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Exploring Macroevolution

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The unity and diversification of life is the key framework of biology and yet is a difficult concept for students to grasp. Here, we study macroevolution by reflecting on the geologic history of the students' home towns and solving fossil puzzles. Participants solve puzzles to explore how paleontologists learn about evolutionary history, and practice using online resources to determine the origin and age of fossils. Most puzzles require some combination of direct observation and online analysis. Students present their findings to demonstrate the varied approaches in each. Fossils samples can be ordered online and these puzzles can be adapted for use anywhere. Student learning assessment is conducted through both oral presentations and a brief written summary. The combination of hands-on experience and online research encourages reflection on both deep-time and the unity of life.

Keywords: macroevolution, fossils, geology

Introduction

The educational goals of this exercise are to enhance students understanding of how scientists use fossils to learn about evolution; and to force students to explain some of the means by which fossil ages are estimated, determine how provenance, origin, and ages of fossils can be useful, and use internet resources to learn about paleontology. The pre-lab exercise is intended to give the students some experience with the websites they will use during the lab period and to provide them with information regarding their home regions. The beginning of lab can be useful in helping students recognize the scope of geologic time and how varied different regions are in geologic age, and finally the puzzles should encourage students to study the details of specific fossils or scenarios. The scenarios draw not only from specific fossil samples, but cover a variety of forms of fossilization and tie in with a variety of historical events and scientific leaps. Once the fossils are on hand, preparation, clean-up, and grading for this lab exercise are minimal.

For this exercise, students explore a puzzle related to a fossil. To solve this puzzle, students must use their internet search skills and some problem-solving to determine the unknowns about their sample. There are a variety of samples, and what is known and what they need to determine varies, so teams may have to discover different things about their samples. Some samples provide more of a challenge than others, so you can (if you wish) target different student groups with more or less challenging puzzles. All of these puzzles can easily be undertaken in under ninety minutes. This leaves time for students to share their findings with one another.

The exercises in this lab emphasize using online resources for research, and specifically focuses on the use of the University of California Museum of Paleontology's *Explorations through Time* (2018), and *Paleoportal* (2018). Some puzzles will require additional internet searching.

Student Outline
Macroevolution

Objectives:

- Recognize how scientists use fossils to learn about evolutionary history
- Be able to explain one way of dating fossils
- Use resources to determine provenance, origin, or the age of a fossil
- Use electronic resources to learn about geology

Background

The features of organisms change with time as various characteristics or attributes become more or less common due to the relative success of different individual organisms. This is referred to as evolution. Although large changes are rarely evident to the casual observer, these changes are quite clear when we look at ancient organisms that have been preserved. We have studied of the preserved remnants of organisms since the Greeks documented them over 2000 years ago. More recently, formalized study of these remnants has been used to inform us about past diversity.

Darwin (and many other early naturalists) noted that the features found on fossils both share some features with modern organisms and yet differ in other notable ways. He also noted that the older rocks, typically the deeper strata, contain remnants that are more different from modern forms than more recent rocks. As with the features of the diverse living organisms that Darwin studied extensively, Darwin argued that the features in fossilized organisms reflect their ancestry: Many organisms share common features because they share common ancestry. Extinctions have been noted in the fossil record since Cuvier noted the phenomenon in the 18th century. Thus, paleontology can inform us about many organisms that no longer exist.

Fossils are best described as the remains or trace evidence (like footprints) of organisms that lived long ago. Fossilization is currently underway in streams, lakes, wetlands, and oceans everywhere. The type of fossil that characterizes a location thus generally indicates what previous life forms lived there. The features of the organism are informative of the environment and living conditions of that place at an earlier time.

Fossil Formation

Fossils form in a variety of ways, but in all cases the organism's body (or an associated trace, like a footprint, waste, nest, or burrow) is preserved. Because of the destructive forces of geologic activity (sediment movement, rock formation, etc.) and biological decomposition (rotting), only a fraction of the organisms that have ever lived and died are ultimately preserved as fossils.

Typically, the fossil remnants are of only the bones, shells, or other “hard” parts of the organism. The whole organism is rarely preserved. However, under certain conditions preservation of an organism and its soft internal tissues can be exquisite - as in the case of subfreezing cold (like a mammoth preserved in a glacier), extreme dryness (such as dinosaur eggs in the Gobi desert of Mongolia), or severe anoxia (i.e., absence of oxygen, as in the swamps of Ireland that have yielded exceptionally preserved "bog people" who were criminals executed many hundreds of years ago). Finally, insects or plant parts become trapped in plant resin that later hardens into amber - resulting in perfect, three dimensionally preserved specimens. You may have heard about this in the movie, *Jurassic Park*.

Fossils can be preserved with little alteration, as in the case of many organisms' hard parts (like shells, reef structures, or bone), or fossils may undergo extensive chemical alterations as a result of the movement of fluids through rock and metamorphosis. For example, plant fossils commonly are "cooked" and "compressed" by the high temperatures and pressure of rock formation, resulting in a flattened film of carbon that outlines the fossil form, called a *compression fossil*. Even in the case of shells, the original shell matter (often composed of a calcium carbonate called calcite) can become transformed into a different calcium mineral, aragonite, called a *chemical replacement fossil.*

Often the original organism’s hard or soft tissues become completely replaced by inorganic minerals, forming what is called a *petrifaction*. These fossils are no longer composed of the individual material from the organism, but are instead made from minerals that retain the shape of the organism. For example, petrified wood is not wood, it is stone.

Other common forms of fossils are molds and casts. A *mold* forms by hardening of sediment surrounding the organism (for example, in the case of a tree log buried in mud. This is followed by the decay and removal of the organism by groundwater, leaving behind the external surface texture preserved in the surrounding sediment. A *cast* can be a continuation of the process of mold making in that once the organism is removed (forming a mold), minerals or sediments fill the space previously occupied by the organism.

Fossil Age

Fossils and rock also can help orient us in geologic time. If you visit the Chesapeake Bay or the Mississippi delta along the Gulf of Mexico, fresh river sediment is deposited on top of older layers of sand and mud. After these layers (or strata) have later hardened to form rock, one can tell the relative age of a rock stratum by its position. Fossils of different ages can be found at the same location, but in different strata. Usually, the deeper the strata, the older the fossils. While this is generally true, in some cases, the shifting of the tectonic plates of the earth can "bunch up" the earth's surface much like pushing in on a tablecloth can cause folds and ripples. Thus, in some places, mountaintops may expose earlier layers that would otherwise remain under more recent deposition.

Given the possibility of rocks upheaving and the order of deposition not always being completely consistent with deposition, we need another means of measuring the age of a rock. Fortunately, all of the elements that occur in rocks change over time. That is, when rocks are initially formed, a "clock" is started, after which, the elements contained in the rock start to decay. This decay occurs at a predictable rate for each type of atom and can be easily measured with a mass spectrometer. All elements decay at slightly different rates, so precise measures of age may be made by a handful of elements that decay at a rate that provides a good measure for that time period. Certain elements decay very quickly and provide good measures of short time periods; for example, carbon can be used to estimate the age of rocks that are younger than 50,000 years old. Other elements decay slowly and provide better estimates of long time periods; uranium can date rocks that are billions of years old but with a margin of error of a few million years. Thus, carbon dating is only one of many methods for dating rocks using decay. Another method can be used with rocks that contain iron. When the rocks solidify, the iron will align with the magnetic north. Magnetic north is not completely stationary, and the migration history is known. Thus, in solid rock, we can discern the location of magnetic north at the time of rock formation to ascertain the age of the rock.

Research to Do Prior to Lab

At the following website, there are a variety of interactive assignments that you can explore to prepare for this week's lab. http://www.ucmp.berkeley.edu/education/explotime.html (University of California Museum of Paleontology 2018).

Go through the following web pages, click on clickable links, and do the final quizzes. The contents of these web sites will be part of your quiz in lab, so contact your instructor if you have any questions.

- Life Has A History:
- Fossil Tour:
- Understanding Geologic Time:
- Stories from Time:

At the following website, you can learn about the formation of fossils, where fossils of different sorts might be found, and how one would find them. This site will also be useful during lab.

http://www.paleoportal.org/ (University of California Museum of Paleontology 2018)

NOTE: This site has proven to be somewhat glitchy. The map does not always work for broad searches. If you wish to see fossils in Virginia (for example), you can get to the Virginia map by clicking on any era, then on Virginia. You can toggle through the different time periods to look for a specific region.

To Hand In at The Beginning of Lab:

1. What is your home town?
2. What is the age of typical rocks from your home town?
3. When were they formed?
4. What geologic events were happening in the world at that time?
5. Which organisms are most commonly found in the fossil record from rocks of this age?
6. List four vocabulary terms related to fossilization and provide the definition for each (in your own words).

There is additional information on this topic in the introduction section of this laboratory.

This Week in Lab:

You will be given a puzzle to solve. This puzzle may include a fossil sample directly or some data to explore. Use the internet (be careful about the sources of your information – not all internet information is equally valid), your book, your professor, and your wits to answer the questions given in your project.

You have been provided a number of possible information sources above, but you can use any additional sites you wish. Once you have verified your findings with your professor, prepare a team presentation on your findings, including:

- background on the puzzle you were given
- how you approached solving the problems you were presented
- your sources of information, and a summary of the answers to your questions
- information on your team's fossil

Finally, submit a word-processed summary of your team's presentation information, be sure to cite any references that you have used. You will be graded on your coverage of the questions and your use of resources in doing so both in written and in oral form.

Additional Resources to Use during Lab

- The following website is a link to a variety of sub-sites where you can find all sorts of information about specific types of fossils, fossil locations, or geologic time-frames. http://www.ucmp.berkeley.edu/help/topic.html (University of California Museum of Paleontology 2018)
- The following website is an interactive (clickable) geologic time scale. This might be useful if you need to figure out which organisms occurred during a particular geologic time-frame. http://www.ucmp.berkeley.edu/help/timeform.html (University of California Museum of Paleontology 2018)
- At this website, you can find the age of the substrate in any state. http://paleoportal.org/index.php (University of California Museum of Paleontology 2018)
- The Virtual Fossil Museum: http://www.fossilmuseum.net/index.htm (Perkins 2015)
- The Paleobiology Database. This website is offered primarily to professionals, but also to amateurs, with data on fossil locations, types, ages, and all sorts of professional data. They also provide data analysis scripts, apps, and other valuable materials. https://paleobiodb.org/ (Paleobiology Database 2018) You may find this very useful to determine which sorts of fossils derive from any geographic area (worldwide) and for information on fossil diversity.

Materials

Fossils packaged with scenarios (plan to use one puzzle for each group of four or five students). A magnifying glass or loupe may be useful for the scenario that has an insect in amber. Internet access. A list of clickable links from this lab through your online course access facilitates student searches for pre-lab and lab assignment

Notes for the Instructor

At the beginning of the session, you can have the students line up in order of age of rocks from home town (oldest to youngest). This helps them clarify the recency of MYA or BYA. This also can be used to create lab groups later. Once lined up, the students present their pre-lab information. This provides students with snapshots that reiterate the evolutionary progression of diversity as well as makes them consider how different regions substrates have different ages. You can then use the line-up to form groups (either in alternating fashion or otherwise, depending on the class dynamics).

Each team is the provided with one of the puzzles with the accompanying fossil (for the puzzles that come with fossils). There are more puzzles than needed for one lab section, this prevents students at the end of the week from arriving already knowing all of the answers and keeps the material a little more fresh for the instructors.

Instructors should regularly check-in with the student teams. While these are generally not too difficult, students get waylaid on a wrong answer and may need redirection. Some students are more internet savvy than others and may need some initial assistance in generating good search terms.

Save at least 45 minutes for presentations during which students practice public speaking, must show their organized progression from puzzle to solution, share their fossil sample with their classmates, and submit their written work.

Links:

Explorations through time: http://www.ucmp.berkeley.edu/education/explotime.html (University of California Museum of Paleontology 2018). A series of exercises to explore different facets of geological time. While written predominantly for K-12, this is a useful starting point for undergraduates unfamiliar with these issues.

Some of these exercises are planned for younger students, but the message is valuable even if college students are accessing younger materials. Within this set of explorations, I have found the following exercises particularly relevant:

- Life has a history:
- Getting into the fossil record:
- Geologic Time:
- Four sections on stories from the fossil record:
- The search index for the overall site.

These other sites will also be useful:

- http://www.paleoportal.org/ (Paleoportal Steering Committee, 2018). The Paleontology Portal, also from UMCP, the Paleosociety, SVP, and the USGS. Searchable site for the age of rocks in different regions, a fossil gallery, K-12 exercises, paleontologists highlighted, and famous fossils: (see additional instruction for navigation in student handout)
- http://www.fossilmuseum.net/index.htm (Perkins, 2015). The Virtual Fossil Museum: A good general reference, with a lot of information on fossils, geological time, and macroevolution.
- https://paleobiodb.org/ (The Paleontology Database, 2018). An active database of paleobiology with geographic information on discoveries.

At the end of lab, each team should hand in a (word-processed) summary of their presentation information. Students are evaluated on their coverage of the questions and their use of resources in doing so.

Table 1. Sample rubric for assessment.

	Presentation	**Paper**
Poor (<60%)	Doesn't clarify the problem, fails to show evidence for conclusion, disorganized.	Disorganized, not well-documented, sources either not credible or unclear.
Acceptable (70-80%)	Puzzle elements incomplete, answer either lacking logical progression or evidence in support.	Progression to solution not logical or sources unclear or lacking, paper may not be completely clear, but should be understood.
Good (90-100%)	Lays out puzzle elements, problems to be solved, and evidence leading to their conclusions.	Shows logical progression toward solution, uses credible sources, documents clearly and concisely.

Puzzle Answer Key

A. Gastropod Cast from Northeastern Mississippi

A mold from the inside of a gastropod shell. Their answer should include that this is a mold of the internal structure, rather than the fossilized shell. These are marine snails, even though this site is in Northern Mississippi. This is known because of the status of that part of the tectonic plate at that time as well as the presence of a large number of shark teeth at the same site. During the Cretaceous, this part of the plate was under the sea.

There is a well-known Cretaceous period fossil bed in New Albany, Noxubee County MS. These are readily available for purchase.

B. Neuropteris Fern from Mazon Creek, Illinois

These ferns are readily distinguishable from the other types mentioned. The *Eremopteris*, *Euspheonoperis,* and *Cyclopteris* all have distinctly different leaf shapes. Among the remaining species, the key features are the veins in the leaf (branching and tangential to the mid-vein and angled toward the distal tip, the mid-vein ends midway to the distal tip) and the base of the leaf (heart-shaped).

La Salle, County, Illinois is the only of the listed sites that has rocks from the Pennsylvanian Epoch of the Carboniferous Period (359-299 MYA). These ferns were present throughout the Carboniferous Period with peak abundance in the Pennsylvanian Epoch (318-299 MYA).

This specimen was purchased from ebay.

C. Petrified Wood from California

There is a bit of an anachronism here, as the forest was "discovered" after the date in the letter (which corresponds to the Gold Rush). Surely, however, the petrified forest was discovered locally prior to being discovered more broadly. Check in on the students to insure that they recognize California (from the Gold Rush discussion), as there is another petrified forest in Arizona. The other petrified forest is somewhat different, and derives from different types of trees and some different minerals make the Arizona petrified forest more colorful.

The timing of this puzzle should lead the students westward from Kansas in the early 1850s to a Gold Rush. The famous gold rush from that period was the California Gold Rush in Northern California. This location should place our character near Sacramento and the Sonoma valley. Thus, the petrified forest is consistent with what we know about California's petrified redwoods. These redwoods were not officially "discovered" until 1870, when "Petrified Charlie" opened a tourist attraction. For our fictionalized account, however, it is reasonable to believe that others found them before Charlie viewed them as a moneymaking opportunity. It is known that (author) Robert Louis Stevenson and (naturalist) Luther Burbank also visited this site under Charlie's ownership. This site is still privately owned, and they charge people for viewing, but apparently do not sell their finds. There are petrified redwoods available for purchase from elsewhere.

These redwoods were apparently knocked down about 3 MYA due to a volcanic eruption near Mt. St. Helens. This violent blast covered everything with pale, yellow ash. The preserved trees are dull in color (as compared to Arizona's Petrified Forest) as they are replacement fossils of silica, due to silica-enriched rainwater seeping through the ash.

The park is privately owned and has a website: http://www.petrifiedforest.org/index.html (PFALLC, 2018)

This specimen was purchased from ebay

D. Sea Urchin - Algeria

Urchins, with their pentameral arrangement, are unmistakably echinoderms. Sea urchin fossils look very little like a living urchin as only the test remains, and the spines fall off. The test of this fossilized urchin is well-preserved and it is quite easy to find photographs of fossilized (and recent) urchin tests. As today, urchins from the Jurassic Period would have eaten by using their Aristotle's lantern to scrape algae and other organic matter from rocks and would move using tube feet.

Students may have a more difficult time isolating the age of rocks from sites outside of North America. However, any google-savvy student should be able to figure it out.

This specimen was purchased from ebay

E. Shark Tooth: Scapanorhynchus raphiodon texanus Tooth from Noxubee MS

This cretaceous period shark is in the spade snout group of sharks, long extinct. The teeth have characteristic shapes (long, sharp, awl-shaped teeth with narrow, smooth-edged blades with no cusplets, strongly bilobed root, large lingual protruberance (bulge) and nutrient groove at center of root).

Noxubee, Mississippi is in northern Mississippi (not far from the borders with Tennessee and Alabama). Thus, this area is no longer shark habitat. Most of Mississippi was underwater at the time that this shark lived, and this fossil bed has been a rich resource for fossil shark teeth (as well as the gastropod cast in puzzle A and a rich variety of other Cretaceous period aquatic creatures.

I collected this one, but they are readily available for purchase.

F. Trilobite: Asaphiscus wheeleri. Coming from the Cambrian Marjum Formation Deposits of Millard County Utah

These trilobites are often found with disarticulated or missing free cheeks. Only this location (of the three) would have trilobites, and trilobites should be pretty easy for them to recognize if they do the pre-lab assignments on the internet.

Trilobites are arthropods, most closely related to the extant horseshoe crabs. Like horseshoe crabs, they were benthic and mobile, as shown by some fossil traces of their tracks). Their traces even suggest that they were able to burrow. They did not have large mouth parts, so it is thought that they were not likely to have been predators. They probably subsisted primarily on debris.

Trilobites from Millard County are available for purchase.

G. Crinoid Stem from Near the Dragon Tooth Entrance to the Appalachian Trail near Catawba, VA.

Crinoids are echinoderms; animals that are still extant today. Today's crinoids are mostly (but not exclusively) deepwater ocean-dwellers.

350 MYA, during the Paleozoic Era, the area now occupied by the National Forest west of I-81 in Virginia, was a vast sea located South of the Equator. The Blue Ridge was a huge mountain range bordering this vast sea. The Blue Ridge supplied sand and silt to the beaches and near-shore waters. The marine creatures that lived on the sea floor were buried in the sand and silt, and preserved as fossils. Similar Appalachian crinoids and crinoid stems are widely available.

I collected our specimen. Crinoids are easily found or purchased.

H. Dinosaur Poop Party Favor

This party favor illustrates the point that trace fossils, the science of ichnology, can often provide information that we would otherwise lack about behavior, habitat choice, diets, and other pertinent natural history about extinct organisms. An excellent resource on trace fossil is "Dinosaurs without Bones" (Martin, 2014).

This was an Amazon purchase.

I. Amber with Insect from the Dominican Republic

The Dominican Republic is a major source of amber. The amber can come in many colors and is often found with embedded plant or insect parts. Dominican Rebublic amber comes from fragmented sedimentary rocks that are often exposed intentionally for the amber trade. Amber in the DR generally dates to about 25 MYA. In that these amber pieces are from the Oligocene Epoch (33.9-23.03 MYA) of the Paleogene (or Tertiary) Period (65-23 MYA) of the Cenozoic Era (65 MYA to the present), no dinosaurs could have been bitten by any insects in Dominican Amber.

An additional challenge to this puzzle is the identification of the insect. Does this insect bite and collect blood? Students may be provided with a lens or a dissecting microscope. In case that is not available, you may include a magnified photograph of your sample.

This insect in our sample is a stingless wasp. For that reason, it couldn't have bitten any animals. They could, however, have coexisted with early horses, early ungulates, and expanding mammal diversity of all kinds. This wasp might have had to avoid predation from many species of birds. Plant life at this time was dominated by grasslands, and marked by the restriction of gymnosperms to higher altitudes.

This was purchased online. There are thousands available.

J. Ammonite (Coelocerus mucronatum,. Jurassic Period, from Toarcien Region of France.

This region in France is well-known to have Jurassic Period (183-176 MYA) fossils. Among these, the ammonites are quite common. The Toarcien time period takes its name from this region. This time period was marked by a strong demarcation in global extinctions of many types of mollusks including many ammonites. It is thought that this extinction event related to widespread

anoxic conditions, probably resulting from volcanic activity.

This cephalopod mollusk may superficially resemble a gastropod mollusk. Unlike gastropods, however, ammonites always show suture marks that distinguish the internal chambers, and tend to be more tightly coiled and smaller toward the center. Ammonites appeared about 400 MYA and experienced substantial radiations and several extinction events, one of which is known as the Toarcien Extinction. The ammonites experienced extinction at the same time as the dinosaurs. Their closest extant relatives are the nautiluses.

This is an online purchase.

K. Scallop: Chesapecten jeffersonius Virginia's State Fossil

These were collected by John Finch (a Scottish geologist) in the Yorktown region of Virginia, where he collected them shortly after his visit with the new President of the United States. Martin Lister described and the fossil in 1687. Thomas Say named it in honor of the President in 1824. These scallops are bivalve mollusks from the Pliocene age (about 4.5 mya), and used to be so abundant that they were used as building foundations.

This scenario has John Finch writing to Adam Sedgwick at Cambridge. While this account is fictionalized, Sedgwick was at Cambridge at that time and had made a name for himself by publishing data of the geological diluviam – the hypothesis that widespread floods accounted for the deposition of superficial deposits of rocks and gravel – as originally proposed by Buckland. Sedgwick later found evidence of local, rather than large scale flooding. Sedgwick later was one of Darwin's teachers and continued to correspond with Darwin while Darwin sailed on the Beagle and thereafter.

These are readily available in Virginia (our sample came from the University's collection). These can be purchased online.

L. The Story Here Relates to the Dynamic and Interesting Discovery of Major Theropod Fossils in Wyoming

This scenario is an account (from the media) on the discovery of the best *Tyranosaurus rex* specimen to date, originally noticed by Sue Hendrickson (after which the fossil was named). Sue (the dinosaur, not the person) is on display at the Chicago Field Museum. Accounts vary on whether it was Sue or the principle investigator that recognized the find for what it was. The ongoing legal battles for the specimen are not completely resolved, and can provide an interesting side-note to the story. The Field Museum has given Sue her own web page: https://www.fieldmuseum.org/blog/sue-t-rex (Field Museum, 2018).

You can sometimes find actual *T. rex* teeth for sale, but should probably not purchase them for ethical reasons (as Indiana Jones would say, "These things belong in a museum").

M. A Historical Representation of an Ancestor Hired by Charles Doolittle Walcott as a Worker at the Burgess Shale

This should provide a background on the Burgess Shale and their importance. This region is one of the most famous fossil sites and contains a diverse assemblage of Cambrian animal fossils. For a quick review, you can refer to this website: http://www.ucmp.berkeley.edu/cambrian/burgess.html Paleoportal Steering Committee 2018) or many others. A quick internet search will provide dozens of academic and popular references to this site.

In Appendices A through M which follow, each is a puzzle which may be accompanied by a figure representing a fictionalized communication and/or a fossil sample for examination.

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About the Author

Kari Benson is a Professor of Biology at the University of Lynchburg. She completed her graduate work at the University of Mississippi and the University of Nebraska. Her research interests have focused on the evolutionary significance of signaling, particularly in reproductive decisions. She has addressed these questions in a variety of taxa including fishes and spiders. Her teaching duties include general biology, evolution, behavioral ecology, and marine biology.

Appendix A: Rock from the Farm

We were just going through your Great Aunt's things after her recent passing and found this letter in a box with this weird rock (Fig. 1).

- How would a rock of this shape be formed?
- What kind of organism would make this?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Elizabeth Hargrade
Cold Comfort Farm
Noxubee County, Mississippi

Dear Cousin Mary,

22 March 1842

Things are going well on the farm. We have had a warm spell this week, so we thought it time to clear some more land for our vegetable garden. While we've got the large fields (cotton and so on) spread out on the flatland, we are putting the vegetables in down near the creek.

We'd just started clearing some of the land and found lots of interesting rocks. We'll send some your way, and maybe sometime you can check with your library and find out what they are. These little corkscrews are just amazing – we've never seen the like. Can you tell us what they are?

Sincerely,
Cousin Beth

Figure 1. Letter from Elizabeth Hargrove for Appendix A.

Appendix B: Fern Gully

Help out this research technician (Fig.2). Use the information provided and the features of the fossil to answer the following:

- Can you figure out where this fossil came from?
- How do you know it has to be this location?
- What kind of organism does this fossil represent? Please give as much taxonomic information as possible. How do you know this?
- How are these organisms fossilized (through what process)?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Attention all Technicians:

Folks, I totally messed up while I was cleaning the lab today – I lost a label!

The boss is on his way back into town, if we can't replace the label with an accurate one – all of us will lose our jobs!

I know that some of the information is missing. Can you figure out exactly what we should put on the replacement label? The Doc will know if we are wrong.

I know that this thing is a fossil fern, but I can't remember which one. It could be *Alethopteris, Eremopteris, Eusphenopteris, Neuropteris, Pecopteris,* or *Cyclopteris*.

I also can't remember which field site this came from. It could be

- York County, Virginia
- La Salle County, Illinois
- Bighorn County, Wyoming

or

- Phoenix, Arizona.

Be sure that you are correct. I don't want to get fired.

Thanks everyone, I know that you can help me out – I promise I'll be more careful next time.

Fern

Figure 2. Note from Fern Gully for Appendix B.

Appendix C: Wood from Out West

This fictionalized account (Fig. 3) provides enough information to isolate the exact type of organism this specimen represents as well as precisely where it was found.

- Why did "Robert" travel?
- Can you figure out where this fossil came from?
- How do you know it has to be this location?
- What kind of organism does this fossil represent? Please give as much taxonomic information as possible. How do you know?
- How are these organisms fossilized (through what process)?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Dear Mother and Father,

22 April, 1853

Sorry that I didn't write sooner. The journey from Kansas took longer than I'd expected and the prospecting out here isn't as good as I'd expected. The big city is a crowded place. There are lots of fellas just like me that came for the gold and got here a bit late to hit it big. I finally got out here about three months ago.

While much of the gold is spoken for... what hasn't been collected is being fought over in the streams and the parcels of land are mostly spoken for. While there are some regulations out here, lots of men are dying just to get to a stream with a pan. I didn't travel so far just to get killed over a few feet of streambed. If I can't make money finding gold, maybe I can make some money feeding gold-diggers.

I figure I'm going to head a bit further west and try to settle there. There may yet be some prospecting and there are some other natural wonders there as well.

One fella gave me this piece of wood he got west of here, where he thinks that there may be farmland and good fishing. The winters here are not too extreme, so I should be able to set up comfortably in a new spot by the new year.

Isn't this piece of wood grand? I understand that there is a whole forest of rock out there.

Best wishes,

Robert

Figure 3. Letter from son Robert for Appendix C.

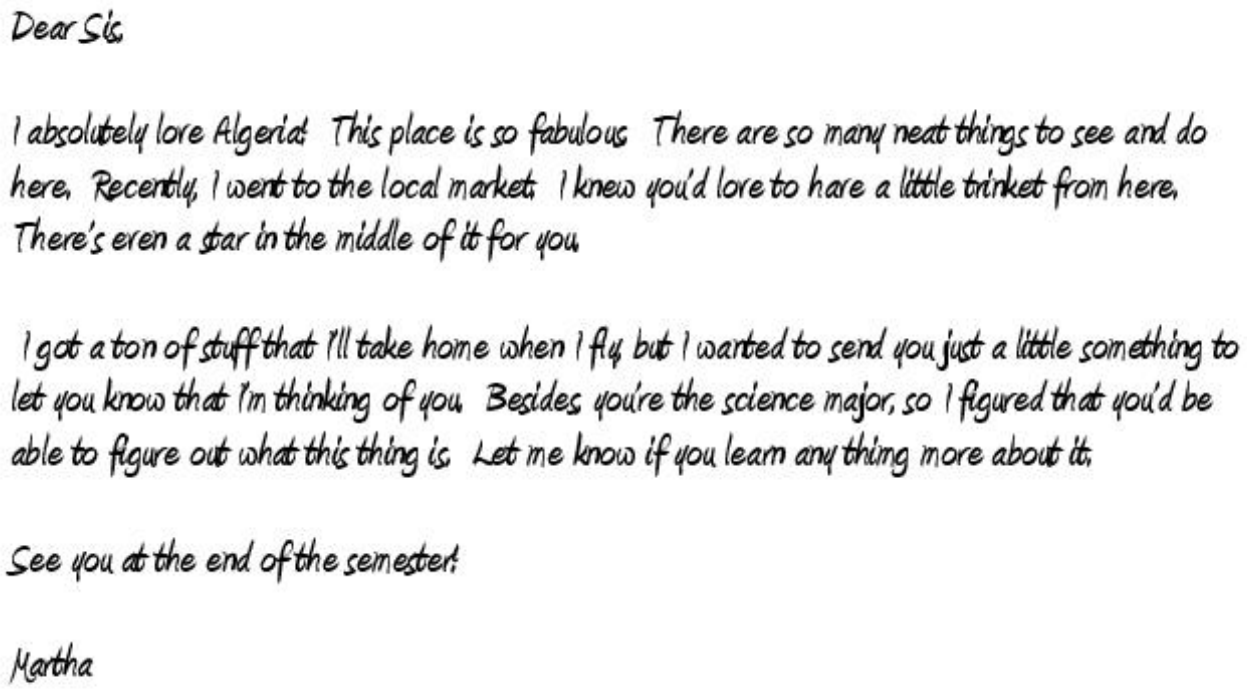
Appendix D: Algerian Fossil

Your sister is doing a semester abroad in Algeria. She misses you and has sent lots of letters. This last letter (Fig. 4) came with a little box containing a rock.

- What kind of organism does this fossil represent? Please give as much taxonomic information as possible.
- When would this organism have been alive?
- How does this organism live? (What does it eat? Does it move? What would it look like in life?)
- Does this sort of organisms still live today?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.



Dear Sis,

I absolutely love Algeria! This place is so fabulous. There are so many neat things to see and do here. Recently, I went to the local market. I knew you'd love to have a little trinket from here. There's even a star in the middle of it for you.

I got a ton of stuff that I'll take home when I fly, but I wanted to send you just a little something to let you know that I'm thinking of you. Besides, you're the science major, so I figured that you'd be able to figure out what this thing is. Let me know if you learn anything more about it.

See you at the end of the semester!

Martha

Figure 4. Letter from Martha for Appendix D.

Appendix E: Rock from Mississippi

On a road trip through Northern Mississippi, we had to stop to stretch our legs. At the rest stop, there was a little country store with a creek out back. While stretching out, we noticed an unusual little dark rock next to the stream. When we picked it up, we found that it looked like a shark's tooth. But, we are a seven-hour drive to the coast.

- What kind of organism does this fossil represent? Please give as much taxonomic information as possible. You should be able to use the morphological features of the tooth to determine precisely which genus of shark this is from and when it lived.
- Shark teeth are very common fossils. Why do we find so many shark teeth?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?
- Identify five other sites that you might visit to find more of this particular type of shark tooth and why you believe that they would be good places to find them.

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Appendix F: Uncle Henry's Rock

Your mother and her sister are cleaning out the house of their dear deceased uncle. While doing so, they send you the attached fossil and letter (Fig.5).

- Can you figure out where this fossil came from?
- How do you know it has to be this location?
- What kind of organism does this fossil represent? Please give as much taxonomic information as possible.
- How are these organisms fossilized (through what process)?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Justin,

Aunt Josie and I are going through Uncle Henry's things. We found a bunch of rocks on his mantle. It was a bit puzzling until we realized that there is a rock up there for each of the places he's lived. There were labels from each of the home sites, but they were in a separate pile from the rocks. Now, we can't figure out which rock came from each place. What a funny thing to keep!

The rock that is enclosed seems pretty interesting. It looks like it might even be a fossil. He also had a photo of each house on the mantle. It sure would be neat to store this rock with the correct tag and photo. Can you figure out which location this rock came from?

The tags are from the following locations:

Millard County, Utah

Calvert County, Maryland

Hot Springs, South Dakota

and

Sweetwater, Wyoming

Let me know if you can figure it out.

Love,

Mom

Figure 5. Letter from Mom for Appendix F.

Appendix G: Fossils from the Hike

Some of your friends invited you to go hiking this past weekend. You had to study for biology class, so you turned them down. The good news is that they were thinking of you and brought you back a present from the trail. See the following email (Fig 6.) to learn more.

- What kind of organism does this fossil represent? Please give as much taxonomic information as possible.
- How are these organisms fossilized (through what process)?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Email:

From: Joe Brown
To: Emily Dickens
Subject: Rocks on the AT?

Em,

You missed out. Bob, Julie and I hiked the AT (Appalachian Trail) near the Dragon's Tooth entrance (in Catawba). We only hiked a few miles in, but there are some great views. Next time you should come along.

We found these really cool rocks in a stream there. I put one of them outside your door to look at. It has these little divots in it that look like Life Savers. You're the science major, can you tell us what's up with this rock?

TTYL,
J.

Figure 6. Email from Joe Brown for Appendix G.

Appendix H: Dinosaur Poop

While this "party favor" is not necessarily intended for serious scientific inquiry, the package indeed contains dinosaur "poop" as advertised. Serious inquiry does follow from the examination of trace fossils such as this, so you can have some serious questions that you can answer about your assigned fossil remains.

- Coprolites are classified differently from paleofaeces. How do they differ?
- How were coprolites first recognized as such?
- What can we learn about a dinosaur from a coprolite? Be specific here, as there are many things that can be learned – incorporate not only what we learn, but the sort of evidence that supports these findings.
- Coprolites are considered "trace" fossils. What are trace fossils and why are these considered traces?
- Where have coprolites been found (give a few examples)?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Appendix I: Peace Corps Amber

This Peace Corps volunteer found some amber at a local market (Fig 7.). It is not uncommon in the Dominican Republic. Can you tell us more about this amber? Answer the following questions.

- Is it possible that there could be dinosaur DNA in this Dominican amber fossil? Explain.
- Describe the process by which these organisms were fossilized.
- Look at the piece of amber under magnification and sketch and/or describe the fossilized organism you can see.
- Can you determine what sort of organism is in the amber or if it shares characteristics with any organisms currently living?
- When would these organisms have been alive?
- What type of habitat existed in the area when this was fossilized?
- How has this habitat changed in the area where the fossil was excavated?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Hi Mom and Dad,

Well, I know I had a lot of apprehensions about joining the Peace Corps, but I'm really enjoying it. Certainly the living conditions here in the Dominican Republic are a little rough, to say the least. But, the people are wonderful and the work is very rewarding. We are currently working on an aqueduct that will supply fresh drinking water to the families in the village.

I enjoy spending time in the local market. There's lots of fresh fruit and locally-made crafts. I bought several pieces of amber that come from the nearby mountains. I've heard mining amber is grueling, dangerous work. But, it does provide income for many men in the area who would otherwise have none. Anyway, I've included one of the pieces for you and this one looks like there are a couple of bugs trapped in it. Hey, maybe one had bitten a dinosaur and scientists could extract the DNA like in Jurassic Park?

Love,

Skeeter

Figure 7. Letter from "Skeeter" for Appendix I.

Appendix J: Fossil from France

This account (Fig. 8) discusses a fossil from a known fossil bed in France. You can learn more about the site and the identification of this specimen.

- Can you figure out where (exactly) this fossil came from?
- What kind of organism does this fossil represent? Please give as much taxonomic information as possible.
- How was this specimen fossilized (through what process)?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Sample J:

Email:
From: Emmy Coyle
To: Ted Foot
Subject: Study Abroad, France

Ted,

You should have come… we are having a fabulous time. We've spent a ton of time in Paris and so on, visiting museums, enjoying the cafes, and getting to practice our French (good thing we have got Dr. Cecile Pied along to help out)!

Now, we are traveling a bit more through the countryside. We've stayed at this lovely place in Toarcien. This part, you'd really love – we went to a nature preserve and were able to dig out these rocks with fossils.

I found this one thing; I thought it was a snail, but they told me it wasn't. I can't remember now what it is. I'll bring one back and you can look it up for me.

TTYL,
Emmy

Figure 8. Email from Emmy Coyle for Appendix J.

Appendix K: Fossil of Virginia

This particular type of fossil is well known (Fig. 9). Further, this fictionalized account references scientists that influenced our understanding of geology. See if you can answer the following questions about this fossil and these scientists.

Letter to Scotland from John Finch about the fossil scallop.

- Can you figure out where this fossil came from?
- How do you know it has to be this location?
- What kind of organism does this fossil represent? Please give as much taxonomic information as possible.
- Who was John Finch?
- Why might Finch feel compelled to write to Sedgwick?
- How are these organisms fossilized (through what process)?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- How did it get there?

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

To the Esteemed Dr. Sedgwick

Cambridge University

19 September 1824

Dr. Sedgwick,

I write this letter from the Americas where I have been working on the strata found in the Virginia Commonwealth. I have been visiting the President Mr. Jefferson and have shared with him some of his interest in rocks and natural history.

Some of our findings may be of interest to you as they may regard the diluvium hypothesis proposed by your Mr. Buckland, as well as related flood hypotheses. While you have focused your work in the Scottish Highlands, we find some comparable evidence in these regions of the New World. Please share these findings with our students where relevant.

Please find, enclosed, one such example of a preserved specimen.

Sincerely,

John Finch

Figure 9. Fictionalized letter from John Finch for Appendix K.

Appendix L: A Fossil Named Sue

In 1990, Sue Hendrickson traveled through Wyoming on a fossil collecting trip. After a fairly unsuccessful day in the field, the day just got worse. On their way out of the field site, their truck got a flat tire. While the rest of the group waited for the repair, Sue went for a walk. She wandered to a nearby hill at which they hadn't sampled and picked up a few bone fragments. The head researcher recognized these fragments immediately.

Sue's discovery was both a major scientific discovery and the start of a long legal battle.

- What kind of organism does this fossil represent? Please give as much taxonomic information as possible.
- Which researcher recognized the remains from a few bone fragments and what characters told him what t ype of organism had been fossilized?
- Why would anyone sue someone else over this?
- When would this organism have been alive?
- What kind of habitat would it have lived in?
- In what kind of habitat was the rock found?
- What else can you tell us about what happened to this specimen in life?

While we don't have any pieces of Sue's discovery for you to put your hands on, when you are ready to do your presentation, you can check out some remains of a similar organism.

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

Appendix M: Fossils from the Canadian Railway

Mom just went through Uncle George's things. In one box, she found some letters to George's father from *his* father. That would be your great-great-uncle. Anyway, apparently when he was a young man, he was a foreman on the Canadian railway and worked out west in British Columbia. Check out the following excerpt from a (fictionalized) letter:

"*The going has gotten quite difficult. The air lacks in quantity, so the newer fellows need time to adjust before they are useful at the rails. The terrain is all rock, requiring more work to lay the rails level. Further, we've all been a bit distracted. The newer excavations have led us to find the most curious stones. These stones appear like bugs, but are truly rock throughout."*

Anyway, when the word traveled to Walcott at the Smithsonian, he got all fired-up about the fossils that these railway men found. So, when Walcott went out west to explore, he hired some of them. Years after digging through rock to lay the rail, your great-great-uncle went back out west to make more money digging rock for some scientist. Here is an excerpt from this expedition:

"*My return will be delayed somewhat. Some fellow, Walcott, from the museum found some of us that sent out the stone bugs from the rails. We'll be back up helping show him where we found the bugs and perhaps digging out some new ones.".*

- Where did your Great-great Uncle work?
- What years might he have worked there?
- How do you know it has to be this location?
- What kinds of fossils might he have helped find?
- How were these organisms fossilized (through what process)?
- What more have we learned about this region since Walcott's research?
- When would these organisms have been alive?
- What kind of habitat would they have lived in?
- In what kind of habitat was the rock found?
- How did it get there?
- Tell us about the man that your Great-great Uncle worked for.

Provide a brief summary of your detective work determining the background of this fossil and please incorporate your answers to these questions and the references that helped you answer them in your written work.

Be prepared to (as a team) introduce this organism to the class. Tell them about what kind of organism produced this fossil and by what means. Tell us about the likely date at which the organism had been alive and how you arrived at this conclusion.

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