SCIENCE 3D

WEST COAST WHITE SHARK

In this packet, sample student answers are provided in red and notes to teachers are in blue.

In this **Mission Research**, students will investigate the geological time scale and change through time using the fossil record of sharks. They will also explore continental drift. Using fossils, they will test a prediction they make about the relationship between the extinct megalodon and modern white sharks. An additional activity allows students to explore natural selection and relatedness using traits in modern day species, including characteristics of embryos.

Sharks have been top predators in Earth's oceans for millions of years. The fossil record (the record of life on Earth) has helped scientists learn how environments have changed through time. New discoveries have helped us improve our understanding of how organisms and the diversity of life have changed as well. These discoveries have helped us learn how organisms are related to one another and piece together ancient family trees, including for sharks. But, before we start working on ancient sharks, let's investigate geological time and the fossil record.

Note: The **Mission Research** for *Sea Turtles 360* provides an exploration of index fossils and how rocks are dated using radiometric data.

ACTIVITY I: GEOLOGICAL TIME AND THE FOSSIL RECORD

The history of Earth is measured on the Geological Time Scale. It starts when the first rocks on Earth started to solidify around 4.5 billion years ago. Geological time is divided up into Eras, Periods, and Epochs. The end and the beginning of each geological time period is determined by major events in the fossil record. The most common animal groups on Earth have changed through time. Our understanding of these animals continues to change as more fossils are discovered. For example, we now know that dinosaurs were covered in feathers, just like their bird descendants! The illustrations below are artists' representations of some of these animals. They used the fossil record to determine what they might have looked like. The illustrations are not to scale!

Opabina
Cambrian Period

Opabina **was a small marine invertebrate from the Cambrian Period, a time when invertebrates were the dominant organisms in the oceans.**

Dunkelosteus
Devonian Period

During the age of fishes, a group called placoderms were the top predators in many habitats for millions of years. The largest of them, *Dunkelosteus*, **grew to almost 9 meters long!**

Eryops
Carboniferous Period

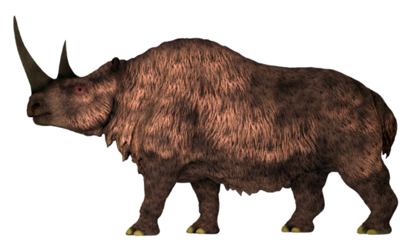
Eryops **was an amphibian that was more than 2 meters long that lived during the Carboniferous and Permian periods, when amphibians dominated many habitats.**

Dimetrodon
Permian Period

Some species of *Dimetrodon*, **a reptile with a sail on its back, grew to over 4.5 meters long. In the Permian Period, reptiles came to dominate land habitats. At the end of the Permian period much of the life on land and in the sea went extinct.**

Tyrannosaurus rex
Cretaceous Period

During the Mesozoic Era, which came after the Permian extinction, dinosaurs, including *T. rex* **(Cretaceous Period), ruled the lands.**



Woolly Rhinoceros
Quaternary Period

When dinosaurs (except for birds) went extinct at the end of the Cretaceous period, mammals came to dominate the land. The woolly rhinoceros first appeared in the Quaternary Period.

Figure 1. Animals from different time periods of Earth's past

We are going to explore the fossil record of sharks. But first, we need to know about things that were happening on the planet while sharks were evolving. The major events going on in the world and the positions of the continents are shown in Figure 2.

ERA	PERIOD	EPOCH/AGE	MILLION YEARS AGO	EVENTS
CENOZOIC *Age of Mammals* **65 mya – present day**	*Quaternary*	*Holocene*	TODAY	Ice Age ends, humans are dominant
		Pleistocene	0.01	First humans appear
	Tertiary	*Pliocene*	1.8	
		Miocene	5.3	Hominids (human ancestors) appear
		Oligocene	23	Grass becomes widespread
		Eocene	34	Mammals are dominant
		Paleocene	56	First large mammals appear
MESOZOIC *Age of Reptiles* **245 mya – 65 mya**	*Cretaceous*		66	K-T extinction event; flowering plants appear
	Jurassic		145	First birds appear; Pangaea splits into Laurasia and Gondwana; dinosaurs are dominant.
	Triassic		201	Pangaea cracks; first dinosaurs appear; first mammals appear; reptiles are dominant
PALEOZOIC **570 mya – 245 mya**	*Permian*	*Age of Amphibians*	252	Pangaea forms
	Carboniferous		299	First reptiles appear
	Devonian	*Age of Fishes*	359	First land animals appear; first amphibians appear
	Silurian		419	First land plants appear; first jawed fishes appear; first insects appear
	Ordovician	*Age of Invertebrates*	444	First vertebrates appear
	Cambrian		485	First fungi appear; trilobites are dominant
PRECAMBRIAN **4600 mya – 570 mya**	*Proterozoic Eon*		541	First soft-bodied animals appear; first multicellular life appears
	Archean Eon		2,500	First unicellular life appears
	Hadean Eon	*Priscoan Period*	4,000 / 4,600	Atmosphere and oceans form; oldest rocks form as Earth cools

FORMATION OF EARTH

CONTINENTAL DRIFT

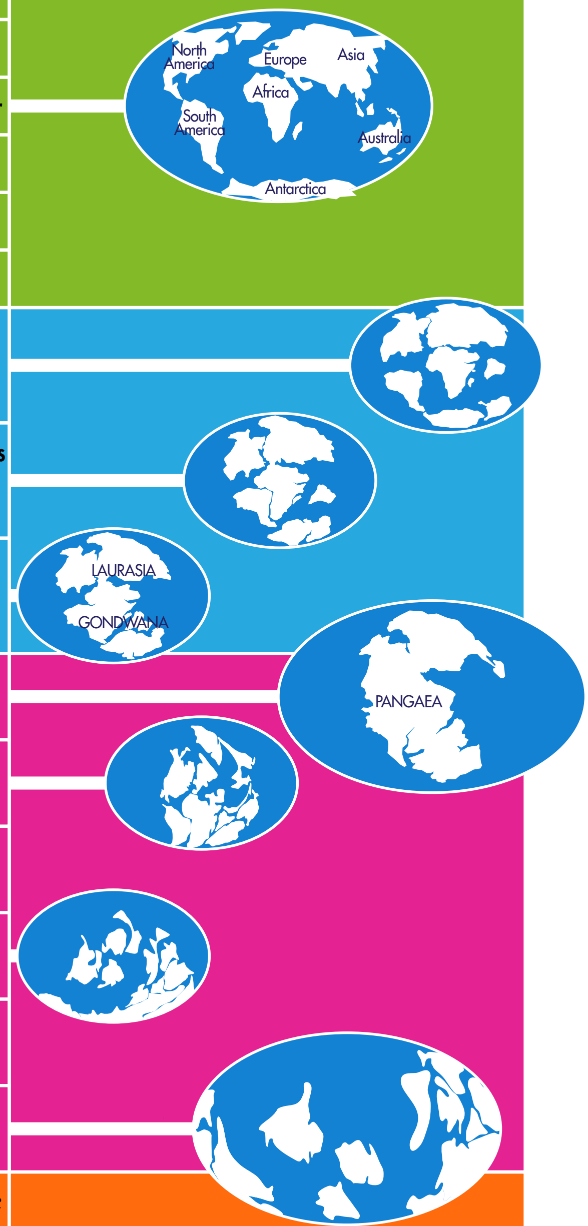


Figure 2. Geological time scale and major events in the fossil record

Use Figure 2 to answer the following questions.

1. **Describe** the arrangement of time on the geological time scale. Are more recent time periods located near the top or bottom of the scale?

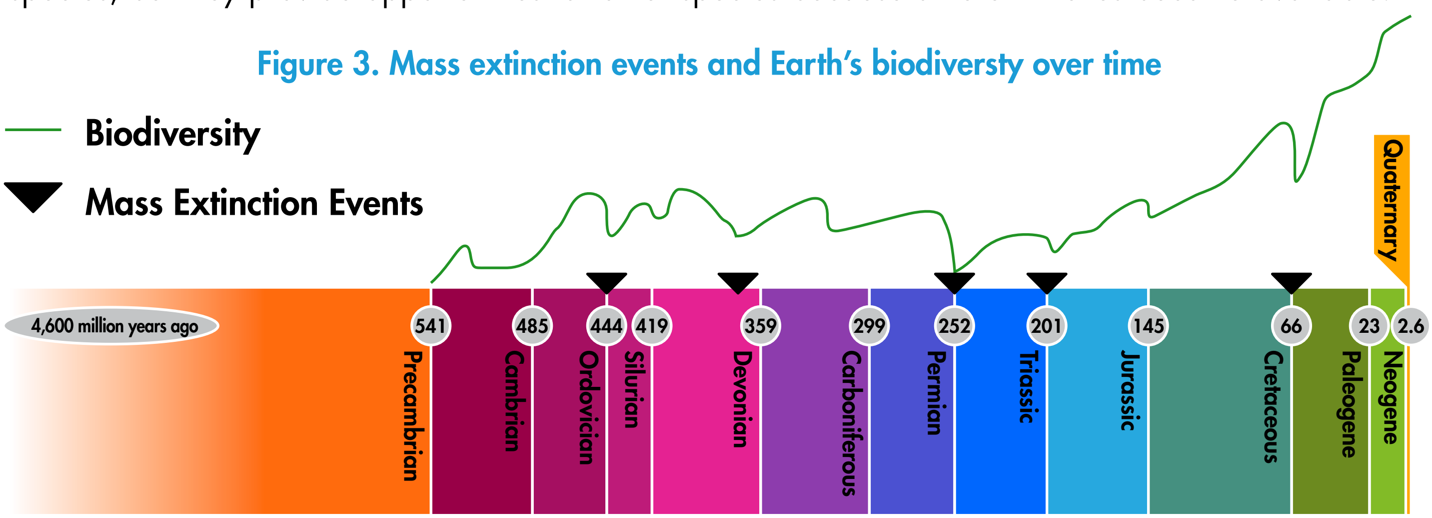
More modern time periods and events are closer to the top of the scale. More ancient time periods are at the bottom of the scale.

2. **Explain** whether or not the boxes that represent the different time periods are drawn to scale. Does the size of the box reflect how long the period lasted?

No, the time periods are not to scale. For example, the Paleozoic Era box represents a 325 million year period, whereas the Cenozoic Era box only represents 65 million years, even though the boxes are about the same size. The Precambrian box is the smallest in size, but represents the most time.

In addition to the movements of continents, large changes have happened to the biodiversity, or the number of species, on Earth through geological time. Figure 3 shows how biodiversity has changed through Earth's history. Mass extinctions have occurred five times in the past. Moving continents, meteor strikes, and huge volcanic eruptions are some of the causes of these events. Today, humans are causing extinctions at a higher-than-natural rate. Mass extinctions are a disaster for many species, but they provide opportunities for other species because different niches become available.

Figure 3. Mass extinction events and Earth's biodiversty over time



3. **Describe** the pattern of Earth's biodiversity through time. What seems to happen to biodiversity immediately following mass extinction events?

In general, the biodiversity on Earth has increased over time. But, there are big declines in biodiversity after every mass extinction event. After mass extinctions, biodiversity increases again.

*See page 21 for an **Extend the Lesson** based on this material.

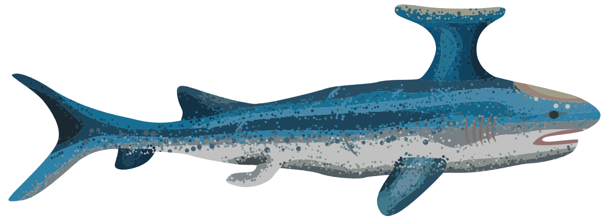
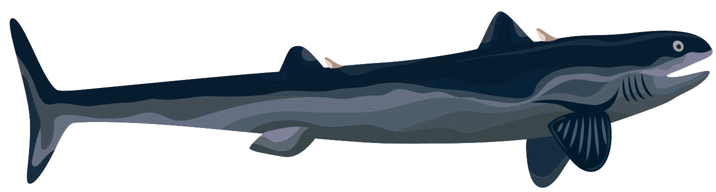
ACTIVITY 2: SHARKS THROUGH TIME

1. **Complete** Table 1 by filling in the correct time period for the different events listed. For events in the Tertiary Period, also fill in the Epoch (for example, you could write "*Tertiary, Miocene*").

Table 1. Highlights from the history of shark evolution

Approximate Age (millions of years ago)	**Time Period**	**Fossil Evidence**
Present Day	Quaternary, Holocene	Modern day sharks inhabit today's oceans.
3	Tertiary, Pliocene	Last *megalodon* teeth are in fossil record.
18	Tertiary, Miocene	*Megalodon* teeth appear in fossil record.
22	Tertiary, Miocene	Scientists think first hammerhead sharks appear, but fossils suggest it may be earlier.
30	Tertiary, Oligocene	Fossils of giant sharks from coastal areas are discovered.
45	Tertiary, Eocene	First white shark species evolve from the mako shark lineage.
60	Tertiary, Paleocene	Bony fish start to become more commonly found in the fossil record than sharks.
65	Beginning of Tertiary/ End of Cretaceous	Most species of large sharks disappear.
100	Cretaceous	First teeth of mackerel sharks (Family Lamnidae) appear.
150 - 195	Jurassic	The first members of other groups of sharks that are still around today appear; sharks with flexible jaws appear.
195	Jurassic	Sixgill sharks appear (the first group of sharks that has species still surviving today).
252	Beginning of Triassic/ End of Permian	Another mass extinction occurs, resulting in the disappearance of 95% of marine species forever.

Table 1 (Cont). Highlights from the history of shark evolution

Approximate Age (millions of years ago)	**Time Period**	**Fossil Evidence**
252	Carboniferous	Early sharks diversify. Some have bizarre forms, including the 60 - 70 cm long *Stethacanthus*. 
360	Beginning of Carboniferous/ End of Devonian	A mass extinction event occurs, resulting in the disappearance of 75% of species, including many groups of fishes.
380	Devonian	Whole body fossils of sharks appear, like *Cladoselache* (1.8 m long) that have some characteristics of modern sharks (like their shape) and some characteristics of ancient sharks (like a jaw fused to their head).  
400	Devonian	First shark teeth appear in the fossil record.
420	Silurian	First shark-like scales appear in the fossil record.
485	Beginning of Ordovician/ End of Cambrian	There are no sharks in the fossil record at this time. Invertebrates (like trilobites) are dominant in the oceans.

2. **Complete** the following table by filling in the shark evolution events based on the fossil evidence of that time period. In the right column, **sketch** a drawing of where the continents were during the Tertiary Period, the Mesozoic Era, the late Paleozoic Era, and the early Paleozoic Era.

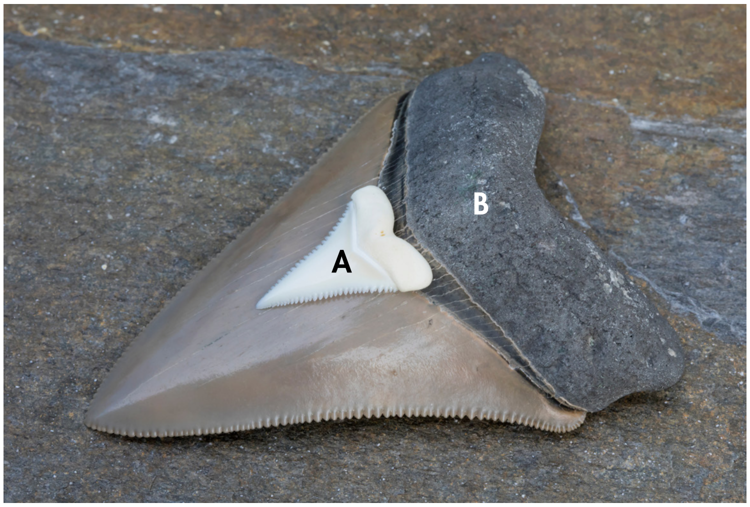
Period	Epoch	Shark evolution event	Where the continents were
Quaternary	*Holocene*	Modern sharks flourish.	
Tertiary	*Pliocene*	*Megalodon* goes extinct.	
	Miocene	*Megalodon* appears.	
	Oligocene	Giant sharks live in coastal waters.	
	Eocene	White sharks first appear.	
	Paleocene	Bony fish become more common than sharks.	
Cretaceous		Mackerel sharks appear. Large sharks start to disappear.	
Jurassic		Sixgill sharks appear. Sharks with flexible jaws appear.	
Triassic		Earth recovers from mass extinction.	

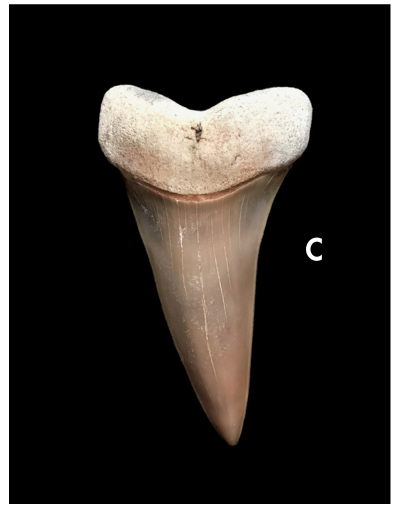
Period	Shark event	Where the continents were
Permian	Mass extinction causes 95% of marine life to die.	
Carboniferous	Early sharks diversify into many forms; some are strange.	
Devonian	Mass extinction causes many fish to die. Sharks with bodies similar to those with modern characteristics appear. First sharks with teeth appear.	
Silurian	First sharks (or shark-like fish) appear.	

Extend the Lesson: There are some incredibly interesting and bizarre sharks that used to prowl the oceans and freshwaters! Have students conduct online research and create a poster about an ancient shark. Be sure the poster includes the locations they were found, the other species in their habitats at the time, and where the continents were positioned when they were alive. Make sure students also present information on what evidence scientists have used to determine what the sharks looked like, when they were alive, and how they might have behaved.

Extend the Lesson Further: Have students create another timeline that compares major events in shark evolution to changes in the fauna on land. Have them see if the big extinctions in the oceans also happened on land. Have them explore what happened after those extinctions. Did the same types of organisms come to dominate land habitats after the extinction events? Alternatively, have them investigate what caused those mass extinctions.

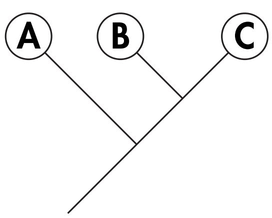
ACTIVITY 3: RISE OF WHITE SHARKS... AND MEGALODON



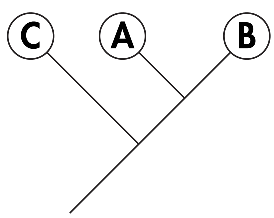


Look at the modern white shark tooth (labeled A) above. Then look at the fossilized *megalodon* tooth (labeled B) it is sitting on. For many years, white sharks and *megalodon* were classified in the same genus, *Carcharodon*, but how closely related are they? Transitional forms are fossils that link a more ancient species to its descendants. Transitional fossils can help piece together the evolution of white sharks and *megalodon*. Observe how the tooth to the right (labeled C) compares to the two to the left. Discuss characteristics of the teeth like size, shape, and serrations along the edge.

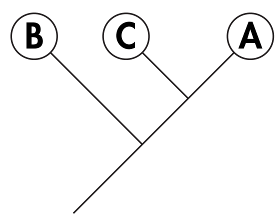
Below are three different possible sets of relationships between the three shark species whose teeth are shown above. The teeth that are more closely linked together on the tree are more closely related to one another.



B and C are most closely related.

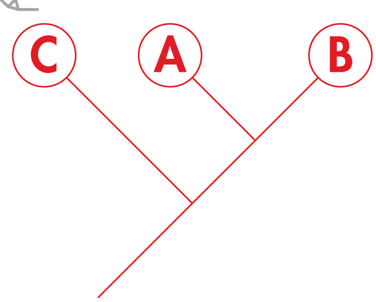


A and B are most closely related.



A and C are most closely related.

1. Based on looking at the teeth above, **draw** the tree that you think describes the relationships of the three shark species. **Describe** the traits that helped you make this hypothesis.



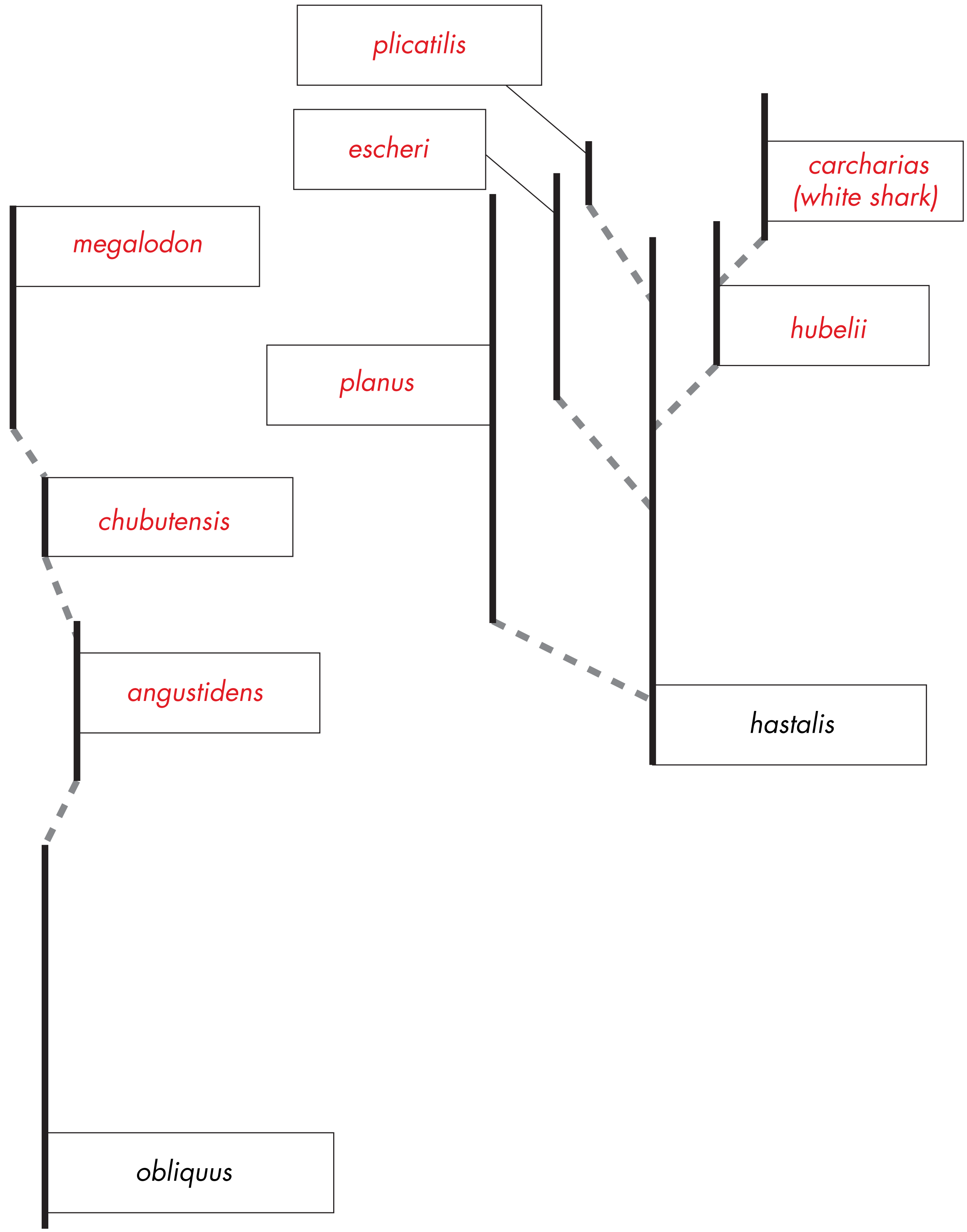
Accept any answer that is reasonably well-defended. A strong answer includes: A and B look the most similar. Both have teeth that are very triangular and have serrations. Their shape is similar. Tooth C is smooth. It is more narrow and pointy.

Now, let's look at drawings of more fossils paleontologists have found that help fill in millions of years of shark history. Figure 4 shows shark teeth from several species from the last 65 million years.

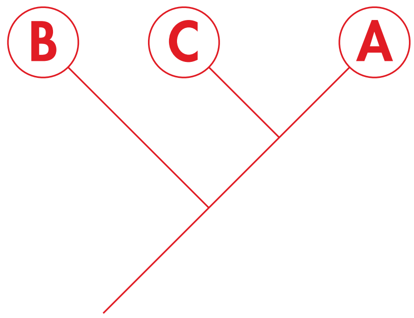
Figure 4. Fossilized shark teeth found from the Cenozoic era

2. **Write** the species names from Figure 4 in the boxes provided below to generate a likely family tree of these sharks. Closely observe the characteristics of the teeth to see which you think are most similar. Black lines indicate where in the Geologic Time Scale species were found, and gray dashed lines connect species that are closely related. Consider having students also draw sketches of the shark tooth they list next to each box to show the changes in the teeth.

EPOCH	MYA
Holocene	
Pleistocene	*0.01 MYA*
	1.6 MYA
Pliocene	
	5 MYA
Miocene	
	23 MYA
Oligocene	
	36 MYA
Eocene	
	57 MYA
Paleocene	*65 MYA*



3. Take another look at the three shark tooth images at the beginning of Activity 3. It turns out that shark tooth C actually belongs to *hastalis*. Based on your work for question 2, **re-draw** a three species tree (like you did in question 1) that shows the relationships between these three species.



A and C are more closely related.

4. Based on your new family tree, was your hypothesis in question 1 correct? **Provide** evidence to support your claim.

Answers will depend on the hypothesis that students made in question 1. A common correct answer includes: My hypothesis in question 1 was not correct. By seeing more species, their relatedness, and when they were alive, it turns out that out that *megalodon* and white sharks are not close relatives. Instead, white sharks are more closely related to *hastalis*.

5. **Describe** how having transitional forms of sharks helped you determine if great white sharks and *megalodon* are close relatives.

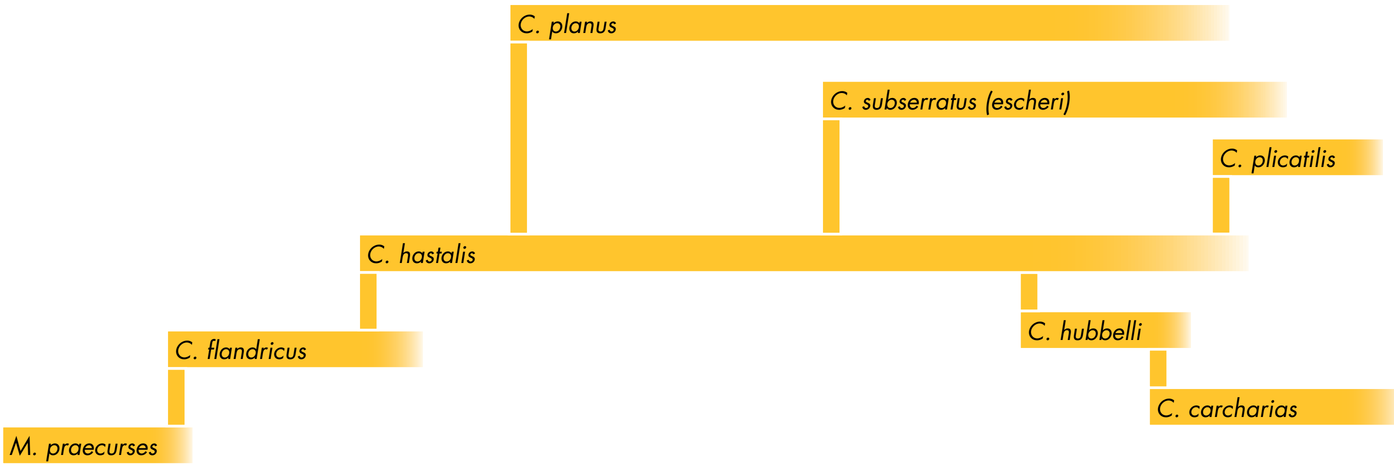
Seeing transitional forms let me put together the steps of change through time that led to white sharks and *megalodon*. They show that white sharks did not evolve from *megalodon*. They are on separate parts of the shark family tree.

6. Based on your tree, did white sharks and *megalodon* share a common ancestor in the past 40 million years?

No, I don't think they did. The transitional forms show that the lines of white sharks and *megalodon* were not together 40 million years ago.

Below is a figure that outlines the timeline of white shark evolution to assist with the questions in Activity 3. Note that the genus name for *megalodon* has changed several times. For a while, the species was "*Carcharodon megalodon.*" Then, it was classified as "*Carcharocles megalodon.*" Now, it is known as "*Otodus megalodon.*" If students mention this, it is a good time to discuss how we update our classifications as more evidence is discovered.

Eocene	*Oligocene*		*Miocene*			*Pliocene*	
LATE	EARLY	LATE	EARLY	MIDDLE	LATE	EARLY	LATE
	34 myo		23 myo			5.3 myo	

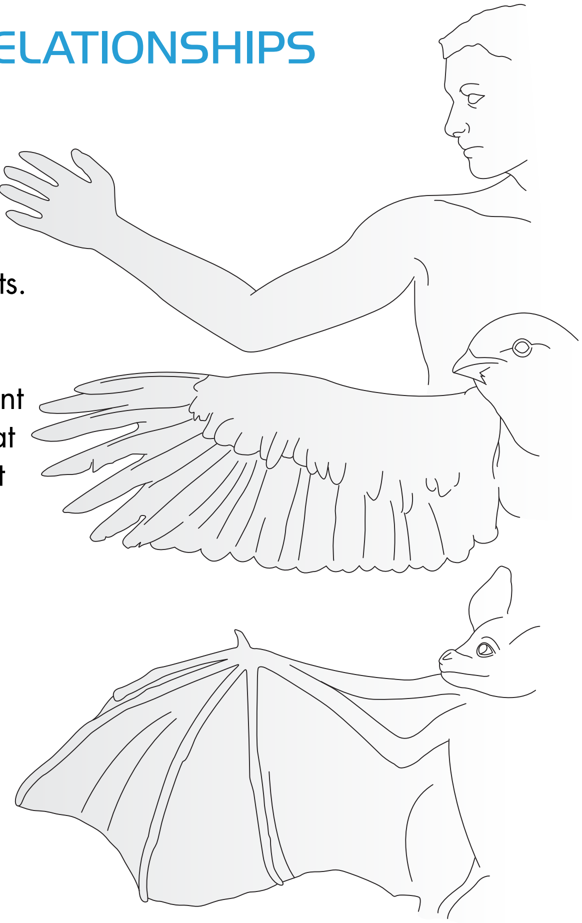


This site has good background material on shark evolution:
https://www.fossilguy.com/gallery/vert/fish-shark/giant-white/index.htm

Extend the Lesson: Some fictional television shows and movies may have convinced students that *Otodus megalodon* might still be alive. But, paleontologists and scientists have found that they have been gone for 3 million years. Have students research the evidence that *megalodon* went extinct and the hypotheses for why they went extinct. Have them write a short essay or create a presentation. Then, students can debate the reasons they think that megalodon disappeared.

Tie to Other Standards: This is a good place to talk with students about other ways that family trees are made. You could have them look at embryos or consider how genetic data are used to reconstruct family trees. For a wonderful genetic reconstruction of relationships among living sharks and rays visit: www.sharksrays.org

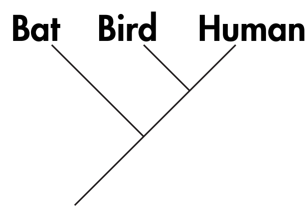
ACTIVITY 4: INFERRING RELATIONSHIPS



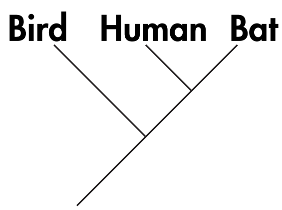
You used fossil teeth and transitional forms to reveal the relationships between today's white sharks and *megalodon*. For ancient sharks, sometimes teeth are the only evidence available to figure out how different species are related. Considering more traits helps scientists get more accurate results. Just looking at one trait can be misleading. Let's investigate!

1. Look at the image to the right that compares the shapes of front limbs of a human, a bird, and a bat. Based on only looking at the shapes, which of the following relationships below is most likely? **Explain** your reasoning.

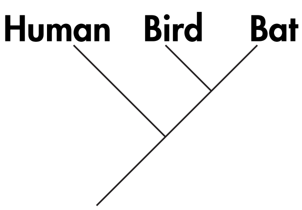
a. Humans and birds are most closely related.



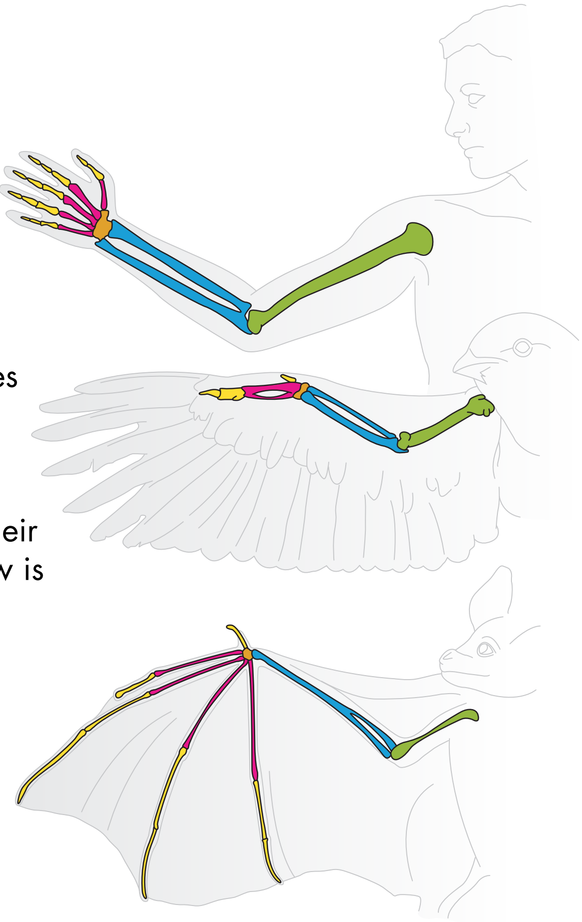
b. Humans and bats are most closely related.



c. Bats and birds are most closely related.



I think that Option C is most likely if all I looked at was the shape of the forelimbs. Bats and birds have wings. Humans don't have wings at all.

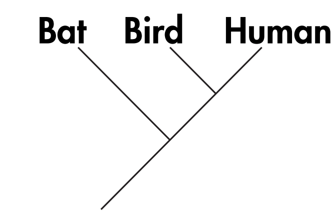


Sometimes, natural selection causes some traits to look very similar even in species that are not related. For example, sharks (fish) and dolphins (mammals) are not closely related, but their bodies are the same shape! Now, let's look at other traits of bats, humans, and birds to see if that changes our view of how these species are related to one another.

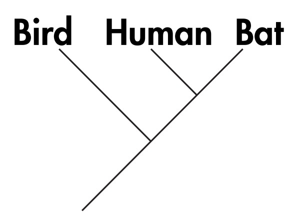
Consider the types of body covering that the different species have (hair/fur/feathers) and the arrangement of the bones inside the front limbs.

2. Based on the arrangement of bones in the front limbs and their external covering, which of the following relationships below is most likely? **Explain** your reasoning.

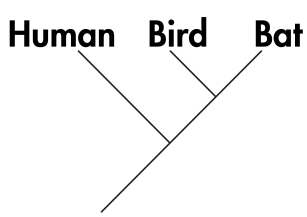
a. Humans and birds are most closely related.



b. Humans and bats are most closely related.



c. Bats and birds are most closely related.

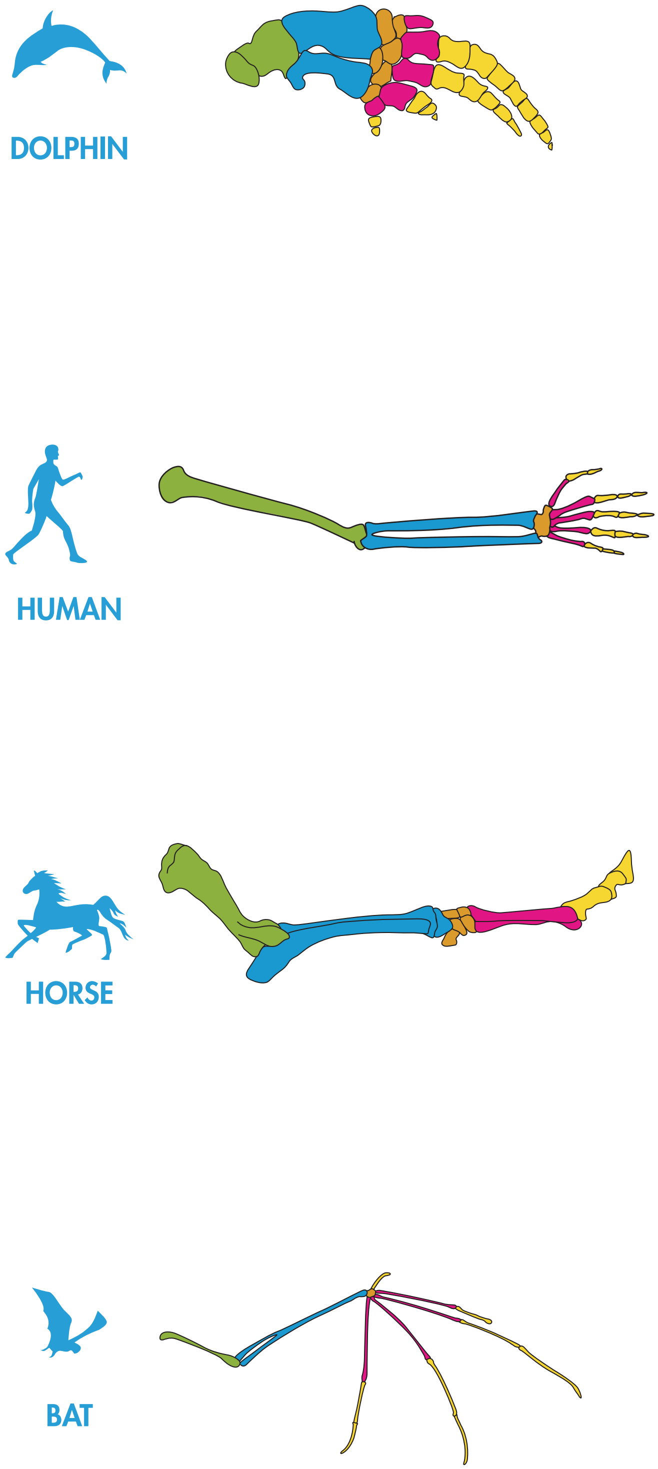


I think that option B is most likely. Birds are covered in feathers. Humans and bats have hair.

The bones inside the wing of the bat look a lot more similar to humans than to the bones in the

wing of a bird.

3. Look at the diagram below. **Compare** and **contrast** the arrangement and function of the bones in the forelimb of each animal. The same types of bones have the same color.

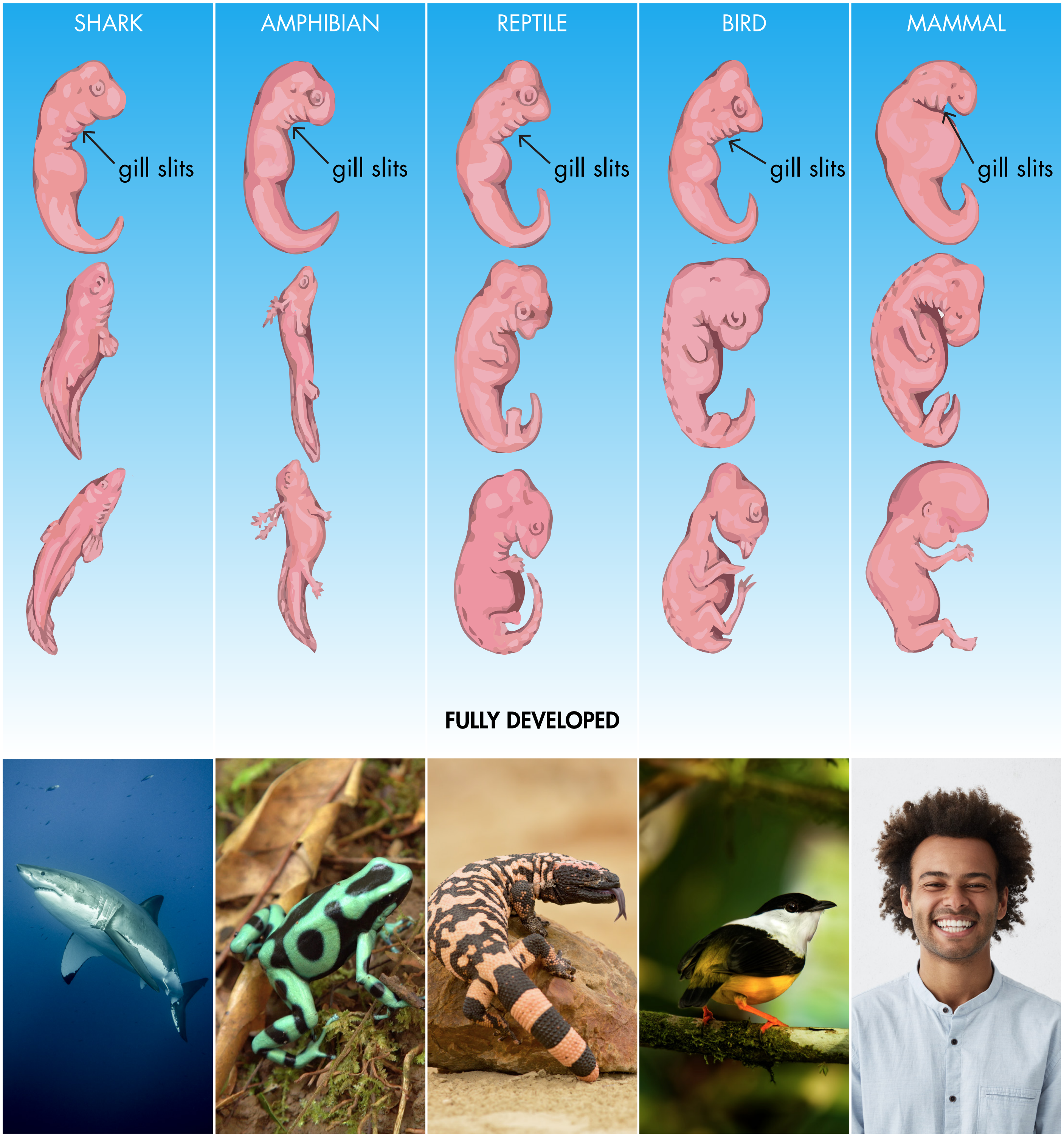


Students should not be expected to answer in tremendous detail but should see the basic pattern. They should see that each species has the same types of bones, but they are adapted to different functions. A complete answer includes:

All of the species have the same basic bones in their front limbs. But, they do different things. The bones in the dolphin make a flipper (help them turn while swimming). A person's bones help grab and move objects. The horse's bones are built for running. And, the bones in a bat make a wing for flying.

Scientists can also use embryos to understand relationships between animals. Animals go through many changes as they develop inside an egg or their mother. Animals that look very different as adults may look similar as embryos. Use the pictures below to answer the following questions.

EARLY EMBRYO



4. **Complete** Table 2 by putting an **x** in each cell if the animal has that trait in *both* the first stage of development *and* when they are fully developed.

Table 2. Characteristics of early embryos (E) and fully developed (D) individuals of different groups of vertebrates

	Fish		Amphibian		Reptile		Bird		Mammal	
	E	D	E	D	E	D	E	D	E	D
Gill folds or gills	x	x	x		x		x		x	
Tail	x	x	x	x	x	x	x	x	x	
Limb buds										
Fins		x								
Legs			x	x		x		x		x
Wings								x		
Eye spot or eye	x	x	x	x	x	x	x	x	x	x
Beak								x		

5. Do the vertebrates you investigated share more traits as embryos or as adults? Use data from your table to support your answer.

The table shows that all the early embryos have the same traits. But, fully developed organisms do not share many traits. For example, they have different type of limbs. Fish have gills, but most other vertebrates do not have gills.

6. **Compose** a paragraph that explains why embryos might help show how organisms are related.

Complete answers should include that embryos could be useful because species that are related share similar characteristics early in life. They become less similar as they develop.

Extend the Lesson: Have students create a table to compare the second and third steps of development. Have them compose a paragraph to explain how the different groups start with similar traits and then change through development. You could also have students investigate very early embryology from the single cell stage to the first stage shown here. Have different students create a poster showing stages of development for different vertebrates. Have the class compare and contrast their posters and discuss how embryos might reveal evolutionary relationships.

***Extend the Lesson** (from Activity 1 on page 5)**:** Have students describe how continents move. You could also use some of the traditional lessons of continental drift. Tell students that understanding how the continents moved is critical for understanding what was happening to life on the planet. New oceans form and old oceans close. Some continents were connected and then broke apart. Have a discussion about what they think would happen to organisms when continents break apart or collide. Use these predictions to make links to the development of new species or extinctions when species that have been apart come into contact. Relate the latter issue to challenges with invasive species today that occur when people move species. For a natural example, students could research the Great American Interchange (https://en.wikipedia.org/wiki/Great_American_Interchange). This event was important for life on land. North and South America joined and the ocean pathway between the Atlantic and Pacific Oceans closed.

Another extension for this investigation is to have students research different animations of continental drift (for example: https://www.youtube.com/watch?v=uLahVJNnoZ4 and https://www.youtube.com/watch?v=UwWWuttntio). Students can also look for different still images of the positions of continents. Have them compare and contrast the models. Have them think about what decisions people had to make in creating these models and the evidence that would have been used to know where the continents were at a particular time.