## Biology in a Box

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## UNIT 1: FOSSILS - PART II



## Homepage Unit 1: Fossils - Part II

Click underlined text below to go to information and exercises!

## Materials List

## Introduction to Fossils

## Exercise 3 - Dating Fossils

Mathematics: The definition of a function, one-to-one functions, recognizing the graphs of linear, exponential, power, and logarithmic functions, inverse functions, exponential and logarithmic functions, solving exponential and logarithmic equations

## Exercise 4 - Fossil Lineages

## Suggested Readings \& Links

See file entitled "Unit 1 Fossils Part I" for Exercises 1 (Fossils T/F) and Exercise 2 (Geological Time Line) Clicking the icon on other slidुes will bring you back to this page!

## An Introduction to Fossils

$\square$ Fossils are the remains of organisms
$\square$ Dead, typically in excess of $\mathbf{1 0 , 0 0 0}$ years
$\square$ Failed to decay
Preserved in some form of bacteriafree environment

## The Student will

$\square$ Gain an understanding of what constitutes a fossil and mechanisms of preservation

DBecome familiar with the concept of geological time and what really big numbers of years mean

Learn about how dates are assigned to fossils

LLearn how fossils are utilized to examine the historical relationships among organisms


## Exercise 3. Dating Fossils

Introduction
$\square$ Estimation of the age of fossils by their locations within strata or layers of sediment is called relative age.
$\square$ Fossils that are located in the lower strata are older than those that are near the top.

$\square$ Geologists and biologists use radiometric dating to obtain an absolute time scale or age for particular strata.
$\square$ Radiometric dating is based on the fact that some minerals have radioactive isotopes that change through time to other minerals through a process called radioactive decay
$\square$ The amount of time it takes for half of a 'parent' (radioactive) isotope to turn into its non-radioactive 'daughter' isotope is called its half-life.

## Students will...

Learn about the different ways geologists date fossils by
$\square$ Learning about mathematical functions, including linear, exponential, power, and logarithmic functions, inverse functions, and solve exponential and logarithmic equations in Exercise 3a: Functions.
 A half-life graphing activity for Grades 3-6 is also available here. $\square$
$\square$ Deciding what radioactive material is best to date a fossil depending on estimates of relative age in
Exercise 3b: Determining the Age of a Fossil
$\square$ Seeing the relationship that exists between the loss of parent decay material and accumulation of daughter product material in Exercise 3c: Half-Life Experiment

## Half-Life Graphing Activity

DFor this exercise, you will need the following materials:
-GGaph paper
$\square 2$ strips of construction paper of equal width (narrower widths around 0.5 ", or the width of the squares on the graph paper used would probably work well)
$\square$ Dcissors
GGlue or tape
aPencils, pens, or markers

## Half-Life Graphing Activity

$\square$ Draw a horizontal and a vertical axis on your graph paper.
$\square$ Label the vertical axis "Amount of Radioactive Parent Isotope Remaining," and label the horizontal axis "Number of Half-lives Elapsed."
$\square$ Lay one strip of paper vertically along the y-axis with one end at the origin. The gridlines on your graph paper should help you line the strip up to make sure that it is properly vertically aligned.
Tape or glue this strip to the graph paper.
$\square$ Now take the other strip of paper, and fold it in half as precisely as possible.
$\square$ Unfold this strip, and cut the strip into two equal pieces along the crease that marks the halfway point. Set one half of this strip aside.

## Half-Life Graphing Activity

$\square$ Take the half strip currently in your hand, and place it vertically on your graph paper, parallel to the first strip, with the bottom of the strip touching the horizontal axis, a small distance to the right of the first strip (or with their edges touching).
$\square$ Glue or tape this strip in place, just as with the first strip.
$\square$ Using the remaining half strip, repeat the previous three steps, placing the new strip on the graph to the right of the previous strip (at a distance equal to the distance between the first two strips).
$\square$ Continue following this procedure, adding new cut pieces of your strips until the pieces become too small to comfortably manage (probably 5-6 cuts, depending on the initial length of the strips).

## Half-Life Graphing Activity

$\square$ Now label, on your x-axis, each of your strips, with your first strip having the number " 0 ", and your last strip having a number equal to one less than the total number of strips on your graph.
$\square$ Using a pencil or marker, make a mark at the midpoint at the distance across the top of each strip on your graph.
$\square$ Now try to join all of these points with a smooth curve (do not just simply connect them with straight lines!).
$\square$ So, what does the graph you just constructed illustrate? Go to the next slide for an explanation!

## Half-Life Graphing Activity

-The graph you just constructed shows the decay of a radioactive element.
-The first strip on your graph represents an initial amount (at a given point in time) of a radioactive element.
DEach new strip that you added represents the amount of the radioactive parent isotope remaining after an amount of time equal to one half-life of the parent isotope has elapsed.

## Half-Life Graphing Activity

$\square$ Each strip represents a particular quantity of atoms of the parent isotope present.
$\square$ Atoms are too small for us to see, so a small sample of a radioactive element may be still be made of many atoms!
$\square$ Even though you may only have been able to add just a few strips of paper to your graph, there would still be some parent isotope remaining after the point in time represented by your last strip.
$\square$ Atoms of the parent isotope would still be present, for perhaps many more half-lives, until only one single atom of the parent isotope remained, and it finally decayed to its stable state.
$\square$ Just remember, after each half-life, the amount of the parent isotope remaining is equal to half of the amount present at the time before that half-life elapsed!


## Exercise 3a: Functions

$\square$ Functions are useful mathematical tools. You can think of a function as a factory that takes elements from a set of inputs called the domain and produces elements belonging to a set of outputs called the range, just as logs go into a paper factory and paper comes out.
$\square$ Let's examine a biological example: a poison dart frog. The picture below illustrates the idea with a function (rule) we call the toxicity function. This function takes organisms as its input and returns the toxicity of the organism as an output.


## Exercise 3a: Functions

$\square$ lt is important to know that a function takes one element from the domain to exactly one element in the range.
$\square$ Graphically this means that every vertical line intersects the graph of a function just one time. Thus, in the previous example, every organism is either defined as toxic or nontoxic. It is impossible to be both.

## Exercise 3a: Functions

$\square$ An example of a function is $\mathbf{g}(\mathbf{x})=\mathbf{x}^{2}$.
$\square$ The domain of this function is the set of all real numbers.
$\square$ (The real numbers represent all of the points on a real number line, where 0 marks the middle of the line. Unlike natural numbers that consist of the numbers used for counting $\{1,2,3,4 \ldots\}$, the real numbers may be fractions like $1 / 2$ or even numbers with infinite decimal expansions like m.)

$\square$ The range of this function is the set of all non-negative real numbers.

## Exercise 3a: Functions

OOne very important
function is the exponential growth function $f(x)=10^{x}$.
$\square$ The domain of this function is the set of all real numbers and the range is the set of all positive numbers. Note that any vertical line that could be drawn on the graph intersects it at most one time.


## Exercise 3a: Functions

In the following exercises we will use another important function called the exponential decay function, $f(x)=10^{-x}$.
$\square$ The domain of this function is also the set of all real numbers, and the
 range is also the set of all positive numbers. Its graph is pictured to the right for the range $-1<x<1$.


## Exercise 3a: Functions

$\square$ Certain functions are one-to-one. A function is one-to-one if it takes distinct values in the domain to distinct values in the range. The toxicity function is not one-to-one, because it takes many different types of organisms to the output "toxic". For example, poison dart frogs and black widow spiders are unrelated organisms, but the toxicity function takes both of them to the value toxic.
$\square$ Graphically, a function is one-to-one if every horizontal line intersects the graph of the function just one time. You can see on the previous slides that both the exponential growth and exponential decay functions are one-to-one.


## Exercise 3a: Functions

If $f(\mathbf{x})$ is one-to-one, then it has an inverse function $f^{-1}(\mathbf{x})$ that undoes what does.
If $f(x)$ is a very simple function, it is easy to find. For example, to undo division by 3 we should multiply by 3 . That is, if $f(x)=x / 3$, then $f^{-1}(x)=3 x$.
Likewise, to undo subtraction of 2 , we should add 2 . That is if $f(x)=x-2$, then $f^{-1}(x)=x+2$.
Combining these ideas we can find the inverse of a slightly more complicated function, $\mathbf{f}(\mathbf{x})=(\mathbf{x}+2) / 3$. Since $\mathbf{f}(\mathbf{x})$ takes $\mathbf{x}$, adds 2 , and divides by $3, \mathbf{f}^{-1}(\mathbf{x})$ does the reverse: it takes $\mathbf{x}$, multiplies by three, and subtracts 2 . That is, $f^{-1}(x)=3 x-2$.


## Exercise 3a: Functions

$\square$ To find the inverse of a function such as the example of $f(x)=(x+2) / 3$, you can imagine $f(x)$ as being represented by $\mathbf{y}$, so that $\mathbf{y}=(\mathbf{x + 2}) / 3$ (when you see an equation with $\mathbf{y}$ expressed in terms of $\mathbf{x}, \mathbf{y}$ is indeed a function of $\mathbf{x}$ !) Solve the equation for $\mathbf{x}$ in terms of $\mathbf{y}$. In this example, then, $\mathrm{x}=3 \mathrm{y}-2$.
$\square$ If you now switch the variables $\mathbf{x}$ and $\mathbf{y}$ in the newlyobtained equation, resulting in $\mathbf{y = 3 x} \mathbf{- 2}$, you have now found the inverse of the original function! So, if $f(x)=(x+2) / 3$, then $f^{-1}(x)=3 x-2$.
$\square$ Remember, though, that in order for a function to have an inverse, it must be one-to-one. Again, this means that in a graph of the function, no horizontal line can be drawn that passes through more than one point on the plot of the function. In other words, each value of $f(x)$ can ONLY be obtained from ONE value of $\mathbf{x}$ !

## Exercise 3a: Functions

## Solve the following question:

Q1. Find the inverse of the following function:
$f(x)=(x / 7)+1$


## Answer Time!

## Solve the following question:

Q1. Find the inverse of the following
function:

$$
f(x)=(x / 7)+1
$$

Answer:

$$
f^{-1}(x)=7(x-1)
$$



## Exercise 3a: Functions

$\square$ The inverse of the exponential function $f(x)=10^{x}$ is called the logarithmic (log) function $\mathbf{f}^{-1}(\mathbf{x})=\log \mathbf{x}$. Thus, $\log \mathbf{x}$ gives the exponent to which 10 must be raised to in order to get $\mathbf{x}$.
$\square$ Examples:

## $\square \log 10^{3}=3$

$\square \log 10^{-2}=2$
$\square$ And since $100=10^{2}, \log 100=\log 10^{2}=2$
$\square$ If we don't know the exponent to which 10 must be raised to make $\mathbf{x}$, then we must use a calculator to evaluate $\log \mathbf{x}$. For example, consider log 27. Since we don't know the exponent $x$ so that $10 \times 27$, we can plug $\log 27$ into a calculator to find $\log 27 \approx 1.4314$.


## Exercise 3a: Functions

Now evaluate the following expressions:

Q2. $\log 10^{-5}=$

Q3. $\log (1 / 10)=$

Q4. $\log 1000=$


## Answer Time!

Now evaluate the following expressions:

Q2. $\log 10^{-5}=$
Answer: $\log 10^{-5}=-5$
Q3. $\log (1 / 10)=$
Answer: $\log (1 / 10)=-1$
Q4. $\log 1000=$
Answer: $\log 1000=3$


## Exercise 3a: Functions

$\square$ Inverse functions are useful, because they can help us solve for variables. We will use this method to solve equations of the form $10^{\mathbf{x}}=\mathbf{y}$ for
$\mathbf{x}$. Using the fact that $\log \mathbf{1 0}^{\mathbf{a}}=\mathbf{a}$, we see that

$$
10^{x}=y \rightarrow \log 10^{x}=\log y \rightarrow x=\log y
$$

$\square$ Solve the following equation for $\mathbf{x}$ :

Q5. $10 \times=17$

Answer: $\log 10^{x}=\log 17 \rightarrow x=\log 17 \rightarrow x \approx 1.2304$

## Exercise 3b. Determining the Age of a Fossil

Which of the radioactive decay measures in the table would you use to date the following fossils?
$\square$ As a general rule of thumb: consider a radiometric dating method to be appropriate if at least 0.01 half-lives, but no more than 10 half-lives, of the radioisotope have elapsed.
$\square$ If a very small portion of a half life or a large number of half-lives of a radioisotope has elapsed, very accurate determination of the concentration of parent or daughter isotope might be difficult.

1) Stromatolites: 1.5 BY
2) Wooly mammoth fur: 10,000$14,000 \mathrm{Y}$

| Parent <br> Isotope | Daughter <br> Isotope | Half- <br> Life <br> (years) |
| :---: | :---: | :---: |
| C-14 | $\mathrm{N}-14$ | 5,730 |
| $\mathrm{U}-235$ | $\mathrm{~Pb}-207$ | $7.0 \times \mathbf{1 0}^{\mathbf{8}}$ |
| Rb-87 | $\mathrm{Sr}-87$ | $4.9 \times \mathbf{1 0}^{\mathbf{1 0}}$ |
| Sm- <br> 147 | $\mathrm{Nd}-143$ | $\mathbf{1 . 0 6 \times 1 0 ^ { 1 1 }}$ |

3) Tree fern leaves: $\mathbf{3 0 0}$ MY
4) Sea urchin: 36-42 MY
5) age of stars from meteorites: 15 BY

## Answers to Exercise 3b. <br> Determining the Age of a Fossil

1) Stromatolites -1.5 BY

Uranium-235 (useful range 10 million - 4.6 by)
2) Wooly mammoth fur- $10,000-14,000 \mathrm{Y}$ Carbon-14 (useful range = 100-~60,000 years)
3) Tree fern leaves - $\mathbf{3 0 0}$ MY

Uranium-235
4) Sea urchin - 36-42 MY

Uranium-235
5) date the age of stars from meteorites -15 BY Rubidium-87 or Samarium-147 (both with useful ranges of billions of years)


## Exercise 3b. Determining the Age of a Fossil

$\square$ To find the time $\mathbf{t}_{1}$ since an organism died, we start by measuring the proportion (fraction) of radioactive parent isotope, $\mathbf{F}\left(\mathbf{t}_{1}\right)$, that remains in the fossil or a rock found associated with it.
$\square$ First we measure the amount of parent isotope that remains in the fossil. Let's call this number $\mathbf{P}$. Then we measure the amount of daughter isotope in the fossil. Let's call this number $\mathbf{D}$.
$\square$ Now since every atom of daughter isotope was once an atom of parent isotope, we know that at the time of death there was $\mathbf{D + P}$ parent isotope in the fossil.

- That means that the fraction of parent isotope remaining is $P /(D+P)$. That is, $F\left(t_{1}\right)=P /(D+P)$.


## Exercise 3b. Determining the Age of a Fossil

$\square$ Since we know (from the previous slide) that the fraction of parent isotope remaining (as a function of time, t) can be given as $F\left(\mathrm{t}_{1}\right)=\mathrm{P} /(\mathrm{D}+\mathrm{P})$.

Combining this information with the fact that the parent isotope decays exponentially, we find that $10^{-}$ $\lambda_{1}=F\left(t_{1}\right)=P /(D+P)$. That is,

$$
10-\lambda t_{1}=P /(D+P)
$$

$\square$ Now we can solve for $\mathbf{t}_{1}$ (which represents the age of the fossil!) by taking the log of each side of the previous equation:
$P /(D+P)=10^{-\lambda t_{1}} \rightarrow \log (P /(D+P))=-\lambda t_{1} \rightarrow(-1 / \lambda) \log (P /(D+P))=t_{1}$

## Exercise 3b. Determining the Age of a Fossil

Q6. Suppose that the fraction of Uranium-235 remaining in fossil number 10 is 0.71 , and the decay constant of Uranium-235 is $4.30043 \times 10^{-10}$. Use this information to find the age of the fossil.

Q7. Assume there is small error in our measurement, and in fact the fraction of Uranium-235 remaining is 0.714 . How does this affect the answer in the previous question?

## Answer Time!

Q6. Suppose that the fraction of Uranium-235 remaining in fossil number 10 is 0.71 . Use this information to find the age of the fossil.
The fossil is $3.4588 \times 10^{8}$, or $345,880,000$ years old.
Q7. Assume there is small error in our measurement, and in fact the fraction of Uranium-235 remaining is 0.714 . How does this affect the answer in the previous question?
The new estimate for the age of the fossil is
 $3.4020 \times 10^{8}$, or $340,200,000$ years old, a difference of $5,680,000$ years.

## Exercise 3b. Determining the Age of a Fossil

$\square$ In the previous table of radioactive isotopes, the half-life of each isotope is related to its rate of radioactive decay $(\boldsymbol{\lambda})$. The half-life, $\mathbf{t}_{1 / 2}$, of an isotope is the time it takes for half of the original concentration to decay. That is,

$$
\begin{gathered}
(1 / 2)=F\left(t_{1 / 2}\right)=10^{-\lambda t_{1 / 2}} \\
\text { OR } \\
(1 / 2)=10^{-\lambda t_{1 / 2}}
\end{gathered}
$$

Answer the following two questions:
Q8. Solve the equation above for the half-life in terms of $\boldsymbol{\lambda}$.

Q9. Given that the decay rate of Radium-226 is $1.8814 \times 10^{-4}$, find the half-life of Radium-226.

## Answer Time!

Q8. Solve the equation above for the half-life in terms of $\boldsymbol{\lambda}$.

$$
(1 / 2)=10^{-\lambda} t_{1 / 2} \longrightarrow t_{1 / 2}=(-\log (1 / 2)) / \lambda
$$

Q9. Given that the decay rate of Radium-226 is
$1.8814 \times 10^{-4}$, find the half-life of Radium-226. The half-life of Radium-226 is 1600 years.


## Exercise 3c: Half-Life Experiment

To repeat, the half life of a particular radioactive isotope of an element is based on the mean, or average, time it takes half of the parent material to decay into the stable daughter material.
The following experiment demonstrates how radioactive decay occurs due to the chance change of individual radioactive atoms into their non-radioactive daughter atoms.
$\square$ Each student will make a table on a sheet of paper or one will be drawn on the board at the front of the room. The next slide shows what this table should look like. It will have 5 columns and 12 rows.

| Time <br> Interval / Trial | \# Parent <br> (radioactive) <br> Light-c chips | \# daughter <br> (stable) <br> Dark-c chips | Decay of <br> Parent <br> \#light/32 | Accumulation <br> of Daughter <br> 1-(\#dark/32) |
| :--- | :--- | :--- | :--- | :--- |
| 0 at death | 32 | 0 | 1.0 | 0.0 |
| 1 |  |  |  |  |
| 2 |  |  |  |  |
| 3 |  |  |  |  |
| 4 |  |  |  |  |
| 5 |  |  |  |  |
| 6 |  |  |  |  |
| 7 |  |  |  |  |
| 8 |  |  |  |  |
| 9 |  |  |  |  |
| 10 |  |  |  |  |

$\square$ In plastic container (Box \#3) there are 32 lightcolored chips \& 32 dark-colored chips.
$\square$ Assume that...
$\square$ The container is a FOSSIL of which you want to determine the age.
$\square$ The light chips are atoms of a radioactive material we will call the parent isotope.
$\square$ The dark chips are atoms of the nonradioactive (stable) daughter isotope.

## **The goal of this experiment is to determine the half life (X) of the light chips (radioactive material).

At the start, assume that your fossil has just died. (Only atoms of the parent radioactive isotope, represented by the light-colored chips, are present.)


## Directions (cont.)

DHave someone sort the chips by color.
$\square$ Distribute the light chips to students (all 32 light chips must be distributed).
$\square$ Set aside the dark-colored chips.
DFlip each light chip you have onto your desk.
$\square$ Exchange each light chip that has landed with the colored center-side up with a dark chip.
$\square$ Record on your table the total \# of light chips remaining in the class after the first flip trial under the parent atom column for the row representing Trial 1. $\square$ Record the total number of dark chips present in the class under daughter atom column for the same row.

## DRepeat the process until...

DAll of the light chips have been removed,
GOR 10 trials have been completed.


You will be given a graph sheet on which to plot the curve of the decay of the parent material, applying a dashed line between points (template on next slide).
$\square$ To obtain the values you need for making the decay curve, you will need to fill in the last column of your table called decay of parent which is the proportion of parent atoms (light chips) that survived at each time interval, here expressed as trials 0-10.
$\square$ The proportion of light chips that have survived each trial = the number of light chips remaining in column 2 under the trial row divided by the total number of light chips at the start of the experiment (32).
$\square$ Thus, proportion of parent material surviving at interval $n=$ \# light chips ${ }_{n} / 32$
$\square$ where $n=$ a trial number from 0 to 10 .
$\square$ *Note that we have already filled in interval 0 for you on the table.


## A. Graph of decay of parent material ( - - - ) \& accumulation of daughter material ( - )(handout)



Now fill in the last column for the accumulation of the dark chips representing daughter product. -Because a dark chip replaced a light chip that decayed, the proportion of dark chips at each interval will be equal to:

1- Proportion of surviving light-colored chips

## Example:

At the death of the fossil (interval 0), the proportion of light chips surviving was 1.0, or all of them.
The proportion of dark chips accumulating was 1-1.0 $=0$
$\square$ Plot the points for the accumulation of this daughter product on the same sheet of graph paper applying a solid line between points.


Answer the following questions after you have completed your experiment:
$\square$ What kind of curve does the decay of the parent material resemble? (See curve figures on next slide for comparison). Note the mathematical formula that underlies the distribution of chip numbers decaying through time.
$\square$ What kind of curve does the accumulation of the daughter product resemble? (See curve figures on the next slide for comparison). Note the mathematical formula that underlies this distribution of accumulating chips over time.

## Examples of lines describing various mathematical functions.



Inverse Exponential: $y=e^{-x}$

Answers





Move on

Logarithmic: $y=\ln (x)$

$\square$ What is the half-life for the light chips in this experiment? Hint, you can determine this by examining your fraction column: How many intervals did it take to get to approximately 0.5 or $1 / 2$ of the light chips surviving)?
Challenge questions: Based on the results of your experiment on the rate of decay of white chips......
$\square$ If you found a box with only 12 light chips in it and 24 dark-colored chips, how 'old' would you estimate this fossil box to be in trial number time?

If you found a box with only 4 light chips in it and 28 dark colored chips, how 'old' would you estimate the box to be in trial number time?

If you found a fossil (box) with 38 light chips and only 4 dark chips, how 'old' would you estimate the fossil box to be in trial number time?
$\square$ What is your conclusion about what determines the fossil age estimate you obtained from your answers to the previous questions?

## Exercise 4. Fossil Lineages

## Introduction

$\square$ Evolution refers to a change in the average values of traits in populations of organisms over time.
$\square$ These may be morphological (e.g., body length), physiological (e.g., resting metabolic rate), or behavioral traits (e.g., temperament) that are passed from parents to their offspring through their genetic material (DNA).
$\square$ Evolution can result in changes within a single species population that are visible on the scale of a few generations. Over longer ecological, historical, and geological scales, sufficient changes may accumulate to result in speciation events, some of these leading to the formation of new branches in a lineage.
$\square$ Delineating fossil lineages is important to our understanding of how evolutionary change in organisms is associated with environmental change, chance events, and gradual modification to better adapt organisms to their roles in the ecosystem they occupy.
$\square$ The information we can obtain on adaptation from the study of fossils is limited to morphological traits and often only those aspects of morphology that are associated with the skeleton, as in teeth, bones, or shells.

DHowever, fossils are valuable to the biologist because they can provide an ordered record of the timing of appearance and/or loss of traits as organisms are replaced by descendents over millions of years of geologic time.

DIn this exercise, you will learn how decisions are made about the historical relationships among organisms through examination of fossil tooth morphology in sharks.

The best way to examine historical relationships among organisms is to examine changes in traits in lineages through time.

1. Organisms that are more closely related share more traits in common.
2. Individuals share more characteristics in common, and thus are more closely related to one another, the further one goes down in the classification hierarchy from the most inclusive category (Kingdom) to the least inclusive (Species):
$\square$ KINGDOM - share fewest characteristics
ロPHYLUM
-CLASS
DORDER
DFAMILY
-GGENUS
-SPECIES - share most characteristics

## Objective

Your goal in Exercise 4 is to understand the relationship between fossil lineages.
$\square$ You will determine a lineage of shark teeth:
$\square$ Exercise 4a

1. by species differences and similarities.
2. by examining the position of species in a cross section of the layers of sediments that have been laid down over time
$\square$ You will also compare two lineages of shark teeth using an outgroup comparison:
$\square$ Exercise 4b $\square$
$\square$ Students in Grades 4 and up can also learn about how to estimate the sizes of sharks from the sizes of their teeth in Exercise 4c.

## Exercise 4a: Determining a lineage.

$\square$ Your teacher will display the five teeth in box \#4: 4a in alphabetical order on the table at the front of the room. (Each tooth has a red dot on the enamel at the base of blade/crown for locating purposes.)
-Carcharocles auriculatus
$\square$ Carcharocles chubutensis
$\square$ Carcharocles megalodon
-Cretolamna appendiculata
■Otodus obliquus

## Directions

$\square$ These teeth are from the shark family
Otodontidae (mackerel sharks), and includes the Giant White Shark (Megalodon) that was long thought
(erroneously) to be the ancestor of the Great
 White Shark of today. The lineage is called the Megalodon Shark Lineage.
$\square$ Your job is to examine the 5 teeth \& pictures of them on the next slides with the goal of placing them in an hypothesized lineage that represents a trend in tooth structure.

|  | Species <br> Order <br> 1ST try | Tooth <br> Trait(s) <br> Based <br> on | Species <br> Order <br> 2ND try | Tooth <br> Trait(s) <br> Based <br> on | Age of <br> Fossil <br> MYA |
| :---: | :--- | :--- | :--- | :--- | :--- |
| Youngest |  |  |  |  |  |
| A |  |  |  |  |  |
|  |  |  |  |  |  |
| Oldest |  |  |  |  |  |

1. Make a table like the one above to show your ${ }_{54}$ decision process.

## Examine the major parts of a shark tooth.


$\square$ Each of the five teeth will be stationed with its name labeled at the front of the room.
$\square$ Line up and visit each station, examining the tooth there. Take notes as to the trait values it possesses. $\square$ For example, the size of the tooth, the width of the blade relative to its height, blade thickness, blade edge (smooth versus serrated), etc.

DNOTE: Teeth take on the color of the sediment in which they are buried. Thus color is not a good trait on which to base relationships!
$\square$ NOTE: Differences in the degree of curvature of the teeth may not be reflective of changes in the lineage over time, as the shapes of teeth within a single species vary with their placement in the mouth. Take another look at the modern shark jaw provided to get a sense of the general trend in tooth shape between anterior (front) and lateral teeth (teeth towards the sides of the mouth).

Using your notes and the figures of the teeth below, place the five species in order of oldest to youngest in $1^{\text {st }}$ Try column, and state reason for order you chose in next column.


Otodus

Giant White: C. megalodon


Cretolamna

C. chubutensis


Click the arrow for the actual lineage


## Answers for Megalodon lineage:



Carcharocles megalodon
Giant White shark

Carcharocles chubutensis
Giant White shark

Carcharocles auriculatus

Otodus obliquus
Mackerel shark
Cretolamna appendiculata Mackerel shark

Using your notes, the actual order of teeth seen in the previous stratigraphy, and the figures of the teeth below, list what traits change in this lineage in the "Reasoning ( $2^{\text {nd }}$ Try)" column.

C. chubutensis


Cretolamna

Otodus


Giant White: C. megalodon
Click the forward arrow for a discussion of the actual changes in the lineage

The general trend in the Giant White shark lineage (Family Otontidae), from oldest to youngest species is:

1. increase in tooth size
2. increase in thickness
3. loss of the secondary cusps due to the increase in thickness
4. acquisition of a serrated cutting edge on the tooth blade (crown).


Cretolamna


Giant White: Carcharocles megalodon

## Exercise 4b: Comparing lineages.

$\square$ In Exercise 4a:, you examined changes in tooth structure that occurred over millions of generations in a single family or lineage. In this exercise, student teams are expected to consider the relationship between the extinct Megalodon/Giant White Shark, Carcharocles megalodon, examined in Exercise 4a, and today's giant shark in the seas, the Great White Shark, Carcharodon carcharias.
$\square$ Each student team should search the web, exploring what is known about the historical relationship between these two species and the families to which they belong. Do they share a common ancestor? If so, what is it?
$\square$ Learn about cladograms, trees that depict the evolutionary relationships between lineages. Then develop a tree (cladogram) that depicts the evolutionary relationship between the two lineages.

## Directions

Examine the relationship between the two families in the cladogram below.

- A cladogram depicts the evolutionary relationship between lineages. The two families are sister lineages, which have the same immediate common ancestor, Cretolamna appendiculatus.



## Exercise 4b: Comparing lineages.

The shark family Lamnidae, culminating with the Great White Shark, Carcharodon carcharis, is closely related to the extinct family (Otodontidae) of the Giant White Shark (Carcharocles megalodon), whose lineage you have already examined.
Compare and contrast the tooth structure of the two lineages, listing the similarities and differences of the teeth.
Below are some images of teeth in the Great White lineage (family Lamnidae) to assist you with your comparisons.


Isurus praecursor
I. hastilis

## Exercise 4b: Comparing lineages.

$\square$ In determining whether traits are either ancestral or derived in a lineage (or multiple lineages), an outgroup is often used.
$\square$ An outgroup is an organism that is not a member of a lineage that is being considered (in other words, is not closely related to, but shares a distant common ancestor with the organisms in question).
$\square$ Comparing the teeth in the Giant White and Great White shark lineages to an outgroup will help in identifying the traits that are shared by the modern day great white shark and the ancient giant white shark, as well as comparing the changes between the two lineages.

We have provided fossil teeth of one outgroup species, a crow shark in the genus Squalicorax (specifically Squalicorax pristodontus), which is pictured below. You may also wish to compare the teeth in your lineages to another outgroup species, a tiger shark. Though you do not have a tiger shark tooth in your box, you can use the image below to compare to your two lineages:


Crow Shark
(Squalicorax pristodontus)


Tiger Shark (Galeocerdo sp.)

## Exercise 4b: Comparing lineages- a team challenge take home assignment

$\square$ Find the bag with the crow shark (Squalicorax pristodontus) tooth in it. This is the outgroup species you can use for comparison.
$\square$ When a particular trait displays multiple states, when the value of a trait of a species is the same as that observed in the outgroup, that trait value is likely ancestral, while a trait value that differs between the organisms in question and the outgroup would represent a derived, or more modern character state, which has evolved since a shared common ancestor.
$\square$ Note that a particular outgroup may not always necessarily display trait values that are only ancestral values of the trait. Because of this, most scientists usually use multiple outgroups in comparing changes ${ }_{66}$ in lineages over time!

Examine the relationship in this cladogram between the Crow Sharks ( 65 mya) \& Tiger Sharks ( 5 mya-present) to the Giant White and Great White shark lineages. Use these outgroups to help identify similarities and differences between the Megalodon and Great White lineages, noting which character states are ancestral, and which are derived.


Click the arrow for differences between lineages.


## Comparing \& Contrasting Lineages

## Family Otodontidae (Megalodon)

1. Neck zone or collum present
$\square$ Provides additional area of attachment to the jaw and prevents tooth loss when biting
2. V or U shaped-roots
$\square$ Also add greater attachment strength
3. Convex face of blade (resembles a "D" in crosssection)
$\square$ Provides greater stability to the blade, making it less likely to break
4. Blade edge with small, even serrations

Click the arrow for differences between lineages.


## Comparing \& Contrasting Lineages

## Family Lamnidae (Great White)

DNo collum
$\square$ Roots of the teeth with no well-branched root lobes $\square$ V or U-shaped roots not observed.
$\square$ Blade with serrated edge, with serrations variable in size but generally larger than in Giant White Shark
$\square$ These significant differences caused the paleoichthyologist Henri Cappetta (1987) to place the Megalodon or Giant White Shark and the Great White Shark not only in separate genera, but in separate families.


## Exercise 4c: Size of the Megalodon

$\square$ For this exercise, you will need the following materials:
$\square$ Megalodon tooth from Exercise 4.1

- Other shark teeth from Exercise 4.1 (optional)
$\square$ Graph paper
The Megalodon was the largest shark that ever lived on earth. We can use the teeth of the Megalodon to help us determine the relative size of this massive animal.
$\square$ Since scientists know the width of the teeth and body length of modern-day sharks are related, we can use this information to determine the approximate size of the ancient Megalodon.
$\square$ You are going to use modern-day shark information to determine the approximate length of the Megalodon shark, or at least the size of specimen from which the tooth in your box came.


## Exercise 4c: Size of the Megalodon

$\square$ The following table includes information gathered about the tooth width and body length of modern-day sharks.

| Tooth Width (cm) | Body Length (cm) |
| :---: | :---: |
| $\mathbf{0 . 5}$ | 66.0 |
| $\mathbf{1 . 3}$ | 137.2 |
| $\mathbf{2 . 0}$ | 254.0 |
| $\mathbf{2 . 5}$ | 322.6 |
| $\mathbf{3 . 6}$ | 457.2 |
| $\mathbf{5 . 1}$ | 635.0 |

$\square$ Graph the information in the chart, using tooth width as your horizontal, or $x$ axis and body length your vertical, or y axis.
$\square$ Note the ranges of both "tooth width" and "body length" in the table above, and use these to help you decide on the scales for both of your axes.
$\square$ However, you will also need to include the size of the Megalodon tooth in your graph, so take that into consideration!

## Exercise 4c: Size of the Megalodon

aConnect the points with a line and extend the line beyond the last point you plotted on the graph.
UNow measure the width of your Megalodon shark tooth by measuring it across the widest point of the root.
$\square$ Record the width, and use the line you drew with the previous points to find the approximate body length of the Megalodon shark represented by the tooth specimen in your box, and answer the following questions:
DAccording to your graph, how long was the Megalodon shark from which your Megalodon tooth was obtained?
uHow does the length of the Megalodon shark compare to the different modern-day sharks listed in the table?
-You may wish to illustrate the sizes of these various sharks by making posters with lines illustrating the actual size of these sharks (or if you're feeling really creative, by drawing life-sized sharks!) and display these in your classroom or hallway.

## Exercise 4c: Size of the Megalodon

DOPTIONAL: Measure each of the other shark teeth provided in this unit, and use the same methods above to estimate the sizes of the individuals of those shark species represented by the teeth that you were provided, and answer the following questions:
DHow do the sizes of these other extinct shark species compare to the size of the Megalodon?
$\square$ If you have already completed the exercise on determining a fossil lineage, you know the approximate ages of each of these teeth, indicating the time periods when these species existed. How did this lineage change, in terms of overall body size over time?
-OPTIONAL: Make another plot, showing body size of these shark species, plotted against time.


## Materials List

-2 clear plastic boxes labeled "Exercise 1. Fossils T/F" containing
-22 specimens (numbered 1-22) NOTE: \#7 is
currently unavailable!

- Magnifying glass
-Plastic deli cup labeled "Exercise 3c. Half-Life Experiment" containing:
- 32 light-colored poker chips (with a colored dot on one side of each)
-32 dark-colored poker chips
-Round plastic container holding
-modern shark jaw



## Materials List (continued)

-Plastic bag labeled "Exercise 4. Fossil Lineages" containing
-Bag labeled "Exercise 4a. Determining a Fossil
Lineage" containing
-5 fossil shark teeth, each labeled and marked with a red dot:
-Cretolamna appendiculata

- Carcharocles auriculatus
- Carcharocles chubutensis
- Carcharocles megalodon
- Otodus obliquus
-Bag labeled "Exercise 4b:. Comparing lineages" containing
-A single fossil shark tooth - Crow shark (Squalicorax pristodontus)



## Radioactive Dating: As radioactive materials

 decay, their decay products accumulate.| Decay of parent isotope |
| :--- |
| Inverse exponential: $y=e^{x}$ |


| Production of decay product <br> Logarithm: $y=\ln (x)$ |
| :--- |




# Suggested Reading - Younger Students 



## Suggested Reading - Higher Grades

## Grades 7+

Dinosaur Tracks and Other Fossil Footprints of the Western United
States - Martin Lockley and Adrian P. Hunt
Reading Between the Bones: The Pioneers of Dinosaur Paleontology Susan Clinton
Dinosaurs: The Most Complete, Up-to-Date Encyclopedia for Dinosaur Lovers of All Ages - Dr. Thomas R. Holtz Jr. \& Luis V. Rey (Illustrator)
Fossil Legends of the First Americans - Adrienne Mayor
An Introduction to Fossils and Minerals: Seeking Clues to the Earth's Past - Jon Erickson

Scientific Journal Articles (PDFs included on Teacher CD!
Botella, H., J.I. Valenzuela-Rios, and C. Martinez-Perez. Tooth replacement ir early chondrichthyans: a qualitative approach. Lethaia 42:365-376.
Hone, D.W.E. and O.W.M. Rauhut. Feeding behaviour and bone utilization by theropod dinosaurs. Lethaia. 10.1111/j.1502-3931.2009.00187.x
Sánchez et al. Cleptoparasitism and detritivory in dung beetle fossil brood balls from Patagonia, Argentina. Palaeontology 52(4): 837-848.



## Links (Underlined text is clickable!)

## General Information on Fossils and Earth's Geologic History

Paleontology News (Science Daily) - get the latest info on new fossil discoveries!
PaleontOLogy: The Big Dig - The main page for the paleontology channel at the American Museum of Natural History's OLogy site. Lots of good stuff here for a broad age range!
Fossils, Rocks, and Time - Good introductory information from USGS.
Paleontology - Online Resources - HUGE compilation of tons of informative links, organized by the United States Geological Survey. Excellent! (Note: Page was last updated in 1999, \& not all links may work. Well worth it for the ones that do, though!)
Statefossils.com - Did you know that most states have an official state fossil? This site provides a list of all state fossils, as well as information about each of those organisms!
UCMP - University of California Museum of Paleontology - Another great comprehensive paleo site! Make sure to check out The Paleontology Portal, too!
The Paleontology Portal: Exploring Time and Space - Even though TPP is mentioned above, this deserves a mention of its own! Includes interactive maps of the US, allowing students to click on a state to see its geological history, with interactive fossil galleries!
Gray Fossil Museum - This museum in Washington County, Tennessee, is located near an impressive dig site, where lots of Miocene mammal fossils between 4.5-7 million years old have been recovered. Sounds like a great idea for a field trip!
Frank H. McClung Museum - This museum, located on the University of Tennessee campus in Knoxville, has an excellent exhibit on the geology and fossil history of Tennessee. Best of all, admission is free!
Fossils - Resources for teachers and students.


## Links (continued)

(Underlined text is clickable!)

## Radioactive Decay and Radiometric Dating

Simulating Radioactive Decay- Exercise 3 is based on this simulation exercise developed by John DeLaughter.
Applet: Decay - This is a Java applet that is a simulation of radioactive decay, in which students can change the half life of a hypothetical radioisotope, and observe the process of decay to daughter material.
Halflife - Website from the Physics department at the University of Colorado Boulder. Offers good basic information on radioactive decay, as well as another web-based applet that allows the students to select from several actual real-world radioisotopes and observe both the decay of parent isotope and formation of daughter isotope, with images of "atoms", as well as graphical output of the process.

## Evolution and Shark Lineages

Understanding Evolution - great source for information on evolution from UC Berkeley
A Golden Age of Sharks - Page about the evolution of sharks from the ReefQuest Centre for Shark Research. Lots of great information here for students interested in sharks!
Megalodon Shark Evolution - An article by Lutz Andres describing the evolution of the Megalodon shark lineage, which students examine directly in Exercise 4.
A Key to the Common Genera of Neogene Shark Teeth - A taxonomic key by Robert Purdy, used for the identification of ancient shark species based on their teeth.

