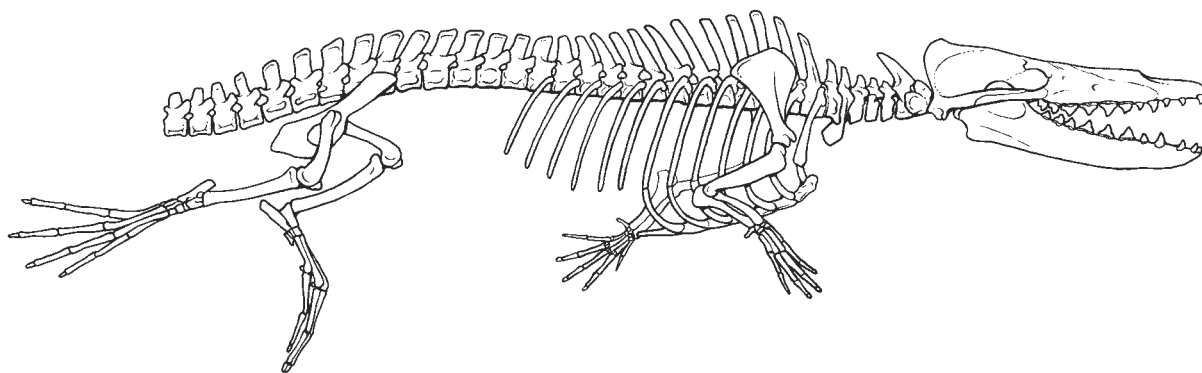
Creature Features: Comparing Anatomy



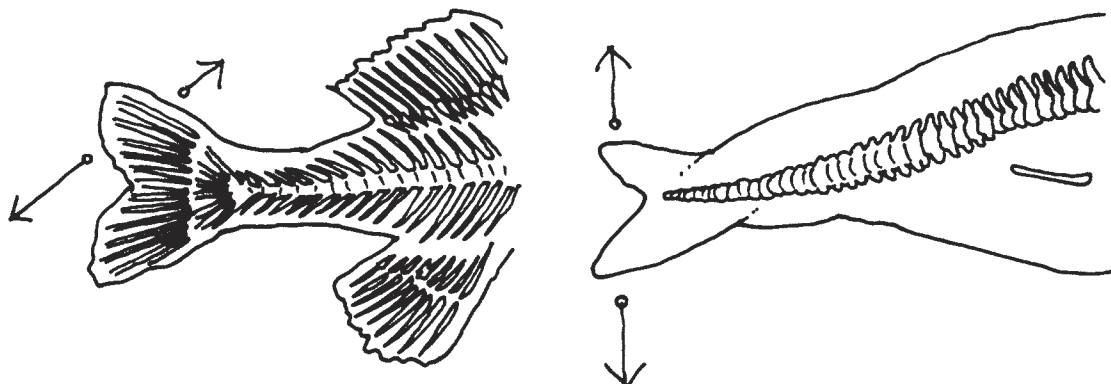
Linda Allison illustration.

2 Consider This

Dr. Gingerich's original article about *Rodhocetus* did not include information about its tail. At that time, no tail for the fossil had been discovered. Try to predict what kind of tail belongs on this ancient whale. Consider the information given below. Then draw the tail on the partial *Rodhocetus* skeleton on the Creature Features: Comparing Anatomy sheet. Explain why you think this is the likely tail for this animal.



Fish and sharks have a finned tail that propels them forward by moving in a side-to-side fashion. Dolphins, like all whales, have a fluked tail that moves in an up-and-down motion.



Linda Allison illustration.

PART FOUR

Be a science reporter

Write a short news story about whales. Tell your readers about new fossil discoveries from Pakistan that suggest whales are related to animals that once lived on land. Based on what you have learned, explain how you think a whale could have an ancestor that lived on land.

P.S. Don't forget the headline.