ENSI ONLINE	**BECOMING WHALES** Experiencing Discoveries of Whale Evolution OR... "The thrill of discovery... The decline of de feet" by Larry Flammer 8 October 1997 http://www.indiana.edu/~ensiweb/lessons/whale.ev.html	NATURE OF SCIENCE Basic Processes EVOLUTION Geological/Paleontological Patterns

SYNOPSIS

Students will experience the historical discovery of fossils which increasingly link whales to earlier land-dwelling mammals. This experience reveals how scientists can make predictions about past events, based on the theory that whales evolved. Such predictions suggest the age and location of sediments where fossils of early whales would most likely be found. This lesson also provides confirmation, with multiple independent lines of evidence, that there IS a series of intermediate forms, showing gradual accumulation of changes, linking certain terrestrial mammals with modern whales.

MAIN CONCEPTS

1. The Process of science: hypotheses lead to predictions which lead to tests which can challenge the validity of those hypotheses.
2. Transitional forms are generally a mosaic of traits, suggesting that some traits evolve faster than others.

ASSOCIATED CONCEPTS

1. New evidence can lead to major changes in scientific concepts.
2. Fossils exist of certain mammals with traits intermediate between terrestrial mammals and modern whales, showing the gradual accumulation of whale traits, and the loss of terrestrial mammal traits.
3. These fossils are found in sediments of the age and with the environmental evidence appropriate to forms transitional between terrestrial mammals and modern whales.
4. Geological events have had profound influence on the pathways taken in evolution.

ASSESSABLE OBJECTIVES

1. Students will recognize the elements of the process of science as reflected in this lesson.
2. Students will recognize the role of predictions in science, and how this helped clarify whale evolution.
3. Students will explain the evidence leading to a possible revision in the likely ancestors of whales
4. Students will give examples of the mosaic nature of evolution in whales.
5. Students will identify which whale-like traits appeared earliest, and which ones appeared later.
6. Students will explain how the tectonic movement of India into Asia caused changes in the Tethys Sea, and how those changes may have contributed to the emergence of whales.

MATERIALS

1. Classroom timeline, showing the Cenozoic era (past 65 million years; 6 pages)
2. "Whale Lengths" chart (optional, for overhead) for making full size whale strips.
3. "Some Modern Whales" (optional, pictures for cutouts and overhead); 4. "Pakicetus 2" Variation.
5. "Family Tree of Whales" (optional, for overhead)
6. "Provisional Phylogenetic Tree of Whale Relatives, Based on DNA Analysis" (optional, for overhead)
7. "Osmoregulation Diagram of Oxygen-18 to Oxygen-16 Ratios in Whales" (optional, for overhead)
8. "Continental Drift and the Tethys Sea" (optional) 9. "Whale Collection Sites in Pakistan" (color)

For each team:

1. Timeline of the Eocene epoch (55 to 34 mya; 2 pages): provided, or to be made by each team.
2. "Whales in the Making" page of picture strips of fossils and reconstructions of 6 whale-type mammals (to be cut apart, #1-5 placed in envelopes, and # 6 handed to teacher to hold.
3. "Discovery: Whales in Transition": Three-page Background, Procedures, Narrative, and Discussion (student handout)
4. "Whale Evolution Data Table" (optional), to be filled in from resources (optional).
5. "Origin of Whales" article" (optional; 9 pages).

TIME: Should require no more than about one 45 min. period.

TEACHING STRATEGY

This lesson can be used in three different contexts:

a. As part of your introduction to the nature of science, it will provide a novel and intriguing vehicle for exploring some of the less often appreciated elements of the process of science.

b. As part of an introduction to classification, especially when you consider organisms difficult to classify, since they don't fit perfectly into one classical group or another, depending on how the diagnostic traits of the groups are defined. Makes logical segue into evolution.

c. As part of your introduction to evolution, this presents an excellent example of transitional forms (a pattern which appears again and again in the fossil record), showing the mosaic nature of evolution, and the gradual accumulation of new traits. [Probably the **best way** to use this lesson, especially for **novice teachers**, as a low-cost alternative to "skulls lab".]

PREPARATION

1. TEACHER: Prepare a Main Classroom Timeline (or assemble pre-printed version) of the past 65 million years (Cenozoic Era). Ideally, use the same scale as the students will use (1 inch = 1 million years). Have it marked at every million years, clearly numbered from NOW near the top, then 1 mya, 2 mya, etc. down to near the bottom end (65 mya). This will require about 65 inches (in this scale). Next, mark and label the range of each epoch ("mya" = millions of years ago):

last 10,000 years (0.01 inch) = **Holocene**	(thin black line at top)
2 mya - 10,000 years ago = **Pleistocene**	(orange)
5-2 mya = **Pliocene**	(blue)
24-5 mya = **Miocene**	(yellow)
34-24 mya = **Oligocene**	(green)
55-34 mya = **Eocene**	(red)
65-55 mya = **Paleocene**	(brown)

   Color in vertical strips of different contrasting colors for the epochs to help students see the range of each epoch more clearly (see suggested colors above). Place the name of each epoch in large letters in its proper place. This chart should be placed vertically in the room so students can see the full range. Their "working" timelines will just be the Eocene epoch, but they can see where it fits relative to the other epochs shown on the classroom timeline. These ranges are the currently (1999) most accurate, according to the Geological Society of America.

2. TEACHER: Cut apart the 6 strips of fossil whales (or have this done by lab assistants). Put #1-5 into envelope for each team. Keep all #6 (*Ambulocetus*) strips (to hand out to each team AFTER someone in each team has drawn the whale fossil traits expected between 46 and 55 mya.)
3. TEACHER: Find and display pictures of modern whales from the two living suborders: the Odontoceti (toothed whales, e.g. sperm whales, Orcas, and porpoises), and the Mysticeti (the baleen whales, e.g. the California gray whale, humpbacks, and blue whales (largest living animal, at 90 feet long). In addition, display pictures of the skeletons of a whale from each group (examples at the end of this lesson).
4. Prepare copies of handouts, one copy for each team.
5. Prepare copies of resource materials (one for each team), and have available as team requests.
6. Students should work in teams of 2-4
7. EACH TEAM prepares its Eocene timeline, using 2 sheets of notebook paper taped together end to end in vertical format, or a two-foot strip of narrow butcher paper. Optional: to save time, this Eocene timeline may be pre-constructed, and used repeatedly by each class (see sample at end of lesson).
8. TEACHER: Come to class on the "dig day" dressed as if you were going on a paleontological dig, with wide brimmed hat, sunglasses, hiking boots, grungy shirt and pants, and your geological pick. You can even heighten anticipation by announcing the dig the day before, providing "field trip permission slips" for parent signatures (if the school normally requires these), and ask students to wear "proper fossil-digging clothes"!

PROCEDURES

1. When all timelines are done, and fossils are cut out and in their envelopes, Announce "We're gong on a dig .... we're going to look for whale fossils. Are you with me???? Good, let's go!" ["Close your eyes and visualize!"]

2. Students may start reading the "Discovery: Whales in Transition" handout. Optional: teacher can read the narrative to the class. As part of this, the teacher can show pictures of some modern whales (some toothed whales, odontocetes, and some baleen whales, mysticetes).
3. As each whale or near-whale species is mentioned, a partner in each team finds and places that strip on the team timeline at the appropriate time level.
4. Be sure to note that the sequence followed in the narrative closely reflects the sequence of discovery, so you get a real sense of the growing excitement amongst paleontologists as they found each fossil piece of the early whale evolution puzzle, gradually filling it in with specimens showing intermediate traits between their likely land-dwelling ancestors and the totally marine whales of today. (One of the advantages of the teacher reading the narrative is that this growing intrigue can be dramatized!).
5. When all 5 strips are in place, student teams predict what an intermediate form would look like to fill the large gap between 55 and 46 mya. As each team shows its "intermediate" drawing to the teacher, the last strip (#6) is given to the team for them to place on their timeline.
6. When all fossils are placed in position, students answer the discussion questions. Be sure they discuss each question (and possible answers) with their teammate(s).
7. Students must be prepared to ask questions and join in classwide, teacher-directed discussion when done.
8. See the extensions and variations for tips and ideas you might want to include as part of class discussion.
9. As a possible homework assignment (or extra class day assignment), students can be asked to gather more detailed information about each species (see details on student handout).

ASSESSMENT & EVALUATION

1. Ask students to list the elements of the process of science reflected in this lesson and give examples of each (for example):
   a. recognition of a problem: how did whales emerge from some land-dwelling mammal?
   b. hypothesis formation: they evolved by gradual change over time, losing tetrapod features, and gaining whale features.
   c. predictions based on hypothesis: what to look for (fossil whales with legs), where to look (Eocene sediments from warm shallow seas)
   d. searching for evidence: (digging for whale fossils in Pakistan, etc.)
   e. independent evidence of fossil sequence (oxygen isotope ratios in bones and teeth)
   f. popular "generally accepted" concepts replaced with new concepts, based on new evidence (DNA analysis and ankle features), suggesting mesonychids not ancestral to whales.
2. Build other questions (essay, or carefully crafted multiple choice questions) around the Assessable Objectives.

EXTENSIONS AND VARIATIONS

1. At some point in this lesson, (introduction, or discussion), it might be useful to demonstrate the **actual sizes** of some modern whales AND the fossil whales presented. An easy way to do that is to prepare strips of adding machine tape cut to the appropriate lengths, each clearly labeled with the name of the whale represented, and its actual (average or maximum) length (in meters). Wherever possible, include a mark where the head ends (at the neck), and indicate the head length, too. This could be a fairly easy assignment for your students to do: each team could be assigned one or two of the whales, and cut off the needed length of paper strip to do this. [Teacher can provide a measuring strip of tape, marked off in cm, along a counter top to facilitate this.] Students can hold up their whale strips as they are discussed, or they can all be mounted on a wall in the room. Display or hand out **Whale Sizes** data table with these lengths (available at end of this lesson).

2. Place large **pictures of modern whales** near the top of the **classroom** timescale, along with their skeletons. Point out that the earliest odontocete and mysticete fossils are only about 34 my old.

3. Growing out of discussion question #5, ask for other possibilities one might expect for the body form of *Pakicetus*. Then, show the diagram of "**Pakicetus #2**", reconstruction variation, found on a Greek (?) museum website, (and also shown in the PaleoWorld video described below in #7). Discuss what clues might suggest the features shown here (remember, we only have cranial fossils, no post-cranial parts of the skeleton). Pakicetus1, shown on the strip, was found in Zimmer's book, page 203. [Pay particular attention to the whale flukes on Pakicetus 2; would they be there that early, especially since *Ambulocetus* probably had none?]

4. After class discussion of question #9, display the **Family Tree of Whales** diagram on the overhead (found on Hans Thewissen's web site, but available at end of this lesson). Note how the several archaeocetes are shown as colateral branches from the direct line of descent to modern whales. A further extension of this could be to show the **Provisional Phylogenetic Tree of Whale Relatives** (a type of cladogram) showing how whales appear to relate to hippos and other artiodactyls, based on very recent DNA analyses (Nikaido, et al, 1999). The earliest mesonychids existed before the earliest artiodactyls, and cetaceans are deeply nested within the artiodactyl tree, so any connection between mesonychids and cetaceans now appears to be rather remote. This is a chance to point out how ideas in science can change with new information and perspectives. [NOTE: This change is still not settled. Some whale scientists have shown that the DNA data are subject to different interpretaions.]

5. A very nice example of another independent line of evidence which reinforces the paleontological evidence indicates habitat changes associated with early whale evolution. This can be seen in the **Osmoregulation Diagram** showing the relative percentage of the Oxygen-18 isotope (significantly higher in the teeth and bones of marine cetaceans than in those of freshwater cetaceans). This is due to their incorporation of the particular ratio of oxygen isotopes in fresh *vs*. salt water ingested. The earliest archaeocetes (e.g. *Pakicetus* and other Pakicetids) have lower O-18 ratios, associated with a freshwater habitat, while *Indocetus* (and *Rodhocetus*), and *Zygorhiza* (*Gaviacetus*), very similar to *Prozeuglodon* and *Dorudon*, all have higher ratios, indicating a fully marine habitat. *Ambulocetus* data show a wide range of O-18 levels, suggesting they lived in a wide range of salinities, as one might expect for a clearly transitional form. The original work on this was published by Thewissen, Roe, and others in 1996.

6. Growing out of discussion question #3, you might find it useful to show pictures of the ancient **Tethys Sea** which existed prior to around 55 mya between the landmass we now call India and the Asian mainland. The Mediterranean represents the westward extension of that sea, but the continental drift pushed India into Asia, pushing the land mass up to form the Himalayan Mountains (and Mt. Everest), and eliminating this eastern portion of the Tethys Sea. If there is an animation in your department showing plate tectonics (on a laser disk or CD), show it to your class, using stop action to step through the stages showing were India moves into Asia. The timing of this event coincides nicely with the Eocene, during which many long-isolated mammals on the rafting India were able to move across to the Asian mainland (and vice versa), introducing a major increase in new competitions and resulting in active selection episodes and increasing diversity. Whale evolution seems to have emerged from that geological event and the resulting biological upheavals. [See PaleoWorld video described below.]

7. If you can get a good **video** of whale evolution, it might provide further reinforcement and perhaps raise further questions for discussion. There may be a useful segment from the recent (Sep. 2001) WGBH-PBS series on Evolution. An older (1994) but interesting half-hour tape in the "PaleoWorld" series was entitled "Return to the Seas", possibly still available in a collection of their tapes, through Carolina Biological Supply. The major caution is that this video gives the impression that each of the "transitional whales" evolved into the next more recent species directly, even using "morphing" animation to show each species gradually changing form to become the next species in time, as a series of "links in a continuous chain". On the other hand, there are nice references to how the movement of India into the Asian continent caused the Tethys Sea to become shallow and saltier, creating a rich food supply for any creature able to take advantage of it, and providing a long term selective pressure favoring adaptations to specialize in such feeding opportunities. The result: whale evolution.

8. If you can prepare and mount a scaled **Earth Timeline** around your room (for the past 4.5 billion years), with the last 540 million years somewhat detailed into the 3 major eras, and showing the main life forms characterizing those eras, you can nicely show where whale evolution fits into the total scheme of time, in relation to the age of dinosaurs, human evolution, and any of the many other events and features of time. The constant presence throughout the year of this timeline helps to reinforce the deep time concept, the spaced-out sequence of events, and provide a convenient focus from time to time to point out when various biological events occurred. For a few approaches to help with this, see the other timeline lessons on this site.

RESOURCES

Book:

Zimmer, Carl. 1998. *At the Water's Edge.* The Free Press. An excellent, recent treatment of the search for evidence of whale evolution, macroevolution in general, and some of the "behind the scenes" stories of the scientists involved. Highly recommended, for teacher and interested students.

Articles:

Sutera, Raymond. 2000. "The Origin of Whales and the Power of Independent Evidence". In *Reports of the National Center for Science Education*, vol.20, no.5 (Sep/Oct 2000), pp. 33-41. An excellent overview of cetacean evolution, and pointing to several different independent lines of evidence in support of the process. (Mildly critical of creationist veiws). [Copy available at end of lesson]

Nikaido, Masato, et al. 1999. "Phylogenetic relationships among cetartiodactyls based on [DNA] insertions of short and long interspersed elements: Hippopotamuses are the closest extant relatives of whales." *Proc. Natl. Acad. Sci. USA*, vol.96, pp. 10261-10266.

Thewissen, J.G.M., L. J. Roe, et al. 1996. "Evolution of cetacean osmoregulation." *Nature*, vol.381, 30 May 1996, pp. 379 380. Study showing oxygen isotope ratios associated with freshwater ingestion vs. seawater ingestion, and whale evolution. [Also see "Osmoregulation" on Thewissen's website]

Blackburn, Daniel G. 1995. "Paleontology Meets the Creationist Challenge". *Creation/Evolution* Issue 36 (July 1995), pp. 30-31 on whale evolution. [Available from NCSE; see website listings below].

Zimmer, Carl. 1995. "Back to the Sea" January 1995 *Discover Magazine*, pp. 82-84.

Wells, Neil. 1994. Review of *Darwinism: Science or Philosophy,*. In *Creation/Evolution* Issue 38 (July 1996), pp. 20-21 on whale evolution, rebuttals to views of Johnson, Behe and Gish. [from NCSE].

Wilford, John N. 1994. "How the Whale Lost Its Legs And Returned to the Sea." In *The Science Times Book of Fossils and Evolution*, ed. by Nicholas Wade, 1998, The New York Times, pp 143-148.

Gould, Stephen Jay. 1994. "Hooking Leviathan by Its Past". May 1994 *Natural History Magazine.*

Gingerich, Philip D. 1994. "The Whales of Tehthys". April 1994 *Natural History Magazine.*

Berta, Annalisa. 1994. "What is a Whale?" *Science* 14 Jan. 1994 (vol.263, pp. 180-181).

Novacek, Michael. 1993 "Genes tell a new whale tale." 28 January 1993 *Nature* (vol. 361, pp 298-299.

Landau, Matthew. 1982. "Whales: Can Evolution Account for Them?" *Creation/Evolution*, Issue X (Fall 1982)., pp. 14-19. [Available from NCSE; see website listings below].

Conrad, Ernest C. 1982. "True Vestigial Structures in Whales and Dolphins." *Creation/Evolution*, Issue X (Fall 1982), pp. 8-13. [Available from NCSE]. Ref. to hind limb buds in whale embryos, etc.

Web Links:

<u>WHALE EVOLUTION</u>

Thewissen: Whale evolution <http://www.neoucom.edu/Depts/ANAT/Thewissen.html>
Transitional Whales <http://www.talkorigins.org/faqs/faq-transitional/part2b.html>
Cetacean Evolution <http://www.ucmp.berkeley.edu/mammal/cetacea/cetacean.html>
Ambulocetus as Transitional Fossil <http://members.home.net/fsteiger/whales.htm>
A Whale of a Tale <http://detnews.com/1997/discover/9707/10/07070019.htm>
Primitive Whales <http://www.enchantedlearning.com/subjects/whales/allabout/Evol.shtml>

<u>GENERAL EVOLUTION</u>

Evolution on line (WGBH/PBS Evolution Web Site) <http://www.pbs.org/evolution>
NAS (National Academy of Sciences): *Teaching About Evol. and Nat. of Sci.* <http://www.nap.edu/readingroom/books/evolution98/evol2.html>
NCSE (National Center for Science Education): <http://www.ncseweb.org> e-mail: ncse@ncseweb.org

<u>GEOLOGIC TIME SCALES (CURRENT)</u>

USGS short version <http://geology.er.usgs.gov/paleo/geotime.shtml>
USGS w/ details <http://vulcan.wr.usgs.gov/Glossary/geo_time_scale.html>
Time Machine (ENSI) <http://www.indiana.edu/~ensiweb/lessons/time.mac.html> (Extensions, Other Res.)

ATTRIBUTIONS

1. Original Source: Larry Flammer (lesson conceived 10/8/1997)
2. Edited / Revised for website by L. Flammer 8/31/2001
3. Front painting of Ambulocetus, courtesy of artist Carl Buell.
4. Re-Drawings for graphic pages, courtesy of artist Janet Dreyer
5. See "List of Credits" for original sources of all illustrations used in this lesson

WHALES IN THE MAKING
List of Credits: Sources for Illustrations

ILLUSTRATIONS (all redrawn for this lesson by Janet Dreyer, Illustrator)

1. Primitive Whales, e.g.: *Dorudon*, *Prozeuglodon*,) ~ 36 mya
    - a. *Dorudon atrox*: Gingerich and Uhen, 1996
    - b. *Prozeuglodon*: Rich *et al*, 1996
    - c. *Prozeuglodon*: Rich *et al*, 1996

2. Mesonychids (Extinct Land Mammals, with whale-like teeth, e.g. *Pachyaena*,*Sinonyx*) ~ 55 mya
    - a. *Pachyaena ossifraga*: Gingerich et al, 1994
    - b. *Sinonyx jiashanensis*: Zhou et al, 1995
    - c. *Pachyaena*: Zimmer/Buell, 1998, p. 157

3. (1983) *Pakicetus inachus* (skull and teeth only) ~ 50 mya
    - a.Zimmer/Buell, p. 165
    - b. Gingerich 1983
    - c. Zimmer/Buell, p. 203

4. (1990) *Basilosaurus isis* (hind leg found) ~ 37 mya
    - a. Thewissen's web site
    - b. Gingerich, 1990
    - c. National Academy of Sciences

5. (1994) *Rodhocetus kasrani* ~ 46 mya
    - a. Gingerich, 1994
    - b. Zimmer/Buell, p. 195

6. (1994) *Ambulocetus natans* ~ 48 mya
    - a. Thewissen, 1994
    - b. National Academy of Sciences

SOURCES

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Gingerich, Philip D., *et al.* 1990. "Hind Limbs of Eocene *Basilosaurus*: Evidence of Feet in Whales" *Science*, vol. 249, page155, 13 July 1990.

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National Academy of Sciences. 1998 *Teaching About Evolution and the Nature of Science*. page 18.

Rich, Patricia V. et al. 1996. *The Fossil Book.* Dover Publications, N.Y. p. 564.

Thewissen, J.G.M., *et al.* 1994. "Fossil Evidence for the Origin of Aquatic Locomotion in Archaeocete Whales" *Science*, vol. 263, page 211, 14 January 1994.

Thewissen, J.G.M. web site: <http://www.neoucom.edu/Depts/ANAT/Thewissen.html>

Uhen, Mark web site: <http://www-personal.umich.edu/~uhen/>

Zhou, X, P. Gingerich & L. Chin. 1995. "Skull of a new Mesonychid from the late Paleocene of China." *Journal of Vertebrate Paleontology*. 15(2): 387-400.

Zimmer, Carl; Illustrations by Carl Buell. *At The Water's Edge*. 1998. The Free Press. [Permission kindly granted by author and illustrator to use any illustrations from this book for ENSI lessons.]