ARTICLE

Explaining Biogeographic Data: Evidence for Evolution

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The publication of *On the Origin of the Species* in 1859 initiated "one long argument" (Mayr, 1991) between those who propose scientific explanations and those who propose non-scientific explanations for questions about the diversity, similarities, and history of life on Earth (Scott, 2005; Miller, 2008). Unfortunately, deliberate attempts to undermine school science programs have taken a toll on biology teaching and the integrity of science. A recent national survey suggests that about one out of every eight high school teachers presents creationism as a valid scientific theory (Berkman, Pacheco & Plutzer, 2008). Moreover, many challenges in evolution education intertwine with issues relating to the nature of science and scientific inquiry (Bybee, 2001). High school students' understanding of evolution is tied to the students' understanding of the nature of science and their general reasoning abilities (AAAS, 2001). Students with strong reasoning skills are equipped to critically examine the theory of evolution in light of the scientific evidence, as well as alternative explanations they encounter outside of school (AAAS, 2001). Consequently, teachers need access to curricula that provide compelling opportunities for students to explore evolution (Bull & Wichman, 2001; Hillis, 2007) within a strong nature of science context (e.g., Cherif, Adams & Loehr, 2001; Bybee, 2001; Nelson, 2008).

The Biological Science Curriculum Study (BSCS) has a proud 50-year history of developing materials that highlight the primacy of evolutionary theory in biology. In the 1960s, BSCS led curricular reforms in biology and emphasized teaching evolution across all of biology (Skoog, 1984). An equally important emphasis was placed on teaching science with inquiry-based approaches. These two emphases provide students with multiple opportunities to practice and reflect on the nature of science. Though BSCS has changed over its half century of existence, its commitment to evolution education and inquiry-based teaching and instructional materials continues now and into the future.

A major focus of the instructional materials developed at BSCS for teaching evolution is helping students develop strong inquiry skills and understandings of scientific inquiry. This article presents "Building Bridges," a brief activity designed for entry-level high school students in either Earth science or biology. This activity demonstrates the approach BSCS uses to help students construct a deeper understanding of how scientists study change over time. The activity is adapted from *BSCS Science: An Inquiry Approach,* a multidisciplinary science program for high school and has students construct explanations of biogeographic data. Biogeographers answer questions related to why species or higher taxa are distributed where they are. Biogeographic data were critical in convincing both Darwin and Wallace that evolution had indeed occurred. In fact, Darwin devoted two chapters of *On the Origin of the Species* to demonstrating how evolution helps explain many biogeographic facts.

Most biology textbooks introduce continental biogeography by discussing the isolation of Australia and the evolution of marsupials on that continent in a general way. In contrast, this activity uses an analogous set of data with taxa in North and South America. Students are challenged to think about geologic changes that have occurred across the Americas over the last 10-12 million years (Myr) and consider how such changes influenced the distribution of mammal lineages. By analyzing maps and geologic records of sediments and fossils, students infer the formation of land bridges between continents and examine how these bridges impacted the fossil record, as well as the current distribution of animals.

In addition to the science content, this activity models an inquiry-based teaching approach designed to help students practice the abilities of inquiry and deepen their understandings of inquiry, including the nature of science.

○ Classroom Activity: Building Bridges

Student Pages*

Materials per Team of Two Students

- access to reference materials such as atlases and maps (in print or online)

Process & Procedure

1. Study the two maps in Figure 1. Use a two column table (a T-chart) to list how the maps are similar and different. Use an atlas to identify geographic features that you do not know.
2. Review your table and circle the main differences that you noted.
3. Figure 2 shows geologic sections (rock layers or strata) with fossil finds at six sites in North and South America. The strata span from today back to 11 million years ago (Mya). At a given site, are older rocks found at a deeper or shallower position? Explain how you know.
4. Pick a site in Figure 2 and make a list of all the mammals recorded at that site. As a class, compile a table that includes a summary of all the mammals at each of the six sites. Which sites have the most mammals? Which have the fewest?

   (HINT: *Check that you can locate the states and countries where each stratum is found on Figure 1.)*
5. Animals or plants that are restricted to a specific region are called endemic. Follow Steps 5a-d to evaluate claims about which animals were endemic to South America 12-10 Mya.

* BSCS. (2008). *BSCS Science: An Inquiry Approach, Level 2*. Dubuque, IA: Kendall/Hunt. Used with permission.

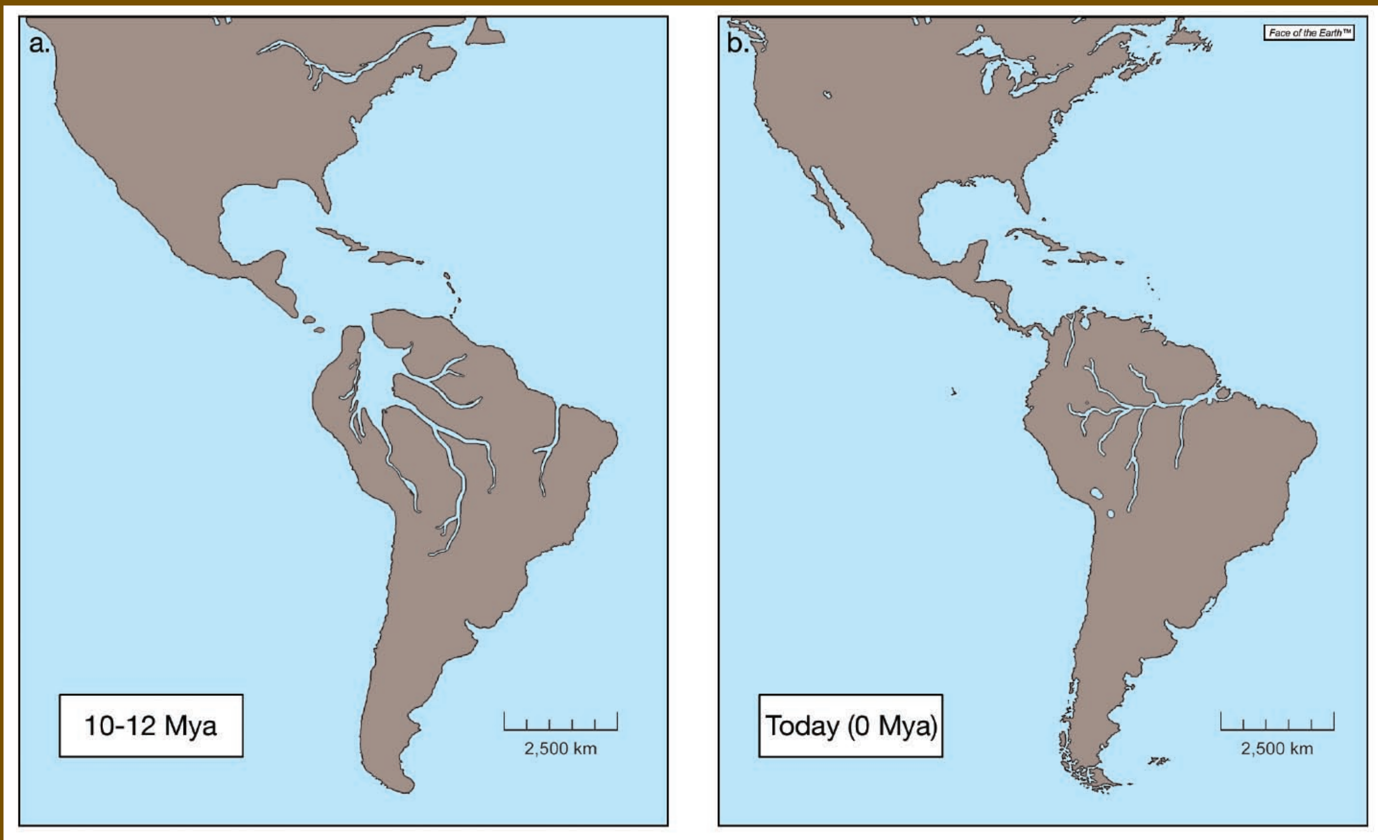

Figure 1. North and South America at two geologic times. The maps show the outlines of North America and South America at (a) 12-10 Mya and (b) today. What changes do you see in the landforms over approximately 10 Myr?

a. Work with your partner to determine how to tell whether an animal may be endemic to a continent or region from the geologic record. Explain this strategy using evidence from the geologic strata in Figure 2.

b. Explain which sites you would study in order to list the mammals that were endemic to South America. Would you search the tops or bottoms of those strata? Write your best response in your science notebook.

c. Make a T-chart that shows animals that might be endemic to South America in the first column and the animals that might be endemic to North America in the second column.

d. Explain why you think the animals identified in Step 5c "might" be endemic.

(HINT: *In your answer, describe whether you think the case for an animal being endemic is stronger for animals on South America or for North America and explain why.*)

6. Answer Questions 6a-d for the animal groups endemic to South America 12-10 Mya.

a. Make a claim about when you think South American animals arrived in North America. List specific evidence from fossils in the strata in Figure 2 and justify how this evidence relates to your claim.

b. How can you explain the arrival of South American endemics in North America?

c. Make a claim about when you think North American animals arrived in South America. List specific evidence from Figure 2 and justify how this evidence relates to your claim.

d. How can you explain the arrival of North American animals in South America?

7. Examine the geologic record of the rhinoceros lineage in Figure 2. In what time range are they found? What inferences can you make about the history of the rhinoceroses? Are there alternative scientific explanations that counter your inferences?

(HINT: *It is helpful to highlight all instances of rhinoceros remains.*)

8. Based on Figure 2, make some inferences about the mammoth lineage.

a. Where are the fossils found?

b. What is the earliest evidence in the fossil record?

c. How can you explain its sudden occurrence?

d. Is there evidence for mammoths in South America?

9. Discuss with your partner the concept of a land bridge. Consider Questions 9a-c related to land bridges and write specific examples from figures in the activity.

a. What do you think is the land bridge between North America and South America?

b. When do you think the land bridge formed? What is your evidence?

c. Which animals did or did not use the land bridge?

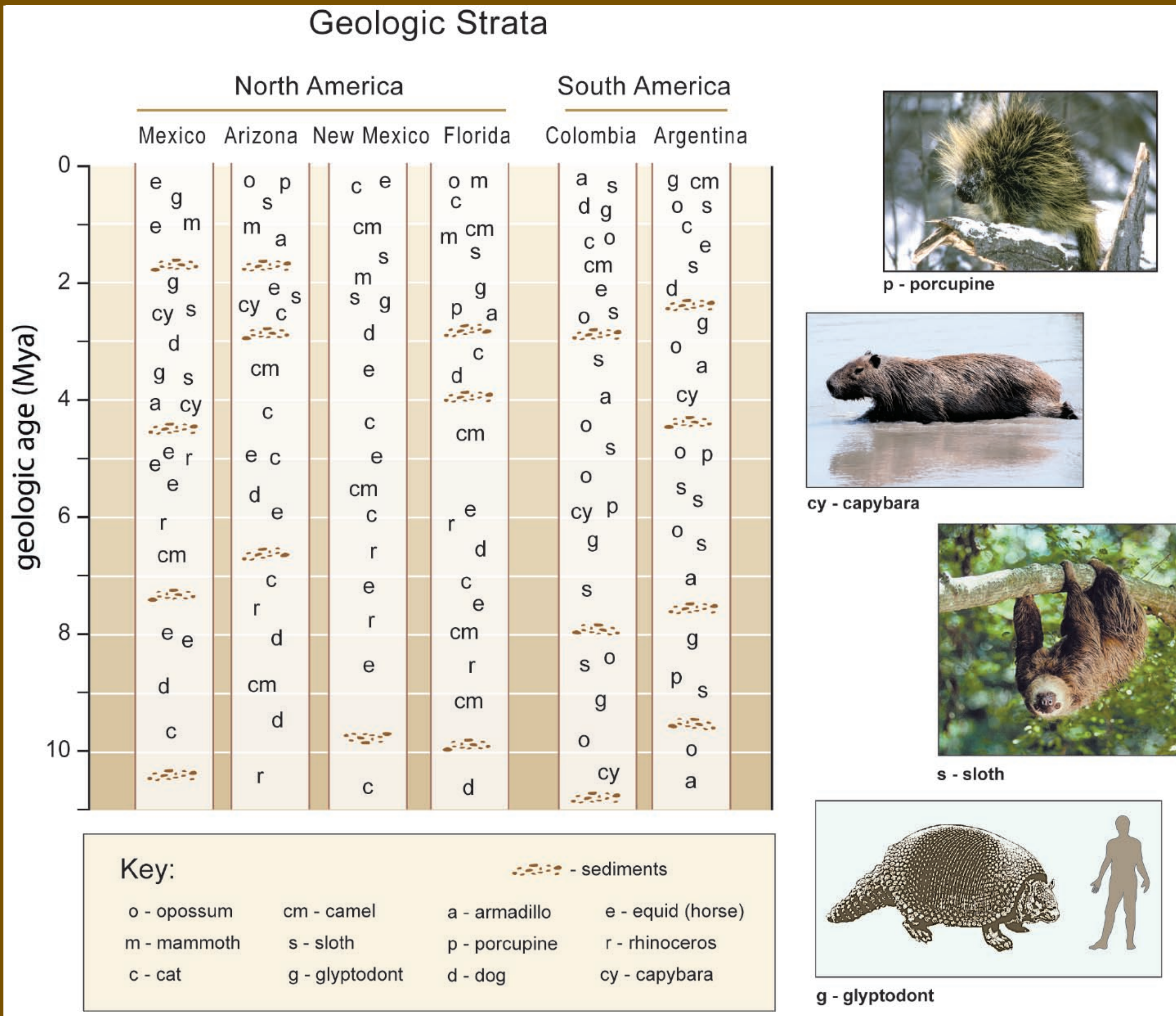

Figure 2. Six geologic sections from North and South America. The fossil finds from six locations are shown as a function of geologic age (left). The key lists 12 representatives of animal families from North and South America. Current examples (right) are the sloth, the capybara (a large rodent), and the porcupine. Glyptodonts are extinct.

10. Consider Figure 2 again. For a given geologic time, do you think each site indicates all the animals that were living at that site? Explain why or why not.

Teacher Pages

Steps 1-2

Student pairs should note main features such as formation of the Central American land bridge, the formation of the Great Lakes (after the most recent ice age), the change in drainage pattern of the paleo–Amazon River, and the rifting of Baja California from Mexico. At 10-15 Mya, rivers in northern South America drained north to a submerged part of the continent. There was no Amazon River at this time. As changes are shared and discussed, learners should be encouraged to infer and predict how the geologic differences between the two maps might impact the biogeography of mammalian populations.

Step 3

The data in Figure 2 represent a summary of findings from hundreds of field sites (e.g., Lindsay et al., 1984; Woodburne & Swisher, 1995).

A key concept and "rule" in Earth science is that for sedimentary and volcanic rocks, the older rocks are found on the bottom of a section of strata. The layers get younger moving up to the youngest at the top. This is called the principle of superposition.

Step 4

Students can tally animal groups per site with a seven-column table showing animals down the first column, then totals in Columns 2-7. The Florida site is rich in fauna, with 11 representatives shown. (In reality, the total number of distinct fossils is much greater, likely on the order of several hundred for the period 0-12 Mya.)

Answers to Steps 5-10

5a. Endemics would only be found in a certain region. A strategy is to group the sites by continent and by a certain time period, such as 6-8 Mya, then investigate patterns of occurrence. Of course, a major uncertainty is what to infer from the absence of fossils in a certain region. Animal groups that have few fossils may have been in regions that lack fossil evidence. However, if a group that is well represented in the fossil record is missing from a region that is similar ecologically to regions in which it is typically found, one may infer that the group did not occur there. Of course, this inference may be challenged by future discoveries of fossils (Futuyuma, 1998). Students are explicitly asked to consider this uncertainty in Steps 5d and 10.

5b. Students should pick Colombia and Argentina to determine South America endemics. They would search the bottom part of the strata, as groups from North America appear to be part of the fauna in the tops of the strata. The other four sites are part of North America.

5c. South American endemics include armadillos, porcupines, glyptodonts, opossums, capybaras, and sloths. North American endemics might include cats, camels, dogs, and horses.

Additional information is needed to evaluate the mammoth and rhinoceros lineages because of the positions and sudden change in status of their fossils (the disappearance of the rhinoceros; the appearance of the mammoth).

5d. An in-depth answer would suggest that the word "might" is used because the students do not have data in this example from the rest of the world. Additionally, the absence of fossils isn't necessarily evidence of absence (as described in 5a). The case for an animal being endemic is stronger for animals in South America because there is visual evidence in Figure 1 that South America was an "island continent." Students cannot see the top of North America in Figure 1 so they don't have complete information about whether North America was isolated in the same way that South America was. In fact, North America is connected to Siberia by the Bering land bridge. This enabled immigrant animals to "show up" in the rocks of North America, such as mammoths at 1.6-1.8 Mya.

6a. South American animals are first recorded in Arizona, Florida, and New Mexico about 2.5-2.7 Mya. Some evidence suggests sloths and glyptodonts arrived in Mexico by 3.5 Mya.

6b. One explanation is migration through Central America after Central America had formed. Evidence for this is the movement for animal groups on two continents in opposite directions at the same time. The land bridge was a two-way street. Challenge students to consider alternative scientific explanations too. For example, ask students why the bridge explanation seems more plausible than an explanation focusing on mammals "island hopping" to South America.

6c. North American animals are first recorded in Colombia and Argentina about 2.5-2.7 Mya. An interesting scientific question is to revisit some of these sites to see if evidence was missed for a trickle of early arrivals from North America to South America by 3.5 Mya. This is the time for evidence of a trickle into Mexico. Use this step to reinforce the concept that scientific explanations are revised as new evidence is found.

6d. One explanation is migration through Central America after it had formed. Evidence for this would be the movement of groups in two directions at the same time.

7. The rhinoceros lineage shows a different pattern of abruptly terminating in the fossil record. This is evidence for an extinction event on the continent. The fossil record has many other extinction examples at many other times. Indeed, even though rhinos evolved on North America, there is no evidence for a single rhino fossil after about 4.8 Mya. Students can then draw the reasonable inference that some members of the rhino family had migrated to Eurasia before the extinction event in North America.

8. Rather than abruptly disappearing, mammoths abruptly appear at a time that is different than appearance of other lineages. They could not have come from South America, as there is no evidence for mammoths in South America before 2 Mya. Rather, mammoths came from somewhere else. Students can infer this as a possibility, but from the information presented, they will not know that mammoths arrived in North America over the Bering land bridge. Mammoths are found in Eurasia before, during, and after their arrival in North America 1.6-1.8 Mya.

9a. Students can now link the actual bridge that they have been inferring and studying with a term to describe it. The land bridge formed in Central America (near present day Costa Rica and Panama).

9b. From the maps, the bridge had to have formed after 10-12 Mya and before today. From the geologic strata, fossil evidence indicates an interchange by 2.7 Mya, so a continuous bridge is inferred by that time. Some evidence from Mexico indicates some periods of land connection or animals swimming occurring by 3.5 Mya. This is a current topic of research.

9c. There is geologic evidence that all animals in the figure except the rhinoceros and mammoth used the Central American land bridge when it formed. For example, each South American endemic is represented in the top of the fossil record in North America, and vice versa. Rhinoceroses could not have used the bridge, as they were extinct in North America before the land bridge was formed.

10. The geologic strata show animals recorded from a sampling of the rock layers at a site. This typically is only a fraction of all the animals that lived in an ecosystem. Moreover, we might expect sampling to favor animals that were large and easy to find as fossils or were more common in the ecosystem (e.g., herbivores versus carnivores).

Emphases on Inquiry

The content standards in the *National Science Education Standards* include both abilities and understandings of inquiry (NRC, 1996). Additionally, the teaching standards include inquiry-based teaching as a central component. In the inquiry supplement to the *National Science Education Standards*, the National Research Council (2000) suggested that inquiry-based teaching and learning have five critical features. Inquiry-based teaching has learners:

- explore scientifically oriented questions
- interact with data and give priority to evidence

- use evidence to construct explanations of scientifically relevant questions
- consider alternative scientific explanations
- communicate and justify their explanations.

In this section, we highlight opportunities within the activity for teachers to emphasize specific features of inquiry.

Scientifically Oriented Questions

"Scientifically oriented questions center on objects, organisms, and events in the natural world; they connect to the science concepts." (NRC, 2000, p. 24). Throughout the investigation, scientifically oriented questions are used to guide, challenge, and refine student thinking. In addition to promoting student understanding, these questions require students to provide a response that makes their thinking transparent and serves as a formative assessment for the instructor.

Evidence & Explanations

As noted in the *Standards*, "... science distinguishes itself from other ways of knowing through use of empirical evidence as the basis for explanations about how the world works." (NRC, 2000, p. 24). Six geologic strata provide real evidence concerning biogeographical changes in mammalian populations that have resided in North and South America. These data not only test previous inferences and predictions that were generated from map observations, but are used as evidence for claims made concerning how changes to the Earth's surface influenced distribution patterns of North and South American mammals. When formulating explanations, the learner is challenged to provide empirical evidence that coherently and effectively supports the claim. Asking students to provide evidence that supports their claims requires students to evaluate and prioritize data based on their current understanding of the science content, make sense of their observations and inferences, and make their personal understanding apparent to themselves, peers, and the instructor.

For example, claiming that a certain mammal is endemic to North America and supporting this claim with fossil evidence suggesting this mammal was found only in North America until its appearance in Argentina at 2.5 Mya is seemingly appropriate. However, there is not enough evidence to sufficiently support this claim. The map used in this investigation does not show the entire North American continent; thus, if the learner had a more robust understanding of an endemic organism, he/she would recognize that observational data from the map does not provide unambiguous evidence that mammals were restricted to the North American continent. An explanation that includes both fossil evidence and evidence of an isolated, island continent shows a more robust understanding of what endemic means.

Alternative Explanations

Asking whether or not other reasonable explanations can be formed from evidence is another important aspect of scientific inquiry (NRC, 2000). Not only does the formulation and justification of alternative explanations challenge and refine understanding of science content, but also mirrors the difficulties of interpreting biogeographic histories of organisms from the fossil record. The geologic strata provide data for the rhinoceros and mammoth lineages in North America. In Steps 7 and 8, students are encouraged to analyze these two groups and explain their histories. The absence of fossils at certain geologic times and at certain North American sites makes the formulation of an explanation by the learner somewhat complex. The sudden occurrence of fossil evidence (mammoth at 2 Mya) coupled with the sudden disappearance of fossils (rhinoceros at 4.5 Mya) allows students to develop multiple explanations concerning lineage histories.

For example, a learner could pose an explanation that includes rhino origins at 10.5 Mya in Arizona with an initial eastward radiation into Florida at 8.5 Mya with an accompanying southward expansion at around 6 Mya. However, an alternative explanation could argue that southward and eastward expansions were simultaneous and justify this assertion by claiming rhino fossil evidence is incomplete between 10 Mya and 6 Mya in what is now present-day Mexico.●

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