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Teacher's Guide
A Whale for Georgia

How A Georgia Whale Possibly Led to All Modern Whales

By
Thomas Thurman
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Slide 1

Title Page; A Whale for Georgia,
How Our Georgia Whale Possibly Led to All Modern Whales.

Slide 2

Dedication "Why aren't we given this?"
This work is dedicated to South Georgia Science Teachers
Especially those attending a 6/June/2018 presentation *Georgia's 500 Million Year Fossil Record* at SW GA RESA in Camilla, GA.
Particularly that one teacher, I don't know her name, which became frustrated when I briefly covered *Georgiacetus vogtlensis*.
"Why aren't we given this?" There was a bit of annoyance in her voice.

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Slide 3
A New Whale Discovered

Georgiacetus (Georgia-seat-us) *vogtlensis* (voe-gull-in-sis)
During the 1983 construction of Nuclear Power Plant Vogtle fossils from three individual whales were recovered. The fossils were discovered 30 feet deep while workers were cutting a reactor cooling channel in the rock.

- One mass which represented 75% to 80% of a single, adult individual with fully erupted molars and no duplication of bones.
    - Sixty fossilized bones and teeth were recovered from the mass.
        - A nearly complete skull
        - left mandible (jaw)
        - 23 vertebrae
        - 12 ribs
        - and both innominates (hips).
- The second animal was represented by a single forward vertebra.
- The third animal was represented by three forward vertebrae, portions of at least four ribs, and the partial crown of a single tooth.
- All three individuals likely belonged to the same species.
- They were protowhales (more correctly, protocetids), a large group of whales with legs, a family of animals transitioning from a terrestrial to a marine life.
- With the help of the construction crews the mass was removed and taken to Georgia Southern University in Statesboro, Georgia for research.

It was 1998 before their results were published.

- A new genus and species of whale was introduced.
- *Georgiacetus vogtlensis* is the 40.5 to 37.2 million year old Georgia-Whale from Plant Vogtle.
- The age of *Georgiacetus* was accurately established by dating the other fossils contained in the recovered matrix.

For more on *Georgiacetus*:
http://www.georgiasfossils.com/10-a-whale-for-georgia.html

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Slide 4
***Georgiacetus* was a large animal.**

The skull

- more than 30 inches long (76 cm)
- 12 inches wide (30.5 cm)
- 24 inches (61 cm) deep,
- fleshed out it would have been decidedly larger.

It's hard to know the total length of the animal as no limbs were found.

- Researchers estimate a length of at 10 to 15 feet (3 to 5 meters) considering the head would have been nearly a meter long for a living animal.

Image of reconstructed skull and skull after preperation;
Georgiacetus vogtlensis skull recovered by Georgia Southern

- Note the large crest to anchor powerful jaw muscles.
- This is the skull of an active, apex predator.
- Relatively small brain case
- Formidable tooth arrangement
- Note two nostril blowhole relocated from tip of snout to bridge of snout.

It was also observed that the mandible, or jaw, of *Georgiacetus* already showed adaptations towards keen, directional underwater hearing.

- But there is no evidence that the Georgia whale could echolocate, as do modern toothed whales & dolphins. *Georgiacetus* lacked the melon organ which allows echolocation in modern whales.

Reminder;
Plant Vogtle stands 93 miles inland from the nearest modern coastline, 40 million years ago this was the bottom of a shallow, fertile, sub-tropical sea.

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Slide 5
The Better To Eat You With

Many teeth were present among the *Georgiacetus* fossils recovered at Plant Vogtle. They represented a somewhat advanced version of the typical protocetid layout.

- Forward peg-like teeth to seize prey.
- Rear triangular teeth to shear & process prey in to manageable chunks.

Those massive jaw muscles powered these formidable teeth.

Images 1 & 2 of right canine

- You will see this same basic canine endure for many millions of years and through many species.

Images 5,6,&7 represent different views of the same molar.

- Notice the beginnings of serrations on the edge.
- We'll see these grow in later whales.

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Fully Marine

It's clear that *Georgiacetus* was fully marine, it was unable to support its own weight out of the water.

Pictured is the right hip, or innominate.
(The left was also found but the right was preserved in better condition.)

- It's on display at Georgia Southern University Museum.
- It's evidence that *Georgiacetus* was fully marine.
    - The hips are free-floating in the muscle mass.
    - The whale's hips were not fused to the spine.
        - Our hips are fused to the spine to support our weight.
- The sacrum is completely absent in *Georgiacetus*
    - It is replaced by normal vertebrae.
- However, notice too well-developed ball sockets on the hip.
    - This is where the femur would attach.
    - No leg bones were present with the fossil, they were likely carried away from scavengers.
    - Still, well developed hip sockets for the femur suggest well developed femurs & legs.

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So…How Did Georgiacetus swim?

At this point paleontologists simply didn't know how *Georgiacetus* swam.
This was an important question, the Georgia whale was an apex predator.
The Plant Vogtle fossils lacked remains from the legs and tail.

- Only the "anterior caudal vertebrae" (vertebra at the beginning of the tail) was present.
- This isn't uncommon with fossils, when an animal dies, predators often dismember it and carry away bits.

The "tadpole" *Georgiacetus* seen on Georgia Power posters was briefly considered early on, but that was quickly abandoned.

- The structure of the vertebrae would make tadpole swimming very painful.
- Sadly, these posters are still floating around.

Early, serious reconstructions of the Georgia Whale often have combinations of flukes, flippers and webbed paws.

- Most paleontologist strongly suspected that Georgiacetus possessed a fluke of some kind.

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Slide 8
Older still… Enter *Carolinacetus ginerichi*

In July 2005 a new protocetid from South Carolina was announced by Jonathan H Geilser, Albert E. Sanders & Zhe-Xi Lou.

- The fossils where slightly older than *Georgiacetus*.
- The difference in age is so small they likely overlapped in life.
- However the teeth and skull are more primitive than *Georgiacetus*.

Carolinacetus was larger than *Georgiacetus*, by about 10% or so.

It's known from a partial skull, the rear portion of both mandibles, 13 vertebrae, and parts of 15 ribs.

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Oceangoing…

The *Carolinacetus* paper is also very interesting in that it discusses possible routes protocetids followed to reach the Southeastern North American from the Tethys Ocean.

- The Tethys Ocean (it's a bit big to be a sea) stood where the Middle East is today.
- Whales emerged in the Tethys Ocean as mammals returning to the sea.
- They adapted, many species emerged, diversified, expanded their range and found extinction.
- They entered the Mediterranean then the Atlantic
- Following the Greenland route they crossed the Atlantic and eventually populated the Southeastern Sea which often covered Georgia's Coastal Plain.

Even following the coastal Greenland route would have meant crossing large areas of open sea, so there is no doubt the protocetids were efficient and capable swimmers.

Plate Tectonics (Continental Drift) tells us that the continents were a bit closer 40 to 45 million years ago, but sea levels were much higher.

- The Earth was much warmer
- Greenland and the poles were likely ice free.

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Slide 10
About 50 Million Years Ago Whales Return to the Sea.

The evolution of whales possibly began with *Indohyus* (meaning India-pig)

- Like modern hippos, *Indohyus* was a herbivore that fed on land but felt safest in the water.
- It was a raccoon sized animal that possessed the characteristic ear bone structure seen in modern whales; "common descent".
- A well-preserved specimen was described in December 2007 by J.G.M. (Hans) Thewissen, a leading expert in whale evolution. Remarkably dense bones revealed that this was an aquatic animal.

This "venture into the sea" happened on the shores of the extinct Tethys Ocean which existed where Pakistan, India & Nepal are today.

- The protocetids (or protowhales) which emerged were diverse but they were all carnivores and radiated out from the Tethys Ocean.

Protowhales (protocetids) shown (From Wikipedia)

- Pakicetus; is an extinct genus of amphibious cetacean which was native to modern Pakistan during the Eocene. The vast majority of paleontologists regard it as a very primitive whale.
- Ambulocetus; (meaning "walking whale") was an early cetacean with short limbs and large feet used for swimming. It is a transitional fossil that shows how whales evolved from land-living mammals.
- Remingtonocetus; is an extinct genus of early cetacean freshwater aquatic mammals native to the coastline of the ancient Tethys Ocean during the Eocene. It was named after naturalist Remington Kellogg.
- Rodhocetus; is an extinct genus of protocetid early whale known from the Lutetian (48.6 to 40.4 million years ago) of Pakistan. The best-known protocetid, Rodhocetus is known from two partial skeletons that taken together give a complete image of an Eocene whale that had short limbs with long hands and feet that were probably webbed and a sacrum that was immobile with four partially fused sacral vertebrae. It is one of several extinct whale genera that possess land mammal characteristics, thus demonstrating the evolutionary transition from land to sea.

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Slide 11
Protocetid & Basilosaurid Teeth Are Related

The progression of tooth development from protocetids to the basilosaurids.

- *Durodon* is a member of the basilosaurid family.
    - Also a common Georgia fossil.
- As you can see the differences between *Carolinacetus* & *Georgiacetus* teeth are greater that the differences between *Georgiacetus* & the basilosaurid teeth.
- The basilosaurid tooth arrangement seems to be an evolved version of *Georgiacetus* teeth.

Canines and incisors intended to catch prey change very little from *Carolinacetus* all the way through the basilosaurids, but as we see in this slide the molars undergo a dramatic transformation.

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Slide 12
Modern Whales; Baleen & Toothed
(Text shown on slide so students may compare & contrast.)

Common ancestor
Shared traits showing a common ancestor to all modern whales & dolphins:

- All whales & dolphins are carnivores
- possess horizontal flukes
- front flippers
- atrophied pelvis
- blowholes (nostrils) at the top of their head
- hearing as a primary sense
- and they're mammals who nurse their young.

Toothed Whale Traits
(Including dolphins)

- Teeth (at least at some point in life)
- Keen underwater hearing
- Single nostril
- Melon or spermaceti organ
- Active & highly developed echolocation
- No sense of smell
- Active predators
- Many species highly social
- Great variation in adult size
    - Smallest; Hector's dolphin, 1.4m (4.6ft)
    - Largest; Sperm Whale, (male) 16m (52ft)

Baleen Whale Traits

- Filter feeding baleen
- Two nostrils
- Retains basic sense of smell
- Excellent unwater hearing
- Echolocation not shown
- Includes fastest whales
- Includes largest whales
    - Blue whales, 30m (98ft)
- Most, but not all, feed on small fish & plankton.
- Passive predators.

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Slide 13
Basilosaurids, the first modern whales.

At 37 million years ago…
Georgiacetus is extinct.
The basilosaurid family is already widespread and diverse.

There is both a basilosaurid family (Basilosauridae) and the genus *Basilosaurus*.

The genus *Basilosaurus* is held as the first of the great whales and includes two species;

- *Basilosaurus cetoides*
  - *Basilosaurus cetoides* is the larger (15 to 18 meters or 50mto 60 feet), and occurs in the American Southeast.
- *Basilosaurus isis*

The basilosaurid *family* includes *Dorudon* which was a smaller, killer whale sized animal at 6+ meters (20+ft) and is well known from Georgia.

Notice; both possess the peg-like from teeth and triangular molars.
This is the same layout of teeth we saw in *Georgiacetus*.

The legs and tails are different than *Georgiacetus*.

- In basilosaurids the rear legs became atrophied & greatly diminished.
- Flukes appear with the basilosaurid family.
  - The skeletal structure supporting flukes, as present in all modern whales, is also found in all but the earliest basilosaurids.

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Slide 14
North America's Known Protocetids

The dates shown for theses animals represents the estimated date of the sediments containing the fossils, these protocetids certainly existed well before and well after. It's even likely they overlapped, with all three in the Southeastern Sea at the same time.

Natchitochia jonesi*;* 39.5-39.9 million years old
- Mark D. Uhen, 1998, Journal of Vertebrate Paleontology
- One of the larger protocetids.
- Known from Natchitoches County, Louisiana; 13 vertebrae and partial ribs.
- Collected in 1943 by Paul H. Jones. Specimens were sent to the U.S. National Museum (which became the Smithsonian) where the Remington Kellogg recognized it as an ancient whale but never published the fossils.

Carolinacetus gingerichi*;* 39.7 - 42.4 million years ago
- Jonathan H Geilser, Albert E. Sanders & Zhe-Xi Lou, July 2005, Museum of Natural History.
- Known from South Carolina. Slightly larger than *Georgiacetus* but shows many features which seem less advanced than the Vogtle Whale.

Georgiacetus vogtlensis*;* 39.8-42.4 million years old
- Richard C. Hulbert Jr, Richard M. Petkewich, Gale A. Bishop, David Bukry, & David P. Aleshire. September 1998 Journal of Paleontology.
- Known from Georgia, Alabama & Mississippi. Most advanced known protocetid. Most complete skeleton.

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Slide 15
Earliest Basilosaurid; *Basilotritus*

Members of the basilosaurid family (Basilosauridae) are recognized by their largish, triangular, twin rooted molars possessing prominent serrations.

- The origins of those teeth can be glimpsed in *Georgiacetus*, whose molars are just beginning to show a trend towards serration.

Members of the genus *Basilotritus* have serrated molars, they're considered the most primitive members of the basilosaurid family.
The genus is represented by two species;

- *Basilotritus uheni*, named in honor of Dr. Mark Uhen
- *Basilotritus wardii.*

Uhen reported that *Basilotritus wardii* had slightly elongated vertebrae which suggested B. wardii was on the larger size. Larger than the protocetids.

Uhen also reported a right innominate (hip bone) from *Basilotritus wardii* which appeared to be of load bearing size and shape. Uhen suspected that *B. wardii* was amphibious. This also leads researchers to suspect that *Basilotritus*, like *Georgiacetus*, probably lacked flukes.

- However, as we've seen the hip bones of *Georgiacetus* were not load bearing.
- This suggest that in some ways *Georgiacetus*, a protocetid, was more advanced than *Basilotritus*, a basilosaurid.
- Clearly, more fossils are needed to resolve this.

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Slide 16
A Southeastern Sea Full of Predatory Mammals

Traditionally; paleontologist state that any single species typically endures for roughly 10 million years, of course that varies wildly.

This means that the sea which covered the Southeast was probably full of predatory whales equipped with some formidable teeth. That's at least five species, two basilosaurids and three protocetids, probably sharing the Southeastern Sea.

- Bear in mind that the original *Georgiacetus* find at Plant Vogtle included three individuals in a relatively small area, this suggest a population, (perhaps a pod?).

It is entirely possible that additional species were present which have yet to be discovered; the three protocetid species were only identified in the last 20 years.

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Slide 17
Flukes

Flukes are the key evolutionary adaptations which gave us of modern whales.

- They emerged 34 million years ago, just before the split between toothed and baleen whales.
- Since then flukes have diversified wildly allowing species to fill many niches.

Durodon, and the other basilosaurids possessed the same end-of-tail vertebrae arrangement as modern whales.

- Because of this it's assumed they possessed flukes.

Of course, It seems likely that *Basilotritus*, the most basic known basilosaurid, lacked flukes. More fossils are needed to resolve this, and other issues.

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Slide 18
Toothed Whales (Odontoceti) Emerge
From the Basilosaurids

Two features shared by all toothed whales.

1. Teeth, though these are almost hidden in some beaked whales.
2. Echolocation, one nostril adapted through a melon to create sound, toothed whales breath through a single nostril.

Just after the extinction of the basilosaurids, about 33 million years ago (mya) the genus Squalodon is present, its tooth arrangement clearly shows ancestry through the basilosaurids.

- The deeply inclined skull above the eye sockets reveals the presence of the melon, an organ involved in echolocation and only found in toothed whales.
- The same feature can be seen in modern dolphin and killer whale skulls.

Squalodon links the basilosaurids and modern toothed whales.

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Slide 19
Baleen Whales (Mysticeti) Emerge Through the Basilosaurids

Nearly all of the earliest Mysticeti occur in the Southern Hemisphere where their greatest diversity persists, it's likely they emerged there.

Llanocetus denticrenatus is known from the 37.2-33.9 million year old sediments of Seymour Island, Antarctica.

- Current research puts it as the earliest known Mysticeti or baleen whale.
- It likely fed by filtering plankton through highly specialized basilosaurid-type teeth.
- This was a large animal with a 2 meter (6.5 foot) long head and a body length of perhaps 30 feet (9.1 meters).
- It was excavated in the mid-1970s and described by E. D. Mitchell in 1989.
- The skull is in on display at Smithsonian National Museum of Natural History in Washington.

The structure of the molars would have allowed *Llanocetus* to filter feed on plankton, in the manner modern crabeaters seals (which don't eat crabs).

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Slide 20
Both Baleen & Teeth; A Transition

The genus *Aetiocetus* emerged 33.9 million years ago and possessed both basilosaurid-derived teeth & baleen, it endured for 10 million years in the Oligocene Epoch. It's known from Oregon, Japan & Mexico

The genus was established 1966 when the first individual was described by Douglas Emlong.

It currently contains 4 species.

- *Aetiocetus cotylalveus*
- *Aetiocetus polydentatus*
- *Aetiocetus tomitai*
- *Aetiocetus weltoni*

Adapted from Wikipedia…

"These whales are remarkable for their retention of teeth and presence of nutrient foramina, indicating that they possessed baleen. Thus, Aetiocetus represents the transition from teeth to baleen in Oligocene mysticetes. The presence of baleen is inferred from the fossil record in the skull of Aetiocetus."

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Slide 21
***Georgiacetus* goes national**

In 2008 Mark D. Uhen, who was at the Smithsonian National Museum of Natural History at the time, published a paper that made the cover of the prestigious Journal of Vertebrate Paleontology and placed *Georgiacetus vogtlensis* as the probable ancestor to all modern whales.

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Slide 22
A Case of Evolution in
Georgia's Natural History

Uhen had access to new fossils; vertebra, teeth and a partial mandible that had come from, Alabama, and Mississippi.

These not only expanded the knowledge of *Georgiacetus* but established that the whale was widespread in the sea which covered the Southeast.

Today Dr. Mark Uhen teaches and continues his research at George Mason University in Fairfax, Virginia.

You can find his work on Facebook as Uhen Lab.

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Slide 23
Flukeless

Image A & B; two views of a probable *Georgiacetus* posterior caudal (end-of-tail) vertebra. This University of Alabama specimen was reviewed by Uhen.
It has two striking features;

- It's longer than it is wide
- & it's flanged.

All but the earliest basilosaurids possessed flukes.

- As seen in the *Durodon* tail illustration (left) the last few vertebrae are compressed & simplified, they lack flanges and are decidedly shorter than they're wide, the same arrangement seen in all modern whales.

Uhen's is the first such protocetid end-of-tail vertebra described, but did it come from *Georgiacetus*? Probably. But that can't be confirmed without other specimens

This single vertebra strongly suggests that all protocetids lacked flukes.

- Therefore, flukes seemingly emerged with the basilosaurids, and as we saw in the teeth above, the basilosaurids emerged from the protocetids.

As we saw in the teeth & hips; *Georgiacetus* remains the most advanced known protocetid…

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Slide 24
The Ancestor of All Modern Whales?

In 2008 Mark Uhen argued that our Georgia whale, *Georgiacetus vogtlensis,* was clearly & closely related to the basilosaurids.

Similarities in the teeth, skull and skeletal arrangement, despite the differences in the tail, revealed enough commonality to establish the Clade Pelagiceti, placing our Georgia Whale as the possible ancestor to the basilosaurids.

Modern whales, as we've seen, are likely descended from the basilosaurids.
In essence, Uhen argued that *Georgiacetus* might be the ancestor to all modern whales.

- *Georgiacetus* led to the basilosaurids.
- The basilosaurids led to the toothed whales (odontoceti) and baleen whales (mysticeti).

On 13/Sept/2008 Mark Uhen was interviewed by
National Public Radio's, All Things Considered;
Legs Propelled Whale Ancestor
https://www.npr.org/templates/story/story.php?storyId=94596835

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Slide 25
Others Have Interpreted the Data Differently

Dr. Jonathan Giesler is another respected researcher into whale's natural history.

Geiseler can be found at Department of Anatomy, College of Osteopathic Medicine, School of Arts & Sciences, New York Institute of Technology.

NYIT maintains a webpage; Evolution of Whales and Dolphins.
https://www.nyit.edu/medicine/evolution_of_dolphins_whales

Locomotion: Unfortunately, very little of the tail of *Georgiacetus* is known, which makes it very difficult to interpret how well this cetacean could swim.

Recently, Uhen (2008) has suggested that *Georgiacetus* lacked tail flukes, based on a partially preserved caudal vertebra of a protocetid from Georgia.

However, it is uncertain whether this specimen can be referred to *Georgiacetus* and whether it was actually situated in the fluke-bearing portion of the tail.

If *Georgiacetus* did not have a fluke, it likely swam using alternate hindlimb paddling or spinal undulation as is seen in otters, which employ the hindlimbs and/or tail as a propulsive surface.

Unlike many earlier cetaceans, *Georgiacetus* lacked a solid contact between the vertebral column and the pelvis.

- In fact, all of the vertebrae
- in the hip region are separate
- indicating that this early whale lacked a sacrum.

Taken together, these observations strongly suggest that *Georgiacetus* could not have supported its body weight on land

Sensory Abilities:
The eyes of Georgiacetus are normally proportioned, indicating vision was an important sense.

- However, it lacked stereoscopic vision, suggesting that it may have located its prey with sound, either passively or with a rudimentary system of echolocation.

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Slide 26
Of course, a new fossil could upset all of these beautiful theories….

12/October/2011 the following headline in Argentina's MercoPress caused a stir in the vertebrate paleontology communities;
"Argentine-Swedish team discovers 49 million-years fossil of fully aquatic whale in Antarctica"

Link to article
http://en.mercopress.com/2011/10/12/argentine-swedish-team-discovers-49-million-years-fossil-of-fully-aquatic-whale-in-antarctica

To quote the article

- "…Those earlier proto-whales were amphibians, able to live on land as well as sea. This jawbone, in contrast, belongs to the Basilosauridae group of fully aquatic whales…"
- "The relevance of this discovery is that it's the oldest known completely aquatic whale found yet…"

In 2016 the paper was published describing basilosaurid fossils from Antarctica and the age of the sediments had been revised to between 46 and 40 million years old; and even this age is still being debated.

However, they are unquestionably basilosaurid fossils.

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Slide 27
Basilosaurids in Antarctica

The fossils have not yet been assigned to any species nor has any new species been created, but the authors do, pointedly, state that the teeth are distinct from *Llanocetus* and should not be assigned as primitive mysticeti, or as a baleen whale ancestor.

The imaged tooth appears to be basilosaurid.

- Several fossils were recovered from several layers in the stratigraphy, most were fragmentary and had to be reassembled in the lab.
- Multiple individuals are represented, from multiple time frames.
- Finds included mandibles, hips and teeth

Age; 40 to 46 million years old, but the authors freely admit that accurately dating the sediments has been problematic.

To paraphrase the paper
"The Antarctic basilosaurids reported appear to represent mid-sized forms, such as *Zygorhiza* and *Dorudon*. Comparisons with other basilosaurids from the Southern Hemisphere revealed more similarities with the New Zealand material than with the Peruvian basilosaurids… More and better-preserved specimens are necessary to determine the diversity of basilosaurids in Antarctica and their relationship with other taxa reported from the Southern Hemisphere."

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So… Did Our Georgia Whale Lead to All Modern Whales?

Probably not.
If the Antarctic basilosaurid finds are confirmed at 42 million years or more, they'll be older than *Georgiacetus*.

Additionally:
Basilotritus uheni has been reported from Ukraine in sediments the same age as *Georgiacetus*, *Basilotritus uheni* is a basilosaurid, but it probably lacked flukes.

Georgiacetus remains the most advanced protocetids.
For a decade, it was considered the most likely ancestor to all modern whales.

Professional paleontologist at universities & museums depend on amateur researchers to do preliminary fieldwork and report fossils.

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References, Researchers & Appreciation