Teacher Resource

National Park Service
Department of the Interior

Hagerman Fossil Beds
National Monument

How did **mammals** in North America **adapt** to **climate** and **habitat change**?

Examining changes in tooth morphology in herbivorous land mammals preserved in the fossil record over the past 40 million years.

Fossil Teeth: A record of Changing Climates and Evolutionary Responses preserved in the Fossil Record.

Key Terms and Concepts:
Convergent and divergent evolution, adaptation, derived traits, climate change, ecology, morphology, habitat, environment.

Summary:
Students will look at changes in tooth size and shape (morphology) in the fossil record of herbivorous mammals in North America using data from a recent paleontological study. Students will infer factors which caused the observed evolutionary adaptations and link biological adaptation with global climate change and localized habitat change.

Education Standards:
This lesson was constructed using the Disciplinary Core Ideas of the Next Generation Science Standards (NGSS) and guidelines for reading and writing from the Common Core State Standards (CCSS). It is intended **for high school biology students** (Introductory, Honors and/or Advance Placement level) grade level 9-12.

Learning Objectives:
- Students will learn about differences in tooth morphology that reflect diet, drawing examples from modern animals and those preserved in the fossil record.
- Students will study an example of evolutionary adaptation in the fossil record using data from a recent paleontological study.
- Students will read from a scientific article and respond to the hypothesis with their own opinion (reading, critical thinking and writing skills).
- Students will interpret data and draw conclusions based on scientific evidence from primary source material (quantitative analysis, scientific reasoning skills).

Prerequisite Knowledge:
- Students should be aware that the Earth's climate has changed in the past, and continues to change today. This has influenced the diversity and distribution of life on our planet throughout geologic time.
- Students should be comfortable with the concepts of *evolution* and *adaptation*. Living organisms on our planet are continually adapting to new climates and environments. Evidence for these changes are preserved in the fossil record.
- This lesson involves reading line-graphs and pie-charts. Quantitative skills, such as defining axes and interpreting trends, are practiced through the graph activity.

Lesson Overview and Timeline

Teacher Note--
Words that appear in bold print in the text of this document are defined in a supplemental glossary (Page 5).

Each set of lesson materials is structured for one 45 minute class period, with the option to assign extension activities as take-home assignments.

(1) Pre-Lesson (45 minutes). Two activities ("Guess the Skull" and "Tooth Types") explore similarities and differences between the size and shape of skulls and teeth of different mammals.

(2) Introductory Lesson (45 minutes). Teacher introduce the concept that changing climates can create new habitats may require animals to adapt, migrate, or go extinct. Students examine data showing changes in tooth morphology in herbivorous mammals over time and learn to identify and describe large-scale trends from the graph.
Teacher uses PowerPoint "Grasslands and Teeth", with accompanying student worksheet ('Vocabulary and Concepts from Grasslands and Teeth PowerPoint').

(3) Primary Lesson (45 minutes). Teacher uses PowerPoint "Fossil Teeth" to provide background about the specific research study from which data for the lesson was derived. Presentation is then followed by accompanying worksheet: Student Graph Analysis (Activity A). Both worksheet and PowerPoint Presentation provide introduction on how to read the graphs used in lesson activities.

(4) Extension Activities (30-45 minutes each). Students probe deeper into the fossil record of tooth-shape change. 'Why do we see a shift in the dominant tooth type of herbivorous mammals in North America 30-15 million years ago?' The activities encourage students to connect patterns in the tooth data with broader patterns of climate and habitat change. Extension activities are structured around guiding worksheets: Activity B (Student Timeline) and Activity C (Student Opinion Article).

Materials:

Pre-Lesson Activities:
- Pre-Lesson Activity #1: "Guess the Skull"
- Pre-Lesson Activity #2: "Tooth Types"

Main Lesson Activities and Extensions
- Teacher PowerPoints (2): "Grasslands and Teeth", "Fossil Teeth"
- Activity A: Graph Analysis Student Worksheet (with Answer Key)
- Activity Extension B: Student Timeline Worksheet (with Answer Key)
- Activity Extension C: Primary Reading and Student Opinion Article

Additional Materials
- Teacher Background: "Grass Evolution"
- Students Worksheet: Vocabulary and Concepts (with Answer Key)
- Sample Student Assessment (with Answer Key)
- Student Survey and Teacher Survey

Teacher Note--
This lesson plan includes surveys for both teachers and students designed to help educators at the National Park Service better evaluate their programs. Please mail surveys and any other feedback to:

Hagerman Fossil Beds
National Monument
Paleontologist
PO Box 570
Hagerman, ID 83332

Teacher Note--
A link between the NGSS content standards and themes of this lesson is provided here in the sidebar.

NGSS.HS.LS2:
Environmental changes lead to changes in diet and lifestyle, which affect physical morphology.

NGSS.HS.LS4:
Changes in morphology reflect evolutionary pressures.

NGSS.HS.LS4:
Adaptation can lead to organisms that are better suited to their environment because individuals with the traits adaptive to the environmental change pass those traits on to their offspring.

NGSS.HS.ESS2:
The properties and conditions of Earth and its atmosphere affect the environments and conditions within which life evolved.

Teacher Note--
Common Core State Standards (CCSS) Formatted after the College and Career Readiness Anchor Standards: http://www.corestandards.org/ELA-Literacy/

Standards

Next Generation Science Standards (NGSS)

NGSS Disciplinary Core Ideas

- HS LS2. Ecosystems: Interactions, Energy and Dynamics. How do organisms interact with the living and non- living environments to obtain matter and energy?
    - HS LS2.A: Ecosystems are dynamic, experiencing shifts in population composition and changes in the physical environment over time.
    - HS LS2.C: Ecosystem dynamics, functioning and resilience. What happens to ecosystems when the environment changes?
- HS LS4. Biological Evolution: Unity and Diversity. Evolution occurs when natural selection changes the distribution of traits in the population over multiple generations.
    - HS LS4.C: How does the environment influence populations of organisms over multiple generations?
- HS ESS2: Earth's systems
    - HS ESS2.D: Scientists can infer climate changes in the past from geologic evidence in the fossil record.
    - HS ESS2.E: As the Earth changes, life on Earth adapts and evolves to those changes, affecting other Earth systems.

NGSS Scientific and Engineering Practices

- HS SEP 4. Analyzing and Interpreting Data
- HS SEP 7. Engaging in Argument from Evidence

NGSS Crosscutting Concepts (HS): (1) Patterns, (2) Cause/Effect, (6) Structure and Function, (7) Stability and Change

Common Core State Standards:

CCSS.ELA-LITERACY.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-LITERACY.RST.11-12.9
Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process or concept.

CCSS.ELA-LITERACY.RST.9-10.6
Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address.

CCSS.ELA-LITERACY.CCRA.W.1
Write arguments to support claims in an analysis of substantive topics or texts using valid reasoning and relevant and sufficient evidence.

Teacher Background:

The rise of **grasslands** between 26 and 22 million years ago created new environments to which land mammals **adapted.**

Earth's climate and biosphere are linked. As climate conditions change, species adapt to new environments. This lesson examines the spread of open areas and grasslands in North America as a result of changing climate, with a focus on specific morphological adaptations in the teeth of herbivorous land mammals.

A major development in the evolution of herbivores was the shift from a diet of browsing leaves to grazing grass in the last 30 million years.

What does the fossil record tell us?

The fossil record from the past 40 million years suggests cooling and drying climates accompanied by increased seasonality of weather patterns shifted the composition of plants, favoring more open habitats to previously dominant tropical forests. A new ecosystem—grasslands, became widespread. Herbivorous land mammals co-evolved to take advantage of these new environments.

How was the spread of open grassland environments connected to changes in the teeth of herbivorous mammals?

Animals feeding in open environments such as grasslands ingest more grit and soil when eating plants low to the ground, as opposed to browsing twigs and sticks from trees. A diet of grasses is especially tough on teeth. High-crowned molars are better adapted for a diet of chewing grass and resisting wear from the grit (dirt, rocks, etc.) that comes with grazing shrubby plants that grow low to the ground.

The change in tooth morphology in herbivorous mammals reflects evolutionary adaptations to new diets and feeding patterns. In this lesson, students will study the timing of changes in tooth morphology in various types of mammals and compare with the timing of grasslands to infer the cause of evolutionary adaptations in the geologic past.

Glossary

Adaptation: Genetic changes in a species in response to evolutionary and environmental pressures. For example, modern horses evolved longer limbs than their shorter ancestors in response to more open grassland environments and the need to outrun predators.

Convergent Evolution: The process by which organisms of different lineages independently evolve similar traits to adapt to similar environments. For example, in North America, a variety of types of mammals evolved teeth that were better adapted for chewing grass when grasslands become more prevalent.

Divergent Evolution: The process by which species accumulate enough distinct traits and behaviors to distinguish themselves as a new species. For example, humans, bats and whales are all derived from a prehistoric family of mammals with 5 fingers and toes, but have evolved into very different physical forms due to different environmental pressures.

Evolution: The process by which life on Earth has developed and diversified over time.

Fossil: The remains of any past life form that has died and been preserved in the rock record. Most commonly, soft organic parts decompose while hard body parts, such as bones, teeth, shells and exoskeletons, are chemically dissolved and mineralized () into rock.

Fossil Record: The combined set of evidence from past life forms preserved in the rock record.

Hypsodonty: "High- crowned teeth," regarding the ratio of the height of a tooth relative to its overall size. The ratio of tooth height to its overall size (called the "hypsodonty index", or HI) is used by scientists that study changes in tooth morphology as a result of diet.

Morphology- The form and structure of certain features of an organism.
Example: Tooth morphology varies amongst browsers and grazers depending on their diet.

Paleoclimatology: The study of how Earth's climate has changed in the past.

Paleontologist: A scientist who studies the fossil record to understand the diversity of life that existed on our planet in the past. Paleontologists use a diversity of techniques to decipher the fossil record, including tools from chemistry, genetics, biology and geology.

Resources for Teachers:

There are a number of companies that supply hands-on educational materials for teaching about paleontology and natural history. Special education kits specific to skull morphology (sets of skull replicas, etc.) are available through Skulls Unlimited (www.skullsunlimited.com) and Bone Clones (www.boneclones.com); discounts are often available for classroom teachers.

Many scientists have websites in which they publish pages that explain the basis and broader context of their research. One such example is the website of Caroline Stromberg, a prominent author in the study of plant evolution and the spread of grasslands. Below is a link to a sample to one of her pages. It is very much acceptable to contact researchers and scientists directly, using contact information listed on the web. Students can be encouraged to reach out as well!
http://depts.washington.edu/strmbrgl/StrombergLab_website/R_grasslands.html

Further resources on teaching evolution for teachers can be found on the PBS website: http://www.pbs.org/wgbh/evolution/educators/index.html and, for information specific to human evolution at the Smithsonian Museums' Human Origin's webpage: http://humanorigins.si.edu/.

Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals is a well written and comprehensive book about the shape of skulls and how to read them (Glenn Searfoss, 1995). The University of Arizona offers a printable lesson on identifying skulls of common wildlife, free to view and download at the following web address:
http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1145.pdf

A lesson on the evolution of horse teeth including templates for 3D printing was developed by the University of Florida Museum of Paleontology in 2015. It is free to use and download, and available at the following link: https://www.cpet.ufl.edu/wp-content/uploads/2015/07/Horse-Evo.pdf.
For another lesson involving interpretation of quantitative data from the fossil record (for high school students), see the following lesson plan published on Earth Education Online:
http://earthednet.org/Ocean_Materials/Mini_Studies/PaleoClimate/Paleoclimate.html

Special acknowledgement and thanks to the authors of the following scientific papers, which were used in the development of this lesson plan. Please email the authors to request a copy of the papers.

Jardine, P., C. Janis, S. Sahney, M. Benton. 2012. Grit not grass: concordant patterns of early origin of hypsodonty in Great Plains ungulates and Glires. *Paleogeography, Paleoclimatology, Paleoecology:* 365-366.

Stromberg, C., F. McInerney. The Neogene transition from C3 to C4 grasslands in North America: assemblage analysis of fossil phytoliths. *Palebiology* 37(1), 2011, pp. 50-71.

What does paleontology look like today?


Start with real people.


(Jurassic Park = NOT real people.)

Misconception: All paleontology ≠ dinosaurs.

Courtesy Library of Congress, Portrait Photographs 1920-1930.

Photos courtesy NPS.
Fossils from the Green River Formation.
Fossil Butte National Monument, Kemmer WY.

Often, fossils looks more like this…

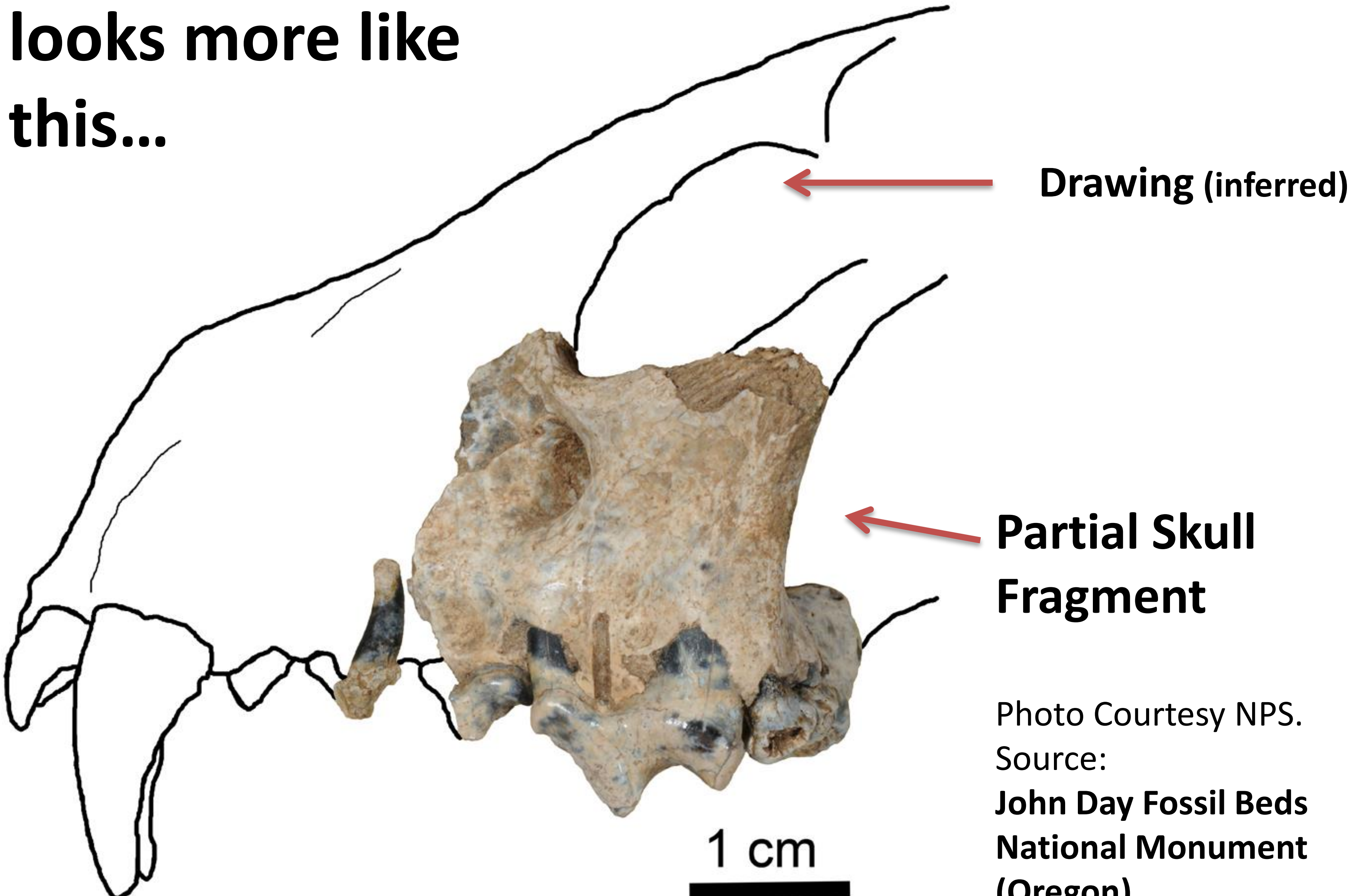


Photo Courtesy NPS.
Source:
John Day Fossil Beds National Monument (Oregon).

Different (dinner**) Strokes for Different Folks**

Today's focus:
One recent study in paleontology that looks at

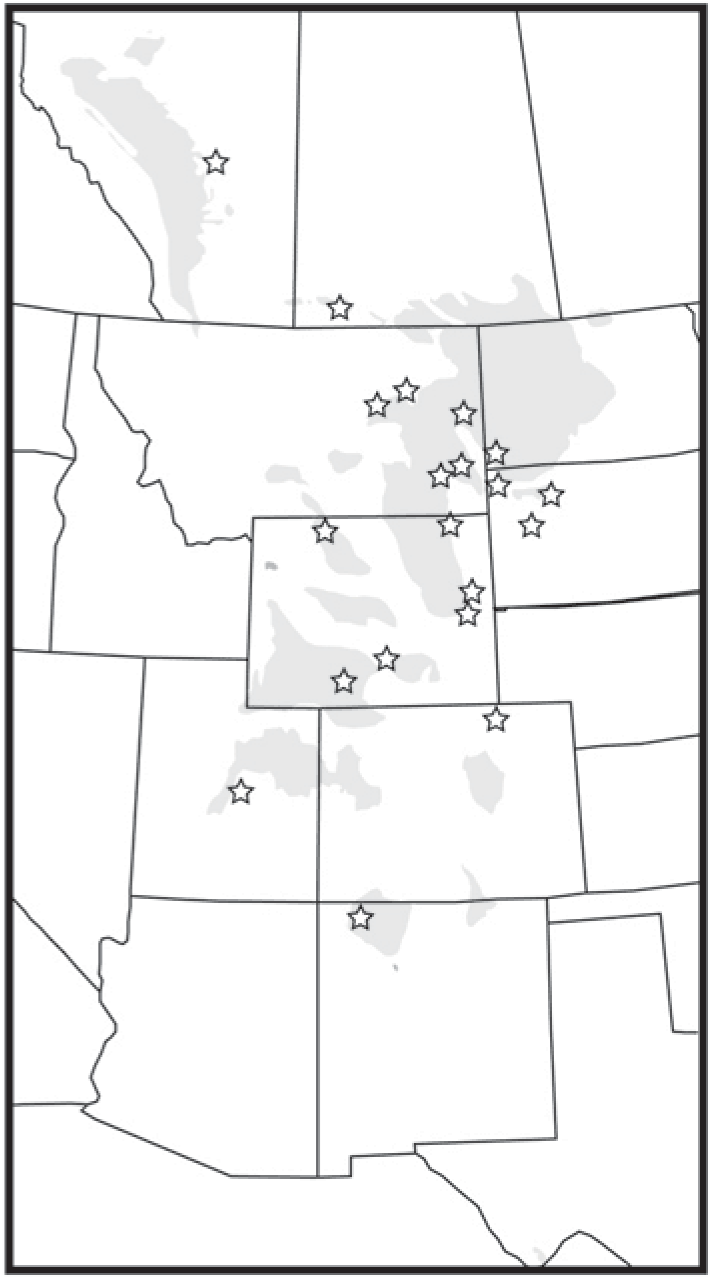
fossil teeth.

Why?

(1) Teeth are **tough and resistant to wear**.

(2) Critters have lots of teeth.

Thus teeth are **one of the most common** parts of an animal **to become fossilized.**



Study Area:

The Great Plains of North America

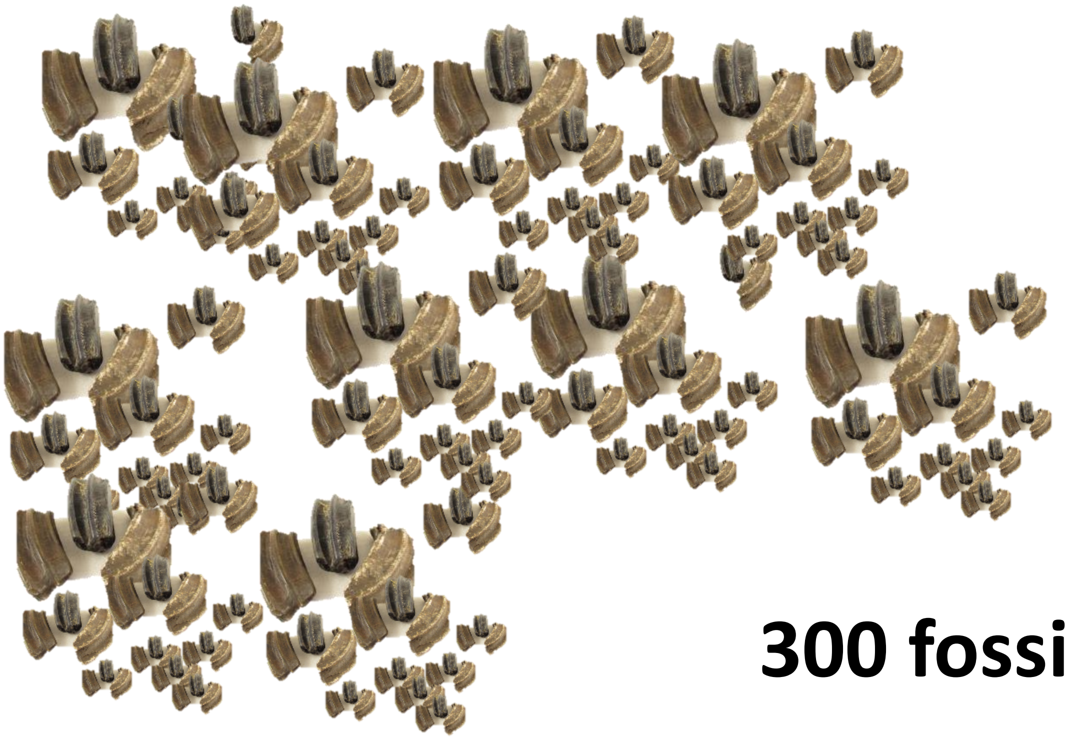

Step 1: finding fossils…

And more fossils…

30 fossil teeth…

30 fossil teeth

And more fossils …

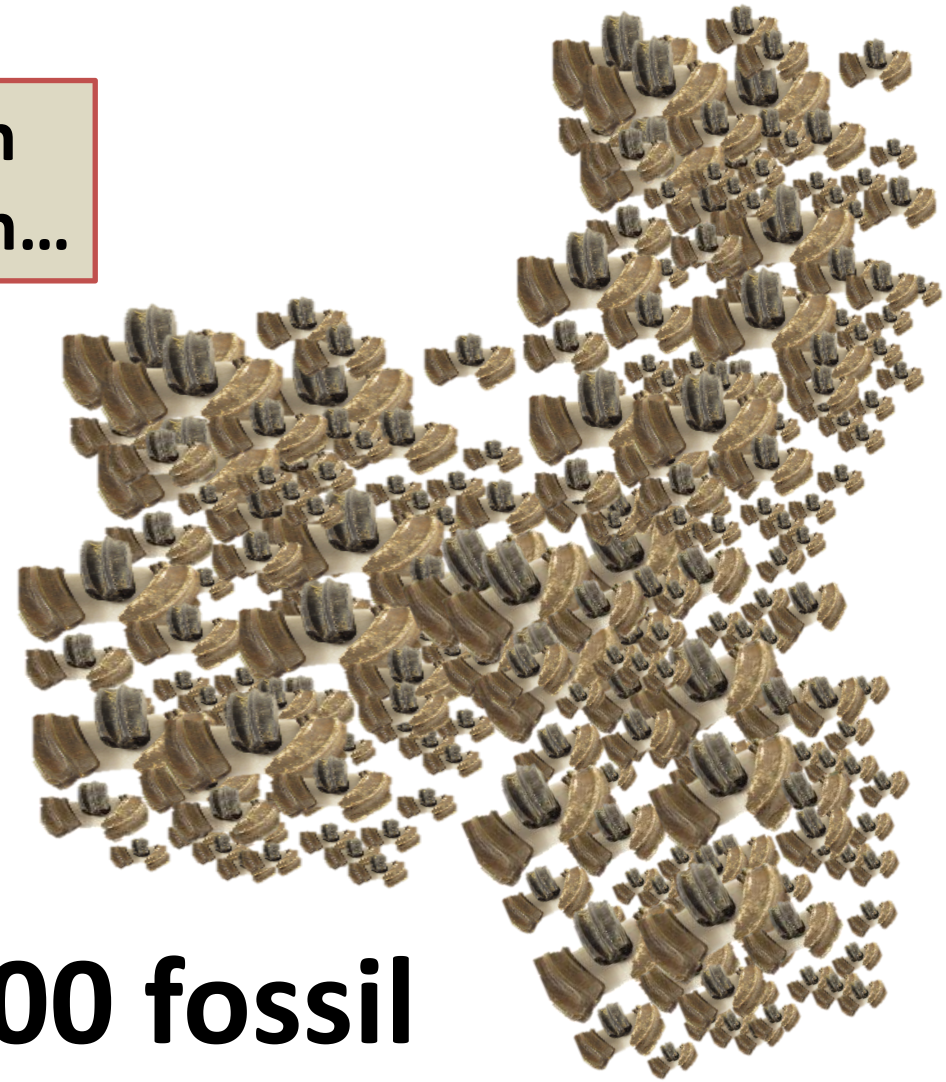


300 fossil teeth…

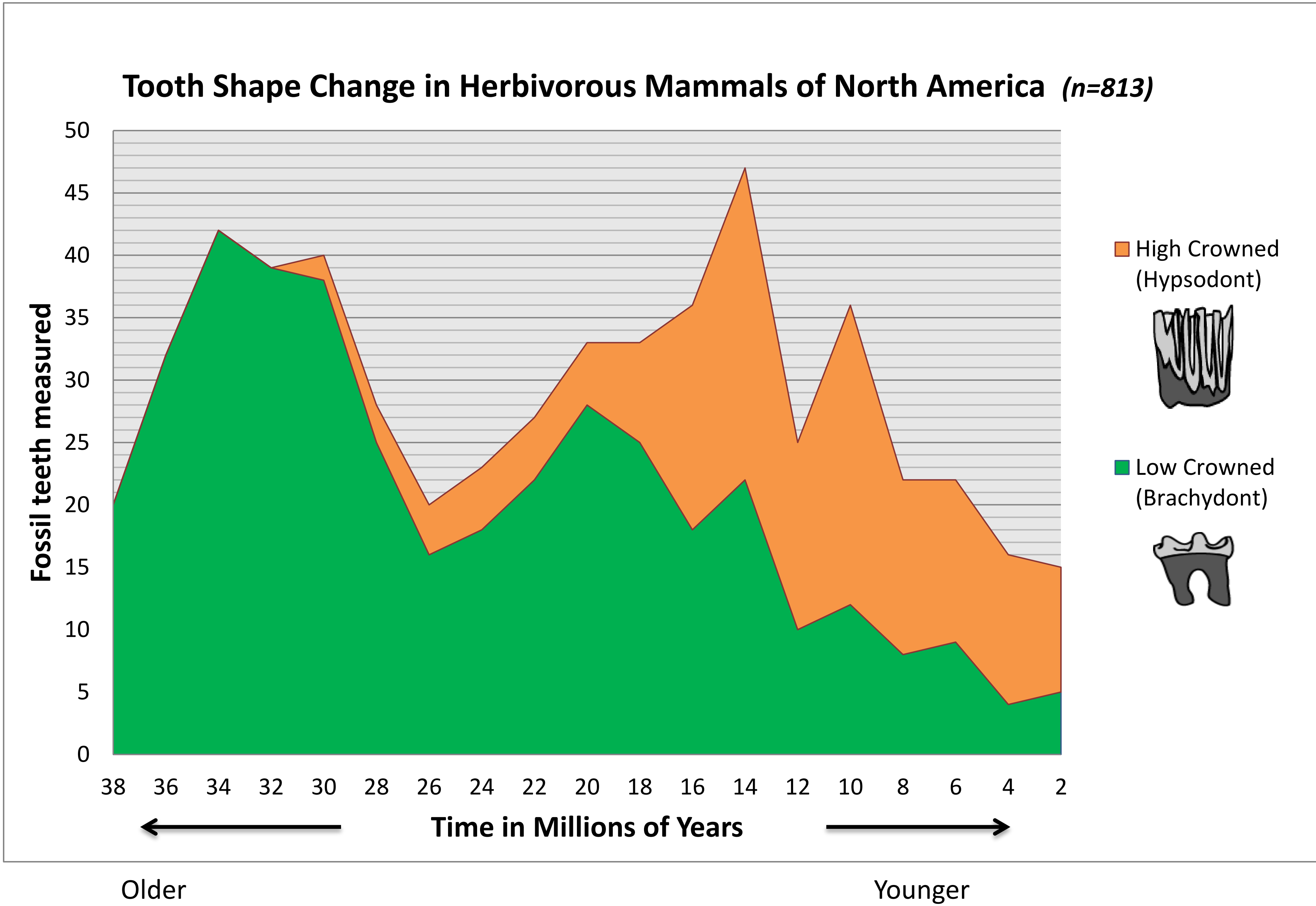
And even more teeth…

30 fossil teeth

300 fossil teeth



800 fossil mammal teeth!



Tooth Shape Change in Herbivorous Mammals of North America (n=813)
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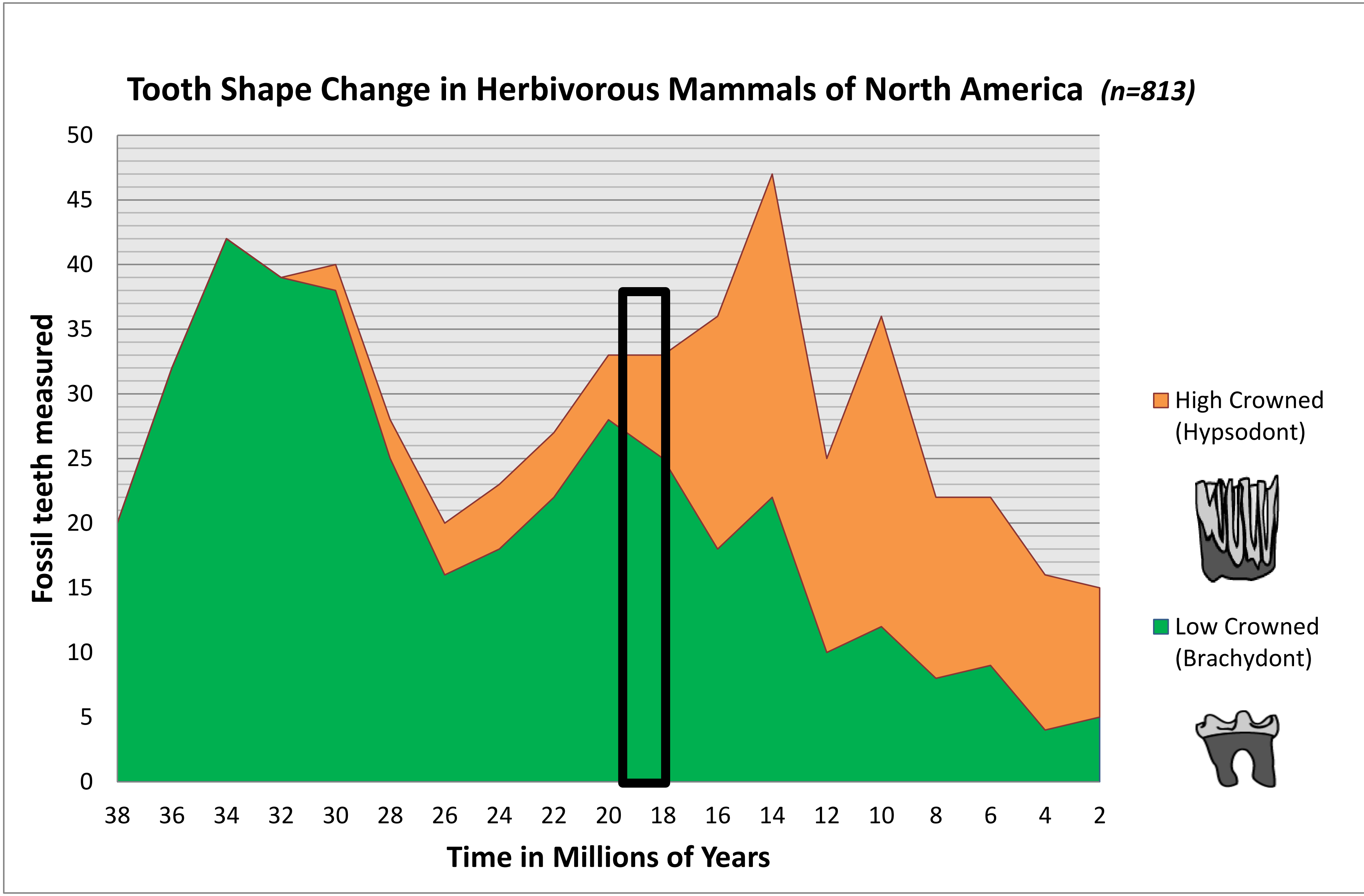
Time in Millions of Years
High Crowned (Hypsodont)
Low Crowned (Brachydont)
Older
Younger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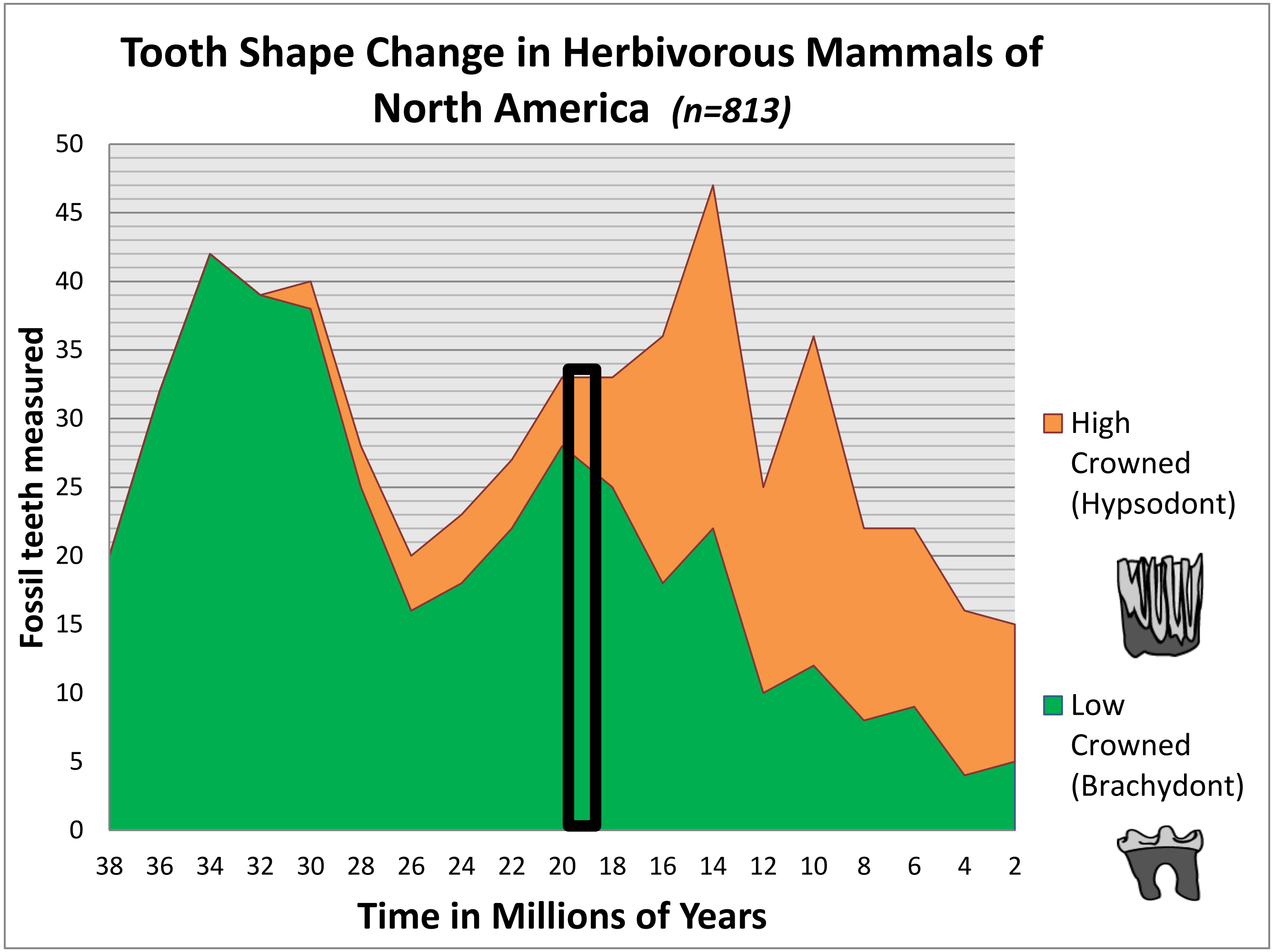

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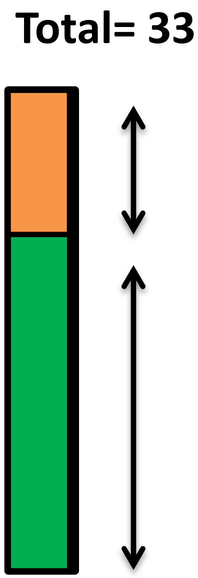

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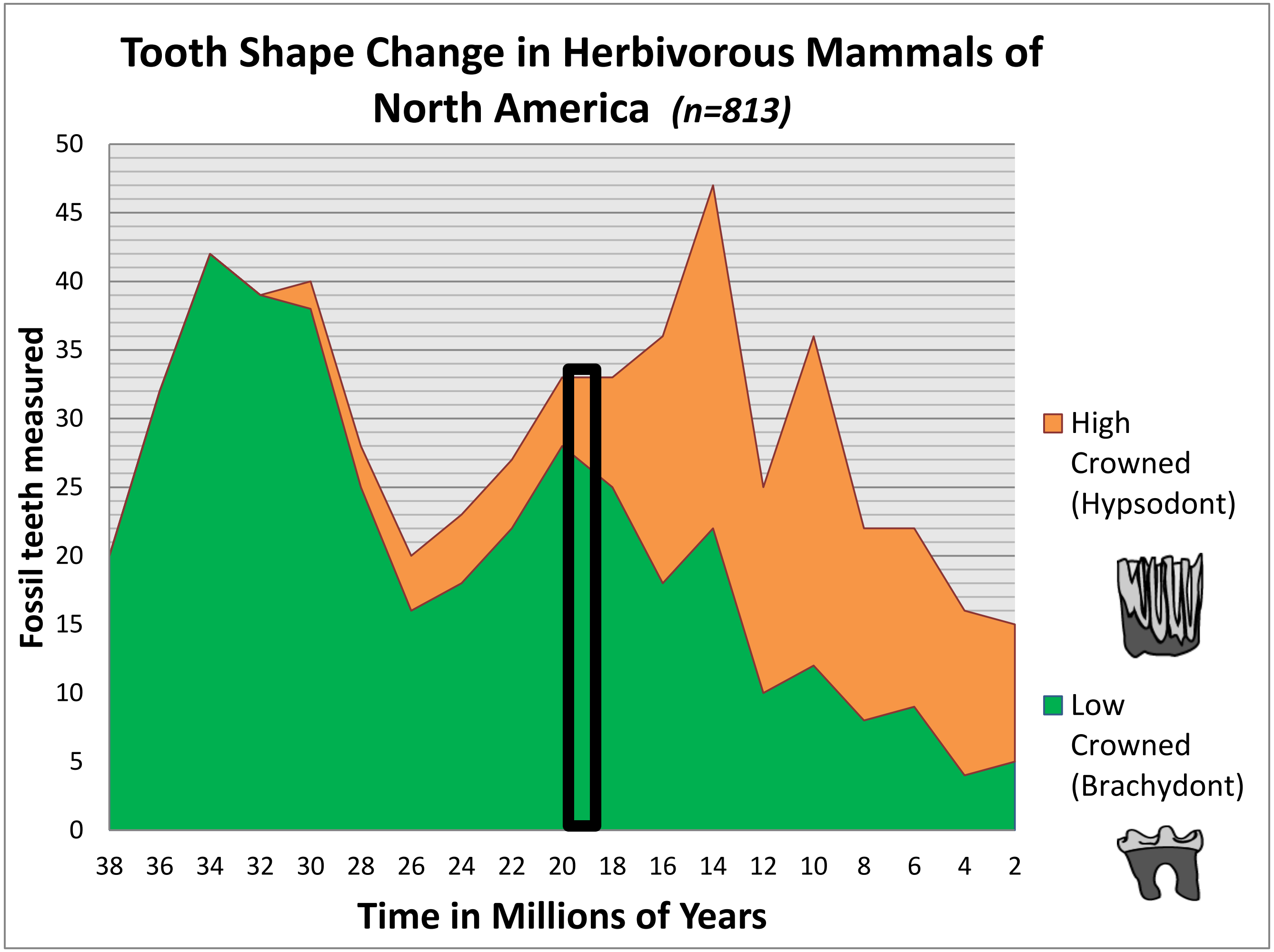

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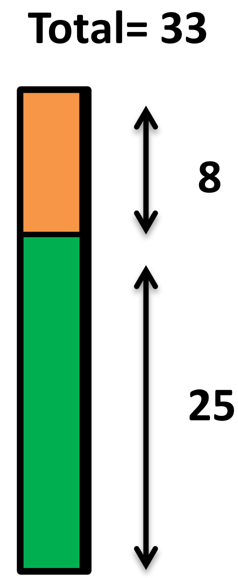

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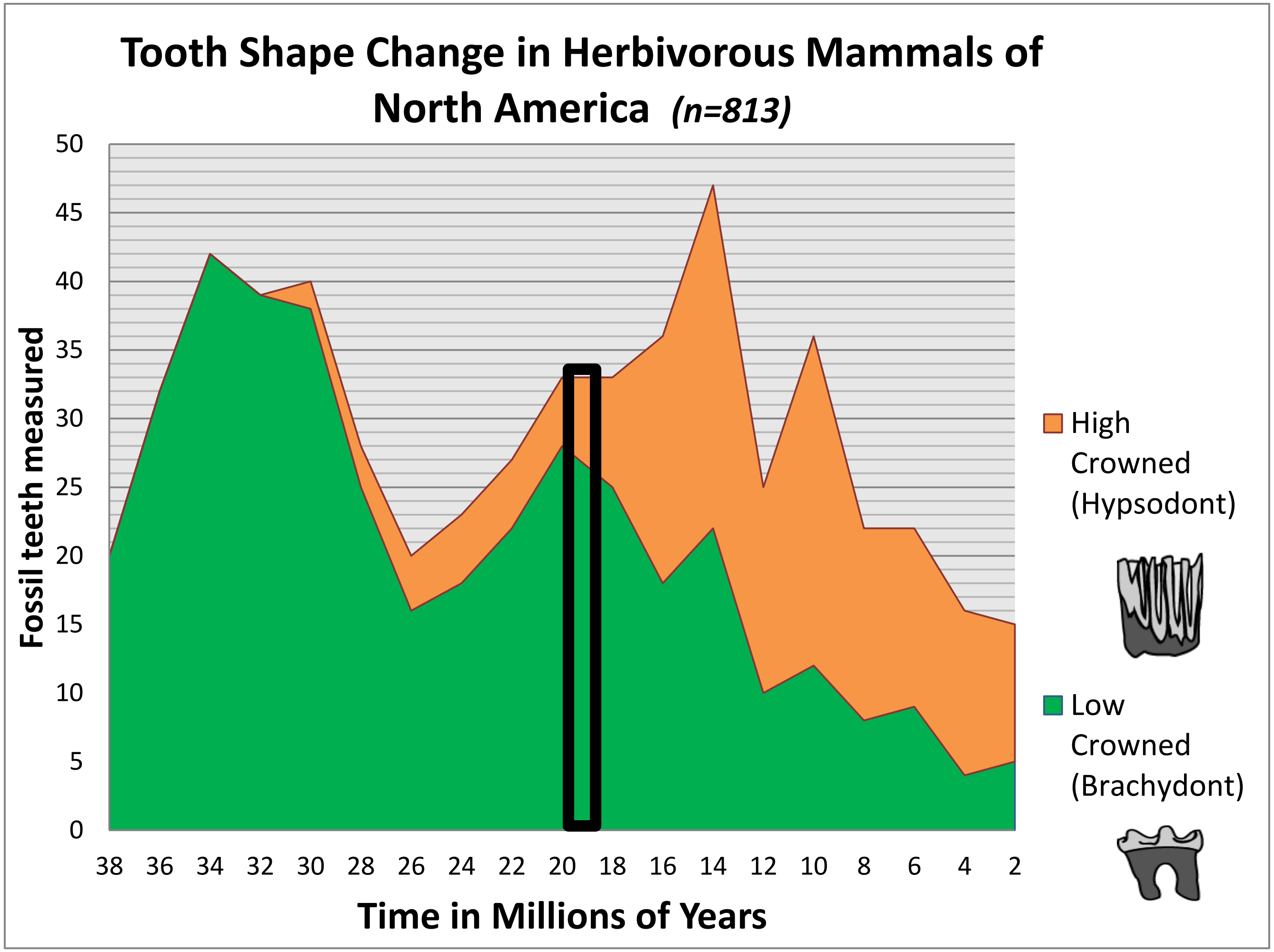
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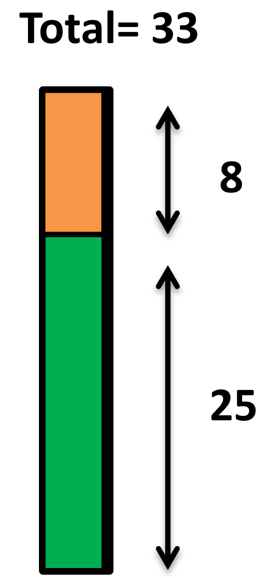
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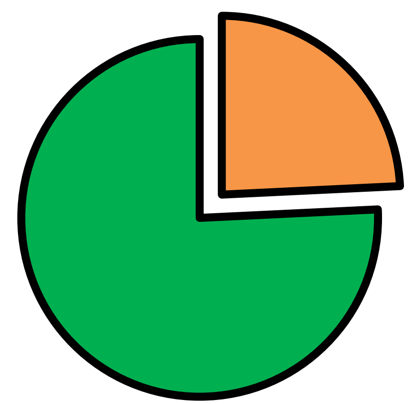

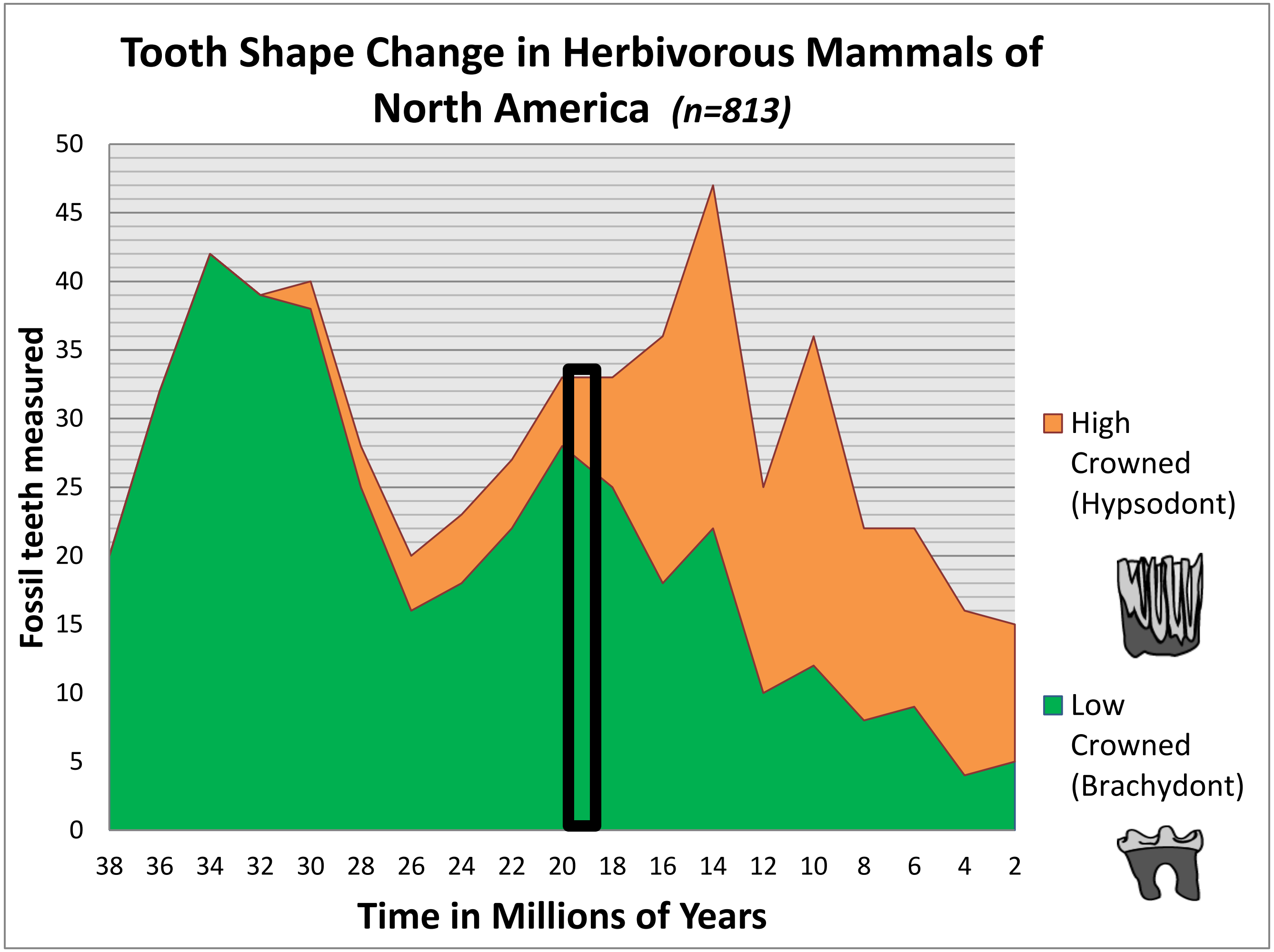
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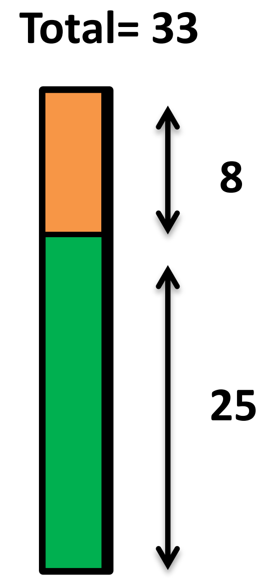
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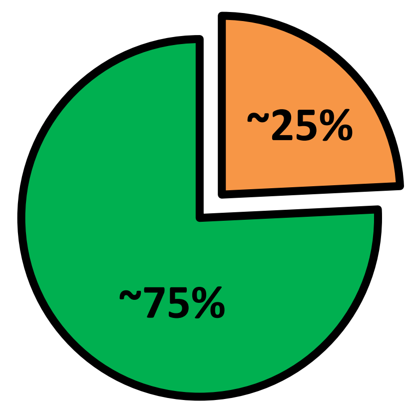
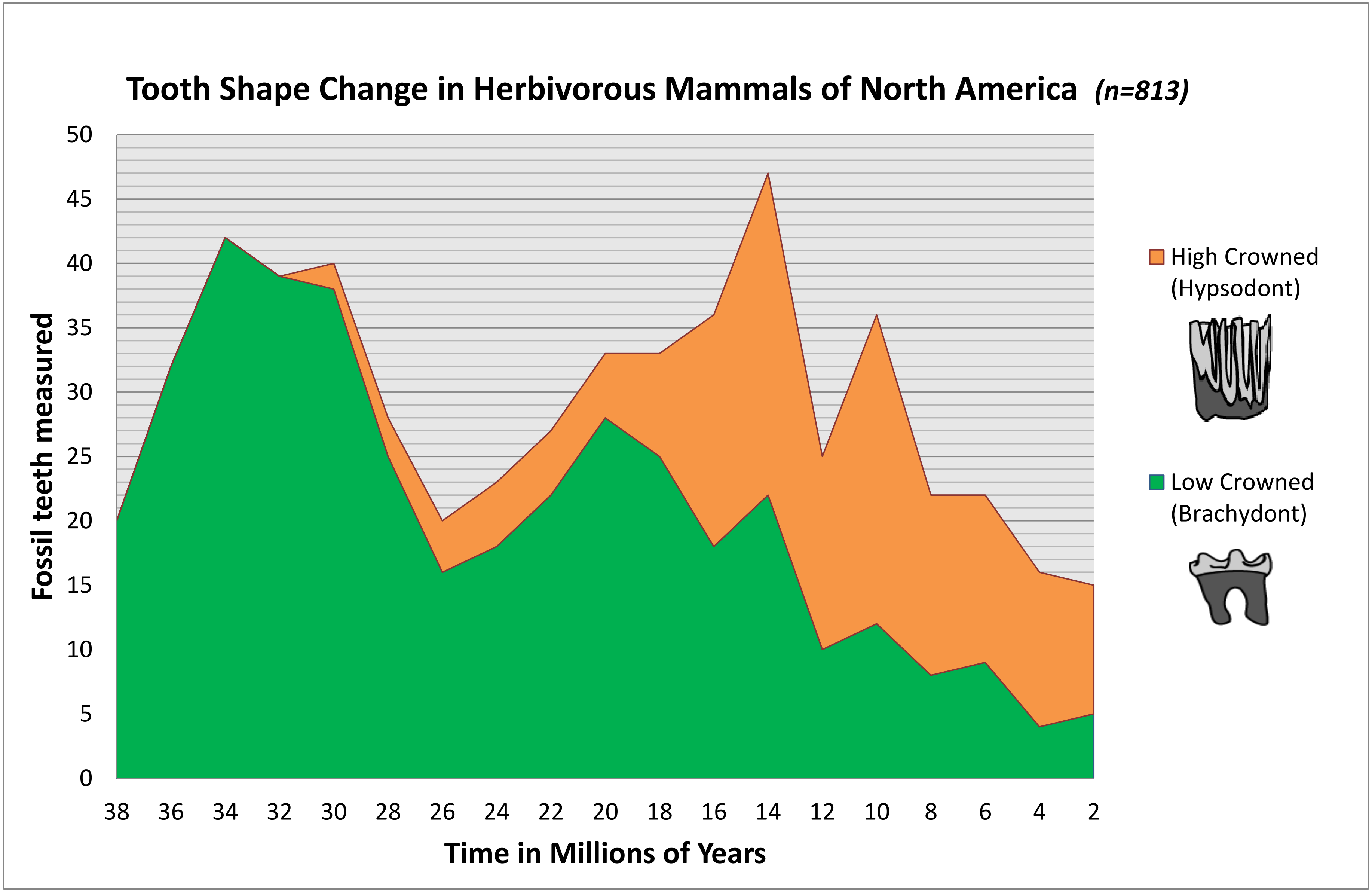

~25%
~75%



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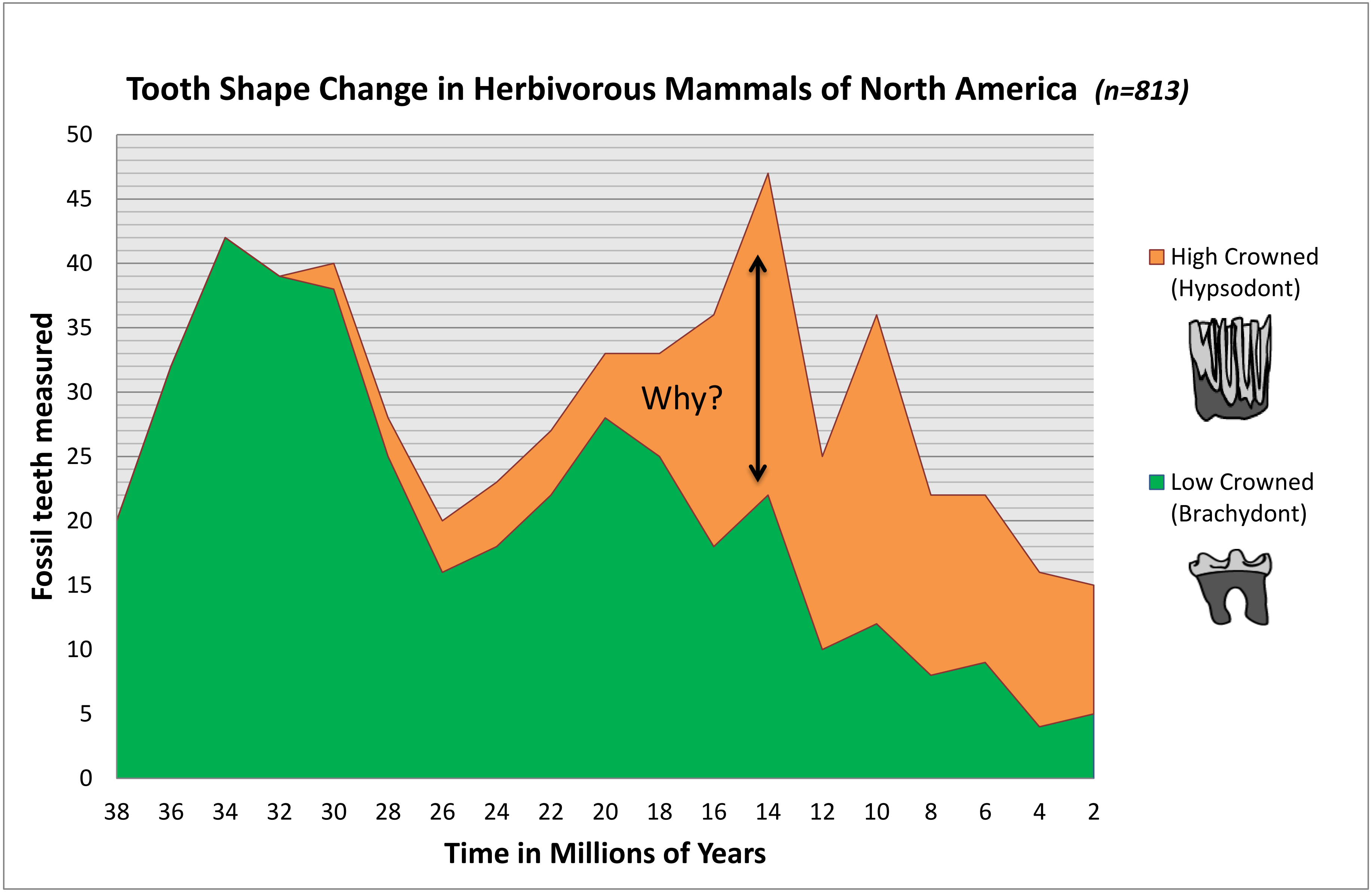

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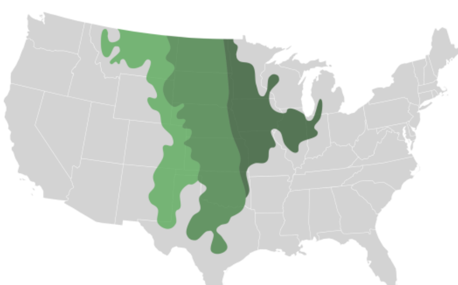
Time in Millions of Years
Why?
High Crowned (Hypsodont)
Low Crowned (Brachydont)

Perhaps the change in tooth shape was a result of new habitats.

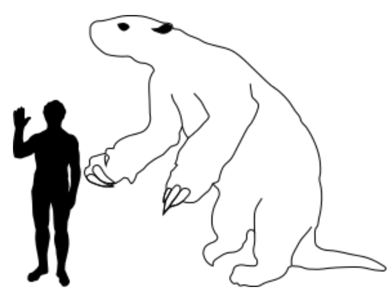
Student Worksheet: Analyzing 'Real-World' Data

The following activity is based on data published by paleontologists in a scientific journal called *Palaeogeography, Palaeoclimatology, Palaeoecology.* The paper, about the evolution of mammal teeth, was published in 2012 by paleontologists Phillip Jardine, Christine Janis, Sandra Sahney and Michael Benton. These are all real scientists with their own public websites….feel free to look them up online!

The data we will analyze come from measurements of **800 fossil teeth**, of ancestral species of horses, deer, rhinos, mammoths, mastodons and ground sloths, collected from various sites in the Great Plains of North America. The teeth represent a diversity of fossil species ranging 40 to 2 million years old.


[1]

Of the fossils measured,
- 1%= giant ground sloths (extinct)
- 62%=even- hoofed mammals (extinct ancestors of deer, camels, pigs)
- 33%=odd- hoofed mammals (extinct ancestors of horses, rhinos)
- 4%= mastodons and mammoths (extinct)

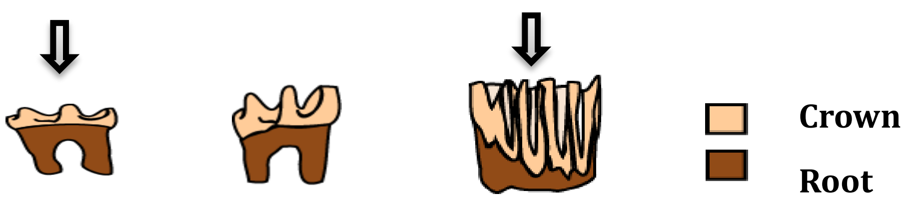
[2]


Fossil teeth were sorted by tooth morphology (shape).

The shape of teeth reflects what animals eat (or, in the case of fossils, ate).

Omnivores, like humans and pigs, which eat a variety of food, have rounded, low-crowned molars.

Herbivores specialized for eating grass ('grazers') have high-crowned molars that are more resistant to wear.



Brachydont **Low-crowned** | **Mesodont** **Medium height** | **Hypsodont** **High-crowned**

What is unique about grass?

A diet of grasses is especially tough on teeth. High-crowned molars are better adapted for a diet of chewing grass and resisting wear from the grit (dirt, rocks, etc.) that comes with grazing shrubby plants that grow low to the ground.

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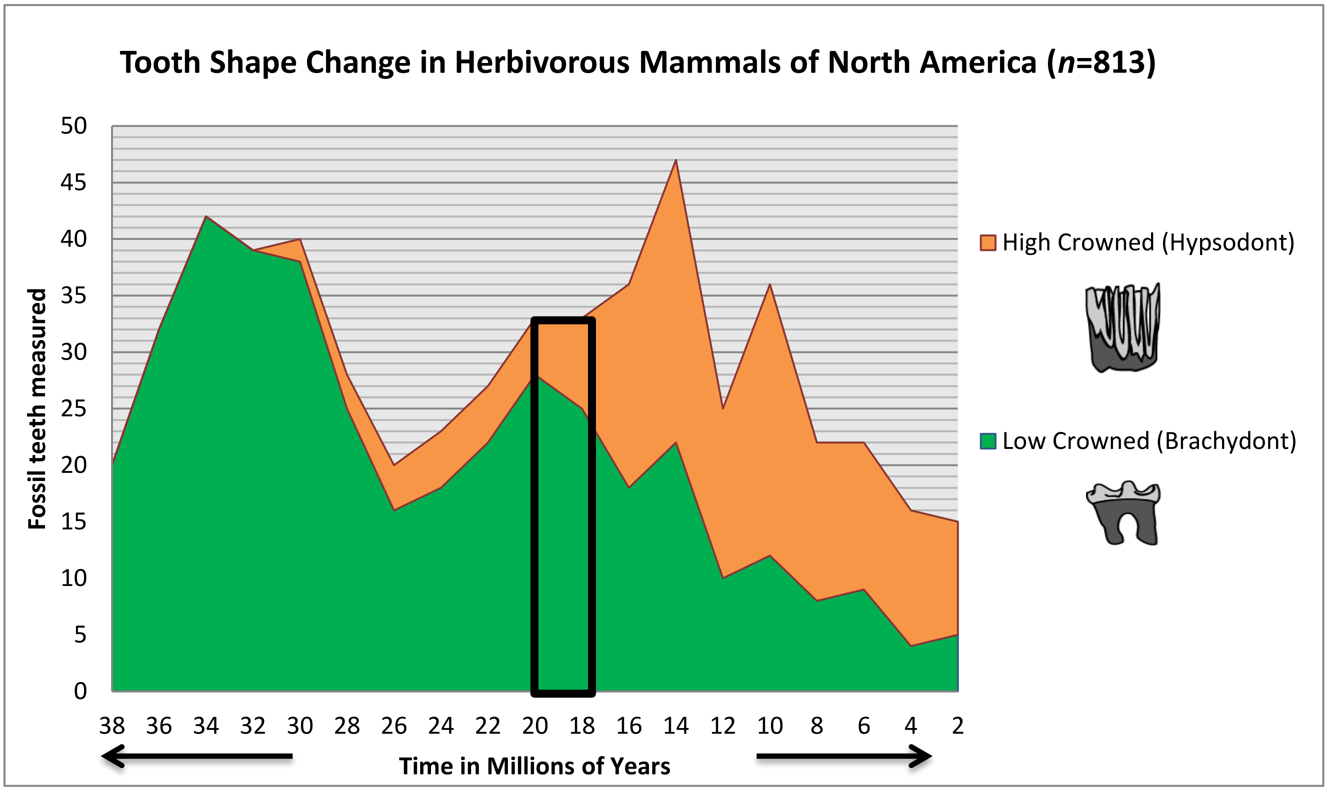
[1] Image: Extent of grasslands in the Great Plains of central North America. Study area for fossil teeth.
[2] Artist reconstruction: giant ground sloth (extinct species of North America); human height comparison.

Student Worksheet: Analyzing 'Real-World' Data

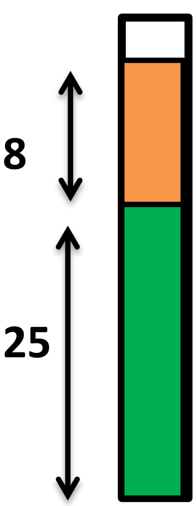
The following graph charts the change in the *relative abundance* of tooth type over time. (Note: this is a different way of graphing that you might have seen in math class!) The x-axis represents time in millions of years, and the y-axis represents the number of fossil teeth measured.

Over time, we see a transition in the fossil record from herbivores with low-crowned teeth (brachydont) to an increased abundance of herbivores with high-crowned teeth (hypsodont). By 15 million years ago, the number of fossil species with high-crowned teeth surpasses the number of species with low-crowned teeth.



Older Younger

How to read this graph:



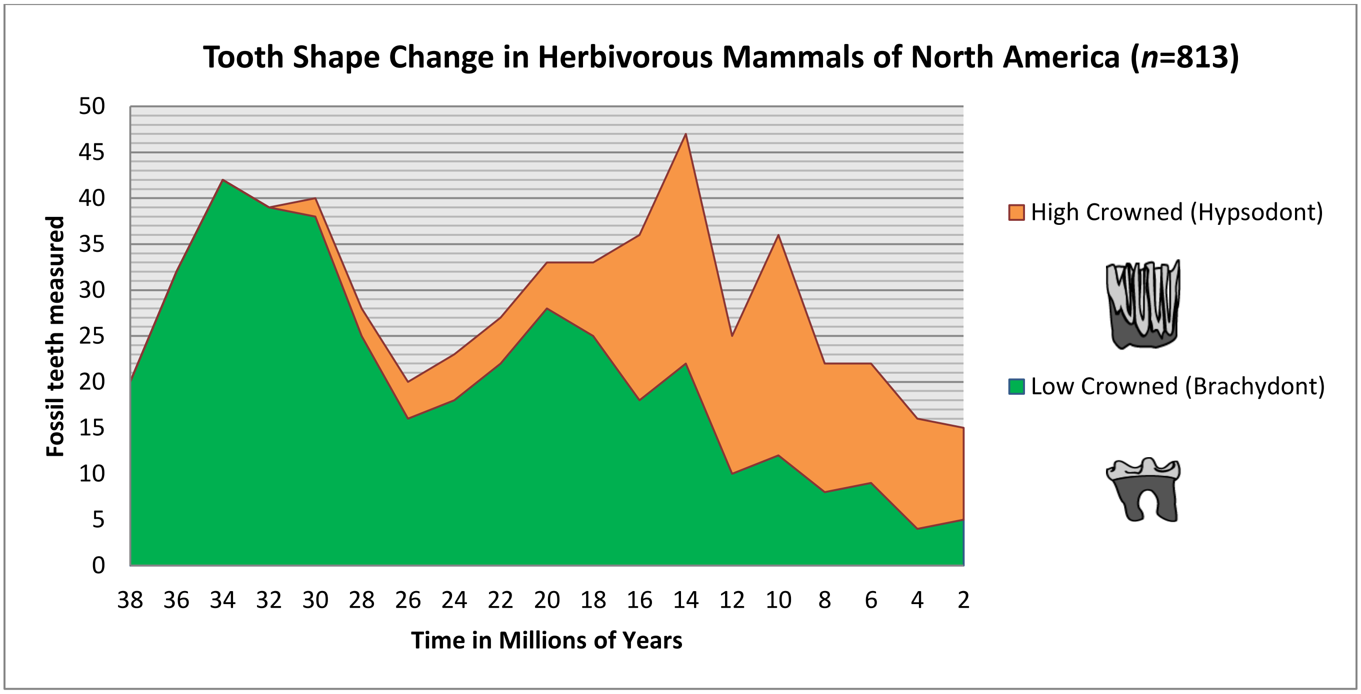
At each point along the x-axis (representing a specific time in millions of years before present), the graph shows a certain amount of green and/or orange. Different colors represent different tooth types (orange= high crowned, green = low crowned).

For example, the box to the left shows a slice of time at ~19 million years.

- The maximum height for both colors combined represents the total (~33) number of teeth measured that were 19 million years old.
- The amount of teeth measured that were low-crowned (green) is ~ 25; the amount of teeth measured that are high-crowned (orange) is the total minus the low-crowned (33-25= 8).
- Though the orange appears "higher in value" on the y-axis, it still represents a smaller proportion of the total teeth measured. <u>In summary, at 19 million years, greater than 50% of the fossil teeth measured were low-crowned (green).</u>

Student Worksheet: Analyzing 'Real-World' Data

Below is a graph showing the change in tooth shape for various groups of herbivorous land mammals. The colors represent tooth shape: Orange= High-Crowned and Green= Low-Crowned.



(1) Look at the x-axis, representing time in millions of years in the past. In what direction is time getting older? Label on the graph where we are in the present day.

___

(2) What is the total number of individual fossil teeth measured over the course of the <u>entire study</u>? (Hint: 'n'= sample size.)

___

(3) Circle the point furthest to the left where orange first appears (reading the x axis from left to right). This represents the time when hypsodont (high-crowned) teeth first appear in mammals. What is the age of this event (in millions of years before present)?

___

(4) When is the first time that amount of high-crowned teeth exceed the amount of low-crowned teeth? (Hint: use the y-axis to compare the relative proportion of green to orange at each point in time).

___

Student Worksheet: Analyzing 'Real-World' Data

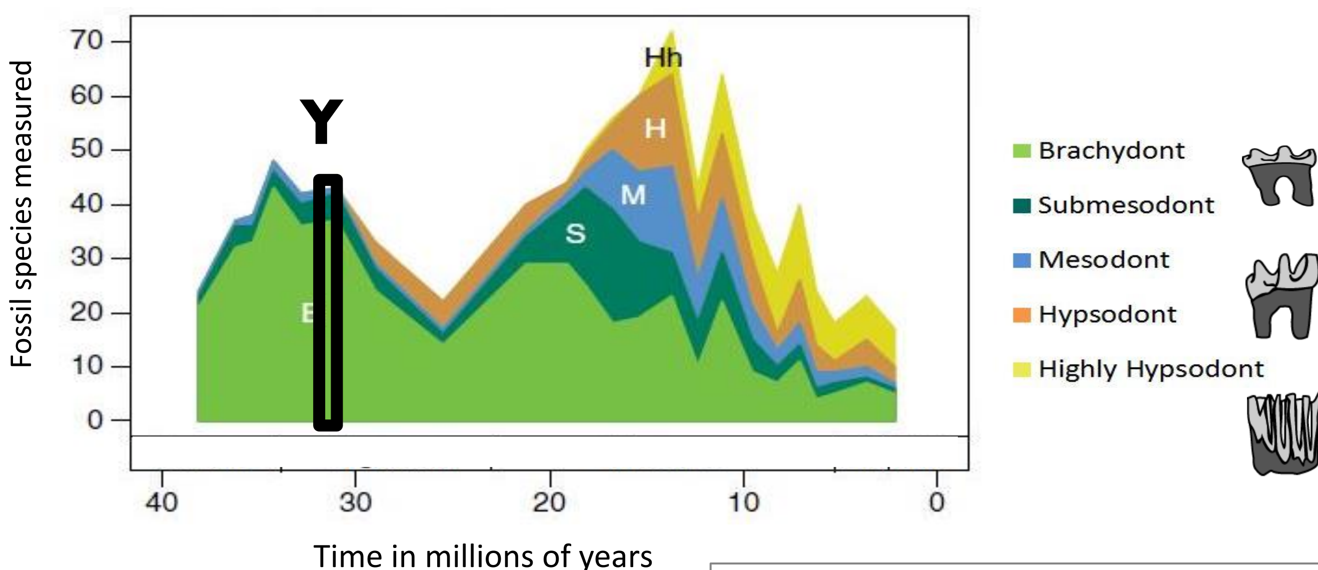
The following graphs are taken <u>directly</u> from the scientific paper published by paleontologists Philip Jardine, Christine Janis, Sandra Sahney and Michael Benton in a scientific journal in 2012.

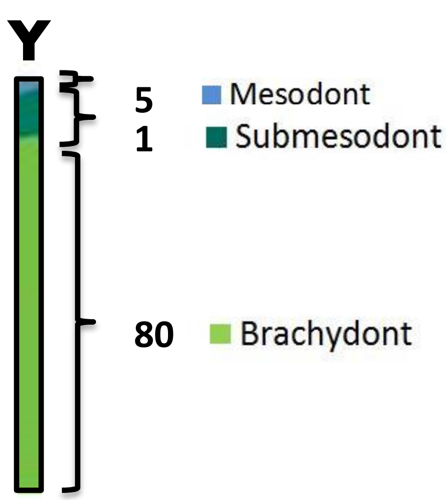
In the actual paper, the paleontologists included several more categories of tooth shape including an intermediate category ('medium-crowned') and an extra high-crowned category ('very high crowned').

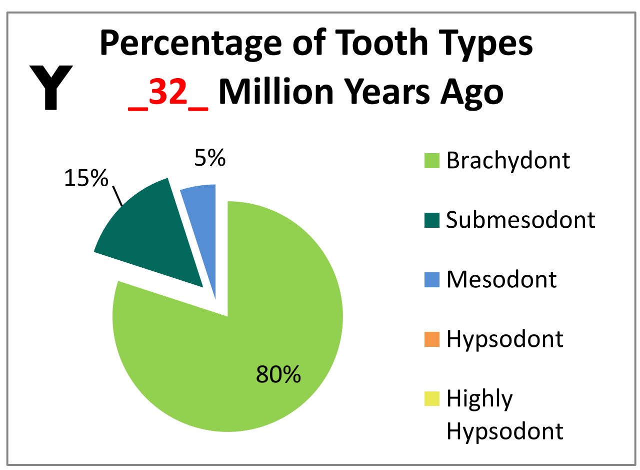
Though the vocabulary is more complex, read the graph below using the same methodology used for the simplified version on the previous page.

Activity: Reading a line graph using pie charts.

Tooth Shape Change in Fossil Mammals (*n* = 813)

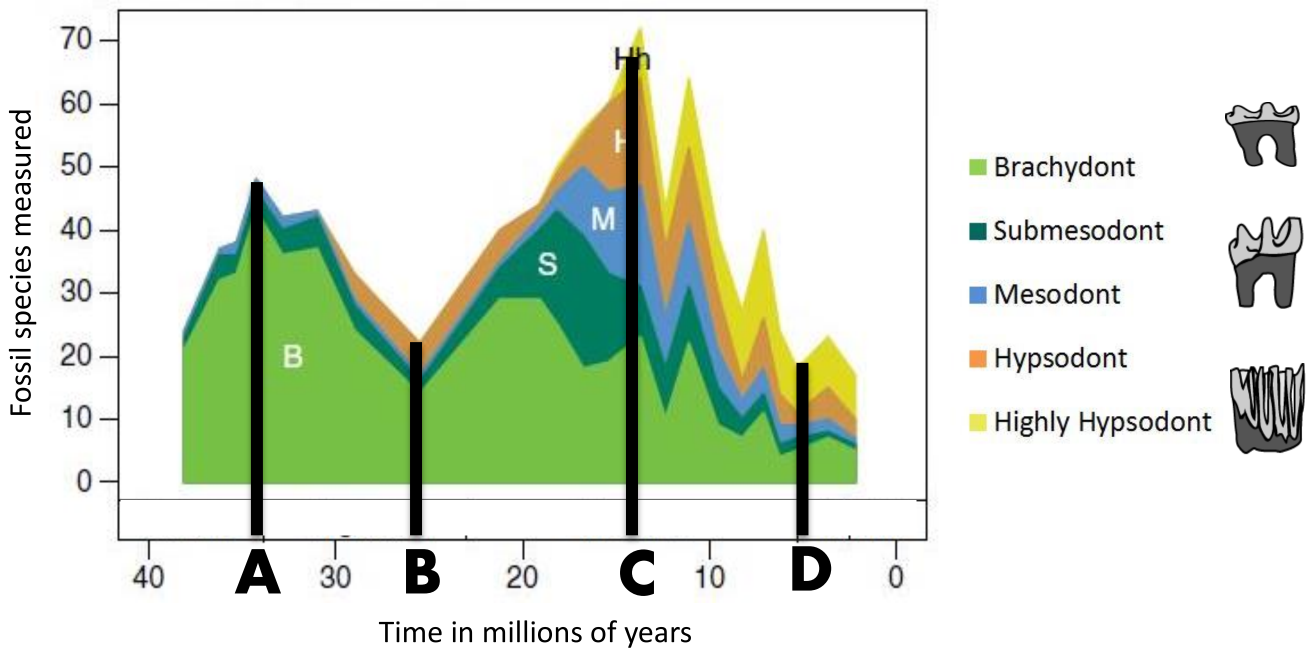






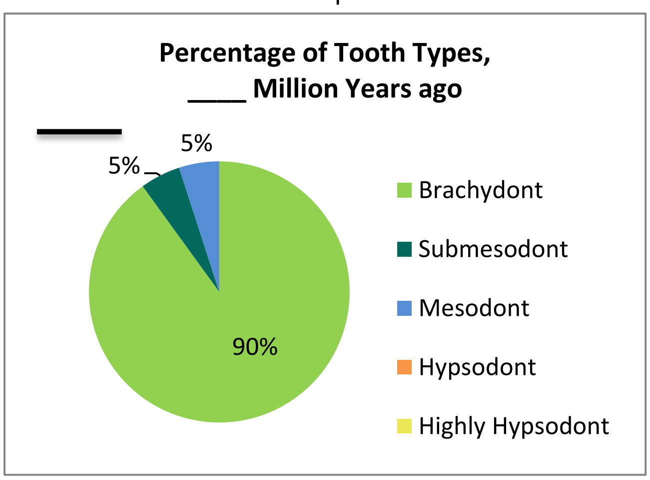
Student Worksheet: Analyzing 'Real-World' Data

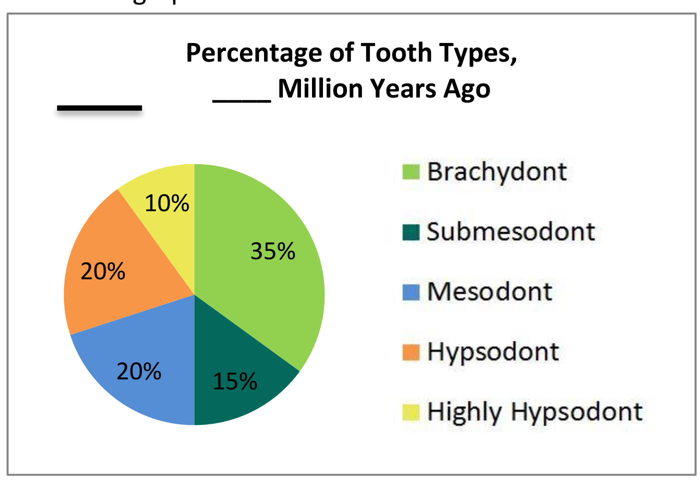
Tooth Shape Change in Fossil Mammals (*n* = 813)

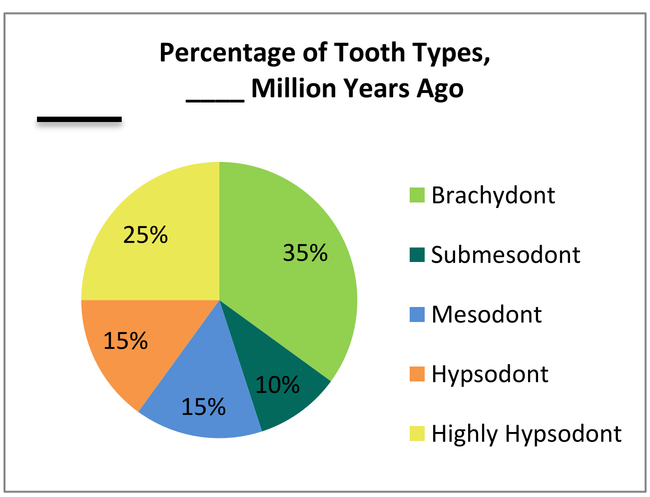


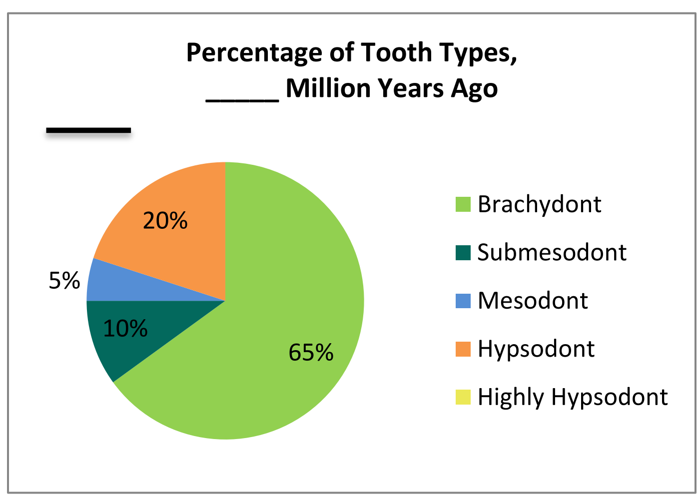
The graph above marks the change in PROPORTION of species with different teeth over time.

Directions: Match each pie chart to the correct location on the graph.



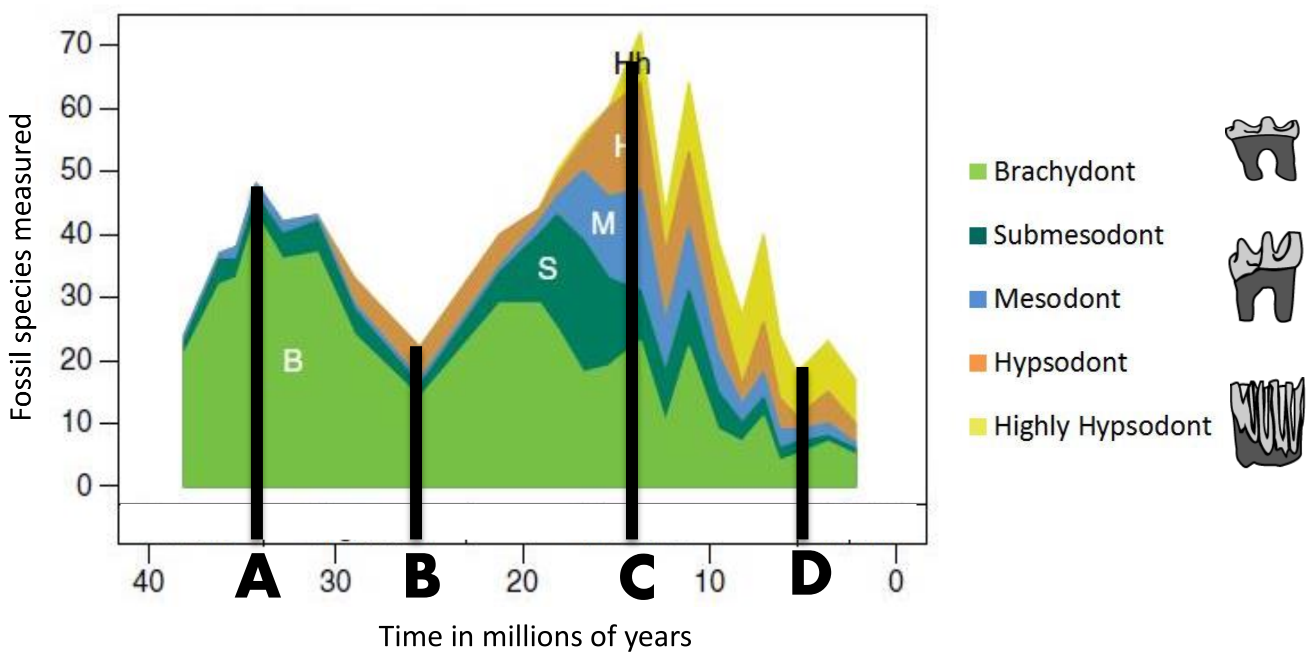






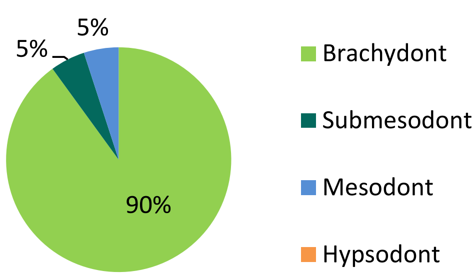
Student Worksheet: Analyzing ‘Real-World’ Data

Tooth Shape Change in Fossil Mammals (*n* = 813)

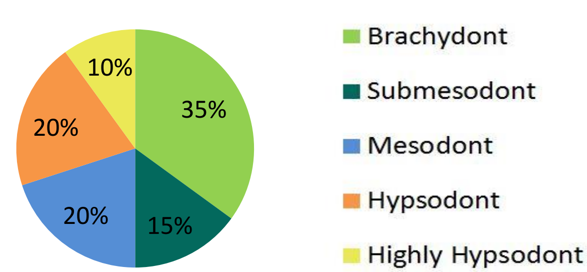


The graph above marks the change in PROPORTION of species with different teeth over time.
Directions: Match each pie chart to the correct location on the graph. TEACHER ANSWER KEY.

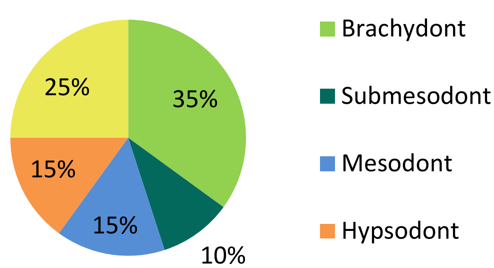
A **Percentage of Tooth Types, _35_ Million Years ago**



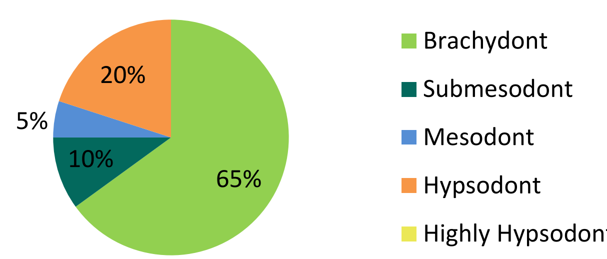
C **Percentage of Tooth Types, _5_ Million Years Ago**



D **Percentage of Tooth Types, _15_ Million Years Ago**



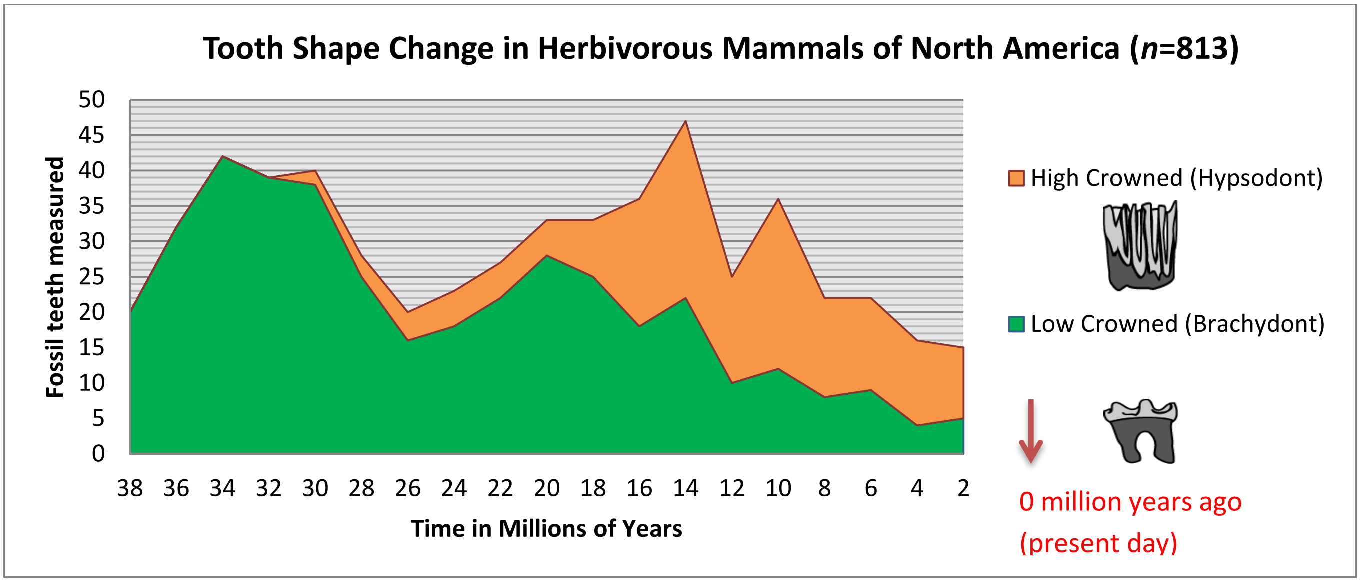
B **Percentage of Tooth Types, _25_ Million Years Ago**



Student Worksheet: Analyzing 'Real-World' Data

Below is a graph showing the change in tooth shape for various groups of land mammals.
The colors represent tooth shape: Orange= High-Crowned and Green= Low-Crowned.

TEACHER ANSWER KEY.



(5) Look at the x-axis, representing time in **years before present**. In what direction is time getting older? Label on the graph where we are in the present day.

Time is getting older towards the LEFT. Present day is 0 million years before present, which is located somewhere to the RIGHT off the end of the graph (on this graph the x-axis ends at 2 million years).

(6) What is the total number of individual fossil teeth measured over the course of the entire study? (Hint: 'n'= sample size.)

813 individual teeth of herbivorous mammals were measured in this study. The majority of samples are from hoofed mammals (now extinct): species of ancestral horses, pigs, rhinos and camels (95% of data). A small percentage of mastodons, mammoths and ground sloths (4% and 1% respectively) were measured.

Note sample size is different from the MAXIMUM y-value. The y-maximum represents the maximum number of teeth that were a certain age, marked on the graph as the number of teeth measured at a given time period. The y-maximum on this graph is ~45, representing 45 teeth that were 15 million years old.

(7) Circle the point furthest to the left where orange first appears (reading the x axis from left to right). This represents the time when hypsodont (high-crowned) teeth first appear in mammals. What is the age of this event (in millions of years before present)?

High-crowned molars first appear in herbivorous mammals approximately 30 million years ago.

---

(8) When does the amount of high-crowned teeth exceed the amount of low-crowned teeth? (Hint: use the y-axis to compare the relative proportion of green to orange at each point in time).

By 15 million years the proportion of low-crowned teeth is less than 50% of the teeth measured.

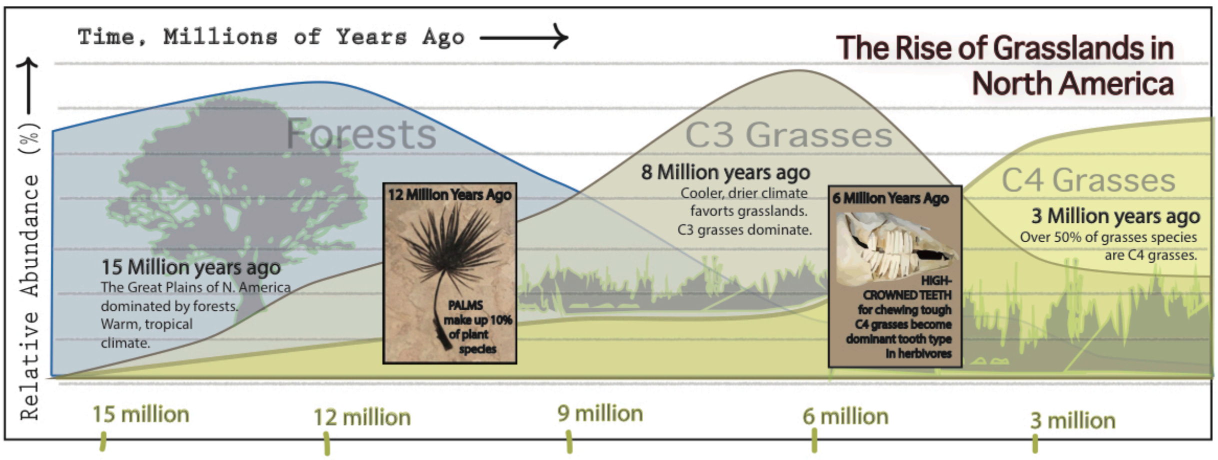
Student Timeline Activity

Instructions: Science communication is important in today's world, where it often takes 10 years for new scientific breakthroughs to reach the public.

Your task: Use the fossil evidence below to create a story about how plants and animals adapt to climate.

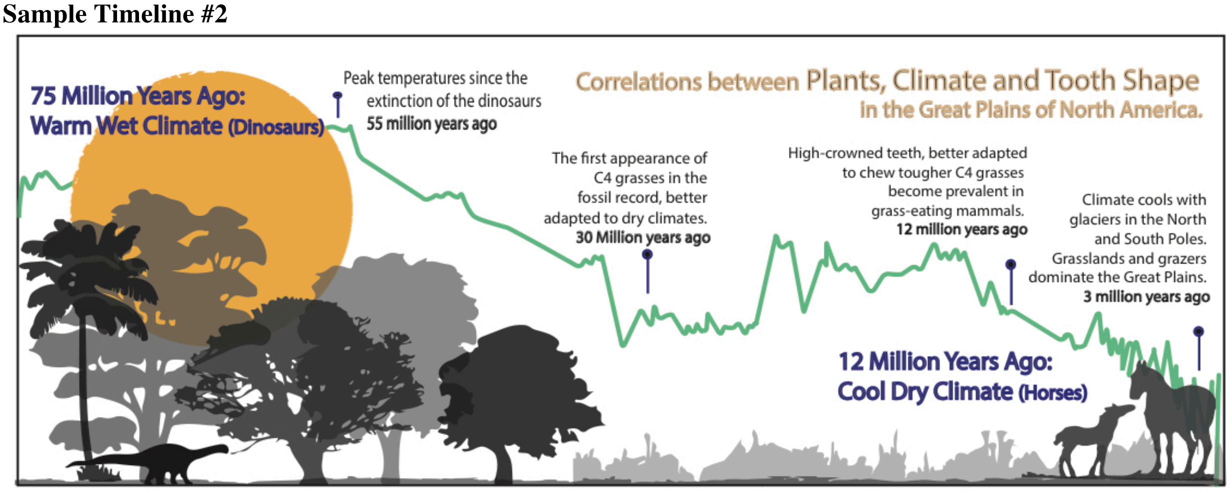
Creativity is encouraged! A few example timelines are shown below. Just be sure to support your design choices with data from the following pages (Lines of Evidence #1-4).

Sample Timeline #1



Design Notes: In Sample #1, the shaded background colors are actually a graph representing different types of plants and how the abundance of various plants changed over time! Each step of the y-axis (the grey horizontal lines) represent a 10% increase in the abundance of each plant type. For example, at 9 million years, 15% of plants are C4 grasses, 40% are C3 grasses and 45% are forests. This matches the graph in Line of Evidence #4 (pg. 4).

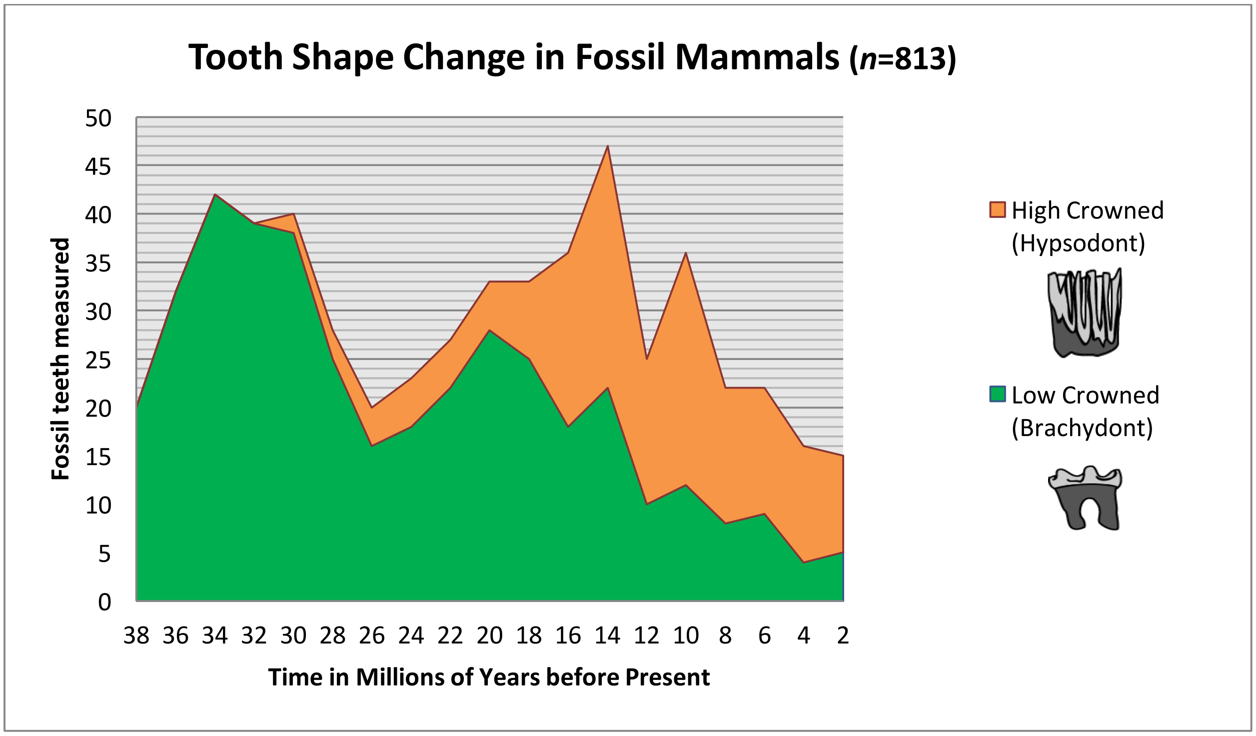
Sample Timeline #2



Design Notes: In Sample #2, the green line is a graph of temperature over time. Higher= hotter and lower= cooler.

Line of Evidence #1: Tooth shape change in herbivorous fossil mammals in North America (horses, pigs, rhinos, camels, and mammoths).

Graph derived from scientific paper: “Grit Not Grass” published by published by paleontologists Phillip Jardine, Christine Janis, Sandra Sahney and Michael Benton in the scientific journal *Palaeogeography, Palaeoclimatology, Palaeoecology* in 2012.



Line of Evidence #2: Dates of the first recorded occurrence of high-crowned teeth in various mammal groups.

Data taken from scientific paper: “Grit Not Grass.”

	First Appearance (millions of years before present)	
Species (grouped by type)	**High-Crowned Teeth (Hypsodont)**	**Very High-Crowned Teeth (Highly-Hypsodont)**
Rodents (mice, rats, beavers)	31 million years	14 million years
Rabbits	22 million years	33 million years
Large mammals (horses, pigs, rhinos, camels, and mammoths)	30 million years	18 million years

Line of Evidence #3: Changes in plants reflect changes in habitats.

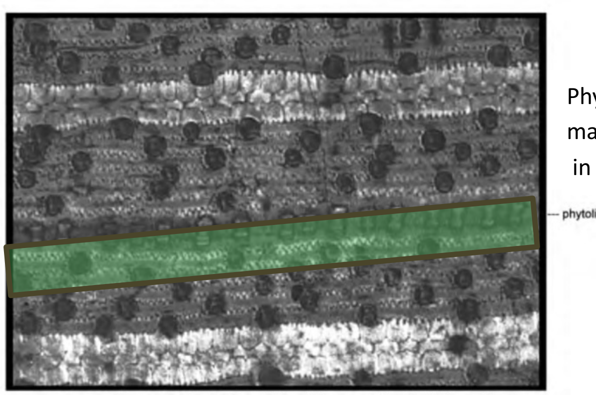
Data taken from scientific paper: "The Transition from C3 to C4 Grasslands in North America: analysis of fossil phytoliths" by paleo-botanists (scientists who study fossil plants) Francesca McInerney, Caroline Stromberg and James White. Published in the scientific journal *Palaeogeography, Palaeoclimatology, Palaeoecology* in 2011.

Grasses are abrasive on teeth.

Grasses contain microscopic structures made of silica called 'silica phytoliths'.
"Phytolith" comes from Greek, meaning "plant stone."

Different types of grasses have large amounts of silica *phytoliths*.

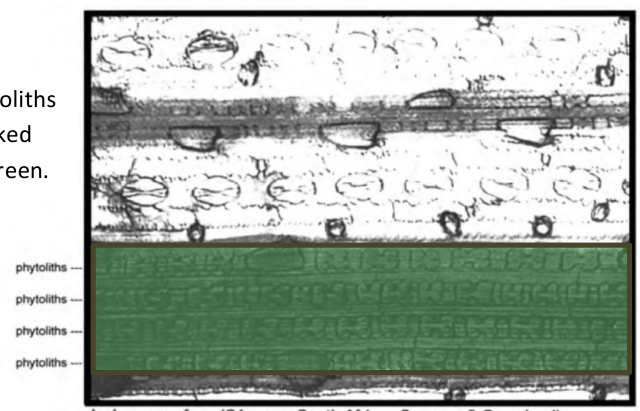
C3 Grasses



Oxytenanthera abyssinica (C3 grass, South African Savanna)

Phytoliths marked in green.

C4 Grasses



Ischaenum afrum (C4 grass, South African Savanna & Grassland)

<u>Data from the fossil record:</u>

C4 grasses first appear in the fossil record 30 million years ago (in very limited numbers, representing only 10-20% of grasses).

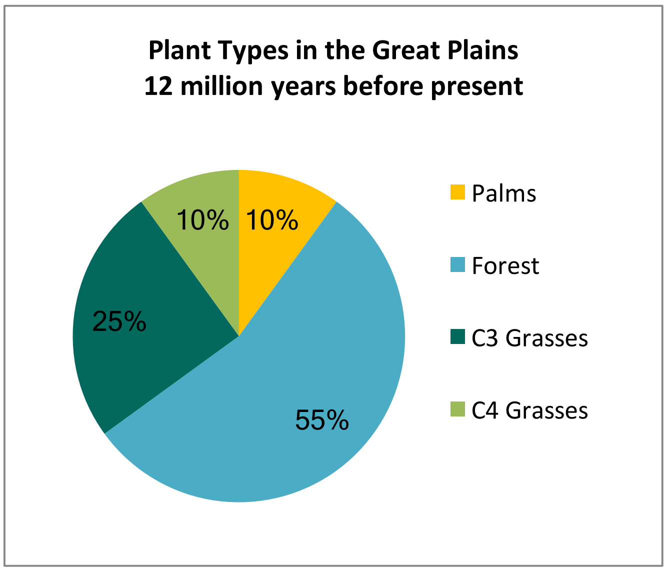
By 10 million years ago, C4 grasses comprise 10-40% of grass types in North American grasslands.

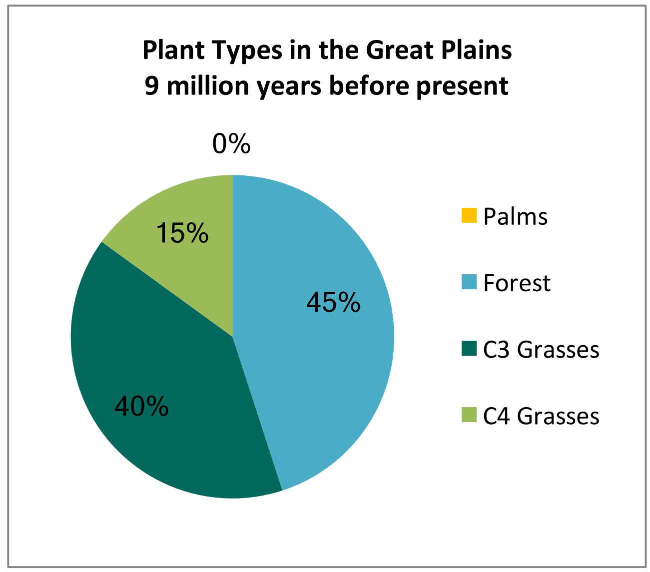
By 3 million years ago, C4 grasses comprise over 50% of grasses in North America grasslands.

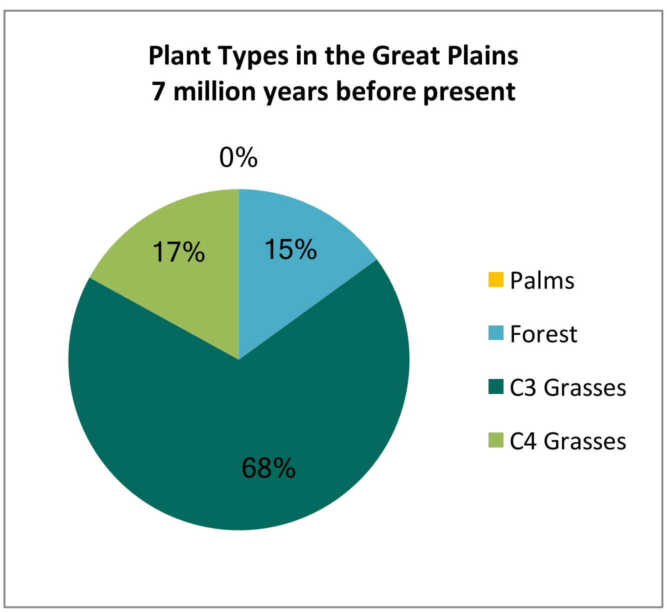
Today, 40-80% of grasslands in the North American Great Plains (Kansas and Nebraska) are C4 grasses.

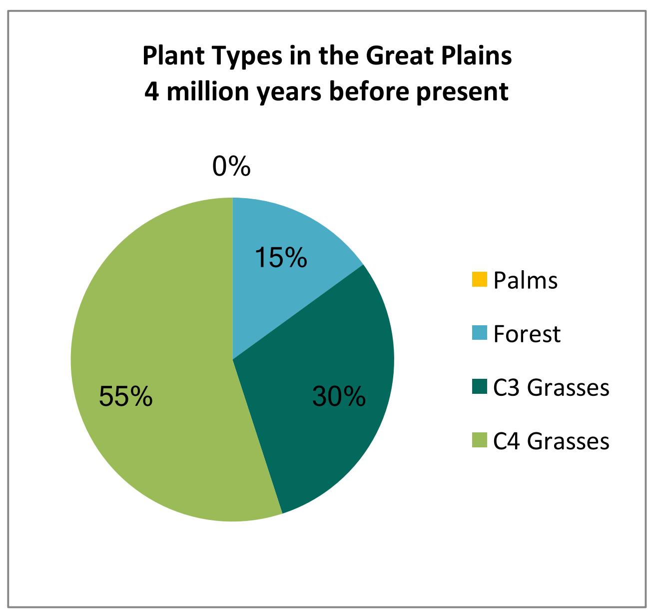
Line of Evidence #4: Changes in plant composition reflect changes in habitat. The graphs below chart changes in the type of plants which grew in the Great Plains of North America between 12 million years ago and today.

Data taken from scientific paper: "The Transition from C3 to C4 Grasslands in North America: analysis of fossil phytoliths" by paleo-botanists (scientists who study fossil plants) Francesca McInerney, Caroline Stromberg and James White. Published in the scientific journal *Palaeogeography, Palaeoclimatology, Palaeoecology* in 2011.





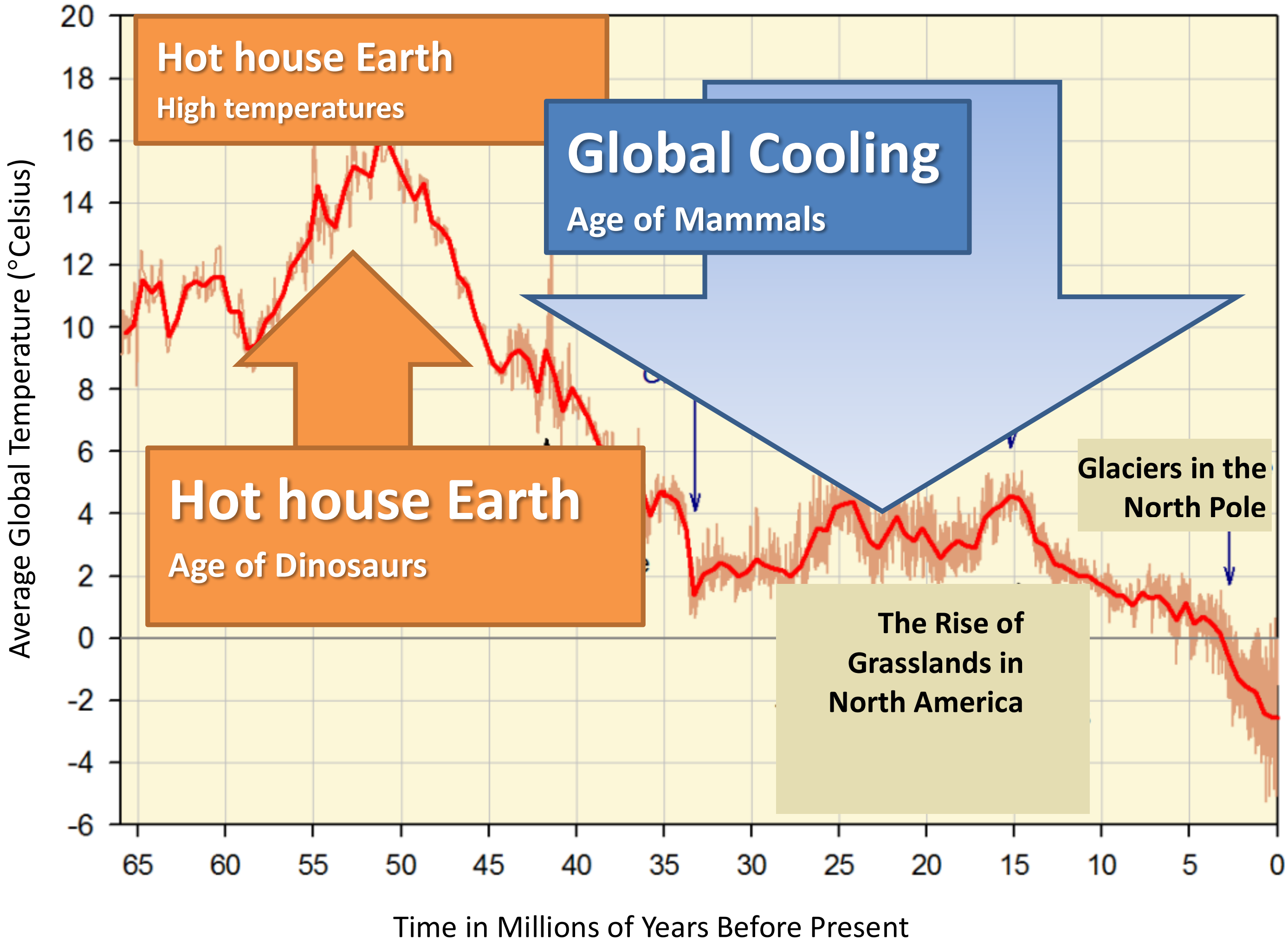




Line of Evidence #5: Record of temperature change from 65 million years to present.

Data derived from climate records in ocean sediments, ice cores, and other evidence in the geologic record.

BIG Climate Changes.



Teacher Guide

In this activity, students are given a selection of reading taken directly from a primary scientific paper published in 2012. This activity can be used as an in-class activity, or as homework or extra credit. It supplements content in the Student Graph Analysis Activity.

Teachers are encouraged to submit a selection of their best student work to the Park Paleontologist at Hagerman Fossil Beds National Monument.

Paleontologist, Hagerman Fossil Beds National Monument
PO Box 570, Hagerman, Idaho, 83332

Selections of student work may qualify to be sent to the authors of the paper (real paleontologists!) according to Park Staff discretion.

Student Worksheet: Grit Not Grass

Instructions:

It is your job to investigate the hypothesis of 'Grit Not Grass' presented by paleontologists Philip Jardine, Christine Janis, Sarda Sahney and Michael Benton in a scientific publication in 2012. The following excerpt is taken from the introduction of their paper.

Using what you have learned about the rise of grasslands in North America, and what you know about how organisms adapt to changes in their environment, your task is to write a letter in response to the hypothesis presented in the paper below.

Your letter must address the question:

Do you support the 'grit not grass' hypothesis as a valid explanation for the early rise of hypsodonty amongst North American land mammals?

Your argument must be supported with information from your data analysis of last class.

If eligible, your letter may qualify to be sent to to the National Park Service paleontologist at Hagerman Fossil Beds National Monument.

Contents lists available at SciVerse ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

ELSEVIER

PALAEO 3

Grit not grass: Concordant patterns of early origin of hypsodonty in Great Plains ungulates and Glires

Phillip E. Jardine [a,*], Christine M. Janis [b], Sarda Sahney [c], Michael J. Benton [c]

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ABSTRACT

A major step in mammalian evolution was the shift amongst many herbivorous clades from a browsing diet of leaves to a grazing diet of grasses. This was associated with (1) major cooling and increasing continentality and the enormous spread of grasslands in most continents, replacing closed and open forests, and (2) hypsodonty, the possession of high-crowned teeth. Hypsodonty is traditionally linked with eating grass because of the contained phytoliths, silica-rich granules, which are presumed to wear away mammalian dental tissues. However, we present evidence from the Great Plains of North America that the origins of hypsodonty in different clades of ungulates (hoofed mammals) and Glires (rodents and lagomorphs) were substantially out of synchrony with the great spread of grasslands, 26–22 Myr ago (latest Oligocene/earliest Miocene). Moderate hypsodonty was acquired by some Oligocene artiodactyls and several rodent families (mainly burrowers) at least 7 Myr earlier. Highly hypsodont ungulates and hypselodont (= ever-growing cheek teeth) rodents post-date the spread of grasslands by 4 to 9 Myr. Lagomorphs follow a different trend, with hypselodont forms present from near the Eocene–Oligocene boundary. These results indicate that hypsodonty was not a simple adaptation for eating grasses, and may have originated in some clades to counteract the ingestion of grit and soil.

Source: Jardine, P., C. Janis, S. Sahney, M. Benton. 2012. Grit not grass: Concordant patterns of early hypsodonty in Great Plains ungulates and Glires.

Grit Not Grass. Student Worksheet.

<u>Instructions:</u>
It is your job to investigate the hypothesis of 'Grit Not Grass' presented by paleontologists Philip Jardine, Christine Janis, Sarda Sahney and Michael Benton in a scientific publication in 2012. The following excerpt is taken from the introduction of their paper.

Using what you have learned about the rise of grasslands in North America, and what you know about how organisms adapt to changes in their environment, your task is to <u>write a letter in response to the hypothesis presented in the paper below</u>.
Your letter must address the question:

> *Do you support the 'grit not grass' hypothesis as a valid explanation for the early rise of hypsodonty amongst North American land mammals?*

Your argument must be supported with information from your data analysis of last class.

If eligible, your letter may qualify to be sent to the National Park Service paleontologist at Hagerman Fossil Beds National Monument.

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Source: Jardine, P., C. Janis, S. Sahney, M. Benton. 2012. Grit not grass: Concordant patterns of early hypsodonty in Great Plains ungulates and Glires.

(The following section was modified slightly from the Introduction of the scientific paper. Except for a few minor changes to help with complex vocabulary, the text is copied almost word-for-word from the original paper, published in a professional paleontology journal in 2012.)

The evolution of hypsodont (high crowned) molars in grassland herbivores is a classic story in the evolution of land mammals in North America. Changes in climate (cooling and drying) after the extinction of the dinosaurs resulted in major environmental changes across the globe. Forests fragmented and many continents saw for the first time the spread of open grasslands. In North America, the spread of grasslands began in the Great Plains region between 26 and 22 million years ago.

Grass is considered to be more abrasive on mammal teeth than leaves because grasses contain higher concentrations of microscopic silica bodies, called *phytoliths*, that occur in plant cells and tissues.

There is a long held view among paleontologists that the change in landscape from forests to grasslands was marked by a shift in the diets of herbivorous land mammals from browsing leaves to chewing grass. This triggered an adaptive evolutionary response in tooth morphology, favoring hypsodonty. Hypsodont (high crowned) molars are more resilient to increased wear from chewing abrasive material.
A rise in the abundance of hypsodont teeth in the fossil record during the last 30 million years has been used to infer the timing of the spread of grasslands. Data from fossil teeth is especially important given the patchy and inconsistent record of environmental change in the plant fossil record.

However, there are two challenges to this seemingly simple story. First, silica phytoliths may not be the only culprit affecting tooth wear. The amount of soil or grit ingested during feeding may be a more abrasive agent than the silica in grasses. In open grassland or prairie environments, herbivores can inadvertently consume large quantities of soil or grit, either because it has been deposited on the vegetation by wind or rain splash, or through the complete uprooting of plants during feeding.

Disentangling the relative importance of grass versus grit is complicated because the same process that favored the ecological expansion of silica-rich grasslands -- climactic cooling and drying and the fragmentation of forest cover-- would also have led to an increase in the amount of grit ingested by herbivores while feeding. Smaller plants (herbs, shrubs of grass) are more likely to be ripped up and consumed whole, with soil covered roots still attached. Herbivores feeding closer to the ground are therefore expected to ingest more abrasive material (grit) than those browsing at higher levels, regardless of whether the plant matter is leaves or grass.

To better understand the relative importance of grass versus grit in hypsodonty acquisition, we carried out a large scale study of changes in tooth height amongst all relevant herbivorous mammals of the North American Great Plains region.

Our results indicate that hypsodonty evolved in several groups of hoofed mammals (ungulates) and rodents on average 7 million years earlier than the reported rise of grasslands 26-22 million years ago.

We conclude that hypsodonty was not a simple adaptation for eating grasses, and may have originated in some mammals first to counteract the ingestion of grit and soil.

Source: Jardine, P., C. Janis, S. Sahney, M. Benton. 2012. Grit not grass: Concordant patterns of early hypsodonty in Great Plains ungulates and Glires.