Walking with Whales: The Origin and Evolution of Cetaceans

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Outline

I. Brief introduction to cetaceans
II. Historical perspectives on cetacean origins
III. Fossil record of the earliest cetaceans
IV. Current areas of inquiry in cetacean evolution
V. Summary and concluding remarks
What is a whale?

• Whales are **MAMMALS**
  – Breathe atmospheric oxygen
  – Feed their young with milk from mammary glands
  – Live birth with placenta
  – Presence of hair
  – Large brains

  – Many skeletal features
    ◦ Double occipital condyle
    ◦ Dentary-squamosal jaw joint
    ◦ Three middle ear bones
    ◦ Socketed teeth in some
    ◦ ...and many more

  But whales are also

**SECONDARILY AQUATIC**
Most mammals are TERRESTRIAL
Some mammals are SECONDARILY AQUATIC
Order Cetacea (Latin: *cetus* = whale)

**Odontocetes** (toothed whales)

**Mysticetes** (baleen whales)
Tursiops truncatus (bottlenose dolphin)

- Paddle-shaped forelimbs
- No external hind limbs
- Fusiform body
- Blowhole
- Short, stiff neck
- Dorsal fin
- Fluke
- Paddle-shaped forelimbs
Drastic change in adaptive zone

Modified from Simpson 1944, Gingerich 2007
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“In North America the black bear was seen by Hearne swimming for hours with widely open mouth, thus catching, like a whale, insects in the water. Even in so extreme a case as this, if supply of insects were constant, and if better adapted competitors did not already exist in the country, I can see no difficulty in a race of bears being rendered, by natural selection, more and more aquatic in their structure and habits, with larger and larger mouths, till a creature was produced as monstrous as a whale.”

- from *The Origin of Species* (ch.6)
1936: Remington Kellogg

“A Review of the Archaeoceti”

- North American and Egyptian whales
- All clearly fully aquatic

Zygorhiza kochii

Basilosaurus cetoides

Kellogg 1936
Hind limb vestiges in modern cetaceans

*Eschrichtius robustus* (gray whale)
“Because of their perfected adaptation to a completely aquatic life, [...] the cetaceans are on the whole the most peculiar and aberrant of mammals. Their place in the sequence of cohorts and orders [of mammalian classification] is open to question and is indeed quite impossible to determine in any purely objective way.”

- from *Classification of Mammals*
1950: Boyden and Gemeroy

Cetacea Heterologous/Homologous Precipitin Tests
(identical would yield 100%)

Cows, sheep, pigs, etc.

Modified from Gingerich 2007
Mesonychids and Cetaceans

Sinonyx

Zygorhiza

Dorudon

Kellogg 1936, Zhou 1995, Uhen 2004
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1981: *Pakicetus inachus*

- Pakistan (50 Ma)
- Fluvial sediments bordering ancient Tethys Sea
- Dentition similar to mesonychids
- Dense auditory bullae other ear features seen *only in cetaceans*
Eocene Epoch (50 Ma)
Wadi Al-Hitan, Egypt
Wadi Al-Hitan, Egypt
1990: *Basilosaurus isis*

- Egypt (37 Ma)
- Marine shales and sandstones
- Strap-like pelvic bones detached from sacrum, well-formed joint surfaces on femur
Pakicetus

Basilosaurus

13 Million Years

Pakicetus

33.9

37.2

40.4

48.6

55.8
1994: *Ambulocetus natans*

- Pakistan (47.5 Ma)
- Shallow marine deposits
- Robust limbs, fused sacrum, flexible elbow/wrist joints → capable of walking on land
- Large hind feet, seemingly powerful back and tail → proficient swimmer
- Clearly a *semiaquatic cetacean*

*Note: composite reconstruction*  
Thewissen et al. 1994, Thewissen and Bajpai 2001

- Pakistan (46.5-47 Ma); marine shales
- Unfused sacrum → sign of increasingly flexibility for dorsoventral undulation
- Structure of hands → limited terrestrial locomotion
- Expanded feet → pelvic paddling in water

*Note: composite reconstruction*
Cetacean Astragali

- **Canus** (most mammals)
- **Rodhocetus**
- **Antilocapra**
- **Artiocetus**
- **Hippopotamus**
Since 2001...

Pakicetus attocki (2001)

Maiacetus inuus (2009)

Dorudon atrox (2004)

2009: Maiacetus inuus

Gingerich et al. 2009
2009: *Maiacetus inuus*

A mother preserved with a fetus *in utero*!  

Gingerich et al. 2009
Eocene Cetaceans

Eocene Cetaceans

Number of Species

Pakicetidae 6
Ambulocetidae 3
Remingtonocetidae 7
Protocetidae 23
Basilosauridae 18

TOTAL: 57

Neoceti
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Locomotor Evolution

How does an animal go from swimming by paddling four limbs (how most mammals swim)...

...to losing its hind limbs and developing a specialized tail for propulsion?
Evolution of the Vertebral Column

*Dorudon atrox*

Lumbar, sacral, & anterior caudal regions

*Cervical region*

*Elomeryx armatus*
Cetacean Phylogeny

Uhen 2010

[Diagram showing cetacean phylogeny with labels for Archaeocetes, Mysticeti, Odontoceti, and other groups with lineages and classifications.]
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Concluding Remarks

• Fossil cetaceans with intermediate anatomies appear during the time periods and in the paleoenvironments when and where we expect to find them.
• Evidence from development, comparative anatomy, genetics, biogeography, and stable isotope analyses corroborate the scenario illustrated by the fossil record.
 VALLEY OF THE WHALES

An Egyptian desert that was once an ocean holds the secret to evolution’s most remarkable transformation.

Imagine this dry expanse underwater, with whales hunting and diving. Today visitors to Wadi El-Hitan walk a stone-lined path to see rocks that host the fossils of the long-gone sea creatures.
Questions?