DISCOVERY: WHALES IN TRANSITION
STUDENT HANDOUT

A. BACKGROUND

Preliminary Observations:

1. Modern whales are typically found in two major groups: the Toothed Whales (Odontoceti) and the Baleen Whales (Mysticeti).
2. Modern whales are clearly mammals which are totally ocean-adapted.
3. Embryos of several modern whales have well-developed rear legs, which then disappear. Sometimes these bones remain in the adult whales. Also, several species of baleen whales have teeth as embryos, which then disappear.
4. Fossils of modern whales appear less and less "modern-like" as we go backwards in time, so that by the Oligocene (24 mya), we no longer find modern type whale fossils, but we do find primitive whale-like mammals (archaeocetes), with a number of whale traits, well into the Eocene (to about 40 mya). Therefore, a good place to look for fossils of the earliest whales would be to search Eocene sediments (ranging from 55 to 34 million years ago).
5. All evidence to date places the emergence of all mammals from a group of terrestrial pre-dinosaur tetrapods, called synapsids, about 200 million years ago.

Question: How did whales get here??

Hypothesis: Whales evolved from terrestrial mammals, gradually undergoing modifications of anatomy and physiology, producing the fully aquatic adaptations we see in whales today.

Predictions: If whales evolved from terrestrial mammals, we should be able to find the fossil remains of early pre-whales, probably somewhat whale-like animals, but with legs of varying degrees of reduction, and certain other features varying in degrees of similarity to the ancestral and modern whales. Also, once fossils are found and dated, searching slightly earlier or later sediments should increase the chances of finding fossils of earlier or later whale-like creatures.

B. SOME IMPORTANT CONSTRAINTS AND CONCEPTS ABOUT WHALE EVOLUTION:

1. ONE OF THE LITTLE-KNOWN RESTRICTIONS THAT EVOLUTION IMPOSES ON US IS THAT, BY FAR, **MOST** OF THE CONCEIVABLE PATHWAYS BY WHICH ANY GROUP OF ORGANISMS MIGHT HAVE EVOLVED WOULD BE **IMPOSSIBLE.**
   For example, since whales are clearly mammals (have mammary glands, hair, and several distinguishing skeletal characteristics of all mammals), it would be **impossible** to expect any direct ancestry of whales from early **fishes** or even the giant **plesiosaurs** (huge ocean swimming reptiles of the Mesozoic). If any fossils suggesting such an ancestry were found, it would seriously weaken a number of well-established perceptions about vertebrate evolution.
2. On the other hand, since whales clearly possess modified mammal traits, there MUST be an ancestral connection to earlier mammals, and we should expect to find, if we're lucky, and look in the right places, **fossils** of animals with traits **intermediate** between modern whales and their four-legged terrestrial mammal antecedents.
3. These "intermediates" (pre-whales and very early whales) would, in all likelihood, NOT be the direct lineal ancestors of modern whales (that's a "needle in a haystack" situation). Such fossils would much more likely be contemporary cousins of those direct ancestors, showing the existence of animals with a **mosaic** mix of pre-whale and modern whale traits, and probably related in a lateral way to the direct ancestors of that time.

C. WHALE HUNT: SEARCHING FOR WHALE FOSSILS: the "NARRATIVE"

1. For many years, we have been finding a number of fossils of various **primitive whales** between 25 and 45 million years old (for which time frame **no** fossils of strictly modern type whales have been found). Examples of these early whales would include ***Dorudon, Prozeuglodon***, and ***Zygorhiza***. Place the **fossil picture strip #1** at about 36 mya on your timeline (actual range about 40-36 mya); ("mya"= millions of years ago).

2. As more fossils have been discovered from the early Eocene epoch (55-33 mya), scientists searched for a land mammal from which whales would have most likely evolved. The group of animals that had the most features common to the earliest primitive whales found was called the **Mesonychids**. A typical example of these animals (e.g. *Pachyaena*, or *Sinonyx*) looked something like a wolf or

hyena, with a large head, but with tiny **hooves** on all its toes! These are considered closely related to the even-toed hooved animals of today known as **artiodactyls**, with many branches evolving into modern deer, cattle, pigs, and hippos. **Place the mesonychid strip (#2)** at about the 55 mya level on your timeline (mesonychids lived from 60-35 mya).

Whale specialists generally agreed that features such as **teeth** and various other skull features placed the now extinct mesonychids as the most likely group of land animals from which all whales of today evolved.

3. This picture of whale evolution was about all we had until **1983**, when the first of a series of discoveries began to fill the empty gap between land animals and whales. That first discovery (reported by whale specialist **Philip Gingerich** and others) was ***Pakicetus***. **Place the *Pakicetus* strip (#3)** on the timeline. It was a fragmented **skull**, with lots of teeth, found in Pakistan in sediments about 50 my old. Some of its teeth were very similar to those in mesonychids, while other teeth resembled those found in the later archaeocetes. Some of its other skull features (including its shape) were also similar to late Eocene whales like *Dorudon*. It was found in river sediments near what was once a shallow sea.

4. In **1990**, in Egypt, **Gingerich** and others reported the discovery of the fossilized **hind limbs** of a large, slender previously known primitive whale known as ***Basilosaurus***, around 37 my old (actually lived from 46 to 36 mya). Its hind limbs were proportionally very tiny (about 35 cm of foot and lower leg), and clearly unable to support any movement on land, but they were better developed than those found embedded in the hip region of some modern whales today. **Add *Basilosaurus* (#4)** to your timeline.

5. In early **1994**, **Gingerich** and others found the remains of ***Rodhocetus***, with well-developed hip bones, (and about 9 million years older than *Basilosaurus*). *Rodhocetus* is about 46 my old. From what we have of its skeleton, we conclude that its hind legs were at least somewhat functional. However, its vertebrae suggest powerful tail muscles, suggesting typical whale-like swimming, possibly with tail flukes. Its skull possessed certain whale-like features, including placement of nostrils further back on the head (toward the blowhole position), and enlarged ear capsule bones, typical of whales. **Place *Rodhocetus* (#5)** on the timeline.

6 At this point, notice the critical **gap** between 50 and 46 mya. Although there are some apparently related fossils from those gaps, there are none showing clearly what the limbs or bodies were like for that period. Since *Rodhocetus* clearly had somewhat functional hind limbs (as indicated by the fairly robust pelvic bones), they were considerably reduced as compared with mesonychids. Discuss with your teammates what traits you would **expect** to find (in the **head**, **limbs**, **tail**, and **body**) in a fossil from that period which would be an **intermediate stage** of an animal evolving from a mesonychid into an animal like *Rodhocetus*. **Describe** those traits, then **illustrate** your **predictions** by making a sketch on a piece of notebook paper, showing what your team would expect. Also, **predict** what **region of the world**, and in rocks of **what age**, would you expect to find this intermediate stage?

7. When you finish step 6, show your teacher what your team predicted, and you will be handed the next **real** discovery...

8. In late **1994**, **Hans Thewissen** (formerly one of Gingerich's students), and his team, reported the discovery in 48 million year old deposits in Pakistan of a nearly complete fossil with teeth similar to mesonychids and early whales. He called it ***Ambulocetus***. **Place the *Ambulocetus* strip (#6)** on the timeline. It was about the size of a large sea lion. Its tail was long and slender, with no evidence of use for swimming. However, it had rather short, strong hind limbs, with huge feet (each toe with a tiny mesonychid-type **hoof**!). The head had a long snout with no blowhole. It probably walked on land like a sea lion, and swam with an undulating up and down motion of its hindquarters (like a sea otter), getting most of its propulsion force from its large feet. It was clearly a 4-legged cetacean.

EPILOGUE: Recent studies of the ankles and DNA of cetaceans and supposed close relatives has resulted in some changes in our understanding of those relationships. Your teacher may have you do a follow-up lesson where you can discover this yourself. If not, ask your teacher for the information.

DISCUSSION QUESTIONS

(Discuss these with your team, record your answers, and be prepared to share with the class)

1. Which typical whale traits were the **earliest** to appear?

2. Which whale traits evolved much **later**?

3. What **age** sediments, and in what **region** of the world, would you search now to get the fossils which would shed more light on whale origins, and what specific **traits** would you expect to find?

4. How closely did your "predicted traits" (expected for an **intermediate** between mesonychids and *Rodhocetus*) match the *Ambulocetus* fossil found? Does *Ambulocetus* seem to fit fairly well into the sequence between mesonychids and *Rodhocetus*?

5. Notice the reconstruction of *Pakicetus*, showing it as a **four-legged animal**. What evidence, if any, would suggest such a reconstruction? (Get your information from the suggested resources and the skull picture). How confident are you of that reconstruction? What additional evidence would give you greater confidence in that reconstruction?

6. As each new "intermediate fossil" was found, filling a "gap", how many new gaps were formed?

7. Can we make predictions about past events? Why?

8. Explain why the **absence** of transitional (intermediate) fossils is **not** a fair argument against evolution.

9. Why is it very **UNlikely** that these fossils of early whale evolution are the **direct** ancestors of whales? How ARE they probably related to those direct ancestors? What is wrong with the popular "missing link" concept of evolution?

10. Several species of modern whales have well-developed rear limbs while embryos. As the embryo continues to mature, these limbs atrophy (shrink) and become nonfunctional. Why do you suppose this happens? (Why do the limbs form, and then why do they atrophy?)

11. Summarize what you have learned about the process of science in this lesson.

12. Summarize what you have learned about the process of evolution in this lesson.

++++++ PLEASE RETURN WHALE STRIPS TO PROPER ENVELOPES ++++++

CLASS DISCUSSION

Everyone on your team should be prepared to answer the above questions during teacher-led class discussion, and have questions to ask.

OPTIONAL (Possible Homework Assignment): You may be given a list of intermediate whale fossils, along with a resource package and websites where information is available. If so, copy that list of fossils into your notebook (most recent at top, oldest at bottom), and for each, provide the following information:

1. Scientific name of the fossil
2. Year it was found (or when report was published), and **who** discovered it, if possible
3. Location of find (country)
4. Age of fossil (in mya)
5. Habitat (inferred from fossil analyses, associated fossils, and nature of sediments)
6. Parts of skeleton found
7. Inferences about mode(s) of locomotion (swimming, walking), based on fossils and habitat
8. Inferences on degree of "whaleness"

OR.....fill in the Whale Evolution Data table provided, using the resources provided.

END