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Understanding Evolution

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| http://evolution.berkeley.edu/evolibrary/images/dot_clear.gif | **The evolution of whales**  The first thing to notice on this evogram is that hippos are the closest living relatives of whales, but they are not the ancestors of whales. In fact, none of the individual animals on the evogram is the direct ancestor of any other, as far as we know. That's why each of them gets its own branch on the family tree.   |  | | --- | | Whale evogram |   Hippos are large and aquatic, like whales, but the two groups [evolved](http://evolution.berkeley.edu/evolibrary/glossary/glossary_popup.php?word=evolution) those features separately from each other. We know this because the ancient relatives of hippos called anthracotheres (not shown here) were not large or aquatic. Nor were the ancient relatives of whales that you see pictured on this tree — such as *Pakicetus*. Hippos likely evolved from a group of anthracotheres about 15 million years ago, the first whales evolved over 50 million years ago, and the ancestor of both these groups was terrestrial.  These first whales, such as *Pakicetus*, were typical land animals. They had long skulls and large [carnivorous](http://evolution.berkeley.edu/evolibrary/glossary/glossary_popup.php?word=carnivore) teeth. From the outside, they don't look much like whales at all. However, their skulls — particularly in the ear region, which is surrounded by a bony wall — strongly resemble those of living whales and are unlike those of any other mammal. Often, seemingly minor features provide critical evidence to link animals that are highly specialized for their lifestyles (such as whales) with their less extreme-looking relatives.   |  | | --- | | Ambulocetus and Pakicetus  Skeletons of two early whales. |   Compared to other early whales, like *Indohyus* and *Pakicetus*, *Ambulocetus* looks like it lived a more aquatic lifestyle. Its legs are shorter, and its hands and feet are enlarged like paddles. Its tail is longer and more muscular, too. The [hypothesis](http://evolution.berkeley.edu/evolibrary/glossary/glossary_popup.php?word=hypothesis) that *Ambulocetus* lived an aquatic life is also supported by evidence from stratigraphy — *Ambulocetus*'s fossils were recovered from sediments that probably comprised an ancient estuary — and from the isotopes of oxygen in its bones. Animals are what they eat and drink, and saltwater and freshwater have different ratios of oxygen isotopes. This means that we can learn about what sort of water an animal drank by studying the isotopes that were incorporated into its bones and teeth as it grew. The isotopes show that *Ambulocetus*likely drank both saltwater and freshwater, which fits perfectly with the idea that these animals lived in estuaries or bays between freshwater and the open ocean.   |  | | --- | | Oxygen isotope ratios for extant and extinct cetaceans  Isotopic analyses help us figure out the likely habitats of extinct whales like*Ambulocetus*. |   Whales that evolved after *Ambulocetus* (*Kutchicetus*, etc.) show even higher levels of saltwater oxygen isotopes, indicating that they lived in nearshore marine [habitats](http://evolution.berkeley.edu/evolibrary/glossary/glossary_popup.php?word=habitat) and were able to drink saltwater as today's whales can. These animals evolved nostrils positioned further and further back along the snout. This trend has continued into living whales, which have a "blowhole" (nostrils) located on top of the head above the eyes.   |  | | --- | | Nostril migration in whales  As whales evolved increasingly aquatic lifestyles, they also evolved nostrils located further and further back on their skulls. |   These more aquatic whales showed other changes that also suggest they are closely related to today's whales. For example, the pelvis had evolved to be much reduced in size and separate from the backbone. This may reflect the increased use of the whole vertebral column, including the back and tail, in locomotion. If you watch films of dolphins and other whales swimming, you'll notice that their tailfins aren't vertical like those of fishes, but horizontal. To swim, they move their tails up and down, rather than back and forth as fishes do. This is because whales evolved from walking land mammals whose backbones did not naturally bend side to side, but up and down. You can easily see this if you watch a dog running. Its vertebral column undulates up and down in waves as it moves forward. Whales do the same thing as they swim, showing their ancient terrestrial heritage.  As whales began to swim by undulating the whole body, other changes in the skeleton allowed their limbs to be used more for steering than for paddling. Because the sequence of these whales' tail vertebrae matches those of living dolphins and whales, it suggests that early whales, like *Dorudon* and *Basilosaurus*, did have tailfins. Such skeletal changes that accommodate an aquatic lifestyle are especially pronounced in basilosaurids, such as *Dorudon*. These ancient whales evolved over 40 million years ago. Their elbow joints were able to lock, allowing the forelimb to serve as a better control surface and resist the oncoming flow of water as the animal propelled itself forward. The hindlimbs of these animals were almost nonexistent. They were so tiny that many scientists think they served no effective function and may have even been internal to the body wall. Occasionally, we discover a living whale with the vestiges of tiny hindlimbs inside its body wall.   |  | | --- | | Skeleton of Dorudon  Skeleton of the early whale *Dorudon*. Notice the tiny hind limbs at left below the tail. |   This [vestigial](http://evolution.berkeley.edu/evolibrary/glossary/glossary_popup.php?word=vestigial+structure) hindlimb is evidence of basilosaurids' terrestrial heritage. Below on the left is a photo of the hind foot of a basilosaurid. You can see that it has a complete ankle and several toe bones, even though it can't walk. The central ankle bone, called the astragalus, ends in a double pulley joint and has a hooked knob that points up towards the leg bones. These features are characteristic of artiodactyls, a group mostly made up of hoofed mammals that includes cows, antelope, deer, sheep, giraffes, camels, hippos … and whales. The picture on the right shows the astragalus of other artiodactyls, and you can see the same features: double pulley joint, hooked process. From the ear bones to the ankle bones, whales belong with the hippos and other artiodactyls.   |  |  |  | | --- | --- | --- | | Comparing ankle bones of extinct whales and modern pronghorn |  | Ankle and foot bones of Basilosaurus | | At left, the ankle bones of two middle Eocene protocetid archaeocetes, *Rodhocetus balochistanensis* (left) and *Artiocetus clavis* (right) from Pakistan, compared to those of the pronghorn *Antilocapra americana* (center). At right, the ankle region and foot of *Basilosaurus*. The pulley part of the astragalus (outlined) connects to the tibia and fibula. | | | | http://evolution.berkeley.edu/evolibrary/images/dot_clear.gif |
| http://evolution.berkeley.edu/evolibrary/images/dot_clear.gif | View this article online at: <http://evolution.berkeley.edu/evolibrary/article/evograms_03>  Whale phylogeny from *The Tangled Bank*, used with permission of the author, Carl Zimmer, and publisher, Roberts & Company, Greenwood Village, Colorado; Photos of *Dorudon*, extinct whale and pronghorn ankle bones, and*Basilosaurus* foot © 1998, 1991 and 2001, respectively, Philip Gingerich. Photo of *Pakicetus* and *Ambulocetus* courtesy of J.G.M. Thewissen, from: J.G.M. Thewissen, L.N. Cooper, J.C. George, and S. Bajpai. 2009. From land to water: The origin of whales, dolphins, and porpoises. *Evolution: Education & Outreach* 2:272-288. Isotopic analyses data from: Bajpai, S., and P.D. Gingerich. 1998. A new Eocene archaeocete (Mammalia, Cetacea) from India and the time of origin of whales. *Proceedings of the National Academy of Sciences* 95:15464-15468. Barrick, R.E., A.G. Fischer, Y. Kolodny, B. Luz, and D. Bohaska. 1992. Cetacean bone oxygen isotopes as proxies for Miocene ocean compostion and glaciation. *Palaios* 7(5):521-531. Thewissen, J.G.M., L.J. Roe, J.R. O'Neil, S.T. Hussain, A. Sahni, and S. Bajpai. 1996. Evolution of cetacean osmoregulation. *Nature* 381:379-380. Yoshida, N., and N. Miyazaki. 1991. Oxygen isotope correlation of cetacean bone phosphate with environmental water. *Journal of Geophysical Research* 96(C1):815-820.  Understanding Evolution © 2011 by The University of California Museum of Paleontology, Berkeley, and the Regents of the University of California |  |