The Origin of Species: The Making of a Theory

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Film Guide
Educator Materials

OVERVIEW

The Making of a Theory is one of three films in HHMI's Origin of Species collection. This film chronicles the epic adventures and the evidence gathered from careful observations of the natural world by British naturalists Charles Darwin and Alfred Russel Wallace. During their voyages across the globe, they documented the variation among individual members of a species, the relationships among species, and the patterns of geographic distribution across many species. Based on such evidence, they independently came to the same revolutionary conclusions: species change over time by means of natural selection, and species descend from other species. The film emphasizes the processes of science, the passions of scientists, and the insights they gained in understanding life on our planet. It serves as an introduction to a unit on evolutionary science and the evidence on which the theory of evolution by natural selection was founded.

KEY CONCEPTS

A. Charles Darwin and Alfred Russel Wallace *independently* discovered the natural origin of species and formulated the theory of evolution by natural selection based on distinct sets of observations and facts.
B. The natural origin and evolution of species provide scientific explanations for both the diversity and the relatedness of species, as well as the sequence of change found in the fossil record.
C. Natural selection acts on variation among individuals within populations. The differential survival and reproductive success of individuals with different traits causes populations to change over time.
D. By comparing organisms living today with the fossil record of extinct organisms, it is possible to reconstruct evolutionary history.
E. Observations of the natural world raise questions. Scientific hypotheses provide tentative answers to such questions, which can then be tested by additional observations, experiments, evidence, and facts, which form the basis of a scientific theory.
F. Not all hypotheses can be tested in a controlled laboratory experiment. For example, the study of evolution requires gathering multiple lines of evidence to support conclusions about events that occurred in the past. As evidence accumulates, some hypotheses will be eliminated, while ever more detailed inferences are drawn.

CURRICULUM CONNECTIONS

Standards	Curriculum Connection
NGSS (2013)	LS2.A, LS3.B, LS4.B, LS4.C, ESS1.C
AP Bio (2015)	1.A.1, 1.A.2, 1.A.4, 1.C.1
IB Bio (2016)	5.1, 5.2, C.1
AP Env Sci (2013)	II.C
IB Env Systems and Societies (2017)	3.2
Common Core (2010)	ELA.RST.9-12.4, WHST.6-12.9, MP2
Vision and Change (2009)	CC1, CC5

PAUSE POINTS

The film may be viewed in its entirety or paused at specific points to review content with students. The table below lists suggested pause points, indicating the beginning and end times in minutes in the film.

	Begin	End	Content Description	Review Questions
1	0:00	5:34	• Darwin and Wallace independently embarked on voyages and made observations of the natural world. • In 1852, Alfred Russel Wallace left the Amazon, but lost his specimens and research notes in a fire. • Special creation was the idea that God specially created each species in its present form and constant. • Darwin discovered the origin of species 20 years before Wallace (in 1832) during his voyage on the HMS *Beagle*.	• When did Wallace and Darwin go on their research expeditions? • What was the predominant view about the origin of species in the mid-1800s?
2	5:35	11:44	• In South America, Darwin noticed fossils of species that were similar to, but different from, modern species. • On the Galápagos Islands, Darwin noticed differences among animals that lived on different islands: the tortoises had different shells and the mockingbirds had different colorations.	• What did Darwin notice about the tortoises and the mockingbirds?
3	11:45	15:30	• Darwin realized that species might change and that organisms today arose from older species. • Darwin shared accounts of his voyage but was reluctant to share his ideas about species changing over time because they were in opposition to the widely accepted idea of special creation.	• What evidence did Darwin use to support his idea that species come from other species? • Why was Darwin reluctant to share his ideas?
4	15:31	21:04	• Darwin and Wallace met in 1853, just before Wallace's second research trip. • From his observations of species in the Malay Archipelago and the Amazon, Wallace concluded that new species arise near similar species.	• When did Wallace and Darwin meet? • What did Wallace conclude about where new species arise?
5	21:05	27:25	• Wallace found more evidence in the patterns of distribution of species, variations among species, and vestigial structures. • Vestigial structures are evidence that species are a modified form of an older species. • The Wallace Line splits the Malay Archipelago according to the distribution of species. Charles Lyell and other geologists of the time argued that landforms had looked different throughout Earth's history. • Individuals within a species vary in small ways. • Thomas Malthus' writing about population influenced Wallace.	• What observations and facts did Wallace use to support his idea? • Who else influenced Wallace's thinking?
6	27:26	30:51	• Charles Darwin and Alfred Russel Wallace *independently* discovered the natural origin of species and formulated the theory of evolution by natural selection based on distinct sets of observations and facts. • Darwin published *On the Origin of Species* in 1859. Wallace also published a book about evolution, titled *Darwinism.*	• Who formulated the theory of evolution by natural selection?

BACKGROUND

The film *The Origin of Species: The Making of a Theory* illustrates the process of science and in particular how attempting to answer questions leads to the development of scientific explanations and conclusions, and how these conclusions are then tested and strengthened by further evidence and research.

While in South America, Darwin asked, "Why do the fossilized remains of extinct animals look similar to animals living today?" And when visiting the Galápagos Islands, he asked "Why do the shells of tortoises on different islands look different?" Wallace independently asked some of the same questions, for example, "Why are similar species found in the same geographical locations?" The exploration of these questions led the two scientists to independently conclude that all living species descend from common ancestors and that species change over time.

The film contains many examples of how observations and questions led to explanations. For example, Darwin observed different species of tortoises and mockingbirds living on different islands in the Galápagos. Such similar but different species living on nearby islands led Darwin to consider the radical possibility that species were not each created separately but that one species might have given rise to many.

Within a single species on a single island, Darwin noted variation among individuals. He realized that these variations could confer an advantage to individuals competing for limited resources. Individuals possessing traits that were advantageous in their environment were more likely to survive and produce more offspring. Over time, these advantageous traits would accrue in the population. In this way, new species of mockingbirds and tortoises could arise.

As he traveled through Indonesia, Wallace noted a curious distinction between the species of birds and animals in the northwestern part of the Malay Archipelago and those in the southeastern part, despite the similar climate and terrain. He traced a remarkably clear boundary that arced through the islands, which later became known as the Wallace Line. To the west of the line, mammals are similar to those found on the Asian mainland (i.e., placental mammals). To the east of the line, species resemble those found in Australia (i.e., marsupials). Wallace knew from the work of Charles Lyell and other geologists of the time that landforms had looked different throughout Earth's history. His observations could be explained if in the geologic past the western islands had been joined to Asia, and species on these islands would have descended from ancestors shared by species on the mainland. Species on the eastern islands shared ancestors with species found in Australia. Today we know that the islands to the west of the Wallace Line were joined together during glacial periods when sea level was lower; the islands to the east were never connected to those of the west because the water between them was too deep.

Darwin and Wallace developed their ideas and explanations using different facts and observations, gathered independently and in different parts of the world. Over time, their work has been supported by a vast amount of evidence, including genetic evidence. Today, the theory of evolution by natural selection is accepted as a central unifying principle in biology. However, biologists continue to investigate and ask questions about the processes that generate evolutionary change. For example, what roles do competition, genetics, the environment, and geography play? How do these factors work together to produce the variety of species in existence today as well as those we have discovered in the fossil record? Some of those questions are explored in two related short films in *The Origin of Species* series: *The Beak of the Finch* and *Lizards in an Evolutionary Tree*.

Timeline of Discovery

The film focuses on a few critical episodes during Wallace's and Darwin's travels and lives and the key evidence they gathered which led to the making of evolutionary theory (Figure 1). But their contributions to science extend

beyond what is covered in the film—in particular, Darwin formulated the first correct theory on coral reef formation, and his prolific work and writing addressed topics from the domestication of animals and plants to the origin of humanity.

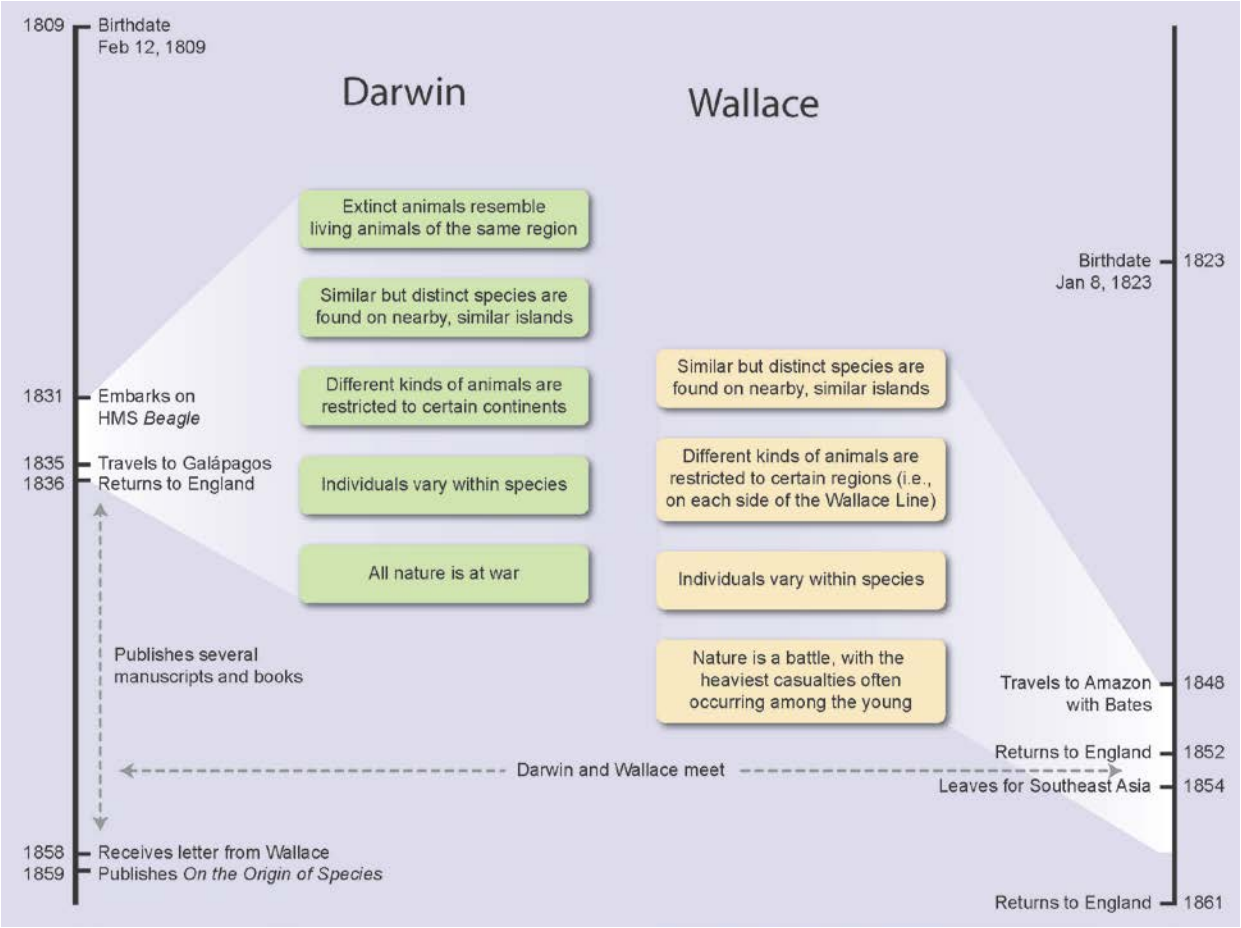


Figure 1. This image shows the timeline of key events in Darwin's and Wallace's lives, including key facts and observations (indicated in the boxes) made by each naturalist.

The film does not unfold in strict chronological order, so students may benefit from some help in understanding the sequence of events. The film opens in 1852 as Wallace was sailing back from a trip to the Amazon. Wallace, who was born in 1823, ended his formal schooling when he was 14 due to family financial difficulties, and he started to work as a land surveyor in England and Wales. An avid insect collector, Wallace became acquainted with Henry Walter Bates, an English naturalist and explorer. In 1848, Wallace and Bates left England on an expedition to the Amazon to be funded by the sale of collected specimens. While there, Wallace and Bates parted ways, and in 1852, Wallace decided to return to England. On his return voyage, his ship caught fire, destroying all his specimens and leaving him adrift in the Atlantic for 10 days. A year later, Wallace reported his observations in several publications, including *A Narrative of Travels on the Amazon and Rio Negro, with an Account of the Native Tribes, and Observations on the Climate, Geology, and Natural History of the Amazon Valley* and *Palm Trees of the Amazon and Their Uses.*

The film then retraces Charles Darwin's earlier voyage on the HMS *Beagle*. When he started the five-year journey, in 1831, Darwin was 22. Born to a wealthy gentry's family, Darwin had attended Edinburgh University with the intent to study medicine. When Darwin discovered he had no stomach for blood and suffering, his father suggested the ministry as an alternative career, and in 1827, at age 18, Darwin began his ordinary studies at Christ College at Cambridge University. He also became an enthusiastic naturalist, collecting beetles and taking classes

from botany professor John Stevens Henslow. Darwin intended to study divinity under Henslow, but Henslow recommended Darwin to be the naturalist and traveling companion to Commander Robert FitzRoy on the survey ship HMS *Beagle.*

Darwin boarded the *Beagle* an orthodox believer in the fixity of species. But the observations he made during the five-year voyage challenged this view, such that within two years of arriving back in England, he had an entirely new, radical theory for explaining the origins of species and their traits. Darwin did not publish it, however, for fear that he would be pilloried. Instead, Darwin published the zoological results of the voyage in a five-part volume entitled *The Zoology of the Voyage of H.M.S. Beagle*, between February 1838 and October 1843. During this time, Darwin also befriended geologist Charles Lyell, and he read Rev. Thomas Robert Malthus' 1798 *Essay on the Principle of Population*, in which Malthus wrote that hunger, disease, and poverty kept human populations in check. Darwin gradually disclosed his theory to a few select close colleagues and wrote a 230-page manuscript in 1844 but did not publish it.

In the following decade, Darwin published numerous books and pamphlets, including *Journal of Researches* (later known as *Voyage of the Beagle*), *The Structure and Distribution of Coral Reefs,* and *Geological Observations on the Volcanic Islands and Parts of South America Visited During the Voyage of H.M.S. Beagle.*

In 1856, Lyell urged Darwin to publish his theory on natural selection, but Darwin remained hesitant, despite having spent 20 years accumulating evidence for both natural and artificial selection. The popular view among naturalists was still "special creation"—or that each species had been individually created by God and had remained unchanged since its creation. Darwin's hand was forced in 1858 when he received a letter from Wallace asking for comments on his essay *On the Tendency of Varieties to Depart Indefinitely from the Original Type.* Wallace had sent this letter while he was traveling and collecting in the Malay Archipelago, having met Darwin briefly in London for the first time prior to setting off on this voyage in 1854.

Darwin recognized that Wallace's explanation matched his own, noting in his autobiography, "*I never saw a more striking coincidence*." His friends, Lyell and botanist Joseph Hooker (1817-1911), presented Wallace's manuscript and some unpublished excerpts from Darwin's writings at a special meeting of the Linnaean Society of London on July 1858. A few weeks later, these writings were published together in a scientific paper with Darwin and Wallace as co-authors. This paper was the first to clearly explain the theory of evolution by natural selection.

Observations of the natural world independently led Wallace and Darwin to the same conclusions. Over time, Darwin has been almost exclusively credited with formulating the ideas and mechanisms of natural selection, primarily due to the significant body of evidence put forth in his book *On the Origin of Species by Means of Natural Selection,* first published in 1859. But in their day, the theory was known as the Darwin-Wallace theory, and both men generously credited one another.

Setting the Stage for Evolution

"*Organic life beneath the shoreless waves*
Was born and nurs'd in ocean's pearly caves
First forms minute, unseen by spheric glass
Move on the mud, or pierce the watery mass
These, as successive generations bloom
New powers acquire and larger limbs assume
Whence countless groups of vegetation spring
And breathing realms of fin and feet and wing"
—Erasmus Darwin, *The Temple of Nature*, 1802

At the time Darwin and Wallace were collecting specimens and making their observations, the prevailing explanation of species diversity from the European perspective was based on special creation by God. Although Darwin and Wallace were the first to formulate the theory of evolution by natural selection, based on scientific evidence, other scientists and thinkers had proposed ideas about biological evolution and change throughout Earth's history. These individuals greatly influenced Darwin's and Wallace's thinking.

Erasmus Darwin (1731-1802), Charles' grandfather, was one of the leading intellectuals of 18th century England. A respected physician, poet, and botanist, Erasmus Darwin wrote his views on the natural origin of organisms and that species change over time in both verse and prose. By the time Charles Darwin was born, French naturalist Jean-Baptiste Lamarck (1744-1829) had proposed an idea of evolution based on the inheritance of acquired characteristics. Although Lamarck was wrong about the mechanisms by which evolution occurs, he is usually credited for being the first Western scientist to make scientific arguments for biological evolution.

At the same time, scientists in other disciplines debated the notion of change in Earth's history. Georges-Louis LeClerc, Comte de Buffon (1707-1788), and later naturalists Joseph Fourier (1768-1830) and William Buckland (1784-1856), claimed Earth had a natural history, beginning as a hot, molten ball that gradually cooled over time, interrupted by violent catastrophes. At the National Museum in Paris, Georges Cuvier (1769-1832), the leading authority on animal anatomy, developed a system by which the anatomy of an animal could be determined from a single bone. When Cuvier used his reconstructive system on fossils, he concluded that it established that species had gone extinct. Like Buckland and others, Cuvier explained these extinctions as the result of catastrophes.

But not everyone thought Earth's history had been shaped by catastrophes. James Hutton (1726-1797), a Scottish farmer, put forward the idea that rocks formed through imperceptibly slow changes, caused by cycles of erosion and settling sediments. William Smith (1769-1839), a British canal builder, added to Hutton's idea of a slowly transformed Earth. As he collected fossils from his construction sites, he noted that one could discern the age of the rocks by the types of fossils present. By marking the places where certain fossils were found, Smith could begin to organize layers of rocks into a geological history.

British lawyer-turned-geologist Charles Lyell (1797-1875), a former student of Buckland, also disputed catastrophism, favoring Hutton's evidence. Lyell published his ideas that Earth's landscapes had been created by a series of small changes in a multivolume work called *Principles of Geology.* In his first volume, Lyell suggested that the forces that shaped Earth had been *uniform* throughout its history.

Darwin studied Lyell's treatise on geology meticulously while he was traveling on the HMS *Beagle*, and Lyell's ideas greatly influenced Darwin's thinking.

TEACHING TIPS

- While the film shows key locations on the globe, it may be helpful to use a globe or map to point out the locations where Darwin and Wallace made their key observations.
- A map showing geologic plate boundaries may help students understand the importance of the Wallace Line that divides the Malay Archipelago.
- To help keep track of important dates in the film, students can create a timeline of important events presented in the film, similar to the one shown in Figure 1. They could create a separate timeline for Darwin and one for Wallace and indicate key events and what they revealed to each scientist.

DISCUSSION POINTS

- The film presents many opportunities to discuss the characteristics and processes of science. Science and scientific explanations are based on the underlying premise that natural processes are sufficient to explain

the natural world. Scientific explanations are built on experimental data when available, and on careful observations linked to scientific principles. Lead students in a discussion of the observations made by Wallace and Darwin, the scientific principles known at the time, and how these fact patterns led both Wallace and Darwin to arrive at the same explanations independently.

- Watch for student misconceptions. Many students think that evolution means that life changes by chance. Natural selection is not a chance process, nor is it goal driven. Genetic variations arise by chance mutations, providing the raw material upon which natural selection can work. Selection, however, is not random. Variations that lead to greater reproductive success in a particular environment are passed on to subsequent generations. However, it is not useful to think of organisms and their traits as optimally fit, because selective pressures and the environment are constantly changing. The products of natural selection are a response to past conditions and were "good enough" for survival and reproduction.
- Another misconception students might have is that individual organisms evolve or adapt. Individuals exhibit variations upon which selection can act. However, individuals neither evolve nor adapt. Evolution occurs at the level of populations. As individuals with particular traits produce more offspring carrying their gene forms, over many generations a population may change.
- Students often think environmental conditions *cause* new variations, or that organisms develop new traits because they *need* them in order to survive. Further, students often struggle with the word *adaptation,* thinking individuals purposely adapt rather than adaptation being a change in a population over generations. Discuss with students that variations occur randomly in populations and selection acts on variations that exist within a population.

STUDENT HANDOUT

We designed the student handout as a learning assessment that probes students' understanding of the key concepts addressed in the film, which can be used to assess students' prior knowledge before watching the film or to guide students as they watch the film. We encourage you to choose the use that best fits your learning objectives and your students' needs. Moreover, because the vocabulary and concepts are complex, we encourage you to modify the handout as needed (e.g., reducing the number of questions, explaining complicated vocabulary for English learner students).

ANSWER KEY

1. (Key Concept A) One of Alfred Russel Wallace's motivations to travel to South America and the Malay Archipelago collecting plants and animals was to sell his specimens to museums and collectors. What was Wallace's other major motivation?
   a. To be a companion to the ship's captain.
   b. To add more evidence to Charles Darwin's natural selection theory.
   c. *To understand the origin of species.*
   d. To save enough money to buy his own ship.

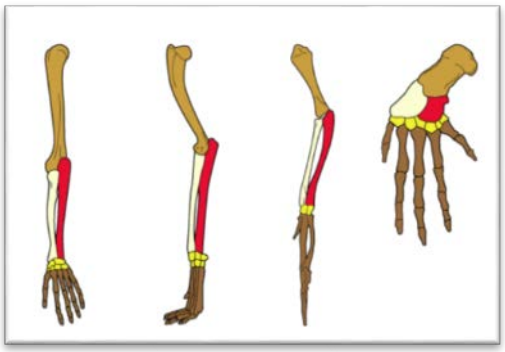
2. (Key Concepts A and B) When Charles Darwin set sail on his five-year journey on the HMS *Beagle*, both he and most of his contemporary scientists thought that
   a. *each species was specially created by God in its present form and did not change over time.*
   b. each species was a product of natural laws and changeable over time.
   c. each species had been selectively bred by humans after the invention of agriculture.
   d. each species had evolved into its present form by way of genetic mutation.

3. (Key Concept A) Which pair of characteristics (similarity and difference) are both correct comparisons of Darwin and Wallace?

	Similarity	Difference
a.	Both Darwin and Wallace were naturalists.	Darwin published his natural selection theory in an 1839 book, whereas Wallace published his natural selection theory in a scientific paper in 1859.
b.	*Both Darwin's and Wallace's ideas about natural selection were revealed to the scientific community at the same time.*	*Darwin's ideas about natural selection were inspired by what he observed on the Galápagos Islands, while Wallace's ideas about natural selection were inspired by what he observed on the Malay Archipelago.*
c.	Both Darwin and Wallace collected specimens on the Galápagos Islands.	Before each began collecting specimens around the Southern Hemisphere, Darwin thought species arose by way of natural causes, while Wallace thought species were specially created by God.
d.	Both Darwin and Wallace formulated the natural selection theory at the same time.	Wallace came from a wealthy, upper-class family, whereas Darwin grew up in a family that did not have much money.

4. (Key Concept A) Darwin and Wallace both gathered a large number of observations and facts on which they based their theories. Which of the following types of evidence was NOT part of the evidence they gathered?
   a. fossil evidence
   b. anatomical evidence
   c. geographical distribution
   d. *genetic evidence*

5. (Key Concept B) The diagrams to the right illustrate the bones in the forelimbs of four different organisms. Although these limbs all look different, they share some common patterns. These common patterns suggest that
   a. These organisms are members of the same species.
   b. The organisms existed at about the same point in time.
   c. *These organisms share a common ancestor.*
   d. These organisms have exactly the same genes.



6. (Key Concepts A–D) The image to the right is the famous "I think" sketch that appears in one of Darwin's notebooks.
   a. In one or two sentences, explain what this sketch represents.

Student answers will vary but should include any one of the following points:

- *Darwin thought that today's species are descended from older, extinct types.*
- *All species are connected to one another in a family tree.*
- *Any species can give rise to new species.*
- *Species come from other species just as naturally as children come from parents.*

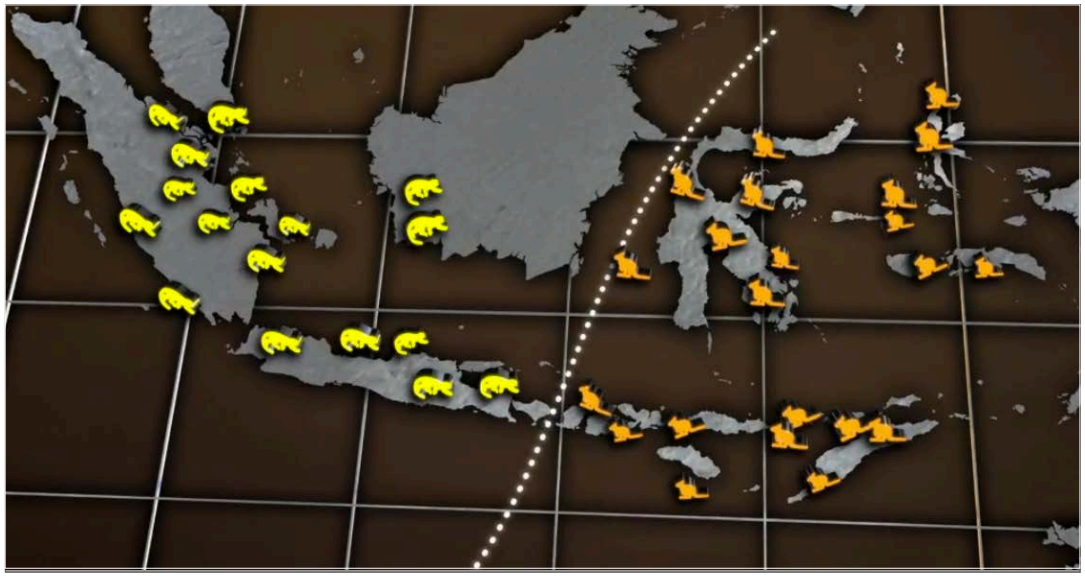
b. Which observations from the list below support the ideas presented in Darwin's sketch? List all the statements that apply.
   i. *Tortoises from different islands of the Galápagos have different shells.*
   ii. *Fossils of extinct animals resemble animals living today.*
   iii. Animals that are extinct were much larger than animals living today.
   iv. The Galápagos Islands have only a few species of animals living on them.
   v. *Mockingbirds on different islands of the Galápagos have different markings.*

c. Select one of the observations from question 6b above and explain in one or two sentences how it supports the ideas presented in Darwin's sketch.

Answers will vary. The observations that different islands of the Galápagos have different species of tortoises and mockingbirds indicate that these species descended from a common ancestor, but after many generations of living on different islands the populations changed in different ways. The fact that animals in the fossil record resemble animals living today suggests that present-day animals descended from species that existed in the past.

7. (Key Concepts D and F) Which observation led Wallace to conclude that all species are connected in a tree of life?
   a. *Around the globe, the more similar two species are, the closer to each other they tend to live.*
   b. Different species migrated from Australia to the islands of the Malay Archipelago.
   c. Both the butterflies and the birds he studied had wings.
   d. Darwin had published the same ideas in *On the Origin of Species*.

8. (Key Concept E) Study the figure below showing the distribution of animals in the Malay Archipelago.



Placental mammals (i.e., monkeys)

Marsupial mammals (i.e., kangaroos)

   a. Explain how the distribution of animals supported Wallace's evolution theory.

Marsupials on the eastern islands of the Malay Archipelago resembled animals from Australia, whereas mammals on the western islands resembled mammals from Asia.

   b. From a geological perspective, how did Wallace explain why placental mammals were found west of the line, and marsupial mammals were found east of the line?

Wallace concluded that the islands west of the line were at one time connected to the continent of Asia, while the islands to the east of the line had been connected to Australia, but that the western and eastern islands had never been connected to each other.

9. (Key Concepts E and F) The image to the right shows the bones found within the flippers of manatees. Similar bones are found in the flippers of whales. What did Wallace conclude from observing these seemingly useless structures and others like them?

Student answers will vary. Some students may remember the finger bones being referred to as imperfections or vestigial structures. The best answer should suggest that these structures made it clear to Wallace that every species is a modified form of an older species.

10. (Key Concept C) Which observations led Wallace to understand **how** species change over time? List <u>all</u> the statements that apply.
    i. The same species are found in different parts of the world.
    ii. *The traits in a population vary from one individual to the next.*
    iii. The characteristics of individuals change when their environment changes.
    iv. *Populations tend to produce more offspring in each generation than will survive.*
    v. *Individuals with traits that give them a slight advantage over other individuals in a population will survive, and over time individuals with those traits will outnumber other individuals.*

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