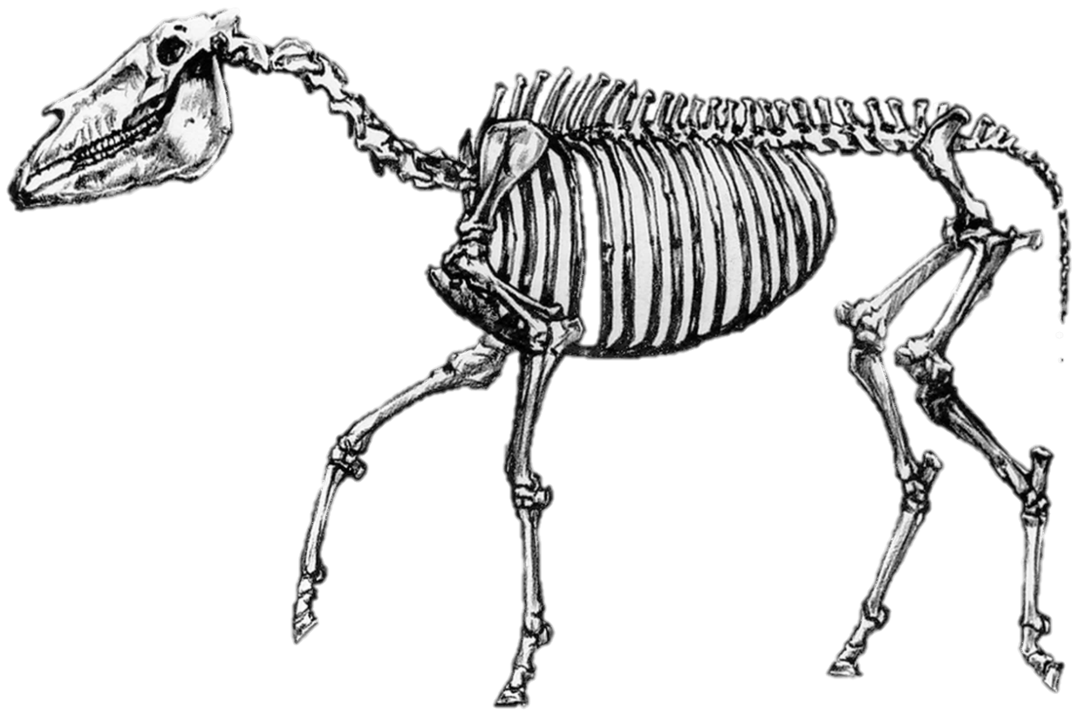
# FOSSIL TEETH

## A LESSON ON CHANGING CLIMATES AND EVOLUTIONARY RESPONSES PRESERVED IN THE FOSSIL RECORD



A set of lesson plans for High School Students developed at Hagerman Fossil Beds National Monument.

With funding through the Geological Society of America Geo-Scientist in Park Program and the National Park Service.

# CONTENTS

# Author's Note

This lesson was designed for the National Park Service Education division to be digitally accessible and downloadable for teachers across the country. It is intended for high school students in Introductory, Honors and/or Advanced Placement Biology in grades 9-12.

Curriculum standards align with the Disciplinary Core Ideas from the **Next Generation Science Standards (NGSS)** and guidelines for reading and writing from the **Common Core State Standards (CCSS).**

- In the lesson, students examine changes in tooth morphology in the fossil record of herbivorous mammals in North America through graphical analysis, critical reading and writing.
- Data was derived from two scientific articles, cited below, and modified to match high-school student learning levels.
- Students learn to interpret primary data to infer factors which cause evolutionary adaptations and link biological adaptation to global climate change and localized habitat change.
- The lesson includes a pre-lesson to provide background about tooth morphology as well as extended resources for teachers (including assessments and supporting documents).

*This lesson is openly published and meant to be distributed, modified and used by teachers in a variety of contexts. Please direct all inquiries to the primary author, Gina Roberti (roberti.gina@gmail.com), or Park Paleontologist at Hagerman Fossil Beds National Monument.*

# Acknowledgements

This project made possible through the Geologic Society of America® Geoscientist-in-the-Parks Program and the National Park Service. The Geoscientists-in-the-Parks (GIP) Program was developed by the National Park Service Geologic Resources Division (GRD) in 1996. The NPS partners with the Geological Society of America (GSA) and Environmental Stewards (ES) to administer the GIP Program. With thanks to the administration and HAFO paleontologist Dr. Prassack at Hagerman Fossil Beds NM.

Special acknowledgement and thanks to the authors of the scientific papers (Jardine et al. 2012, Stromberg, et al. 2011), which provided primary source material used in the development of this lesson plan.

The scope of this lesson was greatly inspired by a similar project developed by the University of Florida Center for Precollegiate Education and Training (CPET).
The lesson is available online at cpet.ufl.edu/wp-content/uploads/2015/07/Horse-Evo.pdf.

# Literature Cited

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. *Paleobiology* 37(1), 2011, pp. 50-71.

# 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:

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.

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

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.

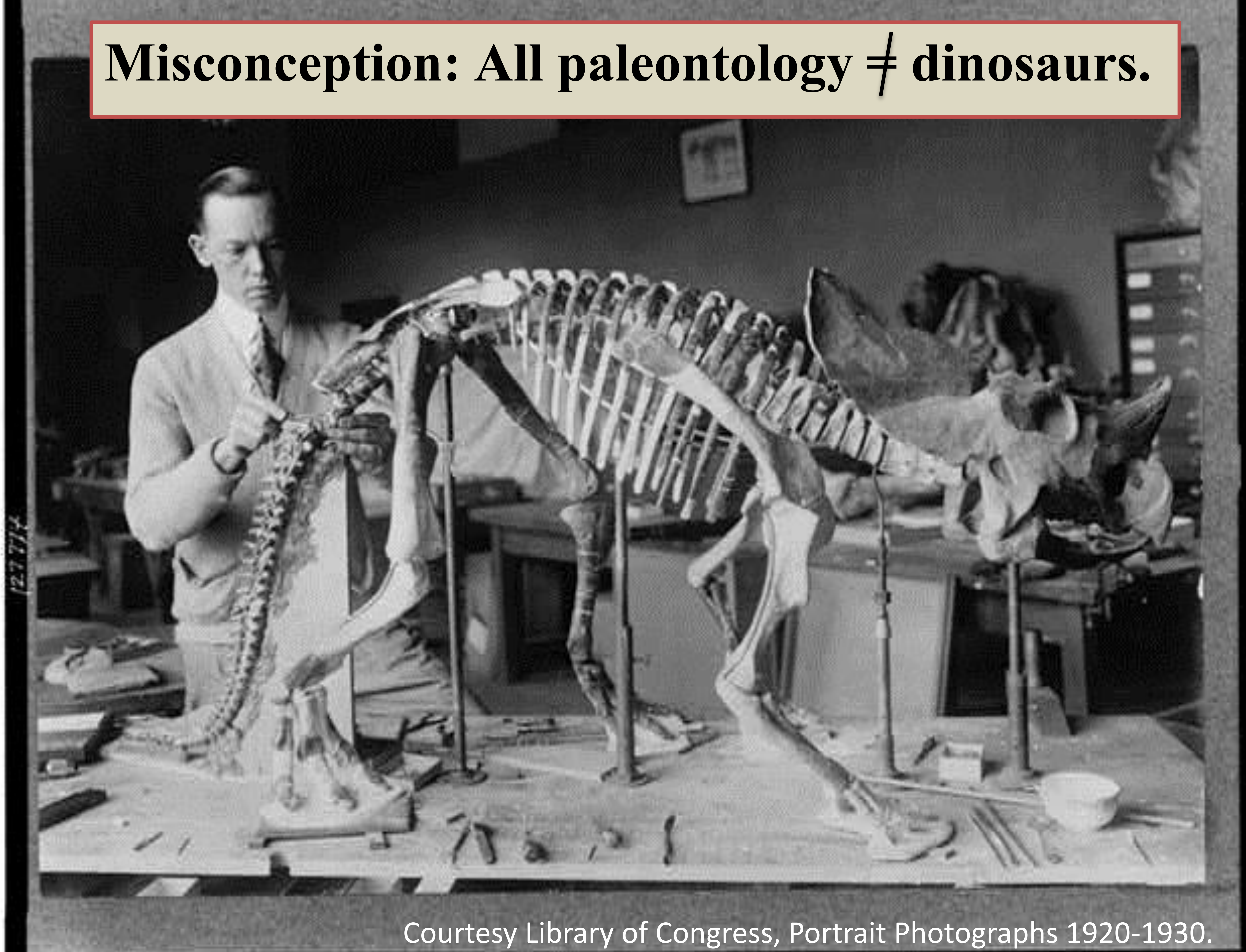
Stromberg, C., F. McInerney. The Neogene transition from C3 to C4 grasslands in North America: assemblage analysis of fossil phytoliths. *Palebiology* 37(1), 2011, pp. 50-71.

What does paleontology look like today?

Start with real people.

**(Jurassic Park = NOT real people.)**

# Misconception: All paleontology $\neq$ dinosaurs.

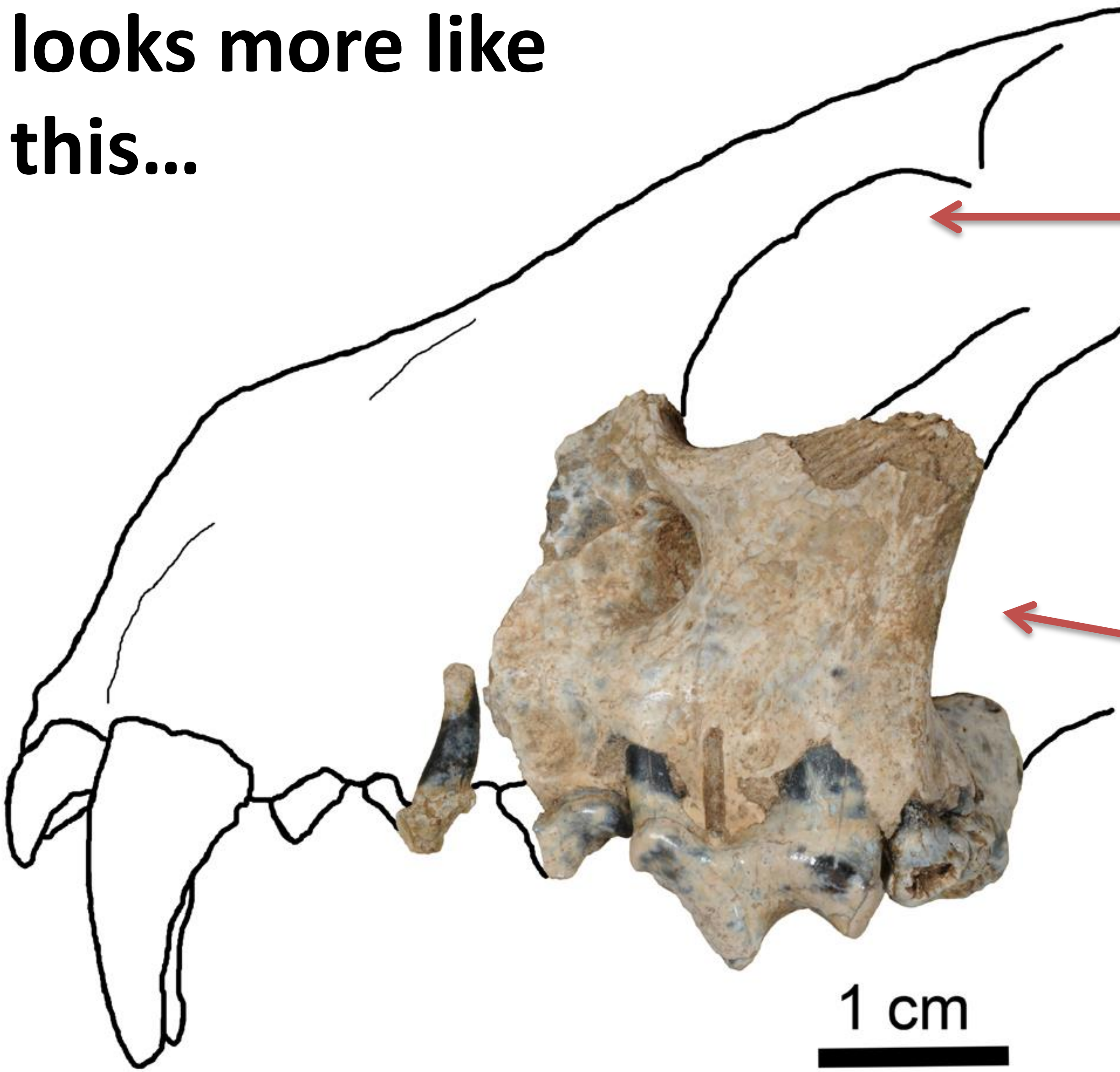


Courtesy Library of Congress, Portrait Photographs 1920-1930.

Sometimes the fossils come out of the ground looking great...

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

# Often, fossils looks more like this…




**Drawing** (inferred)

**Partial Skull Fragment**

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**

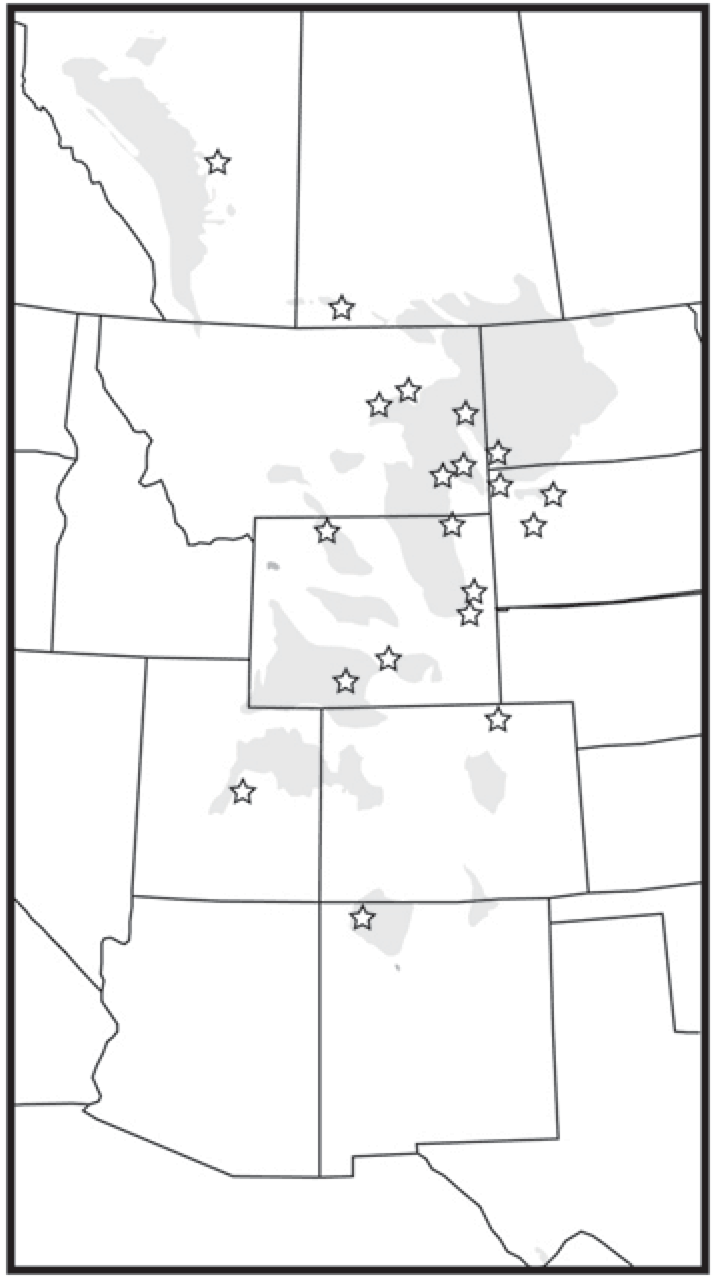
# fossil teeth.

# 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:**

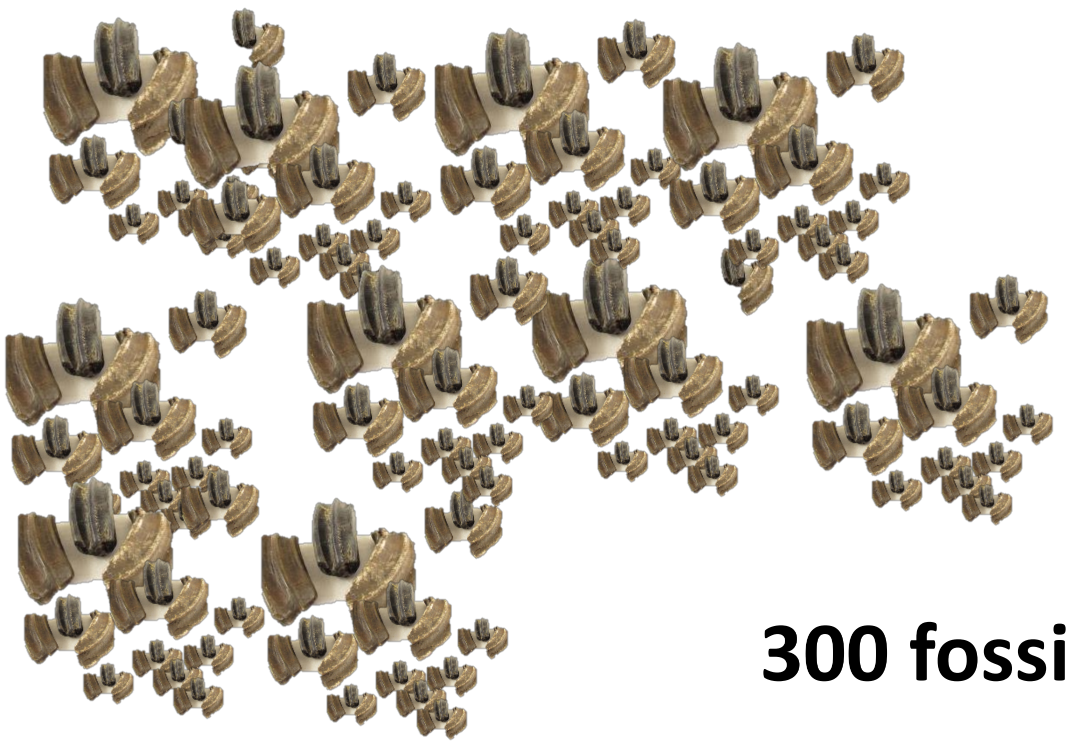
**The Great Plains of North America**


Step 1: finding fossils…

**And more fossils…**

**30 fossil teeth…**

**30 fossil teeth**



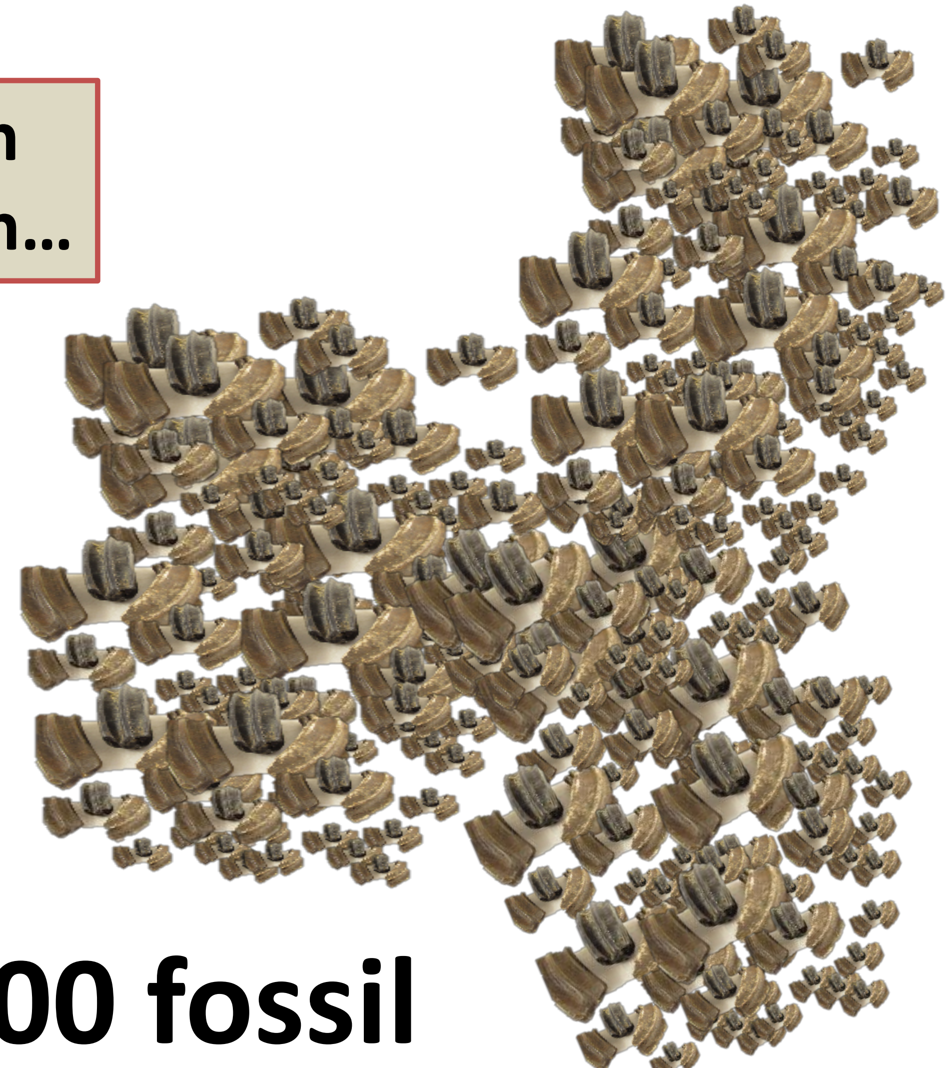
# 300 fossil teeth…

**And more fossils …**

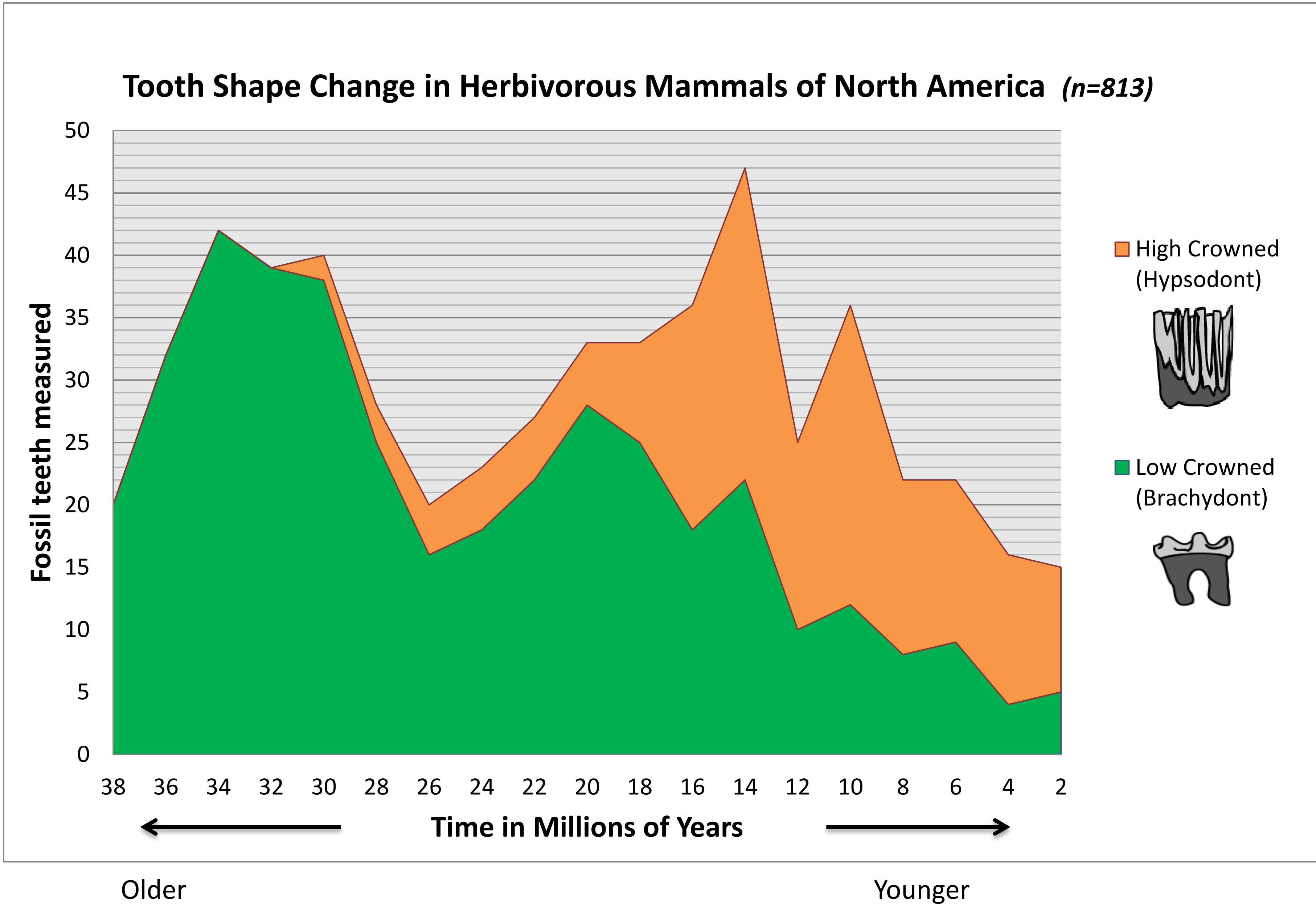
**And even more teeth…**

30 fossil teeth

300 fossil teeth



# 800 fossil mammal teeth!



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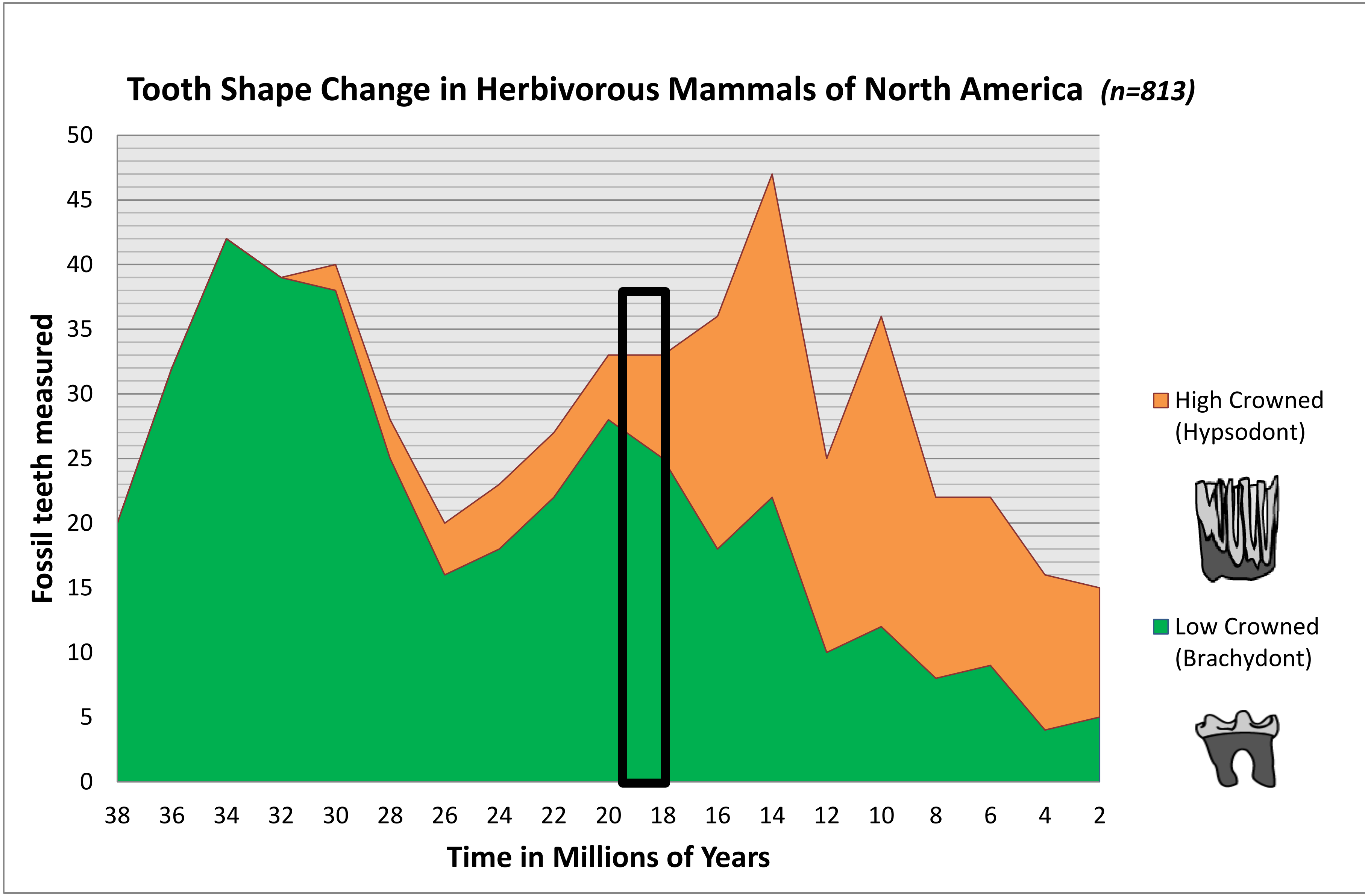
Time in Millions of Years
High Crowned (Hypsodont)
Low Crowned (Brachydont)
Older
Younger



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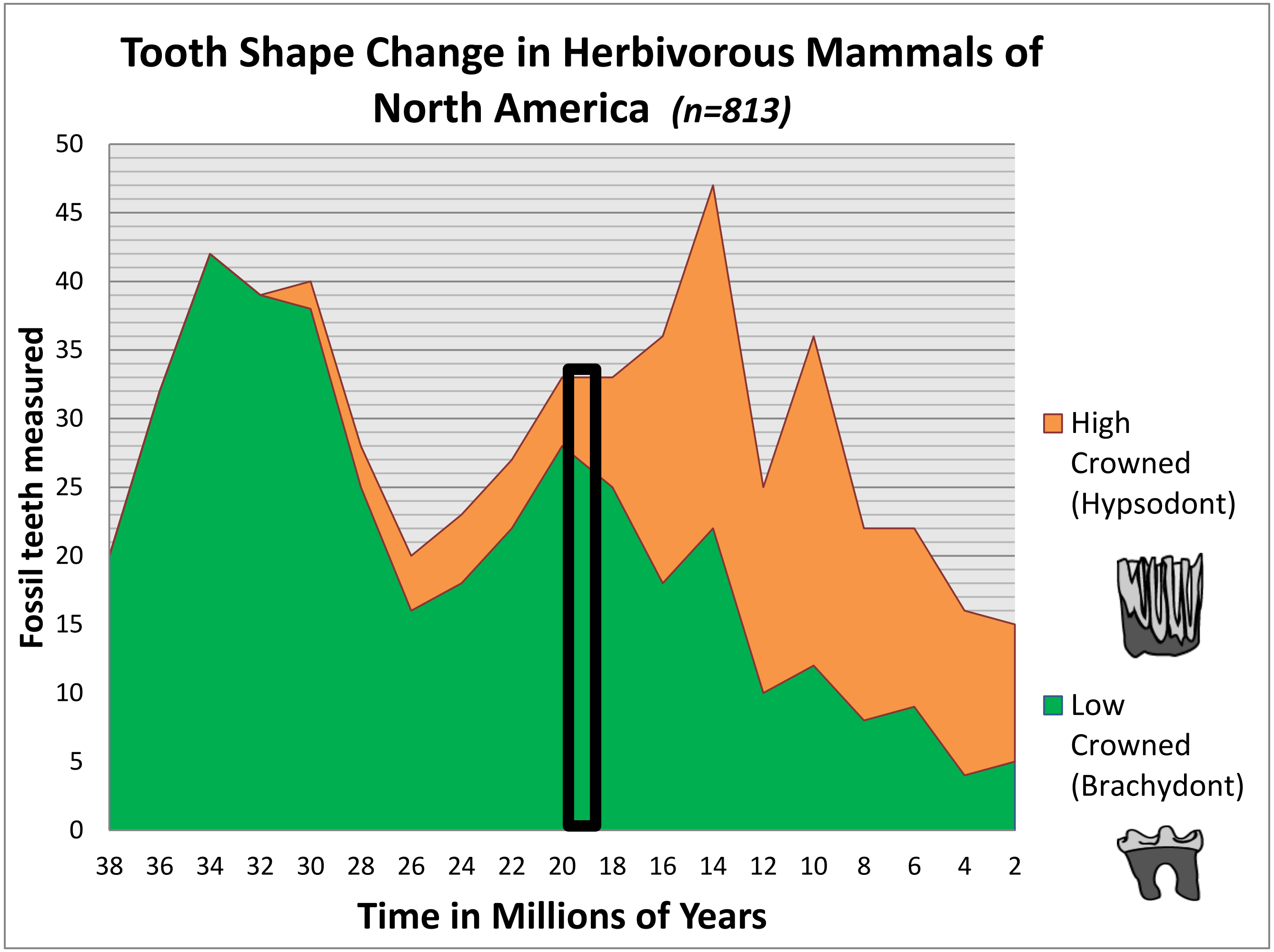
High Crowned (Hypsodont)
Low Crowned (Brachydont)



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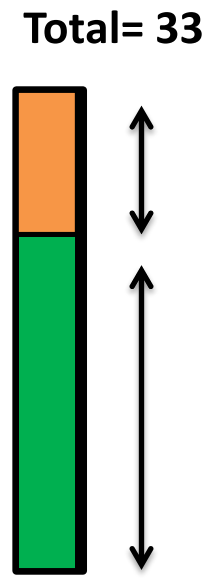

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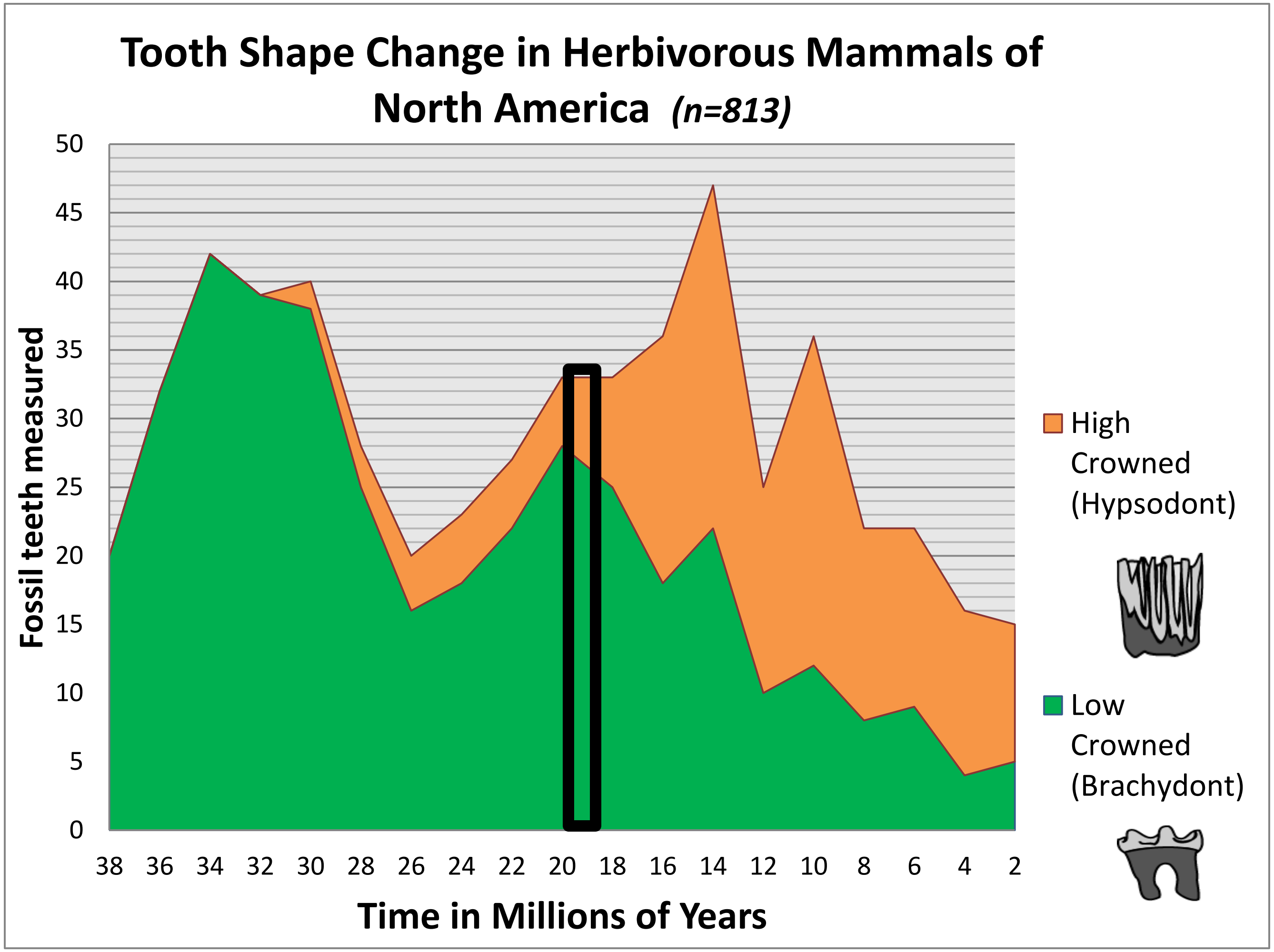

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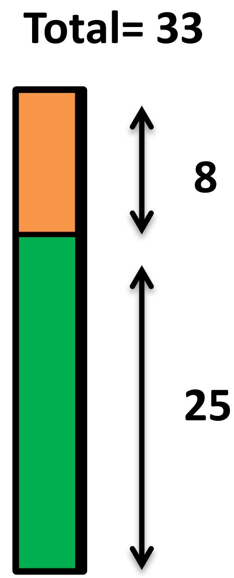

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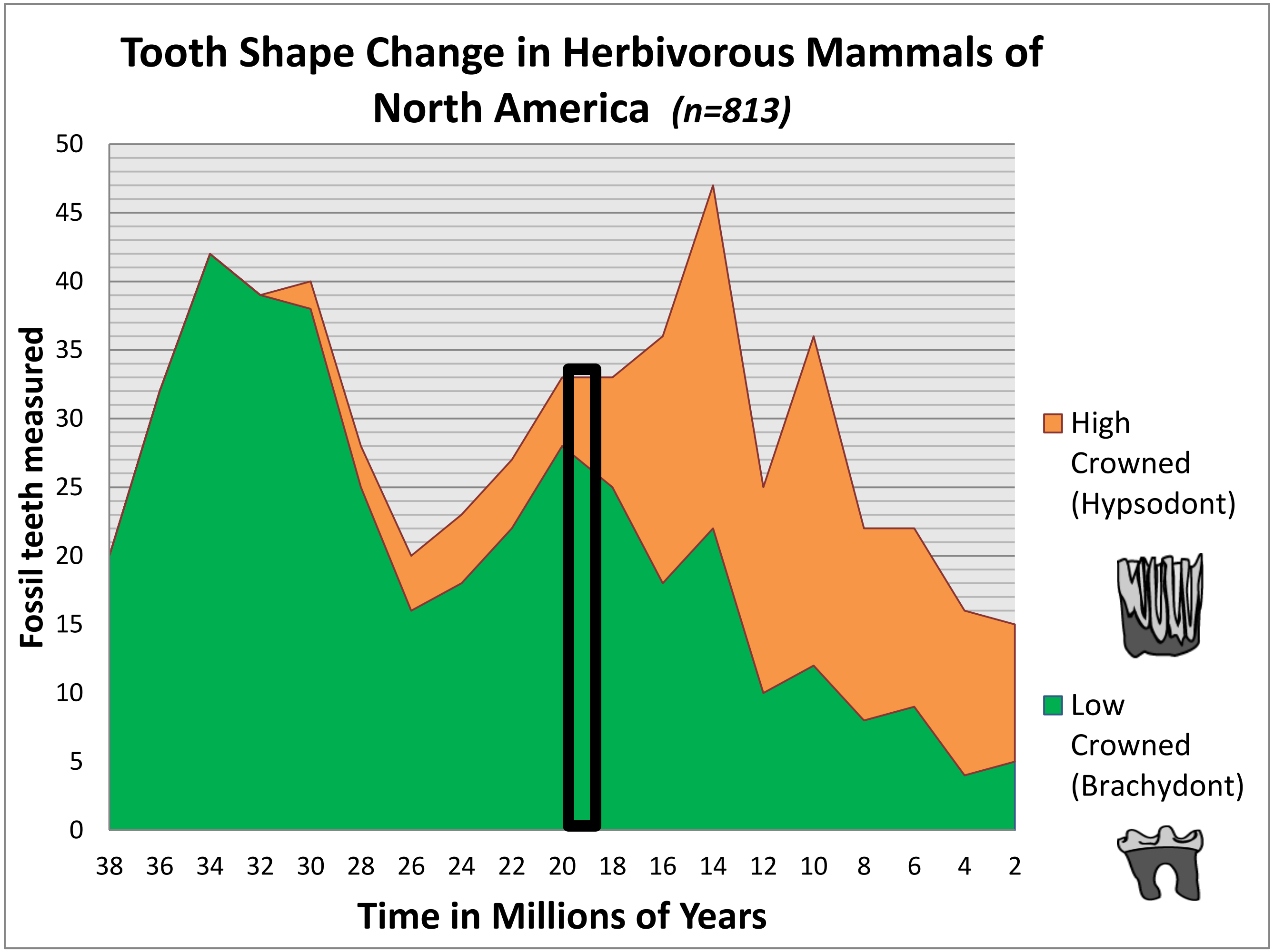

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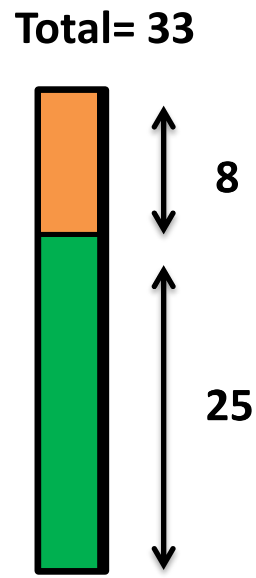

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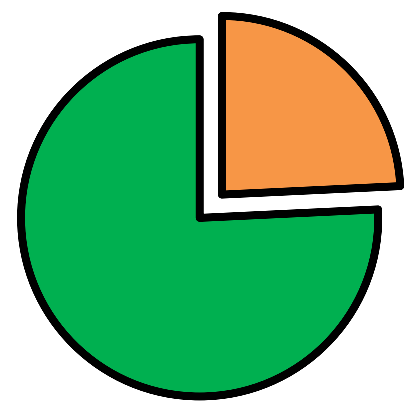

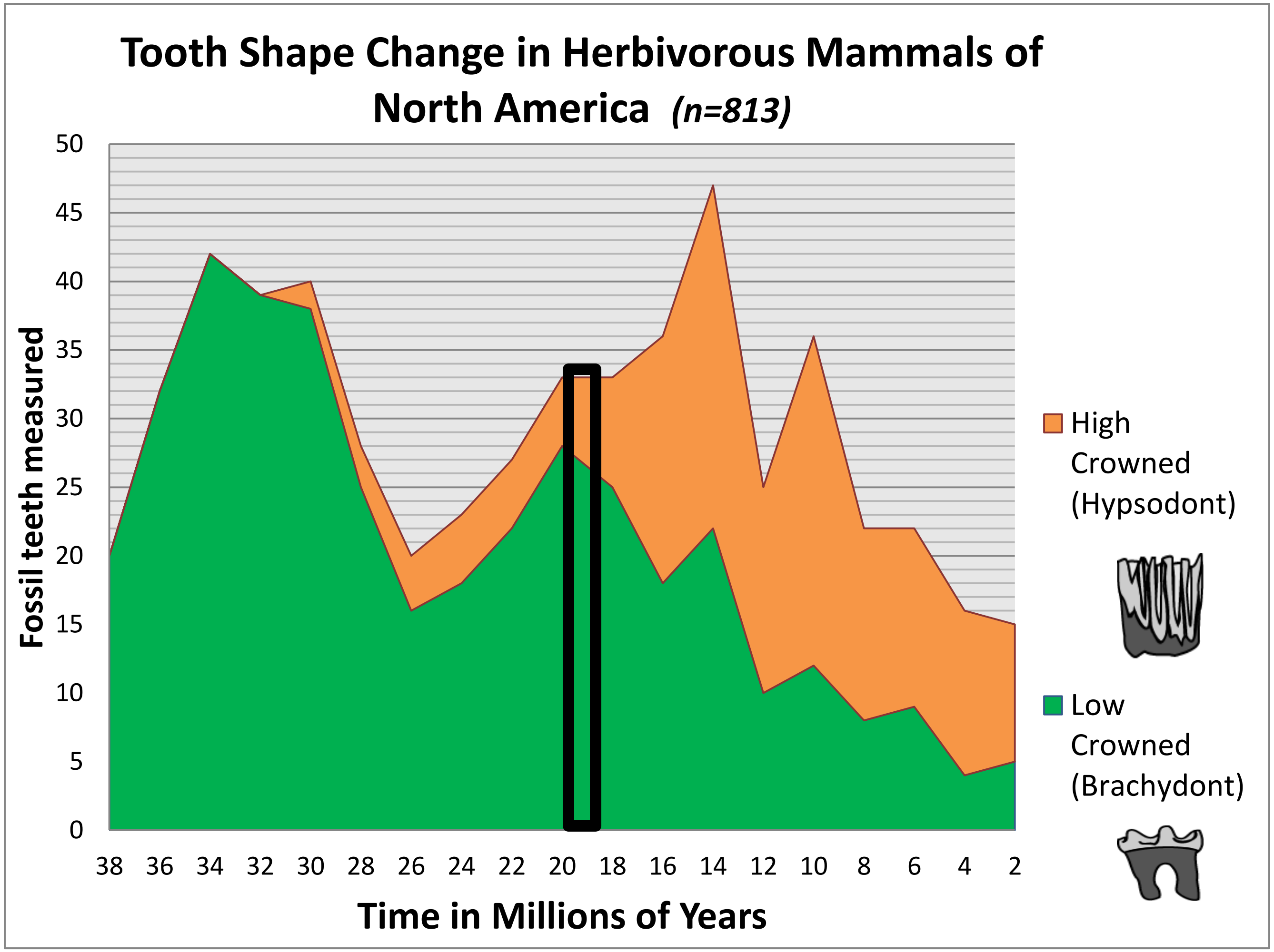
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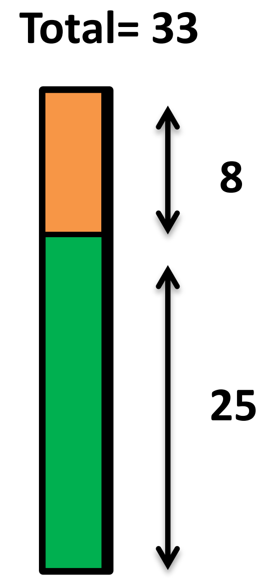
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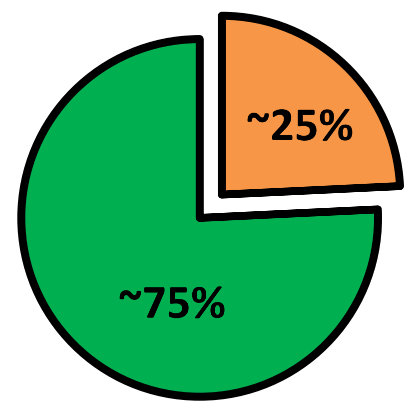
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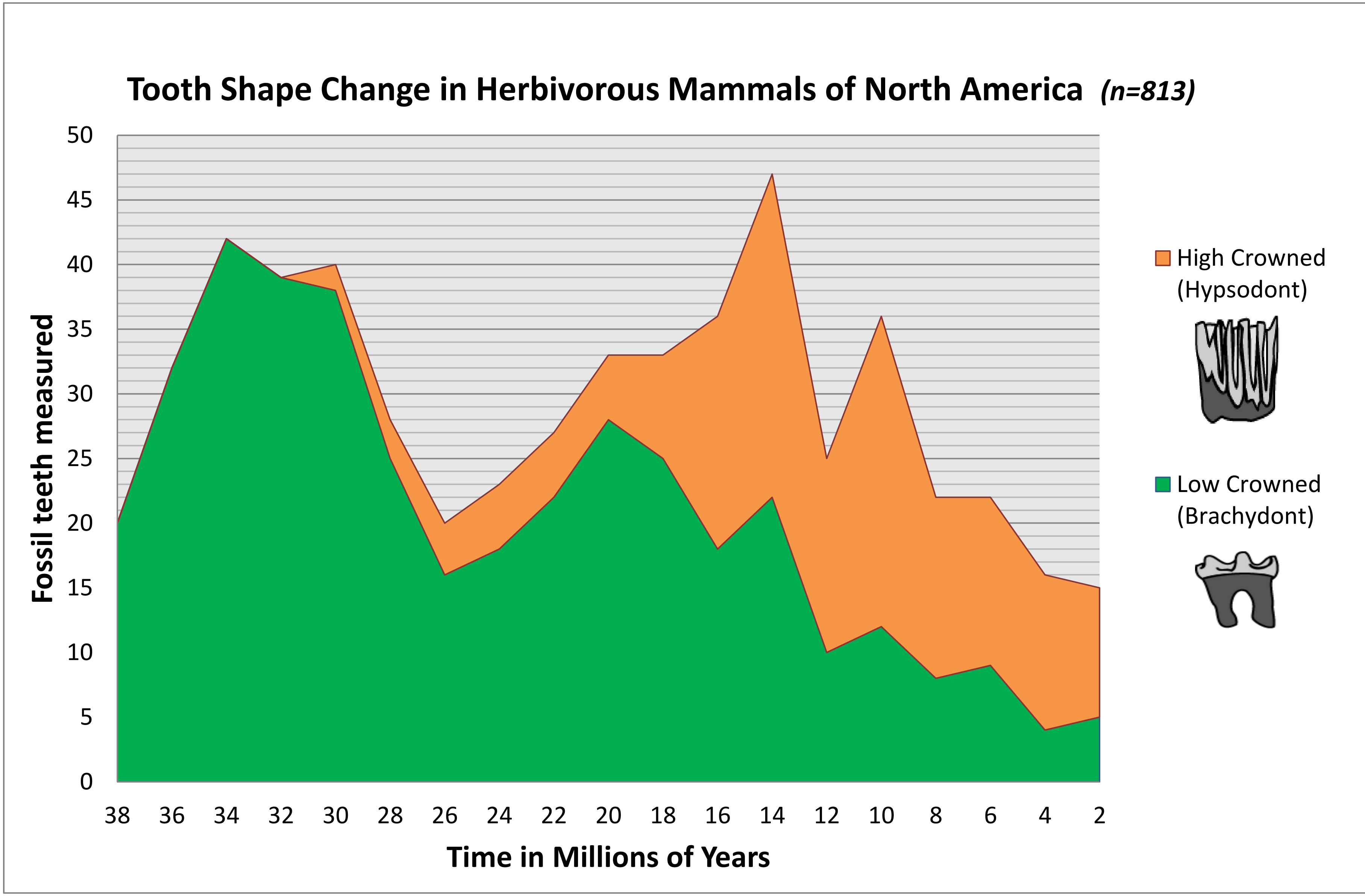
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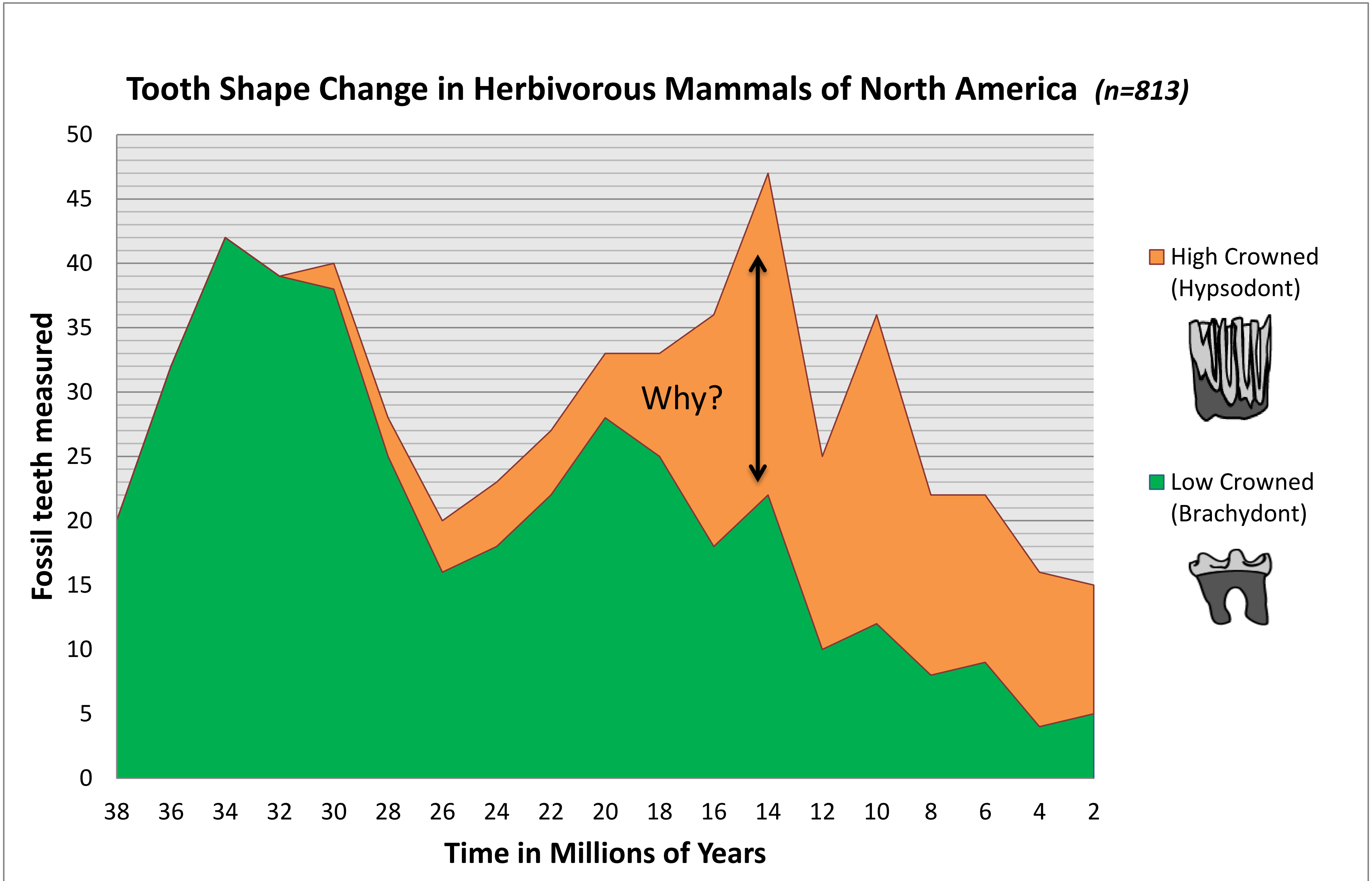

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2
Time in Millions of Years
Why?
High Crowned (Hypsodont)
Low Crowned (Brachydont)

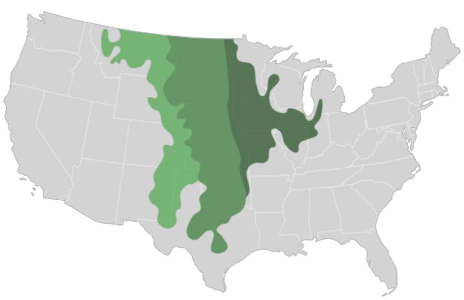
# Perhaps the change in tooth shape was a result of new habitats.

Grassland in Kansas

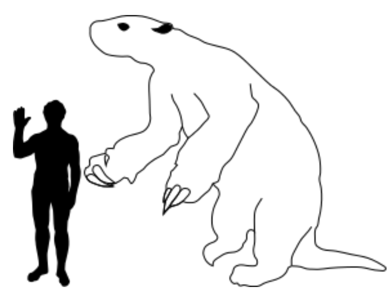
# Student Worksheet: Analyzing 'Real-World' Data

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)

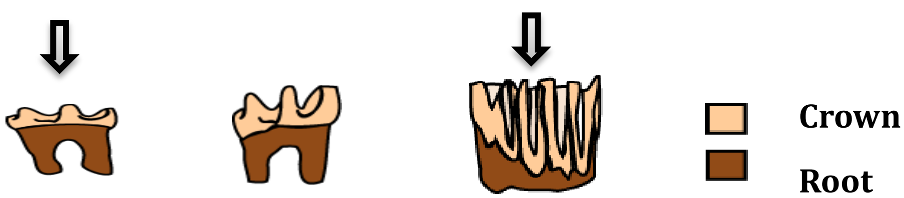
[2]


# 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.

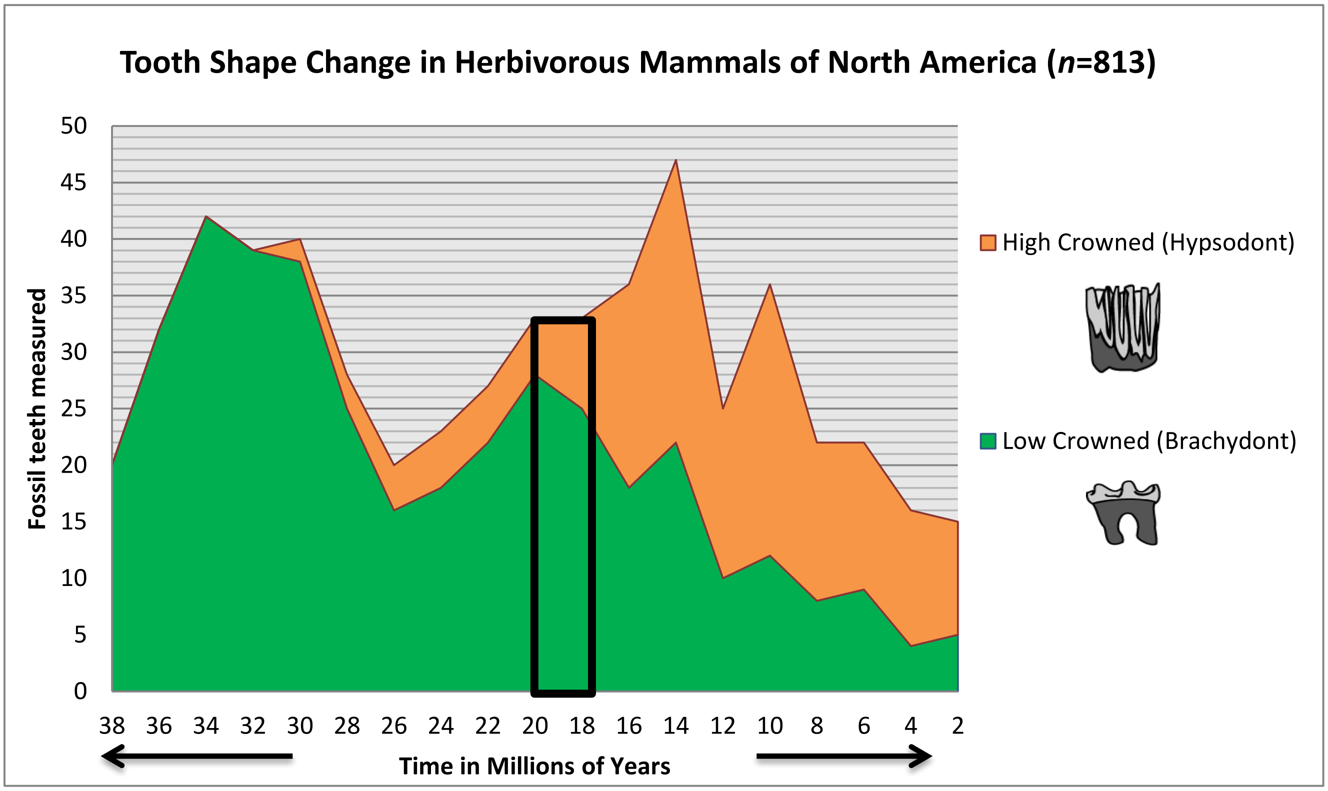
---

[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

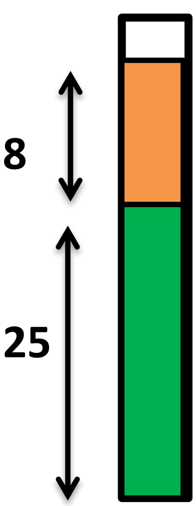
The following graph charts the change in the *relative abundance* of tooth type over time. (Note: this is a different way of graphing that you might have seen in math class!) The x-axis represents time in millions of years, and the y-axis represents the number of fossil teeth measured.

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:



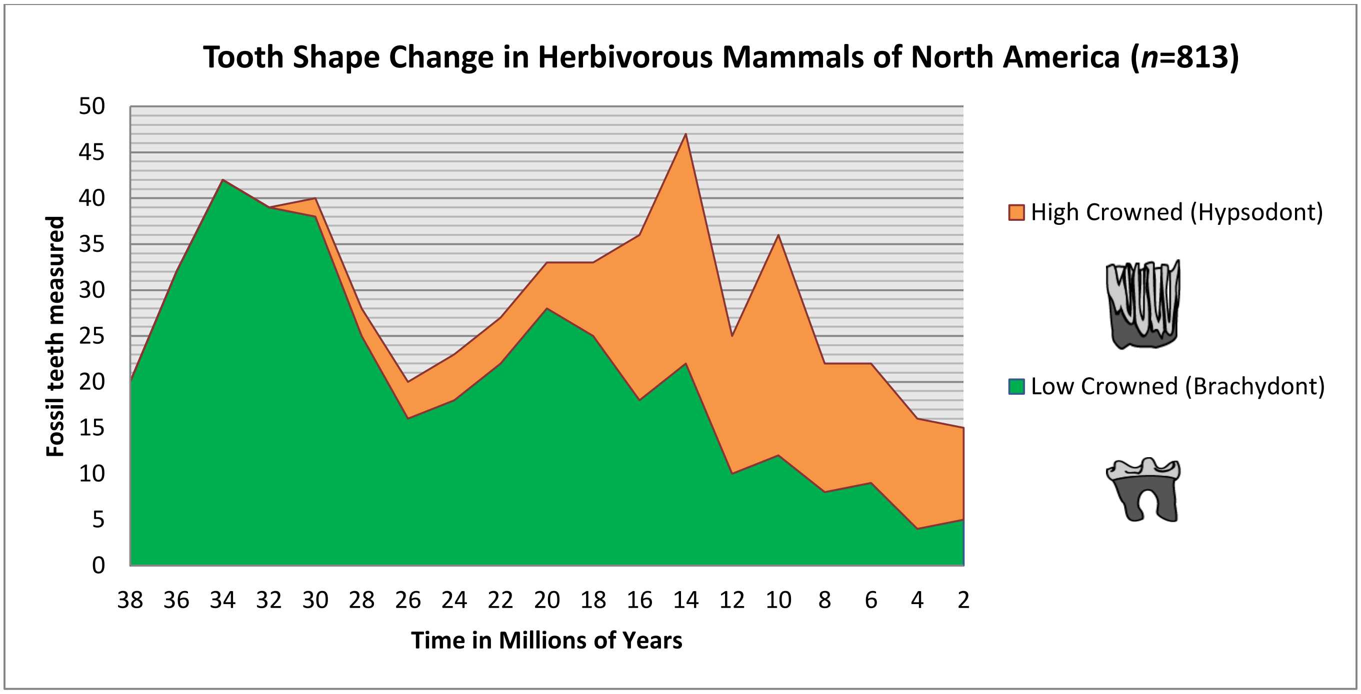

At each point along the x-axis (representing a specific time in millions of years before present), the graph shows a certain amount of green and/or orange. Different colors represent different tooth types (orange= high crowned, green = low crowned).

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

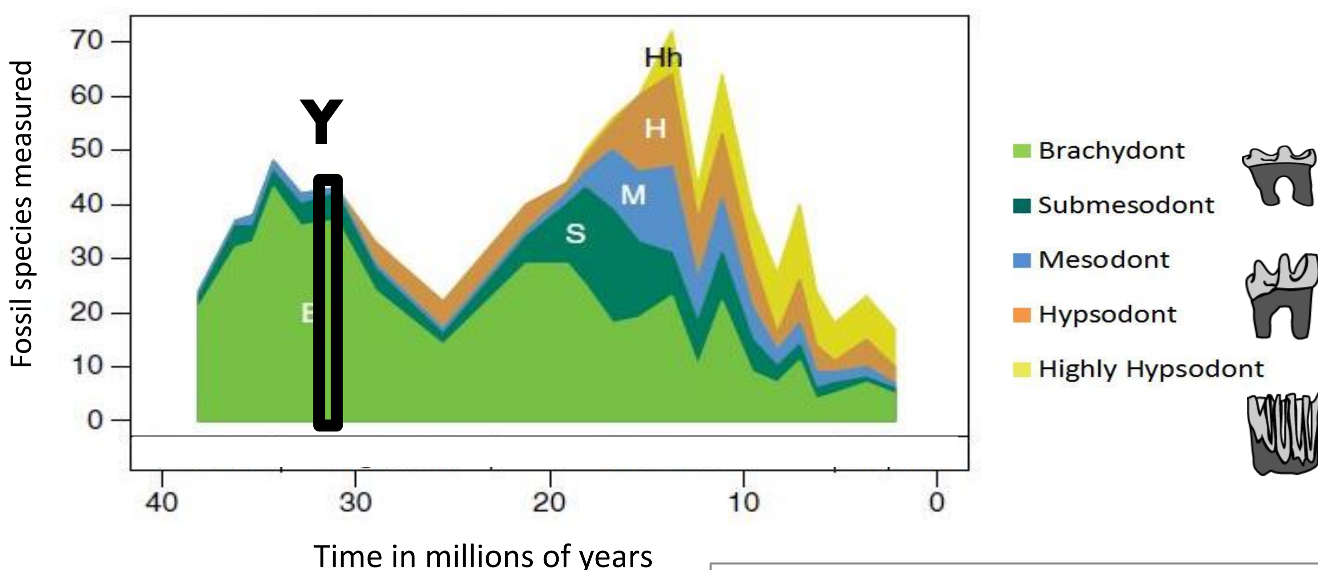
The following graphs are taken directly from the scientific paper published by paleontologists Philip Jardine, Christine Janis, Sandra Sahney and Michael Benton in a scientific journal in 2012.

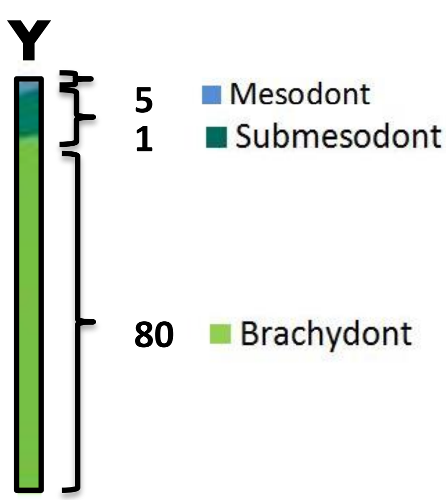
In the actual paper, the paleontologists included several more categories of tooth shape including an intermediate category (‘medium-crowned’) and an extra high-crowned category (‘very high crowned’).

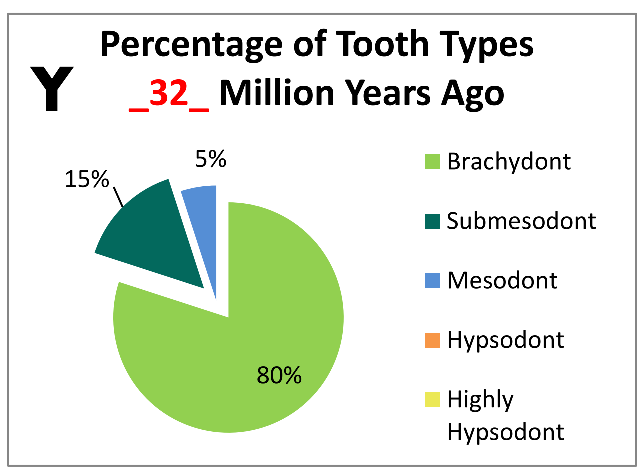

**Though the vocabulary is more complex, read the graph below using the same methodology used for the simplified version on the previous page.**

## Activity: Reading a line graph using pie charts.

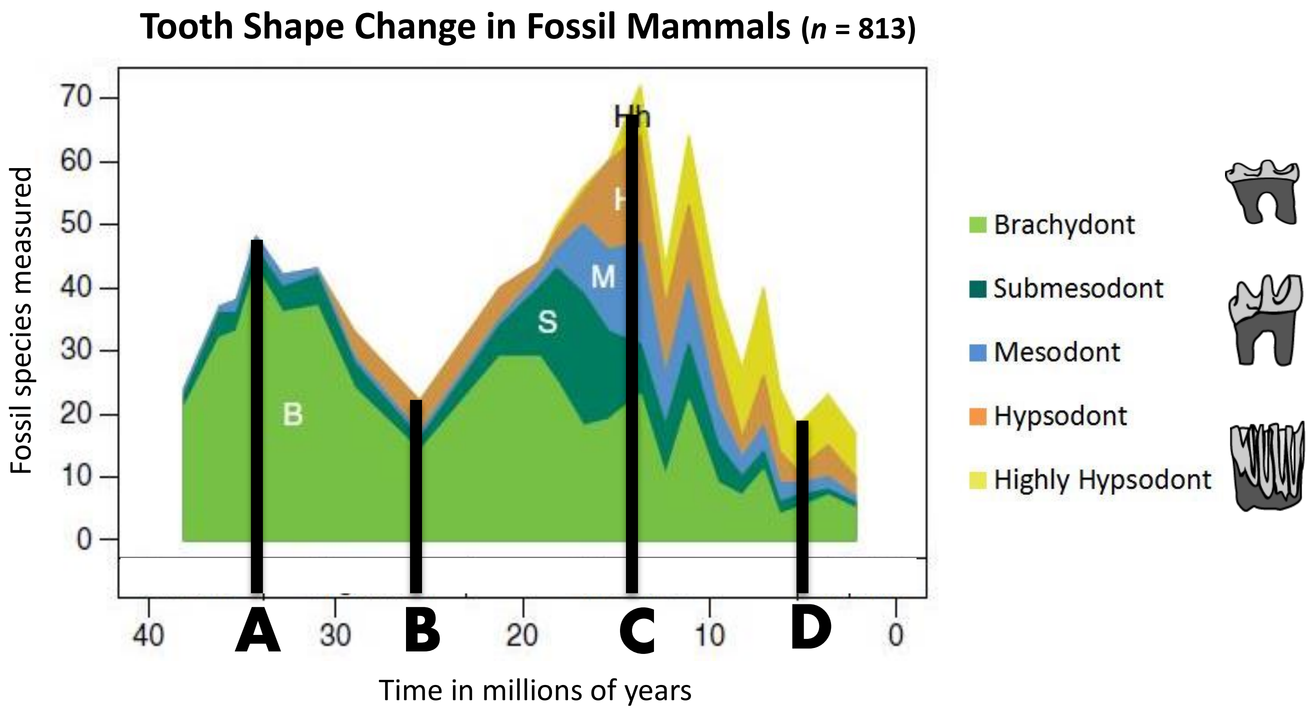
**Tooth Shape Change in Fossil Mammals (*n* = 813)**



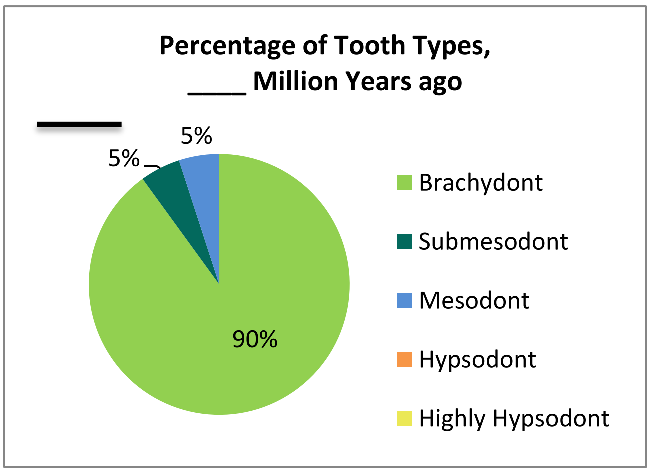



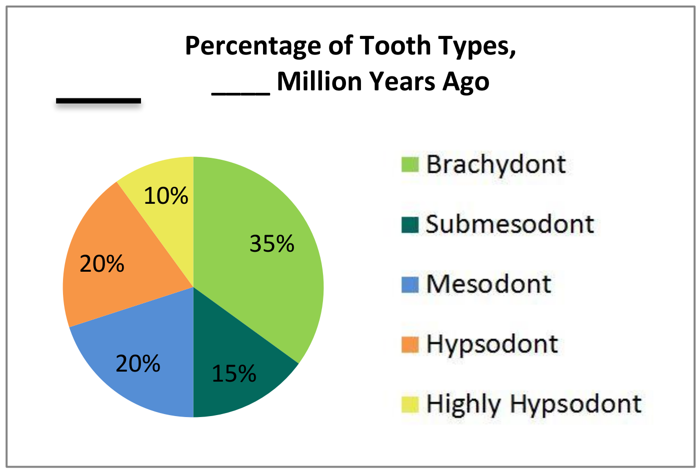
# Student Worksheet: Analyzing 'Real-World' Data

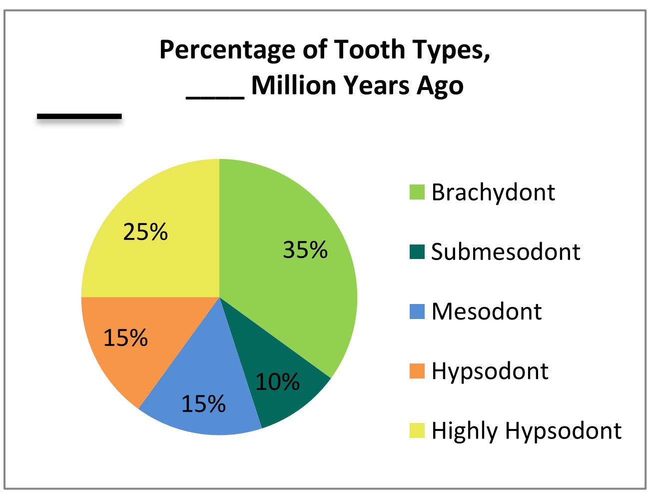


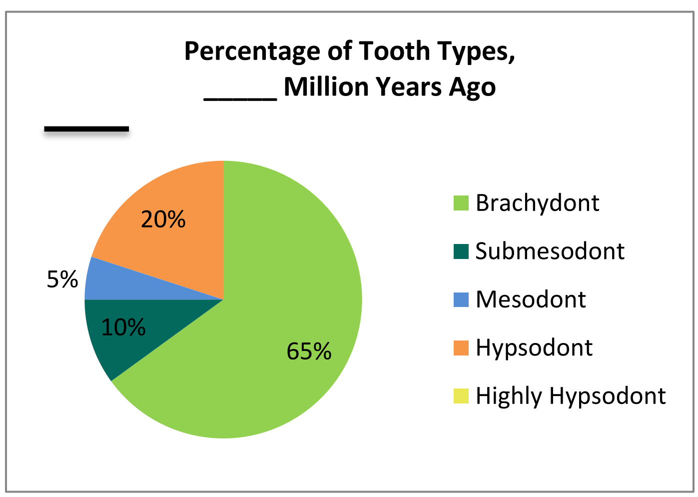

The graph above marks the change in PROPORTION of species with different teeth over time.

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



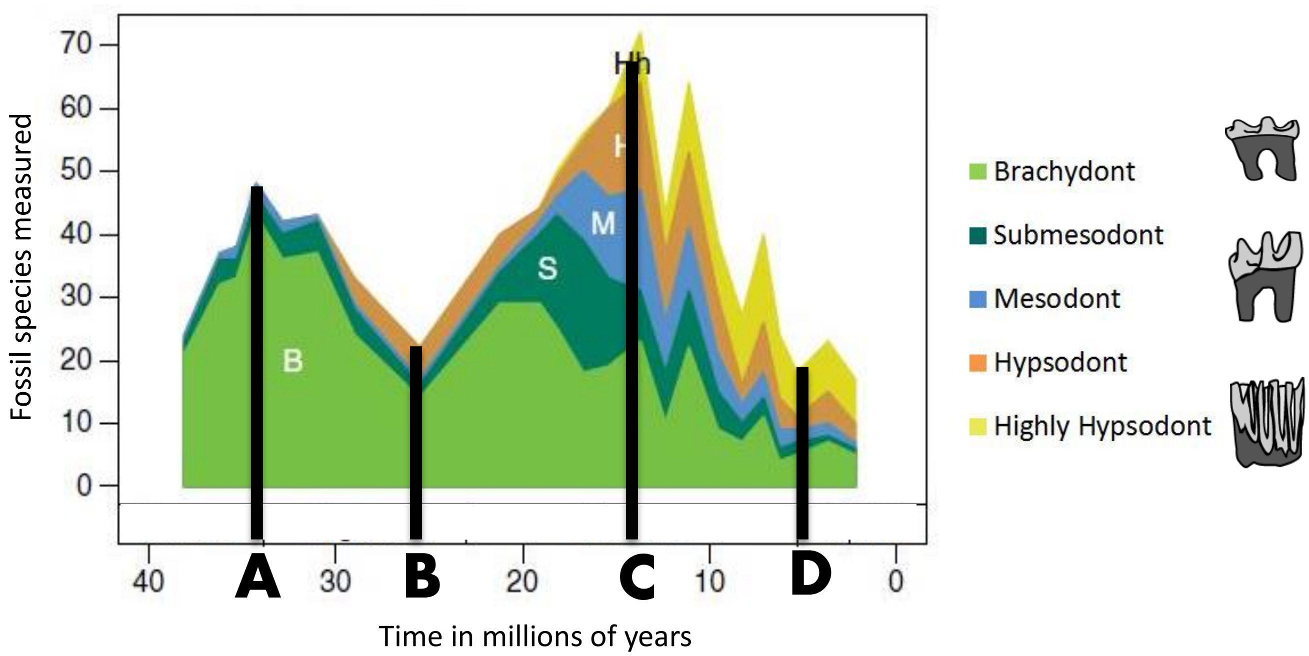



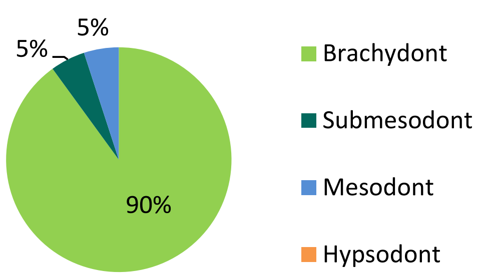
# Student Worksheet: Analyzing 'Real-World' Data

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

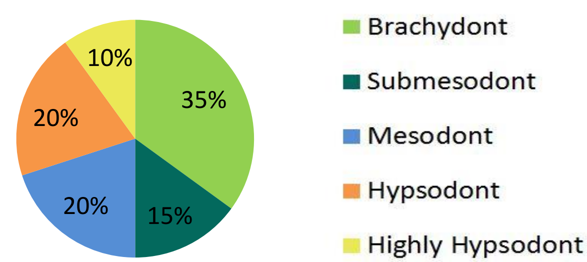



The graph above marks the change in PROPORTION of species with different teeth over time.
Directions: Match each pie chart to the correct location on the graph. TEACHER ANSWER KEY.

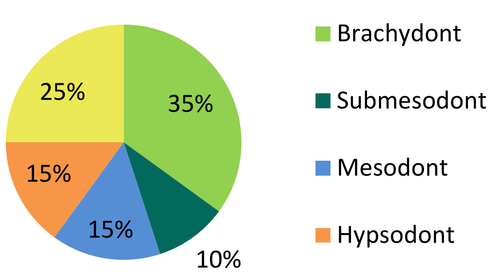
**A** **Percentage of Tooth Types, _35_ Million Years ago**



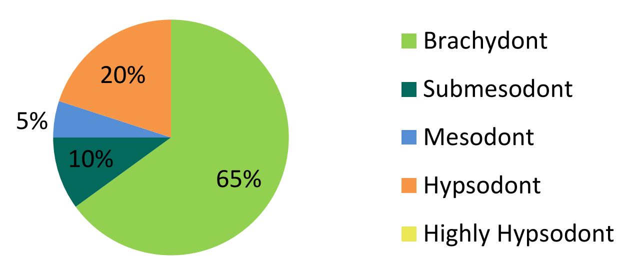

**C** **Percentage of Tooth Types, _5_ Million Years Ago**




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



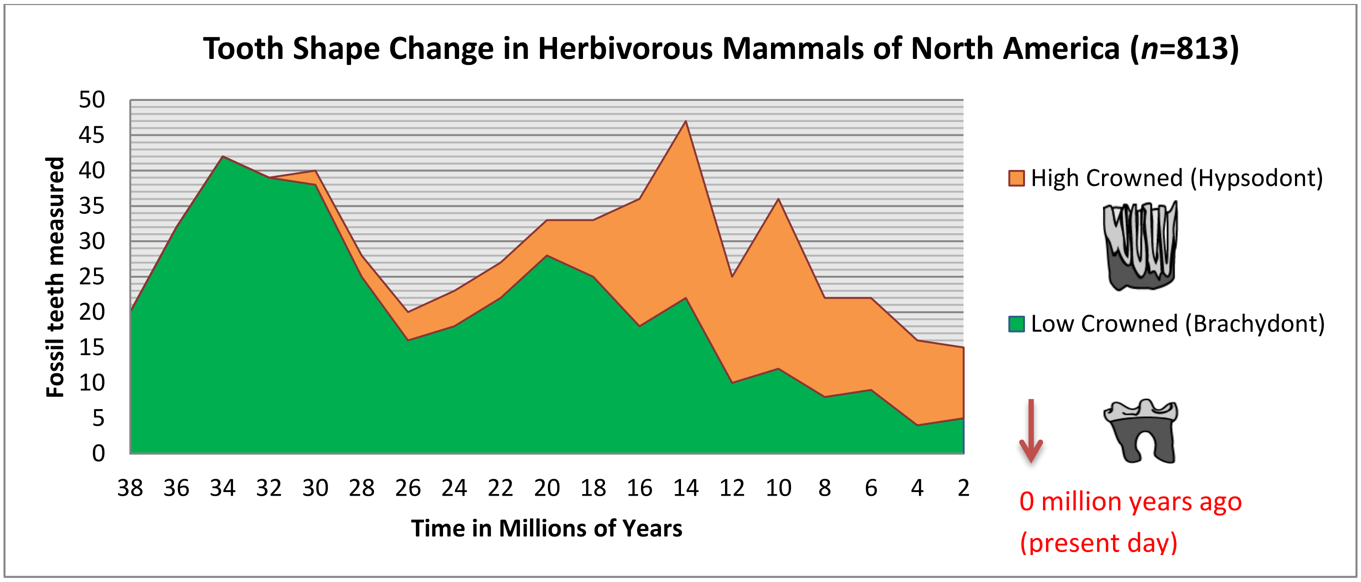

**B** **Percentage of Tooth Types, _25_ Million Years Ago**



# 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.

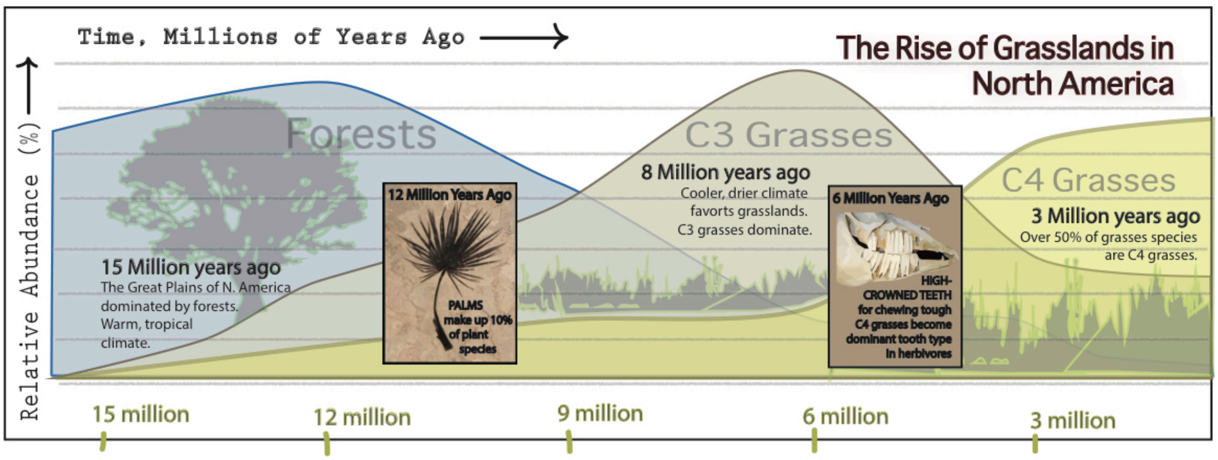
# Student Timeline Activity

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.

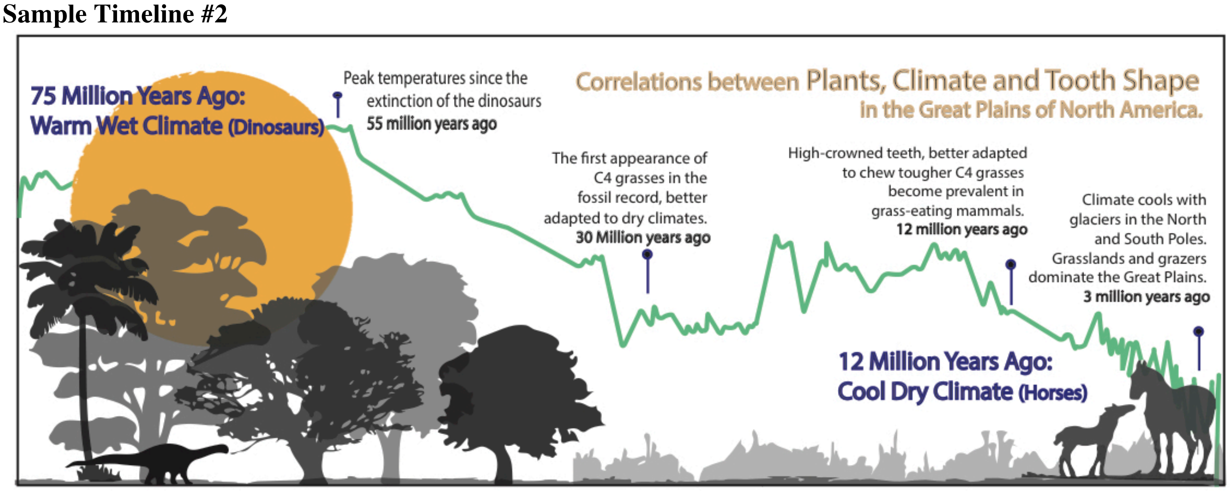
Creativity is encouraged! A few example timelines are shown below. Just be sure to support your design choices with data from the following pages (Lines of Evidence #1-4).

**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).

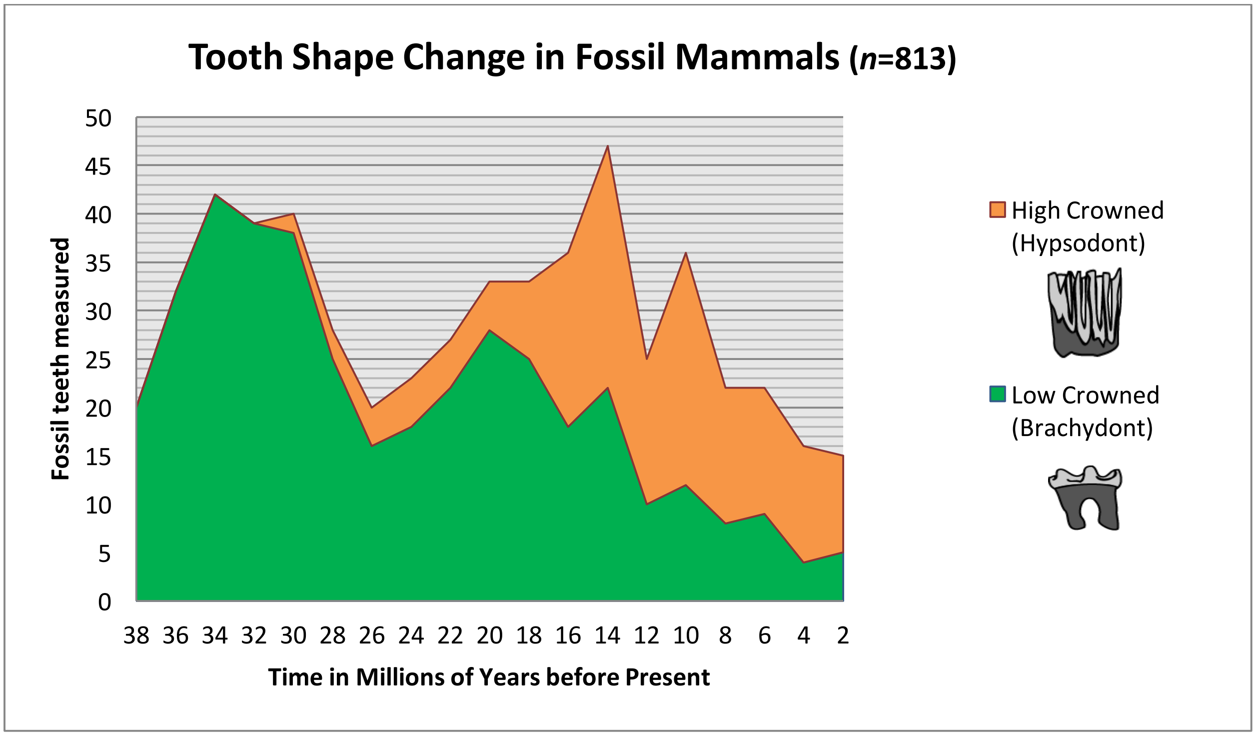
**Sample Timeline #2**




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.

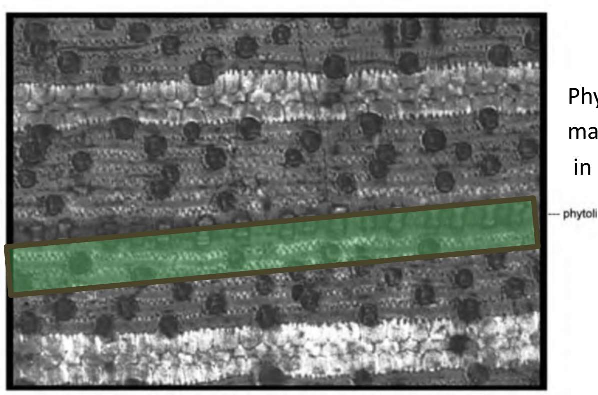
## Grasses are abrasive on teeth.

**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*.

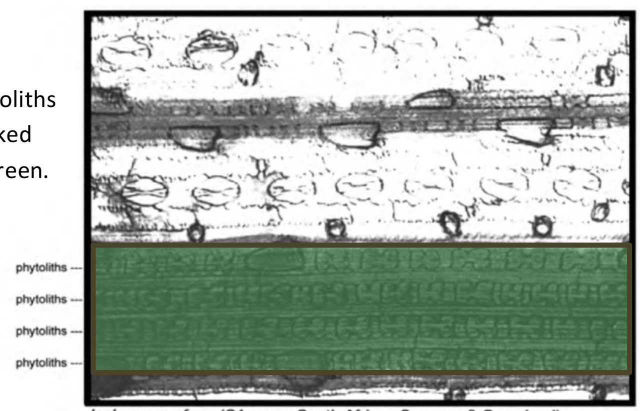
**C3 Grasses**

**C4 Grasses**




*Oxytenanthera abyssinica* (C3 grass, South African Savanna)

Phytoliths marked in green.




*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).

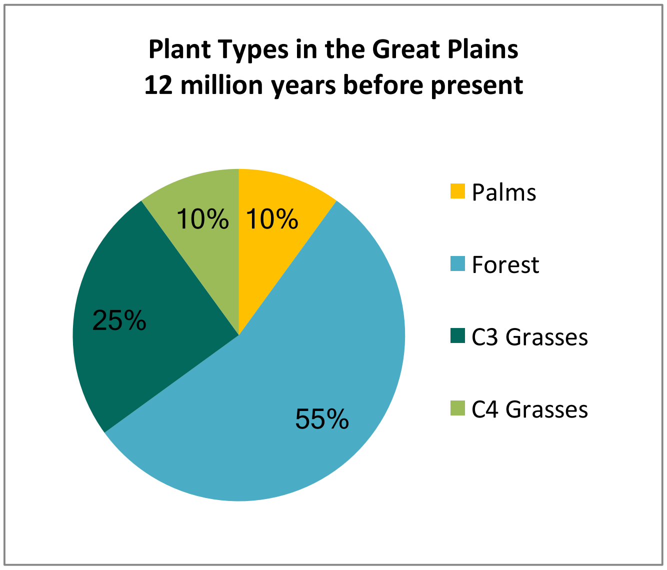
By 10 million years ago, C4 grasses comprise 10-40% of grass types in North American grasslands.

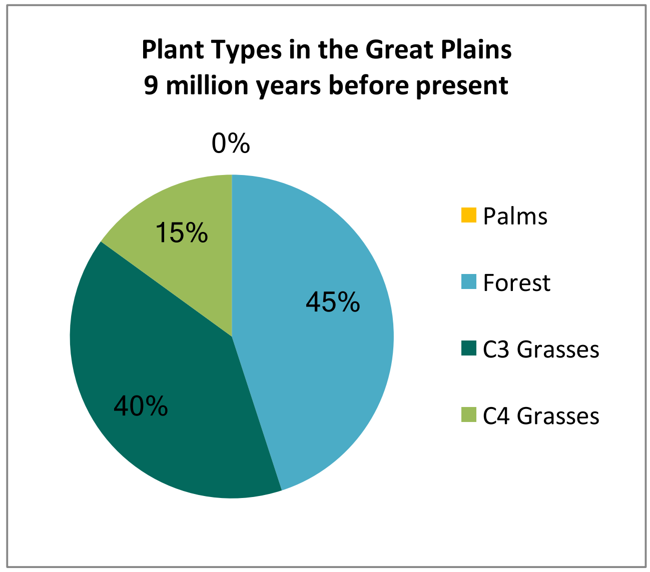
By 3 million years ago, C4 grasses comprise over 50% of grasses in North America grasslands.

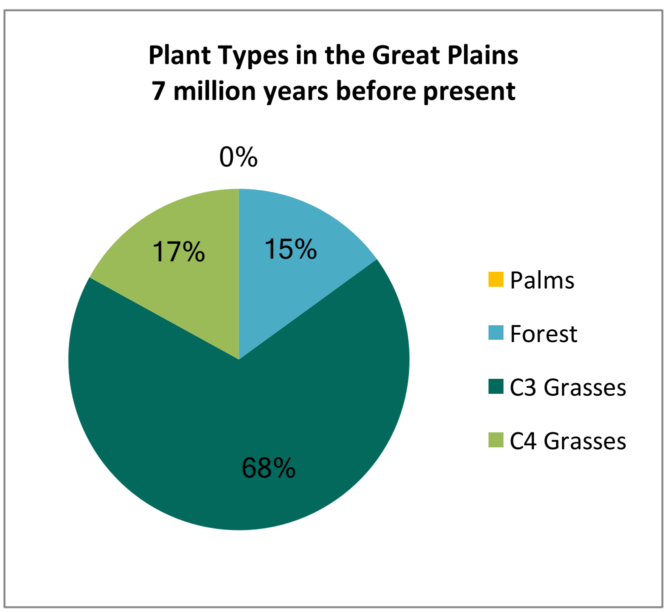
Today, 40-80% of grasslands in the North American Great Plains (Kansas and Nebraska) are C4 grasses.

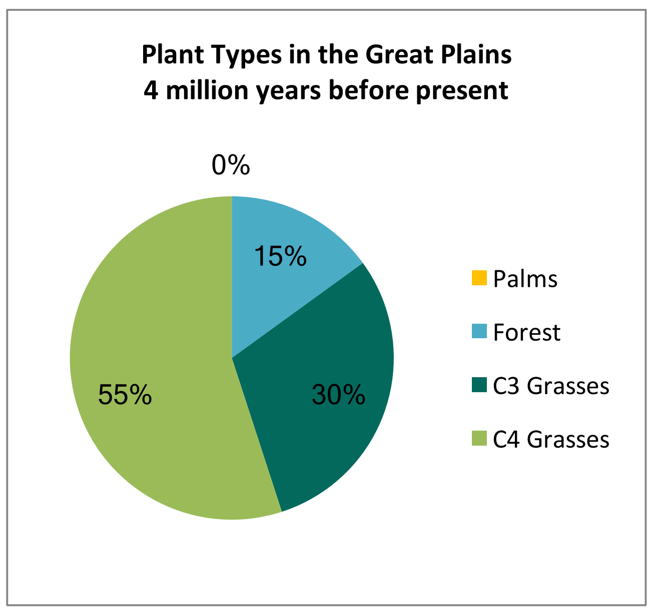
**Line of Evidence #4:** Changes in plant composition reflect changes in habitat. The graphs below chart changes in the type of plants which grew in the Great Plains of North America between 12 million years ago and today.

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.



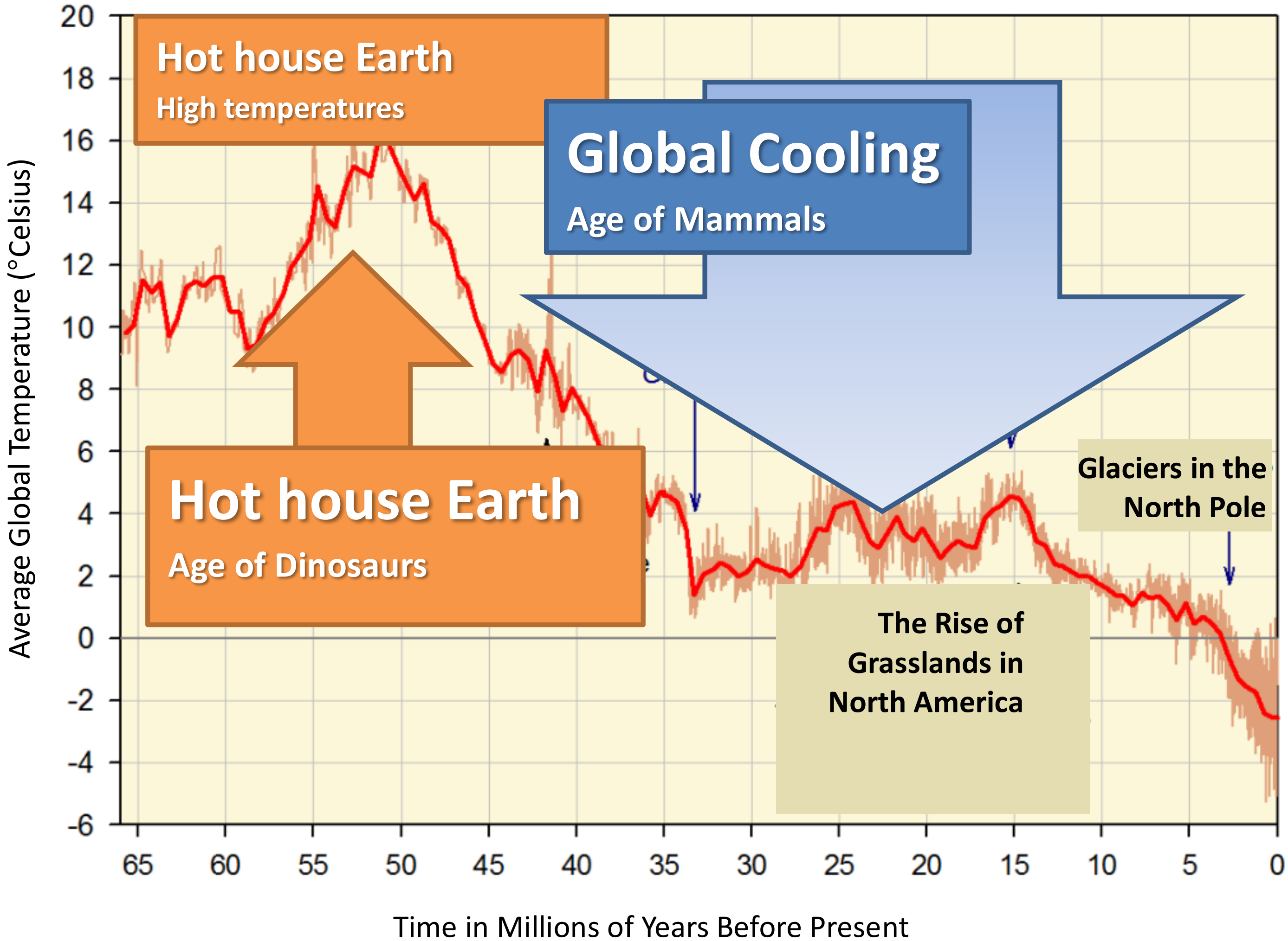



Line of Evidence #5: Record of temperature change from 65 million years to present.

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

# BIG Climate Changes.






Student Timeline Worksheet Paleoclimate. NPS 2016. (5)

**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

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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]

[a] School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
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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.

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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.

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Your letter must address the question:

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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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PALAEO 3

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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.*

# Teacher Background: Grassland Evolution

What distinguishes grasses from other plants?

**(1) Modern plants use one of 3 photosynthetic pathways: C4, C3 and CAM to capture carbon.**

| | | |
|---|---|---|
| C3 | Trees, shrubs, some grasses | Adapted to higher CO2, cooler temps, wetter climate<br>Prefer precipitation during cold season. |
| C4 | Over 50% of all modern grasses. | Can tolerate lower CO2, higher temps, less moisture<br>Prefer precipitation during warm season. |
| CAM | Succulents, cacti | CAM pathway seen in highly drought resistant plants. |

**(2) Many grasses today use the C4 pathway to capture carbon**.

About 20 million years ago**, plants living in hotter, drier climates evolved a new method of capturing energy from the sun: C4 photosynthesis**. Because C4 plants obtain carbon in a different way, they record a different carbon isotopic signature and thus leave a record in the fossil record.

C4 photosynthesis evolved at least 12-20 different times in separate plant lineages.

Grasses today comprise 40% of the Earth's vegetative surface cover.

**(3) Grasses are more difficult for herbivores to eat than other plants.** Grasses have a higher abundance of silica phytoliths in their plant tissues and cells than other plants, which cause abrasive wear on teeth.

**C4 grasses account for over 50% of the world's present-day species of grass**.

**C4 grasses have considerably higher amounts of silica protoliths than C3 grasses**.

When and why do grasslands first evolve?

Large-scale climactic drying and cooling occurred on both global and regional scales in the Oligocene (20-30 million years ago). **Increased aridity, as well as changes in precipitation caused plants to evolve to take advantage of new climates**. Fragmenting forests enabled the spread of open savannas and grasslands.

Why did the C4 pathway evolve?

At the same time we see rise in C4 plants in the fossil record, we see a decline in the abundance of water-loving species like palms.

**C4 plants can better tolerate cooler, drier climates.**

Why did C4 grasses become dominant?

Today, **74% of grass communities in the North American Great Plains contain greater than fifty-percent C4 grasses**. That percentage is even higher (40-80%) in Kansas and Nebraska.

C4 grasses first appear in the fossil record 20 million years ago. Not until over 15 million years later do C4 grasses become dominant (comprising over 50% of grassland composition).

Note: **The first grasslands were dominated by C3 grasses.** Climate changes favored the expansion of C4 grasses *after* grasslands had developed and spread 15 million years earlier. At their rise to dominance 3 million years ago, it is believed that C4 grasses mainly replaced C3 grasses in existing grasslands.

Environmental change is a major driver in ecosystem composition. The paleontological record records the expansion and eventual ecological dominance of C4 grasses in the Great Plains of North America.

# Teacher Background: Climate and Ecosystem Change

**Paleoclimatology:** The study of how Earth's climate has changed in the past. Scientists study a variety of fossil evidence to give clues to the past climate: changes in fossil plankton preserved in seafloor sediments, fossil pollen records in lakes, the chemistry of oxygen and carbon isotopes in ice cores.

The **terrestrial fossil record** preserves information about the behavior and adaptations of now extinct animals in Earth's past. Oftentimes, contextual information derived from the **geologic rock record** is as important in providing information as classifying and describing fossilized specimens. **Modern paleontology** relies heavily on tracing the chemistry of elements such as carbon and oxygen preserved in fossil bones, teeth and sediments.

**Paleontologists** study the fossil record to understand the diversity of life that existed on our planet in the past, and how that diversity has changed over time due to changing climates and environments.

## Timeline of Climate and Ecosystem Changes (30 Million Years to Present)

*Teacher Note: The following list of information was compiled directly from primary scientific literature, to give a sense of the types of evidence used by paleontologists to make hypotheses about the past.*

32-30 Ma (early Oligocene): C4 pathway first developed (originating at least 12- 20 different times in various plant families), perhaps as a result of fluctuations in atmospheric $CO_2$. (Christin et al. 2008, Edwards and Smith 2010)

23 Ma (late Oligocene): Grasslands dominated by C3 grasses spread. C4 grasses comprised ~10-20% of grassland composition. (Evidence of carbon isotopes measured in soil carbonates, Fox and Koch 2003, 2004)

19 Ma (early Miocene): C4 grasses present in early grasslands in the Great Plains. (Evidence from diagnostic phytolith morphology, Stromberg 2005)

15-5 Ma (mid-late Miocene): Plant fossil record shows habitats in North America varied in openness. (Stromberg 2011)

10 Ma: Hoofed mammals (ungulates) show tooth morphology specific to grazing adaptations. (Gordon, Prins 2007).

7 million years ago: grasslands shifted from being dominated by C3 to C4 grasses (McFadden 2005)

8-2 Ma (Late Miocene/early Pliocene): The ecological dominance of grasslands and savannas (>50% ? of habitats) in Great Plains of North America. Habitats became more uniformly open (grasslands/savannas). Stromberg et al. argues that this C4 expansion comes at the expense of C3 *grasses* not necessarily trees and shrubs. Evidence from phytoliths records a shift in the *type* of grasses present but not necessarily the relative size of *grassland habitat*. (Carbon isotopes phytoliths from NE and KA, Stromberg 2011)

3 Ma (Pliocene): Carbon isotopes in fossil soil carbonates record the abundance of C4 plants greater than 40%. (Fox and Koch 2003, 2004)

0 Ma (Present day): 74% of grasslands are dominated by greater than 50% C4 grasses, with higher percentage (40-80%) in the prairies of NE and KA. (Gibson 2009)

Provide an example of an **herbivore**, **carnivore** and **omnivore** that lives in the Great Plains of North America (can be living, or extinct):

What is **hypsodonty?** List 3 mammals that have hypsodont dentition and aspects of their diet that correspond with needing such specialized teeth.

What is the difference between a **savanna** and a **prairie**? Which is characteristic of the North American Great Plains?

Are **shrubs** and plants short in height more common in open grasslands or wooded forests? How might a diet of these short plants affect tooth wear in herbivores?

Why might **silica phytoliths** be better preserved in the fossil record than blades of grass or leaves?

Provide an example (excluding what was learned about mammalian teeth) of how an organisms' **morphology** reflects evolutionary pressures as a result of changes in its environment.

What is the difference between **browsing** and **grazing** (food type, eating habit)?

When did **grasslands** first become an important ecosystem in North America- in the past 20,000 years or 20 million years? What global climate changes influenced the development of these new landscapes?

Pronghorns are an example of a hoofed mammal native to the North American Great Plains. Pronghorns have **highly hypsodont** teeth but only 12% of their diet consists of grasses. Why might this be the case?

Teacher Answer Key to Student Worksheet

Provide an example of an **herbivore**, carnivore and omnivore that lives in the Great Plains of North America (can be living or extinct):

Herbivores: bison, cattle, pronghorn/antelope, horses, etc.; Carnivores: ferrets, coyotes, foxes, etc.; Omnivores: bears, porcupines, etc. Examples of species now extinct-- mammoth, mastodon, ancestral horses-- are also valid.

What is **hypsodonty?** List 3 mammals that have hypsodont dentition and aspects of their diet that correspond with needing such specialized teeth.

Hypsodont teeth = high crowned molars. Hypsodonty evolved convergently in many different classes of land mammals during the Cenozoic in response to changes in the dominant environment and landscape type in North America. Hyspodont dentition evolved in rodents (voles, guinea pigs, mice, rats, beaver), hoofed mammals (camels, horses, rhinos), lagomorphs (rabbits). The morphology of a hypsodont tooth is suited to a more abrasive diet.

What is the difference between a **savanna** and a **prairie**? Which is characteristic of the North American Great Plains?

Both prairies and savannas are grasslands: dominated by grass and low-lying vegetation (as compared to forests).

The primary distinction between a prairie and a savanna is the climate. Savannas, or tropical grasslands, cover almost half of the African continent and prefer warm or hot climates. Prairies, or temperate grasslands, prefer temperatures that vary from summer to winter. Prairies need less rainfall than savannas. Today the grasslands of the North American Great Plains are prairies.

Are **shrubs** and plants short in height more common in open grasslands or wooded forests? How might this affect tooth wear in herbivores?

Grasslands (prairies and savannas) are characterized by low-lying vegetation. Shrubs are short bushy plants common in grasslands. Herbivores eating grasses, shrubs or other low-lying plants in open landscapes are more likely to ingest abrasive particular matter (grit such as dirt, sand, and/or silica protoliths more common in grasses) which would cause increased wear on their teeth. For more information, see material produced by Caroline Stromberg. http://depts.washington.edu/strmbrgl/StrombergLab_website/R_grasslands.html

Why might **silica phytoliths** be better preserved in the fossil record than blades of grass or leaves?

Phytolith comes from the Greek "plant-stone"; silica phytoliths are rigid, microscopic structures in plant cells and tissues that are used for structural support. Because of their hard nature, they often persist after the decay of the plant. When plant tissues decompose, silica phytoliths remain in the soil and can be well preserved in the fossil record. For more information: http://depts.washington.edu/strmbrgl/StrombergLab_website/Phytoliths.html .

Provide an example (excluding what was learned about mammalian teeth) of how an organisms' **dental morphology** reflect a specific diet.

Open ended question. Examples include: rodents and rabbits exhibit 'hypselodonty' (ever-growing teeth)

What is the difference between **browsing** and **grazing** (food type, eating habit)?

In herbivorous mammals, animals adopt a browsing or grazing lifestyle depending on their diet and habitat/available vegetation types. Grazers primarily graze on grass; browsers browse woody twigs and leaves from trees and shrubs.

There are fundamental differences in the plant structure between the types of vegetation consumed by browsers and grazers. Grasses tend to have thicker cell walls made of more slowly-digestible fibers (cellulose). Browsers feed on the leaves and stems of trees and shrubs, which tend to have thin cell walls and comprised of cell components such as lipids, proteins, and sugars that are more easily digestible than grass.

Along with changes in teeth, grass-eaters (grazers) have evolved a specialized gut for digesting grass.

Carnivores, by way of comparison, tend to have a more simple digestive track, teeth built for tearing but not chewing, and rapid passage of material through the digestive system. An example of the tradeoffs of eating plants (high in fiber, difficult to digest) vs. eating meat (high protein, quickly digestible)!

For more information, visit: http://synapsida.blogspot.com/2011/12/grazers-and-browsers-and-how-to-tell.html

When did grasslands first become an important ecosystem in North America- in the past 20,000 years or 20 million years? What global climate changes influenced the development of these new landscapes?

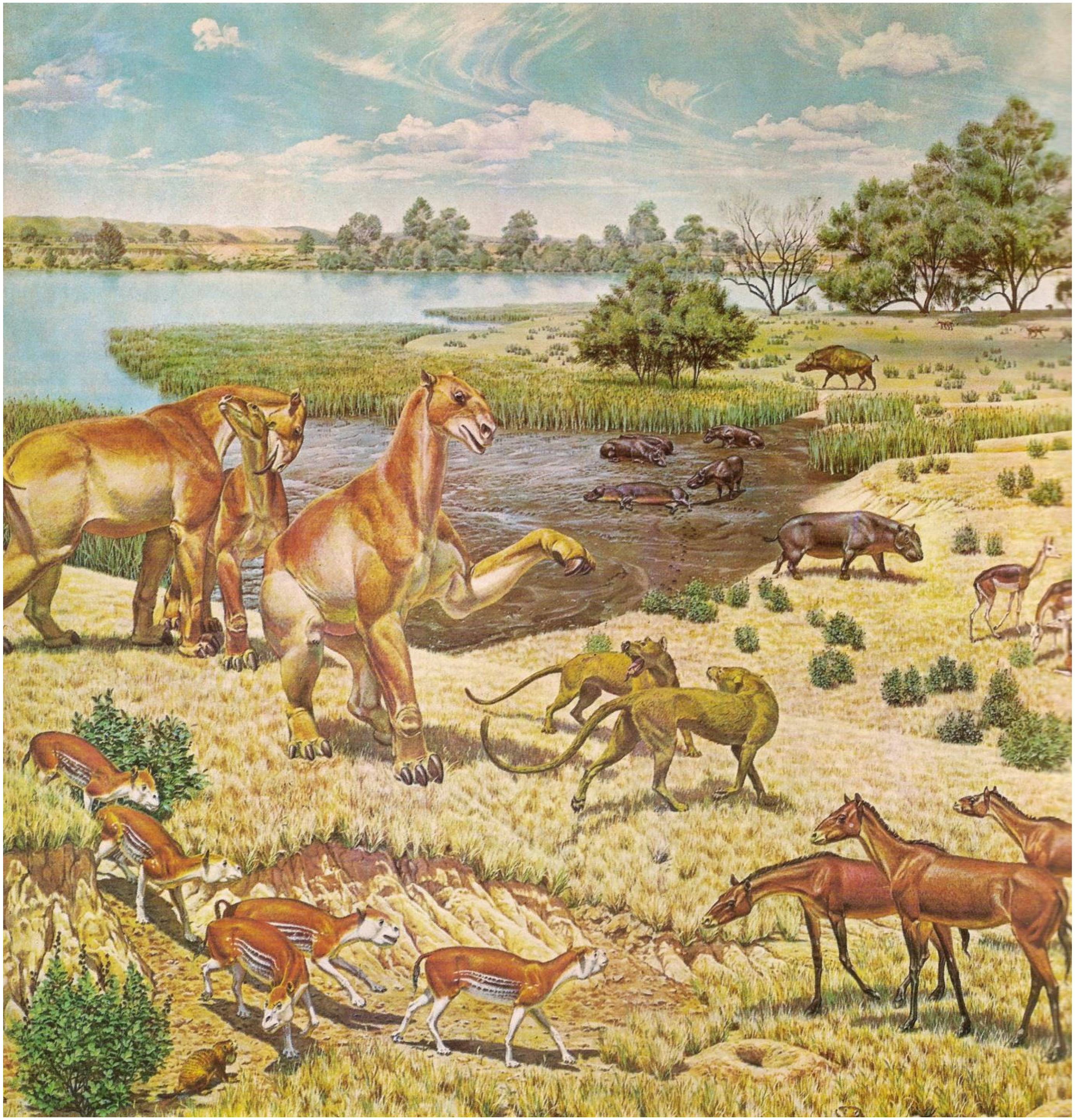
Globally, large scale climactic cooling fragmented tropical forests and reduced tropical species, opening the landscape for dominance by grasslands 20 million years ago. Plants which used the C4 photosynthesis pathway are better adapted to drier climate and became more dominant in grasslands starting 8-5 million years ago. Today over 50% of grasses use C4 photosynthesis.

Pronghorns are an example of a hoofed mammal native to the North American Great Plains. Pronghorns have **highly hypsodont** teeth but only 12% of their diet consists of grasses. Why might this be the case?

Pronghorns consume large amounts of grit and soil by feeding in open prairies on low-lying shrubs and grasses that grow close to the ground.

(Extra Note: Pronghorns (the American antelope) are an example of a ‘relict’ species of megafauna native to the North American Great Plains. The North American pronghorn is one of the fastest species in the world, but today they lack their predatory counterpart, the extinct North American cheetah. The pronghorn is an example of a species which exhibits ‘relict’ evolutionary pressure.)

# After the demise of the dinosaurs…



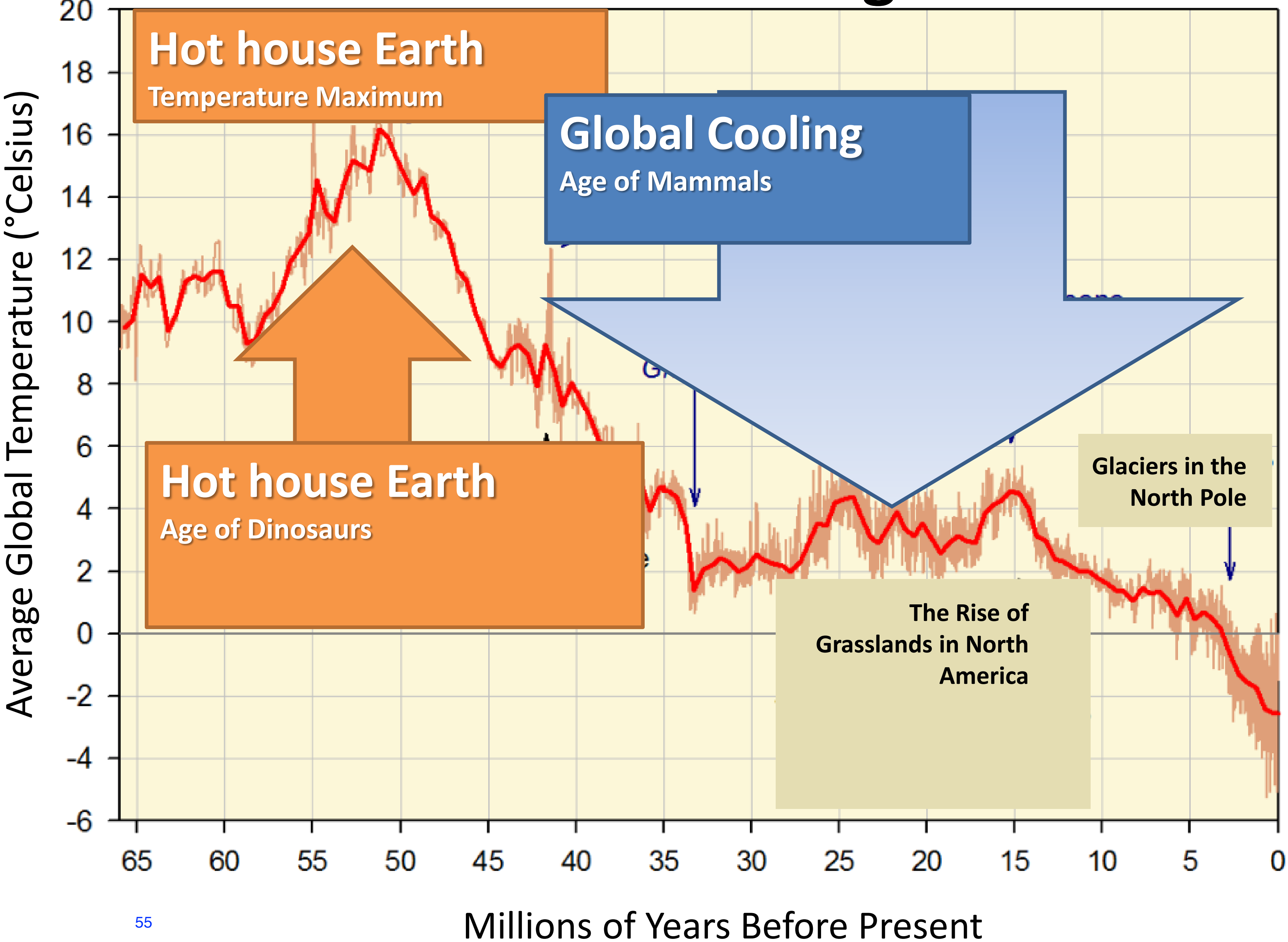
"Miocene" by Jay Matternes; mural for the Smithsonian Museum, 1964. - Scan from the Time-Life book "North America".


Usher in…

# The Age of Mammals

What critters evolved to live in the new climates of North America, 20 million years ago?

# BIG Climate Changes.



Cooler and Dryer Climates led to:

# The Rise of Grasslands

Grassland in Kansas

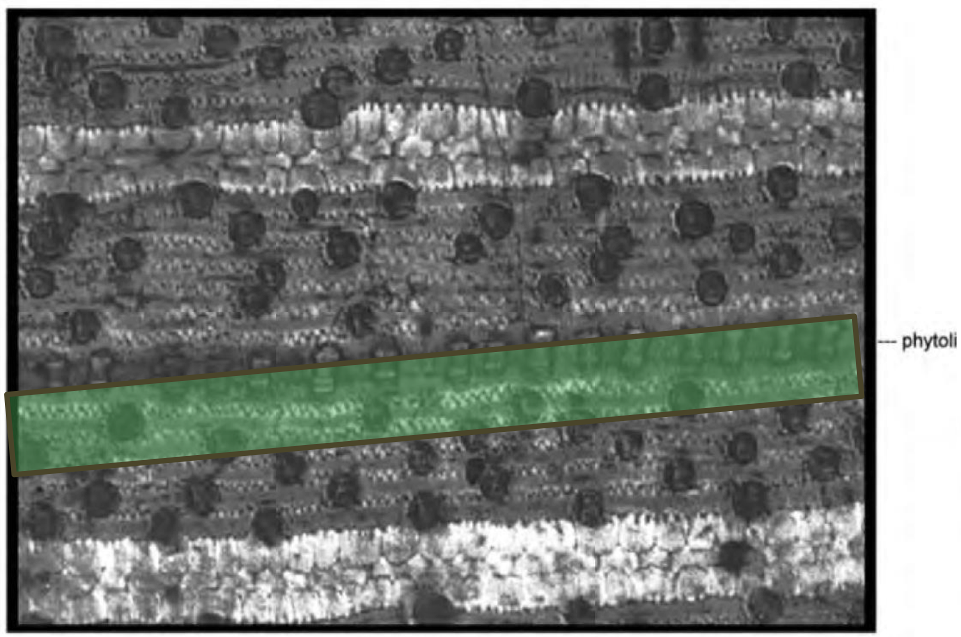
# Grasses are abrasive on teeth.

**Grasses contain microscopic structures made of silica called 'silica phytoliths'.**

"Phytolith" comes from Greek, meaning "plant stone"

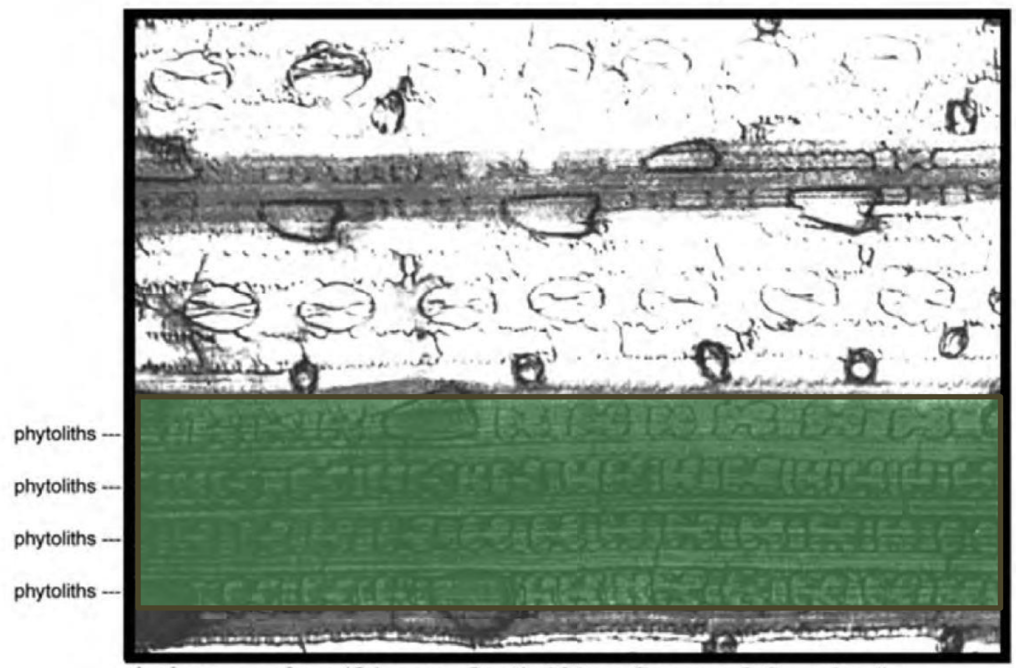
Different types of grasses have large amounts of silica phytoliths.

## C3 Grasses



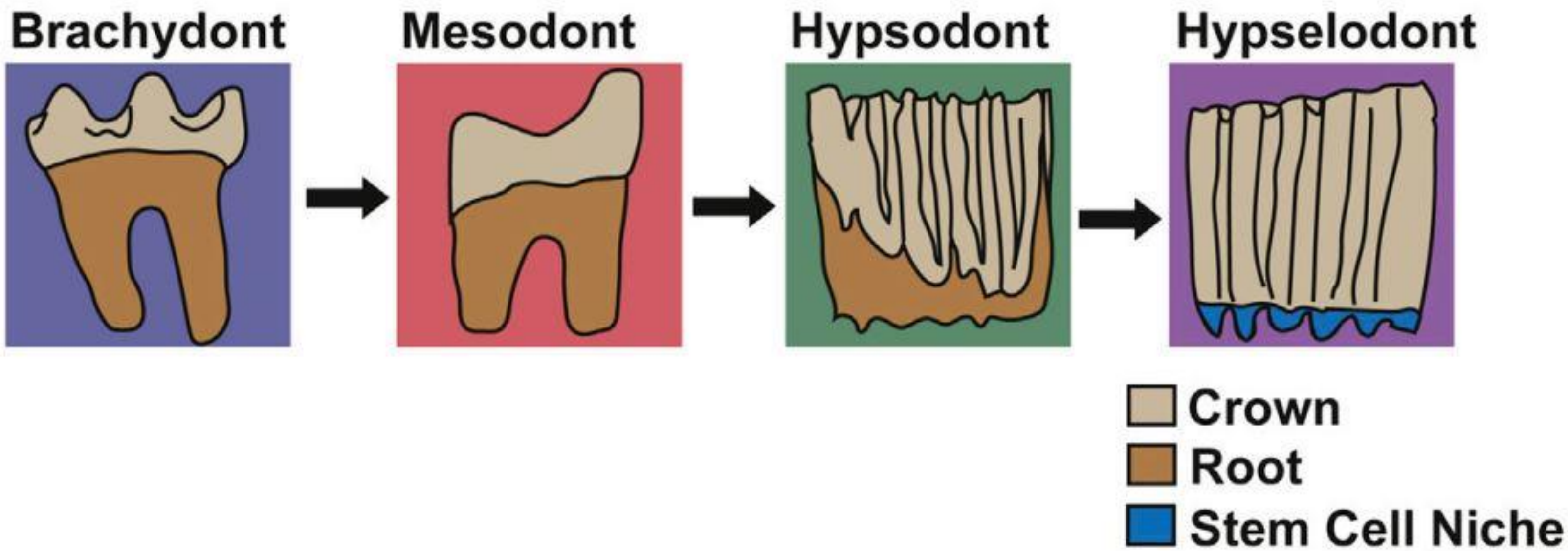

*Oxytenanthera abyssinica* (C3 grass, South African Savanna)

## C4 Grasses




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

# Tooth Height: High-crowned vs. Low-Crowned



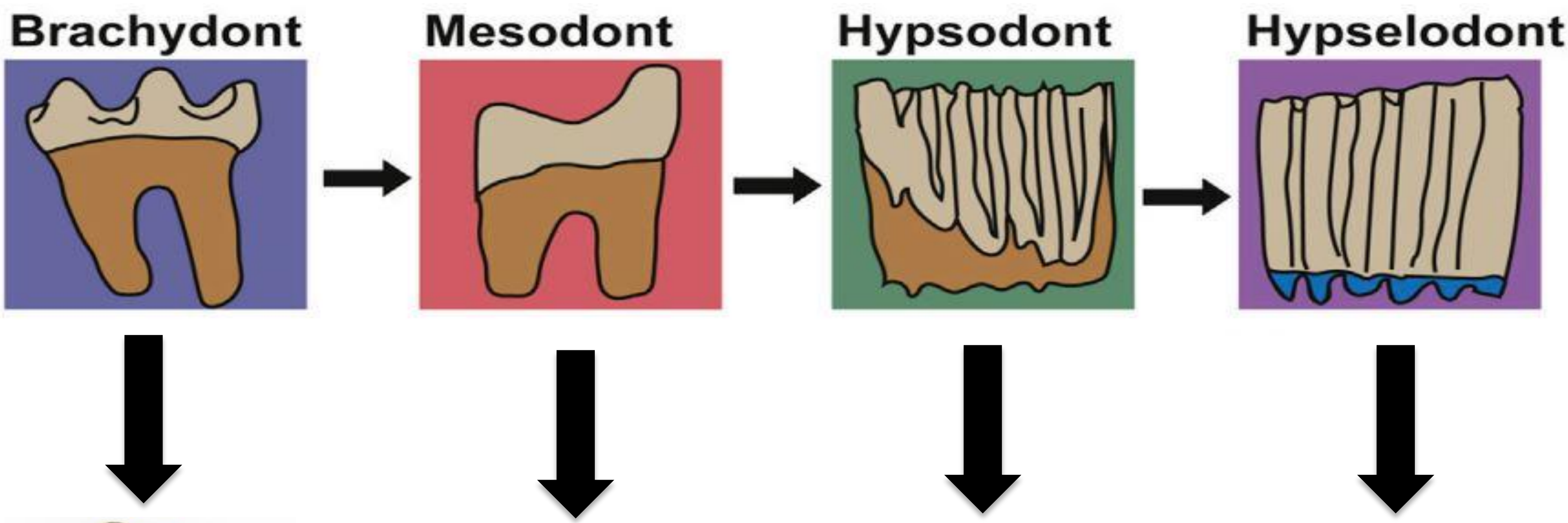

Hypsodont (high-crowned) molars are adapted from lower-crowned teeth.

Higher-crowned teeth are adapted for a diet of more abrasive material, such as grit and grass.

Image source: http://www.cell.com/cell-reports/pdf/S2211-1247(15)00355-1.pdf
Tapaltsyan et al. 2015. Continuously Growing Roden Molars Result from a Predicable Quantitative Evolutionary Change over 50 Million years. Cell Reports *11,* 673-680.

# Tooth morphology (shape) reflects diet.

Higher-crowned teeth are adapted for more abrasive wear.



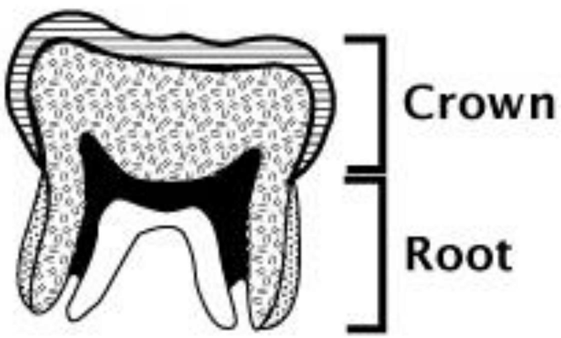

**Canids (dogs)**

**Some rodents**

**Grass-eaters: Camels, horses, rhinos**

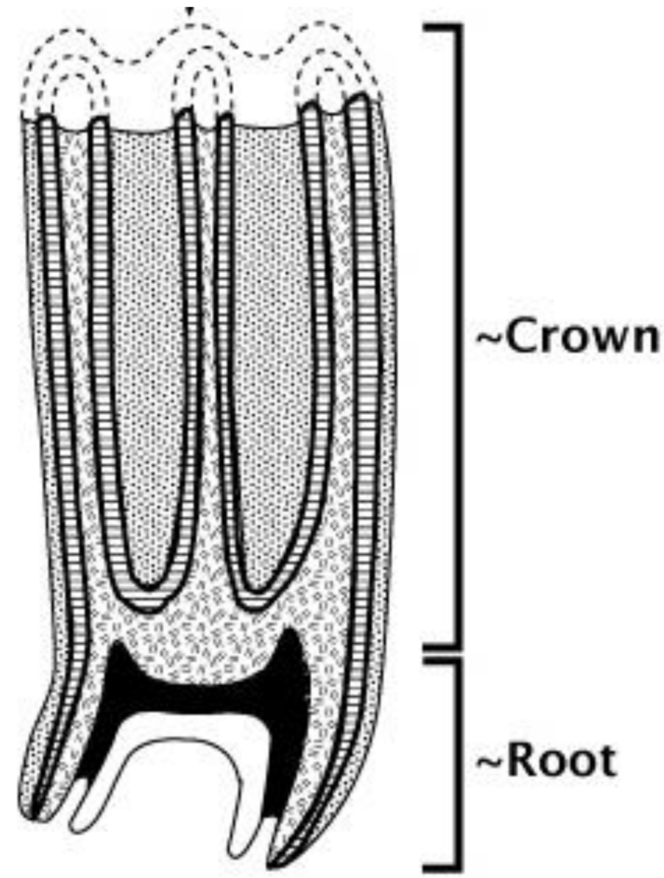
**Ever-growing teeth: Rodents, rabbits**

# Tooth Height: Browsing vs. Grazing




**LOW-CROWNED**

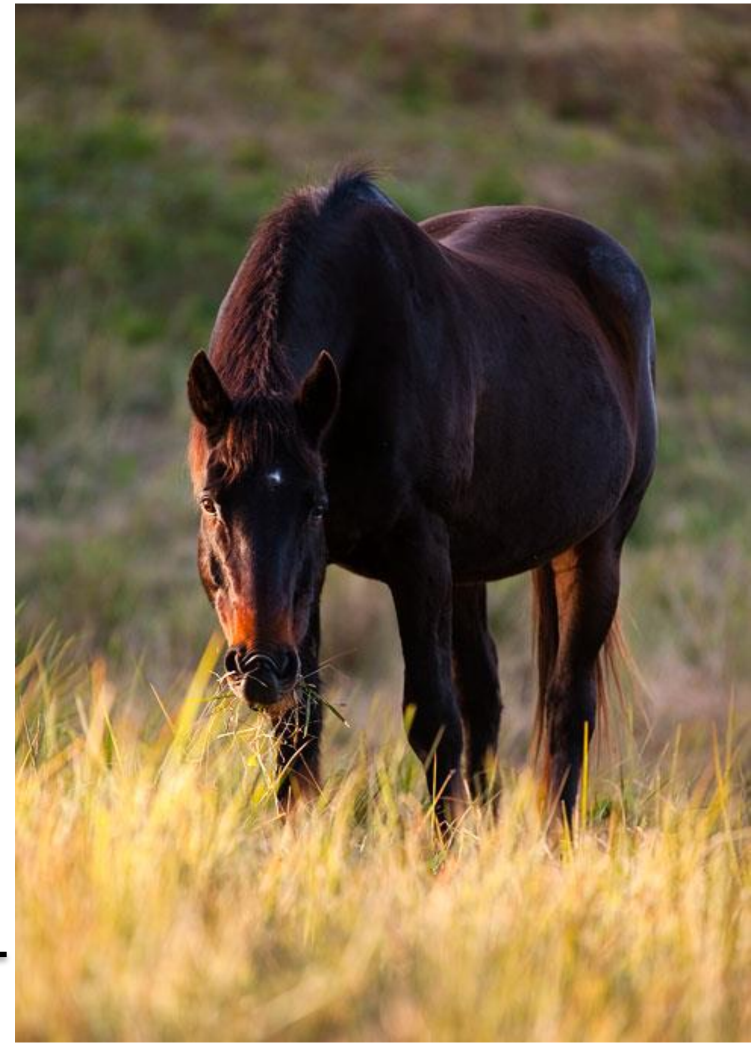
Good for Leaves, stems, nuts, seeds, berries.




**HIGH-CROWNED**

Good for grass.

# Adaptations: Browsing vs. Grazing



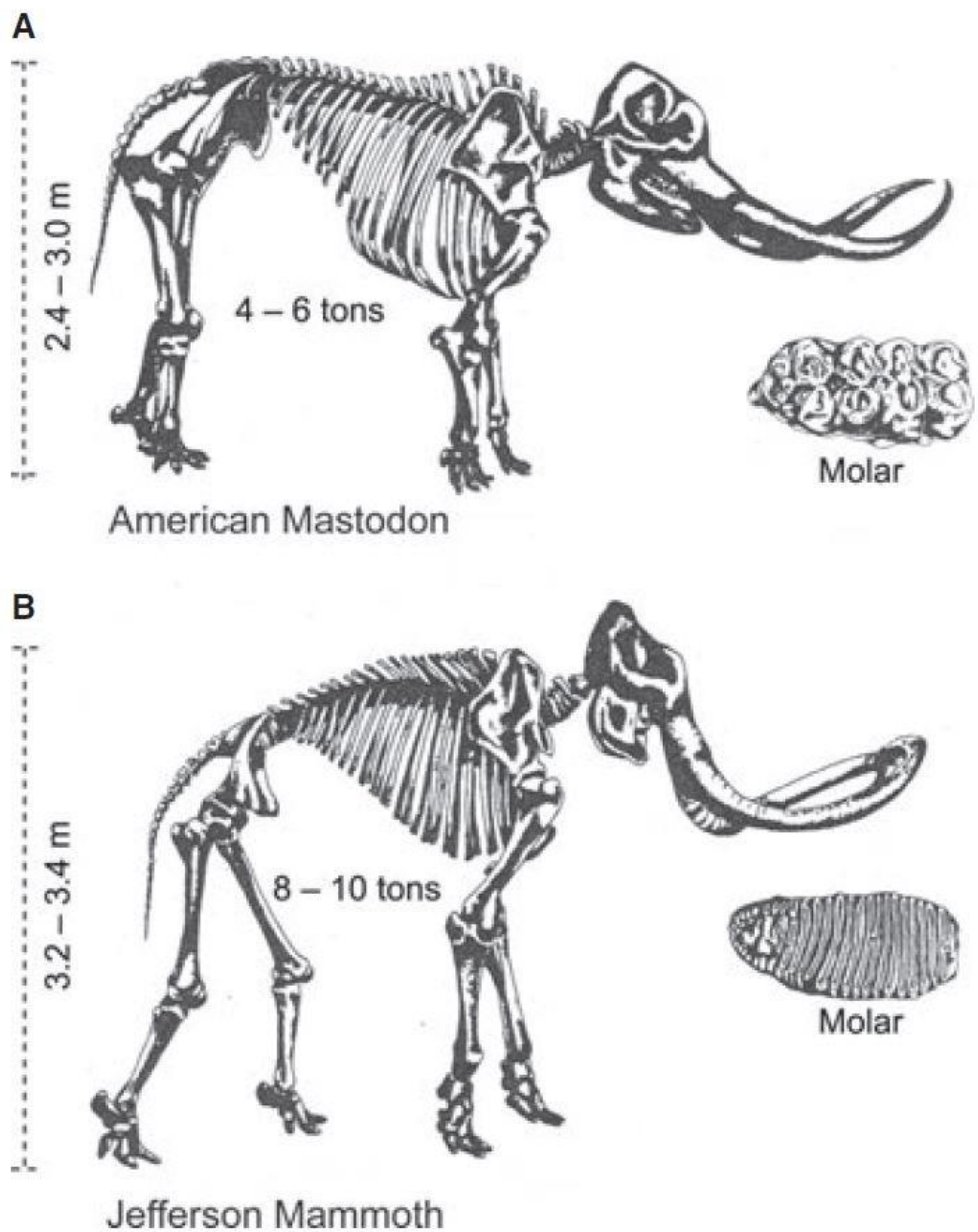
**LOW-CROWNED TEETH**

**Browsing:**
Leaves, woody twigs, branches, seeds and fruits.

**HIGH-CROWNED TEETH**

**Grazing:**
Grasses high in silica.

# Adaptations: Browsing vs. Grazing




Mastodon
(browser)

vs.

Mammoth
(grazer)

# Assessment: Matching.

Match the following term to the correct definition, and then provide an example of tooth change.

An example is provided.

| *Evolutionary Concept* | *Definition* | *Example*. |
|---|---|---|
| **Morphology** | Genetic changes in a species in response to evolutionary and environmental pressures. | *Browsers and grazers exhibit different tooth morphology depending on diet*. |
| **Adaptation** | The process by which a single species evolves into separate species. | |
| **Evolution** | The independent evolution of similar structures or features in species of different lineages. | |
| **Convergent Evolution** | The change in genetic traits of biological populations over successive generations. | |
| **Divergent Evolution** | The form and structure of certain features of an organism. | |

# Assessment. Answer 2 out of 3.

Why might **silica phytoliths** be better preserved in the fossil record than blades of grass or leaves?

When did **grasslands** first become an important ecosystem in North America- in the past 20,000 years or 20 million years? What global climate changes influenced the development of these new landscapes?

Pronghorns are an example of a hoofed mammal native to the North American Great Plains. Pronghorns have **highly hypsodont** teeth but only 12% of their diet consists of grasses. Why might this be the case?

# Assessment Activity: Timeline

Instructions: place events correctly sequenced on the timeline.

| 40 Ma | 30 Ma | 20 Ma | 10 Ma | Present Day |
| --- | --- | --- | --- | --- |

First appearance of C4 grasses in the fossil record (10-20 % of grassland composition).

Grasslands are dominated by C4 grasses, representing over 50% of grass species.

Grasslands represent over 50% of habitat composition in the Great Plains of North America.

First appearance of high-crowned teeth in ancestral horses in the Great Plains of North America.

High-crowned teeth become the dominant tooth type in large land mammals in North America (reprensenting >50% of tooth types measured in the fossil tooth study).

## Critical Thinking: Answer one out of the three.

Respond to the following sample arguments for or against the GRASS OR GRIT hypothesis.

Changes in tooth morphology favoring hypsodonty occur NOT ONLY in horses, but other species (such as rodents) that are not only eating grass. Is it accurate to say that changes in tooth morphology cannot be confined solely to grass?

How does the timing and spread of C4 grasses differ from that of the spread of open areas? How might this affect the evolution of mammals adapting to grassland environments?

What might affect the spread of grassland environments, and favor certain types of grasses over others? (C4 and C3 grasses)

# Assessment: Matching.

Match the following term to the correct definition, and then provide an example of tooth change.

An example is provided.

| *Evolutionary Concept* | *Definition* | *Example.* |
|---|---|---|
| **Morphology** | Genetic changes in a species in response to evolutionary and environmental pressures. | Browsers and grazers exhibit different tooth morphology depending on diet. |
| **Adaptation** | The process by which a single species evolves into separate species. | Land mammals adapting to new open grassland habitats evolved specific morphological traits such as specialized teeth to deal with new diets. |
| **Evolution** | The independent evolution of similar structures or features in species of different lineages. | Many different species of land mammals evolved to match new open grassland habitats. |
| **Convergent Evolution** | The change in genetic traits of biological populations over successive generations. | Teeth with high-crowned molars (hypsodont dentition) evolved independently in rodents, rabbits and horses (all are different types of mammals). |
| **Divergent Evolution** | The form and structure of certain features of an organism. | Land mammals living in open grassland habitats evolved distinct morphological features to support a lifestyle of grazing grass different from other species evolved to live in forests. |

# Assessment. Answer 2 out of 3.

Why might **silica phytoliths** be better preserved in the fossil record than blades of grass or leaves?

Phytolith comes from the Greek "plant-stone"; silica phytoliths are rigid, microscopic structures in plant cells and tissues that are used for structural support. Because of their hard nature, they often persist after the decay of the plant. When plant tissues decompose, silica phytoliths remain in the soil and can be well preserved in the fossil record. For more information: http://depts.washington.edu/strmbrgl/StrombergLab_website/Phytoliths.html .

When did **grasslands** first become an important ecosystem in North America- in the past 20,000 years or 20 million years? What global climate changes influenced the development of these new landscapes?

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Globally, large scale climactic cooling fragmented tropical forests and reduced tropical species, opening the landscape for dominance by grasslands 20 million years ago. Plants which used the C4 photosynthesis pathway are better adapted to drier climate and became more dominant in grasslands starting 8-5 million years ago. Today over 50% of grasses use C4 photosynthesis.

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(Extra Note: Pronghorns (the American antelope) are an example of a 'relict' species of megafauna native to the North American Great Plains. The North American pronghorn is one of the fastest species in the world, but today they lack their predatory counterpart, the extinct North American cheetah. The pronghorn is an example of a species which exhibits 'relict' evolutionary pressure.)

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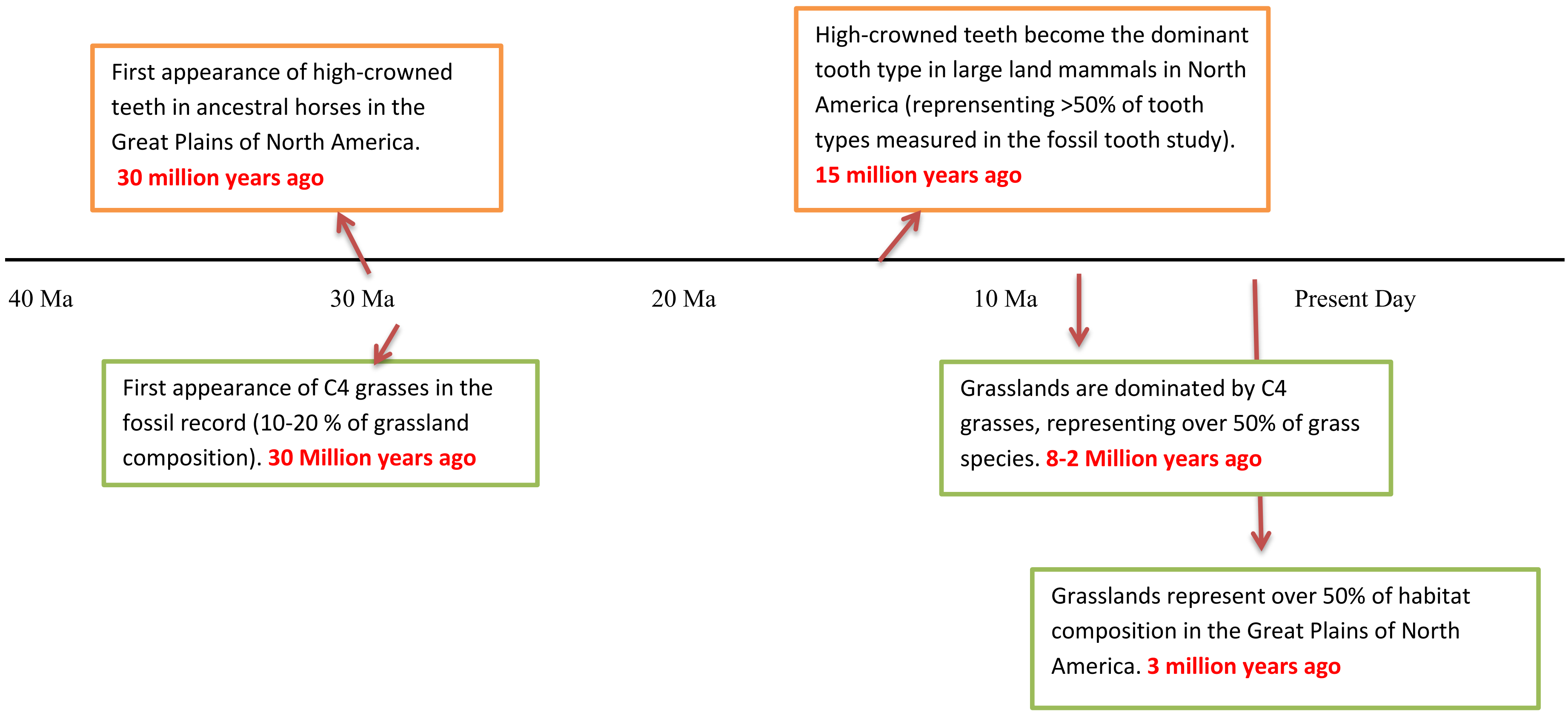

## Critical Thinking: Answer one out of the three.

Respond to the following sample arguments for or against the GRASS OR GRIT hypothesis.

Changes in tooth morphology favoring hypsodonty occur NOT ONLY in horses, but other species (such as rodents) that are not only eating grass. Is it accurate to say that changes in tooth morphology cannot be confined solely to grass?

Changes in tooth types in other mammals who are not restricted just to eating grass suggest that high-crowned teeth developed for different reasons, perhaps due to the ingestion of more grit in small shrubs and grasses that were being consumed in open areas.

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How does the timing and spread of C4 grasses differ from that of the spread of open areas? How might this affect the evolution of mammals adapting to grassland environments?

The spread of open areas (seen in the reduced land area for forests and reduction in warm tropical species such as palms) occurs much earlier than the dominance of grasslands by C4 grasses.

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What might affect the spread of grassland environments, and favor certain types of grasses over others? (C4 and C3 grasses)

Changing climates and changes in the levels of carbon dioxide in the air may have caused plants to evolve specific adaptations such as the C4 photosynthetic pathway.

# Student Survey: Lesson Feedback

School: ____________ Class and Period: _________________ Grade: _____ Teacher: _____________

| | Low | Medium | High | Comments |
|---|---|---|---|---|
| **Was the amount of background information provided for each activity sufficient?** | ☐ | ☐ | ☐ | ____________________ |
| **Were you provided enough time to perform the activity?** | ☐ | ☐ | ☐ | ____________________ |
| **Are the illustrations/charts/graphs helpful?** | ☐ | ☐ | ☐ | ____________________ |
| **Do the review questions on each worksheet help clarify your thinking?** | ☐ | ☐ | ☐ | ____________________ |

1. How relevant was this lesson to what you are learning in your high school biology class?

Comments: ________________________________________________

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all relevant | | Somewhat relevant | | Highly relevant |

2. How much did this lesson shape your understanding of paleontology in the real-world?

Comments: ________________________________________________

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| No change | | Somewhat changed | | Completely changed |

3. How interested are you in learning more about paleontology and/or Earth Science?

Comments: ________________________________________________

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Not at all interested | | Somewhat interested | | Extremely interested |

4. Would you be excited to do a follow-up activity for this lesson in the future? Why?

________________________________________________

# Teacher Survey: Lesson Feedback

School: ________________ Name: ___________________________ Subjects Taught: __________________
Grades Taught: ____________ Email/Contact: _____________________________________________

**Part I: Curriculum Evaluation**

| | Low | Medium | High | Comments |
|---|---|---|---|---|
| Was the amount of background information provided for each activity sufficient, for both you and your students? | ☐ | ☐ | ☐ | |
| Are the topics addressed in line with your course objectives? | ☐ | ☐ | ☐ | |
| Are the illustrations/charts/graphs in the worksheets helpful? | ☐ | ☐ | ☐ | |
| Was the answer key provided for each activity sufficient for teaching the lesson? | ☐ | ☐ | ☐ | |
| Is the overall quality of the lesson plan satisfactory? | ☐ | ☐ | ☐ | |

**Part II: Please provide additional comments about the effectiveness and relevance of the lesson as pertaining to your curriculum objectives.**

5. Which aspects of the lesson plan did you use with your class? Which activities were most successful?

6. Did you or your students have any particular challenges with any of the lesson plan activities?

7. Are there any topics that should be added or deleted from the curriculum?

8. What modifications might you make to this lesson plan and activities before using it again?

9. Would you use this curriculum again, or recommend to other teachers? Why or why not?

Please submit survey feedback and any additional comments to the following National Park Service Unit:
Chief of Interpretation, Hagerman Fossil Beds National Monument PO Box 570, Hagerman, Idaho, 83332

# Teacher Resource

National Park Service
Department of the Interior

Hagerman Fossil Beds
National Monument

## Skulls and Teeth: Clues to diet and behavior.

How do the skulls of **mammals** reflect **adaptations** to different diets and lifestyles?

**Key Terms and Concepts:**
Adaptation, morphology, evolution, biology.

**Summary:**
Students will explore similarities and differences between the size and shape of skulls and teeth of different mammals.

**Next Generation Science Standards:**
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.

**Learning Objectives:**
- Students will learn about differences in tooth morphology that reflect diet.
- Students will work together or in groups to identify and analyze different features between mammal skulls.
- Students will compare **morphological features (differences in size and shape)** between the skulls of different mammals, and think critically about what those differences in shape might mean in terms of diet and lifestyle.

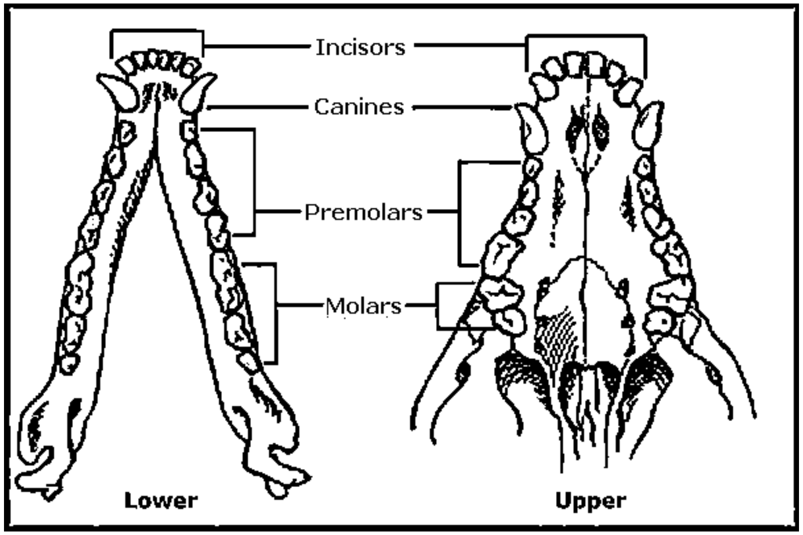
**Materials:**
The following packet includes materials for two lesson activities (total time ~45 minutes).

Examining changes in tooth morphology.

**Note for Teachers:**
The best way to teach about skull morphology is to work with real or model specimens. Students can be encouraged to look for backyard bones (with care for health and safety) to bring into the classroom. 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.

# Comparative Skulls

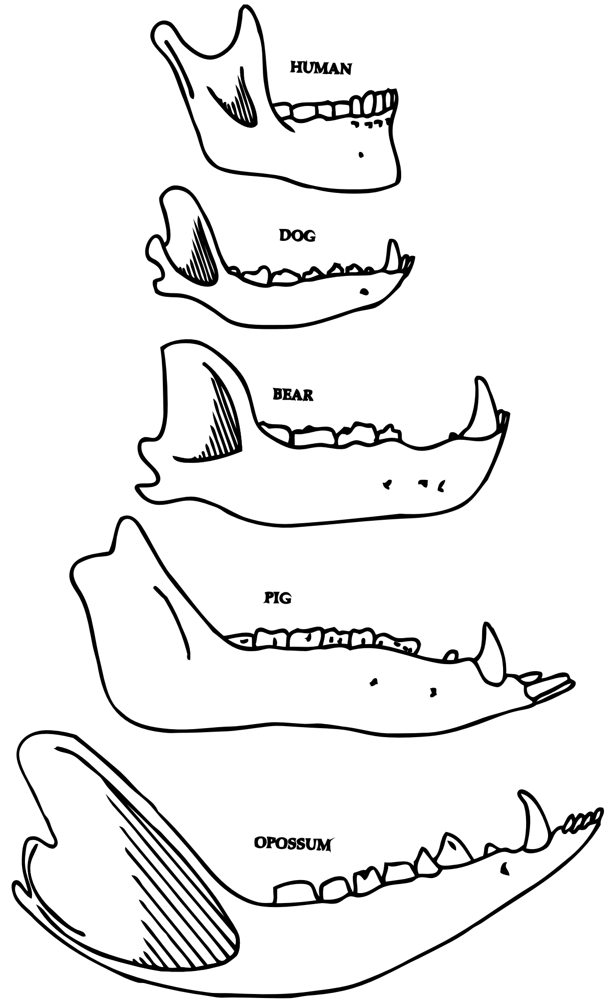
Four types of teeth: incisors, canines, premolars, molars




Each tooth type is shaped to reflect a specific function.
Match the functions with the appropriate tooth type (below).

| | |
|---|---|
| Crushing and Grinding | Incisors |
| Cutting and Breaking | Molars |
| Tearing and Ripping | Canines |

Instructions: Circle and label each of the 3 main tooth types: using I for incisors, C for canines, M for molars



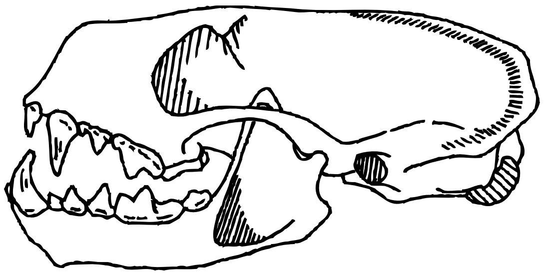

The range of omnivore jaw shapes.



Source of skull diagrams: Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals. Glenn Searfoss, 1995.

# Comparative Skulls

Omnivore, Herbivore or Carnivore? Compare the teeth of the following three mammals. Describe the most prominent diagnostic feature that supports your hypothesis. Which tooth type (incisors, canines, modified premolars, molars) are most specialized (reflecting diet)?



Omnivore, Herbivore or Carnivore? ___________________________________

Diagnostic Feature(s): ___________________________________

Hypothesized diet: ___________________________________

Animal Guess:

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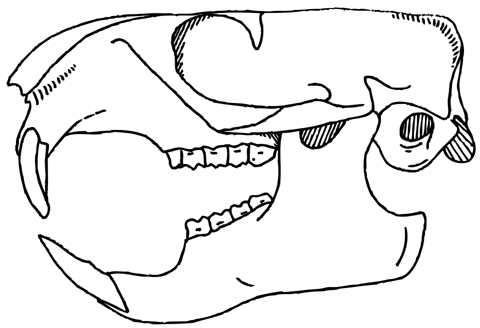

Omnivore, Herbivore or Carnivore? ___________________________________

Diagnostic Feature(s): ___________________________________

Hypothesized diet: ___________________________________

Animal Guess:

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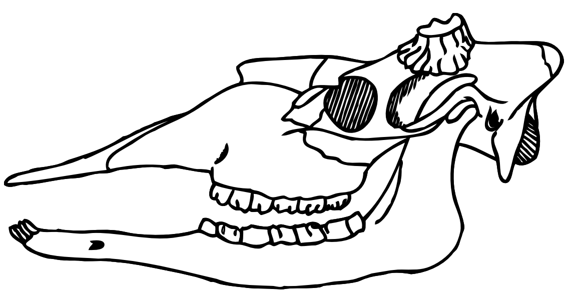


Omnivore, Herbivore or Carnivore? ___________________________________

Diagnostic Feature(s): ___________________________________

Hypothesized diet: ___________________________________

Animal Guess:

---

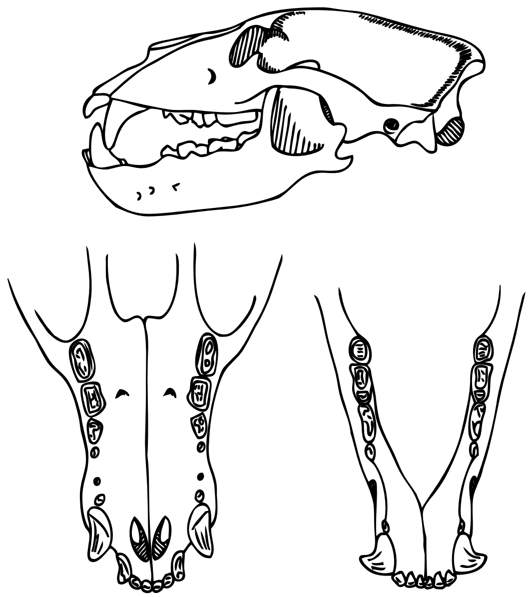


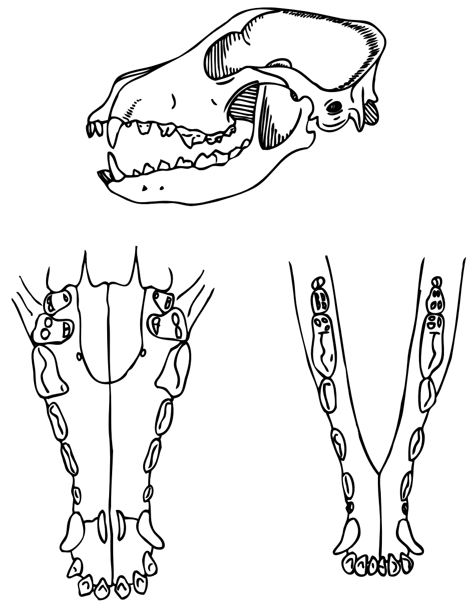
Source of skull diagrams: Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals. Glenn Searfoss, 1995.

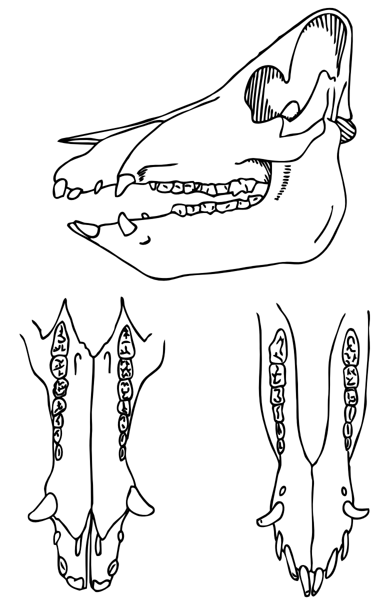
# Comparative Skulls

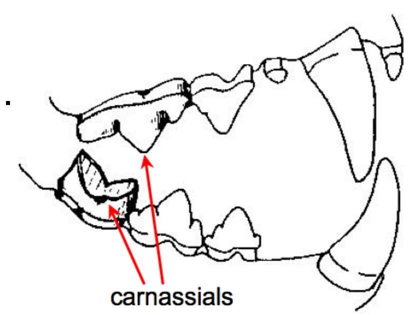
Compare the teeth of the following three omnivores. Omnivore molars have large flat surfaces for grinding food. Canines can be equal in size to other teeth or slightly larger depending on diet.

## Which skull belongs to whom? Identify the skull of the bear, dog and pig.










**Carnivores (meat eaters) have specially adapted teeth for cutting and shearing meat, called *carnassial teeth.*** Which of the three mammals uses carnassial teeth for cutting apart their prey? Carnassial teeth are especially prominent in one of the animals above. Circle the teeth.

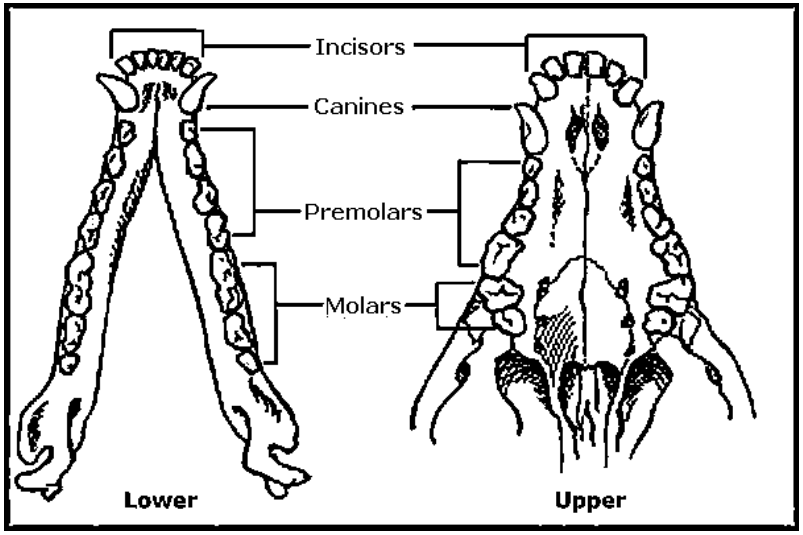
Carnassials are odified pre-molars. Elongated like scissor blades.



Source of skull diagrams: Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals. Glenn Searfoss, 1995.

# Comparative Skulls

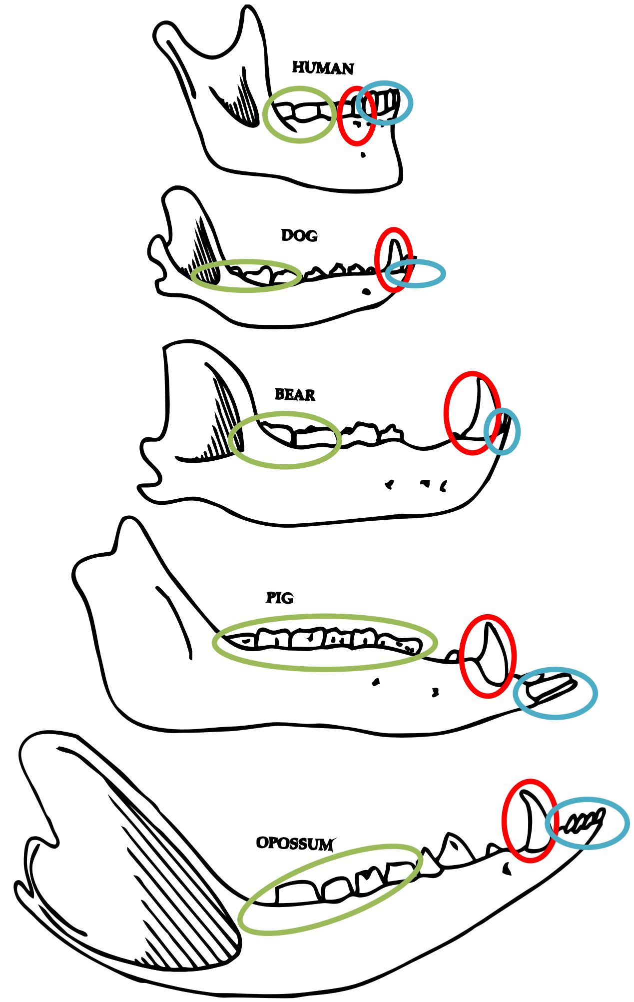
Four types of teeth: incisors, canines, premolars, molars




Each tooth type is shaped to reflect a specific function.
Match the functions with the appropriate tooth type (below).

| | |
|---|---|
| Crushing and Grinding | Incisors |
| Cutting and Breaking | Molars |
| Tearing and Ripping | Canines |

Instructions: Circle and label each of the 3 main tooth types: using I for incisors, C for canines, M for molars

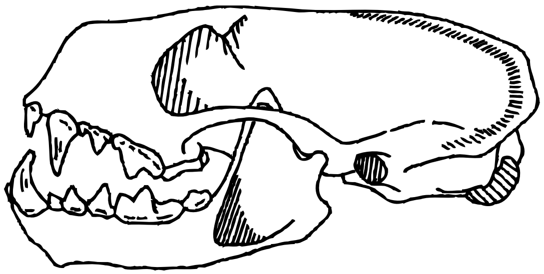



The range of omnivore jaw shapes.

Source of skull diagrams: Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals. Glenn Searfoss, 1995.

# Comparative Skulls

Omnivore, Herbivore or Carnivore? Compare the teeth of the following three mammals. Describe the most prominent diagnostic feature that supports your hypothesis. Which tooth type (incisors, canines, modified premolars, molars) are most specialized (reflecting diet)?



Omnivore, Herbivore or Carnivore? ______CARNIVORE___________________

Diagnostic Feature(s): SHARP TEETH, LARGE CANINES, JAW FOR RIPPING AND TEARING

Hypothesized diet: SMALL RODENTS, BIRDS, BERRIES, CARRION, LIZARDS, SNAKES, ETC.

Animal Guess: SKUNK

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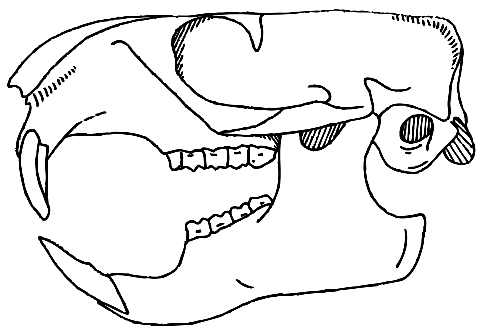

Omnivore, Herbivore or Carnivore? ______OMNIVORE____________________________

Diagnostic Feature(s): _LARGE INCISORS, NO CANINES, FLAT MOLARS FOR GRINDING

Hypothesized diet: ___WILD GRASSES, BERRIES, INSECTS, SMALL MAMMALS, NUTS_

Animal Guess: WOODCHUCK (GROUNDHOG)

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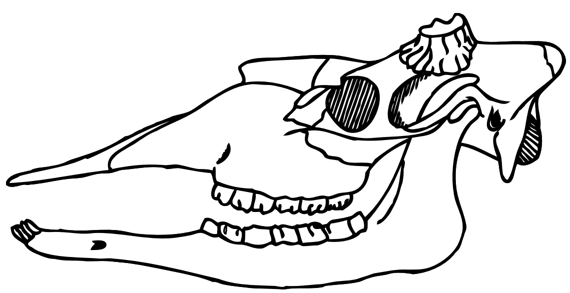

Omnivore, Herbivore or Carnivore? ____HERBIVORE (BROWSER)__________________

Diagnostic Feature(s): __NO CANINE TEETH, FLAT MOLARS FOR GRINDING_______

Hypothesized diet: WILLOW AND BIRCH SHOOTS, AQUATIC PLANTS, GRASSES, LEAVES

Animal Guess: MOOSE

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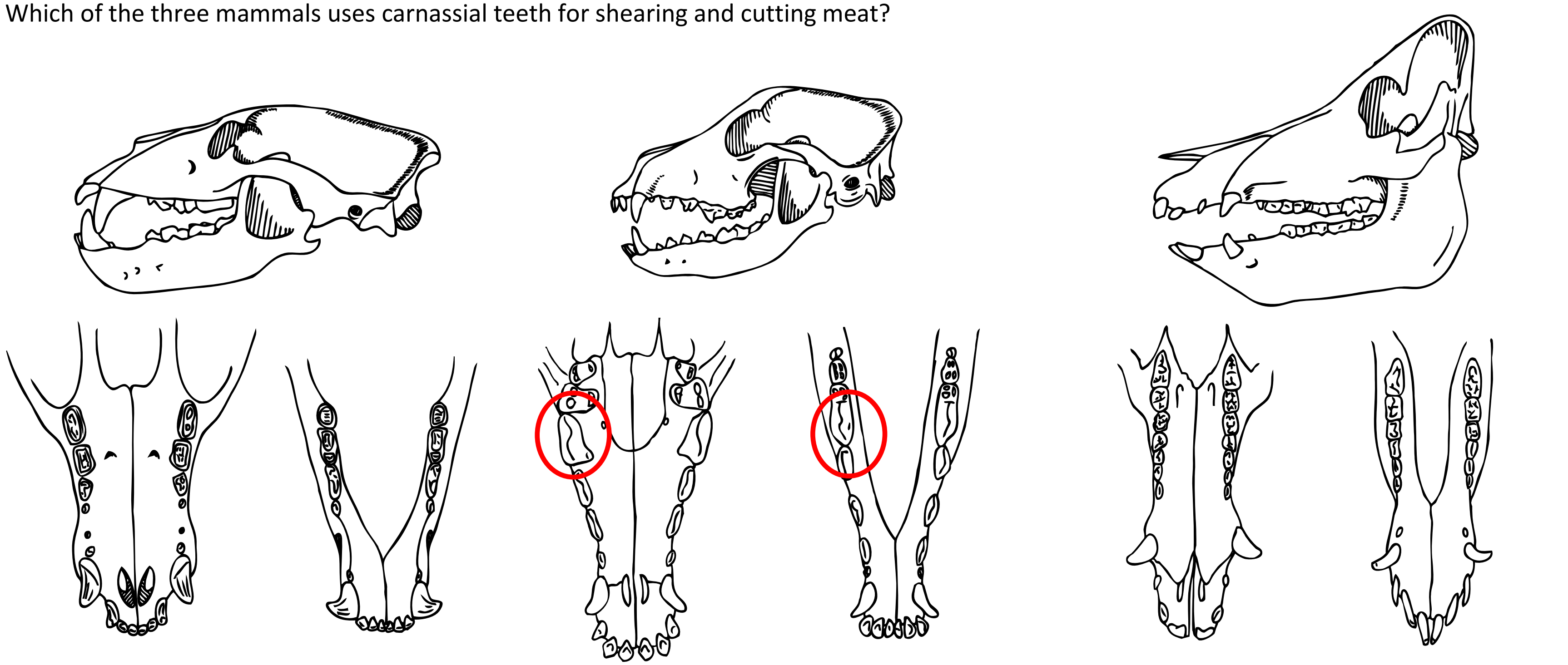
Source of skull diagrams: Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals. Glenn Searfoss, 1995.

# Comparative Skulls

Compare the teeth of the following three omnivores. Omnivore molars have large flat surfaces for grinding food. Canines can be equal in size to other teeth or slightly larger depending on diet. Note the modified premolar carnassial teeth in the dog and bear.

Which skull belongs to whom? Identify the skull of the bear, dog and pig. Circle the prominent carnassial teeth.
Which of the three mammals uses carnassial teeth for shearing and cutting meat?



**Bear** **Dog** **Pig**

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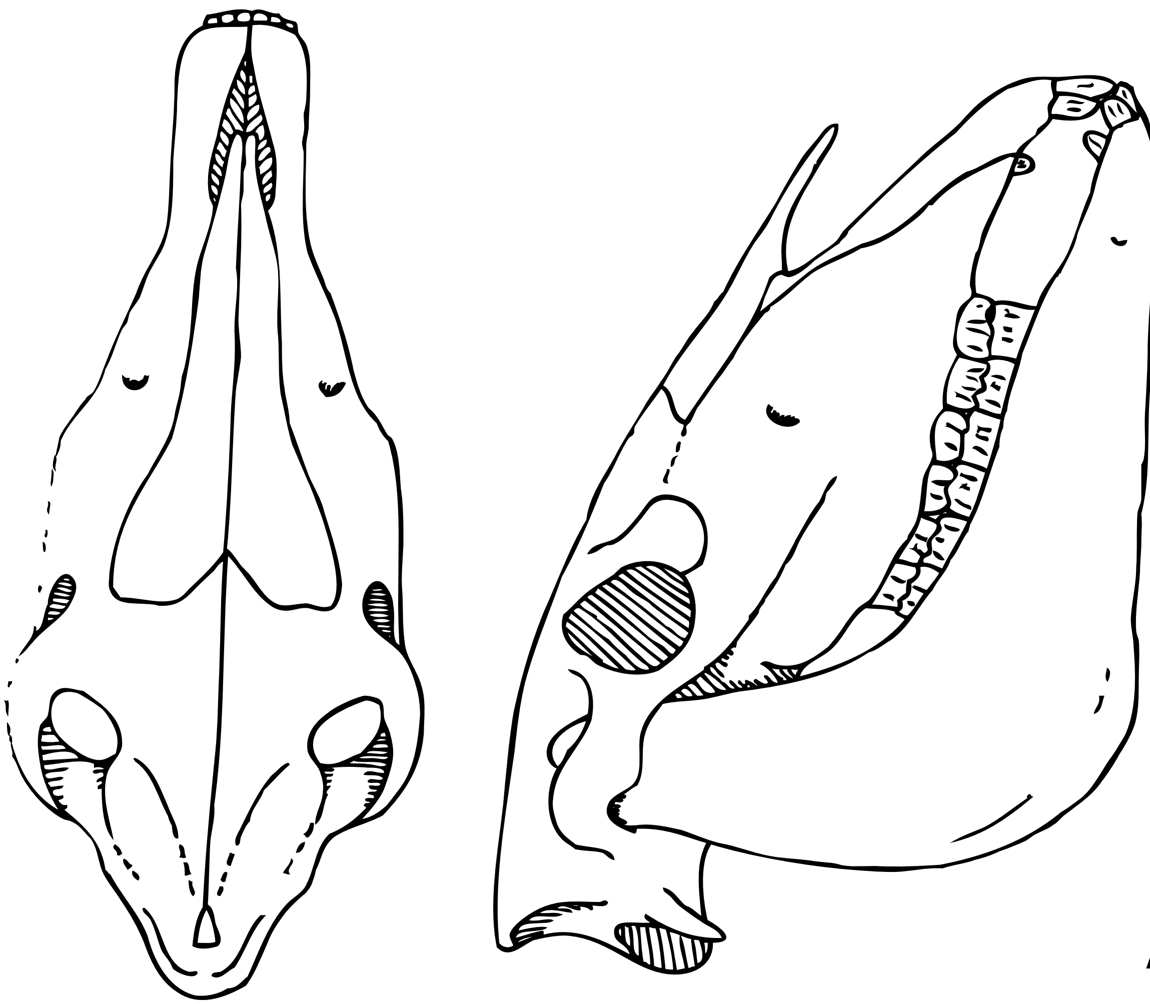
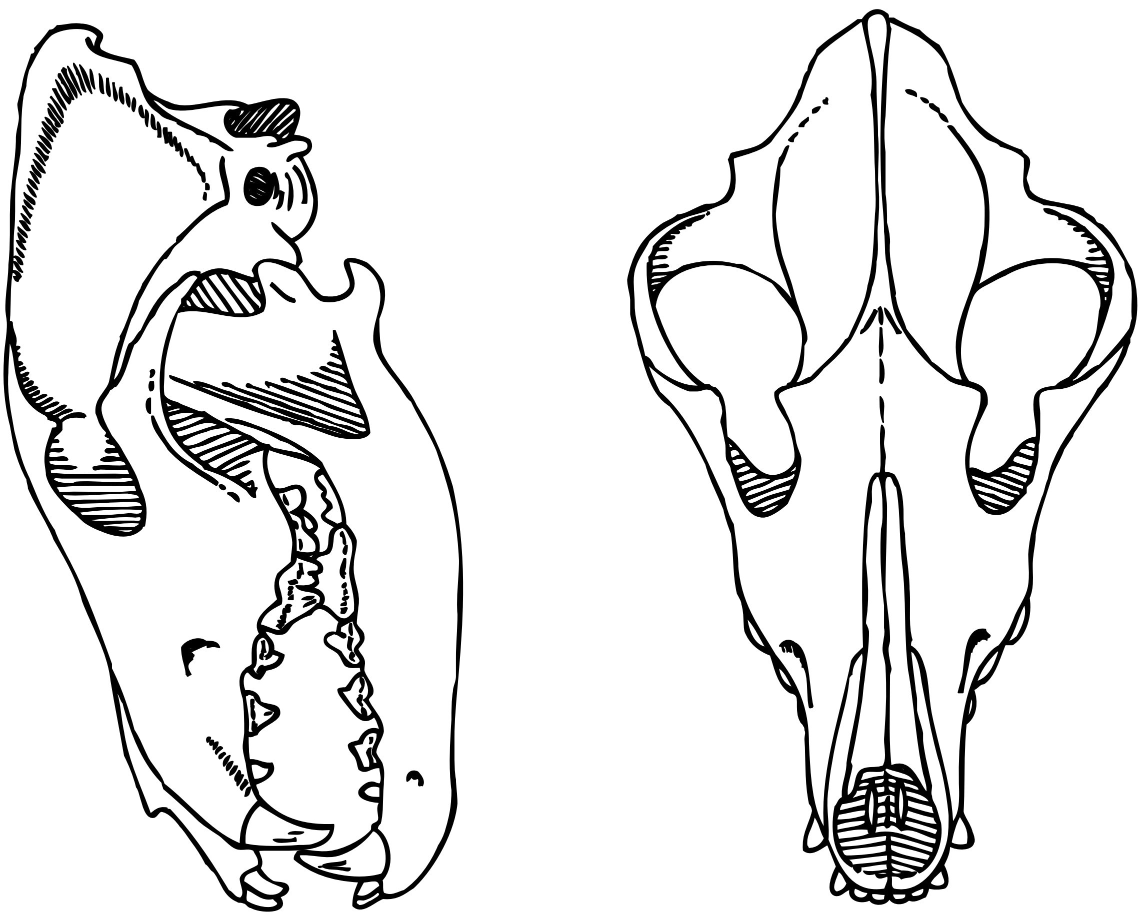
Source of skull diagrams: <u>Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals.</u> Glenn Searfoss, 1995.



A



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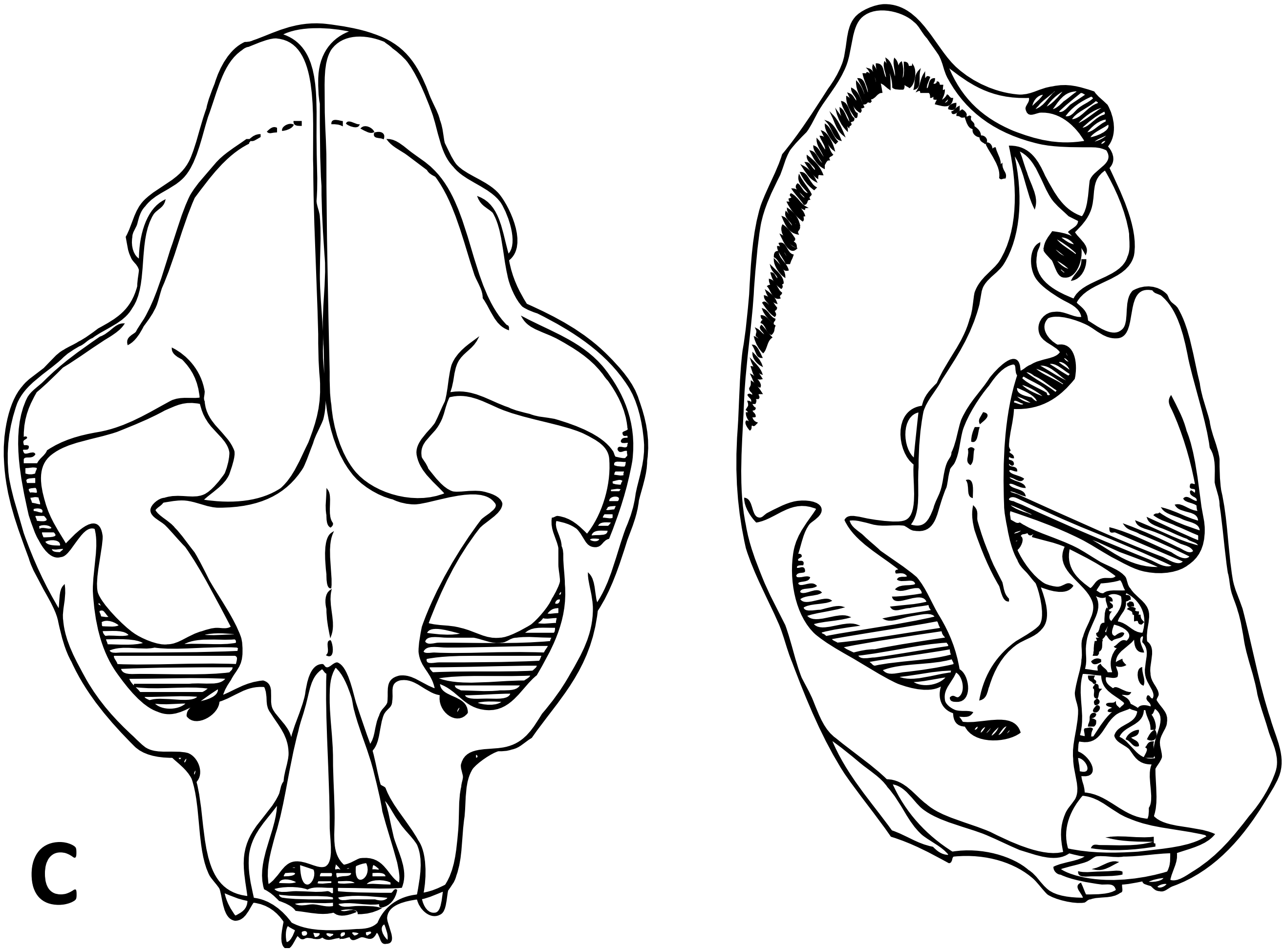

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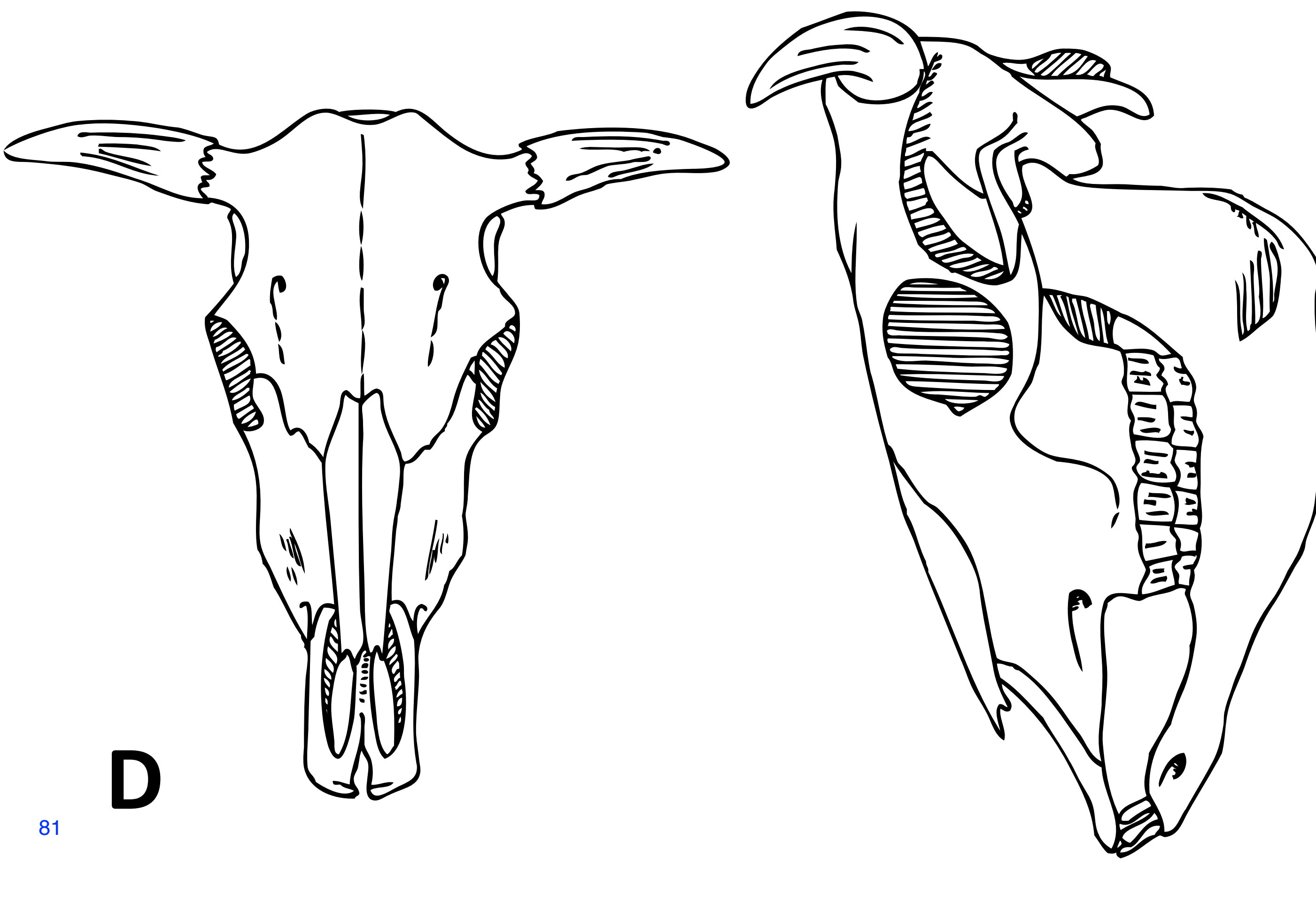

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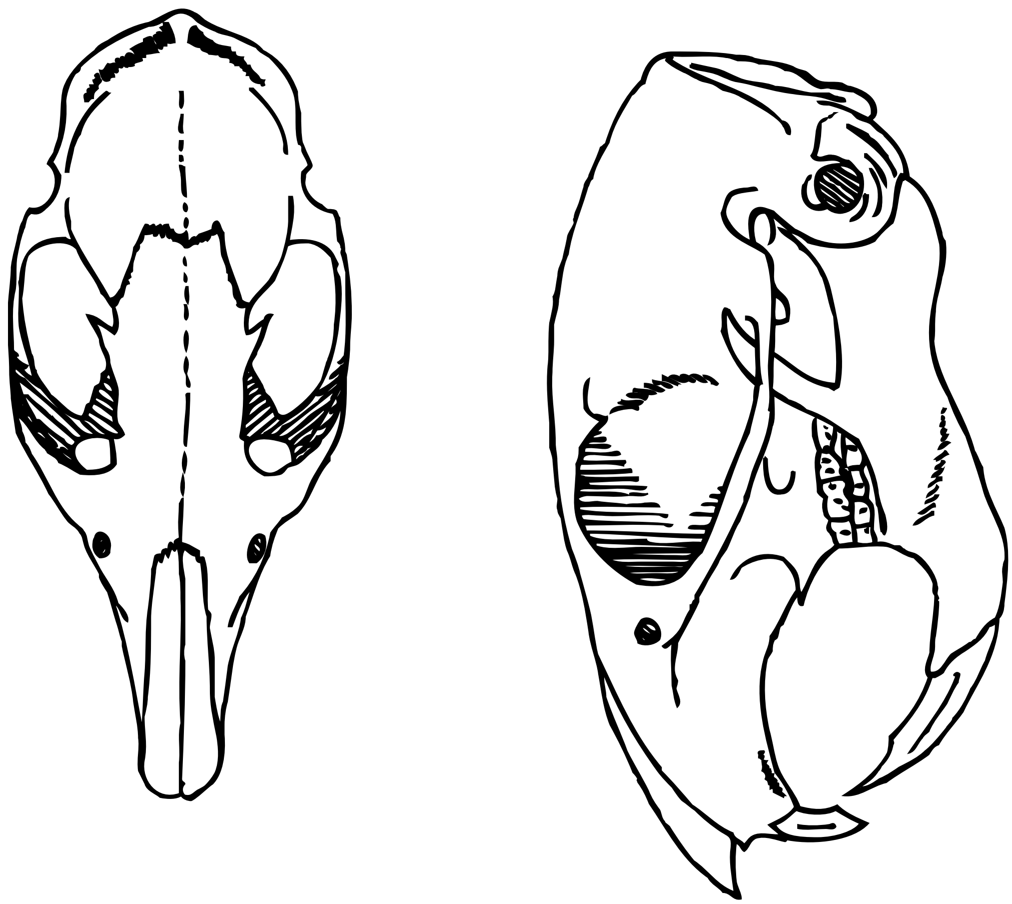

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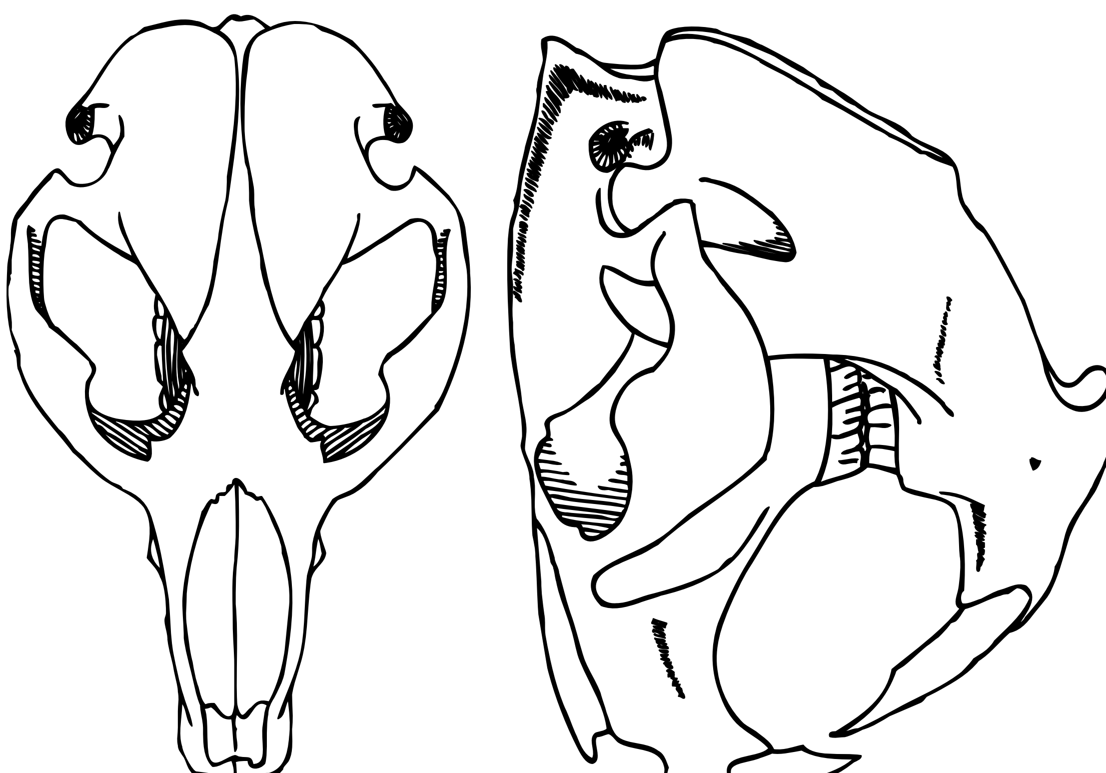
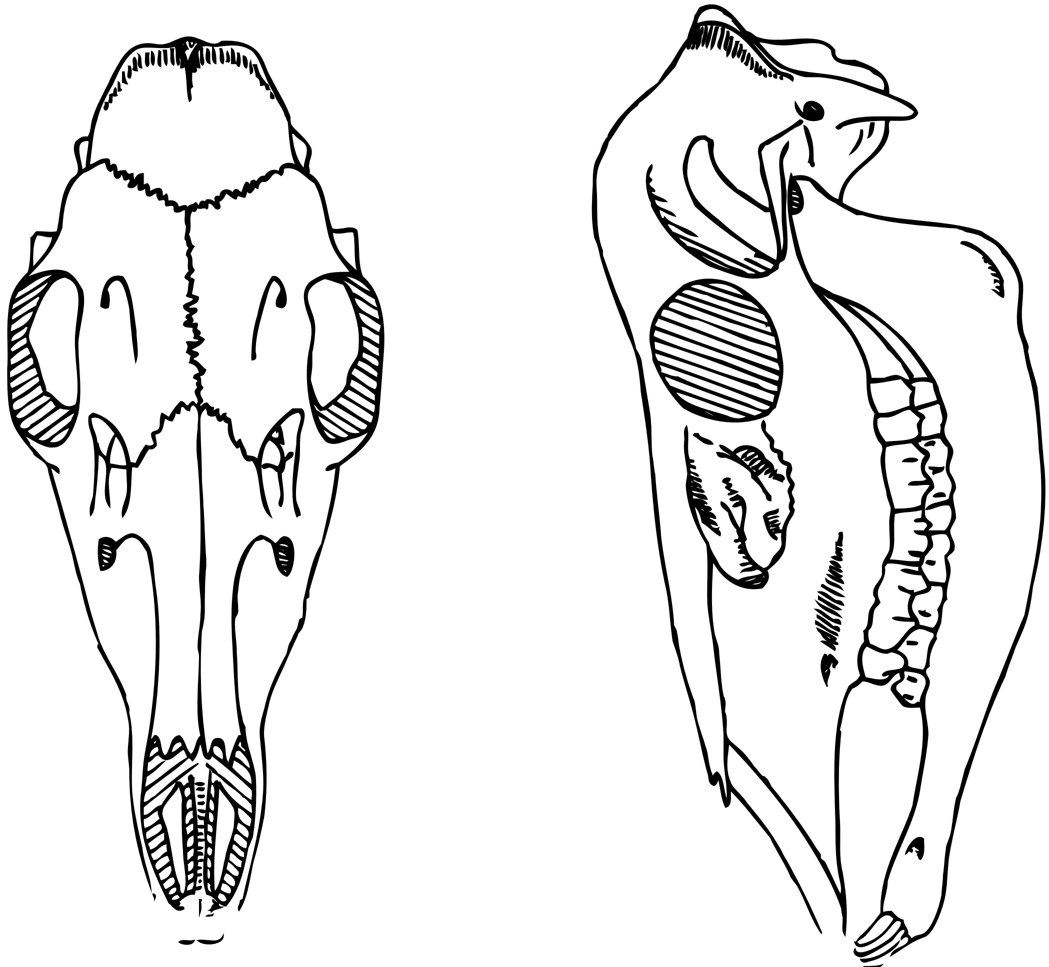


F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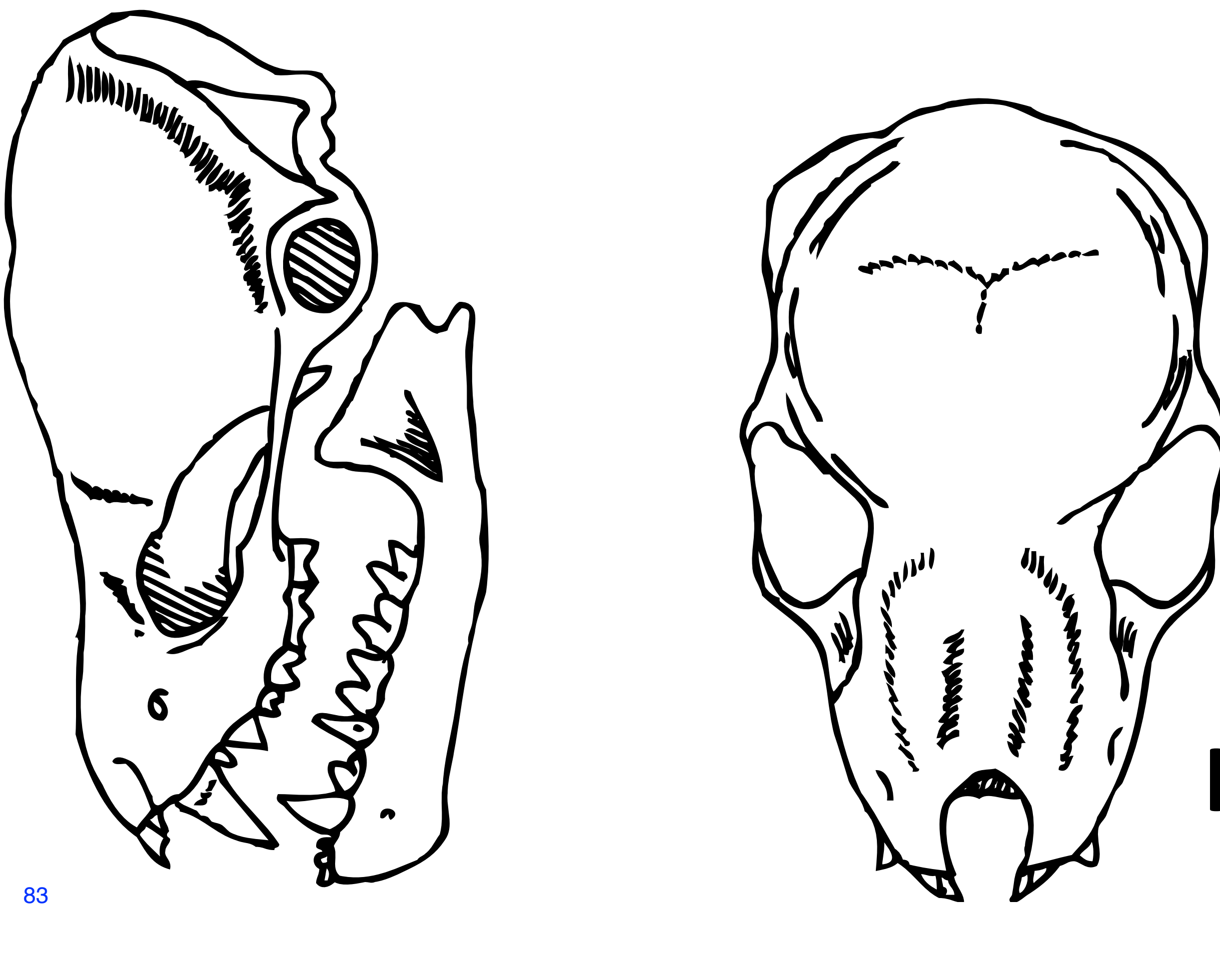
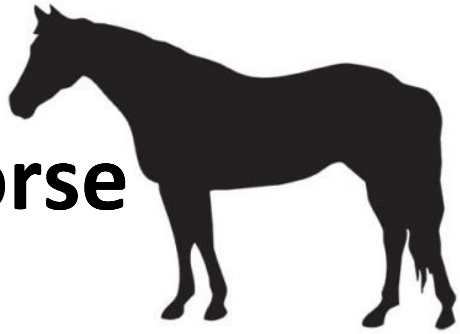
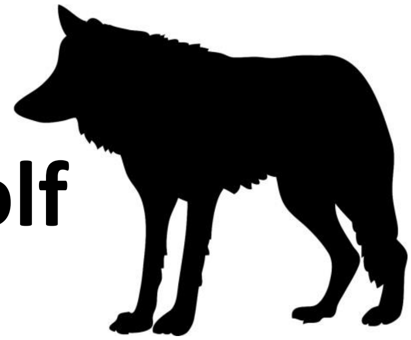
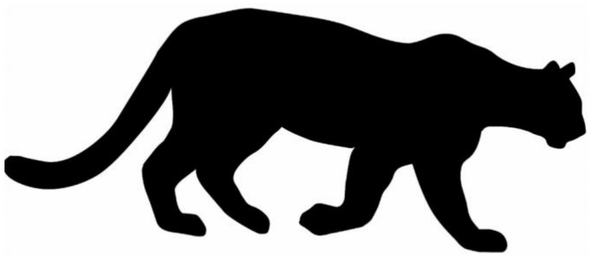

H

Horse



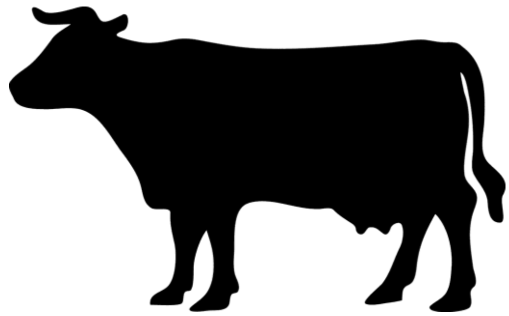
Wolf





Mountain Lion

Cow



Chipmunk

Beaver

Deer

Cave Bat

# Guess the Skull: Comparing Mammals

## Activity Instructions:

Teacher prep: Print and cut out each of the 10 different drawings of animal skulls[1], pasting each around the classroom.

Print the individual name cards, and distribute to students or group. Students (individually or in teams) are asked to match to the name of the organism to the correct skull. There are 10 name cards; depending on the size of the group enough can be printed out, one for each student with overlap if there are more than 10 students. Students can work together as a class.

Each student makes a 'decision' by standing next to the skull they believe matches their animal.

When the class comes to a consensus about how everyone is placed, the teacher or group leader can reveal the correct answers. Students who have guessed wrong are asked to move to the correct skull, thus shuffling the class to the correct matching.

## Learning Objective:

In this exercise students will need to compare different **morphological features (differences in size and shape)** between the skulls of different mammals, and think critically about what those differences in shape might mean in terms of diet and lifestyle.

Each animal is uniquely adapted to a particular lifestyle, and physical features of the skull reflect those evolutionary differences. For example, the size and shape of the jaw and cheek bones allow for the attachment of different muscles which can mean a stronger gripping bite or more strength/force with the back chewing teeth.

The size and shape of bone reflects the size and shape of muscles evolved to perform differently: predators have sharp canine teeth and strong jaws; herbivores tend to have eyes on the side of their heads for better peripheral vision, etc.

For more information, see the accompanying activity on jaw muscles taken from the book: Skulls and Bones by Glenn Searfoss.

**Answer Key**

**A- Horse**

**B- Wolf**

**C- Mountain Lion**

**D- Cow**

**E- Chipmunk**

**F- Beaver**

**G- Deer**

**H- Cave Bat**

[1] Source of skull diagrams: Skulls and Bones: A guide to the skeletal structures and behavior of North American Mammals. Glenn Searfoss, 1995