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Understanding Earth's History and Geologic Time through Evolution

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Introduction

Standing at the edge of the Grand Canyon, it is hard, though not impossible, to imagine that this great landmark was carved by the Colorado River over millennia. It is a testament to the power of time and the slow but steady movement of water. Earth is a dynamic system, constantly changing. This change is sometimes explosive and sudden, but more often it is like the Colorado carving the Grand Canyon – slow and steady. Learning about Earth's 4.5 billion-year history is a lesson in the slow and steady. It is a lesson that teaches us that given enough time, we can see considerable changes not only in geology but in the life forms that have existed.

In science classrooms across the country, students are shown an image of a clock. This clock represents the entire history of Earth in a 24-hour span. It isn't until the clock strikes 11:58:43 p.m. that humans make their first appearance. In fact, it is not until approximately 4:00 a.m. on this 24-hour clock that living organisms, single-celled bacteria, come into the picture.[1] Much of what we know about this considerable story is gleaned from ice and rock. Our ability to understand the past requires that we understand the clues that are given to us in the form of microscopic molecules to life-size preserved fossils to layers upon layers of sedimentary rock. It could be argued that it is the chapters in which life appears that the story gets really interesting. Unfortunately, our story is marred with holes, especially when it comes to the myriad life forms that have existed on Earth. As stated by evolutionary biologist Jerry Coyne, "true, this is a history book torn and twisted, with remnants of pages scattered about, but it is there, and significant portions are still legible."[2] It is through fossils that we are able to reconstruct these significant portions, and it is through our understanding of the relationship between evolution and environment that a robust narrative of the vast majority of Earth's history can be written.

Background and Rationale

In Chicago, IL, students can visit the Field Museum and see evidence of Earth's history with their own eyes. They can see the spectacular *T. rex*, Sue and hundreds of palm sized trilobites. In the Evolving Earth exhibit, students can walk through history, one era at a time, witnessing explosions in life forms as well as mass extinctions. Despite having such rich resources, such as the Field Museum, it can be difficult for students to wrap their minds around the immensity and scale of Earth's history and the timelines on which evolution occurs. Additionally, outside of the occasional class trip, most students do not have the resources to visit exhibits like Evolving Earth. Chicago Public Schools had almost 397,000 students enrolled in the 2014-2015 school year. Of those students, the overwhelming majority are African American (39.3%) and Hispanic (45.6%). Over 86% of students attending CPS schools are considered "Economically Disadvantaged" and just over 16% are designated as ELL.[3]

Students in CPS are required to learn about the concepts of evolution and Earth's history throughout the course of their studies. Middle school science is most often taught in three separate strands: physical science, life science, and Earth science. Although some schools teach integrated science in middle school, it is more common that these strands are taught in apparent exclusivity of each other. At my school, where I teach 8th grade science, students do not learn geologic history and evolution within the same school year. At best, evolution receives a brief paragraph during the lesson on fossilization and how fossils are used to study Earth's past. Students learn about Earth's past more through memorization of events and through basic geologic laws rather than through an integrated study on how life forms changed in response to the selective pressures present at the time. Understanding these selective pressures can paint a much more robust picture of Earth's history. Additionally, people learn better when explicit connections are made between concepts they are already familiar with (studying evolution in 7th grade) and novel concepts (Earth's history).

Before beginning this unit, students at Marquette School of Excellence would have learned some key information about geology that would help in having a deeper understanding of this unit. Although it is not necessarily required to complete this unit, students may benefit from learning basic geologic laws and mechanisms of change, such as how sedimentary rock layers form and can be distorted over time and the concept of uniformitarianism (which I will briefly cover in this unit).

The Geologic Time Scale

As this unit pertains to the concepts of Earth's history, geologic time, and evolution, it makes sense to begin with a brief amount of background information on the geologic time scale. The time scale, for student and standards purposes, does not need to be memorized; however, having a rough sense of where these time periods lie can help students visualize when major events – such as extinctions and climatic/geologic events – occurred throughout Earth's very long history. The development of the now ubiquitous geologic time scale is an endeavor that has spanned over 200 years. When first developed, scientists used the tools they had available to them, including observations of the thickness of sedimentary strata and the salinity of oceans, as well as using their understanding of the input from streams into oceans to figure out how old the oceans were, generally. What these methods yielded was simply the understanding that Earth is much older than was thought at the time.[4] Thanks to the discovery of radioactivity, scientists were able to more accurately organize and subdivide geologic time, beginning to develop the time scale as we are familiar with it today. Scientists now had numerical (absolute) ages for the rock layers they studied.[5] Traditionally, boundaries between geologic time units were made when there was some major shift in observed life forms, a widespread geologic event (e.g., ice age), or a large-scale structural deformation of Earth's crust. Most divisions in geologic time have been refined to major evolutionary events, indicated by the initial emergence of a distinguishable guide fossil.[6] Today, there are six methods commonly used to more precisely determine geologic time – astrochronology, chemostratigraphy, geochronology, magnetic polarity stratigraphy, rock magnetic stratigraphy, and stratigraphy. For the purposes of this unit, it would be most useful to understand three of these methods – chemostratigraphy, geochronology, and stratigraphy. Beginning with the simplest, most well-known of the three, stratigraphy is looking at the physical arrangement of rock layers and sequences (lithostratigraphy) as well as the fossil content (biostratigraphy). This method will result in obtaining the relative ages of rock layers compared to those around them (as opposed to numerical or absolute ages). Geochronology is more commonly known as radiometric dating. Chemostratigraphy can be seen as a sort of extension of geochronology in that is also uses radiometric dating but tells us more about catastrophic events that have a profound effect on the rock record. These two methods provide us with the numerical ages of rock layers.[7]

From longest to shortest, in terms of geologic time, the scale is broken down into eons, eras, periods, epochs, and ages. Precambrian time (approximately 4,500 Ma to 541 Ma) is not technically an era, as it comprises three eons. However, this massive chunk of time is often juxtaposed next to the three most well known eras - the Paleozoic Era (541 Ma – 252 Ma), the Mesozoic Era (252 Ma – 66 Ma), and Cenozoic Era (66 Ma – present). These three eras are then divided into 12 periods.[8]

Fossils: Evidence of Environment and Evolution

As stated above, geologic time periods have been mostly refined by, and named after, the types of living organisms found in the fossil records. Therefore, to understand Earth's history, one must have an understanding of fossils – how they form and what they can tell us.

How Fossils Form

Scientists can study evolution in the present. They can look at rapidly generating populations of bacteria and see evolution happening in the moment. However, if you want to understand evolution on the scale of Earth's 4.5 billion-year history (and, thus, understand more about Earth's history), you need fossils. In order for a fossil to form, the conditions must be just right. Organisms that have a high chance of becoming a fossil are those that end up in places where sediments (e.g. sand, silt, and clay) accumulate, especially in places such as lakes, rivers, and oceans. In fact, fossilization is quite the rare occurrence. Unsurprisingly, it is the hard part of organisms that become fossilized the easiest, including shells and bones. Under the right circumstances, the flesh of an organism may become fossilized, but this is exceedingly uncommon. Most preservation processes include the mineralization of body parts (whether hard or soft) by minerals such as phosphates and silicates. It is possible for fossilization to occur in igneous rock, as long as the object is hardy enough to withstand the process. The more parts an organism has (e.g., a single shell versus the skeleton of a vertebrate), the more difficult it will be for fossilization to occur. This is due to the fact that as an organism begins the decay process, the soft tissues holding together the skeleton will rot away, allowing the various components to disarticulate. If the rotting tissue changes the local chemical environment, it is possible that the remains will become fully or partially encapsulated in what is called a nodule or concretions. This allows the remains to avoid disarticulation, thereby preserving the entire organism. There are many factors that can affect how skeletons are broken down. Already discussed above is disarticulation; however, skeletons may also experience abrasion, bioerosion (broken down by other living organisms), dissolution, encrustation and fragmentation.[9]

Types of Fossils

Generally, fossils are divided into two categories – body fossils and trace fossils.[10] When original material is dissolved away and replaced by other minerals, it is called a cast fossil. If no filling of the cavity occurs, then mold fossils will be formed.[11] Organisms, such as wood, may be preserved via the petrification process, while rarely, whole body organisms can be preserved by being captured in amber or ice. Fossils can even be formed from nests and animal droppings.[12]

Trace fossils (ichnofossils) are unique from body fossils in that they can shed light on the activities of extinct animals, even if the exact animal is unable to be identified. Trace fossils are quite abundant and are formed when an organism makes a track of some sort in sediment and then the cast is filled with more sediment. Animal burrows can be dug into sediment and then left empty to be fossilized or filled with more sediment of a different color. Borings, different from tracks or burrows, are made into harder material, such as rock.[13]

Evidence for Environment in the Rocks

Just like organisms can have unique characteristics that allow us to make assumptions about their lifestyle and behaviors, sediments, too have unique characteristics that allow us to make assumptions about the environment and conditions present when they formed. Sediments formed at a particular site with distinctive characteristics are called sedimentary facie. Different sedimentary facie can be formed at the same time, yet retain their unique characteristics, and the fossils found in those facie can often then be related to the environment in which the sedimentary rock formed. A group of fossils found in a particular sedimentary facie are referred to as facies fauna.[14]

Of course, not all organisms found in a sedimentary facie lived in that environment before they became fossilized. Some travel large distances, perhaps due to their ability to float on ocean currents, before they settle into the sediment. Despite this fact, scientists can tell quite a lot about the environment in which an organism died by looking at modern day sedimentary rock formation. For example, climate affects the kind of sediment laid down. In Arctic regions, one will find a very unique assemblage of different rock types that have been shaped and ground by ice from glaciers. Although fossils are rare in this type of sediment, the edges of ice sheets are often met with mossy bogs that may form deposits of peat and lignite. In this peat and lignite, remains from organisms can be found. Finding organisms in this type of material would hint that they were adapted to life in the higher altitudes.[15] The conditions and environments in which modern sedimentary rocks form would be similar to how they formed in the past, thus allowing us to make these assumptions about environment and conditions. This is called the principle of uniformitarianism, which simply states that geologic processes occurring today also happened in the past.[16]

Sedimentary facie can tell us quite a lot about the conditions surrounding the formation of various sedimentary layers; however, due to the nature of fossilization, the facies fauna we find may not reflect all of the ecological niches (ways that organisms can make a life) in the area at that time. Any given environment is usually broken down into many micro-habitats. Depending on the type of life in these micro-habitats, there may be little to no evidence of their existence in the fossil record. As an example, in bodies of water, organisms are often stratified into different niches. When these organisms die, they all sink to the bottom, thereby obscuring much of the information that could be gleaned about their micro-habitats. Scientists then have to use their knowledge about niches today, as well as other roundabout tools, to learn and make assumptions about ancient environments.[17]

Index Fossils

Fossils are a key without which we would never be able to open some doors to Earth's past. Fossils can preserve information on individual organisms, their evolution, and the environment. They also serve as reference points connecting time and space. Since rocks can be morphed and moved due to geologic processes over time, certain fossils, known as index fossils, can aid in correlating rock layers, and, thus, periods of Earth's history. Index fossils allow organisms to be placed in evolutionary order, despite movement and disturbance over time. In order for a fossil to be considered an index fossil, it must be widely distributed geographically but within a short geologic range. Without knowing the time frames that index fossils provide, it would be much more difficult to understand evolution.[18]

Evolution and Environment

Fossils can give us lot of information about organisms and paleoenvironments, but it is through the coordinated efforts of paleontology, geology, and evolutionary sciences that the most complete picture of Earth's history can be formed. The basic idea of evolution is that species change on a genetic level, generally over many generations, and those individuals whose changes increase their ability to reproduce will result in the overall population becoming more and more suited to their environment.[19] "Everywhere we look in nature, we see animals that *seem* beautifully designed to fit their environment, whether that environment be the physical circumstances of life, like temperature and humidity, or the other organisms – competitors, predators, and prey – that every species must deal with."[20]

Natural Selection

The main driving force behind evolution is natural selection. Misunderstandings and misconceptions around natural selection are quite common in both the general public and in the classroom. Many people may describe the environment as acting on an organism when perhaps the better description is that it is selecting for traits in an organism (the exceptions perhaps being environmental factors that directly cause genetic mutations, like UV radiation). Abhijeet Bardapurkar makes a very simple analogy to describe the difference between natural selection and what he calls transformative action. Imagine you were to act upon a stone by hitting it with a hammer in the attempt to produce grains of sand. On the other hand, you may also choose to sift through rocks for smaller and smaller samples, as they are available, until you have accumulated rocks that are the size for which you were looking. The first scenario is an example of transformative action – acting upon something to create or make what you desire. The second scenario is what Darwin was describing as natural selection – selecting from what is already available.[21] Of course, one must be careful in anthropomorphizing the selective pressures organisms face in nature. There is no conscious choosing or selecting of traits; simply environmental conditions that occur in which organisms with well-suited adaptations stand a higher chance of passing on their genetic material. Therefore, having variety in a population is, almost literally, the spice of life. Selection cannot occur when there is nothing from which to select. Transformative action does have its place in the theory of evolution as the random mutations that occur in genes (changing what is already there) are what provide the variety needed for natural selection to take place.[22]

We can see numerous examples of natural selection in action today. Coyne illustrates a more modern case of natural selection in the coat color in wild mice. There are mice, “oldfield” mice, that have brown coats. They like to burrow in dark soils. In Florida, there are mice called “beach mice” that are the same species but who have light colored coats that naturally obscure them from predators. Over time, and being better suited to survive and pass on their genetics in the lighter, sandy environment, there are more copies of the “light” forms of pigmentation genes found in the populations of mice living in Florida’s Gulf Coast.[23] If you look at a particular environment and study the organisms that live there successfully, you will find adaptations that allow them do so. When looking into the past, we can use a similar logic to recreate ancient environments and events by looking at the organisms found in the fossil record from that time.

Biogeography

The role that the environment takes in shaping evolution cannot be overstated. The field of biogeography looks at the effects of geography and environment on the types of adaptations and the eventual speciations that can occur. Some biogeographers will argue that earth and life evolve together, in tandem. Observations of adaptations of closely related species can allow us to make inferences on environmental conditions during the time their common ancestors began to differentiate. Essentially, the study of biogeography looks for patterns in distribution and how these patterns developed. These patterns may arise due to geologic features (e.g. mountain formation, introduction or removal of water barriers), but can also be the result of meteorological (e.g. new areas of drought) or oceanographic (e.g. changing ocean currents) features.[24] Once separated, species respond to their unique environments and may adapt with traits that eventually prevent them from sharing genetic material with their sister species.

A classic example in the study of evolution and biogeography comes from Darwin’s peer, Alfred Russel Wallace. Wallace realized that differences in all species could not be accounted for simply based on differences in climate, as organisms that lived in the same climates did not exhibit the same adaptations. Much of his work was done in Southeast Asia and Australia. He noticed, through detailed observations, which life forms in these areas differed even though the climate and terrain were very similar. Therefore, Wallace had to conclude that that there was some other mechanism at work to explain the distribution of life forms. In 1915, German geologist, Alfred Wegener, found that two identical species of plant fossils were found on completely different sides the Atlantic Ocean. Since the ocean is much too large for these species to have traveled on their own, Wegener realized that at some point in Earth’s history, these two continents must have been physically joined. Wegener was able to propose a reconstructed ancient environment based on the identical plant fossils he found on the two continents. Although he did not know it at the time, the study of plate tectonics proved that these continents had, in fact, been one in ancient Earth’s history.[25] This is one example of how scientists can recreate paleoenvironments using clues from the fossil record.

Evolution, Extinction, and the Fossil Record

Using the fossil record to determine evolutionary steps, extinctions, and ancient environments is not without its challenges. It would seem that one should be able to directly infer relationships by reading the strata as one would a book, with the ancestors and descendants in unique strata and with ancestors in lower (older layers). However, one may find species that appear to be more closely related to ancient ancestors in younger layers along with their apparent descendants. Unfortunately, evolution does not always transpire in a nice step-wise manner, especially when you come across organisms that are so well-suited to their environments that they are not supplanted by another organism for an extended period of time. Additionally, geologic processes do not always occur uniformly, especially when major events, like storms, disrupt the formation of sedimentary rocks. Rock records may also experience shifts in facie through regular geologic processes, moving the evidence far away from its origin. This can throw off time estimates and make connecting ancestors, descendants, and environments more difficult. For most fossils, the best bet is to look at the features the fossils show us and determine which may have been acquired through evolution. Then, fashion a cladogram (often not thought of as true phylogenetic trees) that hypothesizes about the relationships between organisms.[26] These facts aside, do not discount the value and necessity of using fossils to determine evolutionary relationships and environmental conditions of the past. Despite the challenges, it would not be possible to learn about ancient Earth and its life forms without the information that can be gleaned from the fossil and rock records.

Perhaps as important as illustrating changes in evolution, the fossil record also provides information on extinctions that ultimately opened niches for new species to fill. There are two types of extinction – final extinction in which no genetic material is passed on and the type that occurs as a result of the generation of a new species. In the first, this is akin to the end of a branch in the Tree of Life while the second is part of a longer branch that includes the ancestors connecting living species.[27] Written into the rocks are records of numerous extinctions (mass and otherwise) as well as evidence for the evolution of life forms. In Earth's history there have been five major mass extinctions –446 Ma at the end-Ordovician, 371 Ma at the Frasnian-Famennian (FFB), 251 Ma at the Permian-Triassic (PTB), 200 Ma at the Triassic-Jurassic (TJB), and 65 Ma at the Cretaceous-Paleogene boundaries (KPB). Although we have evidence in the fossil record for these mass extinction events, the jury is still out as to the exact causes for each. It is believed that abiotic events, such as massive climate change, were the main catalysts for the catastrophic loss of life. The fossil record shows a clear indication of the magnitude of loss of marine and terrestrial fauna during these extinction events. It was long held that the flora found during that time weathered the extinction events relatively intact; however, palaeoecological studies of three (PTB, TJB, and KPB) of the big five mass extinction events have indicated that even plant communities collapsed in conjunction with the highest level of faunal extinction at those times.[28]

Mass extinctions are of great interest due to the extreme loss of life forms all at once. As significant as mass extinctions seem, and they are for numerous reasons, extinctions on Earth are more far more common. In fact, it is estimated that approximately 99.9% of life forms that have ever existed on Earth are now extinct.[29] Paleontologists call the slower, more ongoing disappearance of life, background extinction. The mechanisms behind background extinctions are not well understood as they are phenomena of the past that are not directly observable. It is believed that most background extinctions occur when an organism's environment changes in such a way that individual survival trumps reproductive fitness, essentially causing a decline in populations over time. In essence, extreme changes in the environment, abiotic or biotic, occur faster than the reaction of the organism. Background extinctions account for the majority of all extinctions which have occurred on Earth. As communities adapt to their environment, some will continue along the path of evolution, while others will continue their population declines.[30]

Example Organism: The Woolly Mammoth

For the purposes of classroom instruction, it would be wise to have some concrete examples of how understanding evolution and adaptations can shed light on paleoenvironments. There are, of course, numerous organisms one could choose to elucidate the evolution-environment relationship, such as plants. However, for maximum engagement and buy-in, choose organisms that your students may find interesting or may have existed in your geographic area's paleoenvironment. The woolly mammoth is an exciting and well-known organism that is sure to engage students. Although it occupied a rather brief period in Earth's history, the evolution of the woolly mammoth is an excellent example that can be used in the classroom for how fossils can tell us more about evolution and the ancient environments of the past. "The mammoth lineage provides an example of rapid adaptive evolution in response to the changing environments of the Pleistocene." The mammoth is not only well known (even among middle school students), it has one of the most complete records paired with a time in Earth's history that has been well-studied in terms of its environment and changes to its environment. The European mammoths (*Mammoths*) are divided into three species, chronologically. In the Early Pleistocene (2.6 to 0.7 Ma) there is *M. meridionals*, in the early Middle Pleistocene (approx. 0.7 to 0.5 Ma) there is *M. trogontherii*, and finally we have the woolly mammoth (*M. primigenius*) from the late Middle to Late Pleistocene (approx. 0.35 to 0.01 Ma). Over the course of 2.5 million years, the mammoth went through many changes to its cranium and mandible, as well as their teeth (which is believed to correlate with the shift in paleoenvironment and periglacial food sources).[31] Of course, notably, there was a change in amount of hair between the woolly mammoth and its ancestors. Evolutionarily speaking, it was likely that mutations led to some mammoths being hairier than others, and thus better able to tolerate the colder climates (either due to climate change or through migration northward). These better-suited individuals ultimately had more success, reproductively, leading to the woolly mammoth with which we are all familiar.[32] Another reason the mammoth is an excellent example organism is because scientists have been able to uncover DNA from these deep-frozen specimens. While this DNA can only reliably go back so far (approximately 75,000 years), it still provides vital information to construct an evolutionary tree for the mammoth. The DNA extracted from frozen mammoth samples contains accumulated mutations that can be used as a sort of "clock" to tell us when certain mutations arose and became incorporated within the genetic code.[33] These "clocks" are more commonly referred to as molecular clocks. The development of the molecular clock was through the discovery that proteins experience amino acid replacements at a fairly consistent rate across numerous species. Because these replacements are so uniform, by looking at the rate of amino acid substitutions over a particular unit of time and then applying it to protein differences across a range of organisms, scientists are able to figure out when the various lineages diverged from each other.[34]

The woolly mammoth was an organism that was best suited to the cold. However, being an herbivore, the environment in which the woolly mammoth lived was constrained. Throughout the course of its history, the woolly mammoth's range shifted as temperatures warmed (pushing the woolly mammoth farther north) and cooled (pushing them further south). The sheer number of mammoth remains in northern Eurasia makes it an excellent organism for scientists to use to find out information on the climate and flora at the time. By looking at and understanding adaptations, such as the teeth of the mammoth that are specialized to the types of food they ate, they are able to make significant assumptions about the paleoenvironment. Also, the wide range in which scientists have found the remains of woolly mammoths give valuable information on the dynamic nature of the last glaciation period. Scientists have been able to correlate the spatial and temporal distribution of the woolly mammoth with the known requirements of the species (gleaned from the morphology and adaptations) to reconstruct the ancient environment.[35] The extinction of the woolly mammoth is also an interesting story in that the introduction of our own ancestors may have been the direct cause of their demise. It is also plausible that climate change around the Holocene (3,600 years before present) was a factor in their extinction. It is important to note that the woolly mammoth had survived several other warming periods during its nearly 300,000-year existence. With this knowledge, it seems that if encounters with humans had not happened, the woolly mammoth may have been able to survive the climate changes that were occurring during the Holocene and continued as a species for an indeterminable amount of time.[36]

Student Goals and Activities

A typical science unit for the 8th grade students at Marquette School of Excellence includes model-based inquiry activities, labs, mini-lessons, reading and analyzing scientific texts (usually in tandem with a reading strategy differentiated for students), in-class discussions, activities, formative assessments and summative assessments. In this unit, students will be asked to analyze fossils of ancient organisms and create evidence-based models about how the organisms were adapted to their paleoenvironments. The ultimate goal is to get students to demonstrate their understanding of how morphological traits can tell us about environments, since environmental challenges and evolution are so closely linked.

Students will begin the unit by creating an initial explanatory model of an organism and its paleoenvironment. As the unit progresses, students will revisit these models at least two more times to include new evidence that they have learned through classroom activities. These initial models will provide information on preconceptions and misconceptions that students may have, informing the further development of sense-making activities. The models that students will be creating will be based on the example organism noted above, the woolly mammoth. In their model, students will be given a few clues (more to be given throughout the unit) that will help them explain what the paleoenvironment of the woolly mammoth might have been like based on fossil records of the woolly mammoth and their ancestors. The initial models are fairly bare-boned but can include particular prompts if desired. In the models used in my classroom, I would provide some scaffolding, such as headings for the types of evidence for which I would be looking.

Following the creation of their initial explanatory model, students will use a simple model to help them envision the unimaginable expanse of geologic time. This American Biology Teacher activity can be found through searching “Picturing Evolution through Geologic Time.” The activity addresses several challenges students face in comprehending geologic time including: (1) the meaning of a billion years ago or million years ago, (2) understanding when life forms first appeared on earth, (3) putting the time between events in perspective, and (4) clearing the misconception that major life forms only evolved in recent geologic history.[37] For each partner or group doing this activity you will need adding machine tape (6 m long), a metric ruler, Geologic time chart, and a list of key events. It is up to the teacher to decide how detailed students should be with geologic, atmospheric, and biologic events. Students may be given a prescribed scale to use (1 mm = 1 million years) or may be given the responsibility of determining the length and scale of the accounting tape.

Additionally, students may be given list of key events without dates and then given the task to place these events where they think they belong. Once given the key events with dates, students will most likely be surprised by the differences between their initial thoughts and the actual placement of events. There are a variety of questions that could be asked during the discussion portion of this activity. Questions may include simply identifying when events occurred and comparing lengths of time between events. It is recommended that these scales be posted in the classroom and used throughout the unit for revision (perhaps adding additional events) and reference. Homework related to this assignment may include having students create their own, personal time scale for a personal connection to the lesson.[38] Another activity related to understanding the geologic time scale would be to have students chose a particular time period and create a brochure for potential time-traveling visitors to guide them. The brochure should include information on major geologic, atmospheric and biologic events that occurred during the chosen time period. Students may present their brochures in class depending on time constraints.

In terms of activities for learning about fossil formation, there is a wide variety available on the internet. Students in my classroom will experience activities that range from reading articles on fossil formation to hands-on activities, such as creating and analyzing trace fossils and other types of fossils. Students, in partners or small groups, analyze fictitious strata from different geographic locations with a variety of fossils in them and determine which fossils would make good index fossils. The main goals for activities centered on fossils include: (1) understanding how fossils are made, (2) understanding different types of fossils and what they tell us, (3) how scientists use fossils to correlate and date rock strata, (4) how scientists use fossils as evidence for evolution, and (5) how scientists use fossils to reconstruct ancient environments.

When having students utilize fossils to reconstruct ancient environments, it may be best to use a local record. The website www.paleoportal.org offers a wide variety of information on the local paleontology in all U.S. states as well as other supplemental materials found on the online version of the article which the next major activity is based upon. On www.nsta.org, you can purchase the entire lesson, “Using observations of fossils to reconstruct ancient environments.” Using the internet, students should research local fossil records. As a class, the various fossils can be organized into like groups. It is important to include groups that students may not be familiar with, such as vertebrates versus invertebrates. If possible, it would be ideal to have actual fossil specimens that are found in your area for students to use. If not, printing out pictures of these fossils will suffice. When organizing the fossils into groups, a variety of processes could be used, such as think-pair-share. Students must be able to construct sentences that explain why a certain fossil is a member of a certain group as opposed to another. They will then hypothesize the types of environments these organisms lived in based on their morphology. Students should back up their claims with evidence. When sharing out, it is possible that misconceptions will arise that you may have to address later in the unit. This may also offer a good opportunity for students to practice collegial discussion techniques utilizing sentence starters. Students will bring in the concept of uniformitarianism by looking at modern day organisms and their preferred environments to make inferences about the ancient environments in which the sample fossil organisms lived.[39]

As a culminating activity (in addition to the final explanatory models created by students and revised over the course of the unit), students will combine their understanding of geologic time, fossils, evolution, and significant changes in Earth’s various systems in a literacy-based assignment. Students will use the example organism discussed above, the woolly mammoth, to recreate what its paleoenvironment would have looked like. Students will use fossil evidence from woolly mammoths and their ancestors in their reconstructions as well as evidence for evolution. Students will complete a RAFT writing assignment that asks them to take on a role, an audience, a particular format, and topic. The role, audience, and format can be tailored to the students in the classroom. However, the topic should be around the paleoenvironment of the woolly mammoth using evidence as noted above.

Endnotes

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1. Don Buckley, *Interactive Science* (Boston, MA: Pearson, 2011), 121
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Appendix A – Implementing District Standards

This unit addresses two standards from the Next Generation Science Standards.

MS-ESS1-4: Construct a scientific explanation based on evidence from rock strata for how the geologic time scale is used to organize Earth's 4.6-billion-year-old history. This unit emphasizes the analysis of fossils contained in rock formations to establish relative ages of major events in Earth's history. This is done through the lens of the evolution or extinction of particular living organisms.

MS-LS4-1: Analyze and interpret data for patterns in the fossil record that document the existence, diversity, extinction, and change of life forms throughout the history of life on Earth under the assumption that natural laws operate today as in the past. This unit, particularly the activity in which students analyze and interpret local fossil records, uses the concepts of diversity and change over time as well as the concept of uniformitarianism to understand Earth's history.

This unit addresses several Grades 6-8 Common Core State Standards related to the analysis of informational texts and quantitative and technical information expressed visually. These standards come into play when students are reading articles on content specific topics as well as analyzing data sets. Most strongly addressed are those dealing with (1) key ideas and details, such as citing specific textual evidence to support analysis of science and technical texts (RST.6-8.1) and determining the central ideas or conclusions of a text and summarizing the text (RST.6-8.2), as well as the (2) integration of knowledge and ideas, such as integrating quantitative or technical information expressed in words in a text with a version of that information expressed visually (RST.6-8.7) and comparing and contrasting information gained in experiments, simulations, video, or multimedia sources with that gained from reading a text on the same topic (RST.6-8.9).